

Fiberoptic bronchoscopy guidelines for the anesthesiologist

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INTRODUCTION

Fiberoptic bronchoscopy is a widely performed procedure that is generally considered to be safe. The first performed bronchoscopy was done by Gustav Killian in 1897; however, the development of flexible fiberoptic bronchoscopy was accomplished by Ikeda in 1964⁽¹⁾. Flexible fiberoptic bronchoscopy is a key diagnostic and therapeutic procedure⁽²⁾. It is estimated that more than 500,000 of these procedures are performed each year by pulmonologists, otolaryngologists, anesthesiologists, and cardiothoracic and trauma surgeons⁽³⁾. Despite the widespread practice of diagnostic flexible bronchoscopy, there are no firm guidelines that assure a uniform acquisition of basic skills and competency in this procedure, nor are there guidelines to ensure uniform training and competency in advanced diagnostic flexible bronchoscopic techniques⁽⁴⁾.

The purpose of this review is to provide an update on 1) tracheobronchial anatomy, 2) flexible fiberoptic bronchoscopy exam, 3) training and competence on fiberoptic bronchoscopy, and 4) application of flexible fiberoptic bronchoscopy in thoracic anesthesia.

ANATOMY OF THE TRACHEA AND BRONCHUS

The trachea is a cartilaginous and fibromuscular tubular structure that extends from the inferior aspect of the cricoid cartilage to the level of the carina⁽⁵⁾. The adult trachea is, on average, 15 cm long. The trachea is composed of 16–22 C-shaped cartilages. The cartilages compose the anterior and lateral walls of the trachea and are connected posteriorly by the membranous wall of the trachea, which lacks cartilage and is supported by the trachealis muscle. The average diameter

in a normal trachea is 22 mm in men and 19 mm in women. In men, the coronal diameter ranges from 13 to 25 mm and the sagittal diameter ranges from 13 to 27 mm. In women, the average coronal diameter is 10–21 mm and the sagittal diameter is 10–23 mm^(5,6). The tracheal wall is about 3 mm in thickness in both men and women, with a tracheal lumen that is often ovoid in shape. The trachea is located in the midline position, but often can be deviated to the right at the level of the aortic arch, with a greater degree of displacement in the setting of an atherosclerotic aorta, advanced age, or in the presence of severe chronic obstructive pulmonary disease (COPD). With COPD or aging, the lateral diameter of the trachea may decrease with an increase in the anteroposterior diameter. Conversely, COPD may also lead to softening of the tracheal rings with a decrease in the anteroposterior diameter of the trachea⁽⁷⁾. The cricoid cartilage is the narrowest part of the trachea with an average diameter of 17 mm in men and 13 mm in women. The trachea bifurcates at the carina into the right and left mainstem bronchus. An important fact is that the tracheal lumen narrows slightly as it progresses towards the carina. The tracheal bifurcation is located at the level of the sternal angle anteriorly and the 5th thoracic vertebra posteriorly. The right mainstem bronchus lies in a more vertical orientation relative to the trachea, whereas the left mainstem bronchus lies in a more horizontal plane. The right mainstem bronchus continues as the bronchus intermedius after the take-off of the right upper lobe bronchus.

In men, the distance from the tracheal carina to the take-off of the right upper lobe bronchus is an average of 2.0 cm, whereas it is approximately 1.5 cm in women. One in every 250 individuals (incidence 0.1–3%) from the general population may have an abnormal take-off of the right upper lobe

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bronchus emerging from above the tracheal carina on the right side⁽⁸⁻¹⁰⁾. The diameter of the right mainstem bronchus is an average of 17.5 mm in men and 14 mm in women. The trifurcation of the right upper lobe bronchus consists of the apical, anterior, and posterior division. This is a very important landmark to identify while performing fiberoptic bronchoscopy in order to distinguish the right from the left mainstem bronchus⁽¹¹⁾. Also, a bifurcated or quadrivial patterns in the right upper lobe, two with vertical keels and two with horizontal keels, have been reported. This quadrivial pattern is more predominant in males and its incidence is reported to be 2.9%⁽¹²⁾. The bronchus intermedius gives rise to the middle lobe bronchus, with its medial and lateral divisions and the lower lobe bronchus. The segmental bronchi of the right lower lobe consist of the superior, anterior basal, medial basal, lateral basal, and posterior divisions. The distance from the tracheal carina to the bifurcation of the left upper and left lower lobe is approximately 5.0 cm in men and 4.5 cm in women. The left mainstem bronchus is longer than the right mainstem bronchus, and it divides into the left upper and the left lower lobe bronchus. The left upper lobe bronchus has a superior and inferior division (also known as the lingular bronchus). The segmental bronchi of the superior division of the left upper lobe consist of the apicoposterior and anterior segments. The segmental bronchi of the lingular bronchus are the superior and inferior segments. The left lower lobe consists of the superior, anterior medial basal, lateral basal, and posterior basal segmental bronchi. (Figure 1) displays the tracheobronchial anatomy.

FLEXIBLE FIBEROPTIC BRONCHOSCOPY EXAMINATION

Flexible fiberoptic bronchoscopy is a diagnostic and therapeutic procedure of great value in the clinical practice of anesthesia. The most common method to perform flexible fiberoptic bronchoscopy is with the use of a single-lumen endotracheal tube.

When using a single-lumen endotracheal tube (i.e., 8.0 mm internal diameter), an adult fiberoptic bronchoscope should be used (i.e., 5.0 mm outer diameter). The internal diameter (ID) of the single-lumen endotracheal tube relative to the external diameter of the bronchoscope is an important consideration. Bronchoscopes in the non-intubated patient occupy only 10–15% of the cross-sectional area of the trachea. In contrast, a 5.7 mm bronchoscope occupies 40% of a 9 mm ID single-lumen endotracheal tube and 66% of a 7 mm ID single-lumen endotracheal tube. Failure to recognize this may lead to inadequate ventilation of the patient and impaction of or damage to the bronchoscope.

Once the tube is advanced beyond the vocal cords and inside the trachea, the tip of the single-lumen endotracheal

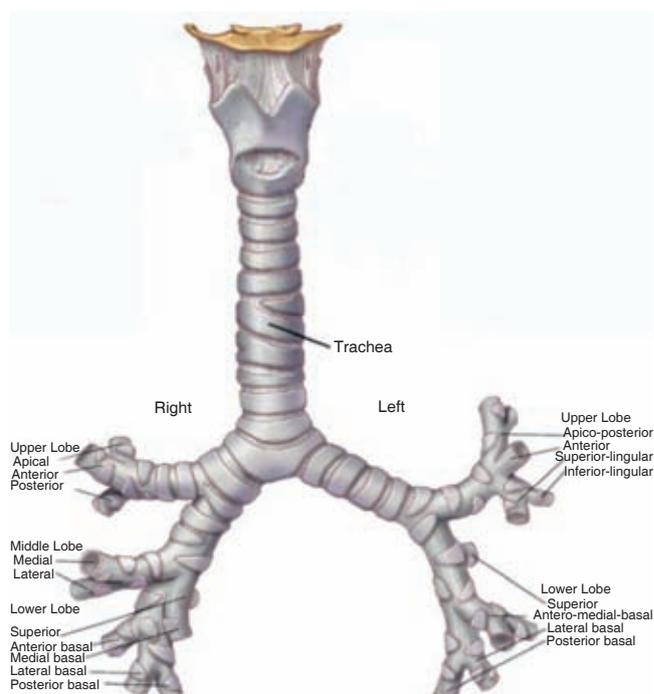


Figure 1. Minnich DJ, et al. *Thorac Surg Clin* 2007;17:571-585.

tube should come to rest 3–4 cm above the tracheal carina. A Portex fiberoptic bronchoscope (SSL Americas, Inc., Norcross, Georgia, USA) swivel adapter with a self-sealing valve is used to facilitate ventilation and manipulation of the bronchoscope at the same time. The channel suction part of the bronchoscope should be attached to suction aspirated secretions. A video screen monitor should be used whenever possible to enhance the views. Another alternative to perform fiberoptic bronchoscopy is with the use of a laryngeal mask airway (LMA). This technique allows visualization of the vocal cords and subglottic structures with lower resistance than a single-lumen endotracheal tube when the bronchoscope is inserted.

A systematic and complete fiberoptic bronchoscopy examination includes a clear view of the anterior wall (tracheal cartilage) and posterior wall (membranous portion) of the trachea below the vocal cords and of the tracheal carina. When advancing the bronchoscope through the right mainstem bronchus, a clear view of the bronchus intermedius should be seen, and at 3 o'clock the orifice of the right upper lobe bronchus should also be seen. As the bronchoscope is advanced inside the take-off of the right upper bronchus, a clear view of the orifices is found: apical, anterior, and posterior segments. This is the only structure in the tracheobronchial tree that has three orifices.

Although previously discussed, a quadrivial pattern (four orifices) can be found in < 2.9% of the population (Figure 2).

After withdrawing the bronchoscope from the right upper bronchus, it is advanced distally into the bronchus intermedius in order to identify the middle and lower right lobe bronchi. The right middle bronchus has the shape of a letter D. Once the complete examination has been performed on the right mainstem bronchus, the bronchoscope is withdrawn until the tracheal carina is seen again. Then the bronchoscope is readvanced into the left mainstem bronchus in which the bifurcation into left upper and lower lobe is visualized. (Figure 3) shows basic fiberoptic bronchoscopy views of the trachea and bronchus.

TRAINING AND COMPETENCE ON FLEXIBLE FIBEROPTIC BRONCHOSCOPY

Despite the widespread practice of diagnostic flexible bronchoscopy, there are no firm training guidelines that assure a uniform acquisition of basic skills and uniform competency in this procedure, nor are there guidelines or recommendations to ensure uniform training and competency⁽⁴⁾. The British Thoracic Society⁽¹³⁾ has developed general guidelines on fiberoptic bronchoscopy without providing specific information on how to perform flexible fiberoptic bronchoscopy and complete examination. In a report by the American Association of Bronchology, the majority of pulmonologists surveyed agreed that at least 50 basic flexible fiberoptic bronchoscopy procedures are necessary to become competent⁽¹⁴⁾. Although anesthesiologists perform flexible fiberoptic bronchoscopy on a regular basis, there are no formal guidelines for bronchoscopy or training facilities in place to enhance their skills.

The bronchoscopic skills of trainees has been subjectively assessed by training program directors and based in part on the number of procedures performed as well as on watching

trainees perform procedure in patients during the course of postgraduate education. The low reliability and poor correlation of these assessments methods has been adequately demonstrated⁽¹⁵⁾. A study involving trainees and attending physicians has shown the reproducibility and validity of two objective measures of basic bronchoscopic skills; one measured the skill of an operator performing a standard diagnostic bronchoscopy with an extra task, while the other evaluated the performance on a series of a structured bronchoscopy step-by-step exercise. Both methods demonstrated high reliability and validity to evaluate competency based bronchoscopy curriculum⁽¹⁶⁾.

Although admittedly difficult to achieve, an effort to appraise and enhance the quality of bronchoscopy training is necessary. Emphasis should be given to acquire the necessary skills to perform a complete fiberoptic bronchoscopy examination by anesthesiologists and maintain an appropriate level of competency. Any bronchoscopy training based on one-to-one instruction by faculty, lecture-based instruction, and use of bronchoscopy lectures or videos all have shown to enhance experience⁽¹⁷⁾. The safety of bronchoscopy in

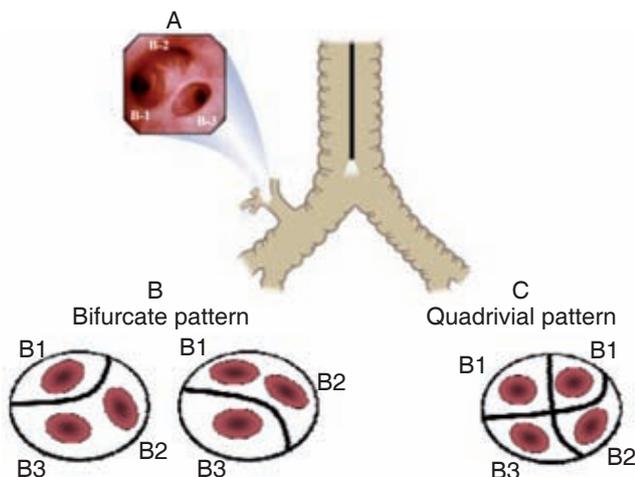
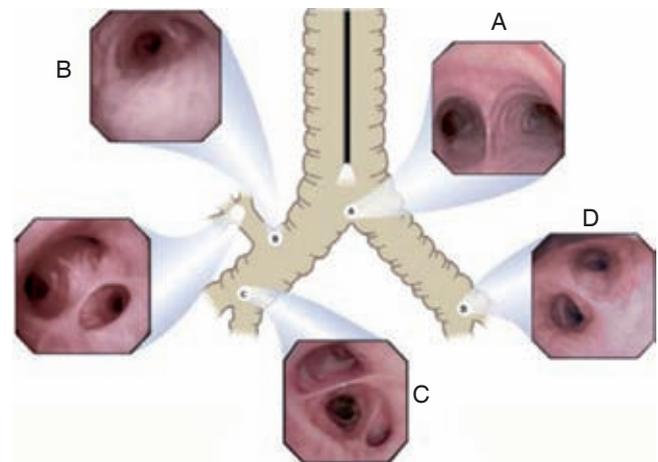


Figure 2. Gonlugur U, et al. *Anat Sci Int* 2005;80:111-115.



Campos JH. *Curr Opin Anaesthesiol* 2009;22:4-10.

Figure 3. (A) Tracheal carina. At 12 o'clock there is a cartilage ring (anterior wall) and at 6 o'clock there is the membranous portion of the trachea. In addition, the longitudinal folds are seen (posterior wall). Also, the entrance of the right mainstem bronchus is seen towards the right, and the entrance of the left mainstem bronchus is seen towards the left. (B, upper) Bronchial carina. To the right, the entrance of the right upper lobe bronchus can be seen, and towards the left the bronchus intermedius is seen. (B, lower) Entrance of the right upper lobe bronchus with three orifices (B-1 apical, B-2 anterior, and B-3 posterior segments). (C) Right middle lobe bronchus at 11 o'clock (resembles the letter D), and right lower lobe bronchus downward. (D) A clear view of the left upper lobe bronchus and lingula bronchus to the right and the left lower lobe bronchus towards the left.

a pulmonary fellowship program has been reported with a complication rate of < 3%; the most common complication was pneumothorax^(18,19).

Anesthesia simulators have been used to enhance learning and improve performance, usually under the personal direction of an experienced clinician⁽²⁰⁻²²⁾. In order to enhance our training in flexible fiberoptic bronchoscopy and placement, and confirmation of optimal position with the use of lung isolation devices, a computer-based simulation center or a training station with an airway mannequin is recommended to allow anesthesiologists to improve their skills of dexterity, speed, and ability to recognize the tracheobronchial anatomy. An educational approach involving a training workstation in an airway simulator facility mentored by an experienced thoracic anesthesiologist is required⁽²³⁾. This workstation must include a training station for a fiberoptic bronchoscopy simulator as well as a computer-based simulation center. The web site www.thoracic-anesthesia.com is one resource to gain experience in simulation related to fiberoptic bronchoscopy, as a first step in training to place lung isolation devices⁽²⁴⁾. In addition, the simulation facility must include an airway mannequin with a tracheobronchial tree anatomy similar to that in humans. The simulation facility must include video monitors and equipment to perform an independent flexible fiberoptic bronchoscopy so that every trainee can practice under the direct supervision of a thoracic anesthesiologist. Continuous medical education in the simulation training facility, at least one session every 6 months, is recommended. The trainee should participate in at least 20 cases where a fiberoptic bronchoscopy exam is performed in the operating room by a thoracic surgeon or thoracic anesthesiologist using a video monitor screen, and a minimum of 20 cases in the simulation room facility under the direction of an expert in thoracic anesthesia to practice flexible fiberoptic bronchoscopy techniques.

FLEXIBLE FIBEROPTIC BRONCHOSCOPY IN THORACIC ANESTHESIA

Klein, et al. reported the role of fiberoptic bronchoscopy in conjunction with the use of double-lumen endotracheal tubes (DLTs) for thoracic anesthesia⁽²⁵⁾. This study showed that after intubation and placement of the DLT by flexible fiberoptic bronchoscopy or auscultation with the patient in supine position, these tubes frequently become malpositioned following turning the patient into lateral position and that fiberoptic bronchoscopy was extremely useful for correcting these malpositions.

However, the use of fiberoptic bronchoscopy to achieve optimal position of lung isolation devices does not guarantee success, as there may be up to 38% incidence of unrecognized malpositions among non-thoracic anesthesiologists with limited experience in lung separation techniques while using

DLTs or bronchial blockers. The possible reported causes include lack of skill with fiberoptic bronchoscopy and lack of recognition of the tracheobronchial anatomy⁽²⁶⁾. It is the author's opinion that fiberoptic bronchoscopy is essential to achieve 100% success in placement and positioning of DLTs and bronchial blockers, as long as anesthesiologists have a clear knowledge and recognition of tracheobronchial anatomy with the flexible fiberoptic bronchoscope⁽²⁷⁻³³⁾. Table I enlists the uses of flexible fiberoptic bronchoscopy in thoracic anesthesia.

Figure 4 shows the optimal position of a left-sided DLT with the bronchoscope.

Figure 5 shows the optimal position of a bronchial blocker.

TRACHEOBRONCHIAL RUPTURE AND FIBEROPTIC BRONCHOSCOPY

Another application of the flexible fiberoptic bronchoscopy includes acute lesions of the tracheobronchial tree. These are very rare and are caused more often iatrogenically than by trauma⁽³⁴⁾. Tracheobronchial rupture is an injury to the trachea or bronchi localized between the level of the cricoid cartilage and the division of the lobar bronchi into their segmental branches⁽³⁵⁾. The causes of these injuries include blunt trauma, penetrating or gunshot wounds, and iatrogenic injuries (during intubation or tracheostomy). Ruptures of the tracheobronchial tree often present as life-threatening situations. The typical presentation includes tension pneumothorax, mediastinal and eventually subcutaneous emphysema, hemoptysis, and an air leak.

A retrospective report by Hofmann et al.⁽³⁴⁾ involving 19 patients with iatrogenic ruptures of the tracheobronchial tree showed that 11 patients had a tracheobronchial rupture by a single-lumen endotracheal tube, 4 patients by a DLT (elective surgery), and in 2 patients rupture occurred during a percutaneous dilatational tracheostomy. In addition, in 2 patients the tracheobronchial rupture occurred due to a stiff bronchoscopy. Many anatomical and mechanical factors may be responsible for iatrogenic tracheobronchial rupture: women are more frequently affected by an iatrogenic

Table I.

• Diagnostic procedures
• Interventional bronchoscopy
• traumatic intubation
• percutaneous tracheostomy
• clearance of airway
• confirm surgical repairs
• Optimal position of lung isolation devices
• Any procedure that involves the use of tube exchangers
• Massive bleeding from single-lumen endotracheal tube

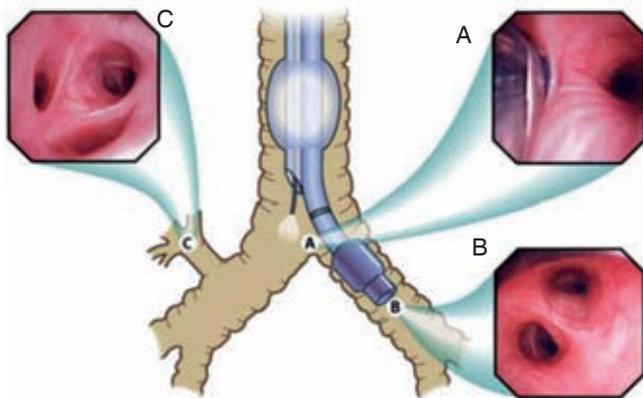


Figure 4. Campos JH. *Curr Opin Anaesthesiol* 2009; 22:4-10. (A) An unobstructed view of the entrance of the right mainstem bronchus when the fiberscope is passed through the tracheal lumen and the edge of the fully inflated endobronchial cuff is below the tracheal carina in the left bronchus. (B) An unobstructed view of the left-upper and left-lower bronchus when the fiberoptic bronchoscope is advanced through the endobronchial lumen. (C) The take-off of the right-upper bronchus with the three segments (apical, anterior, and posterior); this is a landmark to reconfirm a right bronchus.

tracheobronchial rupture, as well as those with small body composition and height < 160 cm, in addition to emergency intubations. The membranous part of the trachea is very friable and susceptible to tearing in the elderly and in women. Patients undergoing esophagectomy are at risk of rupture of the membranous trachea because weakness caused by surgical dissection. Open or percutaneous tracheostomy has been reported as a serious complication of tracheobronchial rupture⁽³⁶⁾.

Airway trauma rupture of the membranous part of the trachea continues to be an isolated problem with the use of DLTs^(37,38). This complication can occur during insertion and placement, while the case is in progress, or during extubation^(39,40).

Airway rupture during the use of DLTs can present as unexpected air leaks, subcutaneous emphysema, massive airway bleeding into the lumen of the DLT, or protrusion of the endotracheal or endobronchial cuff into the surgical field⁽⁴¹⁾. Fiberoptic bronchoscopy is the best tool to confirm the diagnosis and to determine the location and extent of the tracheobronchial rupture⁽⁴²⁾.

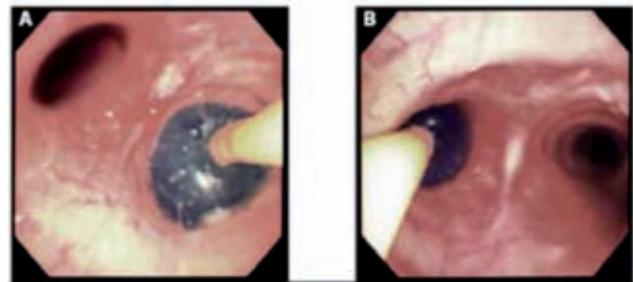
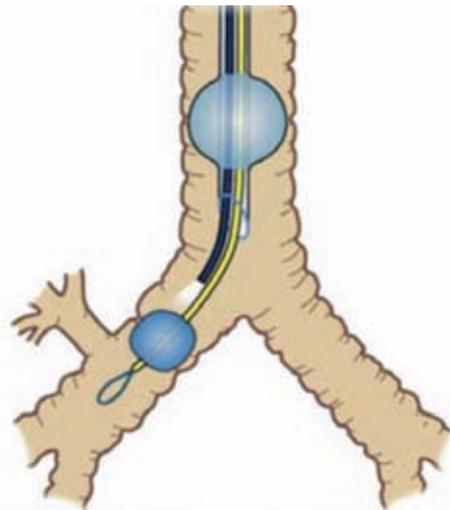


Figure 5. Campos JH. *Curr Opin Anaesthesiol* 2009;22:4-10. The proximal edge of the fully inflated cuff is approximately 5-10 mm below the trachea carina. (A) A bronchial blocker in the right mainstem bronchus. (B) A bronchial blocker in the left mainstem bronchus.

SUMMARY

The use of flexible fiberoptic bronchoscopy should be considered an art in thoracic anesthesia. To master this art, one must be able to recognize tracheobronchial anatomy and changes that occur upon age, understand the anatomical distances of the airway, recognize the take-off of the right upper bronchus, and have familiarity and expertise with the use of the flexible fiberoptic bronchoscope. These will lead to a successful placement of lung isolation devices in thoracic anesthesia and make prompt diagnosis of tracheobronchial ruptures. Also, a uniform training and competence should be included in a trainee's curriculum.

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