Update on tracheobronchial anatomy and flexible fiberoptic bronchoscopy in thoracic anesthesia

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Purpose of review
This review is focused on tracheobronchial anatomy and the use of flexible fiberoptic bronchoscopy in thoracic anesthesia.

Recent findings
A complete knowledge of tracheobronchial anatomy is a key factor in determining proper position of lung isolation devices, namely double-lumen endotracheal tubes and bronchial blockers. In addition, changes occur in tracheobronchial anatomy with age; therefore, it is very important that every anesthesiologist is familiar with these anatomical changes in order to recognize anatomical landmarks and perform a successful placement of lung isolation devices. Flexible fiberoptic bronchoscopy must be considered an art in the practice of thoracic anesthesia.

Summary
Recognition of tracheobronchial anatomy and familiarity with the use of flexible fiberoptic bronchoscope are key components while managing patients undergoing thoracic surgery and anesthesia.

Keywords
bronchial blockers, double-lumen endotracheal tubes, flexible fiberoptic bronchoscopy, tracheobronchial anatomy

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Introduction

Recent progress made in surgical techniques for thoracic, cardiac, and esophageal surgery has led to the increased use of lung isolation techniques with either a double-lumen endotracheal tube (DLT) or a bronchial blocker and the use of fiberoptic bronchoscopy [1]. In addition, there is an increased demand in interventional fiberoptic bronchoscopy for stent placement or laser surgery performed in the operating room [2,3].

In order to achieve optimal position and performance of lung isolation devices, every anesthesiologist must have knowledge of the trachea and bronchial anatomy and its variants. In addition, knowledge of flexible fiberoptic bronchoscopy techniques is required during placement of lung isolation devices and interventional bronchoscopy cases.

This review focuses on the normal anatomy of the trachea and bronchus and the changes that occur with age, a complete fiberoptic bronchoscopy examination and examples of fiberoptic bronchoscopy during placement of lung isolation devices.

Anatomy of the trachea and bronchus

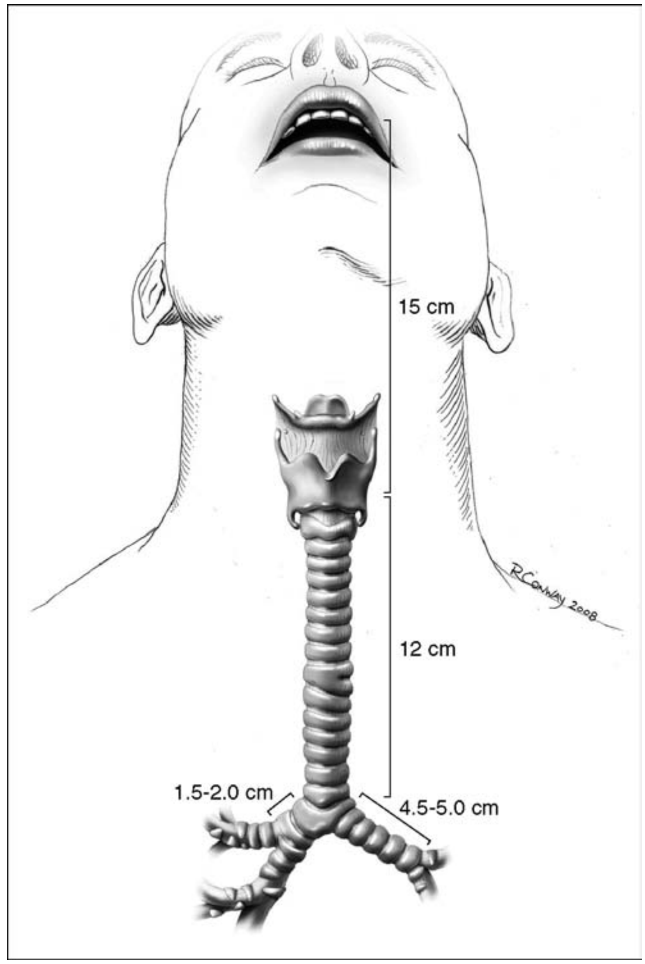
The trachea is a cartilaginous and fibromuscular tubular structure that extends from the inferior aspect of the cricoid cartilage to the level of the carina [4••]. The adult trachea is, on average, 15 cm long. The trachea is composed of 16–22 C-shaped cartilages. The cartilages compose the anterior and 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 is 10–23 mm [4••,5]. 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 obstruction 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 [6••]. 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 average 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 from the general population may have an abnormal take-off of the right upper lobe bronchus emerging from above the tracheal carina on the right side. 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. 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. Figure 1 displays the anatomical distances of the airway. Figures 2, 3 and 4 correspond to a multidetector three-dimensional computer tomography scan of the chest [7•] displaying the trachea and bronchial anatomy in a 25-year-old healthy volunteer (Fig. 2), in a 60-year-old healthy woman (Fig. 3), and in a 60-year-old man with severe COPD (Fig. 4), which shows a deviated trachea and narrow bronchus.

Figure 1 Average length from the incisors to the vocal cords (15 cm) and the distance from the vocal cords to the tracheal carina (12 cm)

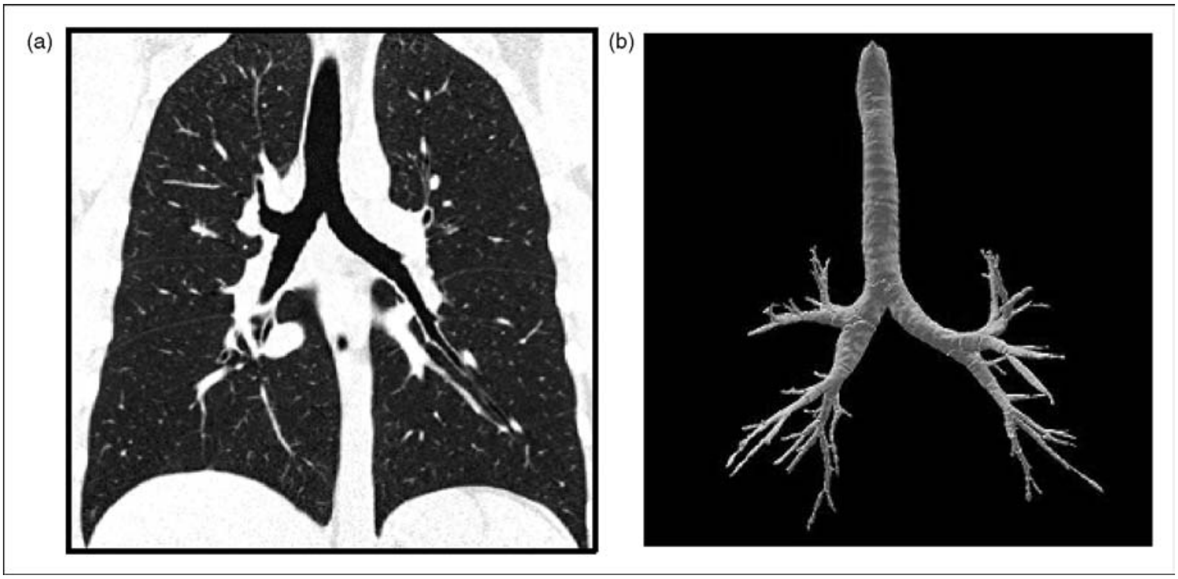


The average distance from the tracheal carina to the take-off of the right upper bronchus is 2.0 cm in men and 1.5 cm in women. The distance from the tracheal carina to the take-off of the left upper and left lower lobe is approximately 5.0 cm in men and 4.5 cm in women. These anatomical distances apply to individuals with a height of 170 cm.

Flexible fiberoptic bronchoscopy examination after intubation

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. Once the tube is advanced beyond the vocal cords and inside the trachea, the tip of the endotracheal 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

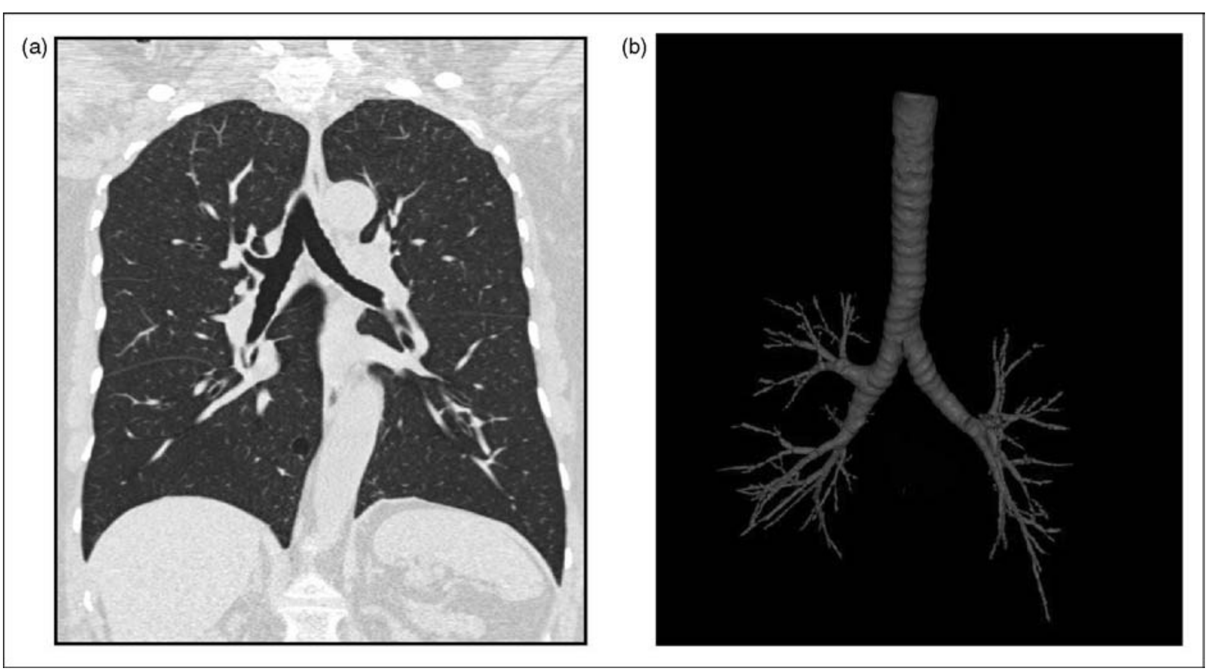
Figure 2 Multidetector three-dimensional computer tomography scan of the chest displaying the trachea and bronchial anatomy in a 25-year-old healthy volunteer



(a) A multidetector computer tomography scan of the chest. (b) A three-dimensional tracheal reconstruction of a 25-year-old healthy volunteer. The trachea is midline with normal distribution of the bifurcation of the bronchus.

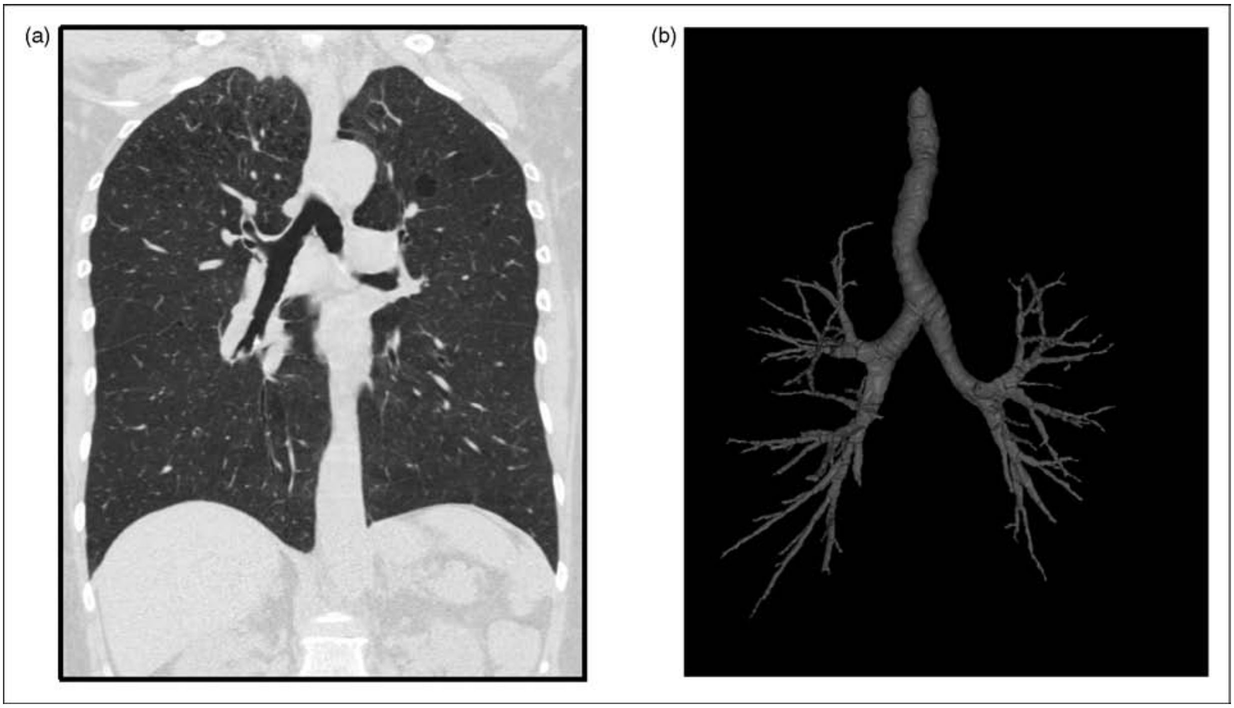
bronchoscope at the same time. When using a large single-lumen endotracheal tube, an adult fiberoptic bronchoscope should be used (4.1 mm inner diameter). Another alternative to perform fiberoptic bronchoscopy is with the use of a laryngeal mask airway (LMA). This technique allows visualization of the vocal cords and subglottic structures with lower resistance than a single-lumen endotracheal tube when the bronchoscope is inserted.

Figure 3 Multidetector three-dimensional computer tomography scan of the chest displaying the trachea and bronchial anatomy in a 60-year-old healthy woman



(a) A multidetector computer tomography scan of the chest. (b) A three-dimensional tracheal reconstruction of a 60-year-old healthy volunteer. The trachea is midline with narrowing of the right and mainstem bronchus.

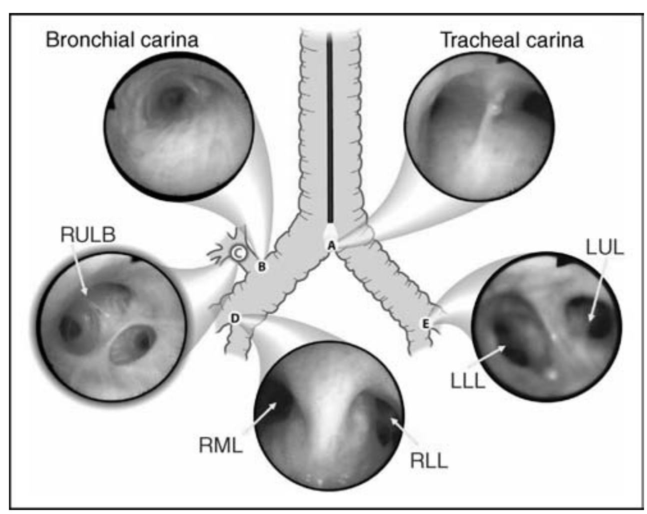
Figure 4 Multidetector three-dimensional computer tomography scan of the chest displaying the trachea and bronchial anatomy in a 60-year-old man



(a) A multidetector computer tomography scan of the chest. (b) A three-dimensional tracheal reconstruction of a 60-year-old male smoker with chronic obstructive pulmonary disease. The trachea is displaced to the right side, and there is a narrowing on the bronchial bifurcation. These changes reflect the smoking history and age.

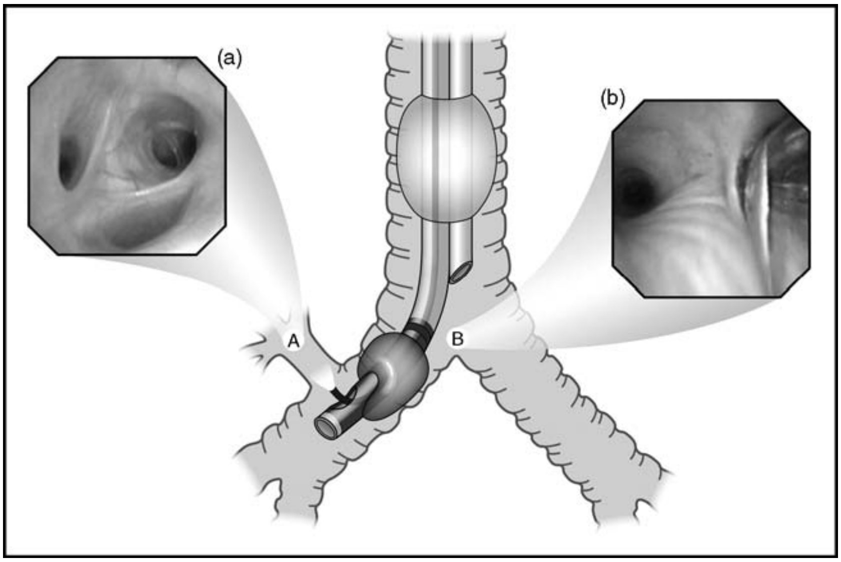
A systematic and complete fiberoptic bronchoscopy examination includes a clear view of the anterior wall (tracheal cartilage) and posterior wall (membranous portion) of the trachea below the vocal cords and of the tracheal carina. When advancing the bronchoscope through the right mainstem bronchus, a clear view of the bronchus intermedius should be seen, and at 3 o'clock the orifice of the right upper bronchus should also be seen. As the scope 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. 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. The anatomical distance from tracheal carina to the bifurcation on the left-sided bronchus is approximately 4–5 cm in length. Figure 5 shows a complete fiberoptic bronchoscopy view of the trachea and bronchus.

Figure 5 A complete fiberoptic bronchoscopy examination



A shows a clear view of the tracheal carina. B shows the take-off of the right upper bronchus. C shows the apical, anterior, and posterior segments of the right upper lobe bronchus (RULB). D shows the right middle lobe (RML) and the right lower lobe bronchus (RLL). E shows a view of the left upper lobe (LUL) and the left lower lobe bronchus (LLL).

Figure 6 The optimal position of a right-sided double-lumen endotracheal tube

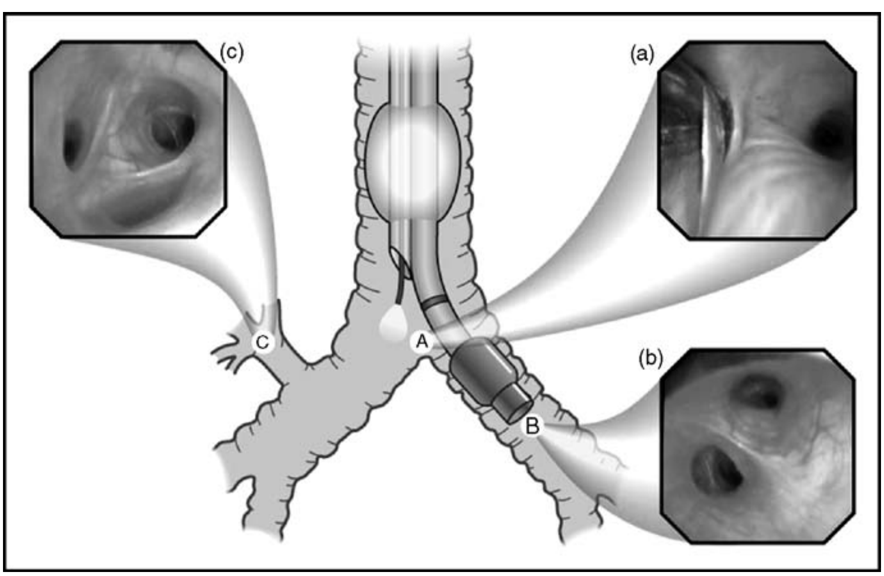


(a) The take-off of the right upper bronchus with three segments (apical, anterior, and posterior) when the fiberoptic bronchoscope emerges from the opening slot located in the endobronchial lumen. (b) An unobstructed view of the entrance of the left mainstem bronchus when the fiberscope is passed through the tracheal lumen and the edge of the fully inflated endobronchial cuff is below the tracheal carina in the right bronchus.

Flexible fiberoptic bronchoscopy and double-lumen endotracheal tube placement

The use of flexible fiberoptic bronchoscopy in thoracic anesthesia has increased the margin of safety and optimal position of DLTs. A study by Klein *et al.* [8] has shown that auscultation and clamping maneuvers alone of one of the limbs of the adaptor for the DLT was not a reliable method to confirm placement, and it led to up to a 35% incidence of malpositions. In contrast, when fiberoptic bronchoscopy was used to reconfirm DLT placement and position, all malpositions were corrected. This clearly

Figure 7 The optimal position of a left-sided double-lumen endotracheal tube



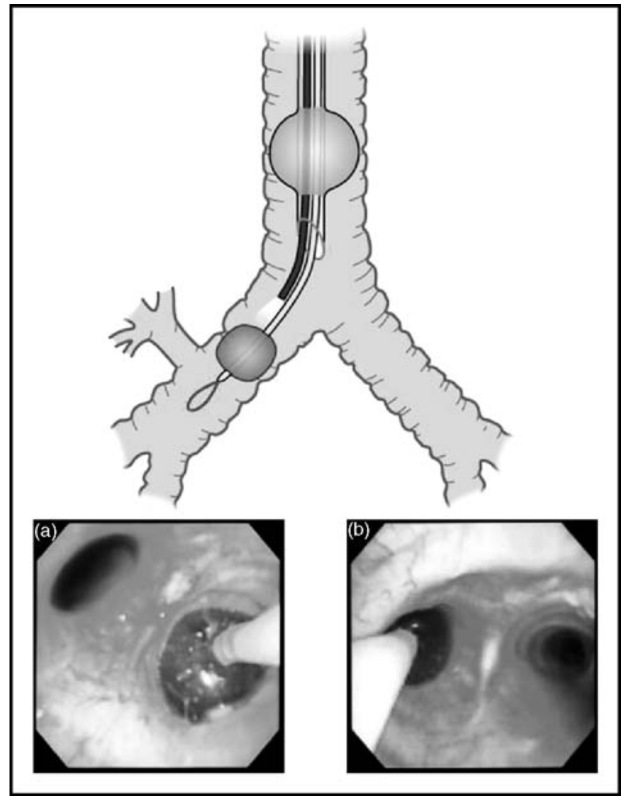
(a) An unobstructed view of the entrance of the right mainstem bronchus when the fiberscope is passed through the tracheal lumen and the edge of the fully inflated endobronchial cuff is below the tracheal carina in the left bronchus. (b) An unobstructed view of the left upper and left lower bronchus 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.

shows the benefits of using fiberoptic bronchoscopy while placing a DLT. A study by Campos *et al.* [9] has shown that anesthesiologists with limited thoracic experience have a high incidence of malpositions (38%) while placing DLTs or bronchial blockers. In this study, one of the factors that contributed to unsuccessful placement of these devices was the lack of recognition of tracheobronchial anatomy.

The basic fiberoptic bronchoscopy examination for achieving optimal position of a right-sided DLT is shown in Fig. 6; Fig. 7 shows the optimal position of a left-sided DLT with the flexible fiberoptic bronchoscope.

Another advantage of the use of flexible fiberoptic bronchoscopy is with the use of bronchial blockers during lung isolation. Previous studies have shown the benefits of using flexible fiberoptic bronchoscopy as an aid to pass a guide-wire bronchial blocker, to achieve the optimal position of the device and correct intraoperative malpositions [10,11]. Figure 8 shows the proper position of an Arndt wire-guided endobronchial blocker (William Cook Europe A/S, Bjaeverskor, Denmark). The optimal position is achieved with the use of a fiberscope. The proximal surface of the fully inflated balloon should be positioned at least 5–10 mm below the tracheal carina in the corresponding mainstem bronchus. While placing a right-sided bronchial blocker, if the distance between the tracheal carina and the take-off of the right upper lobe bronchus is too short (i.e. less than 1.0 cm), a proper adjustment with the fully inflated balloon needs to be made, making sure that the proximal surface of the balloon is located below the entrance of the right mainstem bronchus. Figure 9 shows the proper position of a bronchial blocker on the right mainstem bronchus.

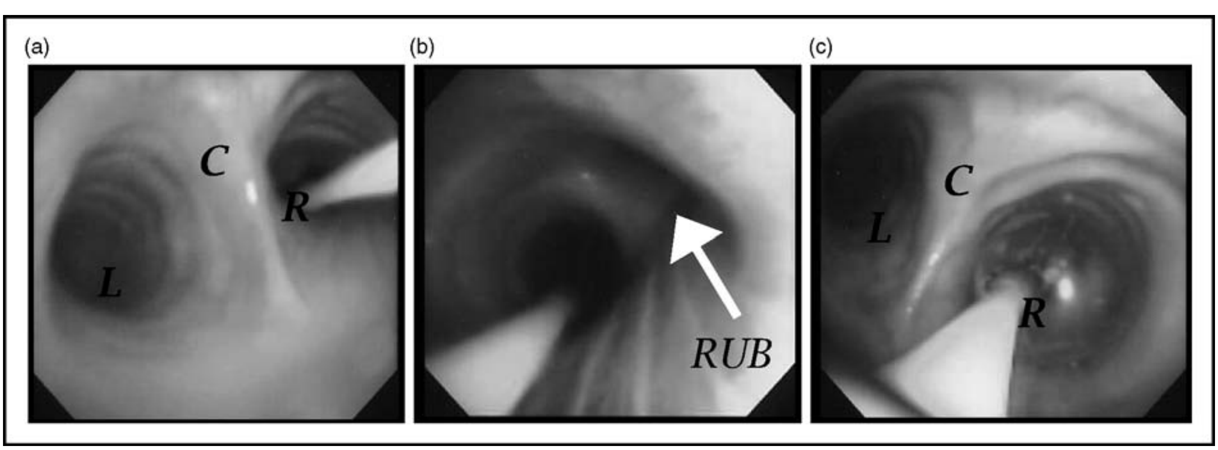
Figure 8 The optimal position of a bronchial blocker in the right and left mainstem bronchus



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; and (b) a bronchial blocker in the left mainstem bronchus.

Flexible fiberoptic bronchoscopy is also used to perform endobronchial metal stent implantation. Another use of flexible fiberoptic bronchoscopy in anesthesia is during the

Figure 9 A fiberoptic bronchoscopy examination during placement of a right-sided bronchial blocker



(a) A view of tracheal carina: L, left mainstem bronchus; C, carina; R, right mainstem bronchus with a bronchial blocker inside. (b) RUB, right upper bronchus, and below bronchus intermedius. (c) C, carina; L, left mainstem bronchus; and R, right mainstem bronchus with a fully inflated balloon just below the tracheal carina inside the right bronchus.

use of airway exchange guide-wire catheters. Complete fiberscope examination is indicated following airway exchange catheter use owing to the potential risk of perforation that the catheter presents to the tracheobronchial tree.

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 with 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.

References and recommended reading

Papers of particular interest, published within the annual period of review, have been highlighted as:
• of special interest
•• of outstanding interest

Additional references related to this topic can also be found in the Current World Literature section in this issue (p. 129).

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