

Bronchoscopy in critical care

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Key points

- Flexible bronchoscopy is a standard of care for specific indications. However, alternative techniques need to be considered.
- Clinical indications are based around a triad of inspection, sampling, and therapy.
- Understanding of the pathophysiological consequences of fibreoptic bronchoscopy in mechanically ventilated patients is essential in order to reduce complication rates.
- Hypoxaemia related to fibreoptic bronchoscopy is associated with an increase in cardiovascular stress and workload. Heart rate, arterial pressure, and cardiac index are increased.
- Mortality is as low as 0.01% with a major complication rate of 0.08–2%.

In recent years, the use of flexible bronchoscopy (FB) has increased in critical care and anaesthesia. It has become a standard of care for examining, diagnosing, and managing critical care patients, and an important adjunct in anaesthetic management of airway problems. Improved knowledge and awareness of the anatomy and physiology of the procedure facilitates appropriate, safe, and effective use of the bronchoscope. This article focuses on FB, with only occasional reference to the techniques involved in rigid bronchoscopy, which are generally beyond the scope of this article.

History

In 1897, Gustav Killian, a German laryngologist and 'the father of bronchoscopy', viewed the trachea and main bronchi through the larynx via a rigid oesophagoscope, and removed a foreign body.¹

In 1904, Chevalier Jackson added an electric light source at the distal end, and a suction channel. In the 1960s, Shigeto Ikeda, a Japanese physician, introduced the first fibreoptic bronchoscope. By the end of the 1980s, Asahi Pentax Company integrated a charge-coupled device, permitting video monitoring of the airway and heightening its educational and clinical benefits.² Over time, a range of various sizes and lengths have been introduced for use across different patient populations.

Types of bronchoscopes

There are two main types of bronchoscopes: rigid and flexible. Rigid bronchoscopy uses a straight metal tube with a bevelled distal tip inserted into the trachea. Although less frequently used than FB in critical care, the rigid bronchoscope has advantages in certain clinical situations, such as massive haemoptysis, removal of large foreign objects, dilatation, or stent procedures to the tracheobronchial tree (Fig. 1).

FB is the most common type of bronchoscopy in critical care. The flexible bronchoscope has a mechanism to flex or extend its distal end, which allows access to otherwise inaccessible areas. There are several variants of traditional FB such as endobronchial ultrasound (EBUS), facilitating transbronchial needle aspiration of enlarged lymph nodes or masses, and ultrathin bronchoscopy (external diameter 2.8 mm), allowing examination beyond third generation of airways.

Traditional FB scopes are becoming replaced by disposable systems. Traditional FBs contain a flexible long tube enclosing a fibreoptic system that attaches to a light source and transmits views from the distal end to the eyepiece, which can attach to a camera or video system displaying images on a screen. Disposable systems do not contain fibreoptic cables, but rather a distal camera illuminated by a light-emitting diode. The image is transmitted via a cable in the device to a re-usable screen. This arrangement combines quality of image with low manufacturing costs. Disposable systems reduce scope downtime by eliminating the need for disinfection between procedures, and potentially reduces cross-contamination and infectious outbreaks.

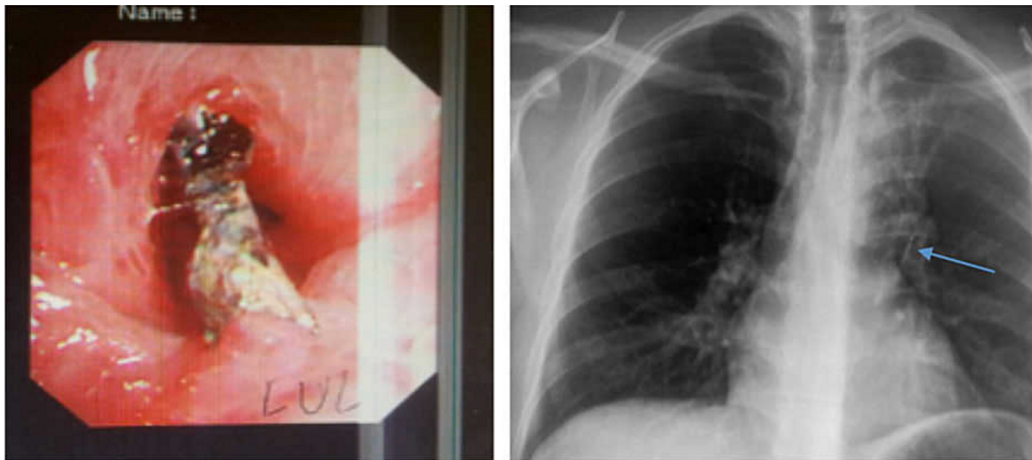


Fig 1 Bronchoscopic image and chest radiograph of a foreign body (metallic pin) inhaled and lodged in the left upper lobe bronchus. (All bronchoscopic images in this article are courtesy of Dr Elankumaran Paramasivam, Consultant Intensivist and Chest Physician, Leeds Teaching Hospitals Trust.)

Table 1 Use of FB in critical care and anaesthesia has multi-modal indications, and all aspects need to be considered before performing FB. PDT, percutaneous tracheostomy; DLT, double-lumen tube; BB, bronchial blocker

Clinical indications	Inspection	Sampling	Therapeutic
Aspiration	x	x	x
Infection	x	x	x
Lobar collapse/atelectasis	x	x	x
Airway management (i.e. difficult intubation, PDT, DLT insertion, BB insertion)	x		x
Airway assessment (i.e. acute inhalation injury, burns, trauma, tracheostomy insertion, mass lesions, tracheoesophageal fistula)	x		x
Foreign body	x		x
Strictures and stenosis	x		x
Haemoptysis/haemorrhage	x		x

Components and physics

The fibreoptic scope is fragile, and vulnerable to damage. This is less of a problem with disposable camera-chip scopes. Understanding the physical principles is important to enable correct use.

Various companies manufacture FBs; however, the overall principle and design is similar. A typical FB contains a:

- **Handle** which contains the eyepiece, a control lever for enabling bending of the FB tip, suction button, and a port to access the suction channel. The eyepiece contains a diopter adjustment ring, enabling the operator to focus the eyepiece to one's vision. The thumb base (bending lever) allows movement of the tip in one plane of motion only, and is usually located at the back of the handle. In addition to the suction port, there is also a separate working channel enabling instillation of local anaesthetic or fluid, and also oxygen delivery.
- The **insertion cord** contains the light and image bundles, suction channel, and the tip bending control wires. These components are held together by a stainless steel mesh and wrapped in water-impermeable plastic coating.³ The insertion cord itself is sheathed in plastic that is inert and forms a hermetic seal, protecting the internal components and allowing the scope to be cleaned and sterilized after use. The cord is flexible and tolerates gentle bending; however, it is the distal tip that is designed for maximum bending. Over-bending of the insertion cord can result in breaking of the fibreoptic fibres.
- **Light source:** In order to distinguish objects during FB, a light source is essential for adequate illumination. Various light

sources are available, although a xenon lamp for white light with switchable filters is used in the majority of scopes. The light source system depends on the manufacturer of the bronchoscope. The autofluorescence endoscopy (DAFE) system is better for diagnosis of tumours (fluorescence is altered by infiltrating tumours), as it does not have white light as its sole emission. The DAFE system is not routinely used in critical care.

A typical fibreoptic bronchoscope contains a coherent (ordered) bundle of *optical fibres* for viewing. The 5000–40 000 fibres are aligned in a coherent fashion, so that the position of the fibres in the image transmission bundle is in the same relative location on both ends of the bundle to represent the true nature of the object being viewed. Alongside the coherent bundles, there are also non-coherent bundles which are used for illumination. The insertion cord connects the distal end to the proximal end, which contains the handle.

Indications and evidence

The common indications for FB can be divided into diagnostic, therapeutic, and combined. These indications are listed in Table 1.

Aspiration

Aspiration of gastric contents is often under-diagnosed in critical care patients, and accounts for significant pulmonary dysfunction. It is an independent risk factor for development of acute respiratory distress syndrome.

Aspirated material is often liquid and disperses rapidly. Hence, routine bronchoscopy with lavage is unlikely to prove useful. In the event that the aspirate is predominantly particulate in nature, with clear radiographic evidence of lobar collapse or major atelectasis, a therapeutic bronchoscopy may prove helpful.⁴ If a substantial volume of gastric content is aspirated, prompt bronchoscopy can remove aspirated gastric fluid and solid material from the central airways, reducing the inflammatory reaction, preventing atelectasis, and reducing risk of infection. A volume of gastric aspirate $>0.3 \text{ ml kg}^{-1}$ of body weight (i.e. 20–25 ml in adults) and a pH <2.5 was traditionally thought to be necessary for the development of aspiration pneumonitis. However, aspiration of particulate food even if the pH >2.5 can cause significant pulmonary damage. Animal studies have shown a biphasic pattern of injury, with an initial peak at 1–2 h after aspiration (direct burn effects) and a second peak at 4–6 h (related to neutrophil infiltration).⁵

Infection

Although 'blind' non-bronchoscopic alveolar lavage has been described (and is used in many units), the most common use of FB in critical care is to collect samples for microbiological analysis in suspected pneumonia. Pneumonia in intensive care patients can be categorized into community-acquired, ventilator-associated pneumonia (VAP), and pneumonia in immunocompromised patients. The role of FB varies between the three.

VAP develops in ~20% of critically ill patients receiving mechanical ventilation. Inappropriate initial empirical antibiotic therapy is an independent predictor of increased mortality. There is variability in the gold standard investigation for diagnosing VAP. There is no superiority of bronchoalveolar lavage (BAL) over less invasive sampling techniques such as blind catheter brushings. Bronchoscopy is more invasive and requires some proficiency to obtain high yielding samples, therefore should not be used in preference to non-invasive diagnostic techniques. In clinically diagnosed VAP, there is good evidence comparing qualitative (presence or absence of pathogens in the culture) and quantitative (with a threshold count of the bacterial growth to differentiate between infection and colonization of the lower airways) cultures obtained in bronchoscopic vs blind techniques, demonstrating no significant differences in mortality, number of days of mechanical ventilation, length of intensive care unit (ICU) stay, or antibiotic change.⁶

The spectrum of infections in immunocompromised patients differs from immunocompetent individuals (Fig. 2). Techniques for obtaining samples depend on the local population, disease prevalence, and host defences.

BAL is considered the gold standard for diagnosis of *Pneumocystis jiroveci* (formerly known as *Pneumocystis carinii*) and, in the absence of prior antibiotic use for treatment or prophylaxis, has a sensitivity between 90% and 98%. Prior antibiotic therapy reduces sensitivity of *P. jiroveci* to 64%. Where PCR is available, high-volume BAL may not be required for the diagnosis of *P. jiroveci*. In patients with pulmonary infiltrates who are immunocompromised but in whom tuberculosis (TB) is thought unlikely, BAL alone is sufficient for diagnostic purposes. In areas of high TB prevalence, transbronchial lung biopsy (TBLB) may be considered in addition, although the overall reported sensitivity for cultures of TBLB is reported to be between 42% and 52%.⁷

Lobar collapse

FB is used in lobar and complete lung collapse in mechanically ventilated patients who fail to respond to treatments such

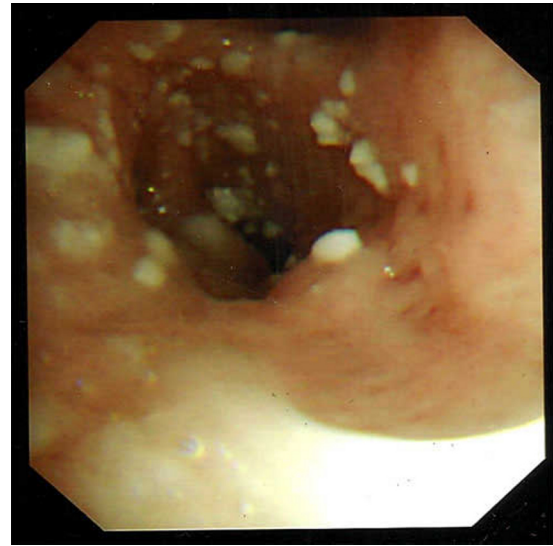


Fig 2 Multiple plaques of candida infection of the left main bronchus.

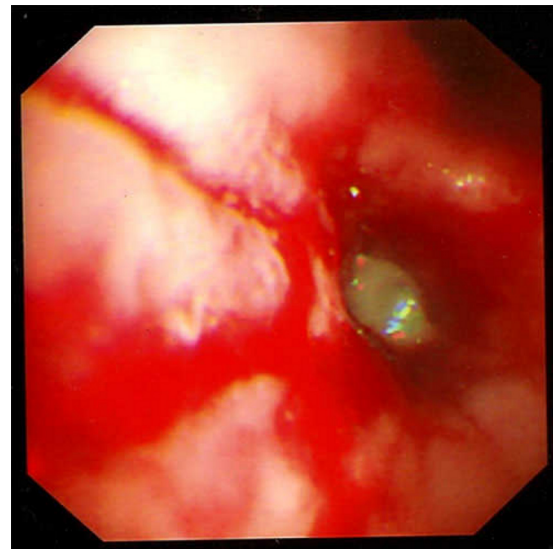


Fig 3 Segmental bronchus blocked with a mucus plug and surrounding inflammation.

as physiotherapy or recruitment manoeuvres. Local, directed suction combined with instillation of saline or mucolytics (e.g. N-acetylcysteine) can be used to treat airway plugging with mucous, blood, or secretions (Fig. 3). Using routine bronchoscopy immediately post-lobectomy to prevent atelectasis, there are no differences in gas exchange, spirometry, radiology, ICU, and hospital stay, when compared with standard care using physiotherapy and suction.⁸

Assessment of airway

Assessing the degree and extent of inhalation injuries has diagnostic, prognostic, and therapeutic value. Early bronchoscopy enables identification of injury and inflammation, and assesses the site and extent of damage. The main therapeutic role for airway inhalation injury (particulate, chemical, or smoke) is airway toilet.

Patients with chest trauma have potential bronchial injury. Clinical manifestation of tracheobronchial injuries is variable and depends on the site and size of air leak. Lesions may not always be clinically evident. Early endoscopic visualization allows diagnosis and early treatment where appropriate.

The awake or patient on NIV

Patients with acute hypoxaemic respiratory failure may already be on non-invasive ventilation (NIV), or require NIV pre-emptively for FB. These patients should be considered high risk for requiring intubation post-procedure; therefore, FB should be performed by an experienced operator in a setting allowing facilities to safely secure the airways.

A number of techniques to facilitate FB during NIV have been described, some requiring specialized equipment.

- Oral bronchoscopy supported by a nasal mask or high flow oxygen (the authors' personal preference).
- Endoscopic facemasks with two orifices; one allowing introduction of endoscope, and the other for administering gas.
- Attaching a T-adapter to a facemask for insertion of the bronchoscope.

Sedation techniques to facilitate FB in an awake patient vary between clinicians. The authors' personal preference is topical application of local anaesthetic directly or as a fine spray; however, a full description of sedation options is too large for the scope of this article.

NIV commenced purely to facilitate FB can prevent respiratory deterioration in spontaneously breathing hypoxaemic patients undergoing FB. A further 10% of patients whom are commenced on NIV to facilitate FB are likely to require intubation within 8 h.⁹ In patients with chronic obstructive pulmonary disease (COPD) due to community-acquired pneumonia, who are unable to clear copious secretions, NIV with early therapeutic FB rather than mechanical ventilation can help avoid intubation and reduce tracheostomy rate. Hospital mortality, duration of ventilation, and hospital stay remain similar.¹⁰

Airway management

Techniques for one-lung ventilation can be accomplished via two methods: double-lumen tracheal tube (DLT) or bronchial blockers (BBs). In critical care, lung isolation may be required either to isolate a diseased lung from contaminating the non-diseased lung or to facilitate ventilation in each lung as an independent unit (i.e. air leak, transplantation, massively different compliance). The indications are few and benefits unproven. Both methods required bronchoscopy for safe and effective lung isolation.

The BB and FB are usually passed down the tracheal tube (TT), allowing placement of BB while still ventilating the patient. Alternatively, BB can be advanced alongside the TT, while FB is advanced down the TT if there is not sufficient internal diameter (ID).

Once the BB is in position, airways distal to the obstruction will collapse. DLTs are inserted without the use of FB; however, confirmation of positioning post-insertion is essential. Using the FB, the (conventionally blue) endobronchial cuff should be identified just below the carina in the appropriate bronchus, by inserting the FB into the tracheal lumen. Additionally, the patency of the upper lobe bronchus needs to be checked by using the bronchial lumen. The outside diameter (OD) of the FB needs to be small enough to fit the lumen of DLT (Table 2).¹¹

DLT, like a BB, can be easily dislodged, therefore confirm position of the tube/blocker once turned to lateral position. A

Table 2 Comparison of how easily an FB will pass through different sized DLTs. Note there is individual adaptability. Adapted from Carin and Hagberg¹¹

FB size OD (mm)	DLT size (Fr)	Fit of FB inside DLT
5.6	41	Easy passage
	39	Moderately easy passage
4.9	37	Tight fit, needs lubricant
	35	Does not fit
3.6–4.2	All sizes	Easy passage
Approximately 2	All sizes	Special arrangements need to be made to obtain this size FB

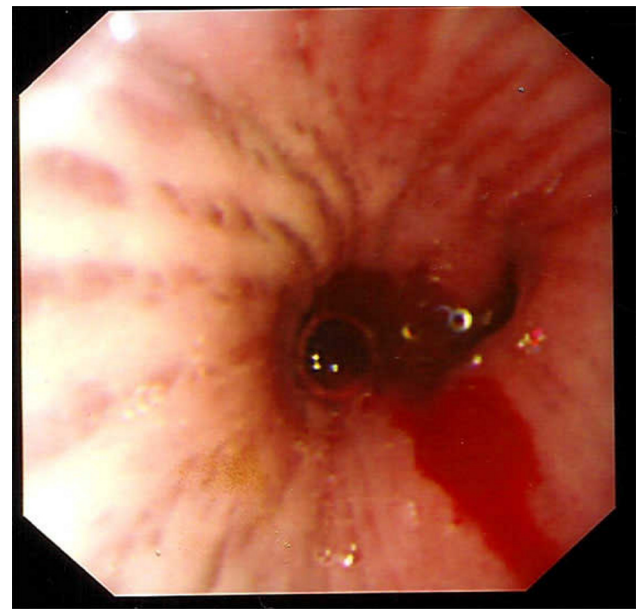


Fig 4 Bleeding from the right lower lobe in a patient with pulmonary haemorrhage.

dislodged cuff of either a DLT or BB can obstruct ventilation or allow contamination of healthy lung.

Percutaneous dilatational tracheostomy (PDT) is a frequent bedside procedure on critical care. Bronchoscopy-guided PDT may have a lower incidence of complications compared without PDT, but studies on this have mixed results. Complications include false airways, pneumothoraces, subcutaneous emphysema, and tracheoesophageal fistulas. Direct visualization with FB may minimize these complications.

FB is an essential component of difficult airway management and an indispensable tool in awake or asleep fibreoptic intubation. Explanation of the role of FB in these settings is beyond the scope of this article.

Diagnosis and management of haemoptysis/haemorrhage

Haemorrhage can range from minor tracheal bleeding from routine tracheal suctioning, to life-threatening haemorrhage from vessel erosion (Fig. 4). FB as the initial and sole use for management of haemorrhage has little value. It is therefore important to consider local resources such as rigid bronchoscopy or interventional radiology as first line. FB should be considered

in the management of haemoptysis or intrapulmonary haemorrhage where this is torrential. FB will aid in positioning of the TT, but visualization will be difficult and FB will not be the definitive treatment. More significant bleeding is likely to require isolation of the affected lobe/lung (where possible) and further imaging. Although FB may be a useful bridging manoeuvre, interventional radiological or surgical treatment may be required.

Anatomy

The trachea is composed of 16–20 C-shaped cartilaginous rings with the trachealis muscle completing the posterior wall. It is ~12 cm long, and 1.6–2 cm in diameter. The trachea terminates at the carina at T4/T5, where it divides into the left and right main bronchus. The surface marking of the carina is at the sternomanubrial junction in a supine patient, but descends inferiorly in the erect patient.

The right main bronchus is 1–2 mm larger in diameter than the left, giving the appearance that the carina is to the left of the tracheal midline. It is 25 mm long. The left main bronchus is 50 mm long. Upper limits of the diameter of the main bronchi in males are 21 mm for the right, and 18 mm for the left. Tracheobronchomegaly is defined as measures greater than these.

The right main bronchus becomes the bronchus intermedius immediately distal to origin of the right upper lobe. The bronchus intermedius is 30 mm long to the origins of the middle and lower lobar bronchi. There are three lobes in the right lung (upper, middle, lower) and two lobes in the left lung (upper with lingular, lower).

The bronchopulmonary segments vary between the lobes (Fig. 5). A useful mnemonic for learning the lobar anatomy is as follows:

- APALM APALM for the right lung.
- APAL APAL for the left lung.

On the left, the lingula of the superior lobe consists of the inferior and superior lingular segments. In the lower lobe of the left lung, the anterior and medial basal segments are often referred to jointly as the anteromedial basal segment, hence the mnemonic of APAL APAL.

The bronchi ultimately become bronchioles, which branch into terminal bronchioles before ending in respiratory bronchioles. Respiratory bronchioles are connected to alveolar sacs.

Major variations of the tracheobronchial tree are found in 2.6% of patients examined by bronchoscopy. The most common main bronchus anomalies are the bifurcate right upper lobe (right upper lobe normally trifurcates), tracheal bronchus ('bronchus sui' or 'pig bronchus' because that is the normal morphology in pigs), and the accessory cardiac bronchus, which are of clinical importance as they may predispose to recurrent pneumonia, cough, haemoptysis, and even malignancies (Fig. 6). The whole right upper lobe or a segment of it may arise from the trachea (0.1–2% prevalence in humans), while a left tracheal bronchus has a prevalence of 0.3–1%.¹² This is relevant with right-sided DLT as they will not isolate/ventilate the right upper lobe.

Accessory cardiac bronchus is a rare congenital anomaly of the bronchus originating either from the right main bronchus medial wall or from the intermediate bronchus opposite to the origin of the right upper lobe bronchus. Its incidence is 0.08% and usually ends blindly. It is lined with bronchial mucosa and normal cartilage wall, differentiating it from a fistula or diverticulum.¹³

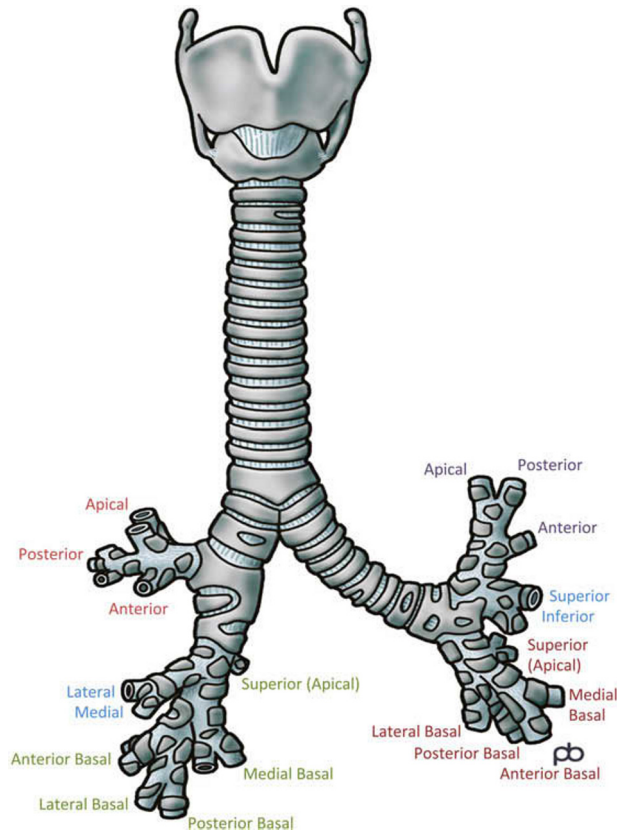


Fig 5 Anatomical representation of segmental anatomy. Right upper lobe: apical, anterior, posterior. Right middle lobe: lateral, medial. Right lower lobe: superior, anterior basal, lateral basal, posterior basal. Left upper lobe: apical-posterior, anterior. Lingular: superior and inferior. Left lower lobe: superior, anteromedial basal, lateral basal, posterior basal. Illustration by Paul Brown, Specialist medical illustrator, Leeds Teaching Hospitals.

Simple practical tips for conducting bronchoscopy include:

- Scope focus, bronchoscopy light source, and white balance must be set before start.
- Orientation: Always keep the bronchoscope in centre of the lumen. If unsure of anatomical location, pull the bronchoscope back and re-identify/re-orientate.
- Remember, the tracheal rings are anterior, and muscularis layer posterior.

The authors recommend <http://www.bronchoscopy.org> for images of normal and abnormal pathology, and video clips.

Physiological changes

Understanding of the pathophysiological consequences of FB in mechanically ventilated patients is essential in order to reduce complication rates. These changes can broadly be categorized and are listed in Table 3.

Increase in airway resistance

Insertion of a bronchoscope causes partial obstruction of the airway, increasing airway resistance, peak inspiratory pressure, reducing tidal volumes (V_t), and increasing PEEP. These variables are further aggravated with decreasing TT size. Assuming laminar flow, the resistance to airflow is inversely proportional to

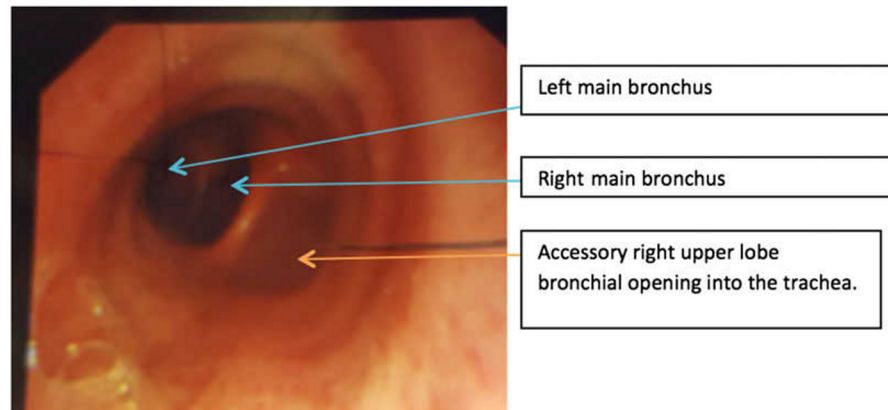


Fig 6 Supernumerary tracheal bronchus: view from the trachea showing the opening of an accessory right upper lobe bronchus opening directly into the trachea in front of the carina.

Table 3 Physiological implications of performing FB

Respiratory	Cardiovascular	Other side-effects
Airway resistance ↑	Cardiac output ↑ or ↓	Intracranial pressure ↑
Changes in lung compliance ↓	Heart rate ↑	
Gas exchange	Pulmonary artery pressure ↑	

the fourth power of the radius of the tube; therefore, obstruction of the airway causes a marked increase in airway resistance. Resistance during FB may be even greater due to the disruption of laminar flow. In non-intubated patients, a 5.7 mm bronchoscope occupies 10–15% of the cross-sectional area of the trachea. In contrast, a 5.7 mm bronchoscopy occupies 40% of a 9 mm TT and 66% of a 7 mm TT. Failure to appreciate the change in diameter and flow will lead to inadequate ventilation.

Intrinsic PEEP increases due to impedance to expiratory flow and insufficient time to complete expiration. A PEEP of up to 35 cm H₂O has been reported with a 7 mm TT, however usually remains below 20 cm H₂O with an 8 mm ETT. There is also a 30% increase in functional residual capacity (FRC) and a 40% reduction in forced expiratory volume in 1 s.¹⁴

Changes in lung compliance

Changes in dynamic and static compliance occur primarily because of alveolar collapse, but suctioning and instillation of normal saline during BAL, which washes out surfactant, can also have effects on compliance.

Gas exchange

Transient hypoxaemia is the most common abnormality, due to a combination of alveolar collapse and depletion of intra-alveolar oxygen due to frequent suctioning and flooding of alveoli during BAL. Hypercapnia is a result of hypoventilation caused by airway obstruction. The presence of FB causes an increase in Pa_{CO₂}, averaging 1.1 kPa, whereas during suctioning, the Pa_{CO₂} increases by 30%. Altering set minute ventilation often does not compensate for the hypercapnia. During suctioning, PEEP and delivered Vt will decrease; as much as 200–300 cm³ of the volume can be lost. Reduced Vt and FRC produce alveolar collapse. Reflex

bronchospasm induced by stimulation of subepithelial vagal receptors in the upper airway is further hypothesized to influence gas exchange.¹⁵ Therefore, it is recommended that suction should not exceed 3 s.

Cardiovascular effects

Indirect effects of FB can cause significant haemodynamic changes. Hypoxia and hypercapnia increases the pulmonary vascular resistance. Changes in intra-thoracic pressure may also affect venous return and afterload, reducing cardiac output. However, an increase in cardiac output secondary to sympathetic stimulation reaching 50% during the procedure, and returning to baseline in 15 min after its completion has been reported.¹⁶ Elevation of arterial pressure, heart rate, pulmonary artery pressure, and cardiac index is caused by a combination of reflex sympathetic discharge secondary to mechanical irritation of airways, hypoxaemia, and hypercapnia.

Precautions, contraindications, and complications

Precautions and contraindications

Critical care patients are often hypoxic, haemodynamically unstable, and have electrolyte and metabolic disturbances. Contraindications to FB include inexperienced bronchoscopist or personnel, inadequate facilities or equipment, and inability to oxygenate or ventilate the patient. All potential and reversible risk factors should be corrected before undertaking bronchoscopy. Table 4 summarizes the conditions or circumstances that increase the risk of bronchoscopy.

Complications

FB is a safe procedure with a low incidence of complications. Mortality rate is as low as 0.01% with a major complication rate of 0.08–2%. Table 5 lists the common complications.

Hypoxaemia related to FB is associated with an increase in cardiovascular stress and workload. Despite this, clinically significant major arrhythmias are infrequent. Increases in systolic arterial pressure and heart rate during FB are associated with ECG changes in 15% (ST-T changes in 4%, transient right bundle branch block in 3%). Unexpected ST changes have been reported in 21% of awake patients over 60 yr of age.¹⁷ Critical care patients

often have inotrope/vasopressor requirements and potentially an element of cardiovascular compromise. Bronchoscopy within 30 days of acute myocardial infarction is associated with 5% mortality, and limited to patients with active ischaemia at the time of bronchoscopy. In the absence of active ischaemia, with good clinical justification, FB can be performed, but is at the discretion of the clinician.¹⁸

A potential complication of FB is an increased intracranial pressure (ICP) during airway manipulation. The use of FB increases the ICP with a concomitant increase in mean arterial pressure; therefore, change in cerebral perfusion pressure is

Table 4 Conditions or circumstances that increase the risk of bronchoscopy

Respiratory and airway
<ul style="list-style-type: none"> Active bronchospasm Presence of pneumothorax Oxygen saturations <90% on FiO₂ 1.0 TT with an ID <8 mm (when using a standard adult bronchoscope of 5.7 mm)
Cardiovascular
<ul style="list-style-type: none"> Haemodynamic instability despite inotropes/vasopressors Unstable arrhythmias Acute ischaemic changes
Haematological
<ul style="list-style-type: none"> Coagulation disorders
Neurological
<ul style="list-style-type: none"> Raised ICP
Metabolic
<ul style="list-style-type: none"> Severe acidosis pH <7.2

Table 5 Potential complications of performing FB

Topical anaesthesia	Bronchoscopy	Biopsy or brushing
Respiratory arrest	Airway obstruction	Pneumothorax
Cardiovascular collapse	Laryngospasm	Haemorrhage
Convulsions	Bronchospasm	
Local anaesthetic toxicity	Hypoxaemia	
	Cardiac arrhythmias	
	Hypotension	
	Vasovagal reaction	
	Pneumonia	
	Pulmonary oedema	
	Haemorrhage	

Table 6 Considerations prior, during, and post-FB on critical care

Preparation	Procedure	Post-procedure
<ul style="list-style-type: none"> Clear indication for FB documented Consent Correct reversible factors Appropriate minimal monitoring Adjust ventilator alarm settings and ventilation settings Enteral feeding stopped or feed aspirated Position patient Position monitors within visual field TT size: ideally at least 2 mm larger than bronchoscope diameter Equipment required available Drugs required available 	<ul style="list-style-type: none"> Ventilator settings Monitoring Experienced operator Manoeuvring the FB Staffing/logistics Situational awareness 	<ul style="list-style-type: none"> Ventilator settings Sterilization Documentation Chest radiograph Appropriate time for recovery and reassessment

limited. FB should still be used with caution in patients with reduced cranial compliance, ensuring that sedation, analgesia, and muscle relaxation are optimized.

Minor bleeding occurs in 0.19% and severe in 0.26% of bronchoscopies.¹⁹ Risk factors for abnormal coagulation include the use of anticoagulant therapy, liver disease, or history or family history of bleeding tendency. Haemoglobin, platelet, and coagulation studies should be performed when clinical risk factors indicate a likelihood of abnormal coagulation; however, abnormal results do not reliably or consistently predict bleeding risk. Over two-thirds of patients who develop bleeding have normal coagulation and no clinical risk factors. Conversely, there is little evidence that correction of clotting pre-procedure reduces clinically relevant bleeding.

The procedure

Before commencing the procedure of FB on ICU, it is important to consider the steps involved. These are summarized in Table 6.

In mechanically ventilated patients, FB is performed through the tracheal or tracheostomy tube by means of a specially adapted valve that facilitates introducing the bronchoscope into the airway circuit without disconnecting from mechanical ventilation. Appropriate sedation needs to be optimized, and muscle relaxation needs to be considered. An optimally sedated and relaxed patient will enable the operator to manoeuvre the bronchoscope easier. Interrupt enteral nutrition prior and during procedure to prevent aspiration risk. Aspirate nasogastric feeding before procedure. If the patient is awake, they should be nil by mouth for 6 h before procedure.

Consider raising the inspired fraction of oxygen (FiO₂) to 1. After the procedure, this can be adjusted to the clinical needs of the patient. Low Vt and significant intrinsic PEEP (PEEPi) may develop unless ventilator modes are carefully considered and selected. PEEPi depends on Vt, respiratory rate, and expiratory time. During pressure-control ventilation (PC), it is important to consider changing present inspiratory pressure to facilitate adequate volume delivery. Changing from square to decelerating flow waveform results in no consistent differences in Vt.²⁰ It is therefore important to appreciate that significant PEEPi may occur regardless of PC or volume-controlled ventilation. Some of the difficulties with ventilation during bronchoscopy can be reduced with modern volume-targeted, pressure-limited (dual control) ventilators.

Decontamination and disinfection should be carried out at the beginning and end of each procedure. Standardized manual cleaning, brushing, and flushing with enzymatic or low foaming

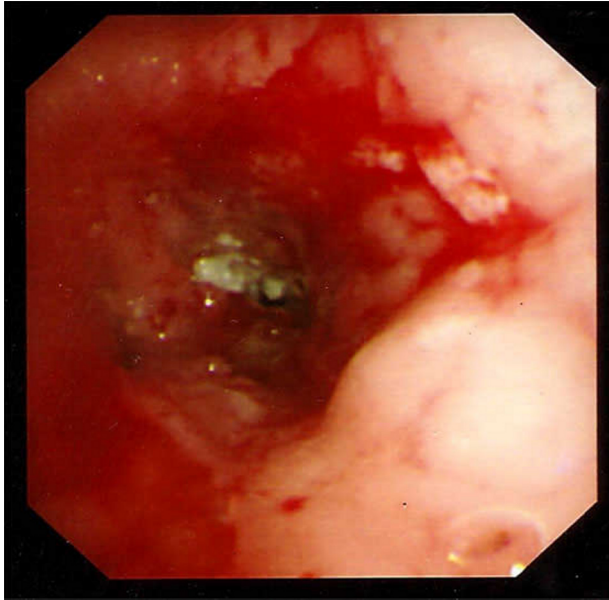


Fig 7 Partial obstruction of the left upper lobe bronchus with tumour infiltration.

detergent immediately after use removes organic materials from FB, enabling thorough disinfection. Choice of chemical disinfectants and disinfection time depends on compatibility with FB and advice from manufacturers, and is completed in an automated endoscope reprocessor. Aldehyde-based disinfectants are no longer recommended as they represent the fifth highest cause of occupational asthma.²¹ Single-use accessories should be selected over reusable accessories wherever possible to prevent cross-contamination. Ensure records of the decontamination process and patient identification are stored and retrievable to facilitate tracing if required.

Investigations

Most infections can be identified from tracheal secretion cultures; however, there are some circumstances in which bronchoscopy and BAL are necessary.

- Some organisms show preference for peripheral airways, that is, *P. jiroveci*, which tracheal secretions or blind brushings/lavage will not reliably access.
- An infection confined to a particular lobe or segment, which cannot be cultured in routine tracheal secretions, i.e. TB, non-TB mycobacteria, and several fungal organisms.
- Distinguish whether the presence of an organism is infection or colonization.

The main investigations during FB consist of BAL, brushings, protected specimen brushings (PSB), and biopsy. There are more advanced techniques such as EBUS transbronchial needle aspiration, which will not be covered in this article.

Bronchoalveolar lavage

In a BAL, multiple aliquots of normal saline are instilled into the required lung segment, and samples are withdrawn by suction. The aim is to apply enough suction to retrieve as much of the sample as possible, without causing airway collapse. The BAL fluid is subsequently stained and cultured for pathogens. A volume of 60 ml will sample proximal airways, whereas volumes

of 100–120 ml will perfuse the entire segment including alveoli, giving the highest microbiological yield. For clinical purposes, it is recommended that 60–180 ml of normal saline is instilled into the segment.

Brushings and PSB

Brushings are used for the cytological diagnosis of malignancy (Fig. 7) and infection. It is accomplished by passing a specialized brush through the suction channel. A normal bronchial brush is not protected from contamination while passing through the channel of FB, therefore is inappropriate for bacterial culture. A PSB is preferred for bacterial culture due to its relatively minimal contamination.

The PSB consists of an external catheter surrounding an inner cannula brush, which is protected by a sterile polyethylene glycol plug at the tip. The FB is advanced to the required segmental bronchi for sampling, at which point, the PSB is advanced until the distal end is visible. The inner catheter is subsequently advanced, pushing the polyethylene glycol plug out. The brush is then advanced through the inner catheter, and moved back and forth in the sampling area. The brush is aseptically cut off into 1 ml of sterile diluent. While inserting the FB, it is advised not to use suction or topical anaesthesia, as this may limit ability to culture bacteria.²²

Biopsy

This is rarely done on critical care. Endobronchial biopsy is performed under direct vision with biopsy forceps being passed through the suction channel. TBLB has a limited role in diagnosis of pneumonia, but invaluable in diagnosis of non-infectious pathologies. Normally, TBLB is done under fluoroscopic guidance, but performed blindly on critical care due to lack of fluoroscopy. There is no convincing evidence that the use of fluoroscopy reduces pneumothorax rate or diagnostic yield in non-focal lung disease.⁷

Summary

FB is a valuable therapeutic and diagnostic tool on selected patient groups in critical care. It is a bedside procedure that should be performed by experienced bronchoscopists whom appreciate the pathophysiological implications and can deal with potential complications. With necessary precautions, FB can safely be performed in critically ill patients.

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Declaration of interest

None declared.

MCQs

The associated MCQs (to support CME/CPD activity) can be accessed at <https://access.oxfordjournals.org> by subscribers to BJA Education.

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