Review article

Bronchoscopy in the intensive care unit

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Abstract. The development of the flexible, fiberoptic bronchoscope has made bronchoscopic examinations possible in ICU patients undergoing mechanical ventilation. Over the years, the number of such procedures has greatly increased, with both diagnostic and therapeutic objectives, such as performing difficult intubation, management of atelectasis and hemoptysis, diagnosis of nosocomial pneumonia in ventilated patients, and early detection of airway lesions in selected situations, such as high-frequency ventilation. The complication rate can be kept low if the endoscopist has a precise knowledge of the many pathophysiological and technical facets particular to bronchoscopy under these difficult conditions. This article reviews some of these aspects, in the light of our personal experience.

Key words: Bronchoscopy - Mechanical ventilation - Hemoptysis - Atelectasis - Bronchoalveolar lavage - High-frequency jet ventilation

The diagnostic and therapeutic usefulness of bronchoscopy is well established [1-3]. Performed for the first time by Killian in 1897 through a rigid tube, it has since then evolved into a practical and much-used technique, thanks to the development of the flexible fiberoptic bronchoscope by Ikeda in the 60’s [1, 4, 5]. Over the years, bronchoscopy has become common practice in intensive care patients [6-9]. However, the bronchoscopist is faced with certain technical problems when these patients are mechanically ventilated. The purpose of this article is to review these problems, and to study the indications for bronchoscopy that are specific to adult critical care patients.

Specific aspects of bronchoscopy in the intensive care setting

1) Type of bronchoscope

Indications for using the rigid bronchoscope have become rare [10]. Indeed, this technique greatly reduces the endoscopist’s scope of vision and manoeuverability, while increasing patient discomfort. Furthermore, it cannot be used during mechanical ventilation. Its use is thus restricted to situations in which it has proved more efficient than the flexible bronchoscope, such as massive hemoptysis, foreign body removal, and Nd-YAG laser therapy [3, 10]. In all other indications, the flexible bronchoscope is preferred [4, 5, 10]. Rigid bronchoscopy was also considered initially to be the technique of choice in small children, but flexible bronchoscopy has now gained widespread acceptance in this patient population [11, 12]. To allow bronchoscopy during mechanical ventilation, special adapting units have been designed [7-9]. They usually consist of a unit connecting the endotracheal tube (ETT) with the respirator tubing. The unit is fitted with a side-port, normally sealed with a cap-lock. The latter is opened and the bronchoscope is inserted through the side port.

2) Consequences on respiratory mechanics

In spontaneously breathing patients undergoing fiberoptic bronchoscopy without intubation, tracheal pressure measured by a transducer connected to the air-filled suction-port of the bronchoscope varies between -5 (inspiration) and +3.5 (expiration) cmH₂O [13] (Fig. 1). The same figures are found in the absence of a bronchoscope. Thus, without intubation, bronchoscopy has little or no effect on intratracheal pressure. When the bronchoscope is passed through an ETT, whether it be oro-tracheal or a tracheostomy tube, the intratracheal pressures, recorded with the same technique, now vary between -10 and +9 cmH₂O [13] (Fig. 1). When the same measurements are performed during bronchoscopy while the patient is mechanically ventilated [13], the following changes are observed (Fig. 2):

(i) the ventilator pressure gauge indicates high maximal inspiratory values, reaching a maximum of 80 cmH₂O in the above-mentioned study [13]. This high peak inflation pressure is due to the presence of the
fiberoscope in the ETT, and represents ventilator back-pressure rather than true intratracheal pressure;
(ii) true intratracheal pressure, measured through the suction-port of the bronchoscope, is much lower. Nonetheless, it is much higher than during spontaneous breathing, averaging 34 cmH2O at end-inspiration [13];
(iii) the intratracheal pressure readings remain positive at end-expiration, between 10 and 15 cmH2O, representing a positive end-expiratory pressure (PEEP) effect. This stems from incomplete lung emptying during the expiratory phase, the presence of the bronchoscope in the ETT adding considerable expiratory resistance. Proof of this was obtained in animal experiments: when suction was applied with the bronchoscope in place, PEEP disappeared [13].

Animal experimentation and clinical studies have shown that these high airway pressures are closely related to the relative internal diameters of the ETT and the bronchoscope [13–16]. Indeed, in the absence of an ETT, a bronchoscope occupies only 10% of the total cross section of an adult trachea [13]. A 5.7 mm internal diameter bronchoscope occupies 40% of the total cross section of a 9 mm internal diameter ETT, 51% of that of an 8 mm ETT, and 66% of a 7 mm ETT [13–16] (Fig. 3).

![Diagram of cross-section of different caliber endotracheal tubes](image)

This considerably increases resistance to flux, up to 11 times in an 8 mm ETT [14]. High inflation pressures result from this, as does a PEEP effect. A PEEP of up to 35 cmH2O has been recorded with a 7 mm ETT [13]. Usually, however, PEEP remains below 20 cmH2O in an 8 mm ETT [13]. Thus, an 8 mm internal diameter is considered the minimum allowing bronchoscopy with a reduced risk of barotrauma [13, 14].

Other effects of fiberoptic bronchoscopy on lung volumes and respiratory mechanics have been documented: in intubated patients, insertion of the bronchoscope induces a 30% increase in the functional residual capacity (FRC), as well as a 40% decrease in the one-second forced expiratory volume (FEV1) [14]. These modifications return to baseline values after removal of the bronchoscope. However, there persists a decrease in mid-expiratory flow rate (FEF 25%–75%), considered to stem from small airway obstruction [14].

### 3) Gas exchange and hemodynamic alterations

The presence of a bronchoscope in the airways induces a slight increase, averaging 1.1 kPa [13] in the PaCO2 and a moderate decrease, averaging between 1.1 [14] and 2.5 kPa [13, 17, 18] in the PaO2 [13, 14, 18]. This probably derives from the smaller tidal volume delivered while the bronchoscope is in place [9]. However, when suctioning is applied, PaCO2 rises by about 30%, while PaO2 decreases by about 40% [13] (Fig. 4). The hypothesized mechanism of these alterations is a reduction in expired tidal volume by suction, thus decreasing the volume participating in gas exchange. Furthermore, as we have seen in the preceding section, suction reduces end-expiratory volume and PEEP. This in turn facilitates alveolar clo-
Fig. 4. Changes in 4 variables during flexible fiberoptic bronchoscopy (FFB) in 6 patients during mechanical ventilation. Pre-bronchoscopy values set at 100%. Reproduced by permission from [13].

sure and venous admixture [13, 14]. These modifications slowly subside following completion of bronchoscopy. The delay before normalization of gas exchange varies from about 15 min for normal lungs to several hours in severe parenchymal disease [13]. These findings have led to the continuous monitoring of arterial oxygenation during and up to 1–2 h after bronchoscopy [17, 19]. It is beyond the scope of this article to compare the various techniques available. Suffice it to say that the method of choice at the present time seems to be pulse oximetry, which allows on-line monitoring of the O2 saturation of hemoglobin by spectrophotometry [20]. It offers more flexibility in its use than transcutaneous PO2 (PtcO2) [17, 19], which requires heating the skin, and offers less reliability in low cardiac output states [20]. In unstable or hypercapnic patients, measurement of the end-tidal expired PCO2 (PetCO2) at the endotracheal tube opening allows a breath-by-breath analysis of changes in the ventilatory status [20].

Few studies have specifically examined the hemodynamic consequences of bronchoscopy in mechanically ventilated patients. In the study by Lindholm [13], cardiac output was measured and showed an increase reaching 50% during the procedure, returning to normal in 15 min after its termination. Heart rate and blood pressure were not reported. A recent study [21] of the cardiopulmonary risk of fiberoptic bronchoscopy in 107 ventilated patients reported no deaths or cardiac arrest during or within two hours of the procedure. There was a 5% incidence of major arrhythmias and a 13% incidence of hypoxemia with a PaO2 ≤ 60 mmHg on FiO2 of 0.8. The latter occurred mostly in patients with ARDS or those that were insufficiently sedated.

These findings tend to confirm the overall safety of fiberoptic bronchoscopy in mechanically ventilated patients. However, in a subset of severely ill patients with limited gas-exchange and hemodynamic reserve close monitoring of key parameters is mandatory.

Thus, guidelines can be drawn in order to minimize the risk of fiberoptic during mechanical ventilation, which are summarized in Table 1.

### Table 1. Bronchoscopy in mechanically ventilated patients

1. Use an endotracheal tube with an internal diameter of at least 8 mm, if a standard fiberoptic size (5.7 mm diameter) is utilized.
2. Discontinue PEEP or reduce by 50%, or monitor bronchoscope tip pressure.
3. Increase FiO2 to 1.0 starting 15 min before procedure and tidal volume by about 30% during bronchoscopy.
4. Check arterial blood gases before and after procedure. Postpone examination if SaO2 < 90% on FiO2 1.0.
5. Monitor SaO2 by continuous pulse oximetry.
6. Monitor tidal volume.
7. Monitor PetCO2 in selected unstable and/or hypercapnic patients.
8. Monitor pulse and blood pressure.

### 4. High-risk patients

#### a) Coronary-artery disease patients.

No study has specifically addressed the issue of evaluating the risk of fiberoptic bronchoscopy in coronary patients. However, from different studies dating back to the 70s, it can be deduced that, in stable coronary patients, there is no increase in the incidence of serious arrhythmias or in mortality resulting from the procedure [22–24]. In a series of 48,000 procedures, there were 10 reported deaths [24]. Ischemic heart disease was documented in 6 of these patients. Cardiac arrest or intractable ventricular arrhythmia during or immediately after the procedure was the cause of death. An 11% incidence of major arrhythmias during bronchoscopy has been recorded in ambulatory patients [25]. All were self-limited and had no hemodynamic consequences. The presence of known coronary disease was not associated with a higher risk of arrhythmia. However, hypoxemia at the end of bronchoscopy (PaO2 < 60 mmHg) did entail an added risk of arrhythmia. The issue of patients in the immediate post-infarction is not resolved. Nonetheless, it seems reasonable to defer if possible the procedure in patients who have just had a myocardial infarction, as well as to monitor with extreme care SaO2 during fiberoscopy in any patient with known coronary disease. Sedation should also be adequate, to prevent tachycardia and oxygen desaturation.

#### b) Asthmatic patients.

Fiberoptic bronchoscopy in asthmatic patients is usually indicated for removing obstructive mucous plugs and secretions from the airways [26]. However, severe laryngospasm and bronchosperm have been described as a result of this procedure [27]. Another study showed no decline in FEV1 after fiberoscopy and bronchoalveolar lavage (BAL) in mild asthmatics. A recent study comparing asthmatic and non-asthmatic patients undergoing bronchialveolar lavage and endobronchial biopsies documented arterial oxygen desaturation and a significantly greater decrease in post-procedure FEV1 in the asthmatic group [28]. The latter correlated with the measured degree of bronchial reactivity 5 days prior to bronchoscopy [28]. There were no serious complications aside from mild, reversible bronchosperm. It is to be noted that the patients in these studies were not under conditions of mechanical ventilation. Thus, it
seems that indications for bronchoscopy, BAL, and endobronchial biopsies should be weighed carefully. If possible, corticosteroids should be administered for a few days prior to the procedure, especially in unstable patients.

c) Other potential high-risk patients. In the study by Suratt [24], all 10 patients who died presented with either ischemic heart disease, as we have already seen, chronic lung disease, or cancer. It is however obvious that belonging to either of the two latter diagnostic categories is insufficient evidence per se of being at higher risk to undergo bronchoscopy. Rather, the degree of severity of these illnesses conditions the risk factor. Finally, respiratory failure requiring intubation and mechanical ventilation after bronchoscopy with bronchoalveolar lavage has been observed in immunocompromised patients [29, 30].

Indications for bronchoscopy in the intensive care unit (ICU)

1) Intubation

Bronchoscopy allows direct visualization of the laryngeal opening and the vocal cords. It is therefore possible, once the fibroscope is in the trachea, to slide an ETT over it, thus enabling intubation when the laryngeal structures cannot be visualized with the laryngoscope [10, 31, 32]. When the bronchoscope is of a small diameter, however, it is possible for it to be bended by the ETT just prior to the laryngeal opening, with resultant esophageal intubation [33]. This can be avoided by continuously viewing the trachea while the ETT is inserted, and by visualizing the tip of the ETT through the bronchoscope before advancing both as a unit until reaching proper ETT position above the carina [32, 34]. Some manufacturers have also developed stiffer bronchoscopes designed to avoid bending by the ETT and esophageal intubation [32]. The claimed merits of such a fibroscope have not, to our knowledge been confirmed by rigorous studies. Bronchoscopy, nonetheless, is seldom used for intubation in the ICU: a recent series showed that intubation represented 0.5% of all indications [31]. We have studied this problem in our institution (general hospital, 1,600 beds): during the year 1987, about 17,000 intubations were performed in the different operating rooms, ICU’s, emergency rooms and wards. Only 12 of these were carried out with the help of a bronchoscope, a mere 0.07% of the total. A detailed analysis of these cases shows 8 elective and 4 emergency situations (Table 2). As can be seen from the short time needed, intubation with the bronchoscope was fairly easy in the elective cases. The only failure to intubate resulted from the inadvertent administration of a muscle-relaxant, which stopped the inspiratory movements that were guiding the endoscopist. Quite different was the situation in the emergency cases: the failure rate was 25%, vs the 14% in the elective cases, and the time necessary to succeed in the intubation was much longer. This stems from the fact that emergency intubations with the fibroscope were performed after many failed attempts with the laryngoscope, the latter having caused local bleeding and edema. Some conclusions can be drawn from this small series:

(i) The bronchoscope is a very helpful tool for intubation, but is needed in only a small number of cases;

(ii) if a difficult intubation is anticipated, it is preferable to use the bronchoscope from the onset, rather than use it after many unsuccessful attempts with a laryngoscope;

(iii) bronchoscopy must be performed by an experienced endoscopist. The preferred fibroscope diameter in an adult is 5.7 mm. A pediatric fibroscope should not be used, as it is more flexible and thus more prone to bending into the esophagus [32, 33]. Intubation can be carried out through the oral or nasal routes. The oral route is preferable, as the presence of a nasotracheal tube has been shown to increase the incidence of purulent sinusitis [35], and, also as the oro-tracheal route allows insertion of a larger internal-diameter tube. This in turns facilitates tracheal secretion aspirations, bronchoscopy if needed, and decreases the patient's work of breathing [36].

2) Atelectasis

Atelectasis is a frequent problem in the ICU. It most often results from retained bronchial secretions, due to increased production and/or decreased cough efficiency (post-operative period, mechanical ventilation, neuromuscular disease) [37–40]. Left untreated, it may impair gas exchange, predispose to infectious complications, or, more rarely evolve into fibrosis [38]. As soon as the fiberoptic bronchoscope was produced, its use to aspirate secretions more efficiently to prevent or treat atelectasis expanded rapidly [39, 41, 42]. The superiority of this approach has not, however, been established through care-

Table 2. Intubations with the help of a fibroscope, Hôpital Cantonal Université de Genève, over a 12-month period

| Patient | Age | Sex | Underlying condition | Time to intubation (min) | Comments |
|---------|-----|-----|----------------------|--------------------------|----------|
| 1       | 62  | F   | RA                   | 5                        | –        |
| 2       | 60  | F   | RA                   | 5                        | –        |
| 3       | 22  | F   | Juvenile RA          | 7                        | –        |
| 4       | 30  | M   | Short neck           | 2                        | –        |
| 5       | 38  | M   | Short neck           | 5                        | –        |
| 6       | 22  | M   | Dysmorphism          | Failure                  | MR       |
| 7       | 42  | F   | Previous failure     | 5                        | –        |
| 8       | 46  | M   | Previous failure     | 0.5                      | –        |
| 9       | 41  | M   | Failed intubation    | Failure                  | Epistaxis|
| 10      | 62  | F   | Failed intubation    | 20                       | UAE, LB  |
| 11      | 54  | M   | Failed intubation    | 18                       | UAE, LB  |
| 12      | 34  | F   | Failed intubation    | 20                       | UAE, LB  |

Abbreviations: MR, Muscle relaxant administered just prior to procedure; RA, rheumatoid arthritis; UAE, upper airways edema; LB, local bleeding (oropharynx and/or nasal)
fully controlled trials. Marini et al. studied intubated and non-intubated postoperative patients with acute lobar atelectasis: no difference was observed in the speed of radiologic improvement between the group treated by respiratory therapy alone and the group undergoing bronchoscopy [38]. An interesting finding was that in each group, the presence of an air bronchogram predicted delayed resolution of the atelectasis. This is probably due to the fact that an air bronchogram indicates patency of the large airways, the only ones accessible to either method [38]. Patients with neuromuscular disease seem to benefit from a bronchoscopic approach. It has been shown that these patients frequently develop proximal atelectasis due to mucus-plug forming as a result of ineffective cough mechanisms and other less well-known causes [37, 43]. We have studied 6 patients with the Guillain-Barré syndrome (GBS) requiring mechanical ventilation due to acute respiratory failure. During the period of mechanical ventilation (mean duration ± SD: 30 ± 20 days), 2 patients did not develop atelectasis. The 4 others had repeated episodes of segmental, lobar or pulmonary atelectasis (total 25), 76% of which were located in the lower lobes. There was no air bronchogram on the chest X-ray. Bronchoscopy was performed immediately, successfully removing mucus plugs. A-a DO2 decreased by a mean (±SD) of 15.9 (±12) kPa. We thus favor rapid bronchoscopy in GBS patients with atelectasis, as the cause is usually located in the central bronchi, and thus accessible to a treatment leading to improved gas exchange.

Finally, a new method of reexpanding atelectatic lung regions, using the flexible bronroscope, has recently been described [44]: it consists of room air insufflation by means of an Ambu bag into the working channel of a bronroscope wedged in a segment of the collapsed region. A pressure gauge is connected by a three-way adapter, and peripheral airway pressure kept below 30 cmH2O, or 10 cmH2O above previous airway pressure. Rapid and complete radiological resolution, accompanied by a substantial decrease of the alveolo-arterial oxygen gradient over the following 24 h, was obtained in 12 of 14 ICU patients. There were no complications [44]. Further validation of this technique is required.

3) Hemoptysis

Bronchoscopy is a very efficient diagnostic tool in patients with hemoptysis [2, 3, 10, 45]. In about 10% of cases, hemoptysis is massive [46]. In such situations, the rigid bronchoscope is often preferable, as it allows better vision, provided that the source of bleeding is proximal, and more efficient aspiration [3, 10, 45]. However, the flexible bronchoscope has been used successfully in cases of more distal bleeding sources [47–50].

When massive hemoptysis occurs, bronchoscopy, in addition to serving diagnostic purposes, can also be therapeutic, by guiding either endobronchial tamponade [45, 47–49] or hemostasis by application of fibrin precursors [50]. Endobronchial tamponade, as classically described, consists of passing a Fogarty balloon catheter through the bronroscope's aspiration channel, and inflating it to occlude the bleeding zone [51]. This either stops the bleeding or buys enough time to perform a thoracotomy [49]. Once the bleeding has stopped, the main problem is determining both the balloon's inflation pressure and the time during which it stays inflated, trying to avoid tracheal mucosal damage [52, 53]. In one series, a period of 24 h is mentioned, but neither inflation pressure nor the presence or absence of mucosal damage are outlined [49]. We have been able to document these aspects in 2 of our patients:

(i) **Patient 1** was a 63-year-old male, alcoholic, cirrhotic, heavy smoker, intubated because of a hemoptysic episode of 600 ml in 12 h. The source of bleeding was in a right antero-superior sub-segment. Persistent hemoptysis despite a continuous infusion of vasopressin would have prompted surgical treatment. However, the patient's general condition was so poor that he was judged inoperable. A Swan-Ganz pulmonary artery balloon catheter was inserted, under bronchoscopic guidance, in the sub-segment, and inflated over the bleeding source (Fig. 5). The balloon was left inflated with a pressure not exceeding 40 mmHg, verified by means of a manometer, for 48 hours. The maximal pressure was set approximately, in line with experimental data indicating an increased risk of mucosal injury when 30 mmHg are exceeded [52, 53]. There was no recurrence of hemoptysis after the catheter's withdrawal. However, the patient died 10 days later of severe hepato-renal syndrome. Autopsy showed only a small bronchial parietal hematoma corresponding to the source of the bleeding, but no zones of mucosal necrosis at or near the balloon's position were detected on serial histologic sections.

(ii) **Patient 2** was a 66-year-old male patient suffering from multiple myeloma, with chronic heart and renal failure. He was intubated for acute respiratory distress. The chest X-ray showed bilateral patchy infiltrates. Bron-
choscopy with BAL and transbronchial biopsy was performed. Soon thereafter, massive hemoptysis occurred. Using the same technique as in patient 1, a Swan-Ganz catheter was inserted under bronchoscopic guidance into the bleeding segment. The bleeding stopped, with minimal impairment of an already precarious gas exchange situation. The balloon was also left in place for 48 h. The situation momentarily improved, but the patient developed multiple organ system failure (MOSF) and died on the 15th hospital day. As in the preceding case, serial histologic examination did not show evidence of bronchial mucosal damage due to the balloon.

These cases document the fact that endobronchial balloon-catheter tamponade is feasible without causing added mucosal damage, for up to 48 h, with an inflation pressure not exceeding 40 mmHg. Furthermore, our choice of the Swan-Ganz rather than the Fogarty catheter merits comment. The Fogarty, inserted through the channel of the fibroscope, cannot, for reasons of size, occlude less than a lobe, or even sometimes an entire lung. The Swan-Ganz, inserted beside the bronchoscope, is smaller in diameter and can be manoeuvred into subsegmental bronchi. This can be helpful to preserve gas exchange as much as possible, as patient 2 illustrates.

Though their description is beyond the scope of this article, other techniques are potentially useful to manage certain bleeding lesions such as iced-saline lavage [54], endobronchial electrosurgery and laser therapy through the bronchoscope [55], and the spraying of fibrin precursors on the site of hemorrhage [50].

It should nevertheless be remembered that surgery has been advocated as the treatment of choice in massive hemoptysis [46, 48], and should always be considered. However, an attractive alternative in experienced hands is bronchial artery embolization, and might be the preferred technique in patients at high surgical risk [56].

4) Diagnosis of nosocomial pneumonia

The incidence of nosocomial pneumonia during mechanical ventilation varies from one study to another, from 20% in a general population of ICU patients to 70% in the adult respiratory distress syndrome (ARDS) [57–59]. In the latter, it must be noted that mortality directly attributable to respiratory failure is only 16%, the principal cause of death being sepsis evolving into multiple organ failure (MOF) [60]. The entry point leading to sepsis is most often the lung [60]. Excess mortality resulting from nosocomial pneumonia is difficult to evaluate, but is estimated at 15% [61]. Rapid diagnosis is thus important. Unfortunately, the usual clinical, laboratory and radiological workup has an insufficient predictive value [57, 61]. A bacteriological examination is thus necessary. The great difficulty in obtaining good quality samples in a mechanically ventilated patient by simple tracheal aspiration [62, 63], has lead to the development of improved techniques of bacteriologic sampling [59, 61, 64–76]. We will briefly discuss the most often used bronchoscopic techniques:

a) Protected specimen brush (PSB). This technique was initially described in 1979 [74]. Its value was subsequently confirmed by Chastre in 1984 [72], in a study showing a good correlation between cultures of PSB and those obtained from lung tissue samples, considered to be the gold standard. However, the method's excellent sensitivity of 100% was accompanied by a specificity of only 80% [72]. In a subgroup of patients already receiving antibiotic treatment, specificity was a very poor 42% [72]. A subsequent study by the same group [71] reported a sensitivity of 100% and a specificity of 90%. Nonetheless, a certain number of technical pitfalls must be kept in mind:

(i) the volume of secretions obtained is very small, around 0.001 ml [74]. This requires very precise sample-handling. It also explains why in most studies other than Chastre's [72] the sensitivity of PSB was lower than that of BAL, which retrieves a larger volume of fluid and explores a larger alveolar volume, estimated at 5–20 million alveoli [64];

(ii) PSB entails an added risk of bleeding and pneumothorax [77].

b) Broncho-alveolar lavage (BAL). BAL has been studied as an alternative to PSB, with improved specificity and less risk of complications [59, 66–68, 78]. It is unfortunately inevitable that some degree of contamination by proximal airway secretions occurs. To minimize its consequences, various criteria have been used [63, 66, 67, 69, 78, 79]. Specificity was shown to be very good when more than 10⁵ colony forming units (CFU) were present in the culture [78]. It is poor, however, when there are less CFU's [78]. It is possible to improve specificity by taking into account the epithelial cell count [67] and/or a bacterial index from quantitative cultures [72]. Studies which have compared BAL and PSB do not reach a definite conclusion as to the superiority of one over the other [61, 63, 69]. An important factor to be considered is time: rapid results are needed, in order to decide whether antibiotic treatment should be initiated or modified. Chastre [79] showed that, in the microscopic examination of BAL fluid, the presence of micro-organisms in more than 7% of macrophages and neutrophils was diagnostic of pneumonia with a sensitivity of 86% and a specificity of 96%. In another study, the Gram stain of a cytocentrifuged BAL sample showed very good correlation with the results of BAL cultures, in predicting the nature of the organism involved [78]. In terms of complications, bleeding and pneumothorax are more frequent with PSB [77]. BAL causes moderate transient hypoxemia, prompting continuous monitoring of gas exchange and an increase the FiO₂ to 1.0 during the procedure [17, 19, 68].

A summary of the different techniques for the study of material retrieved by BAL and PSB, as well as their sensitivity and specificity, is shown in Table 3.

c) Transbronchial biopsy (TBB). Compared to BAL and PSB, TBB offers the added advantage of a histologic examination of the lung parenchyma [10, 80]. Its superiority in the diagnosis of nosocomial pneumonia has not been shown, nor has it proved better than BAL in diagnosing opportunistic lung infections in immunosuppressed patients [81, 82]. It carries a 7–14% risk of pneumothorax [83, 84], as will be discussed in the section on complications.
Table 3. Most widely used bronchoscopic techniques for the diagnosis of nosocomial pneumonia

| Technique | Sample analysis/ diagnostic criteria | Reference | Sensitivity | Specificity |
|-----------|--------------------------------------|-----------|-------------|-------------|
| BAL       | > 7% Macrophages/PMN's containing bacteria | [79]       | 86%         | 96%         |
|           | Gram stain, cytocentrifuged sample ≥1 micro-organism/100 x field | [78]       | 73%         | 100%        |
|           | Quantitative cultures (Bacterial index ≥ 5) | [69]       | 74%         | 92%         |
|           | Quantitative culture (>10^5 CFU/ml + ≤ % SEC) | [67]       | 100%        | 100%        |
| PSB       | Gram stain                            | [113]      | 58%         | N.A.        |
|           | Quantitative cultures (>10^5 CFU/ml)   | [72]       | 100%        | 77%         |
|           |                                       | [113]      | 70%         | 100%        |
|           |                                       | [71]       | 100%        | 90%         |

BAL, Bronchoalveolar lavage; PSB, protected specimen brush; SEC, squamous epithelial cells; CFU, colony forming unit; N.A., information not available; Bacterial index, sum of the log number of the concentration of the different bacteria identified (example: Klebsiella pneumoniae 10^7/ml and Pseudomonas aeruginosa 10^9/ml. Bacterial index = 3 + 4 = 7)

d) Immunosuppressed patients. TBB or open-lung biopsy has been considered as the method of choice for diagnosing opportunistic lung infections in this patient population [10]. A study performed by Williams [81] showed, however, that bronchoscopy with BAL and PSB had a diagnostic sensitivity for infection of 90%. Furthermore, when BAL and PSB were negative, TBB was of no added benefit, while open lung biopsy was marginally contributory [81]. This confirmed results from a previous study by Stover [85]. In patients with the acquired immunodeficiency syndrome (AIDS), both BAL and TBB were initially performed, as they were shown to be complementary [86]. As techniques of microbial identification, in particular of Pneumocystis carinii, improved, TBB was abandoned, as BAL was shown to have sufficient yield by itself [82]. BAL is thus usually the preferred technique, except for the diagnosis of the lymphocytic interstitial pneumonia of AIDS, where TBB is needed, and coccidioidomycosis, where BAL and TBB combined have a higher yield [87].

e) Non-bronchoscopic lavage (NBL). There seems to be a promising future for non-bronchoscopic lavage [75, 76, 88–90]: a recent study from our institution confirms that a simple catheter, introduced blindly in the tracheo-bronchial tree can have diagnostic accuracy comparable to bronchoscopic BAL, irrespective of the segment in which it is located [89]. Another recent study [90] comparing the yield of PSB with that of aspiration from a plugged telescopic catheter showed that the latter was as accurate as PSB in diagnosing nosocomial pneumonia in ventilated patients. Furthermore, whether the catheter was guided into place by bronchoscopy or introduced blindly into the tracheo-bronchial tree, its yield was the same [90].

After reviewing the available data, defining the optimal diagnostic approach to the diagnosis of nosocomial pneumonia in ventilated patients remains a difficult matter. Deciding whether to use BAL, PSB or NBL is often a matter of personal experience. We favor bronchoscopic BAL, as it allows inspection of the tracheo-bronchial tree. A Gram stain of a cytocentrifuged sample and a count of bacterial-containing and squamous epithelial cells provides rapid diagnosis. Quantitative bacterial cultures with a cut-off value of 10^5 CFUs/ml allow diagnostic confirmation, bacteria identification, and antibiotic adjustment.

5) Evaluation of tracheo-bronchial lesions during high-frequency jet ventilation (HFJV)

The use of HFJV has been described in laryngeal surgery, during bronchoscopy, in the treatment of broncho-pleural fistulas, and to improve oxygenation in infant or adult respiratory distress syndrome [91–93]. Clinical and experimental studies have shown that HFJV can cause tracheal and main bronchi damage in the form of mucosal edema and congestion, leading to erosions evolving into hemorrhagic necrosis [94–100], in turn causing airway obstruction [96, 98, 99]. We have studied 7 patients undergoing HFJV for severe respiratory distress [101]. The 7 patients died. A detailed histologic examination showed dramatic tracheal wall lesions in all the patients. The severity of histological damage correlated with the number of jet pulses administered (Fig. 6). These data should prompt caution as to duration and frequency when administering HFJV. Humidification, either too little or too much seems to be an important contributor to the development of tracheal lesions, and should also be monitored carefully [102, 103]. Some authors recommend repeated bronchoscopic evaluations, possibly with tracheal biopsies, during HFJV, to prevent the transition to severe lesions [98, 99]. We try to abide by these recommendations. However, it is not always feasible to perform

![Fig. 6. Correlation between the number of administered jet pulses (jet frequency per min x 60 x number of hours of jet ventilation) and a histological severity index of tracheal wall damage, in 7 patients having received high frequency jet ventilation (HFJV). Reproduced by permission from [101]](image-url)
bronchoscopy in the often disastrous gas exchange conditions of these patients. Furthermore, it remains to be proved that the early detection of lesions can lead to avoidance of the evolution to necrotizing tracheobronchitis.

6) Other indications

a) Trauma. In a series of 53 patients having sustained chest trauma, bronchoscopy performed within 3 days revealed lesions such as tracheal or bronchial transections, lacerations or contusions, hemorrhage or mucous plugging in 53% of the patients [104]. Thus, this examination should be part of the diagnostic work-up of chest trauma patients [104, 105].

b) Airway obstruction. Bronchoscopy is a useful tool in respiratory failure stemming from bronchial obstruction due to foreign bodies [106, 107], or tumor tissue growth. In the latter situation, endobronchial electrosurgery [108] or laser therapy [109] have been successfully used.

Complications of bronchoscopy in the ICU

No study has so far been designed to specifically evaluate the complication rate of bronchoscopic examination in ICU patients. In a recent series of 198 such procedures [31], 76% of which took place during mechanical ventilation, there was a 4% incidence of complications, consisting of either arrythmia, transient hypoxemia, or increased fever. No deaths occurred. The same rate and nature of complications were documented in an older series comprising 446 procedures [7]. There was a 3% incidence of malignant arrythmia or cardiac arrest directly attributable to the procedure [7]. Transbronchial biopsies can be performed during mechanical ventilation, with a good diagnostic yield [83, 84], but indications should be restrictive in view of a 7%—14% risk of pneumothorax reported in these series. In fact, mechanical ventilation has been considered by some as a contraindication to this procedure [110]. One intriguing event is the occurrence of self-limiting fever immediately following the procedure [111]. The causative mechanism is still poorly understood. Bacterial translocation into the bloodstream has been hypothesized, but disproved [112]. A possibility could be the translocation of endotoxin or release of inflammatory mediators. However, in 6% of the patients in Pereira’s study [111], fever was accompanied by radiological signs of parenchymal infiltrate, suggesting that, in some patients, the procedure might be complicated by intrapulmonary infection.

Finally, it should be noted that premedication and local anesthesia may be sources of complications: in a survey of over 24,000 patients [22], excessive premedication resulted in 4 episodes of serious respiratory depression, in one instance requiring intubation. Local anesthesia caused 7 episodes of major side effects (respiratory depression, seizures) and one death (cardiovascular collapse). These figures are quite low, but it must be outlined that the procedures were not all carried out in ICU patients. Thus, present data suggest that the rate of complications is low and that few are life-threatening.

Conclusion

Flexible fiberoptic bronchoscopy has become an indispensable tool in the optimal management of ICU patients with both diagnostic and therapeutic goals. Its feasibility during mechanical ventilation, with a low complication rate, has been amply demonstrated. Nonetheless, precise knowledge of the particular pathophysiological and technical aspects of performing bronchoscopy in a mechanically ventilated patient is mandatory, as is the presence of a skilled operator. Our policy regarding this last point is to always have an experienced pneumologist available during bronchoscopic examinations.

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