Anaesthesia 2020, 75, 1509–1516 doi:10.1111/anae.15112

Review Article

Management of the airway and lung isolation for thoracic surgery during the COVID-19 pandemic

Recommendations for clinical practice endorsed by the Association for Cardiothoracic Anaesthesia and Critical Care and the Society for Cardiothoracic Surgery in Great Britain and Ireland

M. Thornton,[1] **D. Reid,**[2] **B. Shelley**[3,4] and **M. Steven**[2]

1 Advanced Trainee, 2 Consultant, Department of Cardiothoracic Anaesthesia, Golden Jubilee National Hospital, Glasgow, UK
3 Consultant, Department of Cardiothoracic Anaesthesia and Intensive Care Medicine, Golden Jubilee National Hospital, Glasgow, UK
4 Honorary Clinical Associate Professor, Academic Unit of Anaesthesia, Pain and Critical Care, University of Glasgow, UK

Summary

Intra-operative aerosol-generating procedures are arguably unavoidable in the routine provision of thoracic anaesthesia. Airway management for such patients during the COVID-19 pandemic including tracheal intubation, lung isolation, one-lung ventilation and flexible bronchoscopy may pose a significant risk to healthcare professionals and patients. That said, there remains a need for timely thoracic surgery for patients with lung cancer or thoracic trauma. The thoracic anaesthetic community has been confronted with the need to modify existing techniques to maximise safety for patients and healthcare professionals. With appropriate modification, aerosol generation may be mitigated against in most circumstances. We developed a set of practice-based recommendations for airway management in thoracic surgical patients, which have been endorsed by the Association for Cardiothoracic Anaesthesia and Critical Care and the Society for Cardiothoracic Surgery in Great Britain and Ireland.

Correspondence to: M. Thornton
Email: markthornton@nhs.net
Accepted: 4 May 2020
Keywords: airway; anaesthesia; coronavirus; COVID-19; double-lumen tube placement; lung isolation; thoracic surgery
Twitter: @Drthawn; @GJanaesresearch

Introduction

Lung isolation and one-lung ventilation are fundamental to modern thoracic surgical and anaesthetic practice [1, 2]. The need for timely lung resection surgery for patients with lung cancer continues throughout the COVID-19 pandemic. There is, however, a higher exposure risk for thoracic surgical procedures due to the need to perform frequent intra-operative aerosol-generating procedures [3–5].

We aimed to develop clinical practice recommendations from a consensus of expert opinion on an approach to lung isolation that minimises risk to healthcare professionals while continuing to provide effective operating conditions. It was

not our aim to address personal protective equipment during these procedures, and clinicians should follow the latest national guidance [4]. We hope this guidance, which has been endorsed by the Association for Cardiothoracic Anaesthesia and Critical Care (ACTACC) and the Society for Cardiothoracic Surgery in Great Britain and Ireland (SCTS), can be readily integrated into clinical practice for all patients requiring thoracic surgery and lung isolation during the COVID-19 pandemic.

Recommendations

1 Efforts should be made to minimise the number of staff present in theatre for aerosol-generating procedures.
2 Pre-oxygenation to achieve an end-tidal expired oxygen concentration of > 90% should be undertaken before all airway interventions.
3 All airway interventions should be carried out after ensuring adequate neuromuscular blockade, as assessed with a peripheral nerve stimulator.
4 Positive pressure within the breathing circuit should be released by opening the adjustable pressure-limiting valve and discontinuing positive pressure ventilation before all airway interventions.
5 The risk of aerosol generation when opening a double-lumen tube to the atmosphere can be mitigated against by using appropriately placed high-efficiency particulate air (HEPA) viral filter and clamps.
6 The double-lumen tube should only be open to the atmosphere after allowing release of positive pressure within the lung through a HEPA viral filter.
7 Flexible bronschoscopes can pose significant contamination and cross-infection risks. They should be stored in a designated area during the case. Following use, the outer set of gloves worn by the operator should be disposed of and hand hygiene performed.

The COVID-19 pandemic

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is the third novel zoonotic transmission of a coronavirus in the 21st century to cause severe respiratory disease [6, 7]. The main routes of infection appear to be from contact and droplet spread [8, 9]. In the healthcare setting, it can also spread as an aerosol following aerosol-generating procedures [3, 8]. Aerosol generation results from instrumentation of the respiratory tract, and SARS-CoV-2 appears in high concentrations in bronchoalveolar lavage fluid specimens and the sputum of infected individuals [3]. Although the highest viral loads are encountered shortly after symptom onset, high viral loads are also found in the sputum of patients who are in the asymptomatic phase of their illness, highlighting the potential for transmission early in the disease course [10]. There are suggestions of increased severity of illness in those exposed to high viral loads and aerosol-generating procedures are a concern for those involved with airway management [5, 6].

During the COVID-19 pandemic, there will be an ongoing requirement for thoracic cancer and trauma surgery [11]. Guidelines exist for peri-operative management and tracheal intubation of patients in the context of COVID-19 [5, 12]. There are, nevertheless, special circumstances to consider in the context of lung isolation, which require meticulous attention to minimise the risk of aerosol generation [5]. Aerosol-generating procedures encountered routinely in thoracic anaesthesia include: bag-valve-mask ventilation; tracheal intubation; tracheal tube repositioning; bronchoscopy; one-lung ventilation; suction clearance of secretions; and the management of hypoxia during one-lung ventilation.

Thoracic surgery during the COVID-19 pandemic

In its simplest form, lung isolation is the ventilation of the dependent lung while allowing the passive collapse of the non-dependent lung [1]. The primary indication is to facilitate surgical access [1]. It is a skilled and technical task that puts healthcare professionals at risk, as many of the steps involved in achieving and troubleshooting lung isolation generate aerosols [4, 13]. Lung isolation can be provided by utilising a single-lumen tracheal tube alone, a single-lumen tracheal tube with a bronchial blocker or, more commonly, with a double-lumen tracheal tube. In terms of aerosol generation and safety, there are advantages and disadvantages of each technique (Table 1).

During the COVID-19 pandemic, lung isolation is likely to present additional technical and non-technical challenges. Psychological concerns about infection, personal protective equipment and minimisation of aerosol-generating procedures add to the difficulty of tracheal intubation and lung isolation [14]. It would be prudent, therefore, for anaesthetists to use the techniques that are most familiar to them. Special consideration should be given to intubated patients transferred to theatre for surgery where a single-lumen tube is already sited, and similarly, patients who will require postoperative mechanical ventilation in the critical care setting. Patients may require a high fraction of inspired oxygen and have low lung compliance. Tracheal tube exchange carries a significant risk of aerosol generation and clinical deterioration, and the use of a single-lumen tracheal tube

Table 1 Advantages and disadvantages of single-lumen endobronchial intubation, bronchial blockers and double-lumen endobronchial intubation for lung isolation during the COVID-19 pandemic.

Method	Advantages	Disadvantages
Single-lumen tube	● Simplicity and familiarity ● Rapid, efficient tracheal intubation ● Potentially less traumatic ● Can be checked clinically without a flexible bronchoscope ● No requirement for tracheal tube exchange for ongoing postoperative positive pressure ventilation ● Option of adding a bronchial blocker	● The isolated non-dependent lung will expel air passively, bypassing the tracheal tube and polluting the environment ● No access to the non-dependent lung during isolation for bronchoscopy, suction or continuous positive airway pressure ● Unpredictable collapse of the non-dependent lung ● Occlusion with failure to ventilate the right upper lobe when sited in right main bronchus ● Bronchoscopy likely to still be required to railroad and site tracheal tube in the bronchus especially when targeting the left main bronchus
Bronchial blocker	● Sited through a single-lumen tube ● Can be used in an existing tracheal tube when taking a patient with a tracheal tube in situ to theatre. **The minimum tracheal tube size for a 9.0 Fr bronchial blocker is 8.0 mm**	● Absolute requirement for bronchoscopy to confirm correct placement ● High-volume, low-pressure cuff provides a less reliable seal than a double-lumen tube ● Higher incidence of intra-operative displacement and the need for repositioning, requiring bronchoscopy ● Blocker remains open to air during lung collapse with continuous environmental pollution ● No access to the non-dependent lung during lung isolation ● Limited ability to suction or apply continuous positive airway pressure to the non-dependent lung during lung isolation
Double-lumen tube	● The most efficient method in experienced hands ● Repositioning rarely required (left more so than right) ● Access to the non-dependent lung throughout for bronchoscopy, suction or continuous positive airway pressure ● Can be placed without bronchoscopy	● Bronchoscopy is required throughout the case ● The lumen to the non-dependent lung is opened to facilitate collapse. There is direct environmental pollution of alveolar air ● Placement can be traumatic ● Larger sizes cause problems in the difficult airway potentially requiring airway manipulation and multiple attempts ● Too bulky for continued/long-term ventilation requiring exchange to single-lumen tube at end of surgery in patients needing ongoing ventilation ● More difficult for rapid sequence tracheal intubations, leading to prolonged intubation and/or multiple attempts

with or without a bronchial blocker to achieve lung isolation may be the best option [15].

Most lung isolation thoracic surgical cases in the UK are conducted with a double-lumen endobronchial tube, and our clinical practice recommendations focus on the associated techniques [16]. That said, the principles herein can be adapted for use with the other methods of lung isolation.

Tracheal intubation

General principles from recently published consensus guidelines on managing the airway of patients with COVID-19 can be applied in the thoracic surgical population [5]. That said, some modifications are required for the provision of lung isolation and one-lung ventilation. We recommend that the number of individuals present in theatre during intubation should be minimised, and include as a minimum: the anaesthetist; the airway assistant; and a theatre assistant. The most experienced operator should plan and perform tracheal intubation, and the airway plan should be discussed at the team brief. Available equipment should include: laryngoscope(s); bougie(s); an appropriately-sized single and double-lumen tube, together with alternative sizes available from clean areas; two clamps; an additional HEPA viral filter; and a stethoscope.

Viral and bacterial filters may be utilised to reduce the transmission of microbes between patients by preventing colonisation of ventilators and breathing circuits [17, 18]. They are frequently encountered as a combined device with heat and moisture exchangers [19–21]. The filter consists of fibres on a rigid frame, which is pleated to reduce airflow resistance [20]. They provide filtration of particles greater

than 0.3 μm by inertial impaction and interception. Particles less than 0.3 μm are captured by Brownian motion [20]. High-efficiency particulate air filters have a set standard with at least 99.97% of particles of 0.3 μm absorbed [20]. This standard is based on the approximate size of a viral particle suspended in a droplet [22]. Currently, there are no data confirming these filters capture SARS-CoV-2 specifically, although they have been demonstrated to effectively filter other viruses of equivalent size [17, 18, 20, 22, 23].

The patient should be adequately pre-oxygenated for 3 min or until the end-tidal oxygen fraction is greater than 0.9. The aim is to achieve sufficient apnoeic time to allow safe intubation without the need for bag-valve-mask ventilation [5, 12]. The anaesthetic technique should be a modified rapid sequence tracheal intubation using high-dose rocuronium [5]. Facemask ventilation should be avoided where possible, and a two-person technique should be used where necessary. Tracheal intubation should be followed immediately by cuff inflation, circuit connection and ventilation of both lungs [5]

Routine confirmation of positioning of double-lumen tubes involves the use of a flexible bronchoscope to visualise directly the endobronchial cuff and its relation to the carina [24]. If there is a clinical preference to avoid bronchoscopy, it is possible to perform clinical confirmation of positioning, thereby avoiding disconnection of the breathing circuit [25]. Following tracheal intubation with a left-sided double-lumen tube, clinical confirmation should start with no clamp applied and bilateral air entry confirmed with manual ventilation. The bronchial cuff should then be inflated. If there is isolated left-sided air entry with manual ventilation, this suggests the tracheal tube has advanced too far into the left main bronchus. To rectify this, the tracheal tube should be slowly withdrawn with the bronchial cuff inflated until bilateral air entry returns. Isolated right sided air entry suggests a right main bronchial intubation. This will be corrected most efficiently using a bronchoscope, which minimises aerosol generation as compared with other methods.

Once bilateral air entry is achieved, a clamp should be applied to the angle piece supplying the tracheal lumen. If the double-lumen tube is positioned correctly, there should be left-sided air entry only. If bilateral ventilation continues, the distal end of the tracheal tube or the bronchial cuff is above the carina. Deflate only the bronchial cuff and advance the tracheal tube until there is resistance. Re-inflate the bronchial cuff and repeat the steps above. If there is resistance to advancing the tracheal tube or if it is still not possible to confirm correct placement clinically, then bronchoscopy will be required to troubleshoot placement. Once the tracheal tube is placed correctly, the patient should be positioned for surgery. This checking process should be repeated after positioning laterally to ensure the tracheal tube position has not changed.

During the COVID-19 pandemic, it may appear advantageous to avoid the aerosol-generating potential of bronchoscopy in favour of clinical confirmation. As a technique, clinical confirmation has the disadvantage of poor sensitivity and specificity. A bronchoscopic study involving clinical confirmation of double-lumen tubes by the intubating anaesthetist found that up to 39.5% were malpositioned [1, 25]. If clinical confirmation of the double-lumen tube position is used, bronchoscopy must be available. If there is any concern that the double-lumen tube is not in the optimum position for lung isolation, immediate bronchoscopy is essential to rectify this.

We believe that if the necessary preparations are made and the steps below followed, bronchoscopy can be performed with minimal risk and will provide the most reliable means of confirming and troubleshooting tracheal tube placement, ensuring safety for patients and healthcare professionals.

Flexible bronchoscopy

The patient should be pre-oxygenated and the flexible bronchoscope prepared and ready for immediate use. The risk of aerosol generation will be extremely high if attempts are made to perform bronchoscopy while ventilating the patient, or if the patient has inadequate neuromuscular blockade. Deep neuromuscular blockade should be confirmed by the use of a peripheral nerve stimulator [5]. The adjustable pressure-limiting valve should be open and ventilation should be discontinued. These measures should be completed before clamping the tracheal lumen of the double-lumen tube and the angle piece connected to tracheal lumen (Fig. 1a). This ensures the angle piece can be disconnected without aerosol generation (Fig. 1b). A HEPA viral filter can be applied to the tracheal lumen (Fig. 1c) and the clamp from tracheal lumen on the double-lumen tube removed to release pressure from the lung through the HEPA viral filter (Fig. 1d). This should only require a few seconds to complete. The HEPA viral filter can be removed and bronchoscopy performed to confirm tracheal tube placement, orientation of the bronchial cuff and right sided anatomy (Fig. 1e). The bronchial cuff can then be inflated under direct vision. The angle piece can be reconnected and the remaining clamp removed to ventilate both lungs. This process can be repeated on the bronchial lumen to allow bronchoscopic confirmation that the distal end of bronchial lumen is above the left main bronchus

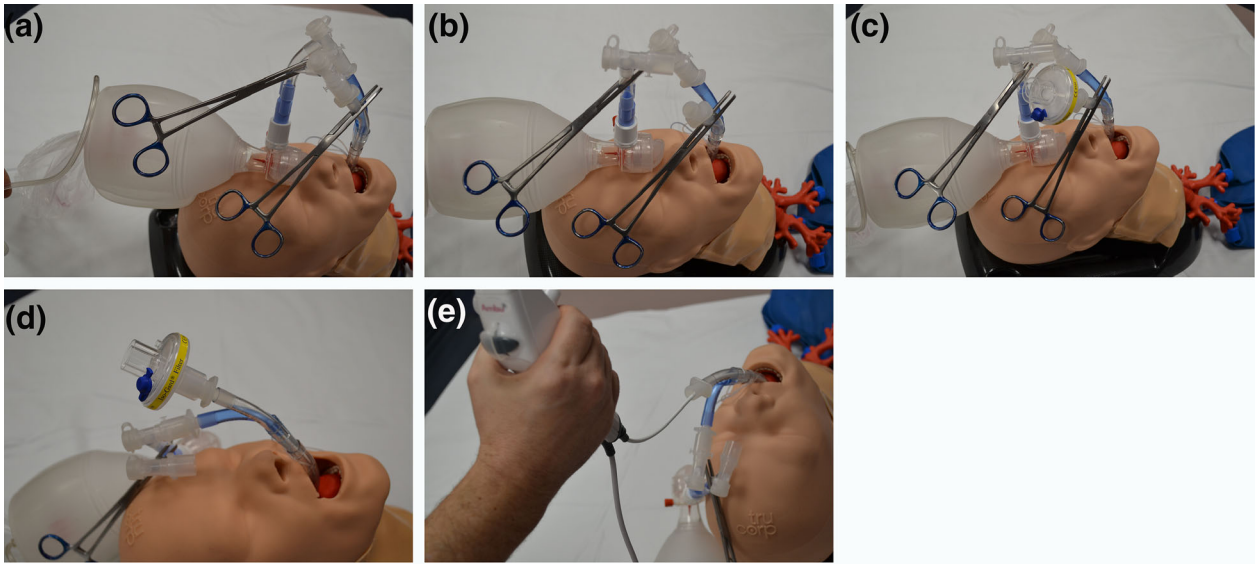

Figure 1 Manikin images demonstrating (a) the clamp applied to tracheal lumen angle piece and double-lumen tube; (b) disconnection without pollution; (c) applying a HEPA viral filter to tracheal lumen; (d) removing the clamp to allow positive pressure from the lung to vent through HEPA viral filter; and (e) removing the HEPA viral filter and performing bronchoscopy.

bifurcation. Once the patient is positioned for surgery, the process should be repeated to ensure satisfactory placement. Once bronchoscopy is completed, the bronchoscope should be placed in its designated area and used only by a single operator. Following each use, the operator should dispose of their outer gloves and perform hand hygiene [12, 26].

Troubleshooting tracheal tube malposition

Following tracheal intubation, a left-sided double-lumen tube may be placed accidentally in the right main bronchus. This is estimated to occur in 4.2% of cases, with an increased likelihood in shorter patients, women and when using smaller sized double-lumen tubes [27]. We believe this is best managed with expedient bronchoscopy, as it will ensure the double-lumen tube is placed in the correct position while minimising aerosol generation and contamination. Again, the patient should have deep neuromuscular blockade, be thoroughly pre-oxygenated, the adjustable pressure-limiting valve should be open and positive pressure ventilation discontinued. While troubleshooting, the tracheal cuff should remain inflated throughout to ensure there is no leak generated while the tracheal tube is manipulated. It will also serve as a brake at the level of the vocal cords to minimise the risk of accidental extubation.

First, the bronchial cuff should be deflated and the bronchial lumen and arm of the angle piece connected to the bronchial lumen should be clamped. This will ensure disconnection of the arm of the bronchial lumen can be undertaken without pollution. A HEPA viral filter is applied to the bronchial lumen and the clamp removed to release positive pressure from the lung through the HEPA viral filter. This should only require a few seconds to complete. The HEPA viral filter can be removed and the bronchoscope inserted to the distal end of the bronchial lumen. This should reveal the terminal bifurcation of bronchus intermedius into the right middle and lower lobe bronchi. The double-lumen tube can be withdrawn under direct bronchoscopic vision until the carina is visible, with the bronchoscope then guided down the left main bronchus. The double-lumen tube is railroaded over the bronchoscope and the distal end of the bronchial lumen is confirmed to be above the upper and lower lobe bifurcation. The bronchoscope is withdrawn, the angle piece reconnected, the clamp removed and positive pressure ventilation resumed. Bilateral ventilation should be confirmed before using the previous steps for safe bronchoscopy to visualise the right main bronchus to confirm correct double-lumen tube placement, and inflation of the bronchial cuff under direct vision.

Double-lumen tubes with an integrated camera

Double-lumen tubes with an embedded light source and camera have been developed to provide continuous monitoring of double-lumen tube position relative to the

carina. Once correctly sited, they may reduce the incidence of bronchoscopy for double-lumen tube adjustments and the risk of exposure during lung isolation [28]. A bronchoscope may still be required if excessive secretions are encountered or if visualisation is required to aid surgical progress, for example, if there is anatomical variation [1]. If the operator is familiar with the use of this equipment, they should conform to their normal practice. The principles of minimising the risk from aerosol generation during lung isolation are the same as for the standard double-lumen tube.

Lung isolation

The main threat of environmental contamination, once the airway is secured and with surgery underway, is disconnection of the lumen of the non-dependent lung. This can be mitigated against by allowing the lung to deflate through a HEPA viral filter. Furthermore, continued application of a HEPA viral filter to the open lumen will protect against any peri-operative loss of lung isolation where a leak of any ventilated gas into the open lumen would otherwise cause environmental pollution and contamination. The patient should be positioned, surgery commenced and lung isolation required imminently. Neuromuscular blockade should be adequate, the adjustable pressure-limiting valve open and ventilation discontinued before the surgical lumen of the double-lumen tube and the arm of the angle piece serving this lumen are clamped. The arm of the angle piece should be disconnected and a HEPA viral filter applied to surgical lumen of double-lumen tube. The clamp is then removed from the surgical lumen of the double-lumen tube to facilitate collapse of the non-dependent lung through the HEPA viral filter (Fig. 1d).

Management of hypoxia during one-lung ventilation

For the purpose of these recommendations, it is assumed that all other measures to address hypoxia have been considered and the diagnosis is that of shunt-driven hypoxia. Although two-lung ventilation is always the default position for critical hypoxia during one-lung ventilation, shunt-driven hypoxia can often be overcome by administering oxygen to the non-dependent lung. [29] The simplest method of administering oxygen to the operative lung is via insufflation through a suction catheter through the open lumen of the double-lumen tube [30]. This nevertheless carries an unacceptable risk of aerosol generation. Instead, the method recommended involves the use of a continuous positive airway pressure circuit with a HEPA viral filter (Fig. 2). As with normal practice, continuous positive airway pressure should be titrated until there is clinical improvement.

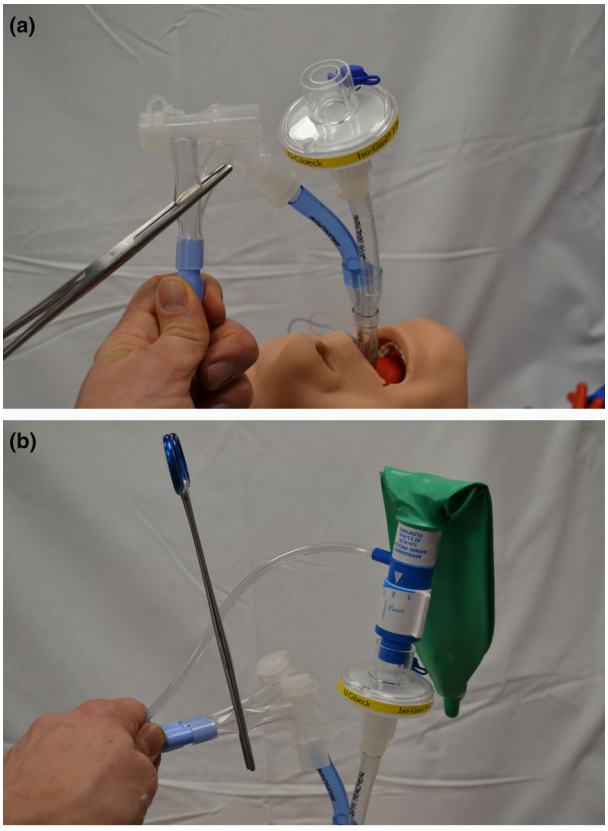

Figure 2 Manikin images demonstrating (a) HEPA viral filter in place on the surgical lumen of the double-lumen tube and (b) a continuous positive airway pressure circuit safely applied.

Continuous positive airway pressure

If a dedicated continuous positive airway pressure circuit is unavailable, it may be possible to safely generate continuous positive airway pressure to the non-dependent lung. The patient should have adequate neuromuscular blockade, the fresh gas flows increased and the fraction of inspired oxygen should be 1.0. The HEPA viral filter on the surgical lumen should be removed and the angle piece reconnected. The clamp on the surgical lumen of the angle piece should remain in situ (Fig. 3a). Positive pressure ventilation should be discontinued and the adjustable pressure-limiting valve should be open. The clamp from the angle piece to the surgical lumen should now be removed and applied to the angle piece supplying the dependent lung. (Fig. 3b). Continuous positive airway pressure should be increased to the desired level using the adjustable pressure-limiting valve. When airway pressure in the non-

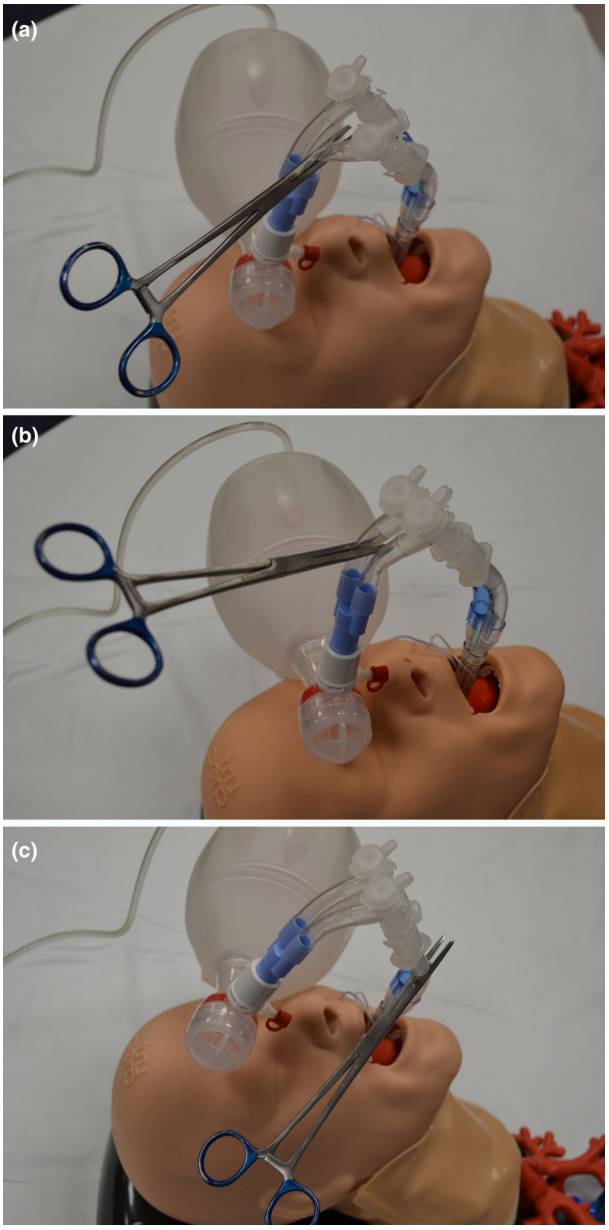

Figure 3 Manikin images demonstrating (a) the clamp applied to the surgical lumen angle piece. The angle piece is connected to the double-lumen tube; (b) the clamp is removed from the surgical lumen angle piece and applied to the non-surgical lumen; and (c) following the application of continuous positive airway pressure, the clamp is applied to the surgical lumen of the double-lumen tube to maintain pressure.

dependent lung has reached equilibrium, a second clamp to the surgical lumen of the double-lumen tube should be applied. This will trap oxygen at the desired pressure within the non-dependent lung. Remove the clamp from the dependent lung and resume positive pressure ventilation at the previous fraction of inspired oxygen (Fig. 3c). A recruitment manoeuvre can be performed as required. It may be necessary to repeat this process at regular intervals to maintain continuous positive airway pressure within the non-dependent lung.

Tracheal extubation

Specific COVID-19 extubation guidance features in recently published consensus guidelines for managing the airway in patients with COVID-19 [5]. These guidelines should be followed with specific adaptations for use with a double-lumen tube. A double-lumen tube is a larger diameter tube, more prone to causing coughing, bronchospasm and biting, all with a high risk of aerosol generation [31, 32]. The common comorbidities among thoracic surgical patients are also associated with reactive airways and copious secretions. Deep extubation may not only appear attractive but it also has specific risks which may necessitate additional airway adjuncts or manoeuvres, which increase the risk of aerosol generation [33].

Only essential staff wearing appropriate personal protective equipment for the patient risk group should be present in theatre for extubation. Oropharyngeal and bronchial suction should be performed before the reversal of neuromuscular blockade. The tracheal tube should not be suctioned at the point of extubation, as this can precipitate coughing. The patient should be positioned in an upright position on a bed or trolley with full reversal of neuromuscular blockade confirmed. They should be breathing spontaneously with no pressure support and with the adjustable pressure-limiting valve open. A clinical waste bin should be placed beside the patient for immediate disposal of the removed tracheal tube. The circuit should be disconnected, leaving the HEPA viral filter and angle piece attached to the tracheal tube. A Hudson mask should be applied immediately. This will avoid changing the facemask at a time when the patient is potentially coughing. Apply a surgical facemask over the Hudson mask. This will cover the entrainment vents on the mask and reduce the risk of contamination from coughing. Wait for 20 min following extubation before transferring the patient from the operating theatre.

Conclusion

The management of thoracic surgical patients during the COVID-19 pandemic requires modifications to normal practice. The risk from aerosol-generating procedures must be reduced wherever possible to ensure the safety of patients and healthcare staff. We have provided clinical practice recommendations for techniques, which will limit the potential for aerosol generation associated with lung isolation and thoracic surgery.

Acknowledgements

No external funding or competing interests declared.

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