Review Article

Difficult lung separation. An insight into the challenges faced during COVID-19 pandemic

ABSTRACT

Difficult lung isolation or separation in patients undergoing thoracic surgery using one-lung ventilation might be attributed to upper airway difficulty or abnormal anatomy of the lower airway. Additionally, adequate deflation of the surgical lung can impair surgical exposure. The coronavirus disease 2019 (COVID-19) has a harmful consequence for both patients and anesthesiologists. Management of patients with difficult lung isolation can be challenging during the COVID-19 pandemic. Careful planning and preparation, preoperative routine testing, protective personal equipment, standard safety measures, proper preoxygenation, and individualize the patients care are required for successful lung separation. A systematic approach for management of difficult lung separation is centered around securing the airway and providing adequate ventilation using either a blocker or double-lumen tube. Several measures are described to expedite lung collapse.

Key words: COVID 19; difficult lung isolation; difficult lung separation

Methods

A review of relevant published articles in peer-reviewed journals from 2009 to October 2020 was conducted. The databases, that is, PubMed and BioMed Central were searched by two independent expert librarians familiar with the literature search. The databases were searched using the following MeSH search terms: "one-lung ventilation," "lung isolation," "lung separation," "thoracic anesthesia," "double-lumen tube," "bronchial blocker," "difficult airway," and "coronavirus disease 2019 (COVID-19)." No language restriction was imposed. Also, references cited by the retrieved articles were analyzed manually to select further relevant studies. This narrative review aims to provide a framework for general recommendations for lung isolation or separation for patients during the COVID-19 pandemic including the preoperative planning, preparation, and testing, protective personal equipment, general safety measures, proper preoxygenation, and individualize the lung isolation technique.

Background

One-lung ventilation (OLV) has been increasingly used because of the demanding advanced technology for the variety of thoracic and minimally invasive cardiac interventions. Video-assisted or robotically assisted thoracoscopic procedures are performed through a narrow room with limited surgical access.

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Alaa M. Khidr, Mohamed R. El Tahan

Department of Anesthesiology, King Fahd Hospital of the University, College of Medicine, Imam Abdulrahman Bin Faisal University, Al Khobar, Saudi Arabia

Address for correspondence: Dr. Alaa M. Khidr, Anesthesiology Department, King Fahd Hospital of the University, College of Medicine, Imam Abdulrahman Bin Faisal University, Saudi Arabia, P.O. 40289 Al Khobar 31952, Al Khobar, Saudi Arabia. E-mail: akhedr@iau.edu.sa

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Lung isolation is usually required to[1] avoid soiling the healthy lung from the diseased lung (e.g., unilateral hemoptysis, lung abscess, or bronchiectasis, or bronchoalveolar lavage for alveolar proteinosis),[2] reduce air leak (e.g., bronchopleural and bronchopleural cutaneous fistulas), or[3] avoid rupture of air cysts or large bullae.[1]

Lung separation is needed to facilitate surgical exposure during the diverse of interventional procedures including robotic, thoracoscopic, and open thoracotomy for pulmonary resections, esophageal, thoracic aortic, dorsal spine, mediastinal, pleural, minimally invasive coronary artery bypass graft, and heart valve surgery, and catheter-ablation procedures.[1]

Two of the likely horrible vivid nightmares for a thoracic anesthesiologist are difficult lung separation and inadequate lung collapse.[2] Lung isolation or separation can be challenging in patients with potential upper airway difficulty or abnormal anatomy of the lower airway.[3-6]

Second wave of coronavirus disease 2019 and future of thoracic surgery

On March 11, 2020, the World Health Organization (WHO) has declared coronavirus disease 2019 (COVID-19) as a pandemic. More than 43.3 million infected COVID-19 cases and 1.2 million deaths were reported to WHO as of October 25, 2020.[7] Because of the relaxation of the public's precautionary measures, the second wave is hitting Europe since the second half of October.[8] The first lockdown has negatively impacted the healthcare of thoracic surgery patients including those with lung cancer. It results in delayed seeking for healthcare services, cancellation or rescheduling elective surgery, and reallocating healthcare resources to increase the intensive care unit capacity with either changing the operating theatres into intensive care units or assigning the anesthesiologists to care for critically ill COVID-19 patients [Table 1]. A consequential second lockdown or shutdown would impact the economic revival[9] [Table 1].

Efforts should be exercised for planning to prioritize the logistics and healthcare resources to avoid interruption of routine care of thoracic surgery patients during the second surge.

Thoracic surgery patients during the second wave [Table 1]

A national modeling study on the impact of the delayed diagnosis on cancer deaths during the COVID-19 pandemic in the United Kingdom reported a 4.8-5.3% increase in the number of deaths because of lung cancer.[10] Immediate pulmonary resection for lung cancer during the COVID-19 pandemic might negatively affect the 5-year survival with 13% increased risk of perioperative contracting the viral infection.[11]

Patients with "confirmed" COVID-19 infection might be presented with pneumonia phenotype "H" with poor pulmonary compliance and high elastance or phenotype "L" with preserved compliance and low elastance.[12] Patients with phenotype H might have higher hospital mortality.[12] That might challenge lung separation in both of nonintubated and intubated patients because of risks of experiencing life-threatening hypoxemia and circulatory compromise.

Additionally, patients infected with COVID-19 might be presented with tracheostomy[13] or emphysema, pneumomediastinum or pneumothorax secondary to ventilation-associated barotrauma.[14] That might further complicate airway management and lung separation.

Postoperative pulmonary complications (PPCs) have been reported in 50% of patients with perioperative COVID-19 infection with an associated high mortality rate.[15]

Thoracic anesthesiologists during the second wave [Table 1]

Thoracic anesthesiologists, as healthcare workers, are prone to considerable risks for work-related exposure to COVID-19 infection from patients who have not been diagnosed with infection particularly during aerosol-generating procedures (AGP) including intubation,[16] lung isolations or separation, collapsing the surgical lung, bronchoscopic examination,[17] pulmonary toilet, and extubation.[18-20]

Anesthesiologists might experience higher levels of depressive and anxiety symptoms,[21] and medium levels of burnout, exhaustion, and disengagement.[21,22]

Difficult airway management and lung separation might have additional stressors for thoracic anesthesiologists during the COVID-19 pandemic. However, that assumption needs to be further studied.

Donning the personal protective equipment (PPE) for long hours during thoracic surgery can be associated with dermatological changes (e.g., eczema, contact dermatitis),[23] communication problems (e.g., affecting discriminative speech),[24] or feeling of heat, thirst, headache, or extreme exhaustion.[25] The perceived shortages of the PPE during the early stage of the first wave have the potential to negatively impact the quality of healthcare service provided to surgical patients. Exposure of the anesthesiologists to the risks of infection and subsequently sick leaves would result in the shortage of the anesthesia staff and subsequently

Table 1: Consequences of the COVID-19 Pandemic

	Consequences
Logistics	Negative impact on economic status which can be reflected on the availability of the resources and quality of healthcare services.[9] Delayed diagnosis or surgery for patients with lung cancer. Cancellation or rescheduling elective surgery. Reallocating healthcare resources to increase the intensive care unit capacity with Changing the operating theatres into intensive care units. Assigning the anesthesiologists to care of critically ill COVID-19 patients.
Patients	Increase cancer deaths due to delayed diagnosis.[10] Decreased 5-years survival after lung cancer surgery in case of perioperative acquiring of COVID-19 infection.[11] COVID-19 pneumonia (Phenotypes H and L).[12] Need for early tracheostomy for patients with severe COVID-19 pneumonia.[13] Barotrauma (surgical emphysema, pneumomediastinum, pneumothorax).[14] Increased risks for postoperative pulmonary complications.[49]
Anesthesiologists	Work-related exposure to COVID-19 infection particularly during the aerosol-generating procedures. Depressive and anxiety symptoms.[21] Burnout, exhaustion, and disengagement.[21,22] Perceived shortages of personal protective equipment (PPE).[26] Adverse effects of donning the PPE for long hours Dermatological changes (e.g., eczema, contact dermatitis).[23] Communication problems (e.g., affecting discriminative speech).[24] Feeling of heat, thirst, headaches, or extreme exhaustion.[25]

COVID-19; coronavirus disease 2019

rescheduling or cancelling elective surgery cases. Alternatives to thinking out of the box are required to avoid shortages of the PPE during the second wave.[26]

Difficult upper airway and lung separation

A recent audit of 209 airway incidents reported in 12 hospitals in Australia and New Zealand over 1 year included a combination of difficult airway management, oxygen desaturation, aspiration, regurgitation, laryngospasm, airway bleeding, bronchospasm, and dental injury.[27]

Patients with lung cancer might have potential upper airway difficulty[27] because of also having carcinoma of the pharynx (5%-8%) with the involvement of the epiglottic area, preoperative radiotherapy, or previous extensive surgery on the airway and the neck.[6] Additionally, thoracic surgery population might also have other predictors for upper airway difficulty including morbid obesity,[28] limited neck movement secondary to cervical spine disease[29] or injury, or tracheostomy.

There are several predicting tests for difficult mask ventilation and tracheal intubation (e.g., the Mallampati test, modified Mallampati test, Wilson risk score, thyromental distance, sternomental distance, mouth opening test, and the upper lip bite test).[30] Unfortunately, all of these tests have low sensitivities despite having higher specificities than sensitivities.[30] The sensitivity of the upper lip bite test is significantly higher than that for the mouth opening test to predict difficult laryngoscopy.[30] The modified Mallampati test has a significantly higher sensitivity compared with mouth opening and thyromental distance to identify difficult tracheal intubation.[30]

Eberhart *et al.*[31] developed a simplified multivariate risk score for difficult intubation including[1] the presence of upper front teeth,[2] a history of difficult intubation,[3] any Mallampati status different from "1" and equal to "4,"[4] and mouth opening less than 4 cm. With each of these predictors, airway difficulty increases from 0 (when no risk factor is present) to 17% (when four or five factors are present).[31] The discriminating power of this score is 0.72 (95% confidence interval 0.63-0.81).[31]

The 3-3-2 rule, a helpful assessment tool for the prediction of unexpected airway difficulty, includes 3: A measurement of three fingers for the inter-incisors distance. 3: A measurement of three fingers for the hyoid-mental distance. 2: A measurement of two fingers for the hyoid-thyroid cartilage distance.[32]

Assessing the inlet of the stoma and the circumferential diameter of the tracheostomy tube should be considered in patients with tracheostomy.[6] Additionally, reviewing the chest radiographs would help in excluding the suboptimal position of the tracheostomy tube [Figure 1a and b].

Evaluating the degree of mouth opening might expose the anesthesiologist for risks for the AGP because of the high viral load in the nose and nasopharynx.[33] In general, proper contact precautions should be considered during preoperative examination of the upper airway during the COVID-19 pandemic including keeping distancing[34,35] and donning of gloves, disposable long-sleeve fluid-resistant gown, and a surgical mask.[35,36] The filtration masks (e.g., FFP3, FFP2, or N95) should be considered for patients

with "no test results," "suspected," or "confirmed" diagnosis of COVID-19 infection.[36]

Difficult lower airway management and lung separation

There are several causes for difficult lung separation as presented in Table 2. The double-lumen endobronchial tube (DLT) is the most commonly used lung isolation tool by the thoracic anesthesiologists in different European and Middle Eastern countries.[37-40] Distorted anatomy of the tracheobronchial tree because of luminal narrowing or deviated trachea [Figures 2-4] might increase the difficulty for placement of the DLT.

Left-sided DLTs are commonly used for both left-sided and right-sided surgery as perceived to be safer in terms of the less likely incidences of malpositioning.[41] The presence of disrupted or obstructed lumen of the left main bronchus precludes the use of left-sided DLT [Figures 5 and 6a, b]. Multiple attempts to adjust the position of the DLT in patients with difficult intubation might be complicated with tracheal or left main bronchial rupture.[42] The use of right-sided DLT is deemed necessary for patients with disrupted or narrowed left bronchus and those undergoing left sleeve-pneumonectomy or left pneumonectomy.

Tracheal bronchus,[43] early takeoff, or steep angulation of the right main bronchus [Figures 7 and 8] preclude the use of right-sided DLT or blocker.

Management of difficult lung separation [Figure 9]

A systematic approach should be considered for lung separation in patients with predicted or unanticipated upper or lower airway difficulty as follows.

I. **Fundamental steps:** include:
   - **I.1.** Call for help from the most experienced thoracic anesthesiologist available.
   - **I.2.** Be prepared ("By failing to prepare, you are preparing to fail." *Benjamin Franklin*).
     Table 3 shows the recommended preparations for difficult lung separation.[20]
   - **I.3.** Plan ahead

   A lack of adequate planning for intubation difficulty or failure contributes to the related malpractice claims.[44] Anesthesiologists must use the airway equipment available which they are well-trained and familiarized to use them.[44] The plan should focus on the following priorities;
   - Priority[1]: Ensure adequate ventilation. Patients with acute hypoxemic respiratory failure are at risk for life-threatening complications during tracheal intubation because of reduced functional residual capacity or ventilation/perfusion ratio.[45,46]

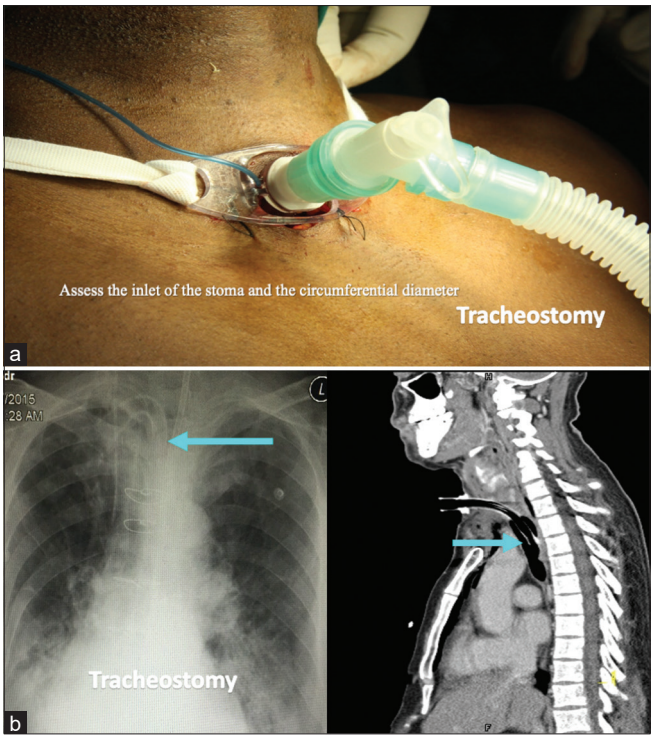

Figure 1: (a) Assessment of tracheostomy stoma and (b) mispositioned tracheostomy tube in chest X-ray and CT-scan

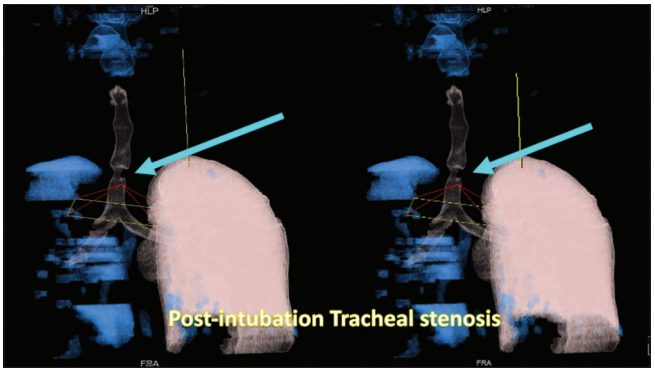

Figure 2: A reconstructed computerized scan of the trachea showing tracheal narrowing

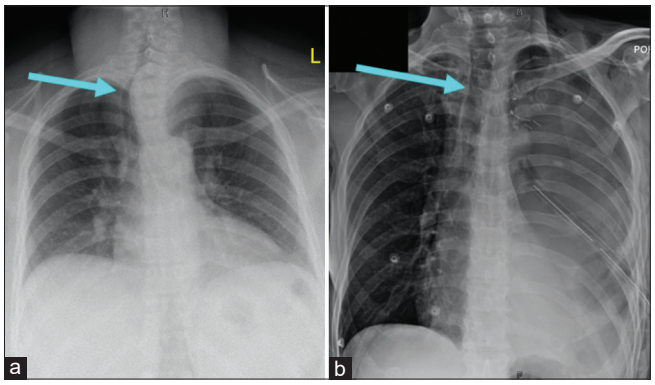

Figure 3: Chest-X ray shows tracheal deviation secondary to (a) thyroid enlargement with a retrosternal extension and (b) postpneumonectomy surgery cardiac displacement

Table 2: Causes of lower airway management and difficult lung separation

Changed Architecture of Tracheobronchial Tree	Tracheal narrowing or stricture [Figure 2]. Deviated trachea secondary to a thyroid enlargement with a retrosternal extension, cardiac herniation, etc. [Figure 3]. Wandering trachea [Figure 4]. Early takeoff of the right main bronchus in case of need for using a right-sided double-lumen tube or bronchial blocker for a right-side surgery [Figure 5]. Tracheal bronchus.[43] Steep angulation of the main bronchus [Figure 6].
Anatomical Disruption	Tracheobronchial injury [Figure 7] or tumor.
Narrowing Bronchial Lumen	Extramural (e.g., aortic aneurysm, lymph node, or tumor mass). Intramural (e.g., an obstructed bronchial lumen with a mucous plug [Figure 8a], endobronchial mass, tracheobronchopathia osteochondroplastica [Figure 8b].

Table 3: Checklist for preparations for difficult lung separation. Adopted from Senturk *et al*.[20]

Anesthetic medications (e.g., etomidate, propofol, ketamine, suxamethonium, rocuronium, opioids, dexmedetomidine).
Resuscitation medications (e.g., atropine, glycopyrrolate, phenylephrine, norepinephrine, epinephrine).
Video laryngoscope with an angulated blade and remote screen (e.g., GlideScope, MacGrath, C-Mac, etc.).
Video laryngoscope with channeled or nonchanneled blades (e.g., Yellow Airtraq, aBlade King Vision).
A video stylet (e.g., Bonfils, Trachway, etc.).
Flexi-tip airway exchange catheters (sizes 11 Fr and 14 Fr).
Bougie.
DLTs (e.g., PVC, Silbronco, or VivaSight DLT) (sizes 35 Fr and 37 Fr).
ETTs (sizes 6.0 mm, 7.0 mm, 7.5 mm, and 8.0 mm).
Bronchial blocker (e.g., EZ blocker, Fuji Uniblocker, Arndt's blocker, Cohen's blocker, etc.).
A swivel with a 15 mm end and bronchoscopy cap.
Intubating laryngeal mask airways (:MA) (e.g., iLMA FasTrach, ProSeal, AirQ, classic LMA, igel, and Aura-i).
A single-use disposable flexible bronchoscope with a display unit.
Stylets.
Nasal oxygen cannula.
Procedural oxygen mask.
Nasal and oropharyngeal airways in appropriate sizes.
Disposable self-inflating resuscitation bag with an incorporated antiviral filter.
An antiviral filter connecting the Y connection to the ETT or DLT.
An antiviral filter incorporated into each of the expiration and inspiration limbs.
Front of neck access kit.
High-frequency jet ventilator.
Water-soluble gel lubricant.

DLT: Double-lumen tube, ETT: Endotracheal tube

- Priority[2]: Securing the airway first with an endotracheal tube (ETT) or a laryngeal mask airway (LMA)[6] [Figure 9].
- Priority[3]: Separate the lungs [Section III].

II. General Recommendations for COVID-19 Patients

II.1. Preoperative Testing

Preoperative screening before elective or emergency surgery using the reverse transcription-polymerase chain reaction (RT-PCR) allows taking adequate precautions for COVID-19 positive patients with the conservation of the PPE.[47] Chest computerized tomography (CT) has a limited added value to the RT-PCR.[47] Preoperative screening of patients for infection with COVID-19 is not a substitute for protection of anesthesiologists because of the possibility of false-negative tests and the fact that the infected persons can be asymptomatic or presymptomatic.[16]

A developed roadmap for surgical resumption during the COVID-19 pandemic includes preoperative testing of all "elective" patients, testing of healthcare workers, social distancing, and a mandatory masking policy.[48]

Additionally, the risks of PPCs and rate of COVID-19 infection can be likely decreased after elective cancer surgery with adopting a COVID-19-free surgical pathway, defined as complete segregation of the operating theatre, critical care, and inpatient ward areas.[49]

II.2. PPE

High level "airborne" PPE is required for patients with predictable difficult lung separation who have been "tested positive for RT-PCT," not tested, or where an AGP is performed in a positive-pressure room.

The airborne level of PPE includes hair covers/hoods, fitted filtering face mask (e.g., FFP3, FFP2, or N95), goggles or face shield, long sleeve fluid-resistant gown,

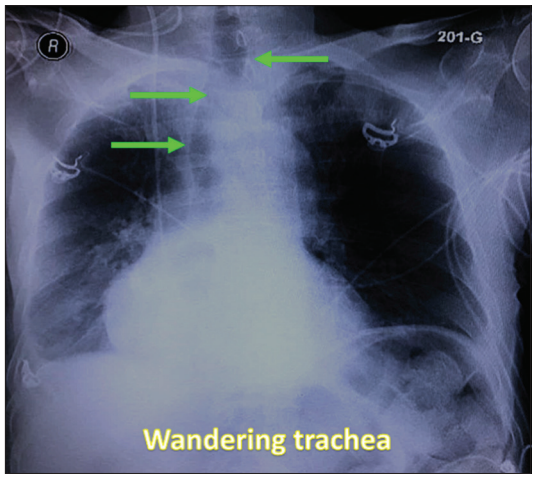

Figure 4: Chest-X ray shows wandering trachea

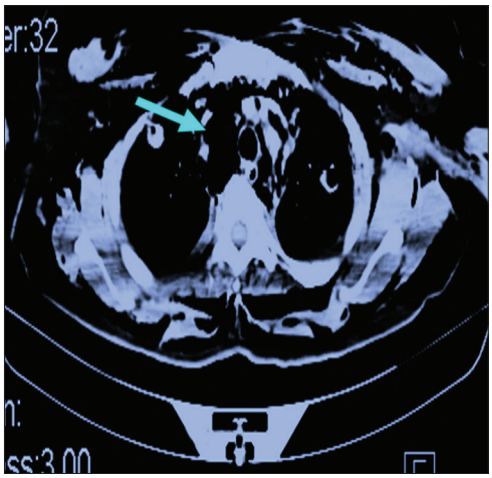

Figure 5: Chest computerized scan shows a disrupted right main bronchus

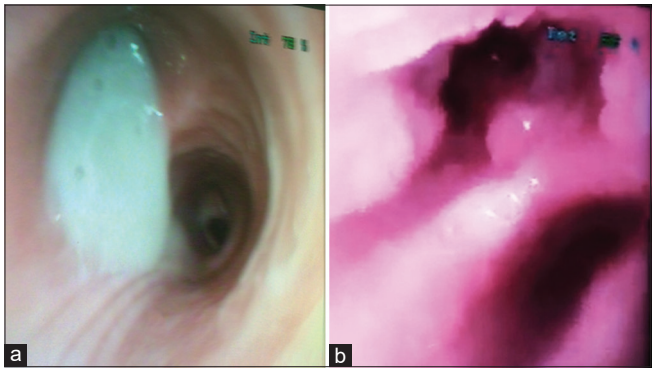

Figure 6: Bronchoscopic examination shows (a) an obstructed bronchus with a mucous plug and (b) tracheobronchopathia osteochondroplastica

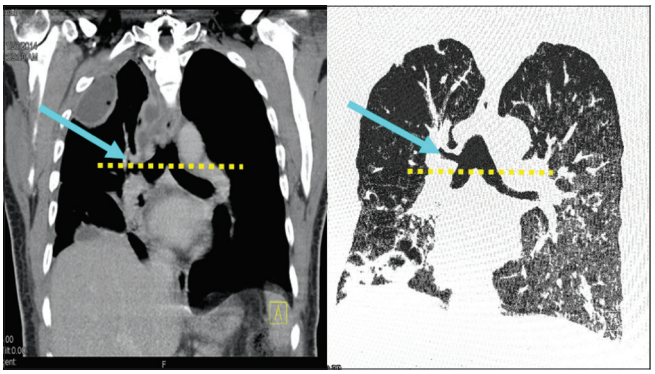

Figure 7: A computerized scan of the chest shows (Left) normal and (right) early takeoff of the right main bronchus with the carina

double layers of gloves, and shoe covers.[20,50] Donning the PPE should be continued for the duration of surgery with frequent hand hygiene and changing the outer layer of gloves after securing the airway and completing lung separation and after each patient's contact.[20]

Training on and observing the proper sequences of donning and doffing should be considered.[20] Effective communication plan during donning the PPE, particularly the powered air-purifying respirators, should be developed in advance of approaching the patient.

II.3. Standard settings

The following standards should be considered for the management of difficult lung separation in patients with "suspected" or "diagnosed" of having COVID-19 infections.

1. Limit the number of staff inside the operating room during performing lung separation.[20]
2. The best skilled thoracic anesthesiologist should take over securing the airway and lung separation.[20]
3. Avoid involvement of the vulnerable staff for COVID-19 infection, such as older anesthesiologists >60 years of age, and having severe chronic cardiac or respiratory disease and recent cancer.[20,50]
4. Intubation is preferable to be performed in a negative pressure room with >12 air changes per hour, if possible. Alternatives include (a) wearing an airborne level of the PPE, (b) inverting the flow of air inside the room with incorporating a high-efficiency particulate air (HEPA) filter, or (c) lowering the pressure inside the room than the other areas of the operating theatre as much as possible with minimizing opening the door.[20,50]
5. Minimize airway manipulation "least is best."[20]
6. Use of a closed suction system,[20] defined as using a multiuse suctioning catheter enclosed in a sleeve-tether equipped with one-way valve without the need for disconnecting the patient from the ventilator, is recommended. Alternatively, a simple closed suctioning system has been described introducing the suction catheter through an ultrasound cover probe into a catheter mount connected to the ETT.[51]
7. Incorporating an antiviral filter between the Y-shape connector of the breathing circuit and the face mask before tracheal intubation and subsequently to the

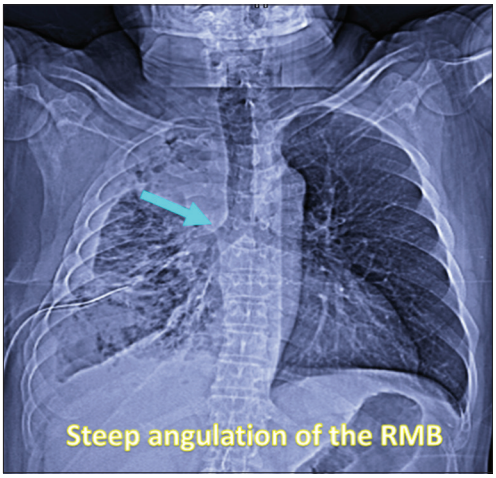

Figure 8: Chest-X ray shows steep angulation of the right main bronchus

DLT or ETT is necessary. Additionally, two antiviral filters should be incorporated into both inspiration and expiration limbs of the breathing circuit.[20,50]

8. Caution should be exercised to minimize disconnection from the breathing circuit. If necessary, switching off the ventilator to the standby mode[20] and pausing gas flow should be considered.
9. A 15-mm swivel-valve connector should be used for introducing the single-use disposable flexible bronchoscope.[20]
10. An antisialagogue medication such as glycopyrrolate can be considered to clear secretions from the airway.[6]

II.4. Preoxygenation

1. Use of the oxygen face mask over the surgical mask is recommended to minimize the risks for aerosol spread without likely compromising oxygen supply.[52]
2. Bag-mask ventilation should be avoided unless deemed necessary to minimize the risks of viral spread.[20]
3. Optimizing preoxygenation can buy more time with the likelihood increased the first pass success.[46,53] The use of noninvasive ventilation (NIV) is more useful than the high-flow nasal cannula (HFNC) in terms of the episodes of oxygen desaturation.[45] However, caution should be exercised during their use in patients with COVID-19 patients due to the risks for viral spread.[50] The use of helmet continuous positive airway pressure (CPAP) could offer alternative safer option.[54]
4. Patients can be asked to forcibly exhale air after taking the deepest breath possible "forced vital capacity."[20] That can be continued for 1 minute or until the exhaled oxygen percentage (EtO_2) value exceeds 80%.[55,56] Alternatively, CPAP/pressure support ventilation of 10 cm H_2O and positive end-expiratory pressure (PEEP) of 5 cm H_2O for 3 to 5 minutes can be used.[20,50]
5. If necessary, a two-person, low-flow, low-pressure bag-mask ventilation technique with a VE grip should be performed to provide tight-sealing.[20,50]

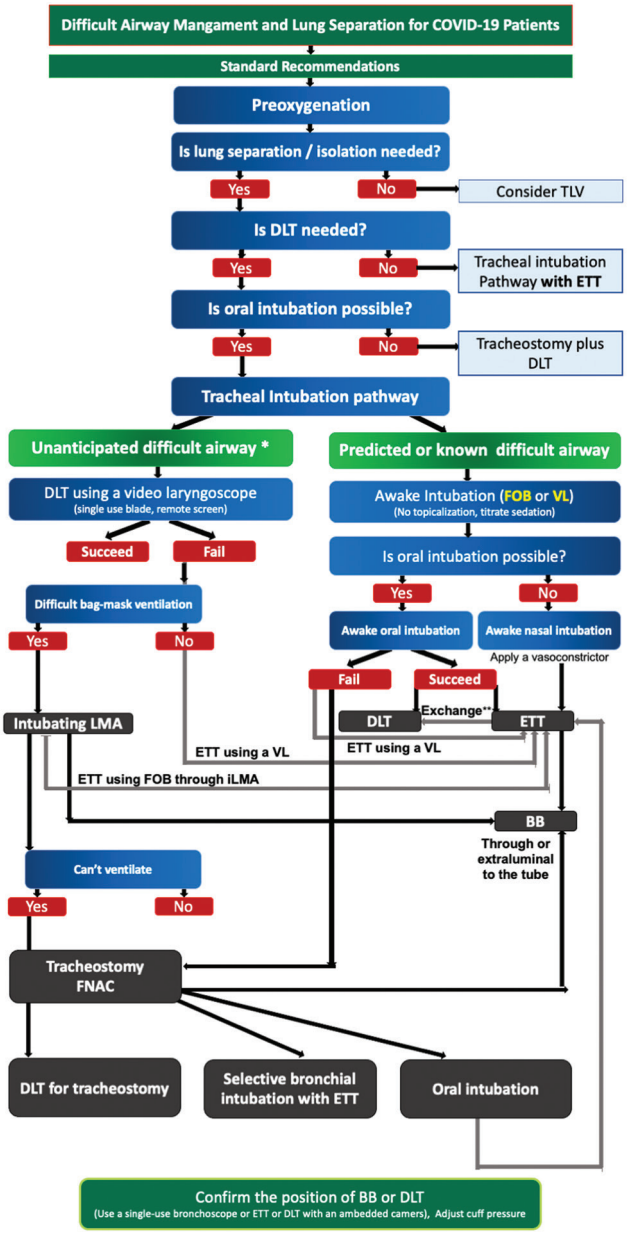

Figure 9: Cognitive aid for the systematic approach for management of difficult lung separation. Modified from Senturk *et al.*,[20] Eldawlatly *et al.*,[67] and Campos,[68] and Brodsky.[3] Abbreviations: COVID-19; coronavirus disease 2019, TLV; two-lung ventilation, DLT; double-lumen tube, ETT; endotracheal tube, FOB; fiberoptic bronchoscope, VL; video laryngoscope, LMA; laryngeal mask airway, iLMA; intubating laryngeal mask airway, BB; bronchial blocker, FNAC; front of neck access

III. Options for Difficult Lung Separation

Thoracic anesthesiologists often debate the preference and efficiency of using DLT or bronchial blocker for difficult lung separation.

III.I. Predicted Airway Difficulty

1. **Option 1**: Awake oral intubation using a flexible bronchoscope or a video laryngoscope with either an ETT or a DLT should be first considered for patients with an anticipated difficult airway.[6] Oxygen might be provided through a nasal cannula or a procedural oxygen mask at low oxygen flow. Topicalization of the airway can be avoided.[20] Instead, using dexmedetomidine can be helpful in COVID-19 patients to make them feel comfortable and reduce coughing.[54] Different types of video laryngoscopes with disposable blades can be used for placement of the DLT [Table 4]. Video laryngoscopes with remote screens are preferable to keep distancing from the airway if possible.[20,50] Following intubation with an ETT, a bronchial blocker (e.g., the EZ-Blocker size 7.0 Fr, Fuji Uniblocker size 9.0 Fr, Arndt wire-guided endobronchial blocker sizes 7.0 or 9.0 Fr, or Cohen FlexTip blocker size 9.0 Fr) can be advanced through or extraluminal to the ETT with the aid of a single-use disposable flexible bronchoscope. Adequate sealing of the bronchial blocker cuff should be considered with an air volume of 5 to 8 ml provided that a larger volume of air is required for the EZ-blocker.[6] If the DLT is deemed necessary, exchanging the ETT with the DLT over a flexi-tip airway exchange catheter (size 14 Fr: for the sizes 39 and 41 Fr DLT, size 11 Fr: for the sizes 35 and 37 Fr DLT) can be considered with the guidance of a video laryngoscope.[6]
2. **Option 2**. Awake nasal intubation with an ETT should be considered in patients with limited mouth opening following careful installing a vasoconstrictor to avoid inducing cough.[6]
3. **Option 3**. Awake surgical tracheostomy with donning an airborne level of the PPE can be considered in case of failed awake intubation.[20]

III.II. Unanticipated Airway Difficulty, Refusal of Awake Intubation, or Noncooperative Patient

1. **Option 1**. Use of a video laryngoscope for DLT intubation.[6,20,57] The use of channeled or style video laryngoscopes can be helpful in patients with restricted mouth opening and limited neck movement considering the large size and bulky DLT.
2. **Option 2**. If fails, video laryngoscope-assisted intubation with an ETT should be considered followed by either placement of bronchial blocker or exchange to a DLT over an airway exchange catheter.[58]
3. **Option 3**. In case of failed intubation and facing difficult bag ventilation, a second-generation intubating laryngeal mask airway (e.g., iLMA FasTrach, ProSeal, AirQ, classic LMA, igel, Aura-i) can be used to optimize ventilation. Then bronchoscopic-assisted tracheal intubation can be performed through the laryngeal mask airway. That can be followed with either placement of a bronchial blocker or exchange to the DLT.[6,20] The use of a ProSeal laryngeal mask airway can be used with a bronchial blocker for lung separation if tracheal intubation is not feasible.[59,60] Of note, a closed supraglottic airway-guided flexible bronchoscopic intubation system with enclosing the disposable flexible bronchoscope with a preloaded ETT into an airtight sealed probe cover with an incorporated antiviral filter has been described to reduce the risks of the AGP.[61]
4. **Option 4**. Front neck access or surgical tracheostomy can be kept as a last option as being a high-risk procedure due to aerosol-generation.[50]

III.III. Tracheostomized Patient[62]

1. **Option 1**. Placement of a bronchial blocker through the tracheostomy tube under bronchoscopic guidance is frequently used for lung separation.
2. **Option 2**. Using a specially designed short double-lumen tube for tracheostomized patients can be considered in patients with a tracheostomy stoma older than 7-days.[6,62]
3. **Option 3**. Selective main bronchial intubation using a placed ETT through an old tracheostomy stoma can be an alternative option.[62]
4. **Option 4**. Advancing an orally introduced ETT beyond the tracheostomy stoma with subsequent placement of a bronchial blocker can be alternatively used to block the main bronchus.

III.IV. Patient with Difficult Lower Airway

1. **Patients with the changed architecture of the tracheobronchial tree**

- **Tracheal narrowing or stricture:**
  If lung isolation is not required, the use of high-frequency ventilation with ensuring adequate gas exhalation can be considered. Otherwise, an ETT can be placed under bronchoscopic guidance just above the stricture edge with advancing a size 7.0 Fr Arndt's blocker through the narrowed area to block the main bronchus.[63] Alternatively, a tracheostomy can be inserted distal to the narrowed tracheal segment with the placement of a bronchial blocker.
- **Angulated or deviated trachea or angulated main bronchus.**

Table 4: Comparisons between the different types of video laryngoscopes for placement of double-lumen tubes. Adopted from El Tahan and Villalonga[58]

Class	Type	Features	Technical tricks for DLT intubation	Tested for Awake DLT intubation
Angulated blades	GlideScope	A 60° angulated blade. Remote monitor or attached to the handle. Variable reusable and disposable blades (sizes 3, 4, and 5).	Bending the stylet of the DLT so that the distal curvature of the DLT curve follows the curve of the blade. Using an Airway Exchange Catheter under the Glidescopic-guidance. The combined use of the GlideScope and flexible bronchoscope. Sequential rotation of the left-sided DLT after introducing the tracheal tip into the glottis with an initial 180° counter-clockwise rotation then, an additional 90° clockwise rotation. Reform the distal tip of DLT to a hockey-stick shape. Using a specifically designed semirigid intubating GlideRite DLT Stylet.	√
	MacGrath	Disposable and reusable "slim" blades (sizes 3 and 4). The X-blade has an angulated tip. A 2.5" LCD display.	The combined use of the McGrath and the Parker Flex-IT™ Stylet. Using a 12-cm pillow height to achieve an appropriate sniffing position. The combined use of the MacGrath and flexible bronchoscope.	
	C-Mac D-Blade	An 80° angulated blade. A remote or pocket monitor.	Using a reshaped distal curvature of the DLT to follow the curve of the D-blade.	
	CEL-100	A 40° angulated blade.		
Channelled	Airtraq	A channeled blade with 90° shape dedicated for the size 35 Fr and 37 Fr DLT. A direct view, WiFi camera, Endo cams, and compatible phone adaptor with smartphones.	Remove the stylet before use.	√
	Pentax Airway Scope	A disposable standard blade with an 80° viewing angle (height: 131 mm; width: 52 mm; depth: 96 mm). A thinner P-Blade (height: 134 mm; width: 52 mm; depth: 95 mm). A 2.4-inch LCD screen with a crosshair displays.	Use an airway exchange catheter in conjunction with the P-Blade for the bulky DLT size 37 Fr or larger. Use an infant-sized Intlock for placement of the DLT size 32 Fr.	
	King Vision	A disposable standard and nonchanneled blade with an 80° viewing angle.	The nonchanneled blade requires the use of a reformed stylet. After the bronchial cuff passes through the glottis, the stylet should be withdrawn and the DLT rotated 180° counterclockwise while advancing it.	
Stylets	Bonfils intubation fiberscope	A 40° angulated video stylet (size 3.5 with a length; 35 cm or size 5.0 mm with a length of 40 cm).	Shortening the length of the connecting tubes of both tracheal and bronchial lumens of the sizes 37 Fr and 39 Fr DLT by 1.5 cm and 3.5 cm, respectively.	
	Trachway	A 32-cm rigid video-stylet with an adjustable malleable angle and a rotatable monitor.	Shortening the DLT bronchial connector with using a shortened 6.5-mm ETT as a modified connector.	√
	OptiScope	A rigid video-stylet with a malleable tip (length: 40.5 cm, an outer diameter: of 5.0 mm) can accommodate a 35 Fr or larger DLT.		√
	Shikani optical stylet	A rigid video-stylet with a malleable tip (length: 37.9 cm, an outer diameter of 5.01 mm).	Shortening of the bronchial lumen of the DLT. Angulating the tip of the Shikani stylet to a hockey-stick shape with the alignment of the tracheal orifice of the DLT with the concave aspect of the distal curvature.	
	Lighted Stylet	It relies on transillumination of the soft tissues of the neck to guide advancement the tube into the larynx.	Cutting the proximal 1.5 cm of the tracheal and bronchial lumens of the DLT. Loading the DLT alongside the lighted stylet with an angulated distal end at 90°. Introducing the DLT with the lighted stylet through the oropharynx and directed anteriorly through the midline towards the cricothyroid membrane under transillumination guidance. After removal of the stylet, rotate the DLT 90° counterclockwise after lifting the jaw anteriorly.	

DLT: Double-lumen tube, ETT: Endotracheal tube

An ETT in conjunction with a bronchial blocker can be placed under bronchoscopic guidance. If DLT is required, it can be advanced into the main bronchus guided with the flexible bronchoscope

following introducing the tracheal cuff beyond the glottis.

- **Early takeoff of the right upper lobar bronchus and tracheal bronchus**
  The DLT placed on the opposite side of the surgery can be used as the first option to provide lung isolation for those patients.[43] A bronchial blocker can be used alternatively to isolate the left main bronchus in case of inability to place a left-sided DLT because of a left-shifted carina or a high takeoff tracheal bronchus. For a right-sided surgery, a bronchial blocker can be placed into the right main bronchus followed by inserting an Anrdt's blocker or a Fogarty arterial embolectomy catheter in the tracheal bronchus.[43]

2. **Patients with a disrupted tracheobronchial tree**
   Inserting the ETT or DLT should be performed under direct visualization using the flexible bronchoscope to avoid passage of the tube through the severed injured segment. Using a DLT placed on the opposite side of the surgery can be used for the bronchial rupture. Management of patients with carinal disruption is challenging. Selective intubation of each main bronchus with a microlaryngeal tube or a catheter connected to high-frequency ventilation might be useful. Alternatively, extracorporeal membrane oxygenation can be safely used for extensive carinal surgery.[64]
3. **Patients with a narrowed bronchial lumen**
   In those patients, a systematic bronchoscopic examination of the tracheobronchial tree should be accomplished before placement of the DLT or bronchial blocker to identify the likely distorted anatomical landmarks.[6] The use of right-side DLT should be considered for patients with narrowed left main bronchus.[6]

Difficult lung deflation

Inadequate lung collapse during one-lung ventilation despite the proper placement of the lung isolation tool can hamper the surgical exposure. The presence of chronic obstructive lung disease or the use of bronchial blockers with narrow lumens has been identified as independent predictors for inadequate lung collapse during one-lung ventilation.[2] Several techniques have been described to overcome that problem including[1] the use of 100% oxygen for 20 min after starting one-lung ventilation,[2,65] continuous suction of -30 cmH_2O through the lumen of the bronchial blocker[2] or DLT, or[3] using carbon dioxide insufflation.[66]

Extubation after surgery

The plan for extubating patients with diagnosed COVID-19 infection and airway difficulty after thoracic surgery should follow the EACTA recommendations.[20]

Conclusion

We presented a suggested framework for the management of difficult lung isolation or separation in patients during the COVID-19 pandemic emphasizing on the preoperative planning, preparation and testing, protective personal equipment, settings, preoxygenation, and the lung isolation options.

Declarations of interest

Mohamed El Tahan received free airway device samples from Ambu US and Airtraq UK in 2014 and 2015, respectively to be used in the other three published studies. He has no financial or direct interest with any industry including Ambu and Airtraq.

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Conflicts of interest

There are no conflicts of interest.

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