Operative Techniques in Otolaryngology 30 (2019) 249–254

Operative Techniques in
Otolaryngology

Airway management in laryngeal surgery[☆]

Verghese T. Cherian, MD[a], Sonia J. Vaida, MD[a,b]

From the [a]Department of Anesthesiology and Perioperative Medicine, The Pennsylvania State University, College of Medicine, Hershey, Pennsylvania
[b]Department of Obstetrics and Gynecology, The Pennsylvania State University, College of Medicine, Hershey, Pennsylvania

KEYWORDS
Laryngeal surgery;
Anesthesia equipment;
Jet ventilation

Airway management and anesthesia for laryngeal surgery poses many challenges. A preoperative endoscopic airway examination and discussion with the otolaryngologist helps in planning the anesthetic management. Although, securing the airway using specialized endotracheal tubes is possible in the majority of cases, the surgeon may occasionally request a "tubeless" field. This can be achieved by ventilating the lungs using jet ventilation or high flow nasal oxygen (HFNO) while providing total intravenous anesthesia. Therefore, in addition to the "difficult airway" cart, equipment to provide HFNO and a high-pressure source of oxygen to provide jet ventilation should also be available.

Introduction

The main anesthetic challenges presented by laryngeal surgery are managing a potentially difficult airway, sharing the airway with the otolaryngologist while providing an optimal surgical access, obtunding the autonomic response of a stimulating procedure and facilitating a smooth emergence from anesthesia.[1,2]

The common benign laryngeal pathologies that present for surgical intervention are tumors (papillomas, cysts), stenosis, infections/inflammatory conditions (epiglottitis, angioedema), injuries or functional obstructions (vocal cord palsy, obstructive sleep apnea). These patients usually present with varying degree of hoarseness, stridor or upper airway obstruction. The common surgical procedure involves direct laryngoscopy for diagnostic assessment followed by instrumentation to excise the lesion and cauterization of the tissue with either the electro-diathermy or by "light amplification by stimulated emission of radiation" (LASER).

Preoperative evaluation

Airway management in patients having laryngeal or pharyngeal surgery can be challenging due to the original pathology or as a result of previous surgery or radiotherapy.[3-5] The analysis of the Danish anesthesia database showed that emergency surgical airway was performed more frequently in patients undergoing otorhinolaryngology surgeries (1.6:1000) compared to other surgeries (0.06:1000).[4]

Therefore, a closer preoperative airway evaluation of a patient planned for laryngeal surgery, should facilitate better intraoperative airway management.[6] The presence of hoarseness and/or stridor is a harbinger of difficult airway and needs urgent evaluation. Inspiratory stridor indicates a supraglottic obstruction while an expiratory stridor

☆ Funding: None
Address reprint requests and correspondence: Verghese T. Cherian, MD, The Pennsylvania State University, College of Medicine, Department of Anesthesiology and Perioperative Medicine, 500 University Drive, H187, Hershey, PA 17033-0850.
E-mail address: vcherian@pennstatehealth.psu.edu

http://doi.org/10.1016/j.otot.2019.09.005
1043-1810/

suggests a subglottic impediment. Tracheal stenosis could cause upper airway obstruction during both inspiration and expiration. Perusing the findings from radiological studies, such as computerized tomography of the neck, if available, can prove valuable. The findings of the flexible nasal endoscopy performed by the otolaryngologist can also offer important information about the airway anatomy. Alternatively, the anesthesiologist can do a preoperative endoscopic airway examination (PEAE), using a flexible bronchoscope following topical anesthesia of the nasal passage.[7,8] Rosenblatt et al found that PEAE affected the planned airway management in 26% of patients scheduled for elective airway procedures.[7]

Securing the airway with an endotracheal tube (ETT) appears the safest option for these patients. However, in a challenging airway, the dilemma is if it should be done while the patient is awake and breathing spontaneously. The algorithm by the American Society of Anesthesiologists Task Force on Management of the Difficult Airway suggests that if there is anticipated difficulty in ventilating with a face mask or a supraglottic ventilatory device, or in performing a laryngoscopy and intubation, then securing the airway while the patient is awake may be prudent, provided the patient is cooperative. Other factors to consider before making this decision are the risk for aspiration, the patient's ability to tolerate apnea and if a front of neck access is available in case of a crisis.[6]

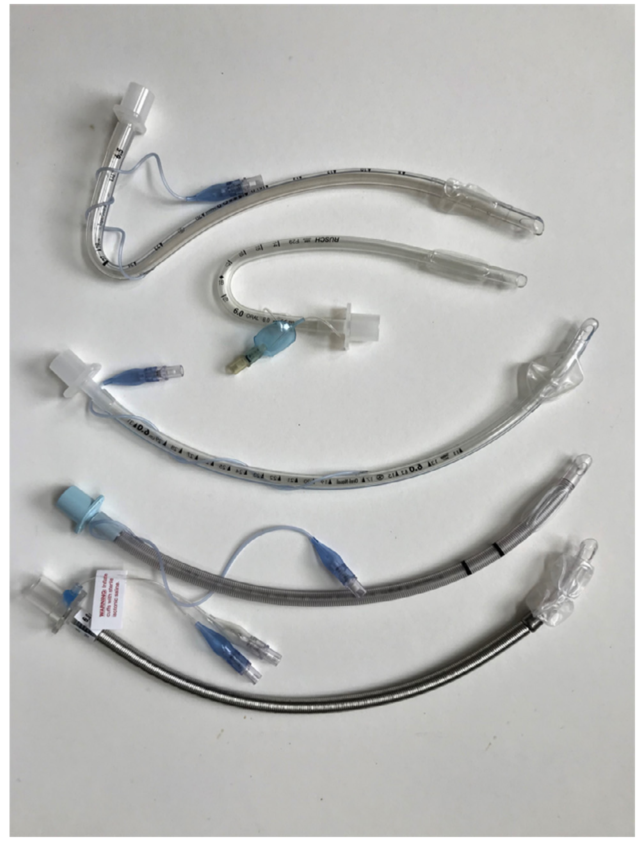

Figure 1 Endo-tracheal tubes used for laryngeal surgery. From top to bottom: Nasal Ring-Adair-Elwyn (RAE); Oral RAE; micro-laryngeal tube (MLT); flexo-metallic; laser flex. The laser flex tube has 2 cuffs.

Preparation and equipment

While anesthetizing a patient for laryngeal surgery, it is wise to have the "difficult airway" cart available in the operating room since the airway may be compromised during, or at the end of the procedure, even if it was not so preoperatively. Equipment to provide high-flow nasal oxygen (HFNO) and a high-pressure source of oxygen (HPSO) for a jet ventilation system should also be available.

In patients with severely compromised airway, an awake tracheotomy under local anesthesia used to be the gold standard, but currently an awake intubation using a flexible bronchoscope is widely practiced. However, this requires a skilled anesthesiologist and a cooperative patient and moreover, the passage of the bronchoscope through the narrow airway causes a "cork in the bottle" effect which could be very distressing to the patient. The use of angulated video-laryngoscope for intubation in an awake patient after topical anesthesia of the oropharynx is an attractive option. The familiarity with these devices, the wide-angled view achieved by minimal force during laryngoscopy, and the fact that the passage of the ETT provides immediate relief to the patient are the main advantages.[9]

General anesthesia with an ETT is used for most laryngeal surgeries. There are specialized ETTs available that provide better exposure of the surgical field (Figure 1). A micro-laryngeal tube has a small internal diameter (4-6 mm) with a standard length as an adult tube (30 cm). The flexo-metallic or the wire reinforced tubes resist kinking when it is retracted by the surgeon. The oral and nasal Ring-Adair-Elwyn tubes are preshaped tubes designed to enable better exposure of the posterior and anterior section of the vocal cords, respectively.

LASER can ignite the polyvinyl chloride ETT and in an oxygen-rich environment could result in airway fires. Therefore, it is advocated to use LASER – resistant ETTs, such as those made of rubber or silicon wrapped with either aluminum or copper foil. Alternatively, stainless-steel spiral "Laser flex" tube can be used. The laser flex tube has 2 cuffs with the distal one as back up if the first one was to be damaged by the LASER. It is recommended that the cuffs should be inflated with saline to provide a "heat sink," and also to add methylene blue to the saline as the blue color in the field would alert the surgeon that the cuff is compromised. A damaged cuff would permit the oxygen-rich anesthetic gases to leak back and fuel an airway fire. Whenever, cauterization of airway using electrical diathermy or LASER is planned, it is prudent to reduce the FiO_2 to below 0.3.[10]

Even the narrow ETT used to secure the airway may obstruct the view of an already compromised larynx, therefore the surgeon may request a "tubeless" field. This can be achieved by intermittently removing the ETT during the surgical intervention while the patient is apneic and reinserting when the oxygen saturation falls below a

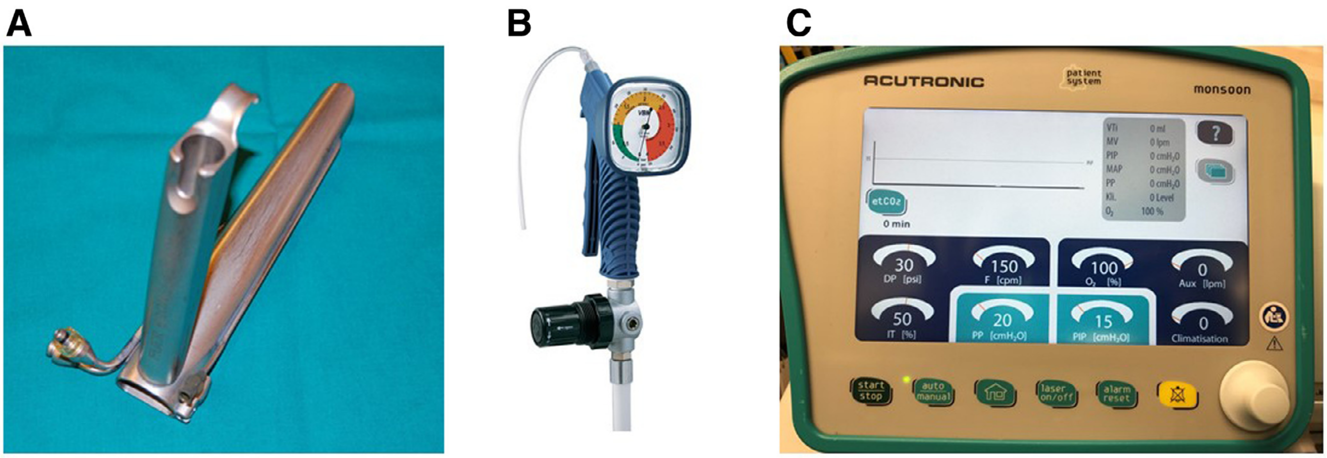

Figure 2 Jet ventilation. (A) Operating laryngoscope with attachment for jet ventilation; (B) Manujet III showing the driving pressure gauge and the knob to adjust it; (C) Monsoon ventilator for high frequency jet ventilation.

predetermined level, usually in the low 90s. During the apneic period, a low flow of oxygen through a nasal cannula may be administered. Since the 1950s, bronchoscopes that enabled ventilation through their side-arm have been available. However, the proximal end of the bronchoscope had to be occluded by an eyepiece or the surgeon's thumb. This meant retraction of the instruments and temporary cessation of surgery. In order to reconcile this problem, Sanders described the technique of jet ventilation that allowed concomitant ventilation and surgical access through an open operating laryngoscope (Figure 2).[11]

Jet ventilation

Jet ventilation using HPSO is a system for ventilating a patient without an ETT. It works based on the Bernoulli's principle which states that a stream of gas at high flow creates an area of low pressure. Therefore, if a short burst of oxygen at high pressure is directed into the airway, the low pressure it creates will entrain the surrounding air and provide alveolar ventilation even in the absence of an ETT. This form of ventilation essentially needs a high-pressure oxygen source which is usually at 50 $lb.in^{-2}$, a control system to regulate the flow, and a channel to direct the gas. Manually operated jet ventilation devices such as the Sander's type injector or the Manujet III (VBM Medizintechnik GmbH, Sulz am Neckar, Germany) (Figure 2) have an adjustable pressure regulator. However, the automated device such as Monsoon ventilator (Acutronic Medical Systems, Hirtzel Switzerland; Figure 2) has many added safety features to control the driving-pressure, ventilation frequency, and inspiratory time.[12] The concept of high frequency (>60 min^{-1}) jet ventilation was muted in 1970s. This provides low tidal volume at a rapid rate and produces minimal movement of the surgical field.

Various needles, cannulas, or catheters are available that can be sited above the vocal cord (supra-glottic), passed between the cords (trans-glottic), or through the cricothyroid membrane (trans-tracheal).

When initiating jet ventilation, it is prudent to begin at a low driving pressure and increase it in increments to observe the rise and fall of the chest. Inadequate ventilation could lead to hypercarbia. However, the dreaded complication of using the HPSO is the misdirection of the jet into the tissue leading to subcutaneous emphysema and pneumo-mediastinum. Therefore, it is crucial to align the jet along the axis of the airway. Another problem of jet ventilation is the failure of adequate exhalation through a pathologically narrowed glottic aperture. This can result in stacking of the tidal volume and raising the intrathoracic pressure, leading to cardiorespiratory collapse. A relatively new device, the "Ventrain" (Ventinova Medical B.V, Eindhoven, Netherlands) is designed to assist egress of the tidal volume by providing suction through the ventilating cannula.[13]

Supra-glottic jet ventilation

A narrow, metallic cannula attached to the proximal end of the rigid surgical laryngoscope is used for jet ventilation. There are 3 important points to consider with this technique.

1. The jet stream can cause movement of the surgical field which becomes crucial when LASER is being used.
2. The surgeon needs to align the laryngoscope with the glottic opening to allow for adequate ventilation.
3. The end-tidal CO_2 monitoring is unreliable.

Trans-glottic jet ventilation

The Hunsaker Mon-Jet (Xomed, Jacksonville, USA) and the Laserjet (Acutronic Medical Systems, Hirtzel Switzerland) are narrow, double channel catheters made of LASER-resistant material that are inserted between the vocal cords (Figure 3).[14] The HPSO is directed through

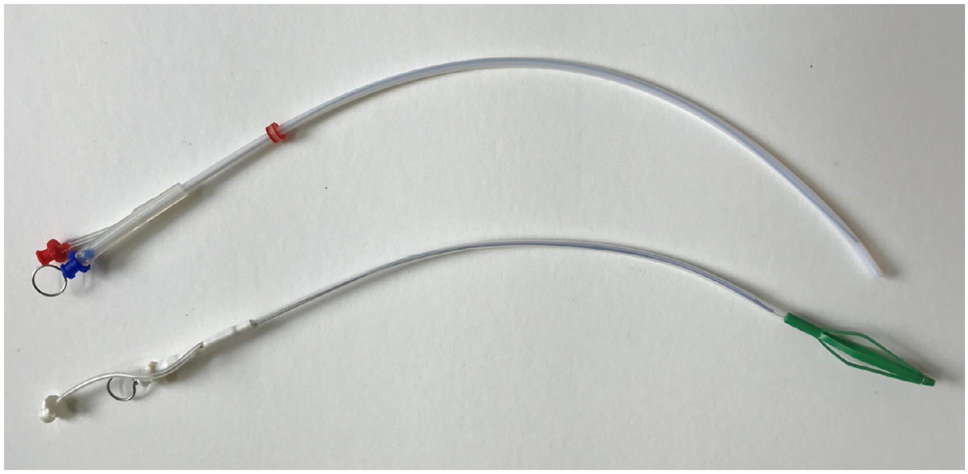

Figure 3 Trans-glottic double lumen catheters for jet ventilation. (A) Laser jet, (B) Hunsaker Mon-jet. The Hunsaker tube has a basket to align it along the tracheal wall.

one channel while the second channel is used to measure the airway pressure or the end-tidal CO_2. The advantages of this technique are that there is minimal movement of the surgical field during ventilation and the measurement of the airway pressure and the end-tidal CO_2 is more reliable.

There are various catheters available, such as the Cook's exchanger catheter (Cook Medical Inc., Bloomington, IN) and the Aintree catheter (Cook Medical Inc., Bloomington, IN) that have a luer-lock attachment and suggested to be suitable for jet ventilation. However, if such long catheters are used, one should ensure that the tip of these catheters is positioned within the trachea while not abutting the tracheal mucosa.

Trans-tracheal jet ventilation

Trans-tracheal jet ventilation can be used as a rescue procedure in "cannot intubate cannot oxygenate" cases.[15] For patients with anticipated difficult intubation, either due to limited glottic access or an obstructing lesion, a trans-tracheal ventilation approach may be preferred. Although, a standard 14-gauge intravenous cannula can be inserted through the cricothyroid membrane, there are specialized cricothyroid cannulas such as the "Ravussin" that can be sited under general anesthesia or in an awake patient after local anesthesia.[16]

Trans-tracheal jet ventilation is a relatively easy maneuver to perform in an airway crisis, but the fact that the glottic opening is obstructed should heighten the awareness of the possibility of impaired egress of the ventilated gas. Monitoring the airway pressure is crucial and the use of automated ventilator should be encouraged over manual jet ventilation to prevent barotrauma. It may also be difficult to align the cannula with the tracheal lumen.

As reported by Jaquet et al, transtracheal jet ventilation is associated with a significantly higher complication rate than trans-glottic jet ventilation, mainly due to barotrauma caused by obstruction of gas outflow.[17]

Ventilation and gas exchange during jet ventilation

At low frequency (10-20 min^{-1}) the ventilation occurs by convective or bulk flow which is like standard manual ventilation. However, at high frequency the tidal volume may be smaller than the combined anatomical and equipment dead space and the normal physiological principles would not apply. The jet stream passes through the airway in a laminar flow with the flow in the center moving faster than along the bronchial wall, creating a parabolic configuration. This difference in flow becomes exaggerated by each breath, with the jet moving the axial gas forward while the gas at the periphery moves out of the lungs. In addition to the axial movement, there is also a molecular diffusion due to the radial concentration gradient secondary to the eddies caused by turbulent flow. This is known as *Taylor-type* dispersion.[18] Regional variation in airway resistance and compliance cause some areas of the lung to fill and empty more rapidly than others. This difference in time constant (resistance×compliance) causes gas to flow from one alveolus to another with a longer time constant and this is known as *pendelluft*.[18] This leads to rebreathing and an increase in the effective dead space. This effect is increased during high frequency ventilation. The other mechanism that contribute to gas exchange during high frequency jet ventilation is mixing due to cardiac oscillations.

Anesthesia during jet ventilation is maintained by intravenous anesthetics with muscle relaxation. In addition to the blood pressure, the electrocardiogram and the pulse oximeter, monitoring the airway pressure and the end-tidal CO_2 is required.

LASER surgery

LASER is commonly used for laryngo-tracheal surgeries such as cordotomy, dilating tracheal stenosis, and excision of lesions. The risks of LASER include damage to the surrounding normal tissues, airway and non-airway fire, and injury to the personnel in the operating room. All the staff involved should be familiar with the safety protocols for the use of a LASER and wear protective goggles. The patient's face should be covered with moistened towels and the their eyes taped and protected with goggles. Specialized ETT and catheter as described above are required. During the use of a LASER, the inspired oxygen concentration should be maintained below 30%, and it is prudent to keep a 50 ml syringe of saline on the surgical instrument table ready to be used in the event of a fire.

High-Flow Nasal Oxygen (HFNO)

The "trans-nasal humidified rapid-insufflation ventilatory exchange" (THRIVE) is designed to provide a high flow nasal oxygen both in an apneic and a spontaneously breathing patient. THRIVE has been shown to maintain oxygenation in patients with difficult airway up to a median apneic time of 15 minutes and up to 30 minutes in patients undergoing laryngeal surgery.[19,20] It has also been shown that the rise in end-tidal CO_2 was about 1 $mmHg.min^{-1}$ suggesting a flow-dependent flushing of the dead space.[20]

During apnea the alveolar partial pressure of oxygen (P_AO_2) falls, leading to a decrease in arterial partial pressure of oxygen (P_aO_2). However, the sigmoid shape of the oxy-hemoglobin dissociation curve manages to keep the hemoglobin saturated until the P_aO_2 falls below 60 mmHg. Alongside, since CO_2 is 20 times more soluble in blood than oxygen, about 20 ml of CO_2 is excreted into the alveoli while about 90% remains dissolved in the blood during apnea. The arterial partial pressure of CO_2 (P_aCO_2) rises about 8-16 mmHg during the first minute followed by 3 mmHg per minute during continued apnea. If the blood flow through the alveoli is present, approximately 250 ml of oxygen is carried away from the alveoli every minute. This difference of about 230 ml between oxygen uptake and CO_2 delivery creates a negative pressure within the alveoli and the gas within the oropharynx can move down the trachea into the alveoli. This is the physiological basis of apneic ventilation and has been described over 70 years ago.[21] However, the prerequisites to effective apneic oxygenation are adequate pulmonary circulation, a patent airway and administration of 100% oxygen.

Conclusion

Laryngeal surgery poses several challenges to the anesthesiologist. A PEAE and effective communication with the otolaryngologist helps in planning the anesthetic management. In addition to the "difficult airway" cart, HFNO and a HPSO, necessary for jet ventilation, should also be available.

Disclosure

The authors reported no proprietary or commercial interest in any product mentioned or concept discussed in this article.

References

1. Reed AP. Laser laryngoscopy. In: Reed A, Yudkowitz F, editors. Clinical Cases in Anesthesia. (ed 4) Philadelphia, PA: Elsevier. 2014, p. 215–220.
2. Hsu J, Tan M: Anesthesia considerations in laryngeal surgery. Int Anesthesiol Clin 55:11–32, 2017.
3. Heinrich S, Birkholz T, Irouschek A, et al: Incidences and predictors of difficult laryngoscopy in adult patients undergoing general anesthesia: A single-center analysis of 102,305 cases. J Anesth 27:815, 2013.
4. Rosenstock CV, Nørskov AK, Wetterslev J, et al: Emergency surgical airway management in Denmark: A cohort study of 452 461 patients registered in the Danish Anaesthesia Database. Br J Anaesth 117(Suppl 1):i75, 2016.
5. Doyle DJ. Anesthesia for ear, nose and throat surgery. In: Miller RD, editor. Miller's Anesthesia. (ed 8) Philadelphia, PA: Elsevier Saunders. 2015, p. 2523–2549.
6. American Society of Anesthesiologists Task Force on management of the difficult airway Practice guidelines for management of the difficult airway: An updated report by the American Society of Anesthesiologists task force on management of the difficult airway. Anesthesiology 98:1269–1277, 2003.
7. Rosenblatt W, Lanus AI, Sukhupragarn W, et al: Preoperative endoscopic airway examination (PEAE) provides superior airway information and may reduce the use of unnecessary awake intubation. Anesth Analg 112:602–607, 2011.
8. Moorthy SS, Gupta S, Laurent B, et al: Management of airway in patients with laryngeal tumors. J Clin Anesth 17:604–609, 2005.
9. Wilson WM, Smith AF: The emerging role of awake videolaryngoscopy in airway management. Anaesthesia 73:1055–1066, 2018.
10. Apfelbaum JL: Practice advisory for the prevention and management of operating room fires: an updated report by the American Society of Anesthesiologists task force on operating room fires. Anesthesiology 118:271–290, 2013.
11. Sanders RD: Two ventilating attachments for bronchoscopes. Del Med J 39:170, 1967.
12. Biro P: Jet ventilation for surgical interventions in the upper airway. Anesthesiol Clin 28:397–409, 2010.
13. https://www.ventinovamedical.com/ventrain/ (last accessed 07.14. 2019).
14. Galmén K, Harbut P, Freedman J, et al: The use of high-frequency ventilation during general anaesthesia: An update. F1000Res 6:756, 2017.
15. Duggan LV, Ballantyne Scott B, Law JA, et al: Transtracheal jet ventilation in the 'can't intubate can't oxygenate' emergency: A systematic review. Br J Anaesth 117(Suppl 1):i28–i38, 2016.
16. Ravussin P, Freeman J: A new transtracheal catheter for ventilation and resuscitation. Can J Anaesth 32:60–64, 1985.
17. Jaquet Y, Monnier P, Van Melle G, et al: Complications of different ventilation strategies in endoscopic laryngeal surgery. Anesthesiology 104:52–59, 2006.

18. Evans E, Biro P, Bedforth N: Jet ventilation. Continuing education in anaesthesia. Crit Care Pain 7:2–5, 2007.
19. Patel A, Nouraei SA: Transnasal Humidified Rapid-Insufflation Ventilatory Exchange (THRIVE): A physiological method of increasing apnoea time in patients with difficult airways. Anaesthesia 70:323–329, 2015.
20. Gustafsson IM, Lodenius A, Tunelli J, et al: Apnoeic oxygenation in adults under general anaesthesia using Transnasal Humidified Rapid-Insufflation Ventilatory Exchange (THRIVE) – A physiological study. Br J Anaesth 118:610–617, 2017.
21. Draper WB, Whitehead RW: The phenomenon of diffusion respiration. Curr Res Anesth Analg 28:307–318, 1949.