Anesthetic Considerations for Automated High-Frequency Jet Ventilation During Electromagnetic Navigation Bronchoscopy

Roger Masters, MS, CRNA
Rabih Bechara, MD, FCCP
Neil R. Seeley, MD
Christopher Parks, MD
Zachary D. Moore, MD

Newly advanced diagnostic bronchoscopic procedures, such as electromagnetic navigation bronchoscopy using navigation system technology (superDimension, Medtronic), provides computed tomography referenced and computerized 3-dimensional imaging. To increase accuracy and higher diagnostic biopsy yield, electromagnetic navigation bronchoscopy necessitates special anesthetic and ventilation techniques providing the interventional pulmonologist minimal respiratory lung motion. This anesthetic meets 2 important goals by limiting almost all interference from diaphragmatic and lung movement while allowing the anesthesia provider to achieve hands-free management. Proposed here is an anesthetic ventilation technique by automated high-frequency jet ventilation (HFJV) via double-lumen micro jet endotracheal tubes. This ventilation technique delivers consistent very low tidal volumes. Automated HFJV provides the pulmonologist the advantage of more accurate navigation and target alignment in this Global Positioning System–guided biopsy procedure. The technique offers essentially no chest motion, without interrupting ventilation. Additionally, HFJV allows the anesthetist better availability to attend to total intravenous anesthesia, adjustments, and interventions. The intention of this article is to detail an anesthetic method that provides a hands-free technique that requires only one anesthesia provider.

Keywords: Electromagnetic navigation bronchoscopy, high-frequency jet ventilation, superDimension, total intravenous anesthesia.

Lung cancer is the most common form of death due to carcinoma in the United States.[1] The American Cancer Society estimates that there are around 229,000 new cases of lung cancer diagnosed per year in the United States and almost 136,000 deaths.[1] Rarely, and if diagnosed in very early stages, there is a potential 10-year survival rate of 88%. Unfortunately, for most patients their lung cancer is diagnosed in more advanced stages, with a 10-year survival of 16%.[2] During the average lifetime, 8% of all men and 6% of women will receive a diagnosis of lung cancer.[3] Most lung cancers may be preventable because 85% of cases are linked to smoking.[4] Of these, 40% of the cases are found in the lung periphery as adenocarcinoma,[5,6] and cure is usually not possible.[7] Staging of the disease, usually done by bronchoscopy, is very important.[3,7] Accurate, endoscopic staging helps determine the prognosis of the disease and potential treatment modalities, which consist of chemotherapy, immunotherapy, radiotherapy, surgery, or a combination modality.[8]

In the last decade, changes and major advancements in bronchoscopic procedures have been made. Electromagnetic navigation bronchoscopy (ENB) can often replace computed tomography (CT)–guided needle biopsy and can significantly decrease the complications of pneumothorax, hemothorax, and hemoptysis.[9] A CT-guided biopsy sometimes requires a chest tube because of the risk of pneumothorax. In the case of video-assisted thoracic surgery (VATS) for biopsy, a chest tube must be placed and thus also necessitates a hospital admission. On the other hand, ENB is done on an outpatient basis, requires only 38 to 86 minutes to perform, and has frequently replaced video-assisted thoracic surgery/biopsy surgery.[10]

Electromagnetic Navigation Bronchoscopy

Electromagnetic navigation bronchoscopy represents major advantages in bronchoscopic biopsy procedures. Use of Medtronic's superDimension technology for ENB now gives skilled interventional pulmonologists the ability to navigate and sample peripheral lung lesions. The procedure involves a bronchoscope with an extension device that is able to reach small nodes and lesions in the distant periphery of the lung, previously not accessible with conventional bronchoscopes. Electromagnetic navigation bronchoscopy can target lesions of less than 20 mm in the periphery using CT-guided location,

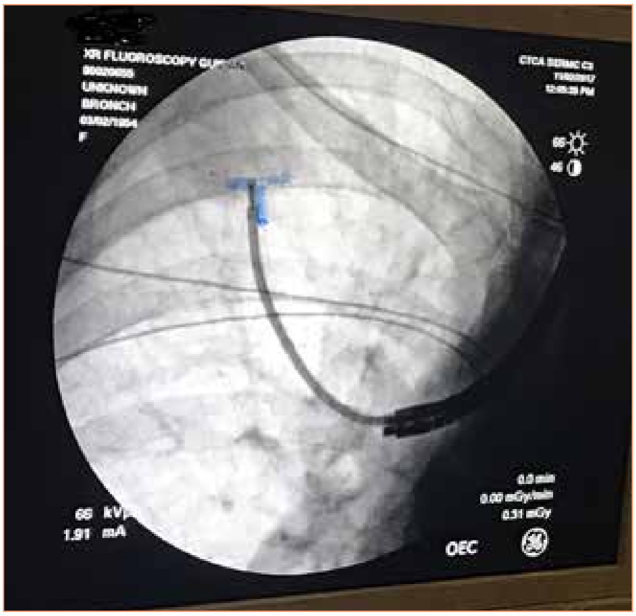

Figure 1. Electromagnetic Navigational Bronchoscopy Using superDimension (Medtronic) With Steerable Catheter Through a Working Channel

Figure 2. Hand-Triggered Manual Low-Frequency Jet Ventilation Hose Described by Sanders[13] in 1967 for Emergency Airway Rescue Intervention

combined with computerized programming and Global Positioning System (GPS) guidance.

The components involved in ENB procedures use advanced technical computerized equipment, which requires planning for navigation stages. The first part of planning is obtaining a CT scan with detailed images of the lesions. This is followed by loading or "registration" of the information into digital software programming for a virtual 3-dimensional (3-D) image of the lung. For the ENB, the patient lies on an electromagnetic board, and navigational reference marker electrodes are placed on the patient's chest. Fluoroscopy is used to aid in locating the retractable sensor tip through the bronchoscopic extended working channel (Edge, Medtronic; Figure 1) using the locatable guide (Edge) intended for use with the superDimension navigation system. By using the virtual 3-D image of the patient's pulmonary airway anatomy on a monitor screen, the pulmonologist can guide the sensor tip to the biopsy site.[10]

The results of this highly precise biopsy allow vital clinical diagnostic information and determination of the specific cell type of the cancer. By staging of the disease, the prognosis and potential treatment options can then be developed. Often, fiducial markers, which are small metal site indicators, can be placed in the lung at the site of the lesion. This serves as future reference if stereotactic radiosurgery is determined to be the appropriate treatment management.[11]

More definitive investigations will help determine if this motionless lung technique improves the success of ENB biopsy of these small and less accessible lesions.[12]

High-Frequency Jet Ventilation for Use in Electromagnetic Navigational Bronchoscopy

A goal of any anesthetic is to provide safe management for the patient and optimal conditions for the physician performing the procedure. In ENB lung biopsy of small peripheral lesions, special ventilation techniques are required. Currently used techniques are described here, including a unique nonlung motion approach called high-frequency jet ventilation (HFJV).

• ***Heavy Sedation of the Patient During ENB.*** Because the patient is more apt to move, cough, and breathe spontaneously with lung lesion motion, this technique is the least adopted.

• ***Bronchoscopy Through Conventional Endotracheal (ET) Tube With General Anesthesia.*** This technique involves muscle paralysis and apneic pauses during attempted biopsy. Disadvantages of this method include that the pulmonologist is forced to work through the limited and restrictive diameter of the ET tube, and there is potential oxygen desaturation during the required periods of apnea, which in the case of a pulmonary-impaired patient adds difficult or technical issues during the actual ENB biopsy.

• ***Manual Jet Ventilation.*** This frequently used method uses a handheld device first described by Sanders[13] in 1967 (Figure 2). The hand-triggered, low-frequency jet hose was designed for, and is still used for, emergency airway rescue intervention.[14] It can be applied through the use of a small-bore double-lumen or single-lumen micro ventilation catheter and is placed in the trachea above the carina. This micro ventilation catheter is 4.0 mm. Disadvantages of manual ventilation during ENB are substantial. Hand-triggered, low-frequency jet ventilation delivers 100% oxygen at 50 psi with a rate that varies

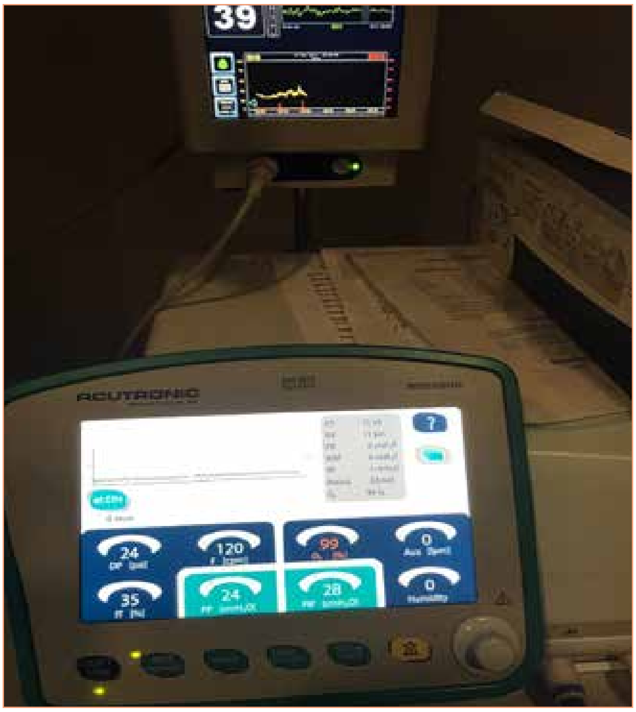

Figure 3. Monsoon III (Acutronic Medical Systems) High-Frequency Jet Ventilator

MONSOON III
SUGGESTED START SETTINGS

Neonate to Toddler		Adults	
%IT:	20% - 30%	%IT:	35-40%
DP:	5-7 PSI	DP:	19-24 PSI
FREQ:	150 CPM	FREQ:	120 CPM
Humidity:	As Needed	Humidity:	As Needed
PP:	10 cmH_2O	PP:	24 cmH_2O
PIP:	12 cmH_2O	PIP:	28 cmH_2O
Laser FiO2%	Max 40% or less	Laser FiO2%	Max 40% or less

These Settings are only suggested; every patient will vary and should be adjusted accordingly! Also Co2 should be monitored and ventilator should be adjusted to obtain proper Co2 values. The most accurate way to obtain Co2 is blood gas or transcutaneous monitoring.

Figure 4. Ventilation Adjustments

subject to the operator, usually in the range of 10/min to 20/min. This low-frequency jet ventilation is subjective, based on the operator's evaluation of chest movement and expansion along with oxygen saturation. Rarely is end-tidal carbon dioxide ($ETCO_2$) or transcutaneous capnography available on handheld devices. Peak pressure may be monitored but requires a separate special device, often not available to monitor airway pressures in the distal trachea.[15] Most importantly, ventilation must be interrupted in periods when the anesthesia provider's hands are needed to attend to management of the required total intravenous anesthesia (TIVA) technique. During such TIVA cases, interruptions are frequently required to adjust infusions to treat blood pressure and heart rate or to check muscle relaxation. These interruptions make it impossible to provide consistent ventilation. The primary anesthesia provider usually requires a second anesthesia provider to attend the TIVA management, to maintain consistent ventilation. Unlike automated HFJV, handheld devices most often lack air/oxygen blenders; therefore, they deliver only 100% oxygen. In rare cases, endoluminal bleeding may occur during this bronchial procedure. Argon plasma coagulation (APC) may even be required by the pulmonologist to obtain hemostasis.[16] This use of APC, of course, requires rapid substantial reduction in fraction of inspired oxygen (FIO_2) to prevent a potential airway fire.[17]

• ***High-Frequency Jet Ventilation.*** In this "quiet lung" procedure, ventilators that are designed for automated HFJV are advocated, providing a respiratory rate of up to 150/min. The authors used the Monsoon III by Acutronic Medical Systems (Figure 3). High-frequency jet ventilation provides many advanced clinical advantages, such as obtaining an almost stationary lung field with exceedingly small chest movement, and adds a touchscreen monitor providing continuous pressure and ventilation feedback data, which guides ventilation adjustments (Figure 4). These ventilator monitors provide great clinical value. In the case of APC use for control of bleeding, the air-oxygen mixer gives a rapid change in oxygen concentration to 30%. Before APC being needed to obtain hemostasis, the anesthetist can quickly press the "Laser OK" button, and the FIO_2 is rapidly reduced to 30% as indicated on the monitor screen. Cauterization may then proceed, the FIO_2 immediately returned to 100% oxygen, and the procedure continued safely. Note that it is not the intent of this article to address the theories and physiology of gas exchange during HFJV. However, a thorough understanding of the physiology of HFJV is highly recommended. The reader is referred to publications that offer more extensive explanation of this form of ventilation and operation of this equipment.[18]

By using an automated HFJV at respiratory rates of 120/min to 150/min, a single anesthesia provider can provide low tidal volumes while receiving feedback monitoring status of ventilation airway pressure, adjustable inspiratory time, driving pressures, and other vital data. In doing so, this provides a minimal lung movement and allows for a practically motionless biopsy target to be accurately biopsied. Equally as important, the anesthetist is now hands-free and able to attend to various needs of the TIVA and patient management.

Because the high-frequency jet ventilator saves the cost of the second anesthesia provider, there is a savings of $3,000 to $4,000 per case. This ventilator is paid for in an estimated 17 ENB procedures.

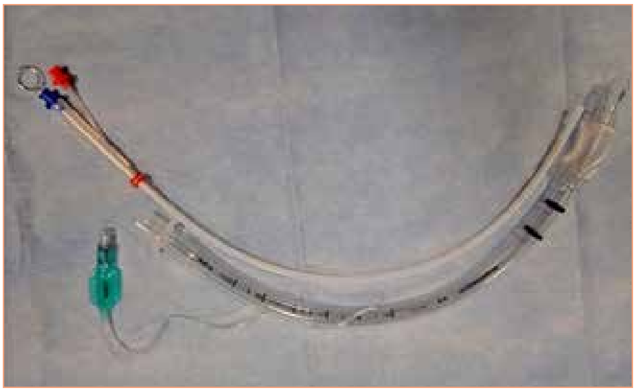

Figure 5. Laser Jet Double-Lumen Jet Catheter (top, Acutronic Medical Systems) Alongside Standard Endotracheal Tube (bottom)

Figure 6. Proper Placement of Laser Jet Tube[a]
[a]Red adjustable-depth marker at right corner of the mouth has been preset before intubation.

Technique: TIVA for ENB Using Automated High-Frequency Jet Ventilation

Since automated HFJV cannot provide vaporized volatile anesthetics to be administered, TIVA is the indicated anesthetic technique. Total intravenous anesthesia requires monitoring of a constant rate of infusion to provide adequate plasma concentration for maintenance, along with monitoring of vital signs and Bispectral Index (BIS) levels. Since there is no end-tidal volatile agent to be monitored, the use of the BIS monitor may aid in recall prevention.[19] Automated HFJV using the Monsoon III (Acutronic Medical Systems) allows the anesthesia provider to view the computerized screen, which lists all important data as to inflation pressures, inspiratory time, driving pressures, FIO_2, peak inspiratory pressures, and other information that makes monitoring and adjusting settings less time consuming and less distracting. This is an important advantage compared with handheld manual jet ventilation. This allows the anesthetist to be hands-free to attend to muscle relaxation, oxygen saturation, and adjustment to TIVA and vital sign changes. Historically, there are many approaches and various TIVA techniques described. The described format of TIVA has proved to be clinically stable and adaptable, and it can be tailored to the individual health status of each patient who requires ENB.

The initial induction is carried out with the American Society of Anesthesiologists' recommended standard monitoring using a conventional anesthesia circuit and machine. High-frequency jet ventilation is best used with this backup standard machine. Preinduction loading with sedative/hypnotic administration of midazolam is administered. Anesthesia induction using an adequate dose of propofol and a short-acting depolarizing muscle relaxant, such as rocuronium, reduces the time to micro double-lumen tube intubation conditions of the jet ventilation tube. Immediate initiation of an intravenous infusion of remifentanil and propofol is initiated during mask ventilation.[18] During this induction, use of constant Bispectral Index (BIS) monitoring is highly recommended for this TIVA, with a target value of 40 to 60 throughout the procedure.[19,20] Remifentanil was selected because it undergoes rapid nonspecific hydrolysis. This means a rapid "on/off" titratable half-life of about 4 minutes. This clinical feature occurs after the drug is dissipated, even after several hours of infusion. Compared with hepatically metabolized synthetic opioids, rapid dissipation of remifentanil is an indication for the group of patients who need no lingering narcotic respiratory depression. Remifentanil infusion provides a very good choice for rapid and emergency recovery. During the initial loading period, remifentanil has many advantages because it has twice the potency of fentanyl and is almost 200 times as potent as morphine.

The infusion range of remifentanil for this procedure is suggested to be 0.08 µg/kg/min to 0.25 µg/kg/min, lean body weight. Propofol, which also offers a rapid emergence, is maintained in a range of 75 to 150 µg/kg/min. Most often the low-dose range is adequate. The provider should be aware of side effects of remifentanil that include bradycardia, rigid chest (if given too rapidly at high dose), and, of course, the potential of hypotension, which can easily be managed with indicated vasopressors as needed.

Once adequate mask ventilation is demonstrated, laryngoscopy is performed and the trachea is intubated with a micro jet laser double-lumen tube with an outer diameter of only 4 mm (Figure 5). The position of the tube is confirmed by bronchoscopy to be midtrachea of the patient (Figure 6). The stylet is removed, and the adjustable length indicator should be positioned at the

Figure 7. Micro Laser Jet Double-Lumen Tube Placed Above Carina Avoiding Impinging Into Tracheal Rings

right angle of the patient's mouth. By placing the jet tube marker at 21 cm for female patients and 22 to 23 cm for males[21] and by situating the marker at the right angle of the mouth, the tip of the tube will be about 4 cm above the carina, but almost any length above the carina is acceptable (Figure 7). This allows for excellent conditions and airway space for the bronchoscope. Duel jet ventilation hoses are attached by a Luer-Lok (BD) connection, and jet ventilation is initiated. One of these jet hoses, 3.9 m (13 ft) in length, provides the inspired ventilation flow. This selected length is preferred because in most cases, the pulmonologist needs a full 180° access to the head of the patient. The second jet hose, also 3.9 m (13 ft) in length, continuously measures airway pressure and can be a source of intermittent $ETCO_2$ measurement by a simple mode adjustment on the jet ventilator. Airway pressures can be monitored for the rare occurrence of tube obstruction from the tracheal rings, which is easily detected and corrected throughout the procedure. This impingement of the micro tube into the tracheal rings can be avoided by straightening the factory-formed stylet so that the tube rests midlumen of the trachea.

The use of automated HFJV has a major advantage for the anesthetist's access to monitor the need for additional muscle relaxation, thus preventing inadequate relaxation, which is paramount relating to potential patient respiratory efforts or other movement during the procedure. Maintenance of TIVA is with propofol and remifentanil infusion with the aid of BIS monitoring.

The often-abrupt completion of the procedure and emergence from anesthesia as the procedure subsides involves discontinuation of HFJV and replacing the micro jet tube with a standard ET tube of usually 6.5 mm, or with a laryngeal mask airway. This airway maneuver is not technically difficult and is done routinely by Certified Registered Nurse Anesthetists and even student registered nurse anesthetists. It allows for a transfer back to the standard anesthesia machine; then further emergence can be safely managed. This choice is determined by clinical judgment of the patient's health status and by airway status of excessive oral secretions, mucus, or presence of potential blood in the airway. Once this airway device exchange is made, all TIVA infusions are discontinued, and nondepolarizing muscle relaxation may be reversed with sugammadex (authors' choice). Although sugammadex is expensive, it is imperative to have no respiratory depression from either the muscle relaxant or other longer-acting narcotics. Short-acting remifentanil is used to aid in this clean emergence and spontaneous respirations. The time for propofol and remifentanil to resolve is usually 8 to 10 minutes and is indicated with the aid of BIS monitoring. Extubation criteria are objective for tidal volume, reversal of muscle relaxant, airway reflexes, and response to verbal command. The imperative rapid recovery is aided by use of remifentanil and sugammadex. The patient is transferred to the postanesthesia care unit and in most cases discharged home within 2 hours.

Conclusion

The anesthetic technique presented here is an advanced method for ENB procedures using automated HFJV and TIVA. Biopsy yield data using the technique of automated HFJV-aided bronchoscopy biopsy is currently being collected by interventional pulmonologists who appreciate the quiet field and small diameter of the micro jet tube, which allows more room for maneuverability of the bronchoscope. One obvious financial advantage of this HFJV technique is the use a single anesthesia provider, instead of requiring one anesthetist to manage the manual handheld jet ventilator and a second anesthetist to manage the requirements of the TIVA technique. The hope is that this guidance will improve other anesthesia providers' ability to provide this safe, "quiet lung" anesthetic technique.

REFERENCES

1. American Cancer Society. Key statistics for lung cancer.https://www.cancer.org/cancer/lung-cancer/about/key-statistics.html. Updated January 12, 2020. Originally accessed July 11, 2018. URL updated January 27, 2020.
2. Henschke CI, Yankelevitz DF, Libby DM, Pasmantier MW, Smith JP, Miettinen OS; International Early Cancer Action Program Investigators. Survival of patients with stage I lung cancer detected by CT. *N Engl J Med.* 2006;355(17):1763-1771.
3. Minna JD. Neoplasms of the lung. In: Braunwald E, Kasper DL, Hauser SL, Longo DL, Jameson JL, Loscalzo J, eds. *Harrison's Principles of Internal Medicine.* 19th ed. New York, NY: McGraw Hill; 2016:562-571.
4. American Lung Association. Lung cancer fact sheet. 2017.
5. Casal RF, Vial MR, Miller R, et al. What exactly is a centrally located lung tumor? Results of an on-line survey. *Ann Am Thorac Soc.* 2016;14(1):118-123. doi:10.1513/AnnalsATS.201607-568BC
6. Tan WW. Non-small cell lung cancer. Medscape. https//emedicine.medscape.com/article/279960-overview. Updated August 23, 2019. Originally accessed November 20, 2018. URL accessed again January 28, 2020.
7. Gomez M, Sivestri GA. Endobronchial ultrasound for the diagnosis and staging of lung cancer. *Proc Am Thorac Soc.* 2009;6(2):180-186. doi:10.1513/pats.200808-081LC
8. Lung cancer 101: non-small cell lung cancer treatment. https://www.lungcancer.org/find_information/publications/163-lung_

cancer_101/269-non-small_cell_lung_cancer_treatment. Accessed November 20, 2018.
9. Geraghtly PR, Kee ST, McFarlane G, Rahzavi MK, Sze DY, Dake MD. CT guided transthoracic needle aspiration biopsy of pulmonary nodules: needle size and pneumothorax rates. *Radiology*. 2003;229(2):475-481. doi:10.1148/radiol.2291020499
10. Gildea TR, Mazzone PJ, Karnak D, Meziane M, Mehta AC. Electromagnetic navigation diagnostic bronchoscopy: a prospective study. *Am J Respir Crit Care Med.* 2006;174(9):982-989. doi:10.1164/rccm.200603-344OC
11. Abderhalden S, Biro P, Helchelhammer L, Pfiffner R, Pfammatter T. CT-guided navigation of percutaneous hepatic and renal radiofrequency ablation under high-frequency jet ventilation: feasibility study. *J Vasc Interv Radiol.* 2011;2012(9):1275-1278. doi:10.1016/j.jvir.2011.04.013
12. Williams JL, Valencia V, Lugg D, et al. High frequency jet ventilation during ablation of supraventricular and ventricular arrhythmias: efficacy, patient tolerance and safety. *J Innovat Cardiac Rhythm Manage.* 2011 Nov;2:528-535. http://www.innovationsincrm.com/images/pdf/crm-02-11-528.pdf. Accessed January 28, 2020.
13. Sanders RD. Two ventilation attachments for bronchoscopes. *Del Med J.* 1967;39:170-175.
14. Klain M, Smith RB. High frequency percutaneous transtracheal jet ventilation. *Crit Care Med.* 1977;5(6):280-287. doi:10.1097/00003246-197711000-00007
15. Krishman JA, Brower RG. High frequency ventilation for acute lung injury and ARDS. *Chest.* 2000;118(3):795-807. doi:10.1378/chest.118.3.795
16. Bollinger CT, Sutedja TG, Strausz J, Freitag L. Therapeutic bronchoscopy with immediate effect: laser, electrocautery, argon plasma coagulation and stents. *Eur Respir J.* 2006;27(6):1258-1271. doi:10.1183/09031936.06.00013906
17. Du Rand IA, Barber PV, Goldring J, et al; BTS Interventional Bronchoscopy Guideline Group. British Thoracic Society guideline for advanced diagnostic and therapeutic flexible bronchoscopy in adults. *Thorax.* 2011;66(11):1014-1015. doi:10.1136/thoraxjnl-2011-201052
18. Juckenhofel S, Feisel C, Schmitt HJ, Biedler A. TIVA with propofol-remifentanil or balanced anesthesia with sevoflurane-fentanyl in laparoscopic operations. Hemodynamics, awakening and adverse effects [German]. *Anaesthetist.* 1999;48(11):807-812. doi:10.1007/s001010050789
19. Avidan MS, Zhang L, Burnside BA, et al. Anesthesia awareness and the bispectral index. *N Engl J Med.* 2008;358(11):1097-1108. doi:10.1056/NEJMoa0707361
20. Hoymork SC, Raeder J, Grimsmo B, Steen PA. Bispectral index, serum drug concentrations and emergence associated with individually adjusted target-controlled infusions of remifentanil and propofol for laparoscopic surgery. *Br J Anaesth.* 2003;91(6):773-780. doi:10.1093/bja/aeg258
21. Evron S, Weisenberg M, Harow E, et al. Proper insertion depth of endotracheal tubes in adults by topographic landmarks measurement. *J Clin Anesth.* 2007;19(1):15-19. doi:10.1016/j.jclinane.2006.06.005

AUTHORS

Roger Masters, MS, CRNA, is employed by Cancer Treatment Centers of America, Atlanta in Newnan, Georgia, in the Department of Thoracic Anesthesia. Email: Alaskan121@aol.com.

Rabih Bechara, MD, FCCP, is the director of the Thoracic Institute, Cancer Treatment Centers of America, Atlanta and is a professor of medicine at Augusta University at Medical College of Georgia, Augusta, Georgia.

Neil R. Seeley, MD, is an anesthesiologist and chief of the Division of Anesthesia, Cancer Treatment Centers of America, Atlanta.

Christopher Parks, MD, is employed by the Departments of Pulmonary and Critical Care Medicine, Cancer Treatment Centers of America, Atlanta; Morehouse School of Medicine, Atlanta, Georgia; and Augusta University Health, Augusta, Georgia.

Zachary D. Moore, MD, is employed by the University of South Alabama, Department of Orthopaedic Surgery, Mobile, Alabama.

DISCLOSURES

The authors have declared no financial relationships with any commercial entity related to the content of this article. The authors did not discuss off-label use within the article. Disclosure statements are available for viewing upon request.