White paper

Clinical importance of anesthesia machine testing: A review

Each year, approximately 313 million surgeries are performed worldwide.[1] As surgical procedures increase in number and more facilities become equipped, the prevalence of general anesthesia administration continues to grow. Common clinical practice entails the use of an anesthesia machine to deliver inhalational anesthetics for rapid sedation. This article will explore the history of anesthetics in surgical use, the components of modern anesthesia delivery systems, the technology of anesthesia gas monitors, and the clinical importance of multi-gas analyzers in vaporizer testing.

Anesthesia in surgical use

The history of inhalational anesthesia dates to the early 19th century, when English physician Henry Hickman demonstrated the anesthetic effect of carbon dioxide on animal subjects.[2] Shortly thereafter, in 1842, diethyl ether was used successfully during both a dental procedure and a growth removal surgery, establishing its clinical utility and prompting an increase in exploration of anesthetic agents.[2] During this time, chemist Humphrey Davy discovered the analgesic (pain relieving) effects of nitrous oxide, an anesthetic still used in modern surgical practice.[3]

Today, anesthetists administer a variety of substances, medical gases and drugs to achieve varying desired effects in patients. Chief among these are immobilization, unconsciousness, and desensitization to surgical stimuli.[4] In addition, amnesic effects are sometimes sought to mitigate potential awareness and intraoperative trauma. In general anesthesia, three components are typically used: a hypnotic agent, an analgesic, and a muscle relaxant.[5] Halogenated anesthetic agents are often used in common practice to achieve muscle relaxation and sedation.

Halogenated inhalational agents are widely used for their rapid induction, emergence and low tissue solubility.[2] The first halogenated agent, halothane, was approved for use in 1957.[6] However, a rare, though sometimes fatal, halothane-associated disease known as halothane hepatitis has seen its decline from surgical use.[6] Shortly thereafter, enflurane was introduced in 1963, followed by its chemical isomer isoflurane in 1965.[6] By the 1990s, sevoflurane and desflurane gained approval for clinical use in the United States.[6] Today, sevoflurane, desflurane, and isoflurane are the most commonly used of the five inhalational anesthetic agents due to enflurane's implications in increasing epileptic convulsions.[8]

Though the precise mechanism of action of the halogenated anesthetic agents is unknown, their effects are well documented. All five agents produce central nervous system depression, decreasing cerebral metabolic rate, and oxygen consumption.[6] In addition, they induce skeletal muscle relaxation and act as respiratory depressants.[4] In standard anesthesia practice, agents are supplemented with analgesics such as opioids.[8]

Modern anesthesia machines

Anesthesia in modern use is administered using an anesthesia machine. This device provides respiratory support and administers anesthetic agents at doses predetermined by the attending anesthesiologist. Anesthesia machines are comprised of five primary components: the fresh gas delivery system, scavenging system, vaporizers, flow meters, ventilator as well as monitors including both breathing and patient.[9]

Inhalational agents are contained within the vaporizers. These devices are calibrated to release a controlled amount of anesthetic to the patient. A diagram of a conventional variable-bypass vaporizer is shown in Figure 1. When anesthesia is initiated, a carrier gas, typically a blend of air, oxygen, and nitrous oxide, is flowed through the input of the vaporizer. Part of this stream is diverted into the vaporizing chamber, which contains the liquid anesthetic agent. To increase evaporation area, the reservoir of anesthetic contains one or more wicks, facilitating greater uptake of vapor by the carrier gas. Past the vaporizing chamber, the saturated gas stream combines with the fresh bypass gas, producing the appropriate concentration for administration to the patient. The proportion of fresh to saturated gas can be adjusted to achieve different anesthetic concentrations.[11] This type of vaporizer can be used with sevoflurane, isoflurane, enflurane, and halothane. Because of desflurane's unique physical properties, it requires a heated vaporizer to achieve controllable flow.

It is very important that the concentration indicated on the vaporizer control dial is identical to the concentration of anesthetic agent being delivered to the patient. Under-administration can lead to intraoperative awareness, a traumatic event which often results in psychological distress and long-term effects. Over-administration presents the risk of triggering cardiac arrest and can be fatal. Ensuring proper vaporizer function and establishing anesthesia monitoring should be a priority of every hospital administering anesthesia.

Anesthesia gas monitoring technology

Anesthesia monitoring technology has seen vast improvement since the introduction of the North American Dräger Narko-Test in the 20th century. This innovative device reported the concentration of halothane vapor by measuring the relax-

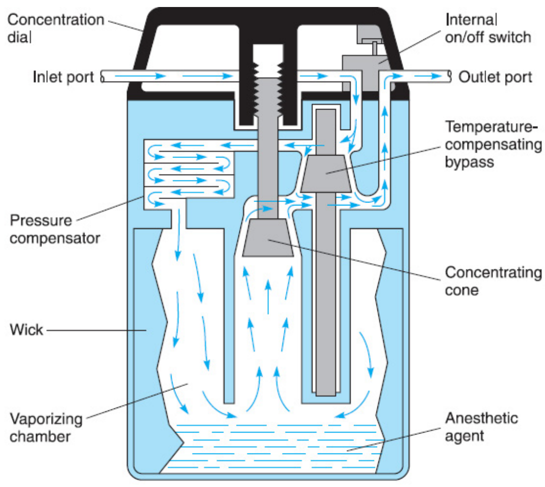

Figure 1: Diagram of a variable-bypass vaporizer.[10]

ation produced in a silicone rubber band, though it could be adjusted for use with other halogenated agents as well.[12] However, the adverse effect of nitrous oxide and water vapor on the output of the Narko-Test limited its accuracy and reliability.[13] Further technological advancements explored the use of mass spectrometry, RAMAN spectrometry, infrared photoacoustic spectrometry, and piezoelectric crystal agent analysis for anesthetic gas monitoring.[12] Despite initial promise, each of these techniques suffered from limitations that resulted in their removal from clinical practice.[12]

One shortcoming common to several monitoring solutions was failure to provide agent identification. Anesthesiologists routinely use multiple inhalational agents intraoperatively for different purposes, such as induction with sevoflurane and maintenance with isoflurane. Further, mistaken filling of a vaporizer with the wrong anesthetic could produce an agent mixture that, if undetected, could cause injury to the patient. Another important application of gas identification is verifying the vaporizer interlock system is functioning properly. It is vital that the vaporizer interlock mechanism prevents more than one vaporizer from dispensing anesthetic agents simultaneously. For these reasons, it is crucial that anesthesia gas monitors provide agent identification and the ability to measure multiple agents from a mix of gases.

Today, the most widely used technology for anesthetic gas monitoring is infrared photospectrometry. This technique relies on the absorbance of specific wavelengths of infrared light by

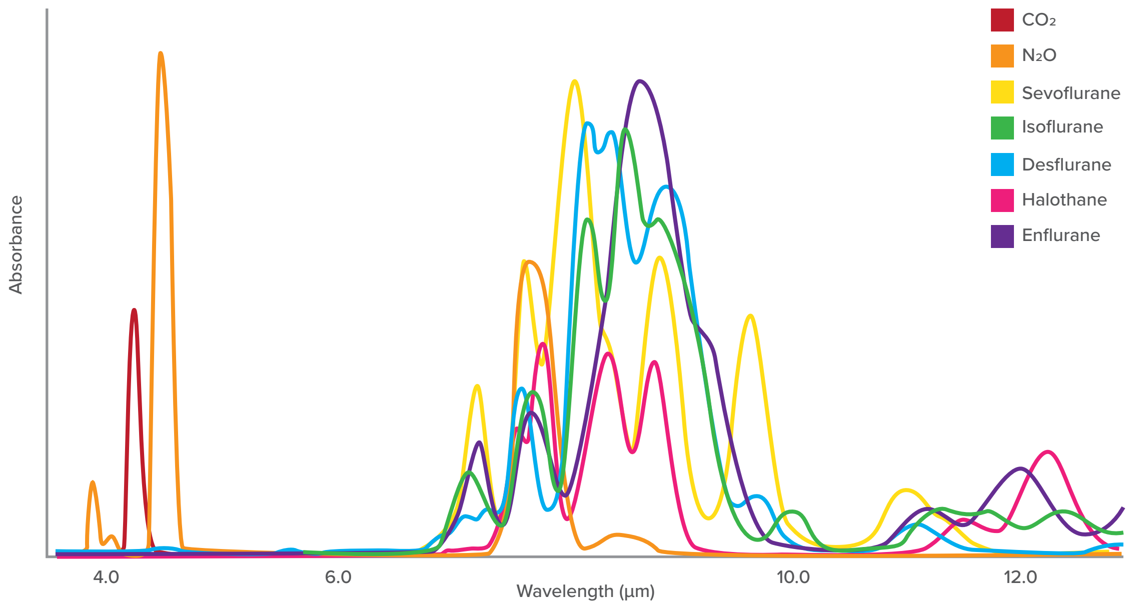

Figure 2: Absorbance spectra of CO2, N2O, and the five halogenated inhalational agents.[13]

molecules in a gas. When infrared light is passed through a gas sample and reaches a detector, the specific wavelengths of light absorbed by the sample can be determined. In this way, chemicals in a sample can be identified based on the absorbance profiles produced by infrared light exposure.[14]

Infrared spectrometry can be classified as dispersive or non-dispersive. In the dispersive infrared (DIR) method, infrared light is passed through one optical filter followed by a prism or a diffraction grating, thereby separating the light into its component wavelengths.[15] Non-dispersive infrared (NDIR) technology utilizes a series of narrow-band optical filters to identify the sample under analysis.[13] Anesthetic agent analyzers most commonly incorporate this detection method. Because the absorbance peaks for the anesthetic agents (Figure 2) lie in the same range (8-13 µm), many of them overlap, requiring integration of complex analytical techniques to accurately discriminate between them.[13]

Anesthesia gas analyzers are configured as either mainstream or sidestream sensors. Mainstream spectrometers are positioned in line with the ventilator gas stream, while sidestream analyzers divert a sample of gas from the breathing circuit for analysis. Though sidestream analyzers face challenges with condensing water vapor and patient secretions due to the cooling effect experienced during transfer from the breathing circuit, this configuration is used for most anesthesia gas detectors in common practice.

Clinical use cases for anesthetic analyzers

One of the most important applications of anesthesia gas detection is for performance verification of vaporizers. Many hospitals outsource their vaporizer testing to manufacturers or independent service organizations. Others perform concentration testing using the anesthesia sensor integrated with the patient monitor. This detector is calibrated with a canister of calibration gas, which is attached to the anesthesia machine and its concentration measured by the integrated analyzer. However, to ensure the accuracy of testing, it is important that the concentration output of vaporizers be confirmed with a factory-calibrated device designed specifically for anesthesia detection and capable of auto-identification of agents.

A study conducted in 2013 analyzed claims from the American Society of Anesthesiologists Closed Claims Project database concerning patient injuries related to gas delivery equipment. This study found that vaporizers accounted for 35 % of gas delivery problems from 1990 to 2011.[16] In 71 % of vaporizer malfunction cases, light anesthesia was administered, resulting in intraoperative awareness or movement.[16] Importantly, it was determined that 35 % of the patient injury claims related to anesthesia gas delivery equipment were preventable by a pre-anesthesia machine check.[16]

A case study published in 2005 further underscores the importance of testing vaporizer function before clinical use.[17] Following induction of a healthy 36-year-old woman, desflurane was administered at 3.5 % for anesthesia maintenance. Shortly after induction, oxygen deficiency and abnormally slow heart activity was observed, followed by cardiac arrest. Anesthesia administration was terminated, and manual ventilation was performed with 100 % oxygen while resuscitation was attempted. Only after epinephrine administration and defibrillator countershock did the patient display normal heart activity. After transfer to the post anesthesia care unit, the patient was further evaluated, revealing an accumulation of fluid in the lungs.

Following the incident, the anesthesia machine was removed from service and thoroughly examined. This evaluation revealed that the concentration of desflurane being administered reached 23 %, a massive excess of the intended 3.5 %. Upon further investigation, it was discovered that the internal control dial of the vaporizer was cracked. Thus, the exterior dial, set to 3.5 %, did not accurately control the output concentration of the vaporizer.

In this case, patient injury could have been prevented by a preoperative vaporizer check or efficacy test. Measuring the output concentration of the vaporizer with a multi-gas analyzer would have revealed the disparity between the set concentration and the patient concentration, allowing the vaporizer to be taken out of service prior to its use in an operation. Furthermore, in some cases, vaporizers were filled with the wrong anesthetic agent. This could cause great harm to a patient, as the potencies of the volatile halogenated agents vary. To prevent over- or under-administration of an anesthetic or use of an unintended agent, vaporizer testing should be regularly performed with a multi-gas analyzer.

Summary

With the prevalence of anesthesia use worldwide and the continuing advancement of gas monitoring technology, anesthesia machine testing is becoming more important and accessible than ever before. From humble beginnings with the Narko-Test to sophisticated gas identification with non-dispersive infrared spectrometry, anesthesia gas monitors continue to become more accurate, reliable, and advanced.

The VT900A and Vapor accessory are intended to aid trained and qualified personnel in the inspection and testing of anesthesia delivery systems and ventilators.

References

1. Weiser, Thomas G., et al. “Size and distribution of the global volume of surgery in 2012.” Bulletin of the World Health Organisation. 2016.
2. Seglenieks, Richard. “The history of modern general anaesthesia.” Australian Medical Student Journal. 2015.
3. “The History of Anaesthesia.” Royal College of Anesthetists.
4. Becker, Daniel E., and Morton Rosenberg. “Nitrous Oxide and the Inhalation Anesthetics.” Anesthesia Progress. 2008; 55(4): 124-131.
5. “An introduction to anaesthesia.” British Journal of Hospital Medicine. 2013; 74(5): C71-C75.
6. Torri, G. “Inhalation anesthetics: a review.” Minerva Anestesiologica. 2010; 76(3): 215-28.
7. Sleigh, James W., et al. “The Electrocortical Effects of Enflurane: Experiment and Theory.” Anesthesia & Analgesia. 2009; 109(4): 1253-1262.
8. Ryu, Kyoungho, et al. “Comparison of the Analgesic Properties of Sevoflurane and Desflurane Using Surgical Pleth Index at Equi-Minimum Alveolar Concentration.” International Journal of Medical Sciences. 2017; 14(10): 994-1001.
9. Pail, Vijaya P., et al. “The Modern Integrated Anaesthesia Workstation.” Indian Journal of Anaesthesia. 2013; 57(5): 446-454.
10. Butterworth, John F., et al. Morgan & Mikhail’s Clinical Anesthesiology. 5th ed., McGraw-Hill, 2013.
11. “Anesthesia Unit Vaporizers.” Health Devices Inspection and Preventive Maintenance System.
12. Lowe, Harry J., and Karl Hagler. “Clinical and Laboratory Evaluation of an Expired Anesthetic Gas Monitor (Narko-Test).” Anesthesiology. 1971; 34(4): 378-382.
13. “Anesthesia Gas Monitoring: Evolution of a de facto Standard of Care.” ProMed Strategies, LLC. 2009.
14. Langton, J.A., and A. Hutton. “Respiratory gas analysis.” Continuing Education in Anesthesia. 2009; 9(1): 19-23.
15. Garg, Rakesh, and Ramesh Chand Gupta. “Analysis of Oxygen, Anaesthesia Agent and Flows in Anaesthesia Machine.” Indian Journal of Anaesthesia. 2013; 57(5): 481-488.
16. Mehta, Sonya P., et al. “Patient Injuries from Anesthesia Gas Delivery Equipment: A Closed Claims Update.” Anesthesiology. 2013; 119(4): 788-795.
17. Geffroy, Jean-Christophe, et al. “Massive Inhalation of Desflurane due to Vaporizer Dysfunction.” Anesthesiology. 2005; 103(5): 1096-1098.

Fluke Biomedical.
Trusted for the measurements that matter.

Fluke Biomedical
28775 Aurora Road
Cleveland, OH 44139 U.S.A.

For more information, contact us at:
(800) 850-4608 or Fax (440) 349-2307
Email: sales@flukebiomedical.com
Web access: www.flukebiomedical.com