

Expiratory Limb Ventilation during Unique Failure of the Anesthesia Machine Breathing Circuit

David M. Seif, M.D.,* Michael A. Olympio, M.D.†

THE anesthesia machine is the most integral piece of equipment used by anesthesia providers. When semi-closed circle systems are used, unidirectional valves become integral components that direct carbon dioxide containing gas across the absorbent and along the inspiratory limb, mixing with fresh gas as it flows into the patient. Unfortunately, human error is known to be the most common source of machine malfunction, particularly of the breathing circuit.^{1,2} Such malfunctions should be detected during the application of the American Society of Anesthesiologists' 2008 Recommendations for Pre-Anesthesia Checkout. In that situation, the self-inflating manual ventilation device (SIMVD) is suggested for first-line backup ventilation.‡ Responses to such critical incidents are taught in simulation courses, which are required by the American Board of Anesthesiology as a component of its Maintenance of Certification in Anesthesiology program.^{2,3}

We present a unique human-induced failure of the breathing circuit in a patient who was turned 180° away from the machine during major ear, nose, and throat surgery. Sequential responses to ventilate the patient were successfully applied by the resident and attending anesthesiologist based upon their experiences in simulation workshops. We

describe the functional aspects of these effective methods for ventilating the patient during this machine failure.

Case

A 53-yr-old, American Society of Anesthesiologists Class 3, 130-kg man was about to undergo parotidectomy and neck dissection in a position 180° away from the conventional General Electric Aestiva/5 anesthesia machine (GE Healthcare, Waukesha, WI). Sufentanil infusion was chosen for its akinesic effect to enable motor nerve monitoring. The patient was draped with adhesive paper sheets, in part stuck to the endotracheal tube, which were tucked and taped to the lateral side of the head of the operating table. After surgical incision, the resident anesthesiologist detected 8 mmHg inspired CO₂. He increased total fresh gas flow to 6 l/min without an adequate reduction in inspired carbon dioxide. After further increasing the flow of 100% O₂ and minute ventilation, he next began to exchange both Medisorb® (GE Healthcare) soda lime absorbent cartridges in the Aestiva/5 absorbent canister. The lower cartridge was easily and quickly exchanged and replaced into the canister. However, the top cartridge was inadvertently placed upside-down and it lodged halfway into the canister, rendering it impossible to dislodge. The patient remained apneic with residual neuromuscular blockade and narcosis during this 3 min period as the SpO₂ began to fall from 100% to 92%. The attending was called as the resident slammed the cartridge onto the floor and backward into the canister, such that the assembly did partially fit back into the absorbent housing. Oxygen flow was increased to the maximum, the machine was switched to manual ventilation, the adjustable pressure limiting valve was fully closed, and the flush button was continuously depressed as the resident squeezed the reservoir bag. SpO₂ was 92% with suboptimal ventilation secondary to a large circuit leak, as the attending entered the room.

Observing this inadequacy of ventilation, the attending immediately disconnected the breathing hose expiratory limb

* Anesthesiology Resident, Department of Anesthesiology, Wake Forest School of Medicine, Winston-Salem, North Carolina. † Professor of Anesthesiology, Departments of Anesthesiology and Urology, Wake Forest School of Medicine, Winston-Salem, North Carolina.

Received from the Department of Anesthesiology, Wake Forest School of Medicine, Winston-Salem, North Carolina. Submitted for publication July 23, 2012. Accepted for publication October 18, 2012. Support was provided solely from institutional and/or departmental sources.

Address correspondence to Dr. Olympio: Department of Anesthesiology, Wake Forest School of Medicine, Medical Center Blvd, Winston-Salem, North Carolina 27157-1009. molympio@wakehealth.edu. Information on purchasing reprints may be found at www.anesthesiology.org or on the masthead page at the beginning of this issue. ANESTHESIOLOGY's articles are made freely accessible to all readers, for personal use only, 6 months from the cover date of the issue.

‡ Recommendations for Pre-Anesthesia Checkout Procedures (2008) Sub-Committee of ASA Committee on Equipment and Facilities. Available at: <http://asatest.asahq.org/clinical/FINALCheckout-Designguidelines02-08-2008.pdf>. Accessed June 20, 2012.

Copyright © 2013, the American Society of Anesthesiologists, Inc. Lippincott Williams & Wilkins. Anesthesiology 2013; 118:751-3

Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are available in both the HTML and PDF versions of this article. Links to the digital files are provided in the HTML text of this article on the Journal's Web site (www.anesthesiology.org).

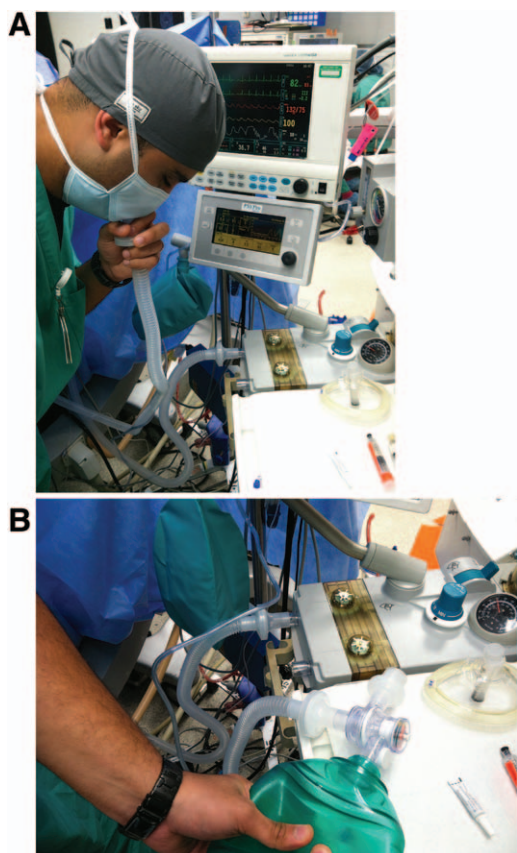


Fig. 1. (A) Reanimated photo of unadvised mouth-to-expiratory limb ventilation, showing the location of disconnection of the expiratory limb of the breathing hose and bacterial filter from the Aestiva/5 (GE Healthcare, Waukesha, WI) expiratory flow sensor. Realize that ventilation into the limb will cause: (1) closure of the inspiratory valve, (2) retrograde rebreathing of patient's exhaled gas, (3) additional "rebreathing" of anesthesiologist's breath, (4) no contribution of machine fresh gas, (5) no function of the adjustable pressure limiting valve, and (6) potential contamination of the circuit and anesthesiologist. Thus, there would be provision of subatmospheric (<21%) concentration of oxygen, in addition to inspired carbon dioxide, as seen in the background capnogram. (B) Reanimation of SIMVD ventilation of the expiratory limb. This would provide 100% O₂ from the SIMVD, added to the dead space of the exhaled patient gas remaining in the expiratory hose. Realize that the patient would exhale through the SIMVD exhalation valve. There is no mixing of exhaled gas into the oxygen reservoir. SIMVD = self-inflating manual ventilation device.

from the Aestiva/5 flow sensor and momentarily initiated retrograde mouth to circuit ventilation (fig. 1A), as the SIMVD was connected to auxiliary oxygen and then connected to the same distal expiratory limb. As the bag was squeezed, there was substantial and effortless chest rise with increasing oxygen saturation (fig. 1B). The patient remained hemodynamically stable on sufentanil infusion as additional help arrived. Another absorbent canister was soon delivered from the operating room supply room and normal machine ventilation was quickly reestablished. The remainder of the case was uneventful and

the patient had no intraoperative awareness. The duration of complete apnea was estimated at 3 min, whereas the duration of backup SIMVD ventilation was estimated to be 6 min.

Discussion

The unidirectional mechanism of gas flow in the breathing hose requires unidirectional inspiratory and expiratory valves. Inspired carbon dioxide detection at the Y-piece thus allows for monitoring of the adequacy of soda-lime chemical absorption and will indicate incompetence of the unidirectional valves.

Conventional semiclosed circle systems (*i.e.*, General Electric Aestiva/5) are not designed to seal the circuit during soda-lime exchange. The human error in this case was the attempt to change the absorbent in a paralyzed patient who required mechanical ventilation. Furthermore, the airway was difficult to access with SIMVD. The absorbent exchange should not have been initiated because high fresh gas flow could have overcome the spent absorbent. However, with modern self-sealing options on some machines (Drägerorb CLIC® [Drägerwerk AG & Co., Lübeck, Germany] and General Electric EZchange® [GE Healthcare, Helsinki, Finland]), it is possible to exchange soda-lime intraoperatively.

Ventilatory emergencies secondary to machine failure would normally require intrusion into the sterile and/or operative field, for example, in neurosurgical cases. Our unique ventilation technique (see Supplemental Digital Content 1, <http://links.lww.com/ALN/A908>, a video showing a simulation of the intraoperative events) used the expiratory limb of the breathing circuit for retrograde flow of air, oxygen, and some anesthetic agent back to the patient. We do not recommend mouth-to-circuit ventilation at all, even though some circuits have a distal bacterial filter. Ventilation of the inspiratory limb is not effective because the gas would flow directly through an expiratory valve that opens. During the expiratory limb ventilation, it is possible that fresh machine anesthetic gas and oxygen would flow antegrade during exhalation, to fill the expiratory hose, or it might flow retrograde out of the open absorbent canister. We suspect the path of least resistance would be retrograde because the inspiratory valve would have to be lifted first for antegrade flow. This would predict no enrichment of oxygen in the expiratory limb, and significant rebreathing of patient gas. Therefore, a higher delivery of oxygen, although without anesthetic gas, would be achieved through use of the SIMVD connected to oxygen. This provides retrograde delivery of pure oxygen up the expiratory hose, mixing with a significant (measured 800 ml) volume of dead space gas. Reciprocal exhalation then flows antegrade down the expiratory hose and out through the SIMVD expiratory valve. There is no mixing of exhaled gas with fresh oxygen within the SIMVD itself, as might occur with a Mapleson D or Jackson-Rees system. This method was successfully used and it increased the oxygen saturation for approximately



Fig. 2. Reanimated photo showing the initial point of friction that prevented extraction of the Medisorb® cartridge (GE Healthcare, Waukesha, WI), once inserted upside down into the canister.

6 min until the canister was replaced. We unfortunately did not observe the level of inspired carbon dioxide, oxygen, or anesthetic agent during this crisis, but this could be

measured prospectively in a separate volunteer study. We are unaware of such measurements, and, in fact, are unaware of any published descriptions of this emergency ventilation technique.

In summary, we used an escalating technique of (1) high oxygen flush to overcome a major circuit leak, (2) momentary mouth-to-tube ventilation of the expiratory limb, and (3) SIMVD to expiratory limb ventilation to successfully ventilate and oxygenate this patient for approximately 6 min, without threatening the integrity of the surgical field.

We also question the need for a tapered design of the absorbent cartridge that allowed this human error to jam a cartridge into a canister (fig. 2). We speculate that the cartridge is tapered to prevent inversion once the proximal end turns purple from spent absorbent, and we welcome the manufacturer's comment on this point.

References

1. Caplan RA, Vistica MF, Posner KL, Cheney FW: Adverse anesthetic outcomes arising from gas delivery equipment: A closed claims analysis. *ANESTHESIOLOGY* 1997; 87:741–8
2. Fasting S, Gisvold SE: Equipment problems during anaesthesia—are they a quality problem? *Br J Anaesth* 2002; 89:825–31
3. Gaba DM, Howard SK, Fish KJ, Smith BE, Sowb YA. Simulation-based training in anesthesia crisis resource management (ACRM): A decade of experience. *Simulat Gaming* 2001; 32:175–93.

GE Healthcare Response to Aestiva CO₂ Absorbent Cartridge Issue

In Reply:

GE Healthcare appreciates the opportunity to respond to the Letter to the Editor from Drs. Seif and Olympio,¹ pertaining to the Aestiva CO₂ absorbent cartridge issue. We thank you for your diligence in informing the anesthesiology community regarding this case and were impressed by your quick actions in solving the issue at hand.

GE Healthcare has shipped almost 2 million Medisorb cartridges with this exact design over the last 10 yr. After reviewing our database for similar events, we found no record of such a problem being previously reported. Your experience demonstrates that this unique human-induced failure can occur, and your report will help raise awareness to further reduce the likelihood of occurrence.

Furthermore, we tested absorbent cartridges from a few alternative vendors and found they are also unidirectional. The consistency of this unidirectional design may be due to

the fact that a taper is required for normal manufacturing as part of the molding process. The taper also allows for proper positioning (centering) of the cartridge in the canister to adequately maintain a seal.

You effectively addressed the issue by swapping the canister. These canisters (0229-3015-800) are available for order in case you would like to have extra canisters available at your facility.

Thank you once again for bringing this to the attention of the anesthesia community.

Tammy Noll, GE Healthcare, Madison, Wisconsin. tammy.noll@med.ge.com

Reference

1. Seif DM, Olympio MA: Expiratory limb ventilation during unique failure of the anesthesia machine breathing circuit. *ANESTHESIOLOGY* 2013; 118:751–3

(Accepted for publication December 11, 2012)