

A Novel Method for Retrograde Ventilation Applied on the Expiratory Limb of Anesthesia Machines

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ABSTRACT

Background: The patient's airway is sometimes inaccessible during a surgical procedure. A novel retrograde ventilation technique may temporarily ventilate the patient in the case of anesthesia machine failure. We investigated the efficacy of oxygen delivery, the degree of rebreathing, and the reduction of inspired vapor for this novel technique.

Methods: At baseline 100% oxygen, 32 mmHg end-tidal carbon dioxide (EtCO₂), and 1% end tidal isoflurane, retrograde SIMVD ventilation was initiated at the same minute ventilation with 100% oxygen. Changes in inspired oxygen (FiO₂), isoflurane (FiIso), and EtCO₂ were measured and then a second set of data was obtained after doubling the ventilation rate. After return to baseline, another data set was obtained ventilating with room air.

Results: Oxygen-priming decreased the FiO₂ to 91% ± 1.0%. Room-air SIMVD significantly decreased the FiO₂ to 53.8% ± 11.4%. EtCO₂ increased from 32 mmHg to 47.8 mmHg ± 4.0 mmHg, while isoflurane fell significantly to 0.32% ± 0.16%. When ventilation was doubled, there were no significant differences in FiO₂ or EtCO₂, rather a further decrease in FiIso from 0.32% ± 0.16% to 0.15% ± 0.22%.

Conclusions: Retrograde ventilation will maintain delivery of supra-atmospheric concentrations of oxygen, with modest hypercarbia, while the volatile anesthetic is reduced clinically significantly. Hyperventilation offers no advantage.

Introduction

What We Already Know about This Topic

During certain surgical procedures, the airway may not be accessible for manual ventilation during a machine failure. Successful emergency ventilation of a patient when the airway and endotracheal tube (ETT) were 180 degrees reversed has been achieved by creating a unique rescue technique of retrograde ventilation with a self-inflating manual ventilation device (SIMVD) attached to the distal end of the expiratory limb of the breathing circuit.¹⁻³ This method temporarily ventilated and oxygenated the patient for 6 minutes during the repair of the machine leak, but the exact composition of the gas mixture was neither precisely nor thoroughly observed during the emergency.

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The anesthesia machine is the primary device to control medical gas flows to and from the patient. Many anesthesia circuit designs have been used to achieve this goal, but the most commonly used circuit is the semi-closed circle type (Figure 1), which eliminates carbon dioxide (CO₂) via the exhalation limb. Gas from the patient travels either: 1) through the one-way expiratory valve towards the reservoir bag (RB) and out the adjustable pressure limiting (APL) valve or 2) antegrade through the soda lime canister upon squeezing of the RB. The soda lime extracts residual CO₂ and directs this recycled gas through the one-way inspiratory valve into the inspiratory limb, as it joins with fresh oxygen and volatile anesthetic gas (FG) entering the circle system. This circuit is modeled in Figure 1, and a leak-free circuit is required to generate controlled positive pressure ventilation. Human error is known to be the most common source of machine malfunction, particularly of the breathing circuit.^{4,5}

What This Article Tells Us That Is New

This prospective study tells us the efficacy of this novel retrograde ventilation technique by measuring inspired oxygen and anesthetic vapor concentrations, and exhaled end-tidal carbon dioxide (EtCO₂) in a controlled environment with human subject volunteers. Neurosurgical and ENT cases frequently position the patient 180° away from the anesthesia machine. Thus, this study is particularly applicable for those anesthesiologists who frequently ventilate patients without direct access to the endotracheal tube.

Materials and Methods

Healthy men and non-pregnant women aged 18-65 scheduled to undergo elective surgery were recruited by verbal discussion of the project when they arrived in the surgical holding room. Subjects expressing interest continued discussions with the study team and were provided with a detailed description of the rationale, methods, risks, and

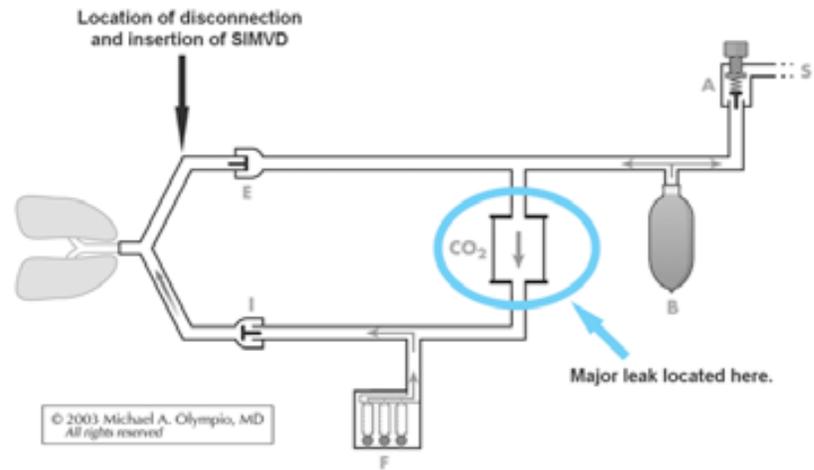


Figure 1: Illustration of semi-closed rebreathing circuit.

benefits of the study; subjects interested in participating then provided written informed consent. The sample population included only patients with an American Society of Anesthesiologists (ASA) classification score 1 or 2 who represent the healthiest patients. Potential subjects were excluded if they were scheduled for laparoscopic surgery or if they had any history of significant cardiac or pulmonary disease. Each patient had his or her own anesthesia care team in constant attendance that functioned to monitor the patient and depth of anesthesia during the research team's intervention and data collection.

Baseline

After achieving a stable course of general anesthesia for surgery using isoflurane anesthesia, narcotics, and neuromuscular blockade with rocuronium, controlled ventilation with two-foot circuit extensions was applied to either the Aestiva™/5 (Datex-Ohmeda Division of General Electric, Madison WI) or Apollo (Draeger Medical, Inc., Teleford, PA) gas machines. The research team brought all patients to the same baseline conditions: EtCO₂ 32 mmHg, inspired carbon dioxide (FiCO₂) 0 mmHg, inspired oxygen (FiO₂) 100% at flow rate 10 L/min, inspired isoflurane (FiIso) 1.0%, 12 breaths per minute, and bispectral index (BIS) (Covidian, Inc.) <50. Propofol infusion of 100 mcg/kg/min was added to the baseline anesthetic and was subsequently

adjusted by the primary anesthesia team as deemed necessary to ensure amnesia during periods of uncertain volatile anesthetic delivery to the patient. Oxygen, carbon dioxide, and volatile anesthetic values were measured and verified using gas analyzers and pulse oximeters (Datex-Ohmeda, Division of GE Medical, Madison, WI). Baseline minute ventilation was measured and recorded using the anesthesia machine and software, while subsequent values were measured using a medical grade respirometer (Draeger Medical, Inc., Teleford, PA).

Manual Expiratory Limb Ventilation with Oxygen-primed SIMVD

The soda lime canister (Medisorb, GE Medical, Inc., Madison, WI) was opened and removed from the circuit to recreate the condition of machine malfunction. The APL valve was completely closed and 100% oxygen-primed SIMVD was connected to the distal end of the expiratory limb of the anesthesia breathing circuit to provide retrograde ventilation. The patient was then manually ventilated by squeezing the SIMVD at the same tidal volume and frequency (minute ventilation) as baseline. Tidal volume and minute ventilation were continually and accurately maintained via the in-line spirometer. After 2 minutes and at steady-state, the following were recorded: FiO₂, FiCO₂, EtCO₂, FiIso, SpO₂, and BIS. After acquiring these data, the soda lime canister was replaced, the SIMVD was disconnected, and the baseline function of the anesthesia machine was reestablished to bring all previously mentioned values back to baseline.

Manual Expiratory Limb Ventilation with Room Air-primed SIMVD

The previous steps were repeated with the SIMVD now primed with room air instead of 100% oxygen.

Effect of Minute Ventilation

In both of the previously described protocols, a final step was taken to determine the effect of minute ventilation. After collecting data in steady-states with the SIMVD, the minute ventilation (tidal volume) was doubled, albeit at the same frequency of 12. Once a second steady-state was reached, the same values were recorded: FiO₂, FiCO₂, EtCO₂, FiIso, SpO₂, and BIS.

Safety Precautions

If FiCO₂ would have risen above 60 mmHg or if SpO₂ would have decreased by more than 3%, the experiment would have been aborted.

Statistical Methods

Changes in FiO₂, EtCO₂, and FiIso were compared using Student's t-test. Pre- and post- intervention values were compared using paired testing with JMP® Pro. Results are reported as mean ± SD. P-values of <0.05 were considered significant.

Results

Twelve patients were enrolled in the study. The parameters used to assess efficacy were FiO₂, EtCO₂, and FiIso. Retrograde ventilation caused the following changes:

FiO₂: This measured the efficacy of oxygen delivery. There was a statistically significant decrease in FiO₂ after moving from baseline ventilation via the anesthesia machine (FiO₂ = 100%) to retrograde ventilation with room air-filled SIMVD (FiO₂ = 53.8% ± 11.4%, p<0.0001). Oxygen-priming raised FiO₂ to 91.0% ± 1.0%, which was a significant increase versus room air-filled SIMVD (p<0.0001). (Figure 2)

EtCO₂: This measured the efficacy of ventilation. There was a statistically significant increase in EtCO₂ from 32 mmHg to 47.8 mmHg ± 4.0 mmHg (p<0.0001) when changing from baseline to SIMVD ventilation (regardless of oxygen-priming or room air) (Figure 3).

FiIso: This measured the efficacy of anesthetic delivery. There was a statistically significant decrease in FiIso from 1.0% to 0.32% ± 0.16% (p<0.0001) when changing from baseline to SIMVD ventilation (regardless of oxygen-priming or room air) (Figure 4).

Effect of Doubling SIMVD Minute Ventilation: There were no significant differences in FiO₂ or EtCO₂. There was a statistically significant further decrease in FiIso from 0.32% ± 0.16% to 0.15% ± 0.22% (p<0.0001) (Figure 5).

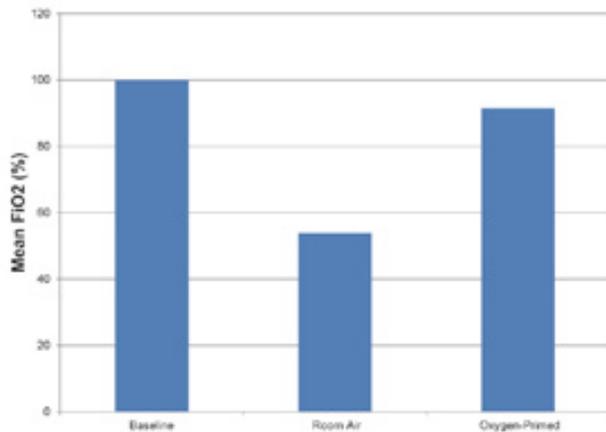


Figure 2: Fraction of inspired oxygen with room air or oxygen-primed self-inflating manual ventilation device (SIMVD) vs. baseline

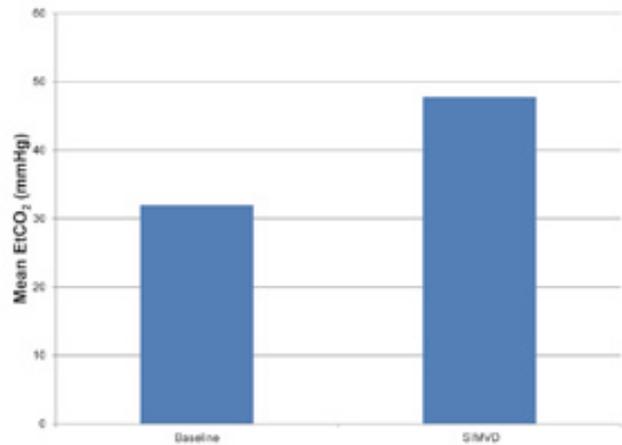


Figure 3: End-tidal carbon dioxide with self-inflating manual ventilation device (SIMVD) vs. baseline

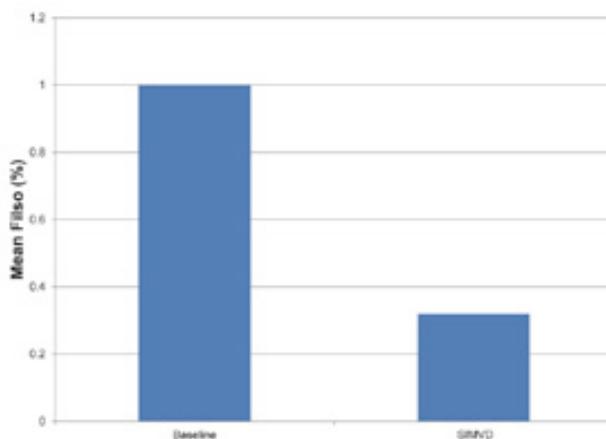


Figure 4: Fraction of inspired isoflurane with self-inflating manual ventilation device (SIMVD) vs. baseline

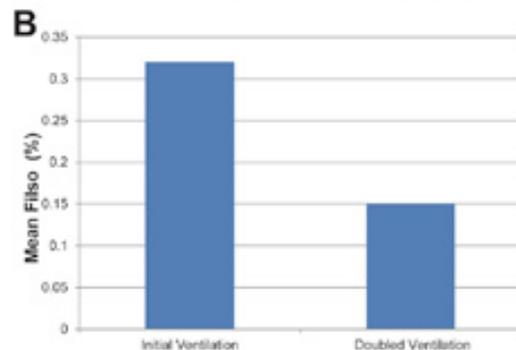
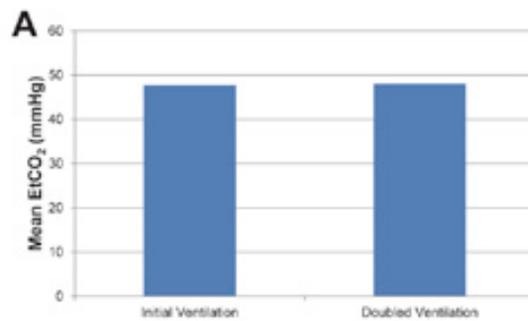


Figure 5: A) End-tidal carbon dioxide doubled vs. initial self-inflating manual ventilation device (SIMVD) and B) Fraction of inspired isoflurane doubled vs. initial SIMVD.

Effects on FiCO₂, SpO₂ and BIS: There were noticeable increases in FiCO₂ with all modes of SIMVD, but we chose to show the resultant and more clinically relevant EtCO₂ instead (above). There were no significant changes in SpO₂, and none with BIS, which remained below the target value of 50.

Discussion

Anesthesiologists are aware that patients may be successfully ventilated at some distance, by using the existing breathing circuit in reverse and this technique has been quantified. Oxygen delivery was successfully maintained using

retrograde ventilation with the oxygen-primed SIMVD. The decrease in FiO₂ from 100% to 92% could be explained by room air entrainment into the breathing system during the leak creation, or into the SIMVD as it was being manipulated

for attachment to the expiratory limb. In the event of using a room-air-filled SIMVD during an emergency, one could still expect oxygen enriched gas to be delivered, if in fact the breathing circuit was primed with oxygen during a machine circuit leak. This might occur if the clinician pressed the oxygen flush button and increased free gas flow (FGF) to 100% oxygen. This was the reason our study baseline was designed to start with 100% oxygen. Oxygen delivery was also adequately maintained during room-air-filled SIMVD. Although there was a decrease in FiO_2 to 53.8%, this is still supra-atmospheric and would confer oxygen enrichment even during a worst-case scenario.

End-tidal carbon dioxide was increased due to the expected and known rebreathing of a large volume (865 mL) of dead space gas in the expiratory limb of a lengthened circuit. Therefore, CO_2 was trapped in this dead space and did not escape readily. To-and-fro movement of gas between the SIMVD and patient in the expiratory limb caused mixing of fresh oxygen with exhaled CO_2 . Buildup of CO_2 in this rescue circuit was observed as FiCO_2 rose to approximately 25 mmHg. It was hypothesized that doubling the minute ventilation might help decrease this FiCO_2 (and therefore EtCO_2); however, the elimination of CO_2 is dependent upon the length of the rebreathing circuit and the amount of FGF to purge that circuit and not upon the minute ventilation.⁶ Doubling the minute ventilation did not overcome the dead space. These findings have particular significance in the neurosurgical patient, whereby a transient elevation in PaCO_2 must be quantified and considered.

Isoflurane delivery was significantly reduced using retrograde ventilation. This is most likely due to the dilution of anesthetic gas with the non-volatile-gas-containing SIMVD as well as significantly reduced antero-grade delivery of fresh gas flow. Furthermore, this emergency breathing circuit is no longer semi-closed, but rather scavenges the gas mixture into

room air via the SIMVD exhaust valve, as it is continuously diluted by the auxiliary oxygen flowing into the SIMVD. The FiIso did not fall to zero, likely because we did not allow adequate time for washout of dissolved isoflurane from the patient's bloodstream. As this decrease in FiIso is significant, supplemental anesthetic and amnestic medications would be recommended, as we did by using supplemental propofol infusion.

In summary, we believe that retrograde ventilation with an SIMVD (with or without a connection to oxygen) is an adequate rescue technique if supplemental amnestic agents are considered. Hypercapnia is expected, so this technique should be used with caution in situations where modest hypercarbia is clinically relevant.

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