EFFECTS OF CIRCUIT LEAK DEVELOPMENT OVER TIME AND RESPONSE DURING LOW-FLOW VOLUME AND PRESSURE-CONTROLLED VENTILATION

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Study Objective: To study the effects of circuit leak development over time and response during volume and pressure controlled ventilation using low flow in human patient simulator and to examine the minimum fresh gas flow needed to compensate for such a leak.

Design/Setting: Prospective study using a patient Simulation Lab at Wayne State University.

Measurements: A human patient simulator was endotracheally intubated. The endotracheal tube (ETT) was connected to the Datex-Ohmeda AS/3 Anesthesia machine. The tidal volume was set to 500ml in the volume controlled trial and the pressure to 6cm H2O in the pressure controlled trial. A hole was created in each experiment placed 10 cm after the inspiratory valve. Leaks were simulated from holes using 4 different needle diameters: 25, 21, 18 and 16G. A series of data were collected using fresh gas flow at 4 different flow rates (0.5, 1, 1.5 and 2 liters.min⁻¹). Data was measured at different time points (baseline, 1, 3 and 5 minutes) in the series of simulated leaking breathing circuits.

Results: Leak alarms were only detected with 16G hole at 5 minutes in the volume control mode versus leaks at 3 minutes with 16G hole and at 5 minutes with 18G hole in the pressure control mode.

Conclusion: When a very low flow of 0.5 L/min is used, volume control is safer than pressure control mode since leak alarms only occurred with 16G hole. However when a flow of 1L/min was used, there was no difference in leak compensation between volume and pressure control modes.

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Institutional Review Board review of this study was not required as all data obtained from a human patient simulator connected to a Datex-Ohmeda AS/3 Anesthesia Delivery Unit.

Conflicts of interest: None of the study authors had any financial relationships or commercial interests with a vested interest in the outcome of this study.
Introduction

Low flow anesthesia was used with cyclopropane to limit the leak of this explosive gas\textsuperscript{i-3}; it became popular after the development of circle systems\textsuperscript{4,5}. The concomitant use of low flow and closed circuit in anesthesia might reduce the cost\textsuperscript{6,7} and the atmospheric and personnel pollution by inhalational agents\textsuperscript{8}, improve inhalational gas humidity and temperature when compared to the use of a high flow anesthesia. However the main factor limiting its use is the possibility of hypoxic anesthetic gas delivery like rebreathing of exhaled CO\textsubscript{2}\textsuperscript{9,10}, rebreathing of carbon monoxide\textsuperscript{11} and accumulation of nitrogen within the breathing circuit\textsuperscript{12}. Another possible limiting factor could be the inability to compensate for a circuit leak, resulting in hypoventilation of the anesthetized patient.

Leak within the anesthesia circuit might lead to inadequate ventilation and hypoxemia\textsuperscript{9} over time and their severe consequences if it went unnoticed. In this study we studied the minimum fresh gas flow that is required to compensate for such a leak.

Methods

Institutional Review Board review for this study was not required as all data obtained from a human patient simulator connected to a Datex-Ohmeda AS/3 Anesthesia Delivery Unit.

A) Selection and description of participants:

We designed this prospective simulator trial to study the effects of circuit leak development over time and response during volume and pressure controlled ventilation using low flow in human patient simulator.

B) Technical information:

A human patient simulator was endotracheally intubated with an 8.5mm internal diameter endotracheal tube (ETT), the cuff was inflated with 15cc or air to create a good seal for air leak. The ETT was connected to the Datex-Ohmeda AS/3 Anesthesia Delivery Unit machine breathing, the tidal volume was set to 500ml in the volume controlled trial and the pressure to 6cm H\textsubscript{2}O in the pressure controlled trial. The respiratory rate is set to 10/min, PEEP to 0cm H\textsubscript{2}O.

A hole was created in each experiment 10cm after the inspiratory valve. Leaks were simulated from holes made in the circuit using 4 different needle diameters (consecutively used 25, 21, 18 and 16 gauge needles). A series of data measurements were collected using fresh gas flow at 4 different flow rates (0.5, 1, 1.5 and 2 liters.min\textsuperscript{-1}).

Data from the anesthesia machine was measured from the ventilator monitor at different time points (baseline then 1, 3 and 5 minutes) in the series of simulated leaking breathing circuits. The two primary variable parameters were the diameter of a hole created in the breathing circuit and the fresh gas flow. Two different scenarios were simulated to measure the primary variables; 1. Volume controlled scenarios (breathing circuit was set at tidal volume of 500ml) and 2. Pressure controlled scenarios (breathing circuit was set at a pressure rate of 6cm H\textsubscript{2}O).

C) Statistics:

The tidal volume, minute volume, peak airway pressure, plateau pressure, positive end expiratory pressure data were collected in 10 separate experiments. Each data point on these simulated cases was an averaged value derived from 5 individual runs on the simulated anesthesia machine. In addition to continuous volume and pressure measurements, categorical data was collected with machine bellows status that was designated as either bellows full or bellows leaking and machine alarm status designated as either alarm present (alarming) or alarm absent (not alarming). Data was collated and analyzed using Microsoft Excel 2010.

PEEP: positive end expiratory pressure
Bellow F: bellow full
Bellow L: bellow leaking
Alarm A: absent (not alarming)
Alarm P: present (alarming)
**Results**

The standard deviation range for all *Pressure controlled* data stayed below 1% of mean values for all data.

The standard deviation range for all *Volume controlled* scenario data was below 10% of mean values data obtained from 25, 21 and 18 gauge produced system leaks. The SD of mean data rose to 25% for 16 gauge system leaks at low flow rates (0.5 l/min and 1.0 l/min) by the 3 and 5 minutes periods.

**Volume controlled data**

When the simulated breathing circuit was set at a tidal volume of 500ml the circuit leak alarm was only detected in the circuit at a gas flow rate of 0.5 l/min at the 5 minute duration when a 16-gauge hole was present. (Panel A, Figure 1). No leak holes regardless of gauge diameter could activate the circuit leak alarm at any time point during gas flow rates of 1, 1.5 or 2 l/min (Panels B, C and D, Figure 1).

**Pressure controlled data**

When the simulated breathing circuit was set at a pressure rate of 6cm H₂O the circuit leak alarm was detected in the circuit at a gas flow rate of 0.5 l/min at 3 minutes duration when a 16-gauge hole was present and also at 5 minutes duration for both 16 and 18 gauge holes. (Panel A, Figure 2). No leak holes regardless of gauge diameter could activate the circuit leak alarm at any time point during gas flow rates of 1, 1.5 or 2 l/min (Panels B, C and D, Figure 2).

**Discussion**

For both pressure control and volume control simulations only the large gauge holes in the breathing circuit occurring during the lowest flow rate (0.5 L/min) will result in a machine alarm. The volume control mode seems safer than the pressure control mode since leaks were only present with a 16G hole at 5 minutes in the volume control mode versus leaks at 3 minutes with a 16G hole and at 5 minutes with an 18G hole in the pressure control mode. The anesthesia machines and inhalational anesthetics currently available allow a safe use of low-flow techniques. Low-flow anesthesia techniques using a fresh gas flow rate of 1 l/min can be performed with almost every anesthesia machine6-13. The major benefit of rebreathing techniques can be reached only if the fresh-gas flow is reduced to 1 l.min-1 or less14. Our results showed that a fresh gas flow of 1 l.min-1 is safe while it is not with lower fresh gas flow of 0.5 l.min-1 in the presence of leaks in the circuit.

Leaks in anesthesia machines can increase the risk of hypoxia, hypoventilation, and can also lead to inadequate delivery of anesthetic gases with possibility of awareness. Small leaks in the low-pressure system (LPS) of the anesthesia gas machine can cause hypoxia or patient awareness15. Small circuit leaks can occur anywhere in the anesthesia machine. It can occur due to APL valve malfunction16. It can occur in unusual places like a circuit leak from capnograph sampling line17, a loose lock nut holding the exhalation port to the body of the CO2 absorber manifold creating a leak18, a crack in a fresh gas circuit valve19, mis-installation of a different but very similar canister20, or a leak within the anesthesia circuit due to a tear near the insertion site of ETT cuff inflation line21, a leakage from the junction of two vaporizers22, soda lime granule trapped in the flap valve of the water trap, rendering that valve incompetent23 or even a fault with the electronically controlled Man-Auto valve causing it to stick in the bypass direction, thereby diverting inspiratory gas flow directly to the scavenging system24.

Administering anesthesia without the use of nitrous oxide facilitates the use of low flow anesthesia since washing out nitrogen is no longer required25. Desflurane and sevoflurane can be used with low flow anesthesia. Another advantage of keeping the fresh gas flow at 1 l.min-1 is that when the flow is reduced to 1 l/min, the inspired desflurane concentration achieved in the initial high-flow phase can be maintained without changing the vaporizer setting. However if the flow is reduced down to 0.5 l/min, the fresh gas concentration has to be increased to a value 1%-2% higher than the inspired nominal value25,26. Because of its low solubility and high maximum concentration delivered by the vaporizer, sevoflurane is suitable...
Fig. 1
Minute volume over time with a set volume of 500ml during gas flow rates (L/min) of A) 0.5, B) 1.0, C) 1.5 and D) 2.0.
Fig. 2

Minute volume over time at a pressure of 6cm H20 pressure during gas flow rates (L/min) of A) 0.5, B) 1.0, C) 1.5 and D) 2.0.
for low flow anesthesia. With careful attention to managing fresh gas flow, anesthetic drugs can be used more efficiently by reducing the waste while achieving the same effect on the patient.

The sensitivity and specificity of the positive pressure tests were 92% and 100% respectively and the possibility of gas leakage around the oxygen flush device is not generally recognized. Therefore a fresh gas flow of 1 l.min-1 will still be safer than lower fresh gas flows in the presence of negative leak test on the checking of the anesthesia machine. The primary cause of the leak is thought to be related to the canister. It is important to inspect the canister if the low flow leak test does not meet the standard.

Low fresh gas flows can be used with laryngeal mask airways. The reduction in the fresh gas flow to 0.5 L min(-1) was possible in 96.7% of the patients managed with a laryngeal mask. The laryngeal mask airway provides a tight gas seal comparable to that of a tracheal tube in this context and would be beneficial in reducing anesthetic gas pollution.

Mucociliary clearance and respiratory function are better preserved in a low-flow anesthesia technique than in high-flow anesthesia. Low fresh gas flow technique using sevoflurane is cost saving compared to intravenous anesthesia in laparoscopic cholecystectomy. Cost-effectiveness has become a major focus in healthcare nowadays. The effect of a new policy on the use of low fresh gas flow during maintenance of general anesthesia effectively reduces the amount of sevoflurane consumed for the same duration of anesthesia. Sevoflurane stability was studied during low flow anesthesia, this showed that there was no connection with nephropathy or liver toxicity and that renal and hepatic effect of moderate duration low-flow sevoflurane and total intravenous anesthesia is similar.

Conclusion

The mechanical effects and consequences, such as volume and pressure changes, that resulted from the interaction of the presence of a leak and low flow in the breathing circuit were studied. Volume control mode seems to be safer than pressure control mode when low fresh gas flows were used. We did not study the possibility or the amount of rebreathed CO2 nor the presence of carbon monoxide or the concentration of inhalational anesthetics or compound A or other degradation products due to the fact that we used a human patient simulator where no gas is consumed.
References

22. Yasukawa M, Yasukawa K: [Hypoventilation due to disconnection of the vaporizer and negative-pressure leak test to find disconnection]. Masui; 1992; 41:1345-6.
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² train-of-four
³ post-tetanic count
⁴ second twitch


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