Original Article

Ventilator-assisted priming of an anaesthesia circuit (VAP technique): An exploratory study

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ABSTRACT

Background and Aims: The speed of inhalational induction depends on a variety of factors, of which priming the breathing circuit with volatile anaesthetics plays a vital role. This study compared ventilator-assisted priming (VAP) and a passive priming technique using different fresh gas flows (FGFs) in neonatal, paediatric, and adult anaesthetic circuits. **Methods:** In both techniques, FGF with 100% oxygen and 8% sevoflurane vaporiser concentration were set at 2 $Lmin^{-1}$, 4 $Lmin^{-1}$, and 8 $Lmin^{-1}$, representing three groups FGF-2, FGF-4, and FGF-8, respectively. The time taken to achieve 6% sevoflurane concentration at the patient end of the circuit was measured. In addition to this, we explored various combinations of tidal volumes and respiratory rates in the VAP technique and recorded the priming time with each combination. The amount of sevoflurane consumed for priming in both techniques was also calculated. **Results:** VAP was three times faster than passive priming in all the FGF groups in the three circuits. In the VAP technique, the shortest priming times were similar for FGF-4 and FGF-8 ($P > 0.05$) but were significantly higher for FGF-2 ($P = 0.001$) in the three circuits. Sevoflurane consumption did not differ in FGF-2 and FGF-4 groups, whereas it doubled in the FGF-8 group using the VAP technique in all three circuits. **Conclusion:** The VAP technique provides a quick and effective method for priming to achieve a high anaesthetic concentration within the breathing circuit for inhalational induction.

Key words: Anaesthesia, inhalation, sevoflurane, ventilator

INTRODUCTION

Inhalational induction is a feasible alternative to intravenous induction when rapid induction is desired, particularly in the practice of paediatric anaesthesia.[1–3] The goal of inhalational induction is to achieve an adequate depth of anaesthesia, minimise induction time, and ensure maintenance of spontaneous breathing while minimising operating room (OR) pollution due to inhalational anaesthetic agents. The speed of inhalational induction depends on a variety of factors, of which priming the breathing circuit with volatile anaesthetics plays a vital role. Sevoflurane has become the anaesthetic agent of choice for inhalational induction[4] due to its minimal impact on the airway and haemodynamic stability.[5]

An inhaled sevoflurane concentration of 6% at the patient end of the breathing circuit has been recommended for vital capacity induction.[6] The time required to achieve this concentration depends on the fresh gas flow (FGF) rate, the concentration settings of sevoflurane on the vaporiser, circuit volume, and the priming technique used.[7] Studies investigating combinations of these factors have reported priming times ranging between 30 seconds and 5 minutes.[2,3,5,7] However, all the priming techniques described so far in the literature have used a passive method of priming, that is, allowing the breathing circuit to fill spontaneously with FGF containing either oxygen alone or an oxygen and nitrous oxide combination

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along with volatile anaesthetics. There are no studies to date that have explored the utility of mechanical ventilation to actively prime the circuit.

We hypothesised that actively pressurising the circle system with the ventilator set in volume-controlled mode provides the fastest method of priming the circuit with the desired anaesthetic concentration. The primary objective of this study was to compare the ventilator-assisted priming (VAP) technique with the passive priming technique for anaesthesia circuits. The secondary objective was to determine the optimum FGF rate along with the tidal volume and respiratory rate combinations that would result in the fastest and most cost-effective method of priming by achieving high anaesthetic concentration within the breathing circuit.

METHODS

All the experiments were conducted on a single Dräger Fabius GS (Drägerwerk AG & Co. KGaA, Lübeck, Germany) anaesthesia machine with a classical rebreathing system (circle system) at Pak Italian Modern Burn Centre. All methods were carried out as per relevant guidelines and regulations. The Fabius GS workstation consists of an electrical piston-driven ventilator, an electronic mixed gas control unit, and out-of-circle vaporisers to deliver the volatile anaesthetic. A fresh carbon dioxide (CO_2) absorber, sevoflurane Tec 7 vaporiser, gas sampling line (Intellivue G5-M1019A) connected at the patient end, and a 2-litre reservoir bag were used for each of the experiments. The experiments were conducted in three circuits of different lengths and volumes: neonatal (180 cm, 500 ml), paediatric (152 cm, 600 ml), and adult (304 cm, 1600 ml) circuits, all in fully expanded positions. The same breathing circuit was used for passive priming and then for multiple VAP tests due to the limited resources. The anaesthesia machine check-out was performed as per the American Society of Anesthesiologists guidelines before beginning the experiment and was repeated after each circuit was changed.

Within each circuit, the baseline readings were taken using the passive priming technique and then the circuits were primed using the VAP technique.

For the passive priming technique, the ventilator was set in manual/spontaneous ventilation mode with the adjustable pressure-limiting (APL) valve fully opened. The reservoir bag was emptied and the patient end of the circuit was occluded against the knob provided in the anaesthesia machine. The FGF containing 100% oxygen (O_2) and 8% sevoflurane vaporiser concentration was set at 2 $Lmin^{-1}$ in the FGF-2 group, 4 $Lmin^{-1}$ in the FGF-4 group, and 8 $Lmin^{-1}$ in the FGF-8 group. The time taken to reach 6% sevoflurane concentration at the patient end of the circuit was noted using a stopwatch.

For VAP technique, the ventilator was set in volume-controlled mode with a pressure limit of 40 cm of H_2O, zero positive end-expiratory pressure (PEEP), an inspiratory-to-expiratory ratio (I:E) of 1:2, and an inspiratory pause–to–inspiration time ratio (T_{ip}:T_i) of 10%. The FGF containing 100% oxygen and 8% sevoflurane vaporiser concentration was kept at 2 $Lmin^{-1}$ in the FGF-2 group, 4 $Lmin^{-1}$ in the FGF-4 group, and 8 $Lmin^{-1}$ in the FGF-8 group, and the patient end of the circuit (Y-piece) was occluded against the knob provided on the machine [Figure 1]. Serial readings were then recorded at different combinations of tidal volume (TV) and respiratory rate (RR) in each group. TV was set initially at 100 mL and the experiment was repeated in 100 mL increments until 500 mL was reached. The RR was initially set at 10 with increments of 2 breaths at a time up to a rate of 20 breaths per minute. A stopwatch was used to record the time taken for each combination of TV and RR to achieve a 6% sevoflurane concentration at the patient end of the circuit.

Three sets of readings were taken with each experiment and the average of the nearest two readings was considered. This gave us nine tests per circuit using the passive priming method (3FGF × 3 times) and a total of 270 tests per circuit using the active priming method [3FGF (5TV × 6RR) × 3 times].

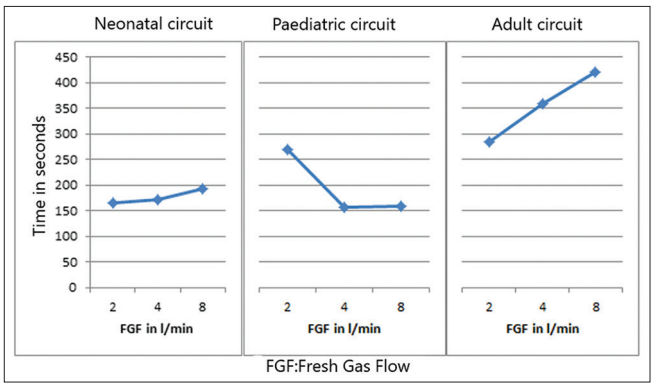

Figure 1: Time in seconds to achieve 6% sevoflurane concentration at fresh gas flow rates of 2, 4, and 8 $Lmin^{-1}$ using spontaneous manual ventilation (passive technique) in different circuits

To ensure that no residual anaesthetic gas was present in the circuit, the reservoir bag was emptied several times between trials and the circuit was flushed with 12 $Lmin^{-1}$ of oxygen until the monitor showed no trace of sevoflurane.

The results obtained were plotted on a graph, and the shortest time required to attain the desired sevoflurane concentration (6%) at each FGF rate using both techniques was noted. The amount of liquid sevoflurane consumed for priming the circuit was then calculated using the equation PFTM/2412d, where *P* is the vaporiser dial concentration (%), F is the total FGF rate ($Lmin^{-1}$), T is the time for which the concentration *P* was set in minutes, M is the molecular mass of sevoflurane (constant at 200.055 mg), and d is the density at 21°C (constant at 1.52 g/ml).[8]

The data in each group in the VAP technique was tested for normality of distribution by looking at Kurtosis and Skewness of data, which revealed a skewed distribution. A non-parametric version of Levene's test was applied to check for homogeneity of variance. Welch test was used following a violation of homogeneity and showed a significant difference among the three FGF groups. Differences between groups were further analysed using Games–Howell's *post hoc* test. All statistical tests were performed using the Statistical Package for the Social Sciences version 20 (SPSS, International Business Machines Corporation, New York, United States of America). A two-tailed variability value of 0.05 was considered significant.

RESULTS

A total of 837 tests were performed in the three anaesthesia circuits (9 + 270 in each circuit). Priming of the breathing circuit with 6% sevoflurane was successfully achieved in all the tests at different time intervals [Table 1].

The least time required to prime the circuit to 6% sevoflurane concentration using the passive priming technique was >150 s in the neonatal and paediatric circuits, and it was more than 250 s in the adult circuit at all the FGF rates [Figure 1].

The priming times using the VAP technique were significantly shorter compared to the passive technique in all the FGF groups in all the circuits. In the VAP technique, the shortest times noted for FGF-2, -4, and -8 were 54 s, 29 s, and 28 s for the neonatal circuit, 58 s, 29 s, and 28 s for the paediatric circuit, and 64 s, 39 s, and 38 s for the adult circuit, respectively. The TV and RR settings that resulted in the fastest priming were the same in the FGF-4 and FGF-8 groups: 100 mL and 20 in the neonatal circuit, 200 mL and 20 in the paediatric circuit, and 500 mL and 20 in the adult circuit, respectively. In the FGF-2 group, TV of 100 mL and RR of 20 attained the least priming time in all the three circuits [Table 1].

The priming times at various TV and RR combinations were significantly higher in FGF-2 when compared to both FGF-4 ($P = 0.001$) and FGF-8 ($P = 0.001$) groups. However, there was no significant difference between the FGF-4 and FGF-8 groups in all three circuits.

In both FGF-4 and FGF-8 groups, a linear relationship between RR and priming time was observed at TVs up to 300 mL in all three circuits, after which there was a random distribution of values without any definite trend. In FGF-2, a linear trend was noted only at a TV of 100 mL after which the values were widely distributed, taking an unusually long time without any definite correlation in all three circuits [Figures 2–4].

The actual delivered TVs remained nearly the same in all groups within each circuit irrespective of the TV set on the ventilator because of the pressure limit of 40 cm of H_2O in the circuit. Therefore, the actual delivered TVs were dependent mainly on the circuit compliance and circuit volume: 25–35 mL in the neonatal circuit, 35–45 mL in the paediatric circuit, and 55–75 mL in the adult circuit [Figure 5].

The sevoflurane consumption was significantly lower using the VAP technique since this technique was three times faster than the passive technique. In the VAP technique, there was no significant difference in the amount of sevoflurane consumed between FGF-2 and FGF-4 groups in all the three circuits, whereas sevoflurane consumption doubled upon increasing the flows to 8 $Lmin^{-1}$ in the FGF-8 group [Table 1].

DISCUSSION

The optimal technique incorporating the shortest times and the most cost-effectiveness for priming the circuit was achieved using the VAP technique at 4 $Lmin^{-1}$ FGF in all three circuits: 29 s in both the neonatal and the paediatric circuits and 39 s in the adult circuit. Doubling the FGF rate to 8 $Lmin^{-1}$ did not significantly

Table 1: The minimum priming times recorded in seconds along with the tidal volume and respiratory rate combinations and the amount of sevoflurane consumed in mL at different fresh gas flow groups in neonatal, paediatric, and adult circuits

Circuit	Key Findings	FGF -2		FGF-4		FGF-8	
		Passive	VAP	Passive	VAP	Passive	VAP
Neonatal	Min. time (s)	166	54	172	29*	193	28**
	TV×RR	-	100×20	-	100×20	-	100×20
	Sevoflurane Consumed (mL)	2.41	0.78	5.00	0.84	11.2	1.62
Paediatric	Min. time (s)	270	58	157	29*	166	28**
	TV×RR	-	100×20	-	200×20	-	200×20
	Sevoflurane Consumed (mL)	3.92	0.84	4.50	0.84	4.83	1.62
Adult	Min. time (s)	285	64	358	39*	420	38**
	TV×RR	-	100×20	-	500×20	-	500×20
	Sevoflurane Consumed (mL)	16.00	0.93	20.83	1.13	24.44	2.21

*VAP with FGF-4 was significant shorter priming than FGF-2 (*P*=0.001). **VAP with FGF-8 was significant shorter priming than FGF-2 (*P*=0.001) but not FGF-4.
TV: Tidal volume; RR: Respiratory rate; FGF: Fresh gas flow; VAP: Ventilator-assisted priming; Min.: Minimum priming

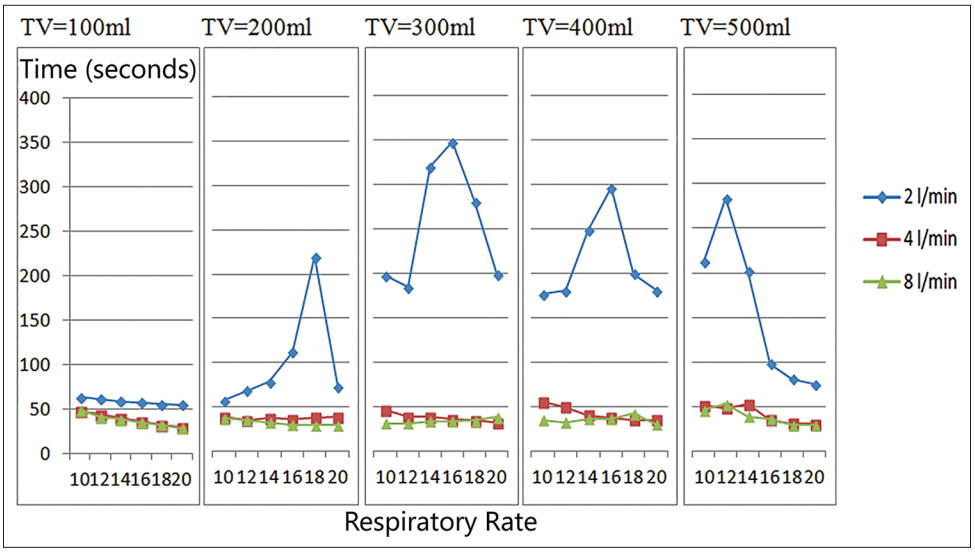

Figure 2: Time trends in seconds to achieve 6% sevoflurane concentration at various tidal volume and respiratory rate combinations in all three fresh gas flow groups in the neonatal circuit; TV: Tidal volume

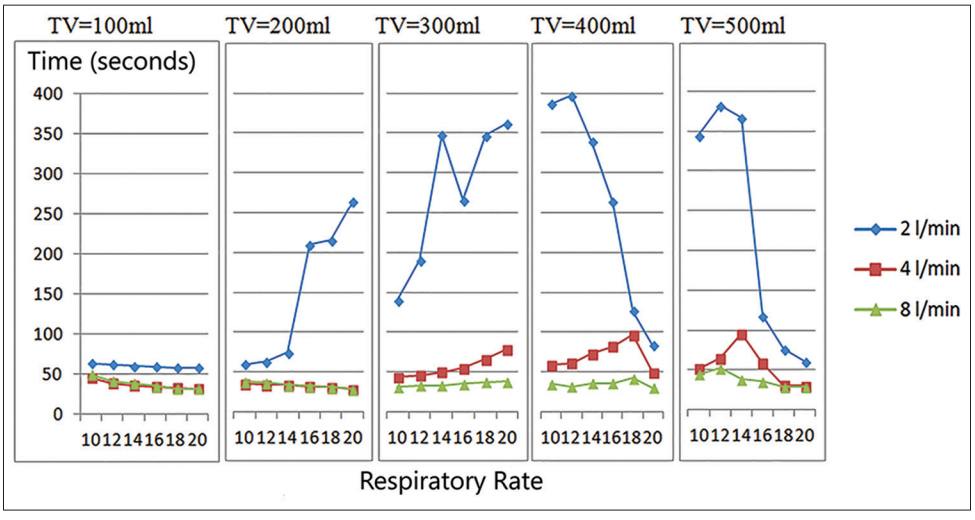

Figure 3: Time trends in seconds to achieve 6% sevoflurane concentration at various tidal volume and respiratory rate combinations in all three fresh gas flow groups in the paediatric circuit; TV: Tidal volume

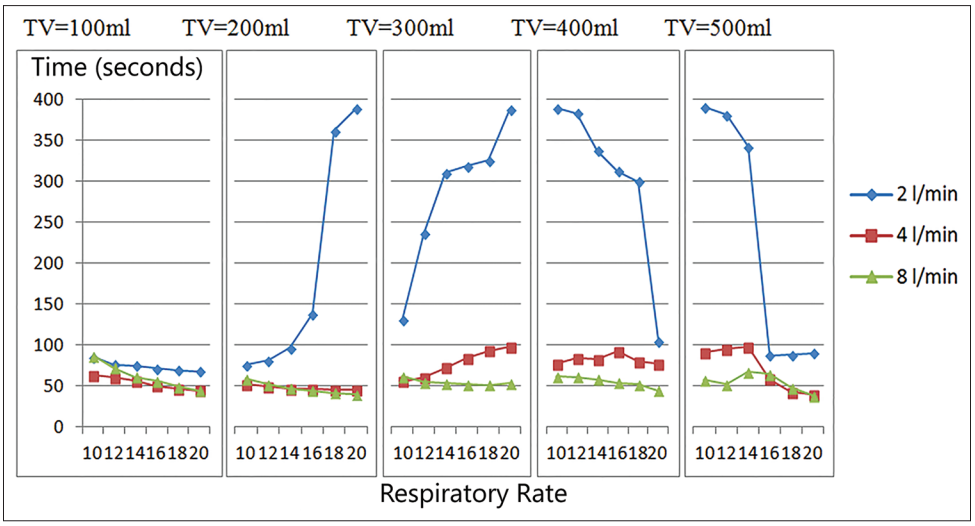

Figure 4: Time trends in seconds to achieve 6% sevoflurane concentration at various tidal volume and respiratory rate combinations in all three fresh gas flow groups in the adult circuit; TV: Tidal volume

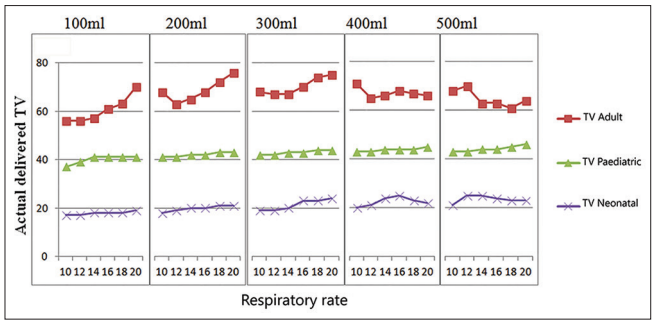

Figure 5: Actual delivered tidal volume (Y axis) at different set tidal volumes and respiratory rates (X axis) in all three circuits; TV: Tidal volume

shorten the priming time, but it did double the associated agent consumption. Halving the FGF rate to 2 $Lmin^{-1}$ significantly increased the priming time from that at 4 $Lmin^{-1}$ while the consumption remained steady [Table 1].

The results of our study using the VAP technique were similar to the 30 s priming technique described by Thienthong *et al.*[7] using 8 $Lmin^{-1}$ FGF and an 8% sevoflurane dial setting. However, they set the end point of priming at 4.5%, and they described the occlusion of the Y piece manually with the intermittent release of gas into the operating room to maintain a constant pressure of 10 cm of H_2O within the circuit.

Philip *et al.*[3] conducted a study wherein priming of the adult circuit was done using manual spontaneous ventilation with 8 $Lmin^{-1}$ FGF (75% O_2/nitrous oxide (N_2O)) and 8% sevoflurane from the vaporiser. They measured >6% sevoflurane concentration in the circuit in approximately 45 s after filling and emptying the reservoir bag thrice against the occluded circuit.[3]

The priming techniques described in previous studies allowed the anaesthetic gas to fill the breathing circuit passively to achieve priming. Our technique is unique in that it actively delivers the tidal volume using the ventilator, pressurising the breathing circuit and thus reducing the time it takes to reach the target sevoflurane concentration. Moreover, all the previous studies in the literature have used more than 6 $Lmin^{-1}$ FGF with or without N_2O to achieve priming, whereas we achieved the desired sevoflurane concentration with just 4 $Lmin^{-1}$ FGF and oxygen alone, making this technique very cost-efficient.

Another feature revealed in our study was that the time required to prime the circuit was relatively faster at lower TVs (100 mL and 200 mL) than at higher TVs in all the FGF groups in all three circuits except for 500 mL TV and RR of 18 or 20. This could be partly due to the interaction of a variety of factors including the circuit and machine dead space, the difference between actual delivered TV and the set TV [Figure 5], I: E ratio, and inspiratory pause. Despite the complex interaction among these physical properties, which are beyond the scope of this article's discussion, we did observe that in all the three groups, the priming times were consistently the least with 100 mL, 200 ml, and 500 mL TVs and RR of 20 breaths/min in neonatal, paediatric, and adult circuits, respectively.

Previous studies have demonstrated that low-flow anaesthesia significantly decreases the consumption

of volatile agents and costs.[9-11] In our study, we only calculated the equivalent volume of the anaesthetic agent used instead of the cost, as the price per unit of the anaesthetic agent could vary with time and place. We observed only a marginal difference in sevoflurane consumption between the FGF-2 and FGF-4 groups: 0.78 mL versus 0.84 mL: for the neonatal circuit; 0.84 mL versus 0.84 mL: for the paediatric circuit; and 0.93 mL versus 1.13 mL for the adult circuit using VAP technique. This was due to a large reduction in the time taken to prime the circuit upon changing the FGF rate from 2 $Lmin^{-1}$ to 4 $Lmin^{-1}$: 54 s versus 29 s in the neonatal circuit, 58 s versus 29 s in the paediatric circuit, and 67 s versus 39 s in the adult circuit.

The sevoflurane consumption approximately doubled between the FGF-4 and FGF-8 groups in all the circuits: 0.84 mL to 1.62 mL in both the neonatal and the paediatric circuit and 1.13 mL to 2.21 mL in the adult circuit. However, only a negligible decrease in time taken to prime the circuit was observed between FGF-4 and FGF-8 groups: 29 s versus 28 s for the neonatal circuit, 29 s versus 28 s for the paediatric circuit, and 39 s versus 38 s for the adult circuit [Table 1].

There were several limitations to our study. Firstly, this was an exploratory study of the technique and further clinical evidence is needed to establish its role in everyday practice. Secondly, we chose to study one of the most common default settings of the mechanical ventilator (i.e. maximum pressure 40 cmH_2O; PEEP = 0; I: E of 1:2). Thus, the results might be different and might require further calibration when using different ventilator settings. Thirdly, we used only five TVs and six RRs while other TVs and RR combinations were not explored for practical reasons. Another limitation was that the same breathing circuit was used for passive priming and then for multiple VAP tests, and we used a 2 L bag for all the circuits. Ideally, 1 L and 500 mL bags should have been used for paediatric and neonatal circuits, respectively. Last but not least, we performed all the experiments on a single anaesthesia machine and did not test the repeatability of our findings in machines of different models. Although we do not anticipate that our study observations will vary significantly in other machines of the same model, it is important to point out that individual calibration of differing models should be performed. Diverse interactions between the ventilator and scavenging system present in alternative models may lead to altered gas mixtures during the priming period.

CONCLUSION

Mechanical ventilation with the ventilator set in volume-controlled mode and 4 $Lmin^{-1}$ FGF rate provides a rapid, consistent, and effective method of priming the breathing circuit with the desired sevoflurane concentration. This VAP technique not only allows anaesthetists to attend to other important clinical tasks but also avoids any hazard of leaking anaesthetic gas into the OR environment during the priming process.

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Conflicts of interest
There are no conflicts of interest.

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