Low-Resistant Stabilized Mini-Vaporizers IN (VIC) and OUT (VOC) of the Breathing Circuits (*manuscript 2010)*

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Abstract

The main problems related to inhalation anesthesia may be solved by using a more advanced vaporizer that would be accurate as a plenum vaporizer, simple and low-resistant as a draw-over one.

Due to the low resistance and virtual independence from fresh gas flow rate, temperature, and ambient pressure, MINIVAP vaporizers are instantly adaptable to needs of both on-site emergency surgery and more sophisticated demands of a general hospital.

MINIVAP vaporizers have been successfully tested in two leading Moscow hospitals (> 100 anesthesias in adults and children 2-14 years) with different anesthesia machines (Drager Primus, STEPHAN Artec, Datex-Ohmeda S/5 Avance, Ru PMT Xena-010).

A MINIVAP vaporizer may be installed either IN a conventional breathing circuit (instant change of inspired concentration) or OUT of breathing circle (high safety) of any anesthesia machine.

Consumption of a liquid anesthetic by MINIVAP is approximately 5-10 ml/hour at mini or low-flow anesthesia (F_G = 0.5-1 L/min) and 1-3 ml in the closed system (during 1- to 5-hour anesthesia).

Keywords

Anesthesia, low-flow, mini-flow; volatile anesthetic, inspired and expired concentration; fresh gas flow, vapor anesthetic; equipment, low-resistant (draw-over) vaporizers, plenum vaporizers; anesthesia machine, semi-closed circuit, closed circuit.

Introduction

Optimal inhalation anesthesia techniques include:

1) Sevoflurane, isoflurane, or desflurane low- or mini-flow anesthesia **[1, 2]**
2) Xenon combined anesthesia **[3, 4]**.

Inhalation anesthesia is especially indicated for children up to 14 years old, who refuse any painful manipulations **[5]**.

Analysis

Main problems of inhalation anesthesia include:

1 – The need for sophisticated and bulky anesthetic equipment (especially compared to what is used for intravenous anesthesia) **[6]**.

2 - Non-stability of the well-known draw-over vaporizers (OMV, Ohmeda PAC, Goldman vaporizers are associated with unpredictable output and inadaptability to gas flows below 4 L/min) **[7, 8]**.

3 – Delayed change of anesthetic concentration in closed and semi-closed systems, while the concentration inspired by the patient is not known with certainty in spite of an accurate VOC. At the minimum oxygen flow 250 ml·min^{-1} the supply of "anesthetic agent reaches its limits…with isoflurane – and that would be more striking with enflurane or halothane – the individual uptake of an adult patient exceeds the amount of agent which maximally can be supplied into the breathing (VOC) system" **[1]**.

The delivered anesthetic vapor flow may be increased by serially connecting agent-specific vaporizers kept out of the circuit **[9]**. On the other hand, the super-complex anesthesia machine (station) PhysioFlex^{TM} with an electronically controlled vaporizer changes sevoflurane concentration from 0 to 2 vol.% in 80 to 510 s **[10]**. However, the mentioned methods and equipment are impractical.

There is a **marked difference** between the inspired anesthetic concentration and the corresponding vaporizer setting in circulation systems (Table 1). The lower the fresh gas flow, the higher the concentration to be dialed at the VOC to maintain a desired anesthesia depth.

Table 1

Data of inspired mixture of Sevoflurane (S) or Isoflurane (I) and O_2 during mini- and low-flow anesthesia with a vaporizer OUT of the breathing circle **[1]**

Fresh gas flow F_G, L/min		0.25	0.5	1
Vaporizer setting / Inspired concentration, C_S/ C_I	S	**8/2.8**	**5/2.8**	**3/1.8**
	I	**5/1.2**	**5/1.8**	**2/1**
Delivered anesthetic flow, $F_{AD}= C_S (1-C_S)^{-1} F_G$, mL/min	S	21	26 (max 42)	31 (max 84)
	I	13	26	20 (max 53)

On the other side, the mentioned problems may be solved by using a perfect vaporizer that would be accurate as a plenum vaporizer, simple and low-resistant as a draw-over one. During induction of anesthesia (about 3 minutes) such a vaporizer installed IN the breathing circuit would enrich the entire inspired mixture at any fresh gas flow. For example, at a minute ventilation (MV) of 5 L/min and a vaporizer setting of 4 vol % the delivered anesthetic flow would be **200** mL/min instead of **13-42** mL/min of any VOC at the mini fresh gas flow (see Table 1).

An attempt to regularize the governing processes (gas flow, mass and heat transfer) within the laminar flow regime enabled us to design new low-resistant vaporizers (pocket MINIVAP-20 and stationary MINIVAP-100, **Fig. 1, 2**), which are capable of dosing out anesthetics at a flow range of 0.2-15 $L \cdot min^{-1}$ just like plenum vaporizers **[11, 12]**.

Technical data of the new vaporizers and analogous devices are shown in Table 2.

Table 2

Novel Low-Resistance Vaporizers and its Plenum and Draw-Over Analogs

Parameters	**Vapor 2000** Drager Germany	**Delta**	**OMV**	**MB-100**	**MB-20**
		Penlon UK		"MINIVAP" Ltd. Russia	
Gas flow range, L/min	0,25 – 15	0,2–15	3-15	0,2-15	0,2-10
Temperature range, °C	10 – 40	15– 35	18-22	5 - 35	
Atmospheric pressure, kPa	100 ± 5	100 ± 5		70 - 110	
Anesthetic volume, mL	360	250	50	150	40
Wick volume (waste), mL	60	60	10	5	3
Pressure drop at 10 L/min, mm H_2O	1100	1000	10	20	10
Angle of tilt, degrees	30	10	30	90	180
Weight, kg	6,5 – 8,5	5,7	2	1,5	0,5

MINIVAP vaporizers conform to relevant Russian and international standards including F1850-00 "Anesthesia Workstation and Their Components" and F1054-01 **"**Conical Fittings".

Results

We compared the delay, i.e. time **(T)** needed to change inspired anesthetic concentration using MINIVAP-20 vaporizer at OUT and IN positions of the breathing circuit of Drager (Primus), STEPHAN (Artec), Datex-Ohmeda (S/5 Avance), and Ru PMT (Xena-010) anesthesia machines (we used a bag or bellow instead of a patient). According to Conway`s formula **[1]**

$$\mathbf{T = V_C \cdot F_G^{-1}} \qquad \mathbf{(1)}$$

Example 1. ***VOC.*** *The concentration delivered by the vaporizer is diluted by the gas already contained in the circuit. At the best, (without a stagnant area) the delay* ***(T)*** *was* ***> 10 min*** *(at $V_C \approx 5$ L and $F_G = 0.5$ L/min). After this time inspired, expired and delivered vaporizer concentrations will be approximately equal (within the tolerances).*

***VIC.** The MINIVAP-20 vaporizer is installed between the inspired fitting 22M and the corrugated tube (volume $V_T \approx 0.4$ L) of any anesthesia machine **(Fig. 2)**. The delay was much less (**Fig. 3**)*

$$T = V_T \cdot MV^{-1} < 5\ s \quad (2)$$

But in this case the anesthetic inspired concentration C_I will be much higher than the scale one C_S at a high minute ventilation and fresh gas flow **[13, 5]**

$$C_I = C_S\ (1-C_S)^{-1}\ MV \cdot F_G^{-1} \approx C_S\ MV \cdot F_G^{-1} \quad (3)$$

Anesthetic gas analyzers or Riken indicator with a water vapor absorber were used in all cases of VIC circulation systems.

MINIVAP vaporizers were successfully tested in two leading Moscow hospitals (more than 100 anesthesias delivered to adults and children aged 2 to 14 years, Tables 3, 4).

Routine anesthetic equipment and non-invasive monitoring were applied; readings were taken every minute during the surgical operation and every 2.5 or 5 min during maintenance of anesthesia.

Inspired and expired concentrations of CO_2, O_2, and N_2O, as well as sevoflurane, isoflurane, or halothane, and respiratory parameters (inhaled and exhaled gas volumes, minute ventilation, inspired and expired pressure) were monitored.

Non-invasive monitoring included electrocardiography with pulse monitoring, arterial blood pressure measurement, and pulseoxymetry.

Table 3

Patients` (adults) and anesthesia characteristics (Botkin Municipal Hospital)

Parameters	Urology	Surgery	Emergency surgery
Breathing circuit	Semi-closed (0.5-1 L/min), VIC	Semi-closed (1 L/min), VOC	Semi-closed, VOC and Semi-open
Anesthetic and duration of anesthesia (min)	Sevoflurane,90-150	Sevoflurane, 90-150	Isoflurane, 30-60
Blood loss, ml	100-2000	700-2000	100
Age	44-76	57-68	19-45
Number of patients	45	2	5

Table 4

Patients` (children) and anesthesia characteristics (Filatov Children’s Hospital)

Parameters	Cystoscopy	Injuries (low-invasive)	Adenotomy and/or Tonsillectomy
Breathing components	Facemask	Laryngeal mask airway	Microlaryngeal tube
Breathing circuit	Semi-open (6 L/min)	Semi-open (6 L/min)	Semi-closed (0.5-1 L/min), VIC
Breathing	Spontaneous	Spontaneous	Artificial lung ventilation
Anesthetic and duration of anesthesia (min)	Sevoflurane or isoflurane, 15-20	Isoflurane or halothane, 30-60	Halothane or sevoflurane, 30-50
Age	9-14	10-14	2-8
Number of patients	13	15	64

There is depth of anesthesia III_1 to control the administration of anesthetic drugs.

*Example 2. A 5-year-old child (body weight 20 kg) had adenotomy under endotracheal anesthesia. After induction (N_2O/O_2 = 2:1 + halothane $C_S = C_I$ = 3 vol %) with a high F_G = 6 L/min during 2 min, tracheal intubation was performed and artificial lung ventilation was carried out throughout the anesthesia (tidal volume= 160 ml, rate = 17 cycles/min, MV = 0.16x17 = 2.7 L/min). Maintenance: N_2O/O_2 = 2:1 + halothane C_S = 0.3 % with F_G = 1 L/min and MINIVAP-20 vaporizer **IN** the semi-closed circuit of Primus anesthesia machine. In that case the inspired concentration, as follows from equation **(3)**, was $C_I \approx 0.3 \cdot 2.7 / 1 \approx 0.8$ vol %. In case of the minimal F_G = 0.5 L/min, the vaporizer scale mark would be set as $C_S \approx 0.8 \cdot 0.5 / 2.7 \approx 0.15$ vol %.*

Monitored inspired anesthetic concentration matched the calculated one with a total tolerance <0.45 *vol.%*, n = 34 (equation **3**).
No complications or adverse reactions were observed (n = 114).
To deepen anesthesia quickly without increasing fresh gas flow, the vaporizer handwheel should be set to the maximum and the delivered anesthetic flow will be

$$\mathbf{F_{AD} = C_S \cdot MV} \qquad \textbf{(4)}$$

*Example 3. According to the data from Example 2 and C_S = 3 %, maximum **VIC** delivered anesthetic flow F_{AD} = 0.03 x 2700 = 81 sm^3/min during **0.5 min.** After that the handwheel was set back to C_S = 0,3 % with $C_I \approx$ 0.8 vol %.*
*The delay (see **Fig. 3**) $T = V_T / MV \approx 0.4 / 2.7 \approx$ **0.15 min < 10 sec**.*
*To deliver to a patient the same anesthetic vapor volume at F_G =0.5 L/min, the **VOC** should at first fill up the circuit volume V = 5 L during T_1 = 5 / 0.5 = **10 min**) and after that work during T_2 = **2.7 min**.*

*The total work time of the **VOC** $T_\Sigma \approx$ **13 min** compared with **0.5 min** of the **VIC**.*
*The actual delay of **VOC** systems is much longer because anesthetic uptake by the patient.*

To improve the efficiency of xenon anesthesia in surgical practice (allowed by the resolution of the Russian Health Ministry No. 363, 1999), a total of 22 laboratory tests with xenon and isoflurane combined anesthesia have been performed.

*Example 4. Anesthesia was delivered to a dog weighing 25 kg. A "MINIVAP-20" vaporizer was installed **OUT** of the closed circuit of Artec (STEPHAN) anesthesia machine. After stabilizing the **Xe:O₂** ratio (70:30) the Xe flow was increased to 50-70 ml/min and the O_2 flow was increased 10% above the initial level. When Xe inspired concentration decreased to 50-60 vol.% owing to the N_2 tissue elimination, we delivered isoflurane (4 times 2 minutes each during a 2-hour anesthesia with the fresh gas flow=0.25 $L \cdot min^{-1}$ and the vaporizer set to 3 %). The inspired isoflurane concentration was stabilized at 0.3-0.5 vol %, and expired one at 0.25-0.4 vol %.*
The calculated consumption of liquid anesthetic by MINIVAP-20 during 2-hour anesthesia

$$F_{AD} = 5.1\, F_G\, T\, C_S\, (1- C_S)^{-1} = 0.64\ ml = 0.96\ g \qquad \textbf{(5)}$$

corresponds to the vaporizer mass difference of 1.2 g measured before and after the anesthesia (differential tolerance = 0.3 g).
*There were the same results when the "MINIVAP-20" vaporizer was installed **IN** the closed circuit of Russian PMT (Xena-010) anesthesia machine.*

Consumption of liquid anesthetic by MINIVAP vaporizer corresponds to the calculation equation **(5) [13, 14]**: at high fresh gas flow (6 L/min) it is about 20 ml/hour, while during mini- or low-flow anesthesia (0.5-1 L/min) it does not exceed 5-10 ml/hour, and in a closed system it is about 1-3 ml during 1-5 hours.
There is a minimum anesthetic wick waste: 3 ml of the MINIVAP-20 compared with 60 ml of the popular analogs (Table 2).

Anesthesia machine modifications

Due to the low resistance and virtual independence from fresh gas flow rate, temperature, and ambient pressure, MINIVAP vaporizers are instantly adaptable to needs of both on-site emergency surgery and more sophisticated demands of a general hospital.

Field conditions

The MINIVAP Anesthesia Kit may be used in military surgery, urgent situations and remote areas, at district hospitals, and in veterinary anesthesia:

- at spontaneous breath and artificial respiration with air or oxygen **(Fig. 6)**;
- with a low pressure oxygen source (concentrator);
- with "to-and-fro" and circle absorption systems;
- during Auto Analgesia **[15]**.

The simplest modification (see **Fig. 6**) is the pocket vaporizer MINIVAP-20 (mass < 0.5 kg) that can be connected directly to a facemask or a tracheal tube by means of a non-rebreathing valve.

Hospital conditions

The vaporizer may be used **OUT** of the breathing circuit (VOC) instead of any other vaporizer at convenient fresh gas flow from 0.2 to 10 l/min **(Fig. 8)**.

MINIVAP-20 may be installed **IN** the breathing circle of any anesthesia machine **(Fig. 7)**.

It is possible to instantly switch over between **In** and **Out** positions of MINIVAP-20 with a special controller **(Fig. 9), [16, 17]**.

Conclusions

1. Due to the low resistance and virtual independence from fresh gas flow rate, temperature, and ambient pressure, MINIVAP vaporizers are instantly adaptable to needs of both on-site emergency surgery and more sophisticated demands of a general hospital.
2. MV-20 vaporizer may be installed either IN a conventional breathing circuit (instant change of inspired concentration) or OUT of breathing circle (high safety) of any anesthesia machine.
3. Delay in changing the anesthetic inspired concentration VIC of closed and semi-closed systems 10-100 times smaller than the VOC.

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Illustrations

Fig. 1 – Vaporizers “MINIVAP-20”.

Fig. 2 – Vaporizers “MINIVAP-100”.

Fig. 3 – Time of inspire anesthetic concentration change (delay) from 0,5 to 1 vol % in semi-closed circles after alteration of the vaporizer setting. (“patient” – bag or bellow)

C_{VIC} – inspired concentration with VIC (MINIVAP-20, MV = 5 L/min, V_T = 0.4 L);

$C_{VOC\,2}$, $C_{VOC\,1}$, $C_{VOC\,0,5}$ - inspired concentrations with VOC (V_C = 5 L, F_G = 2; 1 and 0,5 L/min accordingly).

Fig. 4 – Delivered concentration of the “MINIVAP-20” vaporizer in flow range.

Fig. 5 – Inspired sevofluran concentration of MINIVAP-20 vaporizer in the open circuit: the vaporizer inlet is open, the outlet is connected with a self-inflating bag (C1 = V + B); the vaporizer inlet is connected with a self-inflating bag, the outlet is connected directly to a non-rebreathing valve (C2 = B + V, see Fig. 6).

Fig. 6 - “MINIVAP” Anesthesia Kit (open circuit at spontaneous breathing and with self-inflating bag).

Fig. 7 – 8. “MINIVAP-20” IN and OUT of the circuit of an Anesthesia Machine.

Fig. 9 - Instant switching over In to Out position of “MINIVAP-20” with the special Valve.

Fig. 1 (M 1:1)

Fig. 2 (M 1:3)

Fig. 6

Fig. 7

Fig. 8

Fig. 9

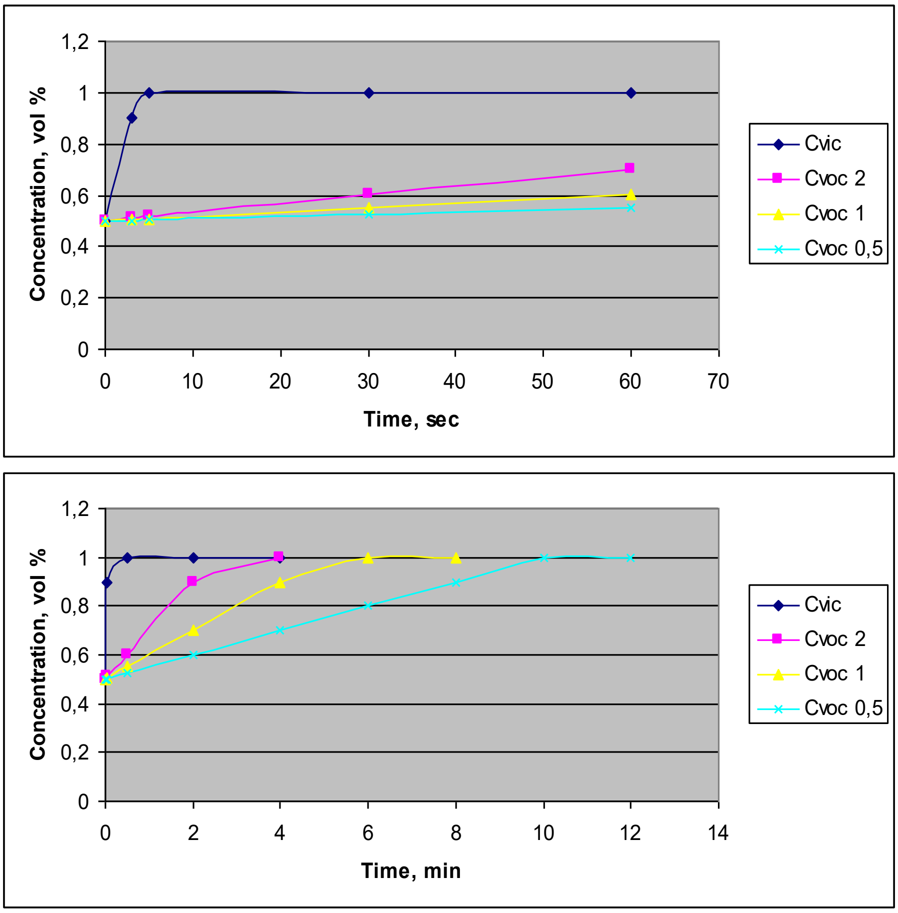

Fig. 3

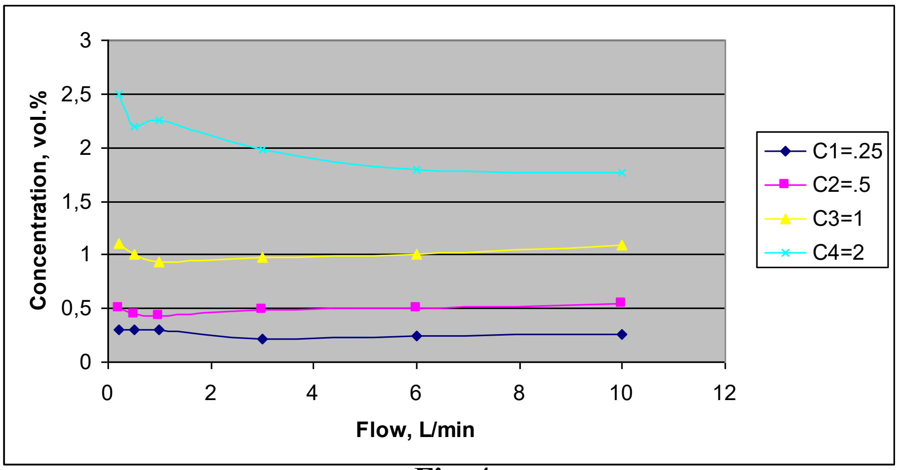

Fig. 4

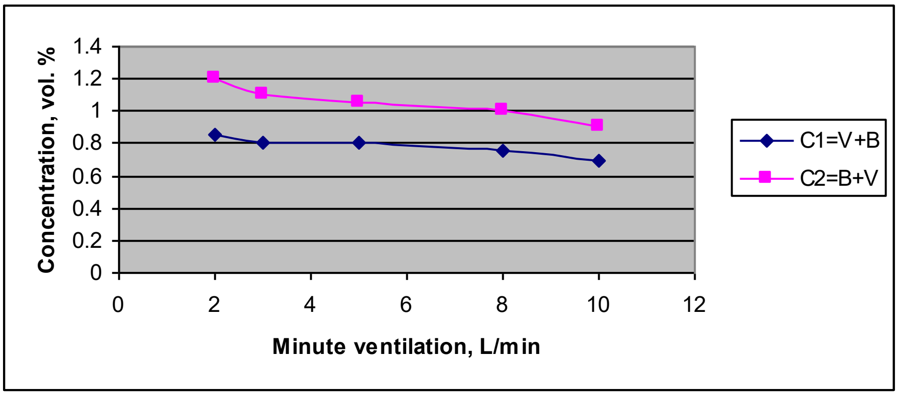

Fig. 5