Title: SEMI-CLOSED HALOTHANE ANESTHESIA BY HIGH FREQUENCY VENTILATION

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Introduction. High frequency ventilation (HFV) has been applied to various surgical procedures under general anesthesia, yet most cases reported in the past were performed by jet ventilation and intravenous anesthesia with nitrous-oxide. A nomogram to estimate the ventilatory volume required for HFV was described by Borg et al.[1] but it can be used only for the respiratory rate of 60 breaths per minute. In the present study, HFV was applied to semi-closed halothane anesthesia and a ventilatory standard calculated by us which was applicable from low respiratory rates to HFV was provided.

Methods. Sixteen adult patients were ventilated at respiratory rates of 14, 40, 80, 120, 160 and 200 bpm during halothane-nitrous oxide general anesthesia for various surgical procedures. Informed concent and institutional approval for the study were obtained. A Nuffield 200 ventilator (up to 80 bpm, I:E ratios of 1:1-1:2) or a HF ventilator designed by us (up to 200 bpm, I:E ratios of 1:3-1:4) were connected to various makes of anesthesia machines via a corrugated tube of internal volume of 600 mL to prevent the ventilator gas from entering the anesthesia circle. Both ventilators were operated with a Inspiron® exhalation valve and jet ventilation was not employed. A co-axial tube (Mera F-respiratory circuit®) was used instead of regular corrugated tubes to reduce compressible gas volume in the anesthesia circuit. A Wright respirometer was attached to the endotracheal tube and patient's exhalation volume was monitored and adjusted to the value of our ventilatory standard based on body weights. The ventilatory standard was calculated by the following equations:

$$\dot{V}_E = \frac{(\dot{V}_{Ae}+ V_Df) + \sqrt{(\dot{V}_{Ae}+ V_Df)^2 - 4r_A\dot{V}_{Ae}V_Df}}{2} \quad (1)$$

$$\dot{V}_{Ae} = \dot{V}CO_2/(1-r_A)PaCO_2/713 \quad (2)$$

where
$\dot{V}_{Ae}$: effective alveolar ventilation (mL/min)
V_D: anatomical dead space (mL)
f: respiratory rate
r_A: alveolar dead space ratio $(0<r_A<1)$
$\dot{V}CO_2$: CO_2 production (mL/min)

End-tidal PCO_2 ($P_{ET}CO_2$) was monitored by two types of infrared CO_2 analysers; DATEX with a sampling tube (slow response) and SIEMENS 130 with a sensor attached directly to the endotracheal tube (quick response). Airway pressure (Paw) was monitored by a regular pressure gauge. Radial arterial blood gas was analysed. Measurements were done 30 minutes after changing respiratory rates.

Results. Table 1 shows the results. $PaCO_2$ was maintained at normal level between 33.5 and 38.2 torr (mean values) by our ventilatory standard up to 200 bpm. Normal PaO_2 corresponding to F_IO_2 was obtained. $P_{ET}CO_2$ fell significantly at respiratory rates above 80 bpm by DATEX CO_2 analyser and above 120 bpm by

SIEMENS 130. The peak airway pressure (peak Paw) showed the lowest value at rate of 40 bpm. With I:E ratios of 1:1-1:2, peak Paw rose signigicantly at rate of 80 bpm while with 1:3-1:4 it rose at rates above 120 bpm. With I:E ratios of 1:1-1:2 min Paw was elevated to 9.9±1.8 cmH2O at 80 bpm while with 1:3-1:4 it remained 7.7±2.6 cmH2O at 200 bpm.

Table 1

RR	PaCO2 (torr)	P_ET CO2 (torr)		peak Paw (cmH2O) I:E ratio	
		DATEX	SIEMENS	1:1-1:2	1:3-1:4
14	35.1±4.2	29.4±3.1	30.8±3.0	12.2±1.1	10.5±2.1
40	33.7±5.6	27.3±5.0	30.1±6.1	9.1±2.1*	8.1±1.0**
80	33.5±5.7	16.8±5.4**	29.3±5.7	16.1±6.2**	9.8±1.7
120	33.6±6.6	-	22.3±4.2	-	14.1±2.7**
160	35.4±6.7	-	17.0±2.1**	-	18.0±4.0**
200	38.2±7.7	-	15.0±1.3**	-	20.4±5.3**

Mean ± SD
Statistical significance was tested against 14 bpm;
* p<0.05, ** p<0.01

Discussion. It has been mentioned by many investigators that HFV could not be performed with a ventilatory system having large compressible gas volume. In the present study, however, halothane-nitrous oxide anesthesia by HFV was maintained successfully and safely with regular semi-closed anesthesia circles by driving by HF ventilators up to 200 bpm. This result suggests that compressible gas volume can be compensated by delivering enough volume of gas from HF ventilators. The result that normal $PaCO_2$ can be maintained at each respiratory rate suggests that our ventilatory standard is applicable in the range from low rates to HFV. The ventilatory standard was derived based on conventional concept of ventilation and this suggests that the conventional ventilatory mechanism might be applied well at least up to 200 bpm. Patient's exhaled volume could be measured well by a regular Wright respirometer at HFV. It is shown that the end-tidal PCO_2 at HFV should be determined by a CO_2 analyser which equips a sensor attached directly to the endotracheal tube, such as SIEMENS 130, though even this type of machine causes a lower CO_2 reading than actually exhaled PCO_2 due to the limitation of operation principle of the machine at rates above 120 bpm. The I:E ratios larger than 1:3 is preferable to reduce the rise in airway pressure caused by air-trapping at HFV.

References.
1. Borg U., Eriksson I. and Sjöstrand U.: High-frequency positive-pressure ventilation (HFPPV); A review based upon its use during bronchoscopy and laryngoscopy and microlaryngeal surgery under general anesthesia. Anesth. Analg. 59; 594-603, 1980