Capnographic detection of anaesthesia circle valve malfunctions

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To determine whether capnographic waveforms can characterize valve malfunction of the anaesthesia circle, which would enable such problems to be identified and rectified immediately, we monitored capnographic respiratory waveforms during anaesthesia with simulated circle valve malfunctions. Ten mongrel dogs were anaesthetized with pentobarbitone, 25 mg·kg^{-1} IV, and halothane, 0.5 to 1 per cent. Respiratory gas was sampled from the elbow of the circle system for capnographic monitoring. At fresh gas flow rates of 2.5 or 5 L·min^{-1} during consecutive periods of controlled and spontaneous ventilation, the inspiratory valve, the expiratory valve, or both valves of the circle system were opened for 15 min. Inspired CO_2 concentration increased significantly every time a valve was opened, except during spontaneous breathing at 5 L·min^{-1}. At 2.5 L·min^{-1}, inspired CO_2 increased from baseline to 0.41 ± 0.28 per cent with the inspiratory valve opened and to 2.22 ± 1.72 per cent with the expiratory valve opened during controlled ventilation and to 0.43 ± 0.20 per cent and 2.02 ± 1.28 per cent, respectively, during spontaneous ventilation. Inspired CO_2 increased to almost 1 per cent when the inspiratory valve was open and to ≥ 1.89 per cent when the expiratory valve was open. The effects with the expiratory valve open and with both valves open were similar. Capnograms were affected in characteristic ways by the valve malfunctions.

Key words

CARBON DIOXIDE: measurement; COMPLICATIONS: accidents; EQUIPMENT: anaesthesia circle valves; MEASUREMENT TECHNIQUES: capnography; MONITORING: carbon dioxide, ventilation. VENTILATION.

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Capnographic waveforms in one reported case led to the discovery of malfunction of an expiratory valve of the circle system during anaesthesia.[1] This experience suggested that certain malfunctions in the anaesthesia circle system likely have a consistent effect on respiratory values. Therefore, since capnography portrays respiratory CO_2 in a reproducible fashion, perhaps circle system malfunctions would be characterized by particular types of capnographic waveforms. If this were the case, capnography would enable valve malfunctions to be identified and rectified more rapidly than would be possible by trying to detect trends in one or more sets of numerical data. Indeed, the pattern of the contamination with expiratory gases is constant. This change would enable the anaesthesiologist to determine the possibility of a valve leak before changes in the patient's gases were dramatic or before adjustments in flow would be necessary to compensate for the admixture of the gases.

We designed a study to evaluate capnograms during various ventilatory conditions commonly used during anaesthesia.

Methods

Ten mongrel dogs weighing 15 to 20 kg were anaesthetized with pentobarbitone, 25 mg·kg^{-1} IV, and their tracheas intubated with an 8.0 mm Hi-Low jet tracheal tube (National Catheter Co., Argyle, Wis.), which has a sampling port in the middle of the tube. An arterial line was placed percutaneously into the femoral artery for blood gas analysis (IL 713 Blood Gas Analyzer, Instrumentation Laboratories, Lexington, Mass.). The dogs were connected to a standard anaesthesia circle system and anaesthesia was maintained with 0.5 to 1.0 per cent halothane in 30 per cent O_2 and 70 per cent nitrogen throughout the experiment. For part of the study, animals were paralyzed with pancuronium, 0.1 mg·kg^{-1}, and ventilation was controlled (Ohio Anesthesia Ventilator, Ohio Medical Products, Madison, Wis.) to keep $PaCO_2$ at 40 mmHg.

For respiratory gas monitoring, gas was sampled from the elbow of the circle system and the mid-cuff port of the endotracheal tube and was routed to a capnograph (Godart-Statham, Bilthoven, Holland); CO_2 waveform tracings were made with a 7D recorder (Grass Instrument

TABLE Inspired and expired CO_2 and $PaCO_2$ during controlled and spontaneous ventilation with malfunctioning valves in 10 dogs

Mode of ventilation	*Inspiratory valve*		*Expiratory valve*		*Both valves*	
	Control	*Opened*	*Control*	*Opened*	*Control*	*Opened*
Controlled						
2.5 L·min^{-1}						
Inspired CO_2 (%)	0.01 ± 0.04	0.41 ± 0.28	0	2.22 ± 1.72	0	2.45 ± 1.64
Expired CO_2 (%)	3.90 ± 0.43	5.22 ± 0.79	4.35 ± 0.56	6.58 ± 0.97	4.65 ± 0.66	6.89 ± 1.32
$PaCO_2$ (mmHg)	42.4 ± 3.9	50.9 ± 6.1	44.3 ± 5.7	57.1 ± 6.1	45.6 ± 6.5	59.4 ± 7.6
5 L·min^{-1}						
Inspired CO_2 (%)	0	0.62 ± 0.68	0	1.89 ± 1.67	0.03 ± 0.08	0.89 ± 0.72
Expired CO_2 (%)	4.03 ± 0.53	5.39 ± 1.54	3.71 ± 0.61	5.63 ± 1.09	3.87 ± 0.69	4.88 ± 0.86
$PaCO_2$ (mmHg)	40.6 ± 4.4	50.5 ± 8.5	39.9 ± 6.2	50.0 ± 7.8	39.8 ± 4.9	46.7 ± 5.6
Spontaneous						
2.5 L·min^{-1}						
Inspired CO_2 (%)	0.08 ± 0.10	0.43 ± 0.20*	0.07 ± 0.10	2.02 ± 1.28*	0.05 ± 0.08	1.70 ± 1.28*
Expired CO_2 (%)	4.78 ± 0.70	5.53 ± 0.88	4.87 ± 0.76	5.75 ± 0.80*	4.85 ± 0.58	5.78 ± 1.16*
$PaCO_2$ (mmHg)	43.6 ± 3.6	48.1 ± 4.0*	45.0 ± 5.5	48.7 ± 7.2*	43.4 ± 5.4	50.9 ± 6.8*
5 L·min^{-1}						
Inspired CO_2 (%)	0.05 ± 0.06	0.73 ± 0.4	0.13 ± 0.05	2.18 ± 2.01	0.20 ± 0.14	1.90 ± 1.83
Expired CO_2 (%)	5.25 ± 0.81	5.60 ± 1.34	5.32 ± 0.95	6.30 ± 1.24*	5.45 ± 0.87	6.00 ± 0.49
$PaCO_2$ (mmHg)	44.2 ± 5.8	47.8 ± 8.8	45.0 ± 7.1	52.1 ± 6.0*	47.8 ± 5.4	51.1 ± 4.9*

Co., Quincy, Mass.). The anaesthetic circle system studied consisted of a fresh gas inlet upstream from the inspiratory valve and downstream from the absorber. Hence gas would collect in the absorber and the components between the expiratory unilateral valve and the absorber. This system is the one most commonly used, although other systems are possible and mixing of expired gases are possible at different locations.

With each dog, spontaneous and controlled ventilation at fresh gas flow rates of 2.5 and 5 L·min^{-1} were applied in random order with the anaesthesia circle system intact for 15 min and with valve malfunctions simulated by propping open either the inspiratory or expiratory valve or both valves. After 15 minutes of each condition, capnograph waveforms were recorded and blood was sampled for gas analysis. Values were allowed to return to baseline with both valves functioning after each test. Data were analyzed by analysis of variance with Duncan's test or with least significant difference, pairwise *t* test; analysis was performed by the Statistical Analysis System (SAS Institute, Cary, NC) on an IBM PC computer.

Results

The effect of the valve malfunctions followed a consistent pattern (Table) that was reflected in the capnogram waveforms (Figure). With the inspiratory valve open, the waveform plateau was prolonged. Waveforms with the expiratory valve and with both valves opened were similar – waveforms never returned to baseline and the plateau was elevated ($p < 0.05$). All three types of malfunction elevated expired CO_2 to similar levels ($p > 0.05$). Inspired CO_2 levels differed by type of malfunction; values with the expiratory valve and both valves opened were similar and were higher than expired CO_2 levels ($p < 0.05$).

Comparison at different flow rates did not show any significant differences nor did a comparison of spontaneous and controlled ventilation. Expired CO_2 levels were all higher than control values but did not differ from each other.

Discussion

The function of valves in the anaesthesia circle system is to eliminate rebreathing. If these valves remain closed, the effect of the malfunction is obvious and readily detected because gas flow is completely obstructed. The effect of inappropriate opening of valves is not as obvious and, once the effect manifests, discovering the problem may take additional time.

Using a capnograph to detect anaesthesia ventilation malfunctions has been inferred in several sources,[2,3] but the magnitude of the malfunction has not been quantitated. Our study shows that capnograms portray a consistent problem and may enable the problem to be corrected almost as soon as it occurs. Increases in end-expiratory CO_2 could be caused by hypoventilation, hence, according to our data, the inspiratory CO_2 waveform would give more information about valve leaks.

In this study, capnograms reflected valve malfunc-

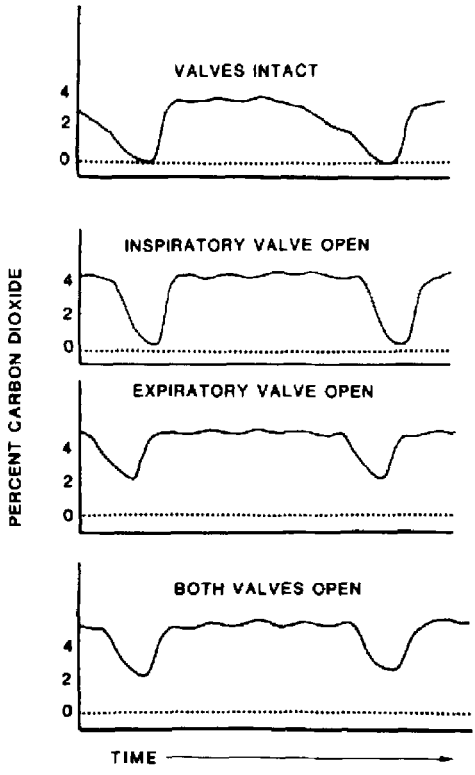

FIGURE Capnograms obtained with an anaesthesia circle system with the inspiratory or expiratory valve or both valves opened compared with capnogram when valves are functioning normally. Note the prolonged plateaus with all malfunctions.

tions, which indicates that capnographic waveforms enables rapid correction of malfunctions before adverse effects occur.

References

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Résumé

Afin de déterminer si l'onde obtenue par capnographie peut détecter un malfonctionnement des valves du circuit anesthésique permettant une correction immédiate, on a étudié ces tracés durant l'anesthésie en simulant un malfonctionnement de ces valves. Dix chiens bâtards ont été anesthésiés avec du pentobarbital, 25 mg·kg^{-1} IV et de l'halothane 0.5 à 1 pour cent. Les gaz ont été échantillonnés du coude du circuit pour étude capnographique. Des flots de gaz frais de 2.5 à 5.0 L·min^{-1} durant des périodes consécutives de ventilation contrôlée et spontanée, la valve inspiratoire, la valve expiratoire ou les deux valves du circuit ont été ouverts pour 15 minutes. Les concentrations de CO_2 inspirées augmentèrent significativement à chaque fois que la valve était ouverte, excepté lors de la respiration spontanée à 5 L·min^{-1}. A 2.5 L·min^{-1} le CO_2 inspiré augmenta de la ligne de base à 0.41 ± 0.28 pour cent quand la valve inspiratoire était ouverte et à 2.22 ± 1.72 pour cent quand la valve expiratoire était ouverte lors de la ventilation contrôlée et à 0.43 ± 0.20 pour cent et 2.02 ± 1.28 pour cent respectivement, durant la ventilation spontanée. Le CO_2 inspiré augmenta jusqu'à environ 1 pour cent quand la valve inspiratoire était ouverte et à ± 1.89 pour cent quand la valve expiratoire était ouverte. Des résultats similaires furent obtenus avec la valve expiratoire ouverte et avec les deux valves ouvertes. La capnographie était caractéristique lors des malfonctionnements de valve.