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Soda lime temperatures during low-flow sevoflurane anaesthesia and differences in dead-space

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Background: Sevoflurane degrades during low-flow anaesthesia to compound A, and high carbon dioxide absorbent temperatures cause increased degradation. The purpose of this investigation was to determine if larger tidal volumes, without increasing alveolar ventilation, decrease the temperature in the carbon dioxide absorber during low- and minimal-flow sevoflurane anaesthesia.
Methods: Prospective, randomized study, including 45 patients (ASA 1–2), scheduled for elective general or urology surgery. The patients were randomly assigned to one of three treatments. Patients in group 1 (NDS) received fresh gas flow of 1 litre/min without using additional dead-space volumes. In group 2 (DS + 1.0), the patients received fresh gas flow of 1 litre/min using additional dead-space volumes, placed between the Y-piece and the HME, and patients in group 3 (DS + 0.5) received the same technique with a fresh gas flow of 0.5 litre/min. The soda lime temperatures, dead-space volumes, end-tidal carbon dioxide, sevoflurane concentrations, ventilation volumes and pressures, absorbent weight and ear temperatures were measured.
Results: The maximum temperature of the soda lime was 44.1 ± 1.1°C in the NDS group, 37.8 ± 0.8°C in the DS + 1.0 group and 38.5 ± 2.7°C in the DS + 0.5 group ($P<0.0001$). The dead-space volume between the Y-piece the tracheal tube was 164 ± 69 ml in the DS + 1.0 group and 196 ± 15 ml in the DS + 0.5 group ($P<0.05$). The ventilator pressure were higher in the DS groups compared with the NDS group ($P<0.001$). Soda lime weight increased in all groups. End-tidal carbon dioxide, sevoflurane concentrations and ear temperatures were similar between the groups.
Conclusion: Increasing dead-space volumes can reduce carbon dioxide absorber temperature during low- and minimal-flow sevoflurane anaesthesia.

Keywords: anesthesia; anesthetics; carbon dioxide absorber; rebreathing circle circuit; sevoflurane; volatile.

IT IS IMPORTANT to find ways of minimizing the factors affecting compound A production, still using low-flow sevoflurane anaesthesia, in order to reduce costs. Several investigators have studied the production of the degradation products of sevoflurane using carbon dioxide absorbents under various conditions (1–3), and demonstrated that fresh gas inflow rate and carbon dioxide production plays a major role of the absorber temperature. When the temperature of the carbon dioxide absorbent is increased, the production of the degradation products is also known to increase (4–11). Low fresh gas flows of sevoflurane are associated with increased temperature in the carbon dioxide absorbent since there is a decrease in the conduction of heat and moisture away from the circle system (4, 5). An increase in temperature from the carbon dioxide production is also a consequence of the accumulation of heat from the exothermic reaction converting carbon dioxide to carbonate (11).

The purpose of this investigation was to determine whether it was possible to reduce the carbon dioxide absorbent temperature when low- and minimal fresh gas flow sevoflurane anaesthesia was used. To accomplish this, the soda lime temperatures were compared to that obtained when an adjustable tube (dead-space volume) (Fig. 1) was placed between the Y-piece and the heat and moisture exchanger. The hypothesis was that larger tidal volumes, without increasing alveolar ventilation, might decrease the temperature of

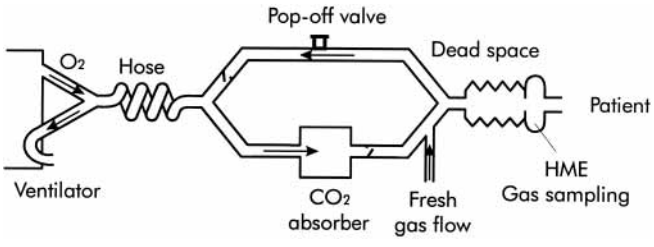

Fig. 1 The low-flow system used in the present study.

the carbon dioxide absorber. We also measured and compared dead space volumes, end-tidal carbon dioxide and sevoflurane concentrations, ventilation volumes and pressures, the absorbent weight and the ear temperature.

Methods

The Ethics Committee approved the study at the University of Lund, Sweden, and written informed consent was obtained from all patients. We studied 45 patients, ASA physical status 1 and 2 scheduled for elective general or urology surgery with sevoflurane for anaesthesia and an anticipated anaesthesia time of 2-h duration or greater. Patients were excluded from the study with a history, laboratory, or physical examination evidence of hepatic, renal, or significant cardiovascular disease. The patients were randomly assigned to one of three treatment groups. Patients in group 1 (no dead-space, NDS) received fresh gas flows of 1 litre/min without using additional dead-space volumes. In group 2 (dead-space, DS + 1.0), the patients received fresh gas flows of 1 litre/min using additional dead-space volumes, and patients in group 3 (DS + 0.5) received the same technique with a fresh gas flow of 0.5 litre/min.

The patients were premedicated with midazolam 7.5 mg rectally 30 min prior to arriving at the operating room. Anaesthesia was induced by administration of 100% oxygen for 3–4 min followed by 2 μg/kg fentanyl, 1.5–2.0 mg/kg propofol and muscle relaxation was produced with 1.0–1.5 mg/kg succinylcholine. Ventilation of the lungs was manually assisted with 100% oxygen via a circle breathing system (1.5 l volume), until tracheal intubation and connection to mechanical ventilation was performed with a Servo 900C ventilator (Siemens-Elema™, Sweden). The ventilator delivers the tidal volumes with oxygen into a large corrugated hose with 2.2 l internal volume (12). Fresh gas flow (60% nitrous oxide in oxygen) was supplied to the circle system with 4.5 l/min (1.5 l/min oxygen and 3.0 l/min nitrous oxide) during the first 5 min and then adjusted to 0.5 or 1.0 l/min with an end-tidal sevoflurane concentration of 1.3%. In group DS + 1.0 and DS + 0.5, an adjustable corrugated tube (dead-space volume of 50–220 ml) was placed between the Y-piece and the heat and moisture exchanger (HME) (Gibeck, Sweden, 35 ml dead space) (Fig. 1). In group NDS (control group) the fresh gas flow was 1.0 l/min, but no adjustable tube was used between the Y-piece and the HME. The lungs were ventilated in the DS + 1.0 and DS + 0.5 groups, with tidal volumes to withhold ventilator pause pressure (P_{paus}) between 14 and 15 cm/H_2O. The corrugated tube was then adjusted to maintain end-tidal CO_2 concentration of 34–35 mmHg. The ventilatory rate was 15/min, the inspiratory and pause time was 33 and 10%, respectively.

During the procedure routine monitoring included electrocardiogram (lead II), heart rate, non-invasive mean arterial pressure (MAP) and haemoglobin oxygen saturation (SpO_2). The inspired oxygen and end-tidal concentrations of sevoflurane, N_2O, CO_2 were monitored (Merlin™, Hewlett Packard) at one-minute intervals during the first 15 min of anaesthesia and thereafter at five-minute intervals through the study. Gases were sampled at the HME and analysed gas returned to a port fitted into the CO_2 absorber. Anaesthetic gases were delivered using a sevoflurane anaesthetic vaporiser (Penlon Sigma Elite™) and an AGA™ (Sweden) anaesthesia machine. Prior to each anaesthetic administration, fresh soda lime (Absorber, Anmedic, 15% water) was used. The soda lime weights were determined before and at 120 min of anaesthesia with a scale (Maul Tronic, Germany). The soda lime temperatures were monitored at every 15-min during the anaesthetic using a temperature monitor (CIE 303K™, Gibeck™, Sweden) and a temperature probe (Gibeck™, Sweden). To permit measurement of the temperature of the soda lime, a hole was made in the canister. We measured the temperature in the middle to lower part of the absorber, identically placed for each experiment. The temperature in the operating room was maintained at 23°C, and the patients' ear temperatures were measured before, at 60 and 120 min of anaesthesia. Additional doses of 1 μg/kg fentanyl were administered if mean blood pressure increased more than 20% of baseline and a similar decrease in blood pressure was treated with 5–10 mg ephedrine i.v. Neuromuscular block was achieved with 0.5 mg/kg atracurium i.v. Incremental doses of 0.1–0.2 mg/kg atracurium were given at two twitches achieved with a train-of-four stimulus. Residual muscle paralysis was reversed using i.v. glycopyrrolate and neostigmine. At the termination of the procedure, oxygen flow rate was increased to 6 l/min and spontaneous ventilation allowed returning. Following eye opening to command the tracheas were extubated.

All data are reported as mean values with variability expressed as SD. The temperature, dead-space volumes, weight of the soda lime, end-tidal sevoflurane and CO_2 concentrations, the ventilator pause pressure and tidal volumes were compared using repeated measures ANOVA where appropriate and Stu-

Table 1

Demographic data (mean ± SD).

	NDS	DS + 1.0	DS + 0.5
Age (year)	51 ± 19	57 ± 15	57 ± 20
Height (cm)	172 ± 7	171 ± 9	174 ± 8
Weight (kg)	76 ± 12	78 ± 13	75 ± 14
Male/female	8/6	7/8	8/8
ASA I/II	5/9	4/11	5/11

NDS = no dead-space volume; DS + 1.0 = dead-space with fresh gas flow of 1.0 l/min; DS + 0.5 = dead-space with fresh gas flow of 0.5 l/min.

dent's *t*-test. Gender and ASA were compared using X^2 test. *P*-values less than 0.05 were considered statistically significant.

Results

All surgical procedures had an anaesthesia time of more than 120 min. No intraoperative problems were noted during the study. The patients recovered from anaesthesia and were discharged from hospital in accordance with normal practice for the surgical procedure. There were no significant differences in demographic data between the groups (Table 1).

The maximum temperature of the soda lime was 44.1 ± 1.1°C in the NDS group, 37.8 ± 0.8°C in the DS + 1.0 group and 38.5 ± 2.7°C in the DS + 0.5 group ($P<0.0001$). At 120 min of anaesthesia the temperature of the soda lime had decreased to 43.4 ± 1°C in the NDS group, to 37.2 ± 1°C in the DS + 1.0 group and to 38.1 ± 3°C in the DS + 0.5 group ($P<0.0001$) (Fig. 2). The ear temperatures at 120 min of anaesthesia were 36.2 ± 0.2, 36.5 ± 0.3 and 36.4 ± 0.2°C, respectively.

The weight of the soda lime increased during anaesthesia in all groups. There was a significantly higher increase in the NDS group compared with the DS groups ($P<0.01$) (Table 2). The end-tidal sevoflurane concentration was kept constant throughout anaesthesia, being 1.3 ± 0.1% in all groups at 120 min of anaesthesia. The end-tidal CO_2 concentration was also kept constant throughout the anaesthesia and was 34.0 ± 0.0 mmHg in all groups at 120 min of anaesthesia.

The adjustable dead-space volume between the Y-piece and the HME was 164 ± 69 ml in the DS + 1.0 group and 196 ± 15 ml in the DS + 0.5 group. There were significant differences in dead-space volumes between the groups ($P<0.05$). The tidal volumes were significantly higher in the DS groups ($P<0.001$) compared with the NDS group (Fig. 3). The volumes, between 30 and 120 min of anaesthesia were relatively unchanged in the groups.

The pause ventilator pressures were significantly higher in the DS groups compared with the NDS group ($P<0.001$). The pause ventilator pressure was 14.7 ± 2.2 cm H_2O in the DS + 1.0 group at 120 min of anaesthesia, 14.6 ± 1.7 cm H_2O in the DS + 0.5 group and 11.4 ± 3.2 cm H_2O in the NDS group.

Discussion

We tried an easy, practical way to reduce the temperature of the soda lime, i.e. by increasing the tidal volume with unchanged CO_2 elimination. This was done by adding a dead-space volume, the adjustable tube, between the Y-piece and the HME. Probably will larger circle system volume with an unchanged end-tidal CO_2 concentration, decrease the temperature of the absorber. A possible explanation of the decreased temperatures is that the minute ventilation through the absorber is increased with the additional dead-space volumes. In the NDS group, the total flow through the absorber is approximately 6.75 l/min (M_v = (450 ml*15) + FGF). In the DS + 0.5 group, the total flow is almost 11.25 l/min (M_v = (750 ml*15) + FGF) (Fig. 2). This higher flow is of importance to ex-

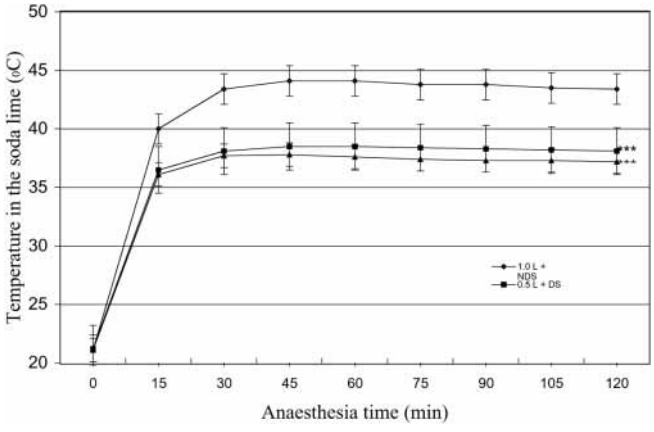

Fig. 2 Comparison of soda lime temperatures in the three groups. No dead-space (NDS) with fresh gas flow of 1.0 l/min, dead-space (DS + 1.0) with fresh gas flow of 1.0 l/min and dead-space (DS + 0.5) with fresh gas flow of 0.5 l/min. All values are expressed as mean ± SD.

Table 2

The soda lime weight at 0 min and 120 min of anaesthesia for the no dead-space volume (NDS) group with fresh gas flow of 1.0 l/min, dead-space volume (DS + 1.0) group with 1.0 l/min and dead-space volume (DS + 0.5) group with 0.5 l/min.

	NDS	DS + 1.0	DS + 0.5
Weight(g) 0 min	644 ± 21	643 ± 20	646 ± 17
Weight(g) 120 min	666 ± 23	661 ± 20	665 ± 17
Difference (g)	22 ± 3**	18 ± 2	19 ± 2

All values are expressed as mean ± SD. $P<0.01$.

plain a decrease in absorber temperature due to the conduction of heat and moisture away from the circle system.

In this study, the temperatures of the soda lime during low- and minimal-flow sevoflurane anaesthesia were measured when the extra dead-space volume was used during at least 2 h of anaesthesia. The mechanical control of ventilation in our study is achieved by using a corrugated hose instead of a bag-in-bottle system (Fig. 1). This is an old, safe and simple technique described by Berntman et al. (12). If leaks occur in the present system, nitrous oxide and the volatile agent will slightly decrease, while oxygen from the hose slightly increases into the circle circuit. There was no such system-related mishap over the 45 patients in the study. Our results showed that the temperature of the soda lime was significantly reduced ($P<0.0001$) when the dead-space volume was used. The maximum temperature of the soda lime in our study was 44.1 ± 1.1°C in NDS group with a fresh gas flow of 1.0 l/min, this corresponds well with the 44.8 ± 0.5 °C found by Bito et al. (4). Using the extra dead-space volume, we reduced the maximum temperature of the soda lime to 37.8 ± 0.8°C in the DS + 1.0 group and to 38.5 ± 2.7°C in DS + 0.5 group.

Fresh soda lime was used for each time anaesthesia was administered. This was done in an effort to obtain the highest temperature. The temperature decreased from the maximum found at 45–60 min of anaesthesia to the temperatures found at 120 min of anaesthesia (Fig. 2). The temperature decrease is probably due to the fact that a fresh new absorber will be exhausted over time and there will be an increase in humidity with a cooling effect of the CO_2 absorbent (13). In our study the soda lime starts at room temperature, which may not be the case if used sequentially on patients during a list of operations. However, the study design demonstrated the highest possible temperatures during normal clinical conditions at our department. Patients with significant cardiovascular disease were not included in the study with the aim that unchanged cardiac output and carbon dioxide production maintains the temperatures of the absorber. Variables influencing absorber temperatures such as demographic data, room and body temperatures did not differ among the groups. In addition, the determined absorber temperatures in this study present a gas tight function of the ventilator and circle system without drastic changes in ventilation or cardiac output.

The present method can be argued since we used additional dead-space volumes and increased tidal volumes with the possible risk for baro- and volotrauma. However, normally when patients are intubated, the anatomic dead-space is decreased. The method used in this study, with a maximum P_{paus} of 14–15 mmHg is in correspondence with a P_{paus} of 10 mmHg added with a positive end-expiratory pressure of 5 cmH_2O. This technique, using a positive end-expiatory of 5 cm H_2O is commonly used today in general anaesthesia.

The temperature probe was placed near the inlet centre of the absorber since earlier measurements have found the highest absorbent temperature here (16). The higher temperature of the soda lime in the DS + 0.5 group compared to the DS + 1.0 group is consistent with the fact that reduced fresh gas flow in-

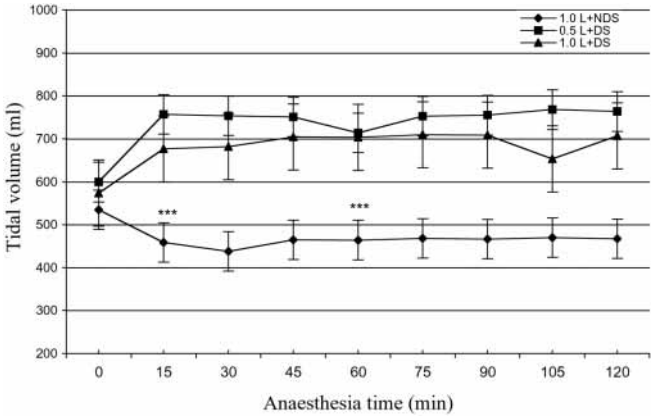

Fig. 3 Comparison of tidal volumes in the three groups. No dead-space (NDS) with fresh gas flow of 1.0 l/min, dead-space (DS + 1.0) with fresh gas flow of 1.0 l/min and dead-space (DS + 0.5) with fresh gas flow of 0.5 l/min. All values are expressed as mean ± SD.

creases the temperature (10, 15, 16). Thus, fresh gas flow is a part of inspiratory tidal volumes, decreased fresh gas flow will increase end-tidal partial pressure of carbon dioxide. In order to maintain the carbon dioxide concentration in the absorber, tidal and dead-space, volumes have to be increased. Since the increase in temperature of the soda lime is carbon dioxide dependent, we tried to keep the end-tidal concentration of carbon dioxide at the same level in all three groups.

The weight of the soda lime in the NDS group increased more than in the other two groups and indicates a higher chemical reaction due to carbon dioxide converting to carbonate. The soda lime temperatures between the DS groups are not statistically significant, although the values are in context with the possibility of a decreased wash out from the circle system when we decreased the fresh gas flow. We used fresh new absorbers with 15% water added. The present method demonstrated no dryness of the absorbent. In addition, the weights of the absorbers in the DS groups have increased almost to the levels of the other group, indicating a water content that preserves the moisture of the circle (13).

The HMEs used in this study may have influence of the water content in the circle system and some studies have indicated that HMEs may conserve the body temperature in children (15). However, using HMEs is routine in our department when using fresh gas flows of 1l/min during anaesthesia for at least 2 h. Further, Bengtsson et al. concluded that fresh gas flows of 0.5l/min is more sufficient to create heat and moisture than HMEs when higher inflow rates are used (16). Therefore in the present study, we limited the bias of different heat and moisture content in the circle system that could influence the absorber temperature. We also measured the body temperatures and there were no significant differences between the groups, which most probably did not affect the results of this study.

Current US Food and Drug Administration recommendations state that fresh gas flows of less than 1l/min with 2 MAC hour in a circle absorber system are not recommended. Earlier studies have shown a positive correlation between the compound A concentration and the temperature of the soda lime (7, 8, 13, 17). The effect of a lower temperature in inhibiting the sevoflurane degradation products is due to the effects of temperature on chemical reactions. Cooling the canister in an ice-water bath was effective in decreasing the concentration of compound A, but has been found to be impractical (7). Our results must be interpreted with caution because there is a difference in methods used compared to other studies. Compound A may still accumulate in the circle with decreased fresh gas flows. Further, apart from the study design, it is also of importance to consider the end-tidal concentration of sevoflurane and time of administration in production of breakdown products compared to the absorber temperatures.

This study suggests that there is a correlation between dead-space volumes and absorber temperatures during low- and minimal flow sevoflurane anaesthesia. Whether the use of additional dead-space volumes has influenced sevoflurane breakdown products is impossible to tell from this study. However, this study probably indicates a decreased degradation of the volatile anaesthetic, because the absorber temperature is decreased (18).

We conclude that increased dead-space volumes can reduce the absorber temperature during low- and minimal-flow sevoflurane anaesthesia.

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