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Desflurane consumption with the Zeus® during automated closed circuit versus low flow anesthesia

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Abstract : *Introduction :* During automated closed-circuit anesthesia (CCA), the Zeus® (Dräger, Lübeck, Germany) uses a high initial fresh gas flow (FGF) to rapidly attain the desired agent and carrier gas concentrations, resulting in a desflurane consumption well above patient uptake. Because both FGF and carrier gas composition can affect consumption, we determined the Zeus' agent consumption with automated CCA and with automated low flow anesthesia (LFA) (= maintenance FGF of 0.7 L.min^{-1}) with 3 different carrier gases.
Methods : After IRB approval, 65 ASA PS I or II patients undergoing general surgery received desflurane in either O_2, O_2/air, or O_2/N_2O, with the Zeus® to maintain the end-expired concentration (F_A) at 6, 6, and 4% and the F_IO_2 at 1.0, 0.6, and 0.4, respectively. In addition, patients were assigned to either automated CCA (O_2 n = 11 ; O_2/air n = 11 ; O_2/N_2O n = 11) or automated LFA (selected FGF 0.7 L.min^{-1}) (O_2 n = 12 ; O_2/air n = 11 ; O_2/N_2O n = 9). Demographics and desflurane consumption at 2, 4, 6, 8, 10, 20, 30, 40 and 50 min were compared.
Results : With the same carrier gas, desflurane consumption was lower with the CCA mode than with LFA mode after 4 min in the O_2 groups, 6 min in the O_2/air groups, and 30 min in the O_2/N_2O groups. Within each mode, desflurane consumption in the O_2 and O_2/air groups was identical at all times. Despite the use of a lower F_A in the N_2O groups, initial desflurane consumption was higher than in the O_2 and O_2/air groups, but it was lower later ($\geq$ 15 min) only with LFA.
Discussion : After 50 min, desflurane consumption with automated CCA is lower than with automated LFA. However, initial agent consumption is complex, and N_2O in particular may increase initial desflurane consumption (though ultimately resulting in lower desflurane usage because of its MAC sparing effect) because initial FGF is increased to rapidly reach the target concentrations. Differences in desflurane consumption only become apparent after FGF has stabilized to the target FGF.

Key words : Equipment ; Zeus® ; anesthesia techniques ; low flow anesthesia ; closed-circuit anesthesia.

Introduction

We previously observed that, paradoxically, automated closed-circuit anesthesia (CCA) (Zeus®, Software version 3, Dräger, Lübeck, Germany) (1) did not reduce desflurane consumption below that with a conventional machine used with early fresh gas flow (FGF) reduction (2 L.min^{-1} O_2 + 4 L.min^{-1} N_2O for 3 min followed by 0.3 L.min^{-1} O_2 + 0.4 L.min^{-1} N_2O) (2, 3) because of the Zeus®' use of initial excessively high FGF (to hasten wash-in) and serial flushing (to attenuate accumulation of unwanted gases) (4). This seems to defeat the main purpose of developing automated CCA : lowering agent consumption towards patient uptake. Because desflurane consumption during automated CCA during the first 5 min (11.7 mL) was higher than during the ensuing 35 min (5.5 mL) (4), we wondered to what an extent the automated CCA mode of the Zeus itself could still significantly reduce agent consumption below that with automated low flow anesthesia (LFA – in this manuscript defined as a total FGF of 0.7 L.min^{-1}). Because the choice of carrier gas may affect agent consumption, consumption was studied with 3 different carrier gases.

Methods

After IRB approval, 65 ASA PS I or II patients undergoing general surgery were enrolled. All patients received oral alprazolam 1 h before the scheduled start of surgery. After preoxygenation

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Table 1

Patient demographics

Flow mode	*Automated closed circuit anesthesia*			*Automated low flow anesthesia*		
Carrier gas	O_2	O_2/air	O_2/N_2O	O_2	O_2/air	O_2/N_2O
F_A*desflurane (%)*	6	6	4	6	6	4
n	11	11	11	12	11	9
Age (years)	58 ± 14	56 ± 17	52 ± 13	59 ± 13	51 ± 6	56 ± 8
Height (cm)	66 ± 9	63 ± 9	71 ± 13	72 ± 8	67 ± 13	78 ± 14
Weight (kg)	166 ± 7	170 ± 9	167 ± 4	163 ± 7	166 ± 10	165 ± 8

All results are presented as mean ± standard deviation ; there are no differences between the groups.

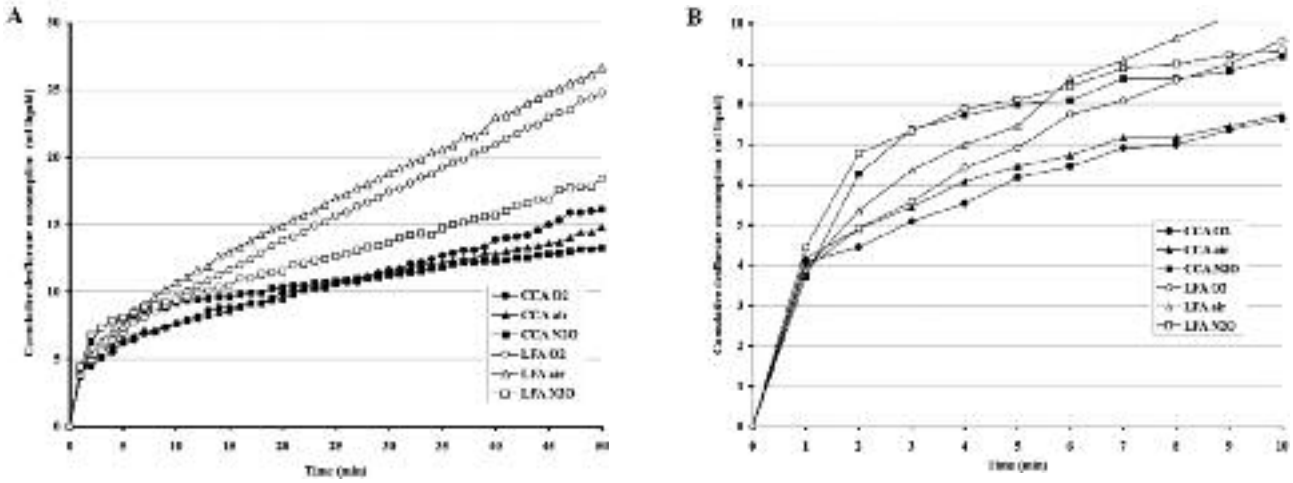

Fig. 1. — Desflurane consumption (cumulative amount, mL liquid) over the entire study period (A) and during the first 10 min (B).
CCA O2 : automated closed-circuit anesthesia with O_2 ; CCA air : automated closed-circuit anesthesia with O_2/air ; CCA N2O : automated closed-circuit anesthesia with O_2/N_2O ; LFA O2 : automated low flow anesthesia with O_2 ; LFA air : automated low flow anesthesia with O_2/air ; LFA N2O : automated low flow anesthesia with O_2/N_2O.

(8 L.min^{-1} O_2 FGF for 3 min), propofol (3 mg.kg^{-1}), rocuronium (0.7 mg.kg^{-1}), and sufentanil (0.1 microgram.kg^{-1}) were administered intravenously. After intubation, ventilation was mechanically controlled. Initial tidal volume and respiratory rate were 500 mL and 10 breaths per minute, respectively ; these settings were later adjusted at the discretion of the attending anesthesiologist.

All patients received desflurane with the Zeus® (software version 3) in either O_2, O_2/air, or O_2/N_2O to maintain the end-expired desflurane concentration (F_A) at 6, 6, and 4%, and the F_IO_2 at 1.0, 0.6, and 0.4, respectively. Patients were assigned to either automated CCA (O_2 n = 11 ; O_2/air n = 11 ; O_2/N_2O n = 11) or automated LFA (FGF = 0.7 L.min^{-1})(O_2 n = 12 ; O_2/air n = 11 ; O_2/N_2O n = 9). Additional sufentanil was administered at the discretion of the attending anesthesiologist.

In- and end-expired agent concentrations were automatically downloaded every 10 seconds. Desflurane consumption (mL liquid agent) was retrieved from the Zeus®. We compared demographics and desflurane consumption at 2, 4, 6, 8, 10, 20, 30, 40 and 50 min using ANOVA, followed by unpaired t-test or the Mann-Whitney Rank Sum Test.

Results

Patient demographics did not differ between groups (Table 1). With the same carrier gas, desflurane consumption was lower with the CCA mode than with LFA mode after 4 min in the O_2 groups, 6 min in the O_2/air groups, and 30 min in the O_2/N_2O groups (Fig. 1, Table 2). When comparing the CCA groups, desflurane consumption was always the same with O_2 and O_2/air. However, it was higher with O_2/N_2O compared to O_2 from 2 to 8 min. When comparing the LFA groups, desflurane consumption was initially higher with O_2/N_2O compared to O_2 and O_2/air (2 and 4 min), but it was lower later on (≥ 15 min).

Table 2

Desflurane consumption

	Mode	*Automated closed circuit anesthesia*			*Automated low flow anesthesia*		
	$F_A$desflurane(%)	*6*	*6*	*4*	*6*	*6*	*4*
	Carrier gas	*O_2*	*O_2/air*	*O_2/N_2O*	*O_2*	*O_2/air*	*O_2/N_2O*
Time (min)	*0*	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
	2	4.4 ± 0.6	4.9 ± 0.8	6.2 ± 1.7	4.9 ± 0.9	5.3 ± 1.1	6.7 ± 1.3
	4	5.5 ± 1.0	6.0 ± 0.9	7.7 ± 2.0	6.4 ± 1.0	7.0 ± 1.0	7.8 ± 1.5
	6	6.4 ± 0.9	6.7 ± 1.2	8.0 ± 2.0	7.7 ± 1.2	8.6 ± 1.3	8.4 ± 1.6
	8	7.0 ± 1.0	7.1 ± 1.2	8.6 ± 1.9	8.5 ± 1.3	9.6 ± 1.8	9.0 ± 1.6
	10	7.6 ± 1.0	7.7 ± 1.5	9.1 ± 2.0	9.5 ± 1.3	10.7 ± 2.1	9.3 ± 1.4
	20	9.9 ± 1.3	9.5 ± 1.6	10.3 ± 1.9	13.8 ± 1.4	14.9 ± 2.8	11.5 ± 1.5
	30	11.6 ± 1.5	11.3 ± 2.2	11.2 ± 2.0	17.5 ± 1.8	18.8 ± 3.9	13.6 ± 1.5
	40	13.8 ± 1.7	12.8 ± 2.4	12.2 ± 1.8	20.9 ± 1.9	23.0 ± 4.2	15.7 ± 1.6
	50	16.1 ± 2.8	14.7 ± 2.7	13.2 ± 1.6	24.8 ± 2.3	26.6 ± 5.0	18.4 ± 1.7

Results are presented in mL liquid agent (mean ± standard deviation). See text for details.

Conclusions

Desflurane consumption with the Zeus is lower with CCA than with automated LFA after 4 min when using O_2 ; after 6 min when using O_2/air ; and after 30 min when using O_2/N_2O. However, the course of the initial agent consumption is complex, especially with the use of N_2O. The Zeus® did not succeed in lowering desflurane consumption during automated CCA below that with automated LFA at the very beginning, indicating that initial average FGF and agent injection rate did not differ much. Indeed, despite selecting "automated CCA" or "automated LFA" with FGF of 0.7 L.min^{-1}, the Zeus® will deviate from these settings because the algorithm gives attaining the desired desflurane F_A or carrier gas concentration priority, overriding the importance of minimizing consumption. Consequently, agent consumption with both automated modes will be higher than with a conventional anesthesia machine used with early O_2/N_2O FGF reduction to 0.7 L.min^{-1} plus a single vaporizer adjustment (resulting in similar gas concentrations) (4). Automated LFA on the Zeus is *not* the same as LFA with a conventional anesthesia machine. New algorithms are likely to affect the performance of automated delivery systems by further reducing agent dosing while still achieving the target concentrations with clinically acceptable delays.

The choice of carrier gas affects desflurane consumption. N_2O selection dictates the initial use of a O_2/N_2O FGF to rapidly attain the desired N_2O concentration, and thereby increases desflurane consumption : despite a lower F_A of desflurane in the N_2O group, initial consumption is higher in the N_2O groups than in the O_2 and O_2/air groups. After reaching the desired FGF, instantaneous consumption in the N_2O group is decreased compared to the O_2 and O_2/air groups because F_A desflurane is lower, ultimately resulting in a lower cumulative desflurane consumption.

In summary, with the Zeus®, desflurane consumption after 50 min is lower with automated closed circuit anesthesia than with automated low flow anesthesia (defined as FGF of 0.7 L.min^{-1}). Initial agent consumption remains well above patient uptake with both modes, especially with the use of N_2O, because the current software places relatively more emphasis on rapidly reaching the desired gas concentrations than on reducing agent consumption by increasing fresh gas flow.

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