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Effects of Flow Rate on Hemodynamic Parameters and Agent Consumption in Low-Flow Desflurane Anesthesia: An Open-Label, Prospective Study in 90 Patients

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ABSTRACT

Background: In surgical patients, decreasing the fresh gas flow rate in anesthesia may minimize costs, reduce environmental pollution, and preserve heat and humidity in the respiratory system.

Objective: The aim of this study was to investigate the effects of 3 low-flow desflurane rates on perioperative hemodynamic stability, end-tidal desflurane concentration, emergence and recovery characteristics, and agent consumption.

Methods: This open-label, prospective study was conducted at the Department of Anesthesiology and Reanimation, University of Gaziantep, Gaziantep, Turkey. Nonpremedicated adult patients scheduled to undergo surgery (ureterolithotomy, cholecystectomy, pyelolithotomy, or thyroidectomy) were enrolled. Patients were anesthetized with propofol and fentanyl and intubated after neuromuscular blockade with vecuronium. Patients were randomly allocated to 1 of 3 groups according to the fresh gas flow rate: medium flow (2 L/min), low flow (1 L/min), and minimal flow (0.5 L/min). Intraoperative fentanyl volume was recorded. Heart rate, mean arterial pressure, and end-tidal desflurane concentration were recorded before (baseline) and after anesthesia induction; immediately before incision; and 5, 10, 15, 30, 45, and 60 minutes after incision. Emergence time and desflurane consumption after extubation were recorded. Aldrete scores were recorded at 5, 15, and 30 minutes after extubation.

Results: Ninety patients (46 women, 44 men; mean [SD] age, 39.74 [13.73] years; 30 patients per treatment group) participated in the study. Means of hemodynamic parameters, intraoperative volume of fentanyl, end-tidal desflurane concentration, emergence time, and Aldrete score were statistically similar between the 3 groups. Mean (SD) desflurane consumption was significantly higher in the medium-flow group compared with the low- and minimal-flow groups (110.43 [28.18] g vs 98.40 [23.62] g and 79.80 [17.54] g, respectively; both, $P < 0.01$). Mean (SD) desflurane consumption was also significantly higher in the low-flow group compared with the minimal-flow group ($P < 0.01$).

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Conclusion: The results of the present study in adult surgical patients suggest that desflurane may be used in low-flow anesthesia, even with the minimal fresh gas flow rate. (*Curr Res Ther Clin Exp.* 2005;66:4–12) Copyright © 2005 Excerpta Medica, Inc.

Key words: low flow, desflurane, flow rate.

INTRODUCTION

Low-flow anesthesia results in at least 50% of exhaled air being returned to the lungs after CO_2 absorption.[1] This degree of "rebreathing" can be achieved if the fresh gas flow rate is reduced to ~2 L/min.[2] To standardize the terminology for breathing circuits, Baker[3] suggested the following modification of Simionescu's classification[4] of fresh gas flow rates in clinical practice: high flow (>2–4 L/min), medium flow (>1–2 L/min), low flow (>0.5–1 L/min), and minimal flow (≤0.5 L/min). Low-flow anesthesia may minimize the cost of the anesthetic, reduce environmental pollution, and preserve heat and humidity in the respiratory system.[5,6]

Desflurane is the least soluble of the inhaled anesthetic agents, with a blood/gas partition coefficient of 0.42. Its pharmacokinetic properties and rapid metabolism make it effective in low-flow systems.[7] A MEDLINE search (key terms: *low flow* and *desflurane*; years: 1990–2004) identified some studies comparing the effects of desflurane with those of other inhaled anesthetics.[8–10] However, studies comparing the effects of differing desflurane flow rates in low-flow anesthesia were unavailable.

The aim of this study was to investigate the effects of 3 differing flow rates on perioperative hemodynamic stability, end-tidal desflurane concentration, emergence and recovery characteristics, and agent consumption in low-flow desflurane anesthesia.

PATIENTS AND METHODS

For this open-label, prospective study, approval of the protocol was obtained from the institutional ethics committee at the Department of Anesthesiology and Reanimation, University of Gaziantep, Gaziantep, Turkey. Written informed consent was obtained from each patient.

Inclusion and Exclusion Criteria

Patients aged 18 to 65 years with American Society of Anesthesiologists physical status I or II (ie, healthy) and scheduled to undergo surgery (ureterolithotomy, cholecystectomy, pyelolithotomy, or thyroidectomy) with general anesthesia (GA) were included. Patients with alcoholism or obesity or a history of hepatic, renal, or cardiovascular disease were excluded from the study. Pregnant, possibly pregnant, or breast-feeding women were also excluded.

Induction of Anesthesia

Patients received no premedication. After preoxygenation, GA was induced with propofol 2.0 to 2.5 mg/kg IV and fentanyl 1 to 3 µg/kg IV. Neuromuscular blockade was achieved using vecuronium 0.1 mg/kg IV, and intermittent positive pressure ventilation was applied using an anesthesia machine (Cato Anaesthetic Workstation, Drägerwerk AG, Lübeck, Germany). End-tidal CO_2 tension ($PETCO_2$) was monitored and maintained in the range of 30 to 40 mm Hg during surgery. The desflurane* vaporizer (Devapor, Drägerwerk AG) concentration setting was adjusted to 4% to 6% after endotracheal intubation, and a high-flow (6 L/min) denitrogenization phase was applied for 6 to 8 minutes to reach a sufficient level of anesthesia.

Using a computer-generated table of random numbers, patients were allocated to 1 of 3 groups according to the fresh gas flow rate (medium, low, or minimal). Before each administration of anesthetic, the absorber canister was filled with fresh soda lime (Ber-kim Ltd., Istanbul, Turkey). In all 3 groups, the desflurane vaporizer concentration setting was adjusted to between 3% and 5%. In the medium-flow group, the fresh gas flow rate was 2 L/min (1 L/min O_2 + 1 L/min N_2O + desflurane); in the low-flow group, 1 L/min (0.5 L/min O_2 + 0.5 L/min N_2O + desflurane); and in the minimal-flow group, 0.5 L/min (0.3 L/min O_2 + 0.2 L/min N_2O + desflurane).

Evaluations of Effects of Flow Rates

Heart rate (HR), mean arterial pressure (MAP), and end-tidal desflurane concentration were Monitored and noted before (baseline) and after GA induction; immediately before incision; and 5, 10, 15, 30, 45, and 60 minutes after incision (PM 8040 Monitor, Drägerwerk AG). Inspired and expired O_2 and N_2O values were also continuously measured. Additional doses of fentanyl 1 µg/kg IV were administered if MAP increased by >20% of baseline, and a similar decrease in MAP was treated with ephedrine 5 to 10 mg IV. The fresh gas flow rate was increased to high (6 L/min) 10 to 15 minutes before closure in all 3 groups. After closure, residual neuromuscular blockade was antagonized using atropine 0.02 mg/kg IV and neostigmine 0.06 mg/kg IV.

After opening their eyes on command, patients were extubated. Emergence time (open eyes, extubation, and response to verbal commands) and desflurane consumption (by weighing the vaporizer) were measured. Aldrete scores[11] (scale: 0 = anesthetized to 10 = full recovery; ≥9 is needed for full recovery) (**Table I**) were assessed and noted at 5, 15, and 30 minutes after extubation. Patients having Aldrete scores >9 were sent to the postanesthetic care unit and patients with Aldrete scores <9 were given 100% O_2 until the score became ≥9. The flow rate was to be increased to 6 L/min in patients experiencing ≥1 adverse effect (eg, hypertension, tachycardia, hypotension, increased $PETCO_2$, decreased peripheral arterial oxygen saturation, bradycardia).

*Trademark: Suprane® (Baxter International, Inc., Guaynabo, Puerto Rico).

Table I. Modified Aldrete scale.

Criterion	Score
Oxygenation	
SpO_2 >92% on room air	2
SpO_2 90%–92% on O_2	1
SpO_2 <90% on O_2	0
Respiration	
Breathes deeply and coughs freely	2
Dyspneic, shallow or limited breathing	1
Apnea	0
MAP	
±20 mm Hg of normal	2
±21–50 mm Hg of normal	1
>±50 mm Hg of normal	0
Consciousness	
Fully awake	2
Arousable on calling	1
Nonresponsive	0
Activity	
Moves all extremities	2
Moves 2 extremities	1
No movement	0
Total score*	_

SpO_2 = pulse oximetry saturation; MAP = mean arterial pressure.
*Scale: 0 = anesthetized to 10 = full recovery; total score ≥9 is needed for full recovery.
Modified with permission.[11]

Statistical Analysis

Statistical analyses were performed using SPSS version 11.0 (SPSS Inc., Chicago, Illinois). One-way analysis of variance and post hoc multiple comparisons (Tukey test for homogeneous groups and Tamhane test for nonhomogeneous groups) were used to compare the between-group results. $P < 0.05$ was considered statistically significant.

RESULTS

Ninety patients (46 women, 44 men; mean [SD] age, 39.74 [13.73] years; 30 patients per treatment group) participated in the study (**Table II**). None of the patients were withdrawn from the study after randomization.

Mean (SD) intraoperative use of fentanyl was similar between the 3 groups: medium flow, 185.00 (41.83) µg; low flow, 181.66 (48.21) µg; and minimal flow, 181.66 (30.74) µg (**Table II**). Mean (SD) desflurane consumption was significant-

Table II. Baseline demographic and clinical characteristics of the study patients (N = 90).

Characteristic	Medium Flow (n = 30)	Low Flow (n = 30)	Minimal Flow (n = 30)
Age, mean (SD), y	39.96 (14.49)	38.46 (15.05)	40.80 (11.63)
Sex, no. (%)			
Female	16 (53.3)	14 (46.7)	16 (53.3)
Male	14 (46.7)	16 (53.3)	14 (46.7)
Body weight, mean (SD), kg	70.70 (9.99)	74.50 (9.65)	70.30 (9.18)
Height, mean (SD), cm	166.53 (9.18)	167.76 (7.01)	166.46 (7.78)
ASA physical status,* no. (%)			
I	24 (80.0)	22 (73.3)	21 (70.0)
II	6 (20.0)	8 (26.7)	9 (30.0)
Surgical procedure, no. (%) of patients			
Ureterolithotomy	12 (40.0)	14 (46.7)	13 (43.3)
Cholecystectomy	9 (30.0)	8 (26.7)	8 (26.7)
Pyelolithotomy	5 (16.7)	3 (10.0)	5 (16.7)
Thyroidectomy	4 (13.3)	5 (16.7)	4 (13.3)
Duration of anesthesia, mean (SD), min	124.00 (32.61)	134.03 (44.82)	140.50 (50.02)
Duration of surgery, mean (SD), min	106.86 (31.29)	118.86 (42.87)	127.43 (49.69)
Total fentanyl dose, mean (SD), μg	185.00 (41.83)	181.66 (48.21)	181.66 (30.74)
Desflurane consumption, mean (SD), g	110.43 (28.18)†‡	98.40 (23.62)‡	79.80 (17.54)

ASA = American Society of Anesthesiologists.
*ASA physical status I and II = healthy.
†$P < 0.01$ versus low-flow group.
‡$P < 0.01$ versus minimal-flow group.

ly higher in the medium-flow group compared with the low- and minimal-flow groups (110.43 [28.18] g vs 98.40 [23.62] g and 79.80 [17.54] g, respectively; both, $P < 0.05$). Mean (SD) desflurane consumption was also significantly higher in the low-flow group compared with the minimal-flow group ($P < 0.01$).

No statistically significant differences in perioperative HR, MAP, or end-tidal desflurane concentration were found between the 3 groups. HR and MAP remained within 20% of baseline values in all 3 groups (**Table III**). Mean emergence times and modified Aldrete scores were statistically similar between the 3 groups (**Table IV**). No adverse effects related to the low-flow anesthesia were observed in any group.

Table III. Mean (SD) heart rate (HR; bpm), mean arterial pressure (MAP; mm Hg), and end-tidal desflurane concentrations (ETD; %) in patients undergoing low-flow desflurane anesthesia (N = 90).*

	Medium Flow (n = 30)			Low Flow (n = 30)			Minimal Flow (n = 30)		
Time Point	HR	MAP	ETD	HR	MAP	ETD	HR	MAP	ETD
Before GA induction (baseline)	76.46 (8.37)	99.84 (6.59)	–	76.66 (7.97)	101.16 (9.13)	–	76.56 (7.95)	99.12 (4.86)	–
After GA induction	65.13 (6.44)	87.13 (8.53)	3.55 (0.38)	64.93 (5.91)	89.46 (3.31)	3.50 (0.39)	66.06 (7.41)	87.04 (4.17)	3.55 (0.49)
Before incision	75.26 (6.80)	89.76 (5.40)	4.26 (0.31)	74.23 (6.19)	90.94 (3.10)	4.35 (0.22)	74.93 (7.61)	90.98 (3.17)	4.23 (0.28)
After incision									
5 min	65.40 (5.60)	88.54 (4.76)	4.16 (0.21)	65.96 (5.28)	89.97 (2.38)	4.23 (0.14)	67.03 (6.73)	89.94 (3.20)	4.12 (0.22)
10 min	68.20 (4.79)	88.91 (4.05)	4.11 (0.11)	68.43 (4.81)	90.27 (2.41)	4.22 (0.15)	69.23 (6.16)	90.31 (2.47)	4.11 (0.19)
15 min	70.30 (4.74)	90.10 (2.91)	4.12 (0.27)	70.56 (4.92)	90.05 (2.29)	4.21 (0.16)	71.20 (5.70)	89.88 (1.87)	4.12 (0.15)
30 min	71.66 (5.07)	89.91 (4.37)	4.11 (0.26)	71.83 (5.31)	90.37 (2.07)	4.20 (0.17)	72.16 (5.57)	90.26 (1.52)	4.14 (0.14)
45 min	71.30 (5.73)	90.49 (3.79)	4.10 (0.24)	71.86 (5.11)	90.91 (1.87)	4.21 (0.16)	71.76 (5.87)	90.80 (1.13)	4.14 (0.14)
60 min	71.63 (5.42)	90.83 (3.12)	4.10 (0.26)	72.16 (5.38)	90.81 (2.47)	4.21 (0.16)	72.03 (5.36)	90.78 (2.47)	4.15 (0.13)

GA = general anesthesia.
*No significant between-group differences were found.

Table IV. Mean (SD) emergence times and modified Aldrete scores[11] in patients undergoing low-flow desflurane anesthesia (N = 90).*

Time	Medium Flow (n = 30)	Low Flow (n = 30)	Minimal Flow (n = 30)
Open eyes, min	7.16 (3.01)	6.00 (2.79)	6.03 (2.57)
Extubation, min	7.96 (3.35)	6.70 (3.03)	6.50 (2.28)
Response to verbal commands, min	9.76 (3.26)	8.23 (2.84)	8.46 (2.95)
Aldrete score			
5 min	8.63 (0.61)	8.50 (0.62)	8.56 (0.67)
15 min	9.46 (0.57)	9.63 (0.49)	9.53 (0.50)
30 min	9.93 (0.25)	9.90 (0.30)	9.93 (0.25)

*No significant between-group differences were found.

DISCUSSION

The advantages of low-flow anesthesia are reduced anesthetic gas consumption, decreased atmospheric pollution with inhaled anesthetics, preserved heat and humidity in the respiratory system, and significantly reduced costs.[5] In the present study, the different desflurane flow rates were not associated with differences in HR or MAP. Although no studies comparing the differing flow rates of desflurane are available in the literature, some studies[8–10] have compared the hemodynamic effects of desflurane with those of some other gases. Bennett et al[8] compared the hemodynamic effects of desflurane and isoflurane in high-flow anesthesia and reported that desflurane controlled hemodynamic alterations more rapidly than isoflurane. Dupont et al[9] reported similar HR, MAP, and oxygen saturation values throughout anesthesia with desflurane, isoflurane, and sevoflurane. Although HR and MAP might be expected to be increased in low-flow anesthesia, Ebert and Arain[10] reported perioperative hemodynamic stability with desflurane, sevoflurane, and propofol. In addition, we found that hemodynamic parameters could be maintained within the physiologic range with low-flow desflurane anesthesia, even with minimal fresh gas flow rates.

Juvin et al[12] reported that desflurane provides rapid emergence from anesthesia. This finding was similar to those in some other studies.[13,14] In the study by Juvin et al,[12] the emergence times from the end of administration of the study drug to extubation and eye opening were reported to be significantly decreased when desflurane was used versus propofol or isoflurane (mean [SD] extubation times: 6.86 [3.0], 13.1 [8.9], and 9.9 [6.5] minutes, respectively [both, $P < 0.05$]; mean [SD] eye opening times: 5.6 [3.4], 11.5 [8.4], and 11.9 [7.6] minutes, respectively [both, $P < 0.03$]). Based on our MEDLINE search, the present study was the first to compare emergence time in low-flow anesthesia with differing desflurane flow rates. We did not find any statistically significant differences in emergence times or Aldrete scores between the 3 groups. Fentanyl consumption adjacent to

desflurane was statistically similar between all 3 groups, suggesting that a decrease in desflurane flow rate does not change the depth of anesthesia or the emergence time, making low flow rates preferable to high flow rates when other factors (eg, consumption) are considered.

Inhaled anesthetics account for >20% of anesthetic drug expenditures each year in the United States.[15] This cost is strictly related to consumption and hence to flow rates, making low-flow anesthesia advantageous. Baum[2] reported a considerable decrease in anesthetic consumption and cost savings resulting directly from decreased flow rate. In the present comparison of the effects of several desflurane flow rates on anesthetic consumption, minimal flow rate was associated with the least consumption.

CONCLUSIONS

In this study of differing flow rates in low-flow desflurane anesthesia in surgical patients, perioperative hemodynamic stability and statistically unchanged end-tidal desflurane concentrations were obtained, with no negative influence on the recovery period. Agent consumption was reduced with decreased fresh gas flow rates. These results suggest that low-flow desflurane anesthesia may be an alternative to high-flow anesthesia in patients with American Society of Anesthesiologists physical status I or II, even with the minimal flow rate.

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