Effects of reduction of carrier gas flow rate on sevoflurane and isoflurane consumption and costs

SATORU TANAKA¹, HIDEAKI TSUCHIDA¹, HAJIME SONODA², and AKIYOSHI NAMIKI¹

¹Department of Anesthesiology, Sapporo Medical University School of Medicine, South 1, West 16, Chuo-ku, Sapporo 060, Japan
²Department of Anesthesia, Kushiro Municipal General Hospital, 1-12 Shunkodai, Kushiro 085, Japan

Abstract

Purpose. To evaluate whether sevoflurane and isoflurane consumption would be actually halved by halving the carrier gas flow rate, as predicted by a theoretical model, we measured the consumed volume of liquid sevoflurane and isoflurane and total costs of anesthetic gas at carrier gas flow rates of 3 and 6 l/min⁻¹.

Methods. Eighty patients of ASA physical status I or II were randomly assigned to one of four groups: sevoflurane at 3 or 6 l/min⁻¹ and isoflurane at 3 or 6 l/min⁻¹. Anesthesia was induced with thiamylal and maintained with sevoflurane or isoflurane, as well as with nitrous oxide in oxygen. The consumption of sevoflurane and isoflurane was measured by weighing the bottle of liquid agent, which was greater in the groups receiving 6 l/min⁻¹ gas than in those receiving 3 l/min⁻¹.

Results. Halving the carrier gas flow rate reduced the consumption of sevoflurane by 41.8% and that of isoflurane by 52.6%. It also reduced the total cost by 44.3% for sevoflurane and 49.2% for isoflurane.

Conclusion. Halving the carrier gas flow rates halved the consumption of isoflurane but not of sevoflurane, indicating that factors other than carrier gas flow rates are involved in determining consumption in the clinical setting.

Key words: Anesthetic cost, Isoflurane, Sevoflurane, Carrier gas flow

Introduction

Theoretical models are commonly used to determine the consumption of volatile anesthetics [1]. However, the theoretical values may differ from the actual ones because of rather complex factors involved in the clinical setting. The consumed volume of liquid volatile anesthetics is dictated by the individual characteristics of the anesthetics and the rate of carrier gas flow [2]. Other individual characteristics, such as the minimum alveolar concentration (MAC) and the blood–gas partition coefficient, also partly determine the consumption of volatile anesthetics. Theoretically, sevoflurane would be consumed at a rate approximately 1.78 times that of isoflurane because the MACs for sevoflurane and isoflurane are 2.05% and 1.15%, respectively (2.05/1.15 = 1.78) [3,4]. The depth of anesthesia is, however, controlled more easily and quickly with sevoflurane than with isoflurane, because the blood–gas partition coefficient of sevoflurane (0.63) is less than that of isoflurane (1.4). Because of this difference between sevoflurane and isoflurane, sevoflurane should be consumed at a rate less than 1.78 times that of isoflurane for the same carrier gas flow rate.

The volume of volatile anesthetic used is also directly proportional to carrier gas flow rate; decreasing the rate lowers the consumption of anesthetics. This relationship is particularly important for anesthetics with high MACs. Low-flow anesthesia is, therefore, recommended for economic and environmental reasons [5]. One major drawback of low-flow anesthesia is that the depth of anesthesia is less easily adjusted. Halving the carrier gas flow rate would double the time needed to reach the desired inspired concentration of an anesthetic, and would increase even more the time needed to achieve the desired end-tidal concentration of an anesthetic. A volatile anesthetic with a lower blood–gas partition coefficient would, therefore, accelerate any increase of end-tidal concentration of the anesthetic.
more than that of an anesthetic with a higher coefficient when low-flow anesthesia is employed. Consequently, reducing the rate of flow should reduce the rate of consumption of sevoflurane more than that of isoflurane.

We measured the consumed volume of liquid sevoflurane and isoflurane at two different carrier gas flow rates, 6 and 31 min⁻¹. In addition, we calculated the total costs of both anesthetics and carrier gases delivered at the two carrier gas flow rates. We tested the hypotheses that (1) the consumption of sevoflurane would be less than 1.8 times that of isoflurane at the same carrier gas flow rate, and (2) halving the carrier gas flow rate would be of greater benefit with sevoflurane than with isoflurane.

Materials and methods

With the approval of the research committee of Kushiro Municipal General Hospital and after obtaining informed consent from the patients, we studied 80 patients of ASA physical status I or II, who were between 20 and 65 years old and who were scheduled for elective oropharyngeal or oral procedures under general anesthesia. The patients were randomly assigned to one of four groups of 20 patients each by drawing shuffled coded envelopes: sevoflurane at 61 min⁻¹ carrier gas flow (Sevo-6), sevoflurane at 31 min⁻¹ carrier gas flow (Sevo-3), isoflurane at 61 min⁻¹ carrier gas flow (Iso-6), and isoflurane at 31 min⁻¹ carrier gas flow (Iso-3). All patients received 2.5 mg midazolam and 0.5 mg atropine intramuscularly for premedication.

Anesthesia was induced with 3 mg kg⁻¹ thiamylal and 0.1 mg kg⁻¹ vecuronium, and was followed by mask inhalation of sevoflurane or isoflurane (up to 2.5 MAC of the inspired concentration) and nitrous oxide (41 min⁻¹) in oxygen (21 min⁻¹). After endotracheal intubation, the lungs were mechanically ventilated at 10 breaths min⁻¹ to maintain end-tidal carbon dioxide tension between 35 and 40 mmHg. Anesthesia was maintained with either sevoflurane or isoflurane, and 66% nitrous oxide in oxygen at total fresh gas flows of either 3 or 61 min⁻¹. In the Sevo-3 and Iso-3 groups, however, the total fresh gas flow was kept at 61 min⁻¹ for the first 8 min of the anesthetic course to achieve the desired level of anesthesia quickly [4]. All patients were monitored with intermittent noninvasive blood pressure measurements and continuous electrocardiography. Heart rate (HR) and systolic blood pressure (SBP) were measured before the induction of anesthesia and every 5 min during anesthesia. An Ohmeda RGM (respiratory gas monitor) 5250 (Ohmeda, Salt Lake City, UT, USA) was used to monitor continuous capnography, inspired and end-tidal concentrations of anesthetics, and hemoglobin oxygen saturation. We used a semiclosed anesthetic circuit system (Excel 110, Ohmeda, Salt Lake City, UT, USA) equipped with SevoTec 5 and IsoTec 5 continuous flow vaporizers (Ohmeda, BOC Health Care, West Yorkshire, UK). Two anesthetists participated in this study: one to administer the anesthetic, and the other to measure the consumption. The goal of the anesthetist was to provide an adequate depth of anesthesia only by adjusting the inspired concentration of sevoflurane or isoflurane according to the changes of hemodynamic parameters (hypotension, hypertension, bradycardia, or tachycardia). If not treated by sevoflurane or isoflurane alone, nicardipine or ephe-drine was administered to keep the blood pressure within the appropriate range. No opioids or regional blocks were used.

We assessed the hemodynamic variability to confirm that comparable levels of anesthesia were administered to all groups. The variability of HR and SBP was evaluated by the coefficient of variation, calculated by dividing the standard deviation by the mean value of each measurement of HR or SBP for 120 min, and expressed as a percentage.

The consumption of sevoflurane or isoflurane was measured at 30, 60, and 120 min after administration. At the beginning of anesthesia, a vaporizer was filled with the volatile agent and refilled at 30, 60, and 120 min after the start of administration. The bottle of liquid agent was weighed on an electronic scale before and after refilling. The volume of liquid agent consumed was calculated by dividing the weight loss of the bottle by the density of the agent (isoflurane, 1.510 g ml⁻¹; sevoflurane, 1.525 g ml⁻¹). The hourly consumption was calculated on the basis of the results at 120 min. The total cost of anesthetic, including nitrous oxide, oxygen, and either sevoflurane or isoflurane, was calculated using the following formula:

\[ S = C_1 \cdot A + C_2 \cdot F_1 \cdot T + C_3 \cdot F_2 \cdot T, \]

where \( S \) is total cost, \( C_1 \) is the cost of the liquid agent (\( \text{¥} \cdot \text{ml}^{-1} \)), \( C_2 \) is the cost of oxygen (\( \text{¥} \cdot \text{l}^{-1} \)), \( C_3 \) is the cost of nitrous oxide (\( \text{¥} \cdot \text{l}^{-1} \)), \( A \) is the volatile anesthetic consumed at three time points (ml), \( T \) is duration of usage (min), \( F_1 \) is oxygen flow (l min⁻¹), and \( F_2 \) is nitrous oxide flow (l min⁻¹). We added ¥159 to the Sevo-3 and Iso-3 groups because we used carrier gas flow rates of 61 min⁻¹ for the first 8 min. In our hospital, both sevoflurane and isoflurane cost ¥107.4 · ml⁻¹, oxygen costs ¥0.24 · l⁻¹, and nitrous oxide costs ¥19.84 · l⁻¹. We did not consider the other costs, such as equipment, other medications, and personnel expenses.

Patient characteristics and hemodynamic variability were analyzed using the chi-square test or one-way analysis of variance. The consumption of sevoflurane and isoflurane was analyzed using two-way analysis of