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SHORT COMMUNICATIONS

Mass Spectrometry Method to Monitor the Sevoflurane Concentration in an Apparatus for Inhalational Anesthesia

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Abstract—The feasibility of real-time monitoring of the inhalational anesthetic (sevoflurane) concentration in the respiratory circuit of an apparatus for inhalational anesthesia using mass spectrometry is considered. It is shown that the absolute anesthetic concentration can be monitored in real time if low-flow ventilation is provided during general anesthesia. The time dependences of the anesthetic concentration are taken at different stages of anesthesia in the inspiration–expiration regime.

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INTRODUCTION

Sevoflurane, or fluoromethyl-1,1,1,3,3,3-hexafluoro-2-propylether ($C_4H_3F_7O$), as an inhalational anesthetic has been applied in clinical practice since 1990. The wide use of sevoflurane in multicomponent anesthesia is due to its ability to provide stable anesthetic protection. Fast induction under the action of sevoflurane at a low flow of a carrier gas in the breathing circuit of the apparatus for inhalational anesthesia (AIA) is well known. Nevertheless, sevoflurane cannot be considered as an ideal anesthetic. Chemical reactions with participation of this anesthetic that can lead to the formation of potentially dangerous products have been widely covered in the literature [1, 2]. This places strict requirements on real-time monitoring of the sevoflurane concentration in the AIA respiratory circuit during general anesthesia.

During anesthesia, the anesthetic concentration is usually evaluated with a calibrated sevoflurane evaporator. In addition, IR sensors are used to determine the anesthetic content in the AIA circuit [3]. It is known that IR sensors make it possible to adequately analyze two-component mixtures, since in this case there arises the possibility of measuring the analyte concentration from its absorption band, which does not overlap with the absorption band of the other constituent. In the AIA circuit, the gas mixture is multicomponent (Fig. 1), so that these sensors are often inadequate to analytical measurements [3]. Recently, the feasibility of using mass-spectrometric methods to measure the anesthetic content in the AIA circuit over a wide dynamical range has been reported [4, 5]. Note that mass-spectrometric methods have long been applied for absolute calibration of evaporators of inhalational anesthetics.

The aim of this work is to demonstrate that mass-spectrometric methods can be used for absolute calibration of the anesthetic flow in the AIA circuit during general anesthesia in the inspiration–expiration regime.

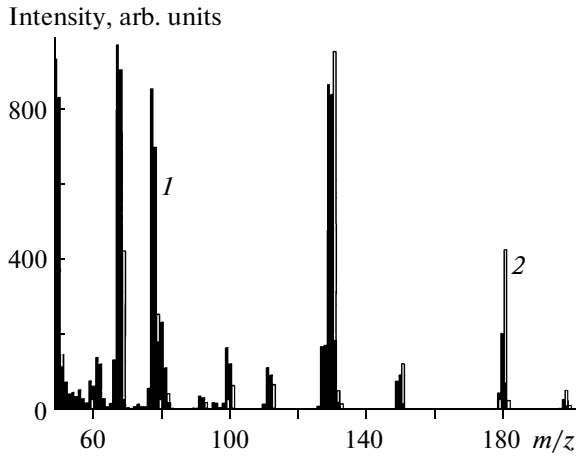

Fig.1. Mass spectra of (*1*) the gas mixture in the breathing circuit of the AIA and (*2*) sevoflurane. Peaks at $m/z = 69$, 131, 181, and 199 correspond to sevoflurane ionization by an electron beam.

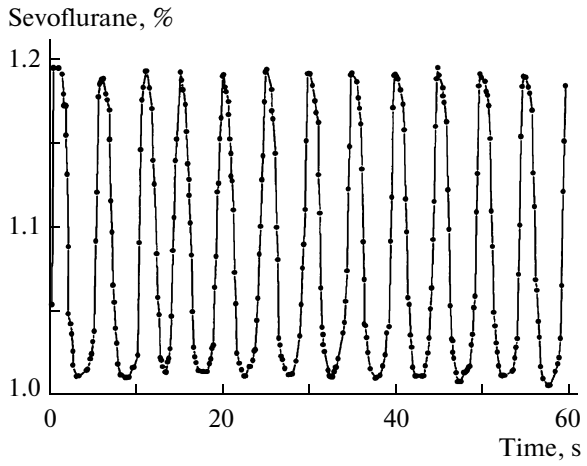

Fig. 2. Time dependence of the sevoflurane concentration in the AIA breathing circuit at the initial stage of anesthesia.

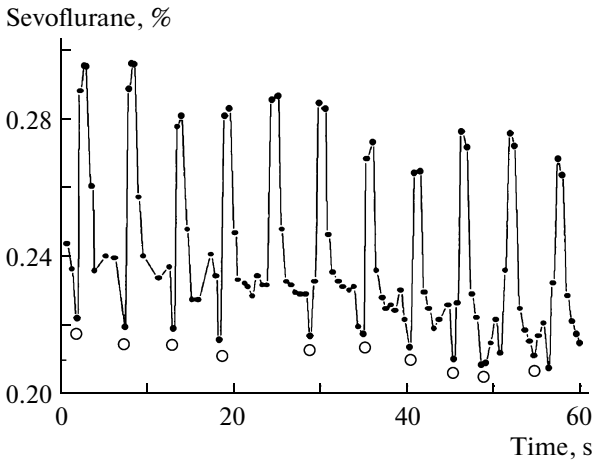

Fig. 3. Time dependence of the sevoflurane concentration in the AIA breathing circuit under the conditions of anesthesia maintenance.

MEASURING TECHNIQUE

To provide real-time determination of the inhalational anesthetic (sevoflurane) concentration in the AIA breathing circuit, a sample was injected to a mass spectrometer at atmospheric pressure. The initial air flow rate measured by a rotameter was 0.5 l/min. The respiratory minute volume of a patient was set equal to 60 ml per kilogram of the body mass at a breathing rate of 10–12 breaths per minute. The sevoflurane evaporator was placed outside the respiratory gas circulation circuit. After the intubation of a patient, the amount of evaporated sevoflurane was set equal to 4.0 vol % until the amount of sevoflurane in the expired mixture was 1.0 vol %. Intravenous opioid analgesic fentanyl (*N*-(1-(2-feniletil)-4-piperidinil)-N-fenil-propamide, $C_{22}H_{28}N_2O$) was introduced in 20 min in an amount of 1.5 μg per kilogram of the body mass. The AIA provided circulation of nitrous oxide and sevoflurane (Sevoran produced by Abbott Co.) in the breathing circuit. An investigation was carried out during neurosurgical operations.

A sample from the AIA breathing circuit was taken using a three-step differential vacuum pump, which was directly connected to the AIA endotracheal tube. The mass spectrometer was evacuated by means of a turbomolecular pump with a capacity of 60 l/s. The differential chamber was evacuated with the first stage of the same pump. The pressure differences between the stages of the differential pump were $1000/3.0 \times 10^{-2}/5.6 \times 10^{-5}$ mbar, respectively. The time dependence of the intensity of the mass peak $m/z = 199$ corresponding to a singly ionized sevoflurane ion was measured with a Prisma (PFEIFFER VACUUM) quadruple mass spectrometer with a sealed ion source.

The sevoflurane content in the AIA circuit was measured with a time resolution of 50 μs and a detection limit of 0.05 vol %. Sevoflurane was introduced into the AIA breathing circuit with the use of an Abbott anesthetic vaporizer. The absolute precalibration of the $m/z = 199$ peak intensity was made based on the readings of the anesthetic vaporizer (built in the AIA) in the absence of external sevoflurane absorption. The volume of a sample taken from the AIA breathing circuit was 1 mm^3/s at atmospheric pressure. The time of response of the mass spectrometer to a change in the sevoflurane content was 50 s.

RESULTS AND DISCUSSION

The mass spectrum of the gas mixture in the AIA circuit is shown in Fig. 1 (starting from $m/z = 50$). The peaks $m/z = 69$, 131, 181, and 199 are due to the sevoflurane ionization by an electron beam with an electron energy of 60 eV. In the experiments, the time evolution of the anesthetic volume content in the AIA circuit was recorded from the peak $m/z = 199$. These evolutions taken at different stages of anesthesia are shown in Figs. 2–4. Each peak in these curves corresponds to one inspiration– expiration cycle. The dependence of the sevoflurane concentration in the AIA breathing circuit 10 min after the onset of general anesthesia is shown in Fig. 2. Such conditions were maintained at the most traumatic stages of operation.

The time dependence of the sevoflurane concentration before introducing intravenous analgesic fentanyl, when the sevoflurane content in the AIA breathing circuit is low, is shown in Fig. 3. The low concentration of sevoflurane is confirmed by spikes marked by empty circles. Since the depth of anesthesia is indicated more exactly by the content of the anesthetic in the expired mixture, the amplitude of negative spikes of the sevoflurane content at expiration can be served as a measure of the depth of anesthesia.

The evolution of the sevoflurane concentration during a respiratory cycle is shown in Fig. 4. The form

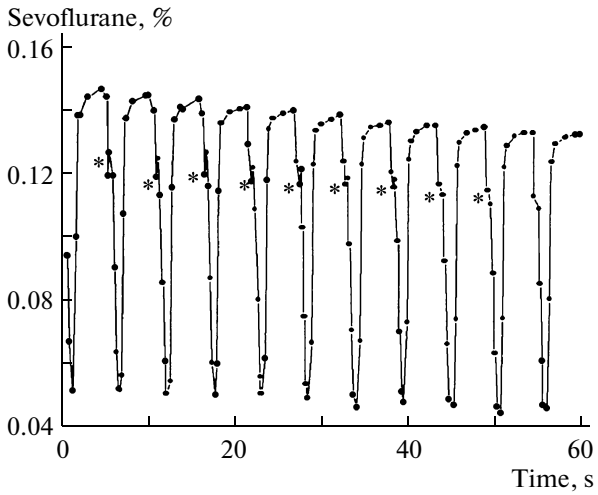

Fig. 4. Time dependence of the sevoflurane concentration in the AIA breathing circuit at the final stage of anesthesia.

of the curve is typical of the final stage of anesthesia, when the oxygen concentration in the AIA circuit is high and the anesthetic vaporizer is closed. In this case, sevoflurane is released from blood and its concentration in the expired mixture is higher than in the inspired one. Patient's attempts at spontaneous respiration are marked by asterisks in the spectrum. Obviously, information about the height and shape of the peak at the final stage of operation not only allows physicians to minimize the anesthetic concentration in the AIA circuit but also makes it possible to exactly determine the time of inhalational anesthetic excretion from blood. This provides more comfortable postanesthetic recovery.

CONCLUSIONS

Thus, it can be concluded that the use of mass spectrometry provides monitoring of the depth of anesthesia and can serve as a basis for designing an alarm detector built in the AIA.

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