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SHORT COMMUNICATIONS

Application of a Mass Spectrometer as a Capnograph

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Abstract—The feasibility of using a mass spectrometer for monitoring the carbon dioxide and inhalational anesthetic concentrations in the breathing circuit of an apparatus for inhalational anesthesia are demonstrated. Mass-spectrometric data for the CO_2 and inhalational anesthetic concentrations are compared with related optical data. The advantages of the mass spectrometer as a capnograph over the optical spectrometer are indicated. The variation of the inhalational anesthetic content in expired air is shown to depend on the muscle relaxation efficiency.

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It has been recently reported that CO_2 measurements taken with a standard apparatus for inhalational anesthesia (AIA) are inadequate for analyzing the synchronization of artificial pulmonary ventilation during low-flow inhalational anesthesia (the flow rate of a fresh gas mixture is 1000 ml/min) [1, 2]. This seems to be associated with the need to selectively determine the CO_2 content in a multicomponent gas mixture entering into the breathing circuit of the AIA. The flow rate of the gas from the breathing circuit of the AIA that is taken for analysis with an IR spectrometer amounts to 250 ml/min [1]. Analysis of this flow is necessary because of a low sensitivity of IR spectrometers, which, in turn, results from low absorption of the CO_2 near-IR radiation by molecules. In the majority of apparatuses for inhalation, pumping of the gas back and forth is not provided because of the need for an additional compressor operating in the inspiration–expiration mode.

Today, low-flow inhalational anesthesia is widely used, in which the flow rate of a fresh gas mixture in the breathing circuit of the AIA is 500 ml/min [3], so that the use of a flow rate of 250 ml/min for CO_2 content analysis seems problematic. In this case, capnograph readings are corrected using mathematical models. The algorithms of these models, yet far from being perfect, are subjects of heated discussion [2].

In this work, which is based on the results of neurosurgeries, a mass spectrometer with a closed ion source having a tungsten cathode is used to reliably determine the CO_2 content in the breathing circuit of the AIA. Samples from the breathing circuit were taken with a two-stage differential pump, which was directly connected to the endotracheal tube of the breathing circuit. The mass spectrometer was evacuated using a turbomolecular pump with a capacity of 60 l/s. The evacuation rate of the differential chamber was 20 l/s. The pressure differences between the stages of the differential pump were 10^5–3–1.5×10^{-4} Pa. respectively. The CO_2 content in the breathing circuit of the AIA was measured with a quadrupole mass spectrometer. The gas mixture in the AIA was evacuated with a rate of 0.01 ml/min [4].

The mass spectrometer–breathing circuit connection diagram is shown in Fig. 1. The signal from the mass spectrometer lags behind the instant the concentration of the gas mixture is measured at the entrance to the capillary by no longer than 20 s. Thus, the mass

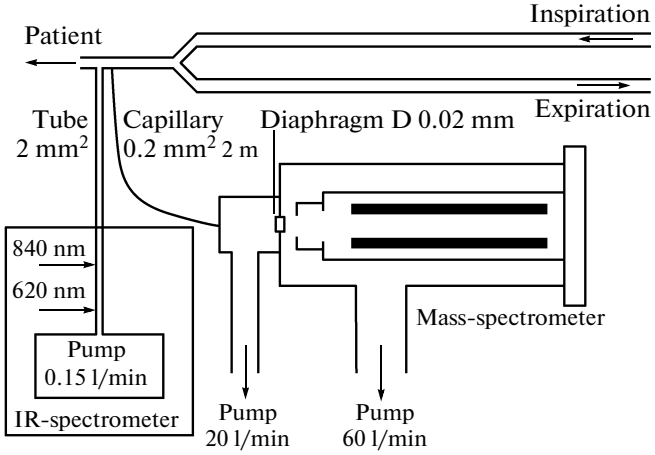

Fig. 1. Mass spectrometer– breathing circuit connection diagram.

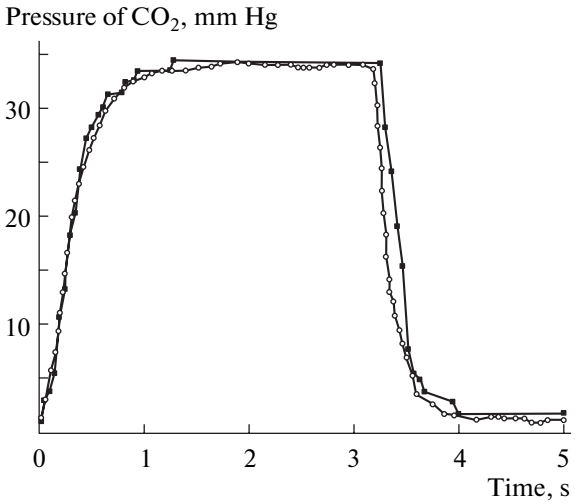

Fig. 2. Time variation of the CO_2 pressure (capnogram): (■) IR spectrometer and (○) mass spectrometer.

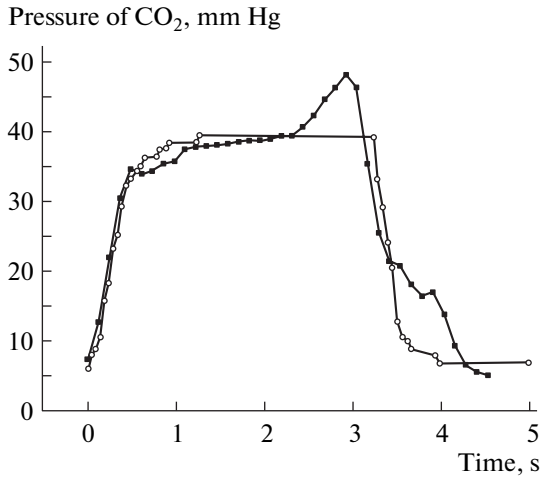

Fig. 3. Time variation of the CO_2 pressure: (○) IR spectrometer and (■) mass spectrometer.

spectrometer is an ideal capnograph by analytical capabilities.

Figure 2 shows two capnograms obtained with the mass spectrometer and an IR spectrometer that absorbs radiations from two LEDs at frequencies 640 and 820 nm, respectively [5]. The capnograms are seen to be almost coincident. The cost difference between these two instruments makes the IR spectrometer more attractive for clinical practice.

In this work, the capnometric potential of a mass spectrometer was tested over a large number (20) of surgeries. In some cases (20% of the total number of observations), the readings of the mass spectrometer and IR spectrometer differed (an example is shown in Fig. 3). This may be explained by the incompleteness of the model, which corrects the readings of the IR spectrometer by hardware. Surges on the capnograms may be associated either with the termination of myorelaxation drug (muscle relaxant) action or with other respiratory pathologies, which call for further investigation.

In our experiments, the mass spectrometer was used both as a capnograph and as a meter of the inhalational anesthetic concentration in the breathing circuit of the AIA. It should be noted that designing an IR spectrometer for inhalational anesthetic sevoflurane is a challenging problem, since the absorption band of sevoflurane is near 10 μm [6], where the radiation intensity of small-size radiation sources is insufficient to provide the operation of an IR spectrometer with a time resolution of 500 ms or higher. In the case of the mass spectrometer, the sevoflurane ($C_4H_3F_7O$) concentration can be determined from the intensity of the peak $m/z = 199$, which corresponds to single ionization by electron impact. The electron energy used was 70 eV.

The time dependence of the sevoflurane concentration in the inspiration–expiration regime from the instance of sevoflurane injection into the breathing circuit to the instance sevoflurane escapes is shown in Fig. 4. The time delay between the optical signal and the signal from the mass spectrometer is 10 min or even more. In critical situations, such a long delay is unacceptable. The sevoflurane concentration measured at inspiration and expiration with the mass spectrometer demonstrates the tendency for a threefold decrease by the end of a surgery—a fact not detected by the optical sensor.

The variation of the sevoflurane concentration in the inspiration–expiration regime is, in essence, an "inverted" capnogram and may show the influence of myorelaxation drugs on the organism. Surges indicate the termination of the relaxant effect in 50% of cases.

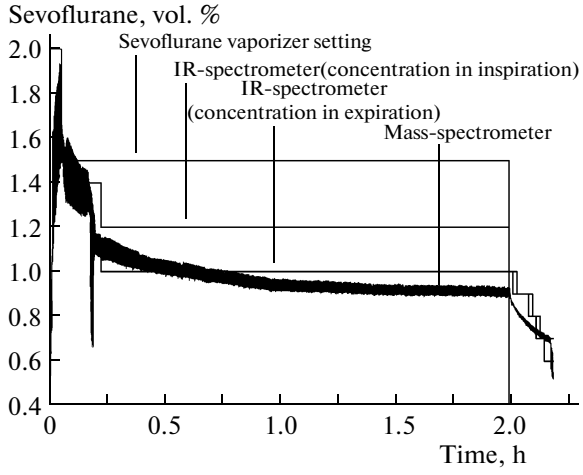

Fig. 4. Time variation of the sevoflurane concentration constructed from the readings of the vaporizer, mass spectrometer, and IR spectrometer.

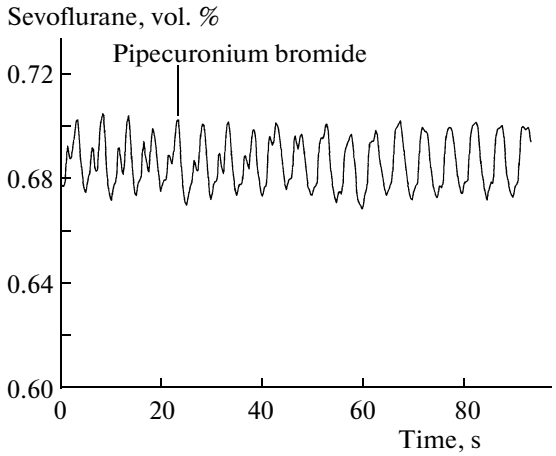

Fig. 5. Time variation of the sevoflurane concentration constructed from the readings of the vaporizer, mass spectrometer, and IR spectrometer before and after the introduction of the myorelaxation drug.

After a myorelaxation drug has been introduced (in our case, it was pipecuronium bromide: 2b,16b-*bis* (4-dimethyl-1-piperazino) 3a,17b-diacetoxy-5a-androstane dibromide), the anesthetic concentration curve smoothes out.

Figure 5 shows the variation of the sevoflurane concentration before and after the introduction of the pipecuronium bromide preparation.

SPELL OK

Thus, we demonstrated the advantages of using a mass spectrometer as a capnograph and its potential for analysis of gases present in the breathing circuit of the AIA and for noninvasive dynamic control of the myorelaxation efficiency in the course of a surgery.

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