ERRONEOUS MASS SPECTROMETER READINGS CAUSED BY DESFLURANE AND SEVOFLURANE

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Abel M, Eisenkraft JB. Erroneous mass spectrometer readings caused by desflurane and sevoflurane.
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ABSTRACT. Objective. Medical mass spectrometers are configured to detect and measure specific respiratory and anesthetic gases. Unrecognized gases entering these systems may cause erroneous readings. We determined how the Advantage 1100 (Perkin-Elmer, now Marquette Gas Systems, Milwaukee, WI) and PPG-SARA (PPG Biomedical Systems, Lenexa, KS) systems that were not configured to measure desflurane or sevoflurane respond to increasing concentrations of these new potent volatile anesthetic agents. **Methods.** Desflurane 0% to 18% in 3% increments or sevoflurane 0% to 7% in 1% increments in 5-L/min oxygen was delivered to the Advantage and PPG-SARA mass spectrometry systems. For each concentration of each agent, the displayed gas analysis readings and uncompensated collector plate voltages were recorded. **Results.** The Advantage 1100 system read both desflurane and sevoflurane mainly as enflurane and, to a lesser extent, as carbon dioxide and isoflurane. For enflurane(E) readings <9.9%, the approximate relationships are: %Desflurane = 1.6E; %Sevoflurane = 0.3E. These formulas do not apply if E >9.9% because of saturation of the summation bus. PPG-SARA read desflurane mainly as isoflurane(I) and, to a lesser extent, as nitrous oxide. PPG-SARA read sevoflurane mainly as enflurane(E) and, to a lesser extent, as nitrous oxide and halothane. The approximate relationships are: %Desflurane = 1.1I (for I < 9%); %Sevoflurane = 2.1E. **Conclusions.** Advantage 1100 and PPG-SARA systems not configured for desflurane or sevoflurane display erroneous anesthetic agent readings when these new agents are sampled. Advantage 1100 also displays falsely elevated carbon dioxide readings when desflurane is sampled.

KEY WORDS. Anesthetics: volatile; desflurane, sevoflurane. Measurement techniques: mass spectrometry.

INTRODUCTION

Magnetic sector medical mass spectrometers (Advantage 1100, Marquette Gas Systems, Milwaukee, WI, and SARA, PPG Biomedical Systems, Lenexa, KS) used to monitor respired gases in the operating room are configured by the manufacturer to detect specific volatile anesthetic agents [1]. Spurious readings from mass spectrometers have been reported following the administration of gases (e.g., aerosol propellants [2–4] and helium [5]) that are not recognized by the mass spectrometry system. Desflurane has recently been introduced into clinical use in the United States and sevoflurane is currently undergoing clinical trials. The sampling of these new potent inhaled agents by mass spectrometers not designed to measure them is likely to result in spurious readings. The purpose of this investigation was to determine how the Advantage 1100 and PPG-SARA medical mass spectrometers configured only for halothane, enflurane, isoflurane, nitrogen, nitrous oxide, oxygen, and carbon dioxide respond when desflurane or sevoflurane is sampled.

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METHODS AND MATERIALS

After institutional approval of the protocol, this study was conducted in vacant operating rooms at The Mount Sinai Medical Center. One operating room suite is served by a Perkin-Elmer (now Marquette) Advantage system, which uses a multiplexed MGA 1100 mass spectrometer analyzer. Another operating room suite is served by a PPG-SARA (System for Anesthetic and Respiratory Analysis) system, which uses a Medspect mass spectrometer. Both mass spectrometry systems are configured to measure the following seven gases: halothane, enflurane, isoflurane, carbon dioxide, nitrous oxide, nitrogen, and oxygen. They are maintained and regularly calibrated according to the manufacturers' recommendations.

To evaluate each mass spectrometry system, oxygen 5 L/min flowed to a concentration-calibrated agent-specific vaporizer mounted on an Ohmeda Excel 210 anesthesia machine (Ohmeda, Madison, WI). The desflurane vaporizer was an Ohmeda Tec 6 (Ohmeda, Steeton, W. Yorkshire, UK) and the sevoflurane vaporizer was a PPV Sigma Vaporizer (Penlon Ltd., Abingdon, Oxford, UK). The gas mixture emerging from the common gas outlet of the anesthesia machine was sampled by a Datex Capnomac Ultima agent-specific infrared gas analyzer (Datex, Tewksbury, MA) and by the mass spectrometry system being studied. The remaining gas was scavenged by an open-reservoir waste gas scavenging system. Before each study, the Datex analyzer was calibrated according to manufacturer's instructions using calibration gas as a standard. The calibration gas (Datex) contained a 2.9% enflurane equivalent concentration. The Datex Capnomac Ultima analyzer is specified by the manufacturer to have an accuracy of ±0.2 vols% (Datex Capnomac Ultima Operator's Manual).

The desflurane vaporizer output concentration was increased from 0% to 18% in 3% increments; the sevoflurane vaporizer output concentration was increased from 0% to 7% in 1% increments. Once a steady state (unchanging agent concentration reading for 60 sec) was attained for each concentration of each agent as measured by the Capnomac Ultima monitor, the mass spectrometer readings obtained for carbon dioxide, nitrogen, nitrous oxide, oxygen, halothane, enflurane, and isoflurane were recorded. The gas concentrations displayed on the mass spectrometry screen in the operating room and the uncompensated voltages, measured from the mass spectrometer collector plates, were recorded. The Advantage 1100 (Perkin-Elmer) mass spectrometer readings were taken with the system in the "real-time" mode. PPG-SARA readings were recorded with the system in the normal monitoring mode. Each system was studied twice with each agent.

The gas analysis values (mean of two) recorded from each mass spectrometry system were plotted against the measured (Datex Capnomac) concentrations of desflurane and sevoflurane. A linear regression analysis was performed between the displayed concentrations of major gases detected erroneously by the mass spectrometry system, and the measured concentrations of desflurane and sevoflurane.

RESULTS

Advantage 1100 (Perkin-Elmer, now Marquette Advantage) System

DESFLURANE. The readings displayed by the mass spectrometer are shown in Figure 1A and the collector plate voltages are shown in Figure 1B. Desflurane was read as enflurane and, to a lesser extent, as carbon dioxide

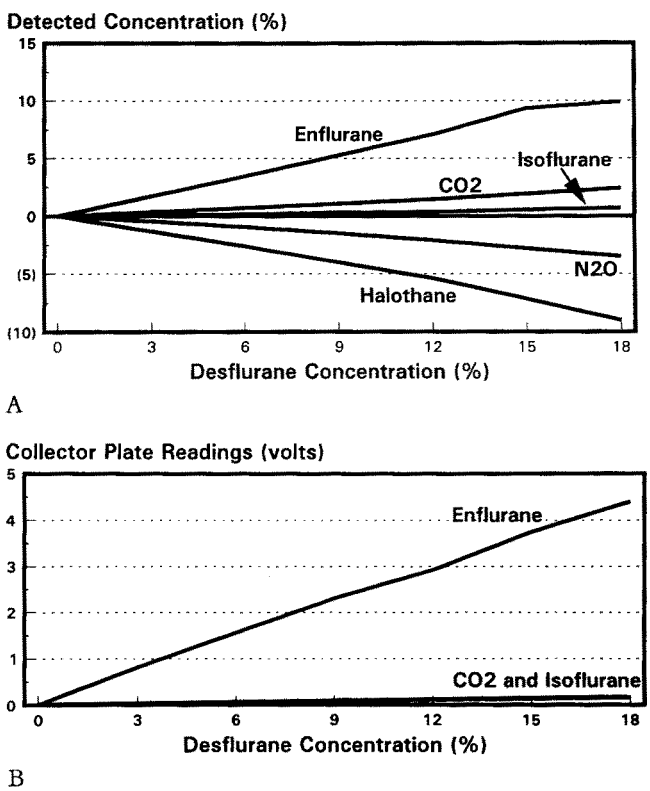

Fig 1. Responses of Advantage 1100 to increasing concentrations of desflurane. (A) Mass spectrometer gas concentration readings. Regression equation for enflurane readings <9.9%: %Desflurane = 1.64 enflurane reading (%) + 0.07 (r = 0.999); Carbon dioxide reading (%) = 0.13 desflurane concentration − 0.06 (r = 0.997). (B) Collector plate voltages.

and isoflurane. Negative concentration values were obtained for halothane and nitrous oxide. There was a linear relationship between the mass spectrometer readings for enflurane (<9.9%), carbon dioxide, and isoflurane, and the desflurane concentration. There was a negative linear relationship between the real-time halothane and nitrous oxide mass spectrometry readings and the concentration of desflurane. Desflurane was detected by the enflurane collector plate and, to a lesser extent, by the isoflurane and carbon dioxide collectors (see Fig 1B).

SEVOFLURANE. Sevoflurane was read as enflurane and, to a smaller extent, as carbon dioxide and isoflurane (Fig 2A). Negative values were obtained for halothane and nitrous oxide. There was a linear relationship between the enflurane (<9.9%), carbon dioxide, and isoflurane readings, and the sevoflurane concentration. The enflurane reading reached a ceiling at 9.9%, when the sevoflurane concentration was between 3% and 4%. There was a negative linear relationship between the halothane reading and the sevoflurane concentration. The halothane reading reached a floor at 10.1%, when the sevoflurane concentration was between 4% and 5%. Sevoflurane was detected by the enflurane collector plate and, to a lesser extent, by the halothane and enflurane collectors (Fig 2B).

PPG-SARA

DESFLURANE. Desflurane was read as isoflurane and, to a lesser extent, as nitrous oxide (Fig 3A). There was a linear relationship between the isoflurane reading (<8.7%) and the desflurane concentration. Desflurane was detected by the collector plates for isoflurane, enflurane, and nitrous oxide (Fig 3B).

SEVOFLURANE. Sevoflurane was read as enflurane and, to a much smaller extent, as nitrous oxide and halothane (Fig 4A). There was a linear relationship between the enflurane and nitrous oxide readings and the sevoflurane concentration. Sevoflurane was detected by the collector plates for enflurane, isoflurane, nitrous oxide, and halothane (Fig 4B).

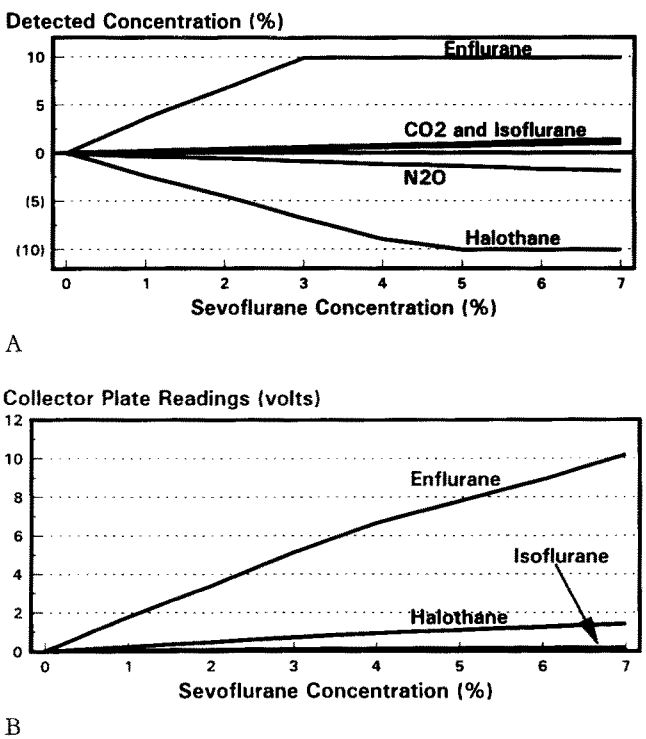

Fig 2. Responses of Advantage 1100 to increasing concentrations of sevoflurane. (A) Mass spectrometer gas concentration readings. Regression equation for enflurane readings <9.9%: %Sevoflurane = 0.30 enflurane reading (%) − 0.02 (r = 0.999); carbon dioxide reading (%) = 0.18 sevoflurane concentration (%) (r = 0.999). (B) Collector plate voltages.

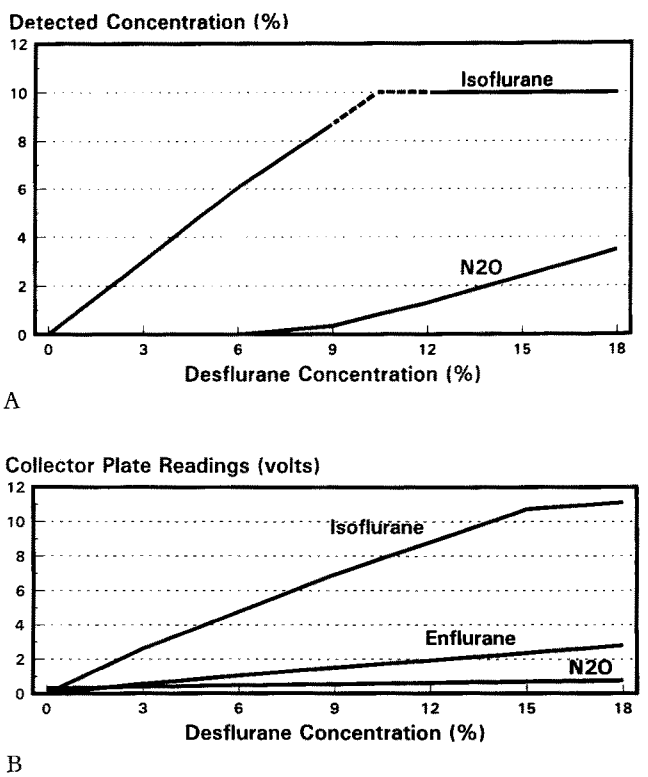

Fig 3. Responses of PPG-SARA to increasing concentrations of desflurane. (A) Mass spectrometer gas concentration readings. The broken line represents an extrapolation of the response from 0% to 9% desflurane. Regression equation for isoflurane readings <9%: %Desflurane = 1.05 isoflurane reading (%) − 0.11 (r = 0.999). (B) Collector plate voltages.

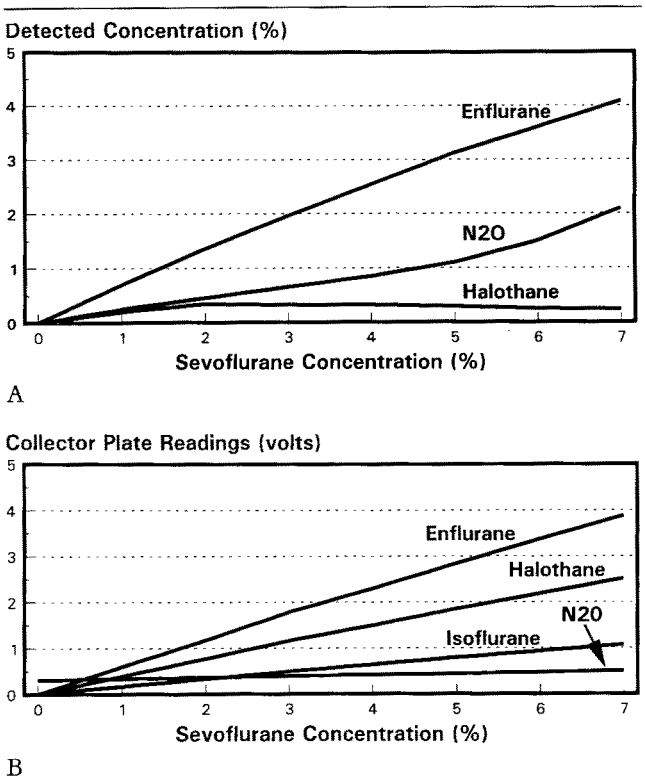

Fig 4. Responses of PPG-SARA to increasing concentrations of sevoflurane. (A) Mass spectrometer gas concentration readings. Regression equation for enflurane readings: %Sevoflurane = 2.08 enflurane reading (%) − 0.35 (r = 0.99). (B) Collector plate voltages.

The results of the regression analyses are shown in the respective figure legends.

DISCUSSION

Our results show that when desflurane or sevoflurane are sampled by mass spectrometry systems not configured for these agents, erroneous readings for anesthetic agent and carbon dioxide are displayed. Such erroneous readings might cause an unsuspecting clinician to misinterpret a clinical situation in terms of inhaled anesthetic and carbon dioxide status.

The mass spectrometer is an instrument that allows the breath- by-breath detection of all gases commonly encountered during the administration of an inhalational anesthetic. The most common design is magnetic sector analysis, so called because it uses a permanent magnet to separate an ion beam into its component ion spectra according to their mass/charge ratios (m/z) [1]. A small amount of the gas sampled enters the analyzer unit high-vacuum system through a molecular inlet leak. The gas molecules are then bombarded by an electron beam, which causes some of the molecules to lose one or more electrons and become positively charged ions. Large molecules, such as the potent volatile anesthetic agents, become fragmented or "cracked" into smaller positively charged ions. The magnetic field influences the direction of the ions, causing each ion species to curve in a trajectory whose arc is related to its m/z. The separate beams thus created are directed to individual collectors, which detect the ion current and transmit it to amplifiers that create output voltages in relation to the abundance of the ions detected. Summing and other computer circuitry (the "summation bus") measure the total voltage from all the collectors, as well as the individual voltages from each collector.

The Marquette Advantage and PPG-SARA systems use magnetic sector analyzers that may have up to eight collectors configured to detect up to eight gases. Usually (as in our two systems) there are only seven collector plates to measure seven gases: oxygen, nitrous oxide, nitrogen, halothane, enflurane, isoflurane, and carbon dioxide. The position of each collector is determined by the m/z of the ion species to be detected [1]. Saturation of individual collector plates occurs at 10 V and 12 V for the Advantage 1100 and PPG-SARA systems, respectively. If the concentration of a particular gas results in saturation of an individual collector plate, no further increase in concentration reading occurs.

The spurious readings obtained with desflurane and sevoflurane are explainable on the basis of the mass spectra of the agents, the locations of the fixed collector plates, the summing circuitry, and the detection algorithms, which differ between the PPG-SARA and Advantage 1100 systems. The mass spectra for enflurane, desflurane, sevoflurane, halothane, and isoflurane are shown in Figures 5 through 9, respectively. The collector plate locations in the PPG-SARA and the Advantage 1100 systems are shown in the Table.

When desflurane enters the Advantage 1100, it is erroneously detected as enflurane in concentrations approximately two thirds of the true desflurane concentration (see Fig 1A). The m/z peak at 69 on the mass spectrum of desflurane results in "hits" on the enflurane collector plate and, therefore, a spurious enflurane reading. The much smaller erroneous readings for carbon dioxide and isoflurane result from fragments at m/z 12 (not shown in Fig 6) and m/z 87 "hitting" these detectors, respectively. The negative reading for halothane is an artifact resulting from the summing circuitry's spectrum overlap compensation.

When enflurane enters the Advantage 1100, it "hits" its specific collector at m/z 69 and, to a lesser extent, the halothane collector at 117 (see Fig 5 and Table). The summing circuitry subtracts the "hits" on the 117

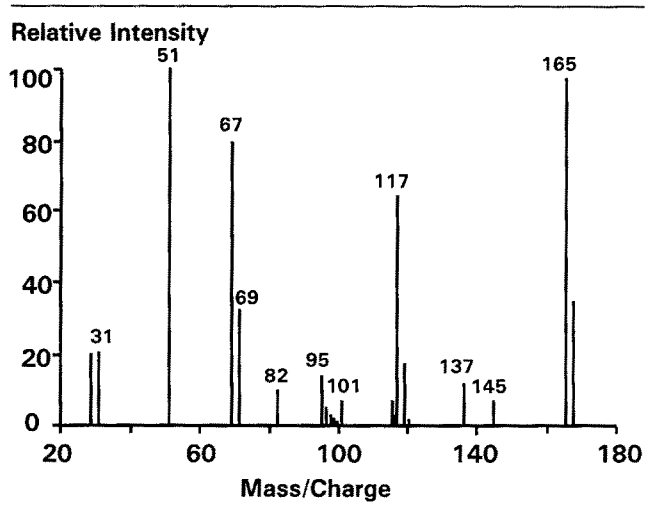

Fig 5. Mass spectrum of enflurane: y axis shows relative intensity of peaks; x axis shows mass/charge ratios (m/z). Drawn from data provided by Ohmeda, Inc., Murray Hill, NJ.

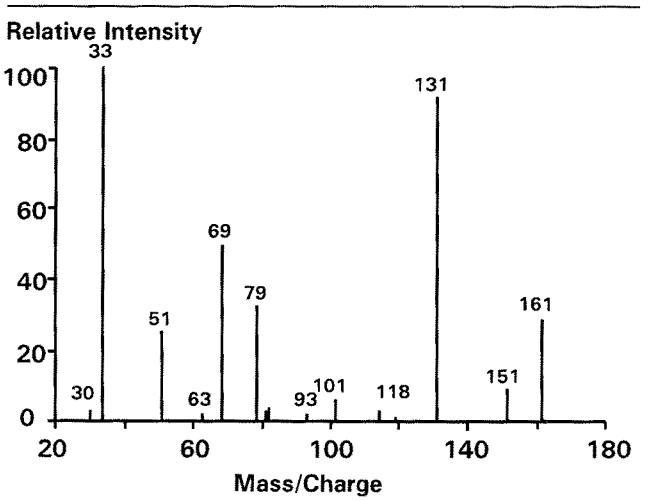

Fig 7. Mass spectrum of sevoflurane: y axis shows relative intensity of peaks; x axis shows mass/charge ratios (m/z). Drawn from data provided by Abbott Laboratories, Abbott Park, IL.

(halothane) collector so that the displayed halothane concentration is 0% when enflurane is the sole potent agent. Thus, a negative correction for halothane (equivalent to a negative halothane concentration) has been applied to the system. Desflurane lacks a peak at m/z 117 (see Fig 6); but, the computerized compensation still occurs, resulting in a negative halothane reading. In Figures 2A and 2B, the small positive voltage but negative concentration reading for halothane is explained by sevoflurane's small peak at m/z 118. Sevoflurane fragments strike the halothane collector at m/z 117, but they do so to a much lesser degree than enflurane, which has a much larger peak at m/z 117. Thus, the computerized compensation occurs as described above. A negative reading for halothane is only displayed in the real-time/analysis mode. In the monitoring (breath detection) mode (i.e., when a capnogram is present), concentration readings that would be negative in the real-time mode are displayed as zero.

Sevoflurane is also read erroneously as enflurane by the Advantage 1100. Sevoflurane has a large peak at m/z 69 (see Fig 7) and, therefore, "hits" the collector plate for enflurane. The erroneous enflurane value is approximately 3.4 times the actual sevoflurane concentration.

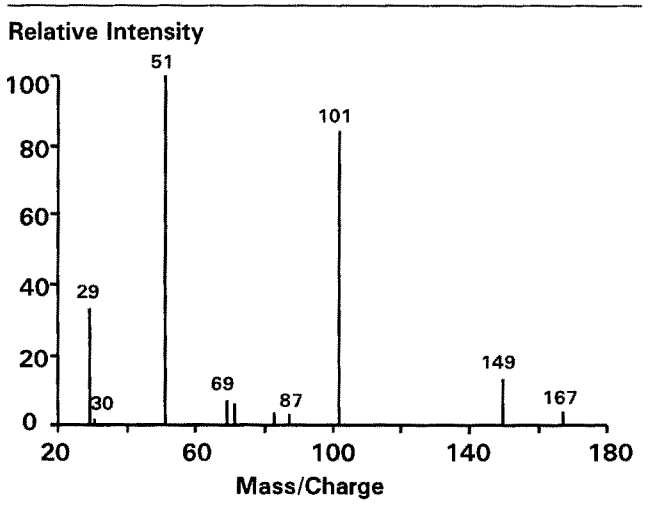

Fig 6. Mass spectrum of desflurane: y axis shows relative intensity of peaks; x axis shows mass/charge ratios (m/z). Drawn from data provided by Ohmeda, Inc., Murray Hill, NJ.

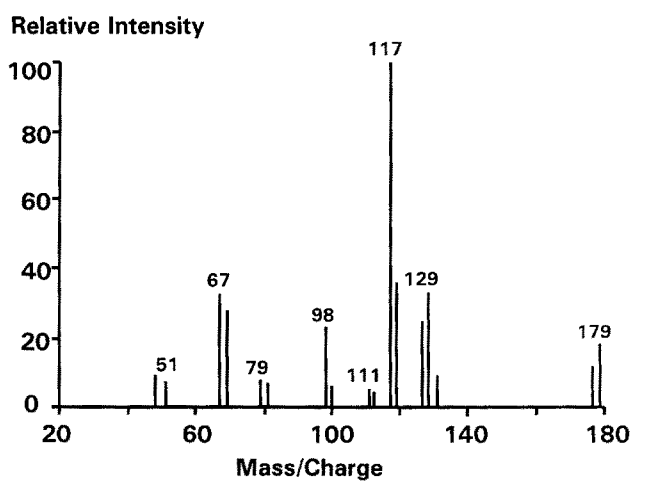

Fig 8. Mass spectrum of halothane: y axis shows relative intensity of peaks; x axis shows mass/charge ratios (m/z). Drawn from data provided by Ohmeda, Inc., Murray Hill, NJ.

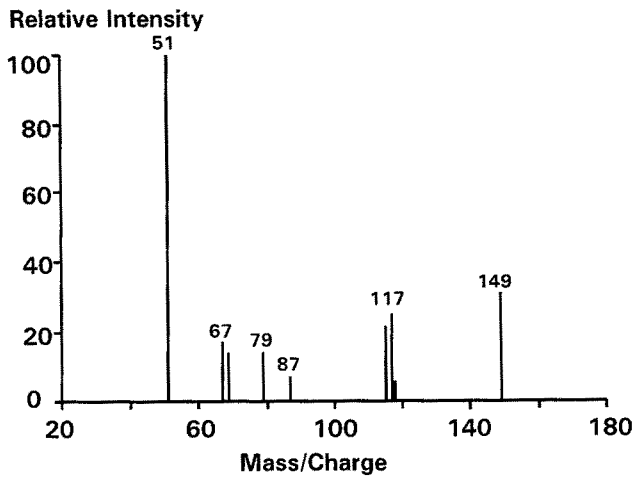

Fig 9. Mass spectrum of isoflurane: y axis shows relative intensity of peaks; x axis shows mass/charge ratios (m/z). Drawn from data provided by Ohmeda, Inc., Murray Hill, NJ.

The explanations for the erroneous carbon dioxide and isoflurane readings, as well as the negative reading for halothane, are due to computer compensations as described above for desflurane.

Both desflurane and sevoflurane produce erroneous concentration readings for carbon dioxide in the Advantage 1100 systems (see Figs 1 and 2). This will result in spuriously increased inspired and end-expired carbon dioxide readings. For example, at a desflurane concentration of 6%, inspired and end-tidal carbon dioxide would be increased by approximately 0.72% or 5.5 mm Hg (assuming atmospheric pressure is 760 mm Hg).

The introduction of desflurane into the PPG-SARA mass spectrometer results in erroneous isoflurane readings. Desflurane's large peak at m/z 51 results in "hits" on the collector plate for isoflurane (see Fig 6 and Table). The erroneous small nitrous oxide reading probably results from the small peak at m/z 30 in desflurane's mass spectrum, as well as "spillover signals" from oxygen and nitrogen at m/z 33 and 28, respectively, causing "hits" on the collector plate for nitrous oxide. The nonlinearity of the nitrous oxide signal (see Fig 3A) may represent a limitation of the summing circuitry in subtracting these spillover signals. Although the mass spectrum of desflurane shows a peak at m/z 69, which results in "hits" on the collector plate for enflurane, these are eliminated by the PPG-SARA compensation circuitry, resulting in an enflurane reading of zero.

Mass/Charge Monitored[a]

Compound	Advantage 1100	PPG-SARA
Halothane	117	118
Enflurane	69	67–69
Isoflurane	87	51
Oxygen	32	32
Nitrous oxide	44	30
Nitrogen	28	28
Carbon dioxide	44 minus 12	12

[a]Information obtained from system manufacturers.

Sevoflurane has a peak at m/z 69 and is erroneously interpreted as enflurane by the PPG-SARA mass spectrometer. Smaller erroneous readings for nitrous oxide and halothane result from small peaks at m/z 118 and 30, respectively, in the mass spectrum of sevoflurane (see Fig 7), as well as from spillover signals as described above. Sevoflurane's large peak at m/z 131 may also contribute to the "hits" on the halothane collector system seen with the introduction of sevoflurane into PPG-SARA. Although halothane is detected by a collector plate at m/z 118, the resolution of the system is poor at the high end of the spectrum [2], allowing the peak at m/z 131 to contribute to "hits" on the collector plate for m/z 118. The nonlinearity of the halothane response at low concentrations of sevoflurane may represent a limitation in the PPG-SARA correction signal.

We conclude that desflurane is read as isoflurane by the PPG-SARA system, but as enflurane by the Advantage 1100. The installation of an additional collector plate and channel for desflurane would allow either system to identify and quantify desflurane. Marquette currently offers an upgrade for the Advantage System to measure desflurane. This involves the addition of an eighth collector plate for m/z 101. PPG-SARA currently has no plans to upgrade its system to measure desflurane (personal communication, PPG-SARA).

Sevoflurane is currently undergoing clinical trials in the United States and ultimately may be approved for clinical use. It is erroneously read as enflurane by both mass spectrometry systems. If enflurane were withdrawn from use in the operating room, the enflurane channel of either mass spectrometry system could be utilized to measure sevoflurane. Indeed, in Japan, where enflurane is not in clinical use, the Advantage 1100 channel at m/z 69 is used to measure sevoflurane. Alternatively, another collector plate and channel could be used to measure sevoflurane, provided that the total number of collectors and channels (and, therefore, measured gases) does not exceed eight.

Anesthetic agent analysis is not currently a standard for basic intraoperative monitoring, but it is commonly used during the administration of inhalational anesthesia. Monitoring of respired carbon dioxide is rapidly becoming the standard of care. Users of Advantage 1100 and PPG-SARA mass spectrometry systems

should be aware of possible spurious anesthetic agent and carbon dioxide readings when new potent inhaled agents, for which these systems are not configured, are introduced into clinical use in their operating room suites.

This study was presented in part at the annual meetings of the Society for Technology in Anesthesia, Orlando, FL, January 1994, and of the American Society of Anesthesiologists, San Francisco, CA, October 1994.

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