Evaluation of isoflurane and sevoflurane vaporizers over a wide range of oxygen flow rates

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Objective—To examine the accuracy and precision of isoflurane and sevoflurane anesthetic vaporizers.

Sample Population—5 identcal isoflurane and 5 identical sevoflurane vaporizers.

Procedures—Oxygen flow rates from 0.02 to 10 L/min were used with different vaporizer dial settings. Agent concentrations were measured at the common gas outlet by use of a refractometer. Accuracy was defined as the difference between measured agent concentrations, and dial settings were expressed as a percentage of the applied dial settings. Precision was defined as SD of the measured agent concentrations for each combination of dial setting and flow.

Results—Isoflurane values were generally greater than the dial settings. Accuracy of the isoflurane vaporizer was > 20% when 0.6% and 1% was dialed. Accuracy of the sevoflurane vaporizer was always within ± 20% but decreased at 0.02 L/min flow and at combinations of high flow and high dial settings. Overall precision of the isoflurane vaporizer was better than that of the sevoflurane vaporizer.

Conclusions and Clinical Relevance—A possible explanation for the inaccuracy of the isoflurane vaporizer may be that it was manufactured to be accurate with air but not oxygen, which must be accounted for when using the vaporizer with oxygen, especially with nonrebreathing systems. The sevoflurane vaporizer may not deliver accurate agent concentrations at high flow and high dial settings. Both vaporizers are suitable for clinical use with a wide range of oxygen flow rates if these precautions are properly addressed. (*Am J Vet Res* 2006;67:936–940)

Dosage ranges of volatile anesthetics at which effective anesthesia is achieved without undesirable systemic effects are narrow; even at those dosages, cardiovascular and respiratory suppression may develop.[1] Therefore, close monitoring of anesthetized patients is important to allow delivery of the minimum necessary amount of anesthetic without compromising physiologic functions. One aspect of delivering safe, accurate anesthesia is the importance of the reliability of anesthetic vaporizers that allow constant delivery of agents in a reproducible manner, independently of the fresh gas flow used.

Few reports have been published that assess the performance of different vaporizers. Data are distributed by the vaporizer manufacturers, but those data often do not include details of the experiments (eg, SD of the data and the number of machines examined). It is also important for others to be able to reproduce the data distributed by the vaporizer manufacturers. Most vaporizers presently being marketed are sold for use in humans, and the distributed vaporizer accuracy data are usually for a range of flow rate from 0.2 to 10 L/min.[a,b] The Matthew J. Ryan Veterinary Hospital of the University of Pennsylvania has been using closed-circuit anesthesia for more than a quarter of a century to anesthetize small animal patients that weigh > 2 kg. Depending on weight, most of those animals need an oxygen flow rate from 0.02 to 0.2 L/min, which is lower than the flow rates used in human anesthesia and for which there are no data from the vaporizer manufacturers. These data are important for use of closed-circuit or low flow rates in small animal patients.

The purpose of the study reported here was to examine the accuracy and precision of 5 isoflurane and 5 sevoflurane vaporizers in our hospital, over a wide range of oxygen flow rates.

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Materials and Methods

Vaporizers—Five identical isoflurane[c] and 5 identical sevoflurane[d] vaporizers were tested in this study. To avoid bias caused by the use of different anesthesia machines, 5 isoflurane vaporizers that were mounted on the same anesthesia machines[e] as 5 sevoflurane vaporizers were used in this study. Only 2 vaporizers (1 of each type) were mounted on the anesthesia machines; vaporizers were mounted in tandem mode with different interlock systems to prevent cross-contamination with different agents. All vaporizers were tested by an external professional service[f] within 6 months prior to the study and performed within ± 20% of the examined dial settings when oxygen was used as carrier gas. All of the vaporizers and anesthesia machines used in this study were in good condition and were used regularly to provide anesthesia for small animal patients. The study was completed within 3 weeks.

Procedures—The order in which the vaporizers were tested was determined by availability (ie, not used for clinical anesthesia at the time). Each vaporizer was tested once with 100% oxygen as the carrier gas. Flow rates were set in the following order: 0.2, 0.15, 0.1, 0.05, and 0.02 L/min (low flow rates), then 0.5, 1, 3, 6, and 10 L/min (higher flow rates). The reason for the decreasing order for low flow rates was that when a vaporizer is used, oxygen must flow to flush out any agent left in the path of gases from previous use. When starting with the lowest flow (0.02 L/min), the output did not stabilize for approximately 1 hour, whereas when starting with 0.2 L/min, the output stabilized within 10 to 15 minutes. When proceeding at decreasing flow rates, the output was more stable and stability developed more quickly. Low flow rates were measured by use of a calibrated glass cylinder, which was filled with water and placed into a tank of water in an inverted position. Gas from the common gas outlet of the anesthesia machine was directed into this cylinder for 1 minute, and the volume of water displaced from the cylinder indicated gas flow from the anesthesia machine (water-displacement method). Flow meters on the anesthesia machines consisted of 2 serially connected flow indicator tubes: one for flow rates < 1 L/min and the other for flow rates from 1 to 10 L/min. These tubes were used to measure high oxygen flow rates (> 0.2 L/min). At each flow rate, different concentrations were tested from lower to higher vaporizer dial settings as follows: 0.6%, 1%, 2%, 3%, 4%, and 5% isoflurane and 0.6%, 1%, 2%, 3%, 4%, 5%, 6%, 7%, and 8% sevoflurane. The time allowed for stabilization of measurement (flow time) was determined in preliminary trials as follows: 0.02 L/min for 20 minutes, 0.05 L/min for 10 minutes, 0.1 L/min for 4 minutes, 0.15 L/min for 4 minutes, 0.2 L/min for 2 minutes, 0.5 L/min for 1 minute, 1 L/min for 1 minute, 3 L/min for 0.5 minutes, 6 L/min for 0.5 minutes, and 10 L/min for 0.5 minutes. The output concentration of both types of vaporizers tended to continuously decrease at flow rates of 6 and 10 L/min, especially at higher dial settings, probably because of the continuous cooling of the liquid agent in the vaporizing chamber. Because of the cooling of vaporizers, we did not wait until the concentration stabilized but uniformly sampled gas for measurement 30 seconds after each change in the dial setting while testing 3, 6, and 10 L/min flow rates. Gas samples were collected at the common gas outlet of the anesthesia machines and analyzed with a calibrated portable anesthetic gas indicator.[g] A similar indicator was used by the professional service[f] that tested the vaporizers. The instrument was calibrated by the distributor 6 months before the experiment, and the accuracy of its readings was claimed to be within ± 3%. Calibration was also checked with air and 100% oxygen before each series of measurements. This gas indicator functions as a refractometer. The refractive index of a gas mixture depends on the gas composition, pressure, and temperature. If the ambient pressure and temperature are kept constant and the carrier gas composition is known (eg, oxygen or air), the volume percentage of a known anesthetic agent can be directly read from a properly calibrated scale. Any agent can be measured by multiplying the scale reading with an agent-specific constant provided by the manufacturer of the instrument. Although the refractometer is a handy and reliable instrument that is suitable for vaporizer testing in hospitals, its accuracy is less than that of other methods (eg, mass spectrometry) used in laboratory situations. However, the accuracy of the refractometer was sufficient for clinical interpretation of a vaporizer's accuracy and is a well-established method for measurement of anesthetic vapors.[2-6]

In this experiment, the rubber hand bulb of the refractometer was used to aspirate samples to the test chamber of the instrument when the oxygen flow was ≥ 0.5 L/min. However, at lower flow rates, the sample gas was allowed to flow directly through the chamber of the instrument to allow more effective collection of the slowly accumulating gas sample. This direct method is not recommended by the manufacturer because of the risk that pressure may increase inside the instrument and lead to erroneously high readings, especially at high flow-rate ranges at which commonly used vaporizers are recommended for use. However, in this study, unusually low gas flow rates were tested, which generate small, unimportant pressure changes inside the instrument. To rule out this possibility, the effect of continuous 0.2 L/min oxygen flow was tested, compared with no flow through the instrument, by use of different concentrations of isoflurane before the study; no difference was evident on the reading scale of the refractometer. Therefore, it was concluded that a direct flow rate of ≤ 0.2 L of oxygen/min through the refractometer would not adversely affect the accuracy of measurements in this study.

Each vaporizer was filled to the maximum level with the appropriate agent at least 2 hours before the experiment. Isoflurane[h] and sevoflurane[i] were used as anesthetic agents. The ambient temperature was approximately 22°C, controlled by air conditioning. The ambient pressure was approximately 102 kPa in Philadelphia when the study was conducted, which was confirmed by comparison with online US weather reports. During the 3 weeks of the study, there was no major change in weather conditions. Knowing the ambient pressure may be important if one wants to apply data from this report to conditions at different altitude.

Data analysis—The mean and SD of the measured agent concentrations were plotted against the flow rates, and the vaporizer dial settings were used as treatment groups. Accuracy was defined as the difference between each measured concentration, and the corresponding dial setting was expressed as a percentage of the applied dial setting. The overall accuracy of each vaporizer type was defined as the mean of the absolute values of all individual accuracy data for that particular vaporizer type. The reason to use absolute values was that the mean of positive and negative accuracy data (eg, sevoflurane concentrations for the 8% dial setting) may be close to zero, thereby falsely reflecting a good accuracy. Accuracy was considered to be good when it was within ± 20%, as recommended by the International Organization for Standardization.[7] Precision was defined as the SD of the measured concentration values for each combination of dial setting and flow. The overall precision of each vaporizer type was defined as the mean of all precision data for that particular vaporizer type.

Accuracy data for each dial setting of each vaporizer type were analyzed separately by use of 1-way ANOVA across oxygen flow rates. Also, accuracy data for each flow rate setting of each vaporizer type were analyzed separately with another set of 1-way ANOVA, with dial setting used as a factor. The precision data of each vaporizer type were analyzed with 1-way ANOVA across dial settings regardless of the flow rate and also across flow rate settings regardless of the dial setting. When significance was found with ANOVA, the Tukey test was used to compare the means. The overall accuracy and precision of the vaporizer types were compared with the unpaired *t* test (2 tailed). For all comparisons, $P < 0.05$ was considered significant. A software package[j] was used for statistical analysis.

Results

The overall accuracy for isoflurane vaporizers (19.3%) was significantly greater than that of the sevoflurane vaporizers (8.6%). Isoflurane concentrations were generally greater than the dial settings (**Figure 1**). The accuracy of isoflurane vaporizers was not within the ideal ± 20% range at 0.6% and 1% dial settings with all of the flow rates and also at the 2% dial setting and 6 L/min flow rate (**Table 1**). Conversely, the accuracy data of sevoflurane vaporizers were always within the ± 20% range. Oxygen flow rate settings significantly affected the accuracy of isoflurane vaporizers at 2%, 3%, 4%, and 5% dial settings but not at 0.6% and 1%. Isoflurane output decreased at the lowest and highest flow rate settings; therefore, the accuracy of isoflurane vaporizers improved at this range. Dial settings significantly affected the accuracy of isoflurane vaporizers at all flow rate settings, resulting in the worst accuracy at 0.6% and 1% dial settings. Oxygen flow rate settings also significantly affected the accuracy of sevoflurane

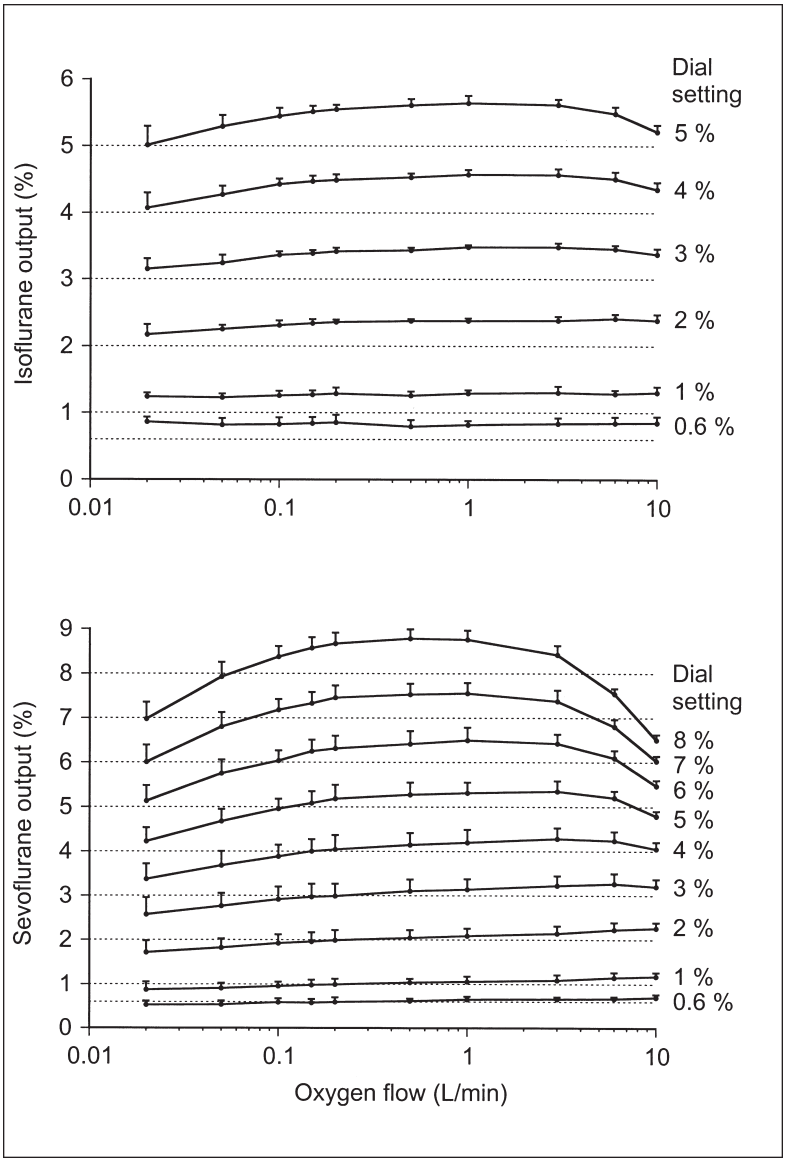

Figure 1—Mean output agent concentrations of 5 isoflurane and 5 sevoflurane vaporizers over a range of oxygen flow rates (log scale) and dial settings. Vertical bars represent SDs and precision of vaporizers.

vaporizers at all dial settings. Differences among the accuracy data were often higher as the dial settings increased, providing lower sevoflurane concentrations at the highest and lowest flow rate settings. Dial settings significantly affected the accuracy of sevoflurane vaporizers at 6 and 10 L/min oxygen flow rates, at which sevoflurane concentrations decreased at the highest dial settings.

The overall precision of isoflurane vaporizers (0.087%) was significantly better than that of sevoflurane vaporizers (0.209%). Dial and flow rate settings significantly affected the precision of both vaporizer types (**Table 2**). Isoflurane vaporizers were significantly less precise at the 0.02 L/min flow rate and also at the 5% dial setting. Sevoflurane vaporizers were significantly more precise at 0.6% and 1% dial settings and also at 6 and 10 L/min flow rates (Figure 1).

Discussion

Our results indicated that the isoflurane vaporizers were less accurate than the sevoflurane vaporizers. Most of the measured isoflurane concentrations were higher than the dial settings. This observation may be related to the method of calibration. The manufacturer recommends calibrating these isoflurane vaporizers with air as the carrier gas, and our vaporizers were probably calibrated this way in the factory. It is known that the composition of the carrier gas influences the accuracy of vaporizers.[8] Gases may differ in their viscosity and density, which influence their tendency to flow in a turbulent pattern (as described by the Reynolds number). A large difference between turbulent and laminar flow is that turbulent flow generates higher resistance, and the relationship between resistance and flow is nonlinear and unpredictable for turbulent flow and this relationship is linear for ideal laminar flow.[9] The vaporizers used in this study were variable bypass vaporizers. The amount of turbulence in different flow paths of vaporizers may unequally change resistance as the fresh gas flow changes; therefore, the split ratio and the output concentration of anesthetic vapor may also change.[8] According to the operating instructions[a] of isoflurane vaporizers, when pure oxygen is used, the delivered concentrations are approximately 5% to 10% higher than the corresponding values for air and approximately 5% to 10% lower when using 70% nitrous oxide in oxygen. Studies with the same isoflurane vaporizers reveal that delivered isoflurane concentrations are generally lower[10] than and halothane concentrations are similar to or lower[k] than the dial settings when air is used as carrier gas. This may explain why the isoflurane vaporizers in the present study delivered more anesthetic than expected when pure oxygen was used. Also, helium is often used in mixtures with oxygen for endoscopic laser surgery[11,12] and may be used for patients with airway obstruction.[13] The output agent concentrations delivered by the isoflurane vaporizers were slightly higher than dialed when helium was a part of the carrier gas, but were not > 10%.[14]

The overall accuracy of sevoflurane vaporizers was better than that of isoflurane vaporizers in this study, probably because sevoflurane vaporizers were calibrated with oxygen by the manufacturer. The composition of the carrier gases may affect the accuracy of these vaporizers as well. According to the instruction manual,[b] a mixture of 70% nitrous oxide in oxygen may decrease the output concentration by up to 15% and use of air may decrease the output by a maximum of 5%. Interestingly, use of helium mixtures with this

Table 1—Accuracy of 5 isoflurane (ISO) and 5 sevoflurane (SEVO) vaporizers indicated as mean differences between measured agent concentrations (%) and dial settings expressed as a percentage of the applied dial settings.

	Oxygen flow rate (L/min)										
Dial setting	**0.02**	**0.05**	**0.1**	**0.15**	**0.2**	**0.5**	**1**	**3**	**6**	**10**	**Critical difference**
ISO 5%	0.2	5.7	8.8	10.2	10.8	12.1	12.8	12.2	9.5	4.2	5.7
ISO 4%	1.8	6.9	10.7	11.9	12.3	13.3	14.3	14.2	12.6	8.8	6
ISO 3%	5.1	8.1	12	12.9	13.9	14.4	16.0	16	15	12.4	5.6
ISO 2%	8.6	12.6	15.4	17	17.9	18.7	18.8	19	20.4*	19.1	7.8
ISO 1%	24*	22.8*	25.7*	27.1*	28.7*	25.6*	29*	30.1*	28.2*	30.3*	NS
ISO 0.6%	44.3*	36.5*	38.3*	40.4*	42.5*	32.6*	36.5*	39.6*	40.9*	41.7*	NS
Crit diff	14.1	14.9	14.8	13.8	17	14.2	9.4	13.9	13.6	15.2	
SEVO 8%	–12.8	–0.9	4.7	7.1	8.4	9.8	9.5	5.2	–5.7	–18.7	6.4
SEVO 7%	–14.2	–2.8	2.6	4.8	6.6	7.7	8	5.4	–2.8	–13.9	7.9
SEVO 6%	–14.5	–4.2	0.6	4.2	5.2	6.9	8.3	7.1	1.6	–8.8	9.2
SEVO 5%	–15.4	–6.4	–0.8	1.7	3.6	5.4	6.2	6.9	4	–4.1	10.4
SEVO 4%	–15.7	–7.9	–2.9	0.1	1.2	3.7	5	7.2	6	1.4	14.6
SEVO 3%	–14.2	–7.8	–2.9	–1	–0.4	3.4	4.6	7.5	8.9	6.8	19.1
SEVO 2%	–14.1	–8.9	–3.8	–2.1	–0.5	2.2	4.5	7.2	11.4	13.2	20.6
SEVO 1%	–12.7	–9.3	–4.4	–1.7	–0.5	4	5.9	9	15.2	17.9	25.6
SEVO 0.6%	–11.4	–10.4	–1.4	–3.6	–0.6	3.7	9.6	10.7	11.8	17.5	26.8
Crit diff	NS	NS	NS	NS	NS	NS	NS	NS	13.4	12.1	

*Value not within the ± 20% range recommended by the International Organization for Standardization.[7]
Crit diff = Significant ($P < 0.05$) critical differences between the means. NS = Not significant.

Table 2—Precision of 5 ISO and 5 SEVO vaporizers presented as SD of the measured concentration values (%) for each combination of dial settings and flow rates.

	Oxygen flow rate (L/min)										
Dial setting	**0.02**	**0.05**	**0.1**	**0.15**	**0.2**	**0.5**	**1**	**3**	**6**	**10**	**Mean**
ISO 5%	0.28	0.17	0.12	0.09	0.07	0.10	0.11	0.08	0.10	0.10	0.12
ISO 4%	0.23	0.13	0.08	0.08	0.08	0.06	0.07	0.09	0.10	0.11	0.1
ISO 3%	0.15	0.12	0.05	0.05	0.05	0.04	0.03	0.06	0.06	0.09	0.07
ISO 2%	0.15	0.06	0.07	0.06	0.04	0.03	0.04	0.06	0.07	0.09	0.07
ISO 1%	0.06	0.06	0.07	0.06	0.09	0.06	0.05	0.10	0.05	0.09	0.07
ISO 0.6%	0.07	0.10	0.10	0.09	0.11	0.10	0.06	0.08	0.09	0.09	0.09
Mean	0.16	0.11	0.08	0.07	0.08	0.07	0.06	0.08	0.08	0.09	
SEVO 8%	0.38	0.32	0.23	0.24	0.24	0.21	0.20	0.21	0.12	0.12	0.23
SEVO 7%	0.39	0.32	0.24	0.26	0.27	0.24	0.24	0.25	0.16	0.11	0.25
SEVO 6%	0.35	0.31	0.23	0.26	0.28	0.30	0.29	0.21	0.17	0.13	0.26
SEVO 5%	0.31	0.27	0.22	0.26	0.31	0.27	0.24	0.24	0.15	0.11	0.24
SEVO 4%	0.35	0.32	0.26	0.27	0.32	0.27	0.29	0.25	0.20	0.15	0.27
SEVO 3%	0.38	0.29	0.29	0.29	0.28	0.26	0.24	0.22	0.23	0.17	0.27
SEVO 2%	0.26	0.21	0.20	0.21	0.23	0.18	0.17	0.17	0.16	0.13	0.19
SEVO 1%	0.18	0.12	0.10	0.12	0.13	0.09	0.12	0.12	0.12	0.09	0.12
SEVO 0.6%	0.09	0.09	0.09	0.08	0.11	0.06	0.07	0.05	0.05	0.06	0.07
Mean	0.3	0.25	0.21	0.22	0.24	0.21	0.21	0.19	0.15	0.12	

The significant ($P < 0.05$) critical differences between mean isoflurane precision values were 0.05% when dial setting was used and 0.07% when oxygen flow was used as independent variable during calculation. The same values for sevoflurane were 0.08% and 0.12%, respectively.

sevoflurane vaporizer may lower the output concentrations, but specific data are not published in the manual.[b] However, the manual indicated that these changes may be outside of the ± 20% range and recommended the use of an agent analyzer if accurate concentrations are desirable when using helium. The data reported here were similar to those published in the instruction manual for higher flow rates.[b] Additionally, the present study confirmed that accuracy of these sevoflurane vaporizers is reasonably good at low oxygen flow rate ranges as well. Other published data about these sevoflurane vaporizers could not be found.

Use of different carrier gas mixtures in certain clinical settings may often challenge the anesthetist. Although the effect of carrier gas composition on the vaporizers tested in this study was not evaluated, according to data from the literature, it seems that isoflurane and sevoflurane vaporizers are similarly affected. Although oxygen is the most commonly used carrier gas in veterinary anesthesia, the accuracy of these isoflurane vaporizers is less than the standard when oxygen is used and the agent concentrations may be higher than the dial settings. This may be clinically more important when using nonrebreathing systems because 0.6% to 1% isoflurane may often be dialed and the agent concentrations inhaled by the patient are the same as the delivered concentrations. Accuracy of the sevoflurane vaporizers is very good when oxygen is the carrier gas, and if the carrier gas was changed, sevoflurane concentrations may decrease.

The concentration of both agents decreased at low oxygen flow rates and higher dial settings, but the accuracy remained within the ideal ± 20% except for 0.6% and 1% isoflurane dial settings. Because agent concentration in the breathing circuit changes slowly during closed circuit anesthesia, the effect of small inaccuracies in vaporizer output is probably clinically negligible in that situation.

Mean sevoflurane concentrations decreased at combinations of the highest flow rates and dial settings in this study, probably because under these circumstances, the flow through the vaporizing chamber was so high that full saturation of oxygen with sevoflurane might not have been possible. This may have clinical importance when using these sevoflurane vaporizers for mask induction of humans[15] or animals or for chamber induction of animals.

Overall precision was better for the isoflurane vaporizers, but it was reasonably good for both vaporizer types; therefore, the user should be able to consistently correct for the inaccuracies. For example, one has to be careful when using these isoflurane vaporizers with oxygen and a nonrebreathing system because the inspired agent concentrations may become somewhat higher than the dialed settings indicate. It should be remembered when performing mask or chamber inductions with the sevoflurane vaporizers that it may not be able to deliver high agent concentrations at high fresh-gas flow rates. Results of this study suggest that both vaporizers are suitable for clinical use with a wide range of oxygen flow rates, if these precautions are properly addressed.

a. Operating instructions, Vapor 19.n, Draegerwerk AG, Lubeck, Germany.
b. Sigma Delta vaporizer user instruction manual, Penlon Ltd, Abingdon, UK.
c. Vapor 19.1, North American Draeger, Telford, Pa.
d. Sigma Delta, Penlon Ltd, Abingdon, UK.
e. Narkovet Deluxe, North American Draeger, Telford, Pa.
f. DraegerService, division of Draeger Medical, Telford, Pa.
g. Riken 1802D, AM Bickford Inc, Wales Center, NY.
h. Attane, Minrad Inc, Bethlehem, Pa.
i. SevoFlo, Abbott Laboratories, North Chicago, Ill.
j. StatView, version 5.0.1, SAS Institute Inc, Cary, NC.
k. Fitzal S, Gilly H, Steinbereithner K. Do modern plenum vaporizers provide accurate anesthetic mixtures irrespective of gas flow (abstr)? *Anesthesiology* 1986;65:A168.

References

1. Stoelting RK. Inhaled anesthetics. In: Stoelting RK, ed. *Pharmacology and physiology in anesthetic practice*. 3rd ed. Philadelphia: Lippincott Williams & Wilkins, 1999;36–76.
2. Edmondson W. Gas analysis by refractive index measurement. *Br J Anaesth* 1957;29:570–574.
3. Sugg BR, Palayiwa E, Davies WL, et al. An automated interferometer for the analysis of anaesthetic gas mixtures. *Br J Anaesth* 1988;61:484–491.
4. Allison JM, Gregory RS, Birch KP, et al. Determination of anaesthetic agent concentration by refractometry. *Br J Anaesth* 1995;74:85–88.
5. Cheam EW, Lockwood GG. The use of a portable refractometer to measure desflurane. *Anaesthesia* 1995;50:607–610.
6. Wallroth CF, Gippert KL, Ryschka M, et al. Refractive indices for volatile anesthetic gases: equipment and method for calibrating vaporizers and monitors. *J Clin Monit* 1995;11:168–174.
7. International Organization for Standardization. Anesthesia machines for use with humans. Reference number: ISO 5358. 2nd ed. Geneva, Switzerland: International Organization for Standardization, 1992. Available at: www.iso.org. February 15, 2005.
8. Palayiwa E, Sanderson MH, Hahn CE. Effects of carrier gas composition on the output of six anaesthetic vaporizers. *Br J Anaesth* 1983;55:1025–1038.
9. Davis PD, Kenny GNC. Fluid flow. In: Davis PD, Kenny GNC, eds. *Basic physics and measurement in anaesthesia*. 5th ed. Philadelphia: Butterworth-Heinemann, 2003;11–22.
10. Gilly H. Limitations of present dosing systems for gases and volatile anaesthetics. In: van Ackern K, Frankenberger H, Konecny E, et al, eds. *Quantitative anaesthesia: low flow and closed circuit*. New York: Springer-Verlag Inc, 1989;81–93.
11. Pashayan AG, Gravenstein JS. Helium retards endotracheal tube fires from carbon dioxide lasers. *Anesthesiology* 1985; 62:274–277.
12. Driessen B, Nann LA, Klein L. Use of a helium/oxygen carrier gas mixture for inhalation anesthesia during laser surgery in the airway of the horse. In: Steffey EP, ed. *Recent advances in anesthetic management of large domestic animals*. International Veterinary Information Service, 2003. International Veterinary Information Service Web site. Available at: www.ivis.org. February 15, 2005.
13. Lu TS, Ohmura A, Wong KC, et al. Helium-oxygen in treatment of upper airway obstruction. *Anesthesiology* 1976;45:678–680.
14. Loeb RG. The output of four modern vaporizers in the presence of helium. *Can J Anaesth* 1992;39:888–891.
15. Yurino M, Kimura H. A comparison of vital capacity breath and tidal breathing techniques for induction of anaesthesia with high sevoflurane concentrations in nitrous oxide and oxygen. *Anaesthesia* 1995;50:308–311.