Evaluation and Control of Waste Anesthetic Gases in the Postanesthesia Care Unit

James D. McGlothlin, MPH, PhD, CPE, John E. Moenning, DDS, MSD, Sandra S. Cole, MS, PhD

Background: *Few studies have addressed waste anesthetic gases (WAGs) in the postanesthesia care unit (PACU) related to exhaled sevoflurane and nitrous oxide.*
Purpose: *To evaluate the effectiveness of a new scavenging system to control WAGs in the PACU.*
Design: *Comparative and descriptive study.*
Methods: *This pilot study compared exposure to WAGs with and without a scavenging system using infrared technology to visualize and quantify exposure to these gases in the PACU.*
Finding: *The results showed a significant reduction ($P < .05$) in both nitrous oxide and sevoflurane at both six inches and three feet from the patient's breathing zone, as well as in the work area of the perianesthesia nurses in the PACU.*
Conclusions: *WAG exposure may be more easily managed through the use of this new scavenging system to better control occupational exposures to these gases among PACU personnel.*

Keywords: *waste anesthetic gases (WAGs), ISO-Gard mask, infrared technology, PACU occupational exposure.*

EVERY PROFESSIONAL ORGANIZATION and governmental agency involved with anesthesia recommends scavenging waste anesthetic gases (WAGs) to reduce occupational exposure to health care personnel.[1] Exposure to unscavenged WAGs in health care environments has been associated with adverse health outcomes.[2-21] As a result, systems and work practices have been developed for hospital operating rooms (ORs) and dental treatment rooms to decrease occupational exposure by scavenging WAGs, thus minimizing potential health problems related to them. However, few studies have addressed exposure to WAGs in the postanesthesia care unit (PACU).[22-27] The monitoring of WAGs, primarily nitrous oxide (N_2O), has been done using dosimetry badges, handheld monitoring devices, and infrared (IR) spectrophotometry.[28-30] Although these measuring devices give readings in the parts per million (ppm) range, they do not allow for the visualization of the gas during or after administration of N_2O to a patient. Visualization can be important when determining leaks or direct exposure from patients exhaling residual levels of anesthetic gases. Recent advances in IR videography technology (IR technology) have made it possible to visualize N_2O because it is part of the IR spectrum. The other inhalation agents (sevoflurane, isoflurane, and

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Conflict of interest: Dr. John Moenning has executed a royalty-bearing license of his patent rights for the design of the scavenging mask (ISO-Gard) to Teleflex Medical. Drs. McGlothlin and Cole have no conflict of interest to report.

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desflurane) are not. Because exhaled N_2O gas can be readily identified with IR imaging, WAGs can be more easily monitored and leaks eliminated by capturing patient exhalations using IR technology. Additionally, the use of IR technology can evaluate the effectiveness of scavenging systems used to control and decrease occupational exposures to personnel in the PACU.

Recommendations on WAGs and the PACU

Both the National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA) developed recommendations and regulations for occupational exposure to WAGs. NIOSH recommends that workers should be exposed to halogenated agent concentrations of less than 2 ppm when used alone or less than 0.5 ppm when used in combination with N_2O over a sampling period of less than 1 hour.[31] NIOSH also recommends that occupational exposure to N_2O, when used as the sole anesthetic agent, should not be greater than the time-weighted average (ppm divided by time) of 25 (ppm) during the time of anesthetic administration (ie, from the time N_2O is turned on until it is turned off). Furthermore, NIOSH recommends that all anesthetic gas machines, nonbreathing systems, and *t*-tube devices should have an effective scavenging device that collects all WAGs.[31] Since those early recommendations, several NIOSH intervention studies that use scavenging systems have been conducted to show how excessive WAG exposure in dental treatment rooms and health care facility ORs could be controlled.[32,33] Currently, OSHA acknowledges the NIOSH recommended exposure limits (RELs) to WAG exposure, but at this time, OSHA has not set its own standards for WAGs. However, OSHA cites, under its General Duty Clause 5a(1) that "Each employer shall furnish to each of his employees employment and a place of employment, which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees."[31-35] For a more detailed discussion of the NIOSH recommendations and OSHA regulations, please refer to the McGlothlin and Moenning article.[36]

The American Society of Anesthesiologists, in its *Guidelines for Non-Operating Room Anesthesia Locations*, approved by their House of Delegates in 1994,[1] and the American Dental Association recommend scavenging all WAGs for all procedures involving anesthetic gases in the dental office.[23] The American Conference of Governmental Industrial Hygienists set a threshold level limit value time-weighted average for N_2O of 50 ppm for an 8-hour work day.[37] Then in 1997, the Joint Commission advised the establishment of educational and orientation programs for all personnel who have contact with hazardous waste, including WAGs. In addition, other countries have set standards for occupational exposure to N_2O, which range from 25 ppm (The Netherlands) to 100 ppm (Italy, Sweden, Norway, Denmark, and Great Britain).[24,28-30] Although the occupational exposure standard regarding ppms varies between some of these government agencies and health care associations, the agencies and associations unanimously agree that the scavenging of WAGs should be performed.

In 1996, the American Society of PeriAnesthesia Nurses (ASPAN) released a position statement regarding air safety in the PACU.[38] The position statement maintained that necessary, suitable, and protective engineering controls, technologies, work practices, and personal protective equipment should be applied in the PACU. ASPAN recommended that occupational exposure to WAGs, as well as blood-borne and respiratory pathogens, should be controlled by following the regulations and guidelines established by nationally recognized agencies, such as NIOSH; the Centers for Disease Control and Prevention (CDC); and OSHA's hierarchy of controls, which are based on the principles of good industrial hygiene.

In seminal work in 1996, Badgwell[39] documented the need to monitor air safety source control technology (transmission of blood-borne and respiratory pathogens and occupational exposure to WAGs) in the PACU. In 1998, Sessler and Badgwell[25] found supporting documentation related to possible health concerns connected with exposure to WAGs, including a host of health-related issues, such as spontaneous abortions and infertility, neuropathies, megablastic anemia, and more. A 2002 pilot study by Krenzischek et al[26] found that N_2O concentrations in the PACU approached 300 ppm in a patient's breathing zone. Additionally, P.R. Austin and P.J. Austin[27] simulated a PACU environment to obtain an understanding of how the concentration of N_2O varies, depending on the distance from the patient. They found that the patient's breathing escalates the amount of N_2O at the level of the nurse and that the respiration of the nurses pulls the plume of N_2O toward them increasing the exposure.[27] Therefore, the further the nurse is from the patient, the less exposure from the patient's respiration. Further research findings by Cope et al[40] and Summer et al[41] also documented exhaled anesthetic agents found in the breath analysis of PACU nurses. These articles and more, as well as the results of air safety control technology for the PACU, are discussed in a 2013 review article by McGlothlin and Moenning[36] in *Clinical Foundations*. Most recently, NIOSH, in its Publication No. 2007-151,[42] again highlighted its recommendations to scavenge and manage exposure to trace concentrations (ppm) of WAGs, work practices to minimize WAG concentrations, conduct medical surveillance for possible occupational exposure in the health care environment, and monitor WAGs.

Methods

Patient Recruitment and Evaluation

Nineteen volunteer patients (9 controls using a nasal cannula or face tent and 10 cases using the ISO-Gard mask [Teleflex Medical, Triangle Park, NC]) were evaluated in this pilot study (Purdue Institutional Review Board #0710006087 and Community Health Network 2010-0374). All patients included in the study were healthy; older than 18 years; required a general anesthetic with sevoflurane and/or N_2O; were 23-hour stay (same day) surgeries; and, if female, had a negative pregnancy test within 7 days before enrollment. Patients excluded from the pilot study were morbidly obese (body mass index $>$40), undergoing pulmonary treatment, or had pulmonary disease. In addition, the investigator's employees at the pilot study site were excluded. These pilot study patients were placed in the same section of the PACU as the other patients and subsequently positioned next to the second patient, continuing toward the other end of the room as they arrived in the PACU throughout the day. On day 1, nine patients in the control study were sampled by the Miran wand at six inches above the patient's nose and mouth to capture the breathing zone of the patient and at three feet from the side of the patient's nose and mouth, averaging approximately 50 minutes for each patient, resulting in a cumulative total of 450 minutes. Each patient arrived in the PACU still intubated and, on extubation; a nasal cannula was immediately applied and set at 4 L of oxygen flow. Patients were extubated in the PACU to establish a standardized start time for WAG measurements. There were totally 25 patients in the PACU on that day. On day 2 of the pilot study, 10 cases were sampled, also averaging approximately 50 minutes for each patient, resulting in a cumulative total of 500 minutes. Once again, each patient presented in the PACU intubated and, on extubation, an immediate reading was taken at six inches and three feet as mentioned previously and the ISO-Gard mask was placed on the patient's face. The mask was connected to oxygen at 4 L/M of flow, and the scavenger tubing was connected to the wall vacuum and set at 30 mm Hg suction flow. There were 47 patients in the PACU on the second day. On both days, the IR camera and an IR spectrophotometer were used to perform qualitative (N_2O) and quantitative (sevoflurane and N_2O) analysis of anesthetic gas levels among the PACU pilot study patients after surgery. The IR camera was placed at the foot of the patient's stretcher to visualize the patient's fugitive emissions of N_2O. Figure 1 shows a screen-capture IR image of a representative patient in the control group without a scavenging mask. The IR spectrophotometer was positioned near the head of the patient between the first and second bed to quantify fugitive emissions of N_2O and sevoflurane. A screen-capture IR image of a spectrophotometer probe to sample for WAGs above the patient's head is shown in Figure 2. Measurements from the IR spectrophotometer were recorded immediately at extubation and at 5, 10, 20, 30, and 40 minutes postextubation. Sevoflurane and N_2O levels were recorded immediately after extubation and until 40 minutes postextubation. All patients were awake, spontaneously breathing, and eventually discharged from the PACU per their normal criteria. Gas samples were taken at 90-second intervals using the MIRAN unit, a single-beam IR, portable spectrophotometer that specifically and accurately measures gases. Details on how both

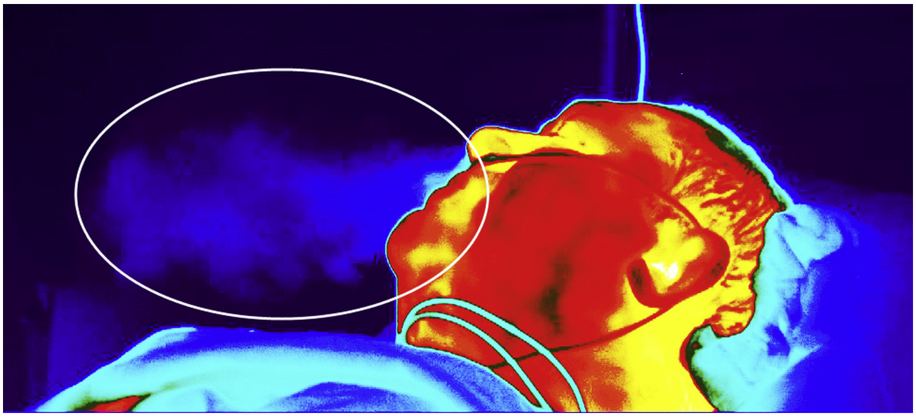

Figure 1. Setup for measurements of the control group. Note the nitrous oxide escaping from the right side of the patient's breathing zone.

instruments work and were used are documented in the later section.

PACU Ventilation

Annual airflow and air-exchange evaluations are required by the hospital and were conducted by a certified outside contractor. Records of airflow to the PACU were examined by the research team on day 1 of the study and again 7 months later. In both cases, the air supply and exhaust data were similar. The size of the PACU is 1,627 square feet, with 8.5-foot ceilings; the total room volume is 13,833 cubic feet. There are eight air supply vents measuring 23 square inches and three exhaust vents measuring 17.5 square inches. The average total air supply to the PACU is 1,833 cubic feet per hour, with a total air exhaust of 741 cubic feet per minute. The air exchange rate is 7.54 air exchanges per hour. The recommended air exchange rate for PACUs is 6 per hour.[42,43] The PACU, therefore, is under slight positive pressure relative to the outside hallways. There is no evidence of outside fresh air being supplied to the PACU.

Environmental Sampling

An IR camera (FLIR SC8303HS InSb [3 micrometers (μm)-5 μm] 1344 × 784 Camera; FLIR Systems, Inc. [1-866-477-3687], Nashua, NH) was used to visualize the patient and the exhalation of N_2O using a spectral notch filter centered around the peak absorption band of N_2O. This IR camera

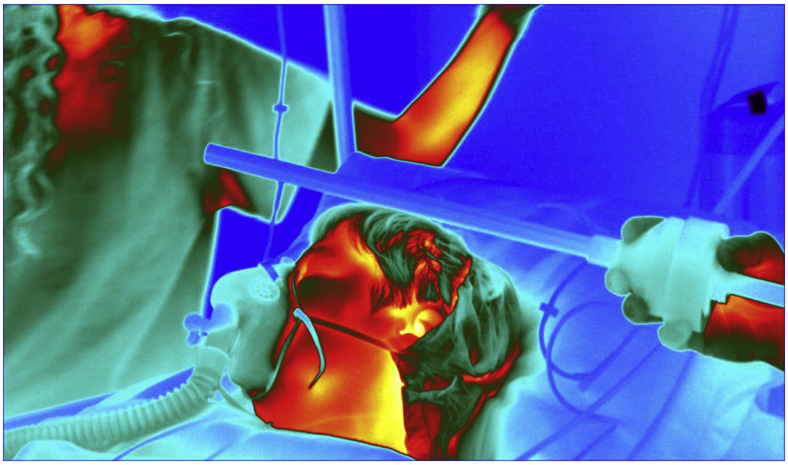

Figure 2. Setup for the Waste Anesthetic Gases (WAGs) scavenging system (Iso-Gard mask). The SapphIRe probe is shown, the Iso-Gard mask is in place, and a nurse is in the background. No nitrous oxide can be seen coming from around the mask.

helped researchers visualize the qualitative fugitive emissions of N_2O escaping from the patient in the PACU. According to an engineer with FLIR Commercial Systems—Advanced Thermal Solutions, N_2O gas can be made visible to the human eye by tuning the instrument to wavelengths that spike in the absorption spectrum. Therefore, spectral filtering can be used to block all wavelengths except the band where N_2O absorbs at 4.45 μm. This wavelength allows the N_2O gas to be seen by absorbing energy from the warm background and blocking the energy going to the IR camera. This results in the N_2O gas appearing as a lower signal or cooler region on the IR camera image. Using this technology has made visualizing N_2O possible, thus enabling strategies to be developed that include using scavenging systems to minimize occupational exposure to personnel. Specifically, this allows researchers to see where the WAGs are escaping from the patient's exhalation into the environment, possibly exposing personnel caring for these patients. The camera administration and calibration was done by a senior scientific segment engineer from FLIR Commercial Systems.

Quantitative Sampling for N_2O and Sevoflurane

A portable IR spectrophotometer (MIRAN 1B SapphIRe Ambient Air Analyzer; Foxborough, MA) was used to detect and quantify N_2O and sevoflurane in the PACU using NIOSH method 6600,[44] which may be used for the sequential determination of two or more analyses by changing the analytical wavelength and path length. The SapphIRe sampling device was placed on a cart next to the patient in the PACU and operated at 1 L per minute. The SapphIRe unit was connected to a wand and four-foot Tygon flexible tubing. As soon as the patient was extubated and positioned in the PACU, the SapphIRe wand was manually placed alternatively at approximately six inches and then three feet away from the patient's breathing zone. Visual reference points of these distances were used for consistency in the sampling. The concentrations of N_2O and sevoflurane were recorded by the SapphIRe detector every 90 seconds. These data were in the SapphIRe and later imported by a USB coupling device to a portable computer containing an Excel spreadsheet for detailed analyses.

Data for N_2O are shown only for eight of the nine control subjects. This was because the IR spectrophotometer used to quantify N_2O and sevoflurane can only sample once every 90 seconds. When sampling for only one gas (in this case, sevoflurane), however, the IR spectrophotometer can sample every second. Therefore, the ninth control subject shows only sevoflurane results. The purpose of the second-by-second evaluation was to allow researchers to more closely examine the decay of sevoflurane over time. The MIRAN unit was calibrated and administrated by a certified industrial hygienist.

Table 1. Average Exposure From WAGs to Nurses at Specified Time Points When Using a Nasal Cannula (Control) Versus Using an Iso-Gard Mask (Cases)

Patient age and sampling probe distance and ppm concentration	Controls			Cases					
	Mean (ppm)	SD (ppm)	n	Mean (ppm)	SD (ppm)	n	*t*-Statistic Calculated	Calculated DF for *t* Test	Significance
Age (y)	47.11	23.19	9	40.5	12.34	10	0.7634	12	$P = 0.4613$
N_2O: 6 inches (ppm)	69.10	62.77	69	23.99	28.57	86	5.4516	91	$P = 3.13 \times 10^{-7}$*
N_2O: 3 feet (ppm)	11.91	5.61	67	7.4	4.61	71	5.1428	128	$P = 9.98 \times 10^{-7}$*
Sevo: 6 inches (ppm)	5.04	5.82	77	1.89	2.01	86	4.5144	93	$P = 1.88 \times 10^{-5}$*
Sevo: 3 feet (ppm)	0.92	0.33	72	0.69	0.3	64	4.2573	134	$P = 3.88 \times 10^{-5}$*

WAGS, waste anesthetic gases; SD, standard deviation; DF, degrees of freedom; N_2O, nitrous oxide.
*α is set at 0.05.

Results

Table 1 shows a comparison between the controls and cases in the case-control study of exposure to nurses in a PACU to N_2O and sevoflurane. The results in Table 1 are found by using standard formulas for mean and standard deviation. The means and standard deviations for exposure to N_2O and sevoflurane are determined from the data recorded on the data collection sheets and from data collected by the MIRAN SapphIRe. Each mean and corresponding standard deviation is an overall mean for all patients and length of stay in the PACU for each day that sampling occurred. The *t* test with unequal variance is used to determine whether nurse exposure to N_2O and sevoflurane at both six inches and three feet is significantly different under conditions where the patient uses a nasal cannula or face tent versus the ISO-Gard mask (case). The average age of patients in the control group is 47.1; the average age of patients who are cases in this pilot study is 40.5. A *t* test using unequal variances shows that the age of the patients in the control group is not significantly different from the age of patients in the case study.

The average exposure of nurses to N_2O at six inches for the control group versus cases is 69.10 ± 62.77 and 23.99 ± 28.57 ppm, respectively. Hence, exposure is approximately 2.9 times greater than that of nurses to the group of patients using the ISO-Gard mask. The difference in exposure between the two groups is significantly different at a significance level of $P \leq .05$ when using a *t* test of unequal variances. At approximately three feet, the average nurse exposure to N_2O is 11.91 ± 5.61 ppm when the nasal cannula is used, whereas the average nurse's exposure to N_2O is 7.40 ± 4.61 ppm when the ISO-Gard mask is used. Therefore, nurse exposure when the nasal cannula is used is approximately 1.6 times greater than that of nurses caring for patients wearing the ISO-Gard mask. The exposure nurses receive is significantly higher at a significance level of $P \leq .05$ when a nasal cannula is used rather than the ISO-Gard mask.

Similar results are observed for sevoflurane at a distance of six inches and three feet. At both six inches and three feet, nurse exposure is significantly higher at a significance level of $P \leq .05$ when a nasal cannula is used rather than the ISO-Gard mask. At six inches, the average nurse exposure is 5.04 ± 5.82 ppm for the controls, whereas it is 1.89 ± 2.01 ppm for cases. Exposure for nurses caring for patients wearing the nasal cannula is approximately 2.7 times greater than that of patients using the ISO-Gard mask at six inches. At three feet, exposure to nurses from the controls and cases is 0.92 ± 0.33 and 0.69 ± 0.30 ppm, respectively. Exposure of nurses to sevoflurane from patients using the nasal cannula is 1.3 times that obtained by nurses exposed to patients using the ISO-Gard mask.

A comparison of nurses exposed to control patients at six inches versus three feet shows that the difference in nurse exposure to N_2O from patients at six inches is 5.8 times greater than at three

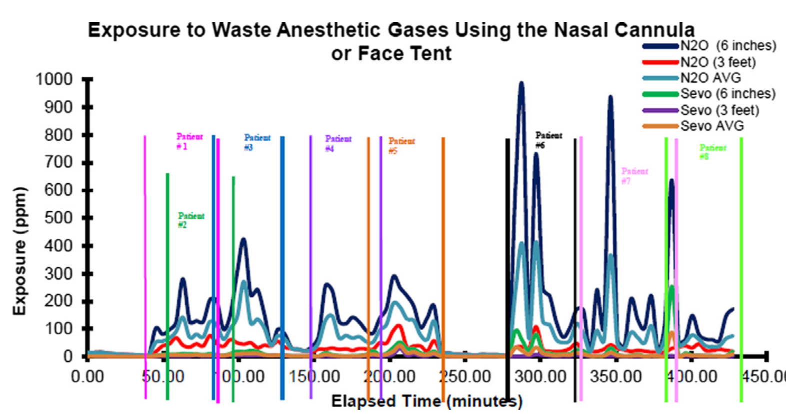

Figure 3. Correlation of real-time exposure to nurses in the PACU to Waste Anesthetic Gases (WAGs) of nitrous oxide and sevoflurane from the sequence of patients using a nasal cannula in the PACU for one day of surgical procedures (427 minutes).

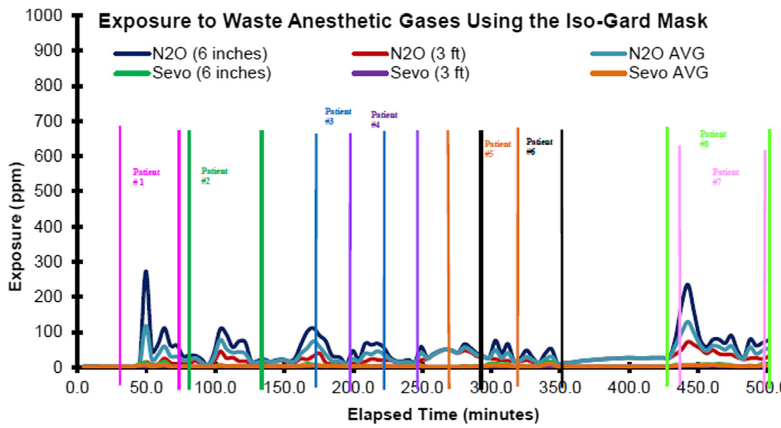

Figure 4. Correlation of real-time exposure to nurses in the PACU to Waste Anesthetic Gases (WAGs) of nitrous oxide and sevoflurane to the sequence of the first eight patients using an Iso-Gard mask in the PACU for one day of surgical procedures (500 minutes).

feet. For sevoflurane, nurse exposure to sevoflurane from patients at six inches is 5.48 times greater than that from patients at three feet. When patients use the ISO-Gard mask, nurses exposed to N_2O six inches from patients is 3.24 times greater than their exposure from patients at three feet. Nurses exposed to sevoflurane from patients at six inches are 2.74 times greater than their exposure at three feet. Data from the MIRAN SapphIRe are plotted in Figures 3-6. Data collected from the MIRAN SapphIRe was in 1.5-minute intervals. It was then summed in 4.5-minute increments starting at 9:53:45 (t = 0) for the control study and at 8:01:23 for the case study.

The exposure data in Figures 3 and 4 are the amount of each gas in the 4.5-minute interval at six inches, three feet and the average in this interval (average concentration measured during the data logging interval for the gas). Figures 5 and 6 show the cumulative exposure, which is an approximation determined by adding the exposure from each 4.5-minute increment to the previous total.

Figures 3 and 4 show the correlation of exposure from N_2O and sevoflurane to nurses in real time. These figures show how exposure to WAGs changes as time in the PACU increases. Additionally, Figures 3 and 4 show increasing the distance

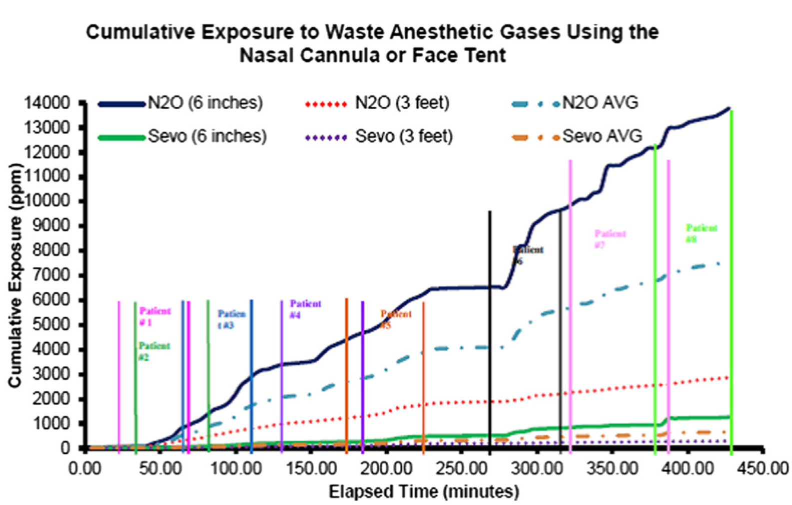

Figure 5. Cumulative exposure to nurses from Waste Anesthetic Gases (WAGs) of nitrous oxide and sevoflurane in the PACU showing the sequence of patients using a nasal cannula for one day of surgical procedures (427 minutes).

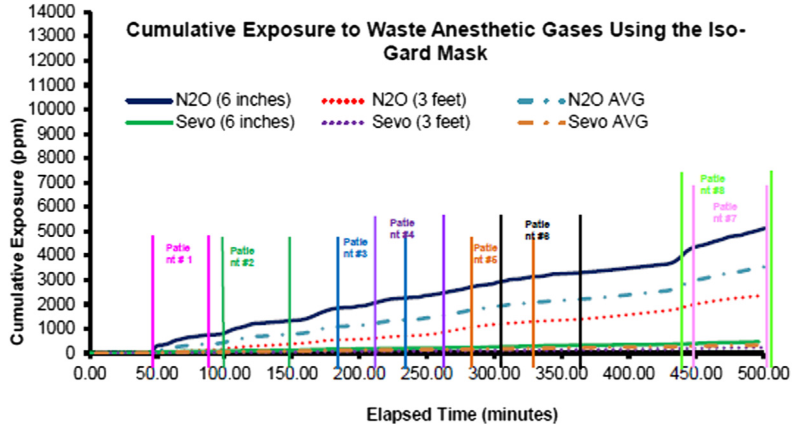

Figure 6. Cumulative exposure to nurses from nitrous oxide (N2O) and sevoflurane when the patient uses an Iso-Gard mask in the PACU for the first eight patients during a time of exposure of 500 minutes.

between WAGs, and the MIRAN detector decreases the amount of WAGs detected. Therefore, nurses will be exposed to less WAGs if they are further away from the patient.

A comparison of Figures 3 and 4 shows that the amount of WAGs detected is much greater when using a nasal cannula than the ISO-Gard mask. The pattern of peaks is similar for the controls and cases for both N_2O and sevoflurane, although the height of the peaks differs. Specifically, for the control study, many peaks at six inches for N_2O are approximately three times the height of peaks in the case study. At three feet, however, the difference between the peaks for the controls versus cases appears to be less. Similar observations are obtained when examining the sevoflurane data in Figures 3 and 4.

An examination of Figures 5 and 6 shows that the cumulative exposure is greater when using the nasal cannula than when using the ISO-Gard mask. The difference in exposure time (control: 427 minutes, cases: 577 minutes) for the 2 days was accounted for by normalizing exposure of the control using the following formula:

$$\text{Normalized exposure}_{\text{control}} = \frac{\text{Time for cases}}{\text{Time of control exposure}} * \text{Cumulative control exposure}$$
$$= \left(\frac{577 \text{ minutes}}{427 \text{ minutes}}\right) * \text{Cumulative control exposure}$$

The relationship between exposure of the control and cases at distance "r" for gas "x" is defined as the ratio of the case to control, which is calculated by dividing normalized exposure of gas "x" at distance "r" for the control group of patients by the exposure of gas "x" at a distance "r" of the case group of patients. Therefore, the cumulative exposure to N_2O and sevoflurane for nurses in the control condition at six inches is approximately three times greater than that obtained when using the ISO-Gard mask. The cumulative exposure to N_2O and sevoflurane for nurses in the control condition at a distance of three feet is approximately 1.5 times greater than that of cases. The average cumulative exposure to N_2O and sevoflurane for nurses in the control study is approximately 2.4 times greater than that for nurses in the case study. Furthermore, the relationship of exposure for a specific gas "x" as a case or control, depending on the distance, is defined by a ratio in which the exposure at six inches is divided by the exposure at three feet for each gas "x" for the control group and for the case group of patients.

Using these ratios, Figure 5 shows that the cumulative exposure of nurses to N_2O when using a nasal cannula or face tent at six inches is 4.82 times greater than exposure at three feet. The cumulative exposure of nurses to sevoflurane when using a nasal cannula or face tent at six inches is 4.32 times greater than exposure at three feet.

Figure 6 indicates that nurses' cumulative exposure from N_2O when using the ISO-Gard mask at six inches is 2.2 times greater than exposure obtained at three feet. Additionally, nurses' cumulative exposure to sevoflurane when using the ISO-Gard mask at six inches is approximately twice the exposure at three feet. The results from cumulative exposure for the case-control study are generally in accordance with those observed from evaluating and comparing the overall means in Table 1.

Discussion

When a patient is given an inhalation anesthetic, the agent is usually delivered as a percentage. An agent representing 100% would be the same as 1,000,000 ppm. Thus, delivering 100% N_2O is 1,000,000 ppm, and 2% sevoflurane would represent 20,000 ppm of sevoflurane. A patient waking from a general anesthetic and beginning to spontaneously breathe at 0.2% sevoflurane would still be outgassing 2,000 ppm when extubated. If the patient is extubated in the PACU and the gas analyzer states 0.1% or less, the patient would still be expelling WAGs at 1,000 ppm or less. WAGs ppm can be high when the patient presents to the PACU, and it takes time for the inhalation agent to be expelled from his or her lungs and decrease to the NIOSH recommended level of less than 2 ppm. The decay curve of WAGs to decrease to NIOSH recommendations has not been studied. Examination of the overall trend for each patient indicates that, for both the controls and cases, a decrease in outgassing of WAGs (N_2O and sevoflurane) progresses with time in the PACU, as shown in Figures 7-10. These figures show that for both N_2O and sevoflurane the highest exposure was in the first 5 minutes when the patient was brought into the PACU. Although the concentrations fluctuated slightly after initial exposure, there was generally a downward trend over the 40 minutes of nurse exposure to the WAGs. Although there were large standard deviations for the WAGs, there was a significant difference between the cases and controls. Figure 3 shows the peak levels of nitrous for each nasal cannula case. These peaks where highest in the first few time intervals. This is important because this is when PACU nurses deliver the most patient care, are closest to their patients' breathing zones, and when patients are arousing from general anesthesia and rapidly outgassing their anesthetic gases. Also, this is typically when nurses state they can smell the WAG from a patient. In the 2007 CDC/NIOSH update on WAGs, it stated, "Anesthetic gases cannot be detected by their odor until concentrations are very high. For example, halothane cannot be detected by 50% of the general population until the concentration is more than 125 times the NIOSH recommended exposure limit."[42] The current pilot study did not perform measurements to see how quickly and for how long anesthetics are outgassed, but it does show a trend that the first 15 minutes will produce the highest quantitative readings of

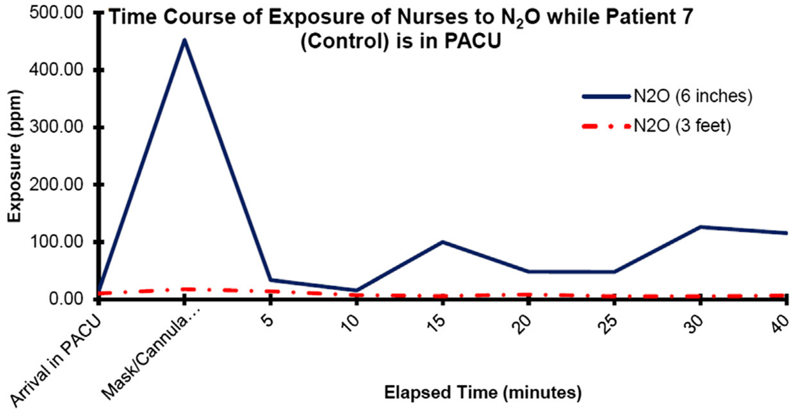

Figure 7. Representative patient N_2O results without the ISO-Gard system. This image is available in color online at www.jopan.org.

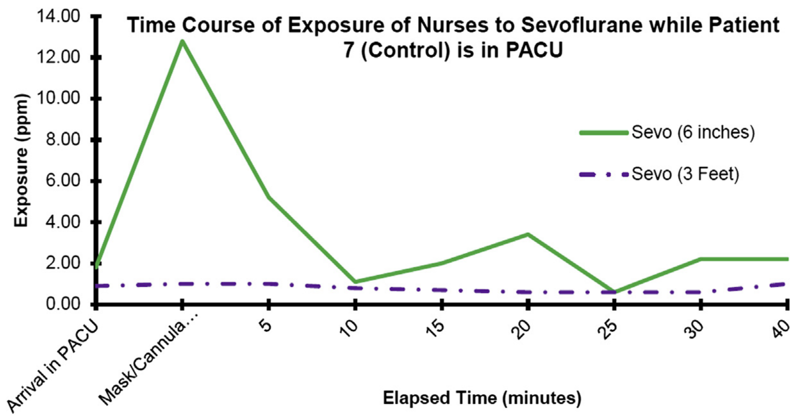

Figure 8. Representative patient sevoflurane results without the ISO-Gard system.. This image is available in color online at www.jopan.org.

WAGs in the breathing zone. The first 15 minutes is also when the IR camera would capture the most profound visual amounts of N_2O being exhaled. The IR technology images were also impressive when PACU nurses asked patients to deep breathe and cough. The N_2O gases could be seen spraying out at a rapid rate and as a plume from the cough.

All patients still had WAG readings at the end of the 40-minute recording period. The use of the ISO-Gard mask significantly reduced WAG levels in the breathing zone in the first few minutes because it is directly connected to the wall vacuum set at 30 mm Hg to scavenge the WAGs and connected to oxygen at 4 L/M. The ISO-Gard mask has a unidirectional flow that allows oxygen to enter the mask in the nasal area, while the WAGs are being removed in the oral area. This is a direct result of the ISO-Gard mask system and shows how controlling the source of the WAG (source control) is most important. Room air exchanges were determined to be 7.5 air changes per hour but did not seem to have as great an influence on the breathing zone area.

On day 1, nine patients were admitted to the PACU and served as controls; the other 16 patients admitted to the PACU that day may have had inhalation agents other than nitrous and/or sevoflurane anesthetic. It is difficult to control extraneous influences such as this in an active PACU, but it illustrates the potential for all types of gases to increase as a day progresses. In poorly ventilated rooms and/or those with poor air exchanges, the PACU's accumulation can be significant. The potential for chronic and low-level exposure in the PACU, therefore, increases the risk for health concerns.

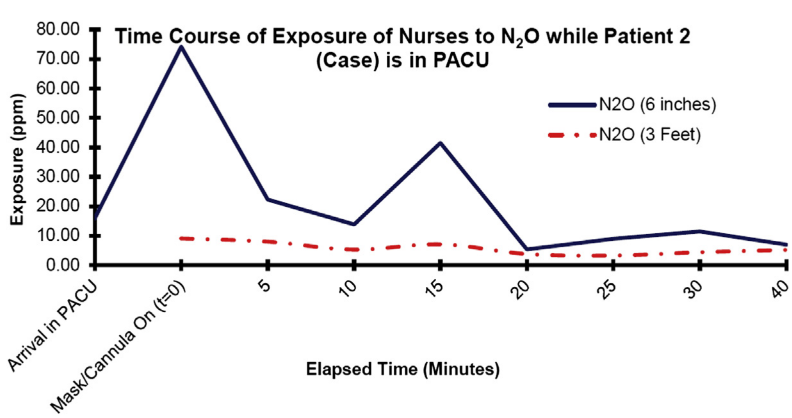

Figure 9. Representative patient N_2O results with the ISO-Gard system.. This image is available in color online at www.jopan.org.

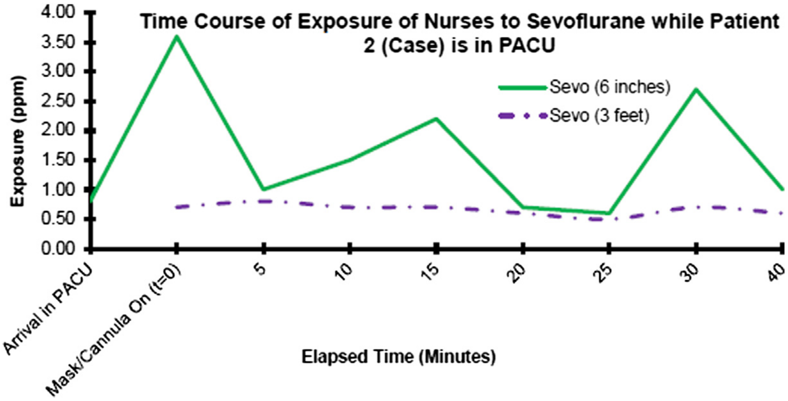

Figure 10. Representative patient sevoflurane results with the ISO-Gard system.. This image is available in color online at www.jopan.org.

In looking at the day 2 results, significant changes were noted. The overall peak levels in the first few minutes at the six-inch measurement were significantly reduced for the ISO-Gard group. These reductions illustrated how important source control measures are. Reductions at three feet were also noted and are influenced by the PACU physical design ventilation and air exchanges. The accumulation measurement was also significantly reduced when compared with the control group on day 1. These readings were more than 50% reduced on the second day, when there were eight patients in the same room as the other 39 PACU patients. Remarkably, with 47 PACU patients, the ISO-Gard mask was still able to reduce the accumulation of WAGs by more than 50%. The WAG levels in the PACU and the accumulative exposure could have been even lower on the second day of the pilot study if only 25 patients were recovered in the PACU, as was the case on the first day. Another factor influencing total exposure was the exposure time for the cases and controls. There were a total of 450 and 500 minutes of exposure on day 1 and 2, respectively. If the exposure data were compared just on exposure time (ie, cumulative WAG levels measure only to 450 minutes for both days), the impact of the ISO-Gard scavenging

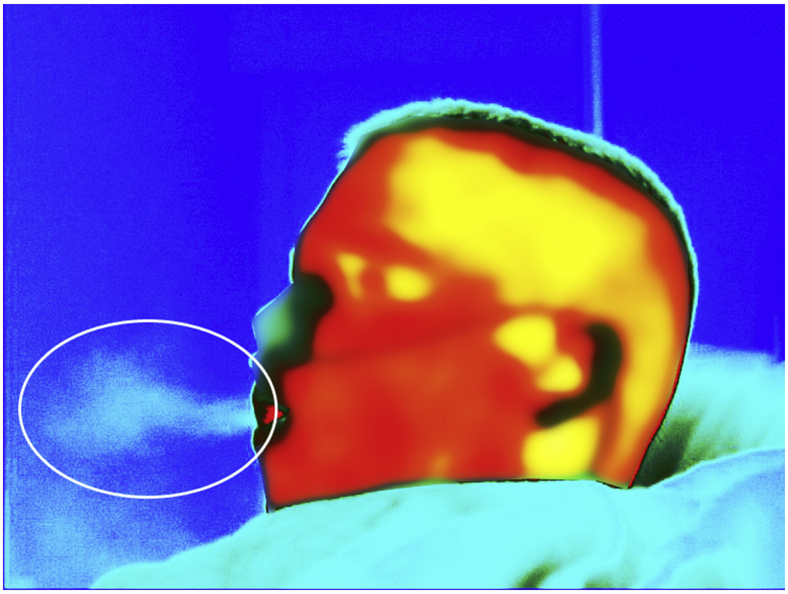

Figure 11. Nitrous oxide is expelled from a talking patient. The nasal canuula is in place and the gas is seen coming from the oral area.

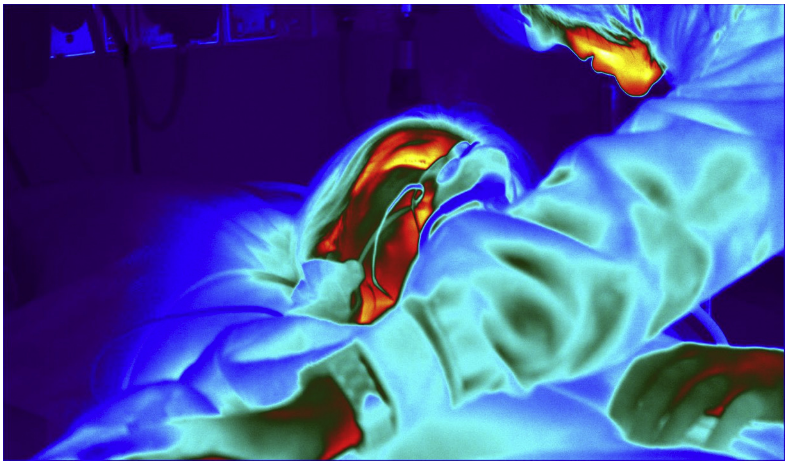

Figure 12. The close working proximity between the PACU nurse and the patient's breathing zone. Use of the scavenging system (Iso-Gard mask) helps to minimize exposure to Waste Anesthetic Gases (WAGs).

system reducing the accumulative exposure would have been even greater.

There are no studies of WAGs in the PACU that are completely comparable with this pilot study. Other studies have looked at ppm in the breathing zone, but no one has used IR technology to visualize WAGs in the PACU. In one somewhat comparable study of PACU nurses' exposure to WAGs in 1998, Sessler and Badgwell[25] reported that 68%of the patients serviced by PACU nurses were found to be in noncompliance of NIOSH RELs for isoflurane, desflurane, and N_2O (levels of WAGS were greater than NIOSH RELS). Among those in noncompliance for the NIOSH REL, their exposure was more than 35% of the 1-hour average recovery time. In the study by Rademaker et al,[45] the authors were able to qualitatively and quantitatively measure N_2O in the dental treatment room.[45]

In addition, the authors stressed the importance of good work practices to control WAGs. These include good source control, good air exchanges in the room, and minimizing patient conversation. Additional best work practices would be fresh air exchanges without recirculating airflow. As noted in Rademaker's study,[45] as WAGs accumulate throughout the day, levels can increase and spread throughout the environment if fresh outside air is not circulated. The CDC/NIOSH bulletin[42] in 2007 stated that a ventilation system that circulates and replenishes air in the OR should have at least 15 air changes per hour and a minimum of three air changes of fresh air per hour. In addition, the PACU should have at least six air changes per hour and have a minimum of two fresh outside air changes per hour to prevent exposure to WAGs exhaled by patients.

Air movement (ventilation) of 7.5 air changes/hour in the study's PACU is adequate when compared with the recommended six air changes/hour recommended for the PACU by the American Society of Refrigeration, Heating and Air Conditioning Engineers[43] and the NIOSH bulletin in 2007.[42] However, issues of proper air mixing, fresh air, close proximity between the patient and nurse along with peak WAG exposures at the beginning of patient treatment in the PACU need to be addressed.

Best work practices can be performed in the PACU. For example, when possible, the nurse should avoid getting close to the patient's breathing zone (12" or less), especially when he or she is active and talking (Figure 11). WAG volumes and concentrations are found to be higher with talking and active coughing. This can lead to direct exposure to WAGs coming from the patient's nose and mouth. When possible, the PACU nurse could make the patient as comfortable as possible and ask him or her to relax and minimize talking. The nurse could consider updating patient records at the foot of the bed, not near the head, to minimize exposure to

WAGs. When it is necessary to provide care close to the patient's head, such as to more clearly hear him or her speak, it is prudent to use a scavenging system (as shown in the IR image in Figure 12) to capture any fugitive emission of WAGs. The scavenging system parts should always be repaired or replaced so that the equipment is working efficiently and properly.

This pilot study could have been improved by limiting the PACU to only patients included in this study as control or cases. This would have created an environment that was more closely controlled. In the future, a study where all patients either wear a nasal cannula or the ISO-Gard mask would be beneficial. Also, a larger sample size for each group, recording the amount of time of the delivered anesthetic, quantitative measurements with the MIRAN unit for a longer time to measure the WAGs until they are below the NIOSH recommendations, patient age, and patient weight would all help to control variables. Even with these variables not recorded or controlled, this pilot study was still able to confirm that WAGs in the PACU can and do exceed NIOSH RELs and that scavenging systems, such as the ISO-Gard, are helpful in significantly reducing WAGs with health-related benefits for nurses and other health care personnel.

Conclusions

By using an IR camera to visualize N_2O and the SapphIRe camera to quantify N_2O and sevoflurane, the authors of this pilot study were able to document occupational exposure to WAGs in the PACU. The peer-reviewed literature presents a compelling case that exposure to fugitive emissions of WAGs is a concern to health care personnel.[2-21] The aim of this pilot study was to determine the level of exhaled gases in the room. This pilot study did not focus on potential health risks from patients outgassing, including how the nurse was affected. Step 2 of this issue is to determine health risks. Even more important, in terms of potential adverse health effects, is the accumulation of WAGs in the PACU throughout the work shift. The ISO-Gard mask demonstrated significant reductions in WAGs, while at the same time delivering oxygen to the patient when compared with the nasal cannula for the controls. Control of WAGs in the PACU environment can be accomplished by using engineering controls, best work practices, and personal protective equipment (such as an effective scavenging system positioned close to the patient). ASPAN further asserts in a position statement that all members should be familiar with perianesthesia air safety issues.[38] Furthermore, ASPAN's position statement strongly advocates that perianesthesia nurses seek opportunities to educate others involved in the decision-making process regarding the PACU environment. Additionally, guidelines have been instituted by governing agencies to inform employees of the potential adverse effects of WAGs exposure and to use all methods to help control exposure to these gases.

From past studies, the authors were able to use IR technology in the visualization and quantification of N_2O in dental treatment rooms.[32,33,45] In this pilot study, the authors were able to replicate using IR technology not only to visualize and quantify exposure to WAGs but also to demonstrate the need for and efficacy of using scavenging systems in the PACU. Furthermore, researchers were able to use the results from this study to emphasize other control sources in the PACU, such as ventilation exchange rates, fresh air exchanges, and wall vacuum scavenging systems. Additional best work practices, such as using the ISO-Gard mask in the PACU and administrative controls, such as routine maintenance of the scavenging systems and information to educate health care personnel on the potential hazards of WAGs, are significant measures to control them. All these sources and factors need to be taken into account when protecting health care workers in the PACU. Creating a safer environment in the PACU for both the patient and health care workers is the ultimate goal as is reducing the potential for unforeseen health problems. This pilot study showed that WAGs in the PACU can be controlled in the breathing zone. More importantly, the accumulation of WAGs in the PACU can be reduced through a cost-effective means that also promotes and protects health care personnel.

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