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Waste Anesthetic Gases (WAGs) among Employees in the Healthcare Industry

James D. McGlothlin, MPH, PhD, CPE and John E. Moenning, DDS, MSD

The scavenging of waste anesthetic gases (WAGs) is recommended by every professional organization and government agency involved with anesthesia to reduce occupational exposure to health care personnel.[1] WAGs in health care environments have been associated with adverse health outcomes in unscavenged situations.[2-21] Operating rooms and dental operatories have developed techniques to decrease occupational exposure by scavenging the WAGs and minimizing potential health problems, but few studies have addressed WAGs in the post-anesthetic care unit (PACU).[22,23] Monitoring of WAGs, primarily nitrous oxide, has been done using dosimetry badges, hand-held monitoring devices, and infrared spectrophotometry. While these measuring devices give readings in the part per million (ppm) ranges, they cannot visualize the gas during or following administration to a patient. This can be important when determining leaks or direct exposure from patients exhaling residual levels of the anesthetic gases. Recent advances in infrared (IR) videography technology have made it possible to visualize nitrous oxide leakage. Because these leak sources can be readily identified from infrared imaging, the WAGs can be more easily controlled through the elimination of leaks, especially to scavenging systems, so that occupational exposures to personnel in the PACU are decreased. In this article, Drs. McGlothlin and Moenning presents a brief overview of WAGs in the healthcare industry, with a focus on healthcare personnel in the PACU. Recent exposure and risk assessment studies using IR thermography cameras and IR sensors to identify and quantify WAG (i.e., N20) exposures among PACU employees are pointing toward an unidentified and relatively new health exposure concern for these employees.[61]

Panel Discussion: Waste Anesthetic Gases: Opinions from the Experts

Panelists: David Farr, MD
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Waste anesthetic gases (WAGs) pose a significant health hazard in the hospital setting and must be controlled to protect healthcare workers. In this panel discussion, three experts discuss the scope of WAGs as an acute and chronic health hazard, both in the operating room (OR) and post-anesthetic care unit (PACU) settings, and review the many health conditions associated with excess exposure to WAGs. Also discussed are the many government guidelines and other publications that outline exposure limits and offer practical solutions to the problem.

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1. Standards and Guidelines for WAGs

Assuring that employers provide safe working conditions for employees was the purpose of the Occupational Safety and Health Act of 1970, Public Law 91-596.[24] This Act created the Occupational Safety and Health Administration (OSHA) under the Department of Labor, and the National Institute for Occupational Safety and Health (NIOSH) under the Department of Health and Human Services. OSHA and NIOSH are federal agencies that are concerned about possible health hazards to employees associated with exposure to WAGs. Other recommending bodies that publish occupational exposure information are the American Conference of Government Industrial Hygienists (ACGIH), the American Society of Anesthesiology (ASA), the American Dental Association (ADA), and the Joint Commission on Accreditation of Healthcare Organizations (JCAHO).

In 1977, NIOSH promoted research on the effects of occupational exposure, the means of preventing occupational injuries, and recommended occupational safety standards.[25] They made recommendations in four areas of occupational health: 1) scavenging and exposure to trace concentrations of WAGs; 2) work practices to minimizing WAG concentrations; 3) medical surveillance for possible occupational exposure in the healthcare environment, and, 4) monitoring of WAGs. NIOSH recommended that workers should not be exposed to halogenated agents at concentrations of >2 ppm when used alone or >.5 ppm when used in combination with nitrous oxide over a sampling period not to exceed 1 hour. They also recommended that occupational exposure to nitrous oxide, when used as the sole anesthetic agent, should not exceed a time-weighted average of 25 ppm during the time of anesthetic administration. In addition, they recommended that all anesthetic gas machines, non-rebreathing systems, and t-tube devices should have an effective scavenging device that collects all WAGs. In these recommendations, they gave a thorough discussion of other work practice techniques, such as turning on the scavenging system before administering anesthetic gases to the patient to minimize exposure of medical staff to WAGs.

OSHA's responsibilities are to adopt and mandate job safety and health standards, to establish the rights and responsibilities of employers and employees for safe occupational conditions, to establish recordkeeping and reporting procedures of injuries, and to evaluate work-related safety practices. They are also responsible for carrying out the NIOSH recommendations.[26] Currently, OSHA recognizes the NIOSH recommended exposure limits (RELs) to WAG exposure, but to date have not set their own standards for WAGs. However, OSHA can cite under the General Duty Clause 5a(1) which states 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."[27]

However, to minimize and create as safe an environment as possible for healthcare workers, OSHA does recommend a well-designed scavenging system as part of an anesthetic delivery system for collecting WAGs. These recommendation levels apply to any place where anesthetic agents are delivered as well as to the PACU. Patients may out-gas (i.e., exhale) anesthetic agents following their procedures so OSHA recognizes that close proximity to patients can result in exposure to measurable concentrations of WAGs. They also indicate that while random room samples may indicate relatively low levels of WAGs, the breathing zone of the nurse in close proximity to the recovering patient may expose them to levels of anesthetic gases that are above the NIOSH RELs.

The ASA, in their Guidelines for Non-Operating Room Anesthesia Locations approved by their House of Delegates in 1994, stated that in any location that inhalation agents are administered, there should be adequate and reliable systems for scavenging WAGs.[1] The ADA recommends scavenging of all WAGs for all procedures involving anesthetic gases in the dental office.[23] In 1989, the ACGIH assigned a threshold level limit value time-weighted average for nitrous oxide of 50 ppm for an 8-hour work day.[28] Finally, in 1997, JCAHO recommended that educational programs and orientation should be established for all personnel who have contact with hazardous materials and waste. Other countries around the world have also established guidelines to occupational exposure standards. These can range anywhere from 25 ppm (the Netherlands) to 100 ppm (Italy, Sweden, Norway, Denmark, Great Britain.)[29-32] While some of these government agencies and healthcare associations have different occupational exposure standards in regard to ppm, they all unanimously agree that scavenging of WAGs should be utilized.

2. WAG Risks: Toxicology and Mechanisms.

Lassen et al, in a 1956 Lancet article, found that severe bone marrow depression could occur after prolonged nitrous oxide anesthesia in some patients who were being treated for tetanus.[33] Later in 1967, the first indication that anesthetic gases could be a problem for humans was reported by a Russian scientist named Vaisman.[34] They reported that female anesthesiologists had had problems with fatigue, nausea, and headaches, and that 18 of 31 pregnancies ended in spontaneous abortion. In 1968, further articles with regard to nitrous oxide and its effect on bone marrow were reported. Banks et al. and Amess reported that nitrous oxide can inactivate vitamin B-12 and thus cause biochemical derangements similar to those seen in pernicious anemia.[35,36] In 1974, Bruce, Bach, and Arbit published their studies dealing with nitrous oxide and audiovisual impairment.[37] The 1977 NIOSH reported that levels of 50 parts per million were the lowest level at which human effects had been reported.[25] They were quoting these audiovisual impairments that Bruce, Bach, and Arbit had been able to illustrate.

In 1980, Cohen et al. published an article reporting on health problems experienced by dentists and chair side assistants who had been exposed to nitrous oxide in their jobs.[9] They considered dentists to have light exposure if they used nitrous 1 to 8 hours a week, or heavy exposure if they were >8 hours a week. They found the following information: nitrous oxide use doubled the likelihood for congenital abnormalities or spontaneous abortions; nitrous oxide was shown to have an increased effect on neurologic problems as well as liver and renal problems for male dentists and the assistants; and nitrous oxide use doubled the likelihood for cervical CA in the female study group.

In 1991, Yagiela conducted a comprehensive review of the literature and looked at occupational exposure to nitrous oxide and its potential health consequences.[38] Yagiela's review cited epidemiologic studies that showed reproductive effects including increased risks of spontaneous abortion, premature births, and infertility in individuals in exposed situations.

In 1992, Rowland and colleagues reported that fertility problems occurred in women exposed to high levels of unscavenged nitrous oxide.[39] They also found a 2.5-fold increase in spontaneous abortions experienced by women who worked in dental operatories that did not scavenge nitrous oxide and found no increase in infertility or spontaneous abortion in women who worked in dental operatories that scavenged waste nitrous oxide.

In a government technical report, McGlothlin et al (1994) reported similar findings from the literature where the effects of acute and chronic occupational exposures have been shown to cause bone marrow depression (primary granulocytopenia), paraesthesia, difficulty concentrating, equilibrium disturbances, and impaired visual effects.[40]

As a result of numerous epidemiological evaluations, the ASA commissioned a group of epidemiologists and biostatisticians to evaluate the significance of these studies with regard to possible health hazards resulting from exposure from WAGs. Buring and colleagues reviewed 17 published studies, and after evaluating these studies for the best statistical controls, concluded that there is a 30% increased risk of spontaneous abortion for women working in operating rooms and a similar, but less consistent increase in congenital abnormities among offspring of exposed physicians.[41] They also concluded that all of the studies reviewed had weaknesses in their response rates and other confounding variables, making it difficult to draw specific conclusions.

An excellent study by Krajewski looked at the alterations in vitamin B12 metabolic status of 95 operating room nurses with a history of exposure to nitrous oxide and compared them to 90 nurses who were not exposed to nitrous oxide.[42] They found significantly lower vitamin B12 status in personnel exposed to nitrous oxide with higher total homocysteine levels. The changes in vitamin B12 status were found to be primarily in subjects who were exposed to nitrous oxide in concentrations substantially exceeding occupational exposure limits.

In 2008, Sanders, Weimann, and Maze published a thorough review of the biological effects of nitrous oxide including how nitrous oxide affects methionine synthase function.[43] As a result of the interaction of vitamin B12 with nitrous oxide, methionine synthase is inactivated resulting in alterations to one carbon and a methyl group transferred, which is important for DNA, purine, and thymidylate synthesis. These alterations potentially may result in the increased risk for reproductive consequences, megaloblastic bone marrow depression, neurologic symptoms, and increased levels of homocysteine which can cause cardiovascular changes.

Leslie et al, in February 2011, published their ENIGMA trial involving 2050 patients who had undergone noncardiac surgery with an anesthetic that lasted more than 2 hours.[44] Patients were randomized into groups of nitrous oxide-based or nitrous oxide-free anesthesia. They concluded that the exact relationship between nitrous oxide administration and long-term adverse outcomes will require further controlled trials but they did find an association between anesthesia and myocardial infarction in patients who had significant exposure to nitrous oxide in their anesthesia.

While the biologic effects of inhalation anesthetics may be debated, the effects of long term, low level exposure to nitrous oxide seem to be supported. Also, while the available evidence for health consequences from inhalation anesthetics is weak and comes mostly from retrospective epidemiological studies, the occupational exposure risk from nitrous oxide is much more substantiated. As a result, all organizations have come to the conclusion that good scavenger systems are needed to decrease these possible health consequences from exposure to WAGs with halogenated agents and/or nitrous oxide gas.

One of the most recent articles related to concerns about WAGs is for environmental impact in terms of global climate change.[45] Yasny et al. discuss the need for reduced WAG emissions among healthcare

Table 1. Inhaled Anesthetic Agents

Generic or chemical name	Commercial name	Year of Introduction	Currently in use
Diethyl ether	Ether	1842	No
Nitrous oxide	Nitrous oxode	1844	Yes
Chloroform	Chloroform	1847	No
Cyclopropane	Cyclopropane	1933	No
Trichloroethylene	Trilene®	1934	No
Fluroxene	Fluoromar®	1954	No
Halothane	Fluothane®	1956	Yes
Methoxyflurane	Penthrane®	1960	Infrequently
Enflurane	Ethrane®	1974	Yes
Isoflurane	Forane®	1980	Yes
Desflurane	Suprane®	1992	Yes
Sevoflurane	Utane®	1995	Yes

from reference 46

personnel but also pointed to the need for capturing and recycling of WAGs. By using a recycling system for WAGs, the authors claim that these used products can be sold to companies who can sell them again for other healthcare needs. The list of anesthetic gases currently in use is shown in Table 1.[46]

3. WAGs in the PACU

In 1996, the American Society of Perianesthesia Nurses (ASPAN) issued a position statement in regard to air safety in the post-anesthesia environment.[47] They stated that necessary, appropriate, and protective engineering controls, technologies, work practices, and personal protective equipment be utilized in the perianesthesia environment. ASPAN recommended that occupational exposure to WAGs, as well as blood-borne and respiratory pathogens, be controlled by adherence to regulations and guidelines set forth by nationally recognized agencies such as NIOSH, the CDC, and OSHA's hierarchy of controls based on principles of good industrial hygiene.

In 1997, an article by Badgwell discussed the air safety source control technology for the PACU.[48] In addition, Brodsky concluded in his review of the literature by stating: "Why risk potential health and reproductive problems while waiting for definitive proof, when this is not likely to be forthcoming. Even without direct proof of cause, we should reduce levels of WAGs to their lowest possible concentration by careful use of efficient control measures.[49] " Badgwell also stated that as a result of the body of research and careful analysis, the inclusion of source control scavenging has become the de facto standard for anesthetic machines in all operating rooms in the United States since 1980.[48] He also reviewed literature related to exposure of PACU personnel to WAGS and concluded that the levels of WAGs in the breathing zone of personnel in the PACU appear to exceed NIOSH REL's. Over the last 10 years, articles have begun to appear with regard to WAG levels in the PACU. Prospective studies have looked at the exposure levels in the PACU. Sessler et al. recently summarized several papers on healthcare personnel exposed to WAGs and the possible health concerns from this exposure.[50] He reported that the majority of these studies concluded that there is a correlation between reproductive toxicity and exposure to WAGs. The majority of these health concerns involve spontaneous abortions and infertility, neurobehavioral effects, megaloblastic anemia, neuropathies, psychophysiological effects of impaired cognitive, perceptual and/or motor function, and more recently vitamin B12 deficiencies and homocysteine elevations.

Sessler found that postoperative nurses were frequently exposed to exhaled anesthetic gas concentrations exceeding NIOSH recommended exposure levels. Interestingly, they found that volatile anesthetic curves did not demonstrate the expected exponential decrease over time. They found that one-fourth of the nurses demonstrated time-weighted averages that exceeded the 25 ppm NIOSH recommendations even though they had been caring for patients that had received nitrous oxide-free anesthesia. They point out that this could have been due to limitations in ventilation air exchanges in the PACU design. Their data suggested that PACU nurses were exposed to exhaled anesthetic gases exceeding the NIOSH RELs.

A more recent study by Krenzischek found that concentrations of nitrous oxide were close to 300 ppm in a patient's breathing zone.[51] Their pilot study identified the potential for staff exposure to WAGs in the PACU setting. A simulated PACU environment was constructed to obtain an understanding of how the concentration of nitrous oxide varies with the distance from the patient. Austin found that the concentration of nitrous oxide decreases with distance from the patient and the patient's respiration increases the level of nitrous oxide at the location of the nurse. Also, the respiration of the nurses pulls the nitrous oxide plume toward them, increasing their exposure to gas.[52] They questioned the inadequacy of attempting to measure levels of gas exposure at random points in a room. There are other articles that have looked at breath analysis to determine whether PACU personnel or operating room personnel are inhaling the gases and then exhaling the gases at a measurable limit. Cope et al. and Summer et al. have found that exhaled anesthetic agents are present in the breath of personnel.[53-54] As a result of these studies it can be surmised that PACU personnel may be exposed to WAGs that are above NIOSH standards.

Most recently in 2007, NIOSH Publication No. 2007-151 reemphasized these recommendations in regard to WAGs.[55] They wanted to increase the awareness of the adverse health effects of these gases, describe how workers are exposed to WAGs, recommend work practices to reduce these exposures, and identify methods to minimize leakage of WAGs into the work environment.

As stated earlier, studies have documented the health consequences of exposure to the WAGs in addition to the potential for cognitive problems that can result from chronic exposure. When nursing personnel are exposed to a large number of PACU patients throughout an 8-hour day, the potential for cognitive problems may increase. This is important considering that the Institute of Medicine (IOM) states that as many as 44,000 to 98,000 people die in US hospitals every year as a result of medical errors.[56] Furthermore, non-fatal adverse events related to medication errors can increase hospital costs by as much as $2 billion a year. The IOM also states that higher error rates may be more common in emergency departments, operating rooms, or ICUs. Helmreich, in analyzing errors in aviation, found that multiple physiological and psychological factors impact attention spans and make medical errors more likely.[57] Some of the causes include increased work load, fatigue, cognitive overload, ineffective interpersonal communication, and faulty information processing. If cognitive problems are known to increase secondary to exposure to WAGs above NIOSH limits,[58] it seems reasonable to conclude that minimizing exposure to WAGs would help prevent possible adverse health consequences to personnel as well as decrease the potential for human error during the times patients are in the PACU.

4. Exposure Assessment Methods for Detecting WAGs

Evaluation of WAGs, particularly nitrous oxide, is typically done through three traditional methods. The first is utilizing nitrous oxide dosimetry badges. These sampling monitors are very similar to radiology monitors where the nitrous oxide gas is absorbed by an absorbent zeolite molecular sieve with a pore size of 5 angstroms. These sampling badges are opened at the beginning of a sampling period. At the completion of the sampling phase, the badge is double-sealed in a bag and then sent to a lab for analysis.

A second method utilizes a small handheld infrared spectrophotometer. An example of one used in PACU's is the Medigas PM 3010 developed by the Bacharach Company in Pittsburgh, PA. This hand-held device pulls in the nitrous oxide to be analyzed by a small port and reads nitrous oxide concentrations by infrared analysis spectrophotometry. However, the device that has been used the longest for nitrous oxide monitoring has been the Miran 1B SapphIRE Ambient Air Analyzer (Thermo Fisher, Waltham, MA). The NIOSH RELs were all established by using the Miran infrared spectrophotometer. While all of these devices measure nitrous oxide as a part per million (ppm) none of these measuring devices can visualize gases.

By utilizing infrared thermography, a new way to visualize nitrous oxide has been established. An infrared camera (Merlin Mid-INSB Midwave FLIR infrared camera, FLIR Systems Inc, Boston, MA) uses the infrared light through a special lens to capture the nitrous oxide molecule absorbing the infrared image in a spectrum of 45 to 50 nanometers. Using this technology has made it possible to visualize nitrous oxide and thus develop ways to minimize occupational exposure to personnel that were not possible before. Specifically, this allows researchers to "see" where the WAGs may be escaping into the environment.

This technology was utilized in an IRB approved study that appeared in the 2009 February issue of the Journal of the American Dental Association.[59] Two nitrous oxide scavenging systems were evaluated to see their ability to control waste gas emissions. As a result of this study, it was discovered that nitrous oxide occurs in the postoperative respirations of individuals long after the discontinuation of the gas. This technique was then taken to the PACU as a proof of concept to determine if WAGs occur in the breathing zone of recovering patients and are exposing nurses to these exhaled anesthetic gases.

To visualize possible WAGs in the recovery room, the identical instrumentation used in the JADA February 2009 issue was utilized. (See figure 1) Preliminary data were collected using three types of instrumentation. These were Infrared thermography by means of an infrared camera (Merlin Mid-INSB Midwave infrared camera), digital videography by means of a camcorder (Handicam, DCR-SR100, Sony, Tokyo), and a real-time nitrous oxide air concentration levels by means of an infrared spectrophotometer (Miran 1B SapphIRE Ambient Air Analyzer). [61]

The ISO-Gard® Mask with ClearAir™ Technology (Teleflex, Durham, NC)

Upon entering the PACU, the infrared camera was utilized to visualize the waste anesthetic gas of nitrous oxide. (See figure 2) The anesthesiologist utilized nitrous oxide during the procedure of a breast reduction. The nitrous oxide was then turned off at the anesthetic machine approximately 30 minutes into entering the PACU. At this time the MIRAN unit was then utilized to measure the nitrous oxide part per million readings in the exhaled air of the patient. The monitoring wand could be seen through the infrared camera. (See figure 3)[61]

The Sony camcorder was then used to videotape the MIRAN unit readings that were displayed on its screen. Thus, confirmation both visually and with the MIRAN visual readout was accomplished to determine the nitrous oxide levels following the completion of the surgical procedure. The preliminary findings were consistent with nitrous oxide being exhaled by the patient in the PACU. These readings were found to range from 300 ppm to 520 ppm. The MIRAN unit was then recalibrated so that it could measure sevoflurane levels, and these were also above NIOSH REL's and found to range from 25-64 ppm.[61]

Summary

By utilizing the protocol to visualize nitrous oxide we were able to document occupational exposure to WAGs in the PACU.[59.61] A review of the literature in regard to possible health concerns from post-anesthetic gases and the conclusions from governing bodies and professional organizations, indicate a general agreement that control of WAGs should be done. Utilizing engineering controls, best work practices, and personal protective equipment (such as a mask) should be used in the PACU environment. Developing methods and practices to minimize these WAGs is important. In fact OSHA has stated, "the preferred and most effective means of protecting workers is to prevent hazards entering their breathing zone in the first place."[60] The position statement by ASPAN further states that all members should acquaint themselves with perianesthesia air safety issues by obtaining and reviewing the referenced documentation developed by ASPAN in support of their position.[47] They further state that perianesthesia nurses must seek opportunities to educate others involved in the decision-making process related to the perianesthesia care environment. All governing agencies have established guidelines to try to minimize possible health consequences to PACU personnel as well as recommend that all employees be informed of the potential adverse effects of exposure to WAGs and utilize all methods to help control the exposure to these WAGs. Through the use of this technology in the visualization of nitrous oxide in dental operatories and as a proof of

Figure 1: Visualization of nitrous oxide (N_20) from the patient's breathing zone in a dental operatory.

Figure 2: Visualization of WAG (N_20) escaping from the nose and mouth of a patient in a PACU.

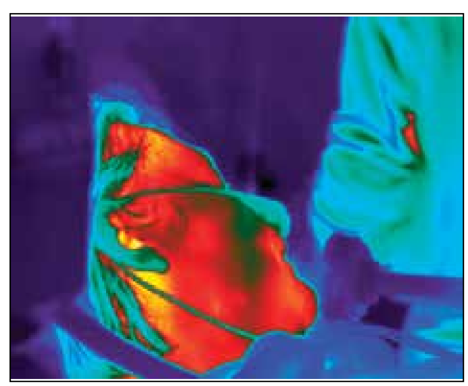

Figure 3: IR camera and IR Sensor (circled and placed near patient's breathing zone) to visualize and quantify nitrous oxide exposure.

concept in PACU environments, researchers could focus on where to target use of: 1) Engineering controls, such as ventilation and wall vacuum scavenging systems, 2) Best work practices, such as care providers using a mask and development of a patient oxygen delivery/scavenging mask, such as the ISO-Gard Mask with ClearAir Technology and 3) Administrative controls, such as routine maintenance of the systems and information to educate health care personnel on the potential hazards of WAGs. All of these areas need to be taken into consideration when protecting healthcare workers in the PACU; thus making the PACU a safer environment for both the patient and the healthcare workers.

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Essential Practices

Panel Discussion

Panel Discussion: *Waste Anesthetic Gases: Opinions from the Experts*

Moderator: **Clinical Foundations**
Panelists: David Farr, MD
Joni Brady, MSN, RN, CAPA
Jim McGlothlin, MD

How would you define waste anesthetic gases (WAGs) as a potential health exposure issue?

Brady: The knowledge that inhalation anesthetic agents pose a potentially hazardous chemical exposure for health care workers is well documented.[1-4] Several issues may cause anesthetic gas exposure, including leakage from faulty equipment seals and post-anesthetic patient exhalation. The latter is of particular concern to postanesthesia care unit (PACU) nurses, who work in very close proximity to the patient's breathing zone during the early postoperative period.

Farr: The standard for defining waste anesthetics as a health exposure issue is the National Institute for Occupational Safety and Health (NIOSH) 1977 report Criteria for a Recommended Standard: Occupational Exposure to Waste Anesthetics and Vapors.[5] In response to health concerns documented in the late 1960's and early 1970's and their own assessment, the 1977 NIOSH report issued recommended exposure limits (REL) for halogenated anesthetics and nitrous oxide (N_2O). The REL for nitrous oxide is a time weighted average (TWA) of 25 ppm during the period of administration. The REL for halogenated anesthetics is a ceiling of 2 ppm in a 1-hour sampling. Whenever there is exposure to both nitrous oxide and halogenated anesthetics the REL for the halogenated agent decreases to 0.5 ppm. These standards apply to all personnel exposed to anesthetic agents escaping into locations associated with the administration of anesthesia (or recovery from it) with the intent to protect the health and safety of workers during their work lifetime in locations where exposure to WAGs occur.[5]

> Whenever there is exposure to both nitrous oxide and halogenated anesthetics the REL for the halogenated agent decreases to 0.5 ppm.
>
> - Farr -

McGlothlin: I would define waste anesthetic gas (WAG) as a potential health exposure risk in the PACU for three reasons: First, very little is understood about how much residual WAG can off-gas from a patient. This is because patient size can vary from a petite individual who may not have a long "decay" curve for WAGs, to a very large individual who may have a very long decay curve for WAGs. Another variable is of type and amount of anesthetic gas administered to the individual. The same small individual may have had much more anesthetic gas administered to them compared to the larger individual and the smaller person's WAG could be much higher when first brought into the PACU. Second, the general ventilation in the PACU may be inadequate in terms of air circulation as well as the introduction of fresh air to keep WAG levels from rising (due to poor air circulation) during the work shift. Third, we don't know the personal body burden of healthcare personnel working in the PACU from WAGs. The discovery that exposure to WAGs in the PACU is significant and is above NIOSH and American Conference of Governmental Industrial Hygienists (ACGIH) guidelines is new. Also, to date there have not been any studies to determine the extent to which WAGs impact this population.

Is exposure to waste anesthetic gases a real health concern among healthcare personnel?

Brady: Yes, this is a significant concern. While health care worker exposure to WAGs exists and has been addressed through regulatory means, its importance is likely underappreciated by those who risk exposure in the PACU setting. In a recent informal query of perianesthesia nursing colleagues, the majority had little awareness of exposure risk to WAGs or its potential adverse health implications. Studies performed in the late 1990s and early 2000s provided emerging details about WAGs and the direct care PACU environment,[4,6] yet awareness surrounding health threats to nurses providing direct patient care may be limited in current practice.

Farr: I think concerns of healthcare individuals are for the most part, with exceptions, reflected by their organizations. Responding to a 2006 NIOSH-064 request for information regarding the development of RELs for the newer halogenated agents isoflurane, desflurane and sevoflurane,[7] the American Society of Anesthesiologists (ASA) published a response from its Task Force on Waste Anesthesia Gases, "there are no reports that demonstrate adverse effects in workers from older volatile agents for which RELs exist and to the newer ones, isoflurane, desflurane and sevoflurane, for which there are no RELs."[8] A new attitude may be emerging from the ASA in light of recent research. As stated from the ASA president, cosigned by the president-elect of the Society for Pediatric Anesthesia and the Chair of the Section on Anesthesiology and Pain Medicine, Academy of Pediatrics, in referring to anesthesia in young children, "unfortunately, potential harm exist despite our best efforts and current state of knowledge."[9] It remains to be seen if this is a signal of a new attitude toward RELs.

McGlothlin: First, it has to be established that WAG exposure among healthcare personnel is serious and that there are several well-conducted peer-reviewed studies that show that there are short-term (high WAG concentrations), and long-term (low WAG concentrations) health consequences from exposure. While some healthcare personnel such as those in operating rooms and in dental operatories are aware of the health risks, especially young female workers, those in the PACU are generally not aware that there is a significant WAG exposure risk in their work environment. Raising awareness that WAGs are a health concern is the first step. Then providing the parade of evidence is the second step by providing study after study that the problem is prevalent and that exposures are significant. Third is to communicate that a combination of best work practices and engineering controls, particularly those that control WAG exposure at the source (i.e., the patient) are available, affordable and should be used.

What is known about waste anesthetic gases in terms of acute and chronic health effects?

Brady: Unscavenged WAGs have been linked to an increased potential for adverse reproductive and neurological effects in exposed workers and their offspring.[3,10] Health issues related to long-term WAG exposure include: kidney and liver diseases, cancer, spontaneous abortion, and congenital anomalies.[1] Smith (2010) reports short-term and long-term effects related to WAG exposure.[11] Immediate inhalation effects commonly experienced by workers include fatigue, dizziness and lethargy; when the exposure is removed these symptoms dissipate. Chronic long-term effects show a relationship with the gas concentration (measured in parts per million) and duration of exposure. Retrospective and prospective studies

> Unscavenged WAGs have been linked to an increased potential for adverse reproductive and neurological effects in exposed workers and their offspring.
>
> -Brady -

produced workplace standards for exposure, scavenging, measurement, and monitoring in the US.[11]

A 2007 health and workplace exposures survey asked nurses to supply health status and exposure data. Over 1500 American nurses from every state detailed personal health issues and those of biological children. WAG exposure was reported by 168 of the participants with commonly incurred health issues comprising: chronic headaches and migraines, peripheral neuropathy, allergies, depression, dermatitis, anemia, and multiple sclerosis. Nurses with low or no WAG exposure had considerably lower rates of migraines, anemia and depression. Pregnant nurse participants in this study who reported high WAG exposure, versus those with low or no exposure, reported higher rates congenital defects in the central nervous system (113%), genitourinary (506%) and congenital musculoskeletal (824%) system.[10]

Farr: The health effects of waste anesthetic gases have been described in anecdotal reports since the first volatile anesthetic was used in 1840's. The modern era of documented evidence began with a paper from the Soviet Union in 1967 in which Vaisman describes a health survey of 198 male and 110 female anesthesiologist. Results showed that 18 of 31 pregnancies of those exposed to waste anesthetic gases (nitrous oxide, halothane and diethyl ether were the predominant anesthetics) ended in spontaneous abortions.[12] There were also complaints of fatigue, irritability and headache.

Today it is recognized that most acute health effects of waste anesthetic gases are generally central nervous system-related and include headache, irritability, fatigue, nausea, drowsiness and difficulties with coordination and judgment. These were the predominate concerns of the 1977 NIOSH document with regards to the REL of nitrous oxide.[5] Chronic health concerns for waste anesthetic gases are related to reproduction and kidney and liver damage. These chronic effects were highlighted by the 1974 ASA survey report- Ad Hoc Committee on the Effects of Trace Anesthetics on the Health of Operating Room Personnel.[13] This report surveyed over 70,000 healthcare professionals, almost 50,000 exposed to waste anesthetic gases and almost 24,000 non-exposed professionals. The results showed the females in the exposed group had an increase in spontaneous abortions, congenital abnormalities in children, cancer and hepatic and renal disease. Increases in congenital abnormalities were also found in the unexposed wives of exposed males. Exposed males also had an increase in hepatic disease similar to the exposed female group.

Other important epidemiological reviews were published in 1985. A study by Buring et al. showed evidence of a 50% increase in hepatic abnormalities in both male and female workers and a 30% increase in renal disease in females.[14] There was also an increase in spontaneous abortion rate and a small increase in cervical cancer. They concluded risks were small and could be explained by confounding variables and responder bias. The Tannenbaum and Goldberg review showed a 1.5-2x increase in the spontaneous abortion rate in exposed workers, but did not find increased risks for cancer, congenital abnormalities, or increased risk to the reproduction of the spouses of exposed men.[15] The need for prospective studies was mentioned. In 1990, Guirguis et al. compared mailed questionnaire results from 8032 hospital personnel exposed to anesthetic gases in the OR and PACUs to 2525 non-exposed personnel.[16] When confounding variables were removed by advanced statistical methods, the results in the exposed group showed a 198% increase in spontaneous abortions and a 224% increase in congenital anomalies. These investigators concluded that the consistency of the findings among different studies made it obviously important to minimize circulation of anesthetic gases in the operating rooms and recovery rooms.

There are many animal studies that show reproductive problems, usually in very high levels of prolonged exposure to anesthetics. Whether or not these effects are due to physiologic effects from the anesthetics or from the anesthetics themselves is controversial. Much less controversial is the issue of high clinical exposure to nitrous oxide. In unscavenged dental rooms using nitrous oxide there is an increase in spontaneous abortions, reports of neuropathy, and reports of hematologic variation. Nitrous oxide is known to irreversibly oxidize the cobalt atom of vitamin B12, inactivating it and part of B12-dependent enzyme systems like methionine synthetase.[17] Methionine is important in nervous system maintenance and structure and DNA synthesis in rapid proliferating tissues. Therefore nitrous oxide is associated with neuropathy, blood disorders and increased blood levels of homocystine and potential reproductive disorders. In studies of female dental assistants, Rowland et al. showed that working in an unscavenged nitrous oxide environment led to decreased fertility.[18] Three hours of exposure per week or more would lead to a 260% increase in spontaneous abortions. With these issues under consideration, NIOSH issued report 94-100 and 94-118 issuing a warning of the health effects of nitrous oxide and steps to monitor and reduce exposure.[19,20]

McGlothlin: There has been evidence that WAGs were a health hazard in both human and controlled animal studies. Acute effects range from asphyxiation to passing out when used recreationally or for harm, also when there is a cylinder leak. For chronic health effects there have been several studies dating back to the 1960's showing that WAGs are a potential health hazard. Since that time, there have been many other studies what have found similar reproductive hazards for females and males where anesthetic gases are administered. Similar results were demonstrated when anesthetic gases, in particular nitrous oxide at 500 ppm to rats for 8 hours per day showed reduced fertility. Other studies have shown that WAGs may be responsible for adverse carcinogenicity and mutagenicity, liver and kidney effects, and is detrimental to the central nervous system. The exact mechanism for adverse health effects from WAG exposure is not exactly known. However, it does appear that anesthetic gases such as nitrous oxide inhibits enzyme synthesis where B12 is a cofactor and this may account for some of the adverse neurologic health effects.

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- McGlothlin -

If waste anesthetic gases are a potential health issue, is there enough information in the literature to control these gases in healthcare environments.

Brady: The Occupational Safety & Health Administration (OSHA) Waste Anesthetic Gas Workplace Exposure guideline identifies the PACU patient as a primary source of WAG emission. Although the literature provides information on WAG control in the operating room (OR), the PACU is presently a non-scavenged environment which is prone to less effective methods of waste gas removal. These factors make control of clinician WAG exposure more difficult in a PACU environment. Additionally, ambient PACU WAG measurements do not generally capture the WAG levels encountered within the breathing zone, or sequentially measure room concentrations across peak patient volume periods.

Farr: The NIOSH 1977 document recommended several steps to reduce occupational exposure to waste anesthetic gases. They included scavenging and disposal of gases away from exposure areas, institution of work place practices and engineering controls to reduce exposure, medical surveillance and maintenance of records of personnel to detect possible health effects and monitoring waste anesthetic gases.[5]

The result of the above recommendations is that the modern operating rooms have point of source scavenging from the anesthesia machines and at least 15x (including at least 3 fresh) air exchanges per hour ventilation.[21] Anesthesia machines have software programs to perform system leak tests and vaporizers have secure ways to be filled to eliminate leaks and spills. These and other work place practices recommended by NIOSH have reduced the WAG in the OR environment. Since recovery rooms have no point of source scavenging, ventilation dilution/disposal is the solution for removing anesthetic gases. Recovery rooms should have at least 6x (including 2 fresh) air exchanges per hour.[21] It has been estimated that scavenging according to NIOSH standards reduces WAG by 90% compared to unscavenged in the OR.

McGlothlin: There have been several publications indicating that WAGs in operating rooms and dental operatories are a serious health hazard and as such should be controlled through a series of steps first starting with programs that effectively manage waste gases. Such programs go into detail about how to detect leaks from cylinders and anesthetic gas delivery systems; best practices; scavenging systems; and good general ventilation. Reputable publications on this subject have been available for the past 15 to 20 years ranging from Federal Government agencies such as NIOSH to Associations such as the American Association of Nurse Anesthetists and the American Conference of Governmental Industrial Hygienists.

Are you aware of government recommendations to minimize health effects from waste anesthetic gases? If so, are they adequate to prevent adverse health effects among exposed healthcare personnel?

Brady: The Centers for Disease Control and Prevention (CDC) National Institute for Occupational and Safety Health (NIOSH) established WAG management, monitoring and measurement parameters, and much has been done to effectively scavenge gases and minimize exposure in the OR environment.[11] While the government recommendations have merit, the issue of WAG exposure for PACU practitioners remains concerning. Immediate postanesthesia care delivery necessitates the nurse be in close proximity to the patient. In my experience, it has been a common occurrence to smell anesthetic gas on inhalation while performing a baseline admission assessment and during continued PACU patient care. A gap in WAG exposure protection is evident.

Farr: Despite modern OR safety standards, there remains many sources of exposure to WAGs. A single milliliter of spilled anesthesia liquid creates about 200 mL of vapor and is enough to raise a small OR room above the REL limit. Workplace practices still account for over 90% of WAG exposure. Loose mask fit, reserve tank leaks, scavenger shut-off or disfunction, loose anesthesia circuit connections, uncuffed or underinflated cuffed endotrachial tubes, or poorly sealed laryngeal mask devices are some of the many sources still present in the OR. A more complete list of leak sources is in Table 2 of the 1999 ASA Publication on Waste Anesthetic Gases: information for management in anesthetizing areas and the postanesthesia care unit.

McGlothlin: There are Federal Recommended Exposure Limits (REL) from NIOSH at 25 ppm during the time of administration of the anesthetic gas to the patient (from the time the gas is turned on until the time it is turned off). There is also an American Conference of Governmental Industrial Hygienists (ACGIH), a professional association, that recommends 50 ppm over an 8-hour day for WAG. However, what is missed for the ACGIH recommendation is that no exposure level should exceed 3 times the recommended Time-Weighted Average (TWA) exposure over a short time period of 15 minutes. Therefore, if exposures to WAGs, like nitrous oxide exceed 150 ppm then the healthcare workers are overexposed and at risk for adverse health outcomes. OSHA does not have a standard for WAGs. However, it can issue citations under the General Duty Clause of 5a(1) that states that no work environment shall expose workers to known safety and health hazards. Aside from the anomaly of the ACGIH recommendation not exceeding 150 ppm over a short exposure period, the NIOSH REL is based on a safe exposure to which no adverse health effects are seen. This level was established in the NIOSH Criteria Document on Control of Anesthetic gases in 1977 that found that there were neurologic effects from 50 ppm for such things as delayed reaction time and mental errors. In today's climate the problem of healthcare workers being under pressure not to make medical errors may play into this area of concern.

Are waste anesthetic gases known to be a potential problem in the Post-Anesthetic Care Unit (PACU)?

Brady: Interestingly, studies on the effects of WAGs have most often focused on OR staff. A limited number of studies involving perianesthesia nurse WAG exposure support the finding that such emissions regularly occur when a post-anesthesia patient exhales[4,22] thereby placing the postanesthesia nurse directly at risk. Study findings support that repeated exposure to exhaled anesthetic gases occurs in the PACU, particularly due to the close proximity of the nurse to a patient's breathing zone. The second-hand WAG effect can become highly problematic because it is known to cause increased lethargy and fatigue, potentially increasing the nurse's risk for health problems and dangerous medical errors and/or omissions. This aspect is particularly concerning in light of emerging issues surrounding qualified nurse staffing shortages and related assignment fatigue. While air exchange mandates and gas-scavenging systems have reduced WAG exposure for OR and anesthesia personnel, the PACU environment of care remains an area of significant concern for WAG exposure for which further research and targeted intervention is warranted.[6,10]

Farr: The primary source of WAG in the PACU is the exhaled breath or out-gassing of anesthetics from recovering patients.[23] Since there is no point of source scavenging, ventilation diffusion/disposal is the method used to rid the PACU of WAG. PACUs have many variables that may impact the WAG load. Patient census, duration and type of anesthetic (MAC hours) the patient was administered, whether or not the patient is extubated, time of anesthesia discontinuation before admission to the PACU, PACU size and ventilation adequacy, and number of simultaneous patients cared for by a nurse, and the time of the exposure are but some of the variables that can effect WAG exposure in the PACU.[24,25] Important to the understanding of why patients, even though awake, bring a significant WAG load to recovery room is the concept of "MAC-awake." MAC-awake by definition is the concentration of inhaled anesthetic in the patient which 50% don't respond to verbal stimuli and 50% do. This happens around 0.3 MAC with some (variation depending upon the agent).[26] This corresponds to 1.8% desflurane (18,000 ppm) 0.34% (3400 ppm) isoflurane and 0.6% (6,000 ppm) sevoflurane. The need for efficiency in OR utilization and the ubiquitous use of laryngeal mask devices may result in even higher levels of anesthesia exhaled in PACU. The patients may arrive in the PACU with the airway in place; or the airway removed while the patient was more deeply anesthetized before the patient is at MAC-awake. One the techniques recommended is the remove the laryngeal mask devices from deeply anesthetized at MAC levels to reduce coughing or airway irritation.[26] WAGs have been measured to be higher in PACU than in the OR with halothane having been detected in the blood and breath of PACU nurses in a 1972 study by Pfaffli and Nikke, et al.[25] In a poorly ventilated PACU, Sessler et al. showed that PACU levels of WAGs can exceed RELs by a large amount for a significant duration.[27] Cope et al. showed that even with exposure below the REL of gases (nitrous oxide and isoflurane) after a work shift, PACU personnel still showed a biological effect with depression of central neurorespiratory activity.[4] Study subjects had CNS respiratory depression as measured by end-expiratory occlusion pressure and had a small but measurable amount in their breath.

McGlothlin: The discovery of WAGs in the PACU is relatively recent. The reason for this is that WAGs were not considered a problem in an area where anesthetic gases are not being administered. The very notion is counterintuitive. However, studies that have been done over the past 10 years have pointed to WAGs being a potential problem for PACU healthcare personnel. Another reason that WAGs have been discovered as a potential health issue in the PACU is that advances in technology now allows researchers to "see" the WAGs using infrared (IR) thermography. Powerful, portable IR cameras can now be set up in any environment where anesthetic gases are used and with special filters, these cameras can now visualize and capture on film the WAGs escaping from the patient's breathing area. Add this camera technology with an IR instrument calibrated to quantify WAG and not only can one see the gas, it can be quantified. Recent studies have indicated that such levels exceed the NIOSH recommended exposure limits (RELs) and the ACGIH Threshold Limit Values (TLVs). As such, these WAGs in patients exhalation may be at a level that is potentially hazardous to PACU personnel; not only when they first arrive from the operating room but they can "off gas" WAGs for up to 45 minutes after they arrive.[28]

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Questions

1. **It has been known for decades and reported in the literature that exposure to Waste Anesthetic Gases (WAGs) among healthcare personnel can potentially cause adverse health effects ranging from neurologic deficits, to birth defects, to spontaneous abortions.**
   A. True
   B. False

2. **The Occupational Safety and Health Administration has a Waste Anesthetic Gas standard of 50 parts per million over an 8-hour day.**
   A. True
   B. False

3. **The National Institute for Occupational Safety and Health (NIOSH) has a Recommended Exposure Limit (REL) of 25 parts per million during the time of administration. This means the time from when the gas is turned on until the gas is turned off. Why is this different from the 50 ppm over an 8-hour period?**
   A. The NIOSH REL is focused on the effectiveness of anesthetic gas delivery systems when they are turned on and when they are turned off.
   B. The NIOSH REL is more stringent at 25 ppm during administration
   C. OSHA is an enforcement agency while NIOSH is a research agency.
   D. OSHA regulations will not allow citations to be issued that are as low as NIOSH RELs.

4. **The American Society of Anesthesiologists in their Guidelines for Non-Operating Room Anesthesia Locations was approved by their House of Delegates in 1994 and stated that in any location that inhalation agents are administered should have adequate and reliable systems for scavenging waste anesthetic gases.**
   A. True
   B. False

5. **While waste anesthetic gases are a problem, there are no practical and effective means to capture and control such gases in healthcare environments.**
   A. This is only true for surgical suites where the patient's mouth and nose can be covered to administer and exhaust such gases.
   B. This is only true for dental operatories where scavenging masks have been available for years.
   C. This is not true post anesthetic care units because scavenging systems don't exist and anesthetic gases are not an issue because anesthetic gases are not being administered in the PACU to patients.
   D. Scavenging systems have been shown to be effective in reducing and controlling waste anesthetic gases for healthcare personnel.

6. **PACU does not have issues with exposure to waste anesthetic gases because there is not a source where such gases are administered to patients.**
   A. True
   B. False

7. **Today, nitrous oxide is being used less and sevoflurane is being used more among patients who are administered anesthesia during surgery. This is okay since nitrous oxide is more toxic than sevoflurane and has lower recommended exposure limit.**
   A. True
   B. False

8. **Nitrous oxide is more toxic than sevoflurane and the government Recommended Exposure Limits (RELs) for sevoflurane are higher than for nitrous oxide.**
   A. True
   B. False

9. **Waste anesthetic gases such as nitrous oxide can be visualized and quantified using infrared thermography tools such as infrared cameras and real-time infrared sensors calibrated to detect waste anesthetic gases.**
   A. True
   B. False

10. **Discovery of waste anesthetic gases in the Post Anesthetic Care Unit was relatively recent because it was thought that patients administered anesthetic agents would not be a significant source of occupational exposure among PACU healthcare personnel.**
   A. True
   B. False

This program has been approved for 2.0 contact hours of continuing education (CRCE) by the American Association for Respiratory Care (AARC). AARC is accredited as an approver of continuing education in respiratory care.

This education activity is approved for 1.0 contact hour. Provider approved by California Board of Nursing, Provider #14477

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6. Accreditation expires Jan. 19, 2018 (RTs), Oct. 16, 2017 (Nurses).
7. Faculty Disclosure. Dr. McGlothlin disclosed he is a paid consultant (Teleflex) No conflicts were disclosed for any other faculty.

Participant's Evaluation

1. What is the highest degree you have earned? Circle one. 1. Diploma 2. Associate 3. Bachelor 4. Masters 5. Doctorate
2. Indicate to what degree the program met the objectives:

Objectives

Upon completion of the course, the reader was able to:

1. Describe the health consequences from chronic low dose exposure to waste anesthetic gases

   Strongly Agree Strongly Disagree
   1 2 3 4 5 6

2. List the availability of scavenging to minimize exposures to waste anesthetic gases

   Strongly Agree Strongly Disagree
   1 2 3 4 5 6

3. Identify government agencies to contact and are responsible for establishing safe exposure limits to waste anesthetic gases

   Strongly Agree Strongly Disagree
   1 2 3 4 5 6

5. Please indicate your agreement with the following statement. "The content of this course was presented without bias toward any product or drug."

   Strongly Agree Strongly Disagree
   1 2 3 4 5 6

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Answers

1	6
2	7
3	8
4	9
5	10

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