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Environmental and Occupational Considerations of Anesthesia: A Narrative Review and Update

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[See Article, p 825](#)

With an estimated worldwide volume of 266 million surgeries in 2015, the call for general inhalation anesthesia is considerable. However, widely used volatile anesthetics such as N₂O and the highly fluorinated gases sevoflurane, desflurane, and isoflurane are greenhouse gases, ozone-depleting agents, or both. Because these agents undergo minimal metabolism in the body during clinical use and are primarily (≥95%) eliminated unchanged via exhalation, waste anesthetic gases (WAGs) in operating rooms and postanesthesia care units can pose a challenge for overall elimination and occupational exposure. The chemical properties and global warming impacts of these gases vary, with atmospheric lifetimes of 1–5 years for sevoflurane, 3–6 years for isoflurane, 9–21 years for desflurane, and 114 years for N₂O. Additionally, the use of N₂O as a carrier gas for the inhalation anesthetics and as a supplement to intravenous (IV) anesthetics further contributes to these impacts. At the same time, unscavenged WAGs can result in chronic occupational exposure of health care workers to potential associated adverse health effects. Few adverse effects associated with WAGs have been documented, however, when workplace exposure limits are implemented. Specific measures that can help reduce occupational exposure and the environmental impact of inhaled anesthetics include efficient ventilation and scavenging systems, regular monitoring of airborne concentrations of waste gases to remain below recommended limits, ensuring that anesthesia equipment is well maintained, avoiding desflurane and N₂O if possible, and minimizing fresh gas flow rates (eg, use of low-flow anesthesia). One alternative to volatile anesthetics may be total intravenous anesthesia (TIVA). While TIVA is not associated with the risks of occupational exposure or atmospheric pollution that are inherent to volatile anesthetic gases, clinical considerations should be weighed in the choice of agent. Appropriate procedures for the disposal of IV anesthetics must be followed to minimize any potential for negative environmental effects. Overall, although their contributions are relatively low compared with those of other human-produced substances, inhaled anesthetics are intrinsically potent greenhouse gases and pose a risk to operating-room personnel if not properly managed and scavenged. Factors to reduce waste and minimize the future impact of these substances should be considered. (*Anesth Analg* 2021;133:826–35)

GLOSSARY

B = bioaccumulation; **CFC** = chlorofluorocarbon; **FGF** = fresh gas flow; **GHG** = greenhouse gas; **GWP** = global warming potential; **IV** = intravenous; **MAC** = minimum alveolar concentration; **NIOSH** = National Institute for Occupational Safety and Health; **OSHA** = Occupational Safety and Health Administration; **P** = persistence; **PACU** = postanesthesia care unit; **T** = toxicity; **TIVA** = total intravenous anesthesia; **vB** = very bioaccumulative; **WAG** = waste anesthetic gas; **WHO** = World Health Organization

Since the 1950s, the climate system has warmed, causing changes that are projected to have an increasing effect on environmental and social determinants of health such as the need for clean air, safe drinking water, sufficient food, and secure shelter.^{1,2} According to a 2014 report by the World Health

Organization (WHO), such effects are expected to cause an additional 250,000 deaths/y in the coming decades.² With the human influence on global climate becoming clearer over the last several decades, integrated evidence-based responses from individuals, institutions, and governments are needed more than ever to mitigate

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the ecological and health effects of climate change. A key contributor to climate change is the emission of greenhouse gases (GHGs),^{1,3} which includes release of waste anesthetic gases (WAGs) from surgical procedures into the environment (Figure 1). Although anesthesia gases contribute a relatively small portion of GHGs, a strong body of evidence supports the importance of minimizing WAG release into the environment to limit contributions to climate change and associated health risks on the global level and, on an individual level, to minimize occupational exposure and risk of adverse effects.

The importance of this issue is further supported by the considerable worldwide volume of surgical procedures, many of which call for general inhalation anesthesia. A 2019 study of global surgery metrics estimated that 266 million surgeries were performed worldwide in 2015, with a global median of 4171 procedures per 100,000 individuals.⁷ Just in the United States, an estimated 36 million surgeries were performed in 2015, corresponding to 11,113 surgeries per 100,000 individuals. This large surgical volume exposes a broad range of health care workers, including anesthesiologists, dentists/dental personnel, nurse anesthetists, operating-room nurses, operating-room technicians/personnel, recovery-room nurses/personnel, and surgeons, to volatile anesthetics.⁸ In the United States alone, during 2015, more than a quarter of a million health care workers were potentially exposed to anesthetic gases that leak during procedures (ie, WAGs) and are consequently at risk for associated adverse health effects.⁹

Given these considerations, this narrative review aimed to summarize the current understanding of

the environmental (climate change health effects, greenhouse effect/gases that impact the atmosphere, and effect of anesthetic gases released into the atmosphere) and occupational (agents used, early research on exposure and health impact, exposure limits, and modern exposure and health effects) exposure aspects of volatile anesthetic gases. In this context, specific strategies and recent innovations for hospital anesthesia waste-minimization efforts are also discussed (volatile/inhaled and intravenous [IV] anesthetic alternatives and current strategies to minimize environmental and occupational exposure, including “greening the operating room/operating theater”).

SEARCH STRATEGY

A PubMed search for English-language articles published from January 1, 2000, to June 30, 2020, using the search string (anesthesia and “greenhouse gas”) was conducted to ensure inclusion of the most current literature. Of the 23 articles identified by the PubMed search, 7 did not discuss environmental or occupational exposure to inhaled anesthetic gases or the mitigation thereof and were therefore excluded. The remaining relevant articles were retrieved and reviewed, and relevant references cited in retrieved articles were also reviewed.

VOLATILE ANESTHETICS: ENVIRONMENTAL RELEASE AND POTENTIAL IMPACT

Of the volatile anesthetics, the most widely used include N₂O and the highly fluorinated gases sevoflurane (eg, Ultane/Sevorane, AbbVie Inc, North

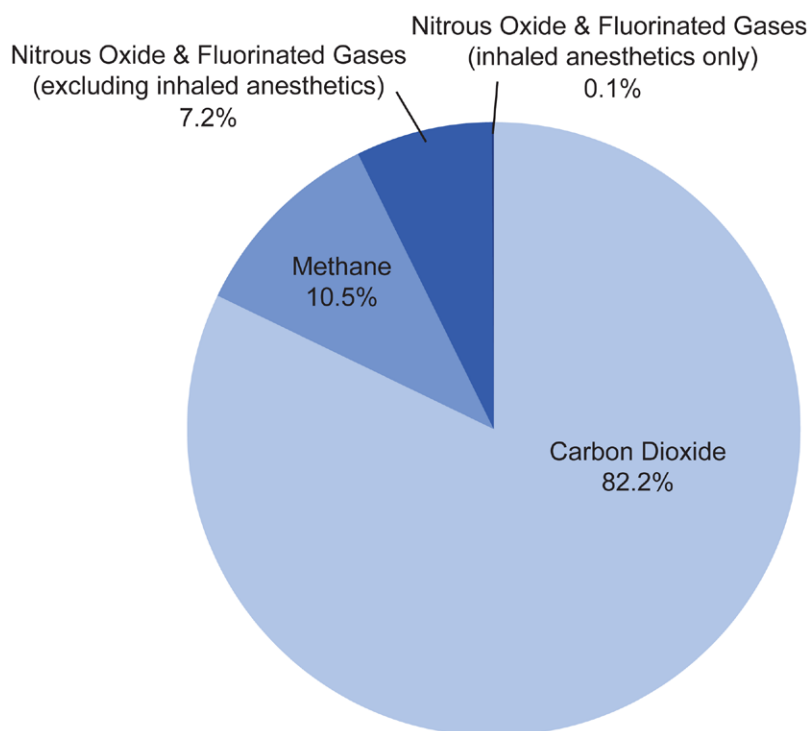


Figure 1. The total annual US GHG emission in 2012 was 6.2 gigatons of CO₂ equivalent, of which 6.8% comprised N₂O (4.3%) and fluorinated gases (3%; hydrofluorocarbons, perfluorocarbons, sulfur hexafluoride, and nitrogen trifluoride).⁴ The contributions of inhaled anesthetics (N₂O, desflurane, isoflurane, and sevoflurane) to US GHG emissions for 2011–2013 were estimated to be 5.6 million tons of CO₂ equivalent (excluding dental, laboratory, and veterinary medicine),^{5,6} comprising approximately 1% of GHG emissions from the US health care sector⁶ and approximately 0.1% of total US GHG emissions.^{4,6} GHG indicates greenhouse gas.

Chicago, IL), desflurane (eg, Suprane, Baxter Healthcare Corporation, Deerfield, IL), and isoflurane (eg, Forane, Baxter Healthcare Corporation) (Figure 2A), all of which have been recognized during the last decade to contribute to climate change by altering the photophysical properties of the atmosphere (Table 1).^{14,15} N₂O and halogenated gases containing chlorine or bromine, such as isoflurane and the older drug halothane, can deplete ozone and diminish the ultraviolet radiation–shielding effect of the ozone layer.^{15–17} While halogenated gases that lack chlorine or bromine, such as sevoflurane and desflurane, do not catalytically destroy ozone, they remain important examples of climate-harming GHGs because trace amounts in the earth's atmosphere absorb and reduce outgoing infrared thermal energy, thereby warming the environment. Although the contribution of volatile anesthetics to total GHG emissions is small (0.1%) compared with CO₂ (82.2%; Figure 1), it is still important to consider the long-term, cumulative impact of inhaled anesthetics on climate change

and pursue strategies to minimize the introduction of these agents into the environment.^{15,18}

During clinical use, volatile anesthetics undergo little metabolism in the body and are, for the most part, eliminated via exhalation.^{14,19–22} For example, ≥95% of N₂O, desflurane, isoflurane, and sevoflurane are exhaled unchanged.^{10–12,23} These agents are typically scavenged in operating rooms from patient exhalation to minimize occupational exposure. However, these medical waste gases are then released into the atmosphere with little to no further processing, where they function as GHGs.^{22,24}

The contributions of GHGs and other agents to climate change are quantified using the global warming potential (GWP), which takes into account the radiative and atmospheric properties of a particular agent.^{1,15,22,25} Because global warming is assessed in terms of CO₂, GWP compares the contribution of a GHG with the same mass of CO₂ over a given period of time.

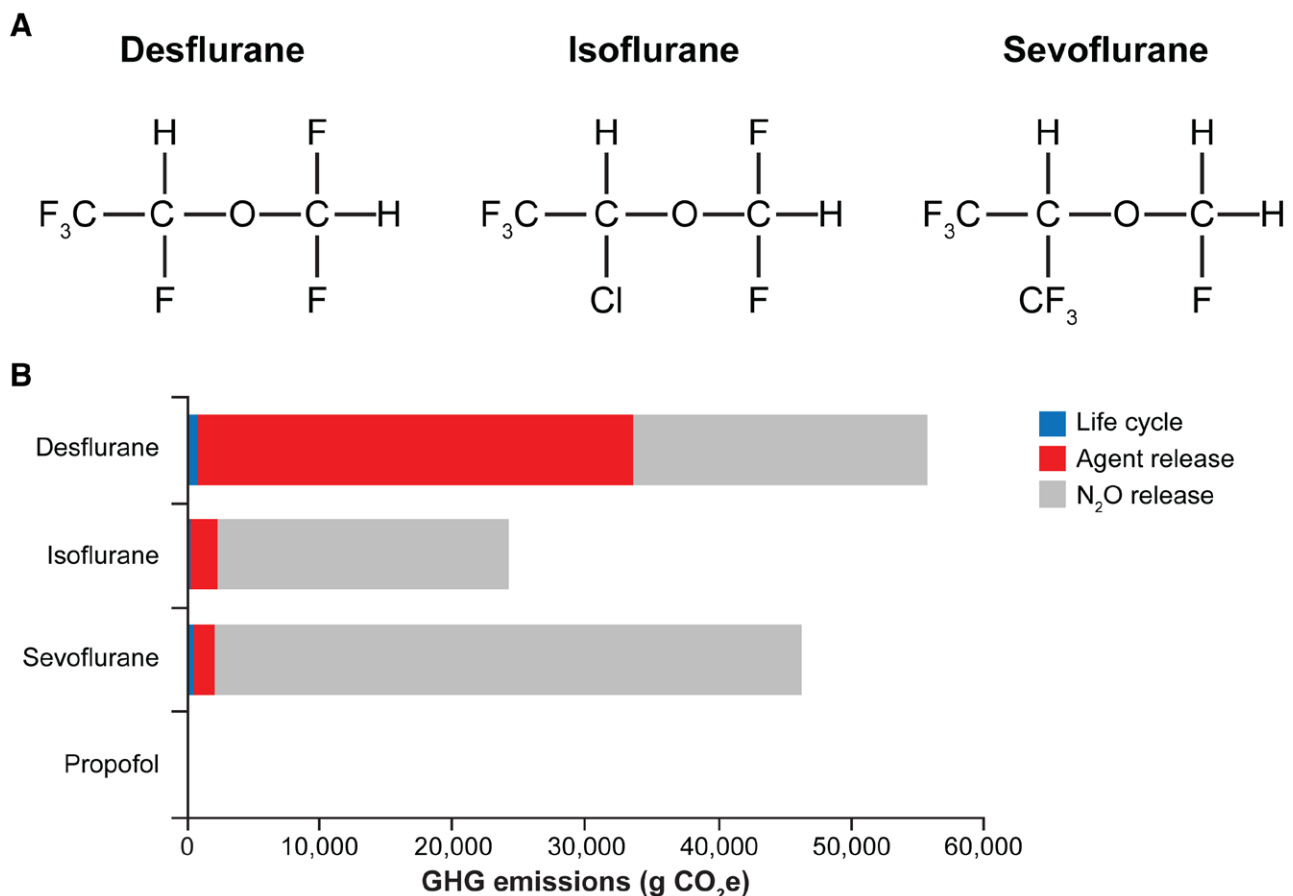


Figure 2. Structure and life-cycle GHG emissions of fluorinated volatile anesthetics. A, Structural formulas of the most frequently used fluorinated volatile anesthetics.^{10–12} B, Life-cycle GHG emissions of anesthetics, including waste anesthetic gas emissions of halogenated drugs and N₂O.¹³ Life-cycle GHG emissions shown in (B) are based on a functional unit of 1 MAC or MAC-equivalent for propofol, for maintenance anesthesia for an average 70-kg adult patient for 1 h (1 MAC-h). Panel B and 1 MAC-h definition have been reprinted from Sherman J, et al.¹³ by permission of Wolters Kluwer Health on behalf of the International Anesthesia Research Society. GHG indicates greenhouse gas; MAC, minimum alveolar concentration.

Table 1. Volatile Anesthetics That Are Ozone Depleters, Greenhouse Gases, or Both

Anesthetic	Chemical formula	Ozone depleter	Greenhouse gas
Nitrous oxide	N ₂ O	✓	✓
Halothane	CF ₃ CHBrCl	✓	✓
Isoflurane	CHF ₂ OCHClCF ₃	✓	✓
Sevoflurane	CH ₂ FOCH(CF ₃) ₂		✓
Desflurane	CHF ₂ OCHFClCF ₃		✓

Data were derived from Sulbaek Andersen et al,¹⁵ Langbein et al,¹⁶ and Fahey and Hegglin.¹⁷

Table 2. Atmospheric Lifetime of Trace Gases, Including Common Volatile Anesthetics

Compound	Lifetime (y)
N ₂ O	114
CFCs	50–100
CO ₂	5–200
Desflurane	8.9–21.0
Halothane	1.0–7.0
Isoflurane	2.6–5.9
Sevoflurane	1.1–5.2

Abbreviation: CFCs, chlorofluorocarbons.

Data were derived from Ishizawa,¹⁴ Sulbaek Andersen et al,¹⁵ and Bosenberg.²⁶

Atmospheric lifetimes vary among volatile anesthetics; of the 3 most commonly used highly fluorinated drugs, sevoflurane has the shortest lifetime (1–5 years) and a lower estimated GWP compared with isoflurane (3–6 years) or desflurane (9–21 years) (Table 2).^{14,15,26} Overall, life-cycle GHG emissions with desflurane are 15 times larger than those with sevoflurane and 20 times higher than those with isoflurane (Figure 2B).^{13,18} The use of N₂O as a carrier gas

for volatiles and as a supplemental with IV anesthetics further contributes to these impacts.^{13,18} An Australian study confirmed the disproportionate contribution of desflurane to GHG emissions compared with sevoflurane and isoflurane—while desflurane represented a small proportion (21%) of inhaled anesthetic bottles purchased for use in public hospitals in 2011, it accounted for the majority (81%) of the total annual GHG emissions attributed to these inhaled anesthetics.²⁷ In contrast, sevoflurane and isoflurane contributed much smaller proportions (17% and 2%, respectively) of the total annual GHG emissions. The 100-year GWP was calculated to be 893 CO₂ equivalents/kg for desflurane, compared with 48 for sevoflurane and 191 for isoflurane.²⁷ Furthermore, a US-based calculation has contextualized GWPs of these anesthetics by estimating that 1 hour of anesthesia with desflurane is equivalent to automobile emissions from driving a distance of 235–470 miles, whereas 1 hour of isoflurane or sevoflurane equates to driving 20–40 or 18 miles, respectively (Figure 3).¹⁸

To provide additional context around the contributions of volatile anesthetics to climate change, the discussions by Sulbaek Andersen et al^{15,28} on the climate impact of isoflurane, desflurane, and sevoflurane assumed that in the region of 200 million procedures involving these gases are performed each year. In their report, they tabulated best estimates of atmospheric lifetimes, ozone-depletion potential, radiative efficiencies, and GWP for N₂O, halothane, enflurane, isoflurane, desflurane, and sevoflurane.¹⁵ Based on these data, they concluded that, although inhaled anesthetics are estimated to represent a small

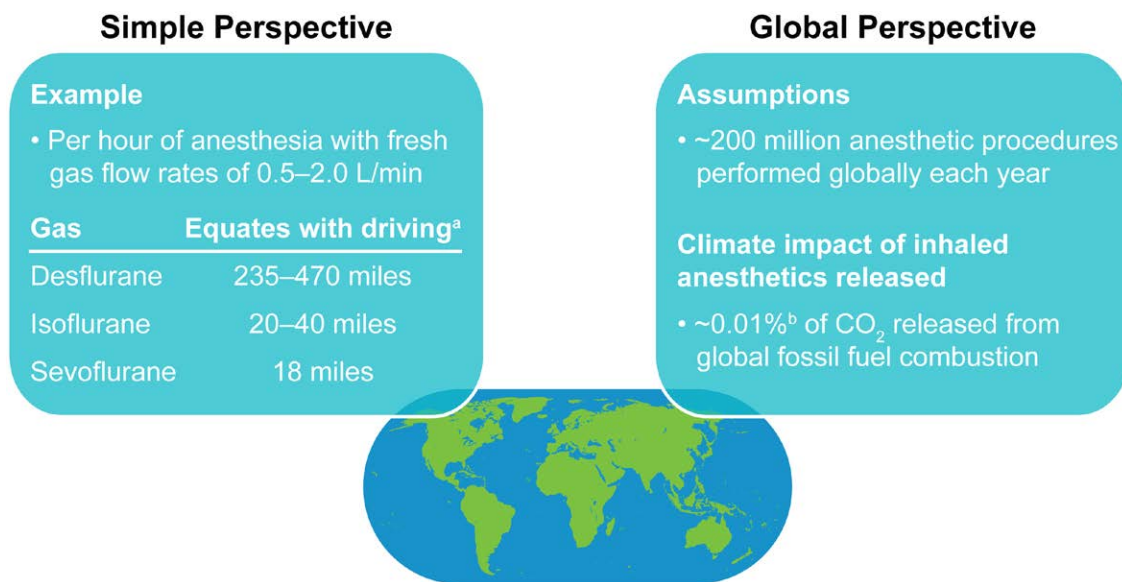


Figure 3. Global warming impact of inhaled anesthetics in perspective.^{15,18} ^aAssumes a US automobile average for CO₂ emissions of 398 g/mile. ^bDetermining the precise climate impact of worldwide anesthetic procedures is complicated because of limited available data on usage or production of anesthetic agents.

contribution relative to CO₂ and total GHG emissions (around 0.1% of CO₂ released from global fossil fuel combustion [Figure 1]), it remains important to consider the long-term, cumulative impact of inhaled anesthetics on climate change (Figure 3).¹⁵

VOLATILE ANESTHETICS: OCCUPATIONAL EXPOSURE AND POTENTIAL IMPACT

Minimizing the impact of anesthetic gases not only contributes to the protection of the environment but also takes into account the potential health hazard to individuals who experience chronic risk of occupational exposure from waste gases.

Potential Occupational Hazards Associated With Volatile Anesthetics

Early survey-based studies from the 1970s suggested some risk of health hazards (eg, liver disease, renal disease, neurologic disease, cancer, spontaneous miscarriage, or congenital abnormalities) among health care personnel exposed to inhaled anesthetics (primarily N₂O, diethyl ether, halothane, and enflurane²⁹) in working environments with poor or inadequate scavenging of inhaled anesthetics.^{30–34} Compared with the anesthetics and scavenging systems presently used, exposure levels of anesthetic gases in the operating room were, in general, higher in the era in which these studies were conducted (eg, halothane and N₂O at levels >2 and >25 ppm, respectively, with reports as high as 85 and 7000 ppm [time-weighted averages]).^{32,35–37} More recently, the potential for genetic damage and oxidative stress caused by exposure to WAGs has been recognized,³⁷ and guidance on exposure limits has been put in place to decrease health risks associated with occupational exposure.^{38–40}

Governmental Implementation of Exposure Limits

To ensure occupational safety around inhaled anesthetics, several countries have established recommended exposure limits (Table 3).³⁹ In 1977, the US

National Institute for Occupational Safety and Health (NIOSH) recommended that occupational exposure to halogenated anesthetics agents should not exceed 2 ppm or N₂O >25 ppm within a 1-hour period (time-weighted average for exposure duration) and that anesthetic gas machines, nonrebreathing systems, and T-tube devices have effective scavenging devices to collect all WAGs.³⁵ The current guidance from the US Department of Labor Occupational Safety and Health Administration (OSHA) for workplace exposures, created in 1999 and last revised in 2000, recommends minimizing exposure to all waste and trace gases for worker health and safety.⁴¹ Following these safety measure regulations in the United States, many other countries have followed suit with their own guidelines,³⁷ although occupational exposure to inhaled anesthetics has been shown to exceed exposure limits in some circumstances (eg, 8-hour time-weighted averages of halothane and N₂O of 10 and 100 ppm, respectively).^{42,43}

Impact of Waste Anesthesia Gas Regulations in the Workplace

With the implementation of guidelines limiting workplace exposure, studies have confirmed little to no increase in adverse effects associated with WAGs when gases are scavenged effectively.^{37,39,44} A 2016 systematic review of occupational exposure showed that evidence for adverse effects due to volatile anesthetics for personnel at risk of exposure is scarce and inconsistent, with evidence from many studies weakened by flaws in methodology and data collection.³⁹ Furthermore, no compelling evidence of significant adverse effects (eg, genotoxicity, congenital anomalies, and biomarkers of dysfunction) was found when environmental levels were kept within recommended exposure limits by using adequately designed and appropriately maintained facilities and exposure-minimization approaches.³⁹ However, some studies in facilities with poor air control or scavenging efficiency or in developing countries have demonstrated

Table 3. Recommended Exposure Limits for Volatile Anesthetics (Daily Exposure Limits in ppm)

Country	N ₂ O	Halothane	Desflurane	Isoflurane	Sevoflurane
Finland	100	1	10	10	10
Sweden	100	5	10	10	10
Denmark	50	5	5	5	5
Norway	50	0.02	20	2	20
Austria	100	5	-	10	10
Germany	100	5	-	-	-
United Kingdom	100	10	-	50	-
Switzerland	100	5	-	10	-
Belgium	50	50	-	-	-
Spain	50	50	-	50	-
United States (NIOSH)	25 ^a	2 ^a	2 ^a	2 ^a	2 ^a

Adapted and reprinted from Molina Aragonés et al³⁹ with permission from the Oxford University Press on behalf of the Society of Occupational Medicine.

Abbreviation: NIOSH, National Institute for Occupational Safety and Health.

^aExposure level that cannot be exceeded during a 1-h period.

oxidative stress, genotoxicity, and adverse health effects resulting from occupational exposure to anesthetics.^{37,45–47} Therefore, a potential health risk may remain for individuals chronically exposed to inhaled anesthetics in non-scavenged working environments or in workplaces with poor or inadequate air control where WAG exposure may exceed recommended limits.⁴¹

STRATEGIES FOR ENVIRONMENTAL AND OCCUPATIONAL IMPROVEMENT: HOSPITAL ANESTHESIA AND MINIMIZATION OF WASTE AND EXPOSURE

Around the world, the identification of environmental and occupational hazards for WAGs spurred the implementation of regulations by many governmental authorities. Consequently, hospitals and other settings that deliver inhaled anesthesia have increasingly sought to mitigate negative effects of WAGs through a variety of strategies and recent innovations.

Approaches to Minimize the Environmental Impact of Volatile Anesthetic Gases

Updated strategies recommended by the American Society of Anesthesiologists and other experts to decrease WAGs include avoiding N₂O as a carrier gas and minimizing fresh gas flow (FGF) rates.^{5,18,48–51} Ryan and Nielsen¹⁸ have estimated that the best approximations of ideal FGF rates would be achieved by reducing FGF to 2 L/min with sevoflurane and to 0.5–1 L/min with desflurane and isoflurane. Use of closed-circle breathing systems and low-flow anesthesia further increases the efficiency of administration and reduces the amount of inhaled agents used and associated environmental and occupational exposure.⁵²

Because N₂O is both an ozone depleter and a GHG, with an atmospheric lifetime of 114 years, use of N₂O as a carrier gas versus air/oxygen substantially increases the global warming effects of sevoflurane and isoflurane.¹⁸ Compared with sevoflurane and isoflurane, desflurane has much higher life-cycle GHG emissions (15 and 20 times higher, respectively), owing to a combination of higher required concentration and higher radiative forcing effect.^{5,13} Therefore, avoidance of both N₂O and desflurane is recommended, unless use of either could reduce morbidity and mortality compared with other anesthetics.^{5,50}

New technologies are also being investigated to reduce WAG release into the atmosphere. In a study comparing manual versus automated control of end-tidal anesthetic gases, automated control significantly reduced GHG emissions by 44%.⁵³ A second study demonstrated that changing from a traditional CO₂ absorbent to one that is nonreactive allowed for further reduction of FGF rates, which reduced both the amount of volatile anesthetic needed as well as the

amount vented into the environment.⁵⁴ A recent proof-of-concept study of a photochemical exhaust gas destruction system demonstrated efficient removal of desflurane and sevoflurane, although removal of N₂O requires further optimization.⁵⁵ These and similar strategies provide valuable reductions in the environmental impact of volatile anesthetic gases that can often be implemented in a cost-neutral or even cost-saving fashion.^{53–55}

Approaches to Minimize Occupational Exposure and Potential Health Impact of Volatile Anesthetic Gases

To manage and minimize occupational exposure to WAGs, NIOSH and others highlight the pivotal importance of using an efficient air ventilation and scavenging system,^{8,23,56,57} and, although a full list of countries is not available, reports suggests that this approach is being adopted around the world.^{56,58,59} Survey data have shown that approximately 97% of anesthetic administrators report consistent use of a waste gas scavenging system.⁹

Scavenging systems need to be in place not only in operating rooms but also in postanesthesia care units (PACUs) where residual gases exhaled by patients also need to be removed by effective ventilation methods.⁵⁶ Scavenging devices/anesthetic conserving devices have been shown to limit occupational exposure in recovery units following use of fluorinated inhaled anesthetics (ie, maintaining sevoflurane and desflurane time-weighted averages <2 ppm).^{60,61} Although trace amounts of sevoflurane have been detected in PACUs equipped with controlled air exchange systems, occupational limits were not exceeded.⁶²

Overall, regular monitoring of airborne waste gas concentrations should be performed in all personnel breathing zones.⁸ This may include not only operating facilities or recovery rooms/PACUs with no (or suboptimal) ventilation/scavenging systems but also similar settings with good scavenging/venting systems in place. Even in the latter case, health care workers may be exposed as a result of anesthetic breathing circuit leaks (eg, connectors, tubing, and valves), gas hookup and disconnection issues, gas seepage from patient mask or endotracheal apparatus (eg, during pediatric anesthesia if the mask is poorly fitted), induction leaks, or other dental surgery issues.^{8,42} Daily checks for leaks of anesthetic gases and the correct functioning of the scavenging and ventilation systems are required, and regular maintenance of all equipment, including preventive maintenance, should be performed and documented.^{8,63}

In conjunction with facility-based leakage monitoring, a medical surveillance program of all staff exposed to waste gases is also recommended.⁸ For example, in the United States, NIOSH recommends

obtaining baseline values and periodic monitoring of hepatic and renal function for exposed personnel as well as documentation of pertinent medical history information such as pregnancy outcomes for both female workers and female partners of male workers.⁸

To minimize WAGs in settings that administer volatile anesthetics, preventive measures are discussed in the current US guidance on WAGs from NIOSH and include the following:

- A complete anesthesia apparatus check should be performed each day/before each use^{8,41}
- Face masks must fit properly and provide an effective seal^{8,23,56}
- Cuffs on tracheal tubes and laryngeal masks must be inflated adequately^{8,23}
- Vaporizers should be carefully filled in well-ventilated areas⁸
- Vaporizers with a closed filling system should be used (risk for accidental spillage and leakage is negligible)⁵⁹
- Before disconnecting a patient from a breathing system, residual gases should be eliminated through the scavenging system as much as possible^{8,41}
- FGF rates should be minimized as much as possible^{8,52}

Added protection may also be gained from use of filters in anesthesia machines. Charcoal filters are often used as the final capture device to prevent halogenated anesthetic agents from dispersing into the atmosphere.^{5,64–66} Use of a closed filling system for vaporizers has also been shown to decrease ambient air contamination by inhaled anesthetics. One vaporizer system with an integral valve filling adaptor that connects directly into the vaporizer reduced sevoflurane contamination of ambient air by approximately 60% compared with other systems that used screw cap closures and vaporizer-specific adaptors for filling.⁶⁷ This closed filling system also maintained sevoflurane exposure (0.10 ppm) in the operator breathing zone that was well below the recommended maximum levels (2 ppm for 1 hour or 20 ppm for 15 minutes) and may help minimize occupational exposure.⁶⁸

Total Intravenous Anesthesia

Based on the issues associated with volatile anesthetics discussed above, total intravenous anesthesia (TIVA) may be considered as an alternative to volatile/inhaled anesthetics.^{13,42,51,57} By its nature, TIVA is not associated with the risks of occupational exposure inherent to volatile anesthetic gases; however, TIVA is not entirely devoid of potential negative environmental effects and the total environmental impact of TIVA must be taken into account.⁵⁰

Prediction of environmental hazards and the potential environmental impact of pharmaceuticals can be categorized by their impact on an aquatic environment according to a precautionary principle composed of 3 characteristics⁶⁹: persistence (P; ability to resist degradation in the aquatic environment), bioaccumulation (B; accumulation in adipose tissue of aquatic organisms), and toxicity (T; potential to poison aquatic organisms). Based on these characteristics, the “hazard score” indicates the environmental hazard associated with a particular substance such as a certain volatile or total IV anesthetic, calculated by assigning a numerical value of 0–3: P: 0 (not persistent) or 3 (persistent); B: 0 (does not bioaccumulate) or 3 (does bioaccumulate); T: 0–3, (nontoxic, very toxic, highly toxic). When summed, these characteristics provide a total PBT index that ranges from 0 to 9, with a higher value indicating a greater environmental hazard.⁶⁹ For example, if a compound is “P,” “B,” and “T” (ie, fulfills the specific criteria for all 3 properties), then it is automatically categorized as hazardous to the environment. Likewise, if a compound fulfills the criteria for “very persistent” and “very bioaccumulative” (vB), then it is also considered hazardous to the environment, regardless of predicted levels of exposure and toxicity. Because insufficient evidence exists to assess risk, desflurane, isoflurane, sevoflurane, and N₂O do not have hazard scores, indicating that environmental risk cannot be excluded.^{69–71} In comparison, although the widely used IV anesthetic propofol has demonstrated toxicity in aquatic organisms and disposal via incineration is recommended,⁷² propofol has a hazard score of 4, indicating low environmental risk.^{73,74} However, studies have shown that 32%–49% of dispensed propofol is unused and disposed of as waste,^{75,76} and not all institutions incinerate unused propofol.⁷⁷ While improper disposal methods and subsequent release into the environment may add to the negative impact of TIVA with agents such as propofol, accumulation of propofol in the environment has not been reliably estimated.^{13,76,77} Regional or multimodal anesthesia, either alone or in combination with TIVA or inhaled anesthetics, may also be viable alternatives for some procedures.^{51,78,79}

CONCLUSIONS

In providing a narrative overview of the impact of anesthetic waste and the significance of overall hospital waste, we have noted that inhaled anesthetics contribute to GHG emissions, although their contributions are lower than those of other human-produced substances. This notwithstanding, these volatile agents may also pose a potential health risk to operating-room personnel if not properly managed and scavenged.

Overall, factors to reduce waste and minimize the future impact of these substances should be considered. Specific measures that can be implemented to help reduce occupational exposure and the environmental impact of inhaled anesthetics include utilizing an efficient ventilation and scavenging system, regularly monitoring airborne concentrations of waste gases to maintain environmental levels below recommended limits, ensuring that anesthesia equipment is well maintained without leaks, avoiding desflurane and N₂O if possible, and using appropriate FGF rates. TIVA may also be an alternative to inhaled anesthetics, because it is not associated with risks from occupational exposure, but agents such as propofol must be disposed of appropriately. In addition, use of these mitigation measures has demonstrated not only reduced environmental and occupational impact but also reduced financial impact.⁸⁰ Further research may be needed to understand fully the long-term impacts and occupational exposure risk and outcomes associated with such exposure, and an increased focus on education and awareness among individuals, institutions, and governments may help to mitigate the environmental and occupational health footprint associated with global surgical use of volatile anesthetics. ■

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