Review Article

Paving the way to environment-friendly greener anesthesia

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Abstract

Health-care settings have an important responsibility toward environmental health and safety. The operating room is a major source of environmental pollution within a hospital. Inhalational agents and nitrous oxide are the commonly used gases during general anesthesia for surgeries, especially in the developing world. These greenhouse gases contribute adversely to the environmental health both inside the operating room and in the outside atmosphere. Impact of these anesthetic agents depends on the total consumption, characteristics of individual agents, and gas flows, with higher levels increasing the environmental adverse effects. The inimical impact of nitrous oxide is higher due to its longer atmospheric half-life and potential for destruction of the ozone layer. Anesthesiologist of today has a choice in the selection of anesthetic agents. Prudent decisions will help in mitigating environmental pollution and contributing positively to a greener planet. Therefore, a shift from inhalational to intravenous-based technique will reduce the carbon footprint of anesthetic agents and their impact on global climate. Propofol forms the mainstay of intravenous anesthesia technique and is a proven drug for anesthetic induction and maintenance. Anesthesiologists should appreciate growing concerns about the role of inhalational anesthetics on the environment and join the cause of environmental responsibility. In this narrative review, we revisit the pharmacological and pharmacokinetic considerations, clinical uses, and discuss the merits of propofol-based intravenous anesthesia over inhalational anesthesia in terms of environmental effects. Increased awareness about the environmental impact and adoption of newer, versatile, and user-friendly modalities of intravenous anesthesia administration will pave the way for greener anesthesia practice.

Keywords: Anesthesia, environmental pollution, greenhouse gas, health care, propofol

Introduction

Human beings are the biggest contributors to environmental pollution. The need for safeguarding of environment has dawned upon people from all walks of life. While a lot of ground is being covered by politicians, policymakers, and public at large for preserving and improving the environmental health, there is an increased scope for examining the role of health-care settings and how they can assist this cause. The operating room (OR) is a major source of environmental impact within a hospital,[1] and greenhouse gases (GHGs) such as inhalational anesthetics and nitrous oxide contribute to environmental pollution both inside the OR and in the outside atmosphere.[2] Impact of these anesthetic agents depends on the volumes used, characteristics of anesthetic agents, and total gas flows, with higher levels increasing the environmental adverse effects. The harmful impact of nitrous oxide is higher as it causes destruction of the ozone layer and has a longer atmospheric half-life.[3]

With millions of anesthetics administered annually across the globe, the role of anesthesiologist in minimizing the deleterious effects of anesthesia on the environment cannot be overemphasized. Adopting green anesthesia practice is one

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of the simple yet effective steps in this direction. While the developed world with lesser population has moved to intravenous anesthesia-based technique, developing and poor nations who have a substantially larger population (>80% of the world's population) that are anesthetized every year continue to use inhalational anesthetics and nitrous oxide. Hence, limiting the use of inhalational anesthetics to specific situations and avoiding nitrous oxide in these countries are likely to result in substantial gains in terms of climate safety for the entire world. Increasing awareness among stakeholders (anesthesiologists, OR managers, and hospital administrators) on the harmful environmental effects of certain anesthetics and providing knowledge about environment-friendly alternatives is the first step in this direction.

In this narrative review, we discuss about the environmental harms of inhalational anesthetics, the potential benefits of using alternative anesthetic techniques, and the role of anesthesiologists in contributing to the human and environmental health. This knowledge is expected to help the anesthesiologists appreciate the need to incorporate environment-friendly anesthetic techniques and pave the way for greener anesthesia practice.

Methods

We searched the literature using the PubMed search engine on July 4, 2022 using the key words "anaesthesia" AND "environment" AND "pollution." There was no restriction regarding the language, type of article, or year of publication. We performed assessment of the abstracts and full-texts to identify articles relevant to our narrative review. The references of these articles were manually searched to further obtain potential articles relevant to the discussion on the topic.

Results

We retrieved 297 articles. The 51 articles finally included in this narrative review are listed in the references. The included articles were review articles, reports, recommendations, editorials or web publications (n = 31), original articles (n = 19) and case report (n = 1). All except one included article were in English language.

Discussion

Inhalational anesthetic agents

General anesthesia that is administered to most surgical patients in India and several other countries mostly involves inhalational technique.[4-6] This is largely due to factors such as comfort of administration, easy availability, lower cost, and preference of anesthesiologist. However, there is a growing realization about their adverse implications on the health of OR personnel and the outside environment. It is reported that about 8% of the total GHG emission in the world is due to health care,[7] out of which 20%–30% is generated by the ORs, most of which are caused by inhaled anesthetics including nitrous oxide.[8]

Adverse effects on OR personnel

All personnel working in the OR and nearby areas are exposed to waste anesthetic gases (WAGs). It is believed that long-term exposure to even small concentrations of WAGs could have adverse health effects.[9] The amount of occupational exposure depends on type, amount, duration, frequency of use, and presence and efficiency of scavenging and air conditioning systems. The three most commonly used inhaled anesthetics, isoflurane, sevoflurane, and desflurane, when used in therapeutic doses undergo very little metabolic degradation (5%, 2%, and 0.02%–0.2%, respectively).[10,11] The exhaled anesthetic gases remain inside the OR for a long period unless active and powerful scavenging and air conditioning systems are operational that circulate and replenish the OR air. Chronic exposure to halothane may cause mutagenesis and teratogenesis.[12] Nitrous oxide is reported to result in bone marrow depression, developmental neurological abnormalities, reproductive derangements including spontaneous abortion, and other health issues.[13-15] A higher rate of spontaneous abortion among female anesthesiologists exposed to WAGs is reported.[16] Hence, it is suggested that presence of a pregnant woman in OR may be considered as a new indication for total intravenous anesthesia (TIVA).[17] Similarly, isoflurane and sevoflurane are also known to cause adverse health conditions including nausea, dizziness, fatigue, headache, irritability, reduced mental performance, postoperative delirium, and cognitive decline.[18] Almost the entire desflurane administered is exhaled into the OR and, subsequently, into the atmosphere. Although a recent systematic review noted inconsistent evidence of adverse effects associated with inhaled anesthetics on the exposed personnel,[19] other studies report occupational hazards including DNA damage and oxidative stress on exposure to WAGs.[20] The personnel working outside the OR are also at risk, as higher than recommended exposure limits (RELs) of WAGs are observed with inhalational anesthesia.[21]

Adverse effects on the environment

Inhaled anesthetics and nitrous oxide ultimately gain access to the atmosphere from the ORs as medical waste after little or no degradation or treatment.[22] They remain in the atmosphere as GHGs for long periods, adding to environmental pollution.[8] The pollution produced after use of 100 l of inhaled anesthetics (average volume used/year by a busy mid-size US hospital) is reported to be equal to emission from 100–1200 passenger cars/year, depending on the anesthetic used.[23] Sherman *et al*. studied the climate change impact (GHG emissions) of five anesthetics: sevoflurane, desflurane, isoflurane, nitrous oxide, and propofol.[24] All inhaled anesthetics had significant GHG effects, with desflurane producing 15 times more emission than isoflurane and 20 times more than sevoflurane on per minimum alveolar concentration (MAC)-hour basis. The GHG emissions increase significantly for all anesthetics when administered in nitrous oxide/oxygen mixture. The GHG impact of propofol was comparatively insignificant.[24] Studies on atmospheric concentrations of different WAGs have shown that desflurane concentration is increasing rapidly.[25] Nitrous oxide not only produces more greenhouse effects than most inhaled anesthetics, but also contributes to ozone layer depletion. Moreover, it remains in the atmosphere for >100 years.[26] Addition of 60% nitrous oxide to fresh gas flow (FGF) increases the global warming impact of desflurane by 40%, isoflurane by 290%, and sevoflurane by 590% at FGF of 2 l/min.[27] On a 100-year time horizon, the global warming potential (GWP) measured as carbon dioxide equivalents (CDE) was 19 times higher for sevoflurane with 60% nitrous oxide than with air/oxygen, nine times higher for isoflurane, and equal for desflurane. This was despite desflurane having the highest GWP with or without nitrous oxide.[28] Andersen *et al*.[29] have summarized the radioactive efficiencies, atmospheric lifetimes, and GWPs of nitrous oxide and inhaled anesthetics. Table 1 compares the ill effects of nitrous oxide *vis-à-vis* desflurane on OR personnel and the environment.

Measures to reduce adverse impact

Anesthesia providers have an obligation to minimize atmospheric pollution by utilizing techniques that can reduce the adverse effects of WAGs on the environment. Health-care setups that use anesthetic gases are responsible for ensuring that all anesthesia equipment including the scavenging system are effective and routinely maintained. Awareness about health hazards from WAGs is poor among primary stakeholders, the anesthesiologists, in India.[5] Hence, this should be addressed first by enhancing awareness. Next, several measures can be adopted to reduce risks to exposed health-care personnel and environmental pollution from WAGs. These include minimizing inhalational anesthetic use, considering TIVA technique, supplementing with regional and/or intravenous anesthesia, and using adjuvant anesthetic-sparing drugs.[8] When inhaled anesthetics are used, monitoring the depth of anesthesia and exhaled anesthetic concentration,[30] restricting the FGF to <1 l/min, and using closed breathing circuit with carbon dioxide absorber should be considered. However, when lower FGF is used, precaution must be taken to prevent hypoxemia. Other interventions include turning off FGF and vaporizer when not required, preventing anesthetic leakage during filling, avoiding flushing of breathing circuit at the end of anesthesia, using well-fitting face mask, avoiding gas leakage from the trachea due to ineffective cuff or inappropriate tracheal tube/laryngeal mask airway size, using mainstream capnograph, and timely maintenance and repair services to avoid harms from machine malfunction. Venting out of WAGs is faster and complete with active scavenging and efficient air conditioning systems. Scavenging reduces exposure to OR personnel, but not environmental pollution. Both can be minimized by reducing use of inhaled anesthetics, especially nitrous oxide and desflurane.[24] Connecting the scavenging system from multiple machines to a single common unit, and collecting WAGs, cold condensing them, and retrieving inhaled anesthetics and purifying for reuse will also be beneficial.[8]

Table 1: Comparison of ill effects of nitrous oxide *vis-à-vis* desflurane[2,29]

Parameter	Nitrous oxide	Desflurane
Recommended exposure limits in the USA and the UK, respectively (ppm/day)	25 and 100	2 and 0
Atmospheric lifetime	114 years	14 years
Global warming potential on 100-year time horizon	298	2540
Ozone depletion potential	0.017	0
Radioactive efficiency (W/m^2/ppb)	0.003	0.469

Intravenous anesthetic agents

Intravenous anesthesia is a safer alternative to inhalational techniques with regards to environmental health, but is largely restricted to intravenous sedation for short procedures, anesthesia services outside the OR, and during surgeries requiring intraoperative neuromonitoring. While modalities of administration, cost, and availability of intravenous anesthetic agents have improved significantly, inadequate awareness about their environmental benefits remains a major impediment to change in practice.

Environmental impact of propofol intravenous anesthesia

Propofol is a short-acting intravenous anesthetic agent[31] primarily and rapidly metabolized by the liver, resulting in water-soluble inactive substances that are excreted by kidneys. A small fraction of the drug is metabolized via extrahepatic routes, mainly lungs, intestines, and kidneys.[32,33] Hence, its environmental effect is minimal compared to the inhalational anesthetic agents which remain largely unmetabolized and are exhaled in the OR and ultimately into the atmosphere.[23] The GWP of propofol is very low (21) when compared to desflurane (2540) and sevoflurane (130). Similarly, the carbon footprint (CDE/kg) for a 7-h anesthetic duration is also significantly lower for propofol (0.084) when compared to desflurane (820) and sevoflurane (70).[34]

The use of TIVA is not without adverse environmental impact as it requires plastic syringes and tubings, which increase slow or non-biodegradable plastic waste. The TIVA technique, especially using target-controlled infusion (TCI) pumps, also has costs of equipment procurement and disposable consumables.[35] In addition, TIVA mandates the use of depth of anesthesia (DOA) monitoring to titrate anesthesia, unlike inhalational anesthesia where minimum alveolar anesthetic concentration monitoring is sufficient. The DOA sensors are disposable consumables adding to both cost and environmental pollution. In a survey among Indian anesthesiologists, it was observed that although 72% of the respondents used TIVA frequently or occasionally, 62.5% did not have access to air, implying use of 100% oxygen during TIVA.[5] Medical air is still not available in many ORs in India. Apart from the clinical consequences of using 100% oxygen for prolonged periods, such as free radical formation and lung damage, and its increased costs compared to air, it contributes to carbon dioxide footprint, which most of the anesthesiologists are not aware.[35]

Clinical benefits of propofol intravenous anesthesia

The hemodynamic stability and recovery time after intravenous anesthesia with propofol are comparable with inhalational anesthetics, while propofol is superior in terms of clear-headed awakening and postoperative nausea and vomiting.[36] Propofol provides better brain relaxation and lowers intracranial pressure (ICP), cerebral metabolic rate for oxygen, and cerebral blood flow (CBF) compared to inhalational anesthetic agents. Cerebral autoregulation and cerebrovascular reactivity are not significantly affected.[37,38] These characteristics make it most suited for neurosurgical procedures both in terms of clinical and environmental benefits due to the prolonged duration of neurosurgical procedures. Propofol decreases blood pressure and heart rate in clinical doses. This property can be harnessed for providing hypotensive anesthesia to reduce bleeding during surgery.[39] Propofol is a bronchodilator and decreases wheezing in asthmatic patients.[40] Hypoxic pulmonary vasoconstriction (HPV) is a protective reflex to match lung perfusion with ventilation and optimizes oxygen uptake in atelectasis, pneumonia, asthma, and adult respiratory distress syndrome. While inhalational agents inhibit HPV, propofol has no effect on HPV and is hence advantageous in patients with respiratory pathologies.[41] All these clinical benefits along with environmental-friendly properties make propofol intravenous anesthesia an attractive proposition in anesthetic practice.

Advances in propofol formulations

Despite several advantages, there are a few concerns (pain, allergy, bacteria growth, and hyperlipidemia) with the use of available propofol formulations. Novel propofol derivatives (non-emulsion formulation) are devoid of the side effects of 6-di-isopropylphenol emulsion. Slight modification in the three-dimensional isomeric structure of propofol results in a drastic change in its action, including attenuation of propofol injection pain. The recently available nanotechnology might enable production of propofol pro-drugs devoid of bacterial growth a possibility and increase its potency, shelf-life, and safety.[42,43] Availability of these newer propofol formulations for routine care will eliminate the side effects and facilitate increased use of propofol intravenous anesthesia.

Advances in administration of TIVA

Innovations in computer technology, pharmacokinetic modelings of drugs, and infusion delivery have led to the development of TCI systems. A TCI pump contains a microprocessor programmed with pharmacokinetic model of the drug. Several guidelines have been developed to efficiently use TCI for administering TIVA.[44] In open-loop TCI system, user enters the patient characteristics and selects the drug and its pharmacokinetic model from the incorporated device library, and the pump determines the initial bolus and subsequent infusion rates.[45] As the system lacks real-time feedback from the patient, it requires continuous clinical assessment, including DOA monitoring and frequent adjustments in target concentrations.[46] In closed-loop systems, measured output is used by a target controller to determine the drug input in appropriate dosage.[47] As manual and TCI systems have not been able to handle hemodynamic instabilities caused due to inter- and intra-patient dose–response variability, researchers have developed automated anesthesia delivery systems utilizing linear or sliding mode controls.[48] Scientists are working on developing propofol-loaded infusion pumps, where dose regulation is based on continuous DOA monitoring.[49] The decrease or increase in DOA value automatically lowers or increases the delivery of propofol, making anesthesia safer and user-friendly and increasing its acceptance among anesthesiologists.

Marching toward green anesthesia practice

Apart from anesthetics, several items used during management of anesthesia, such as single-use and reusable items containing plastics, glass, steel, rubber, cotton, and so on, electricity for various equipment and sterilization, and the pharmaceuticals used also contribute to carbon footprint and require equal consideration.[35] The carbon impact of regional anesthesia techniques is substantially lower than that of inhalational anesthetics even after accounting for the preparation, administration, and disposal of the consumables,[50] and hence should be considered wherever feasible. The advantages of green anesthesia practice on health of patients, OR personnel, and environment are too many to ignore. Moreover, incorporating green anesthesia in clinical practice demonstrates anesthesiologists' collective commitment and shared responsibility with other stakeholders to the cause of environmental protection. The recent action guidance for addressing environmental pollution from anesthesia has recommended certain measures such as avoiding inhalational anesthetics, decommissioning centralized nitrous oxide and reducing FGF as mitigation priorities than waste treatment technological solutions.[50] However, since awareness among anesthesiologists about the environmental impact of anesthetics is low (as demonstrated by the choice of anesthetics in day-to-day clinical practice), it becomes a rate-limiting step in the greener anesthesia practice. Figure 1 summarizes an easily implementable five-step approach to minimizing GHG effects during anesthesia management.

Lastly, an important area where anesthesiologists should get actively involved for effective green anesthesia practice is the organization of ORs. In many developing countries including ours, local guidelines for OR construction, including scavenging systems, are either absent or not strictly implemented and monitored by the health authorities. The OR consumes up to six times more energy than other hospital areas due to the requirements of recommended air changes per hour.[51] Computer-controlled adjustments of the heating, ventilation, and air conditioning system and real-time monitoring of pressure relationships of the ORs as part of the infrastructure standards of the OR construction will help combat environmental and occupational health hazards and contribute to greener ORs and hospitals. Knowledge about these aspects will help anesthesiologists in participating and providing critical inputs during design, development, and operational stages of ORs.

Conclusions

Awareness about the harmful effects of inhaled anesthetics on patients, OR personnel, and environment and increased knowledge about safer intravenous alternatives will help anesthesiologists to provide patient care with environmental responsibility. As its environmental effect is minimal, propofol fulfills all requirements of a "green anesthetic." Green anesthesia practice will enhance credibility of anesthesiologists among scientific community and public at large. To paraphrase Neil Armstrong's quote, green anesthesia practice may be one small step for an anesthesiologist, but a giant leap for health-care–related environmental protection.

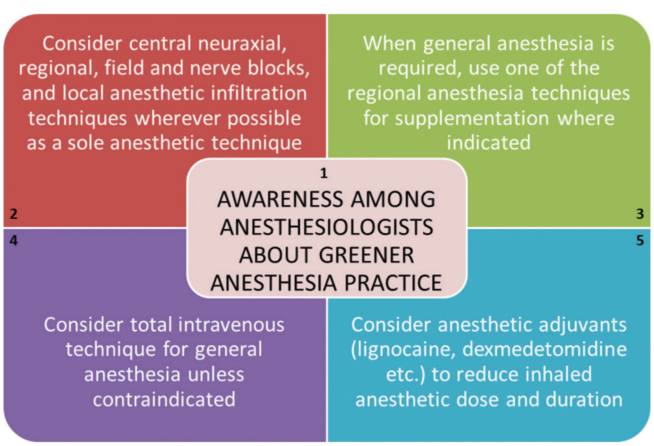

Figure 1: A five-step approach to minimizing greenhouse gas effects during anesthesia

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Conflicts of interest

There are no conflicts of interest.

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