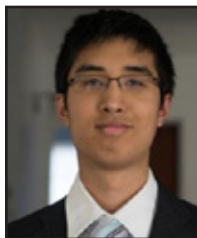


2012 Medical Student First Prize Paper

Environmental Effects of Waste Anesthetic Gases

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Intersex fish, antibiotic-resistant bacteria, falling sperm counts, and contamination of drinking water: these are just some of the potential consequences related to the growing problem of pharmaceutical pollution. With the rising use and complexity of modern pharmacologic care, many investigators have focused their efforts on demonstrating that drugs administered to patients will inevitably find their way into the general environment, where they may mediate toxic effects on biological organisms and produce chemical contamination of air, water, and soil. The field of anaesthesia, with its widespread use of inhalational pharmacologic agents, has not been beyond such scrutiny. In fact, because anesthetic gases are excreted virtually intact and vented directly into the atmosphere, their contribution to global warming and ozone depletion has been studied since the 1970s.

The prospect of environmental damage caused by anesthetic gases was first raised by Fox et al. in 1975¹. At the time, the anesthetic compounds in common usage included N₂O and the volatile agents, halothane and enflurane. Subject to little *in vivo* metabolism, these drugs were usually released directly into the atmosphere following excretion by the patient. There, their effects were theorized to be two-fold: enhancement of ozone depletion and action as potent greenhouse gases. Research conducted in the 1980s suggested, however, that the environmental threat posed by these compounds was minimal^{2,4,5}; the volatile agents were deemed environmentally benign and anesthetic use of N₂O was found to contribute only modestly to ozone depletion and climate change. Indeed, despite their close resemblance to the ozone-damaging CFCs, the volatile anesthetic agents, with tropospheric lifetimes of only 2-6 years^{2,3}, proved too short-lived to diffuse significantly into the stratosphere, where the brunt of ozone damage occurs. Furthermore, despite their potency as greenhouse gases, worldwide production of anesthetic agents was deemed too small to exert a significant effect on global warming^{4,5}. Although these early results proved promising, the landscape of anaesthesia and environmental science has since shifted.

Today, the most commonly used inhalational anesthetics include N₂O as well as the newer volatile agents, sevoflurane and desflurane. Furthermore, worldwide production of anesthetic compounds is increasing to meet rising demand in developing countries, and a ban on

CFC production following the 1987 Montreal Protocol has greatly increased the relative contribution of anesthetic runoff to ozone depletion. Continued examination of the effects of current anaesthesia practice on the global environment is therefore warranted on the basis of recent changes in clinical science and environmental policy.

Like their predecessors, sevoflurane and desflurane contribute little to ozone depletion due to their short tropospheric lifetime^{3,6}. In addition, because they are halogenated solely with fluorine, they are considered to be even safer than previous volatile agents, which were halogenated partly with chlorine⁶. This is because the ozone-depleting potential of volatile anesthetics is dependent upon their ability to produce free chlorine radicals, which catalyze the destruction of ozone molecules. Production of free fluorine radicals, on the other hand, produces no significant ozone damage because free fluorine reacts strongly and rapidly with water to form HF, rendering it unavailable for further reaction with ozone⁷. The ozone danger posed by the newer anesthetic agents can therefore be considered close to negligible. A much greater impact on ozone depletion, however, is derived from anesthetic use of N₂O. The potential ozone-damaging effect of N₂O stems from its degradation into NO_x species in the upper atmosphere, which destroy ozone through a catalytic process very similar to that mediated by free chlorine radicals. Historically, the role of N₂O in ozone depletion was considered minor in comparison to the dominant effect of CFCs. However, the near complete abolition of CFC production following the highly successful Montreal Protocol has greatly increased the relative contribution of N₂O to this phenomenon. N₂O is now expected to become the foremost ozone-depleting substance throughout the 21st century⁸, with anesthetic use being responsible for up to 2% of total emissions^{6,11,12}. Fortunately, the popularity of this anesthetic gas has been waning in recent years^{9,10}, due partly to its uncertain clinical benefit, the availability of new highly-controllable inhalational agents, and its harmful ecological impact^{11,12,13,14}. Whether this will endure into a lasting trend remains to be seen.

The effect of anesthetic agents on global warming is harder to quantify, partly due to difficulty comparing different gases with varying properties and atmospheric lifetimes in an objective manner. Indeed, the relative contribution of different gases can vary heavily depending on the metrics used to compare them (such as GWP₂₀, GWP₁₀₀, GTP), the choice of which is often somewhat arbitrary¹⁵. Despite this shortcoming, in recent studies published by Ryan et al. and Sulbaek et al., the newest volatile anesthetic, desflurane, has been implicated as a much more potent greenhouse gas than previous compounds^{16,17}. According to Ryan et al., when calculated over a 20-year time horizon, desflurane pres-

ents roughly 3714 times the global warming potential of CO₂ (GWP₂₀ of 3714), compared to a GWP₂₀ of 349 and 1401 for sevoflurane and isoflurane, respectively. The impact of desflurane is further amplified by its low anesthetic potency relative to other volatile agents, thus requiring the administration of greater concentrations to achieve an equivalent clinical effect. Applying these numbers to clinical practice, 1 hour of desflurane anaesthesia delivered at 1 MAC and 2L of fresh gas flow is estimated to produce a climate impact equivalent to 186 kilograms of CO₂ emissions¹⁶. Such findings suggest that volatile anesthetics, and in particular the newer agent desflurane, may exert a more significant carbon footprint than once anticipated, although the proportion of total global warming attributable to these gases remains difficult to ascertain¹⁶. The effect of N₂O, on the other hand, is mixed; N₂O is itself a long-lived greenhouse gas, but its usage in anaesthesia allows decreased concentrations of the much more potent volatile agents. When used as a carrier gas for sevoflurane, N₂O increases the total GWP₂₀ of the gas mixture, but the opposite is true when N₂O is used with desflurane. Calculation on a longer 100-year time horizon, however, yields an unequivocal increase in GWP whenever N₂O is added as a carrier gas: a discrepancy that can be ascribed to its prolonged atmospheric lifespan¹⁶. With desflurane and N₂O demonstrating, respectively, very potent and very prolonged global warming potential, recent research seems to indicate that anesthetic gases may yet account for a small but significant portion of total greenhouse gas burden. The potential ecological threat they pose, therefore, cannot be taken lightly.

The scale of anesthetic pollution does not necessarily warrant drastic corrective measures, but the production of waste gases should nevertheless be mitigated as much as possible through reasonable and cost-effective means. Traditionally, the healthcare sector has been spared from the brunt of environmental scrutiny, because its services are deemed essential and because clinical necessity should rightly take precedence over environmental concerns¹⁸. However, with the growing medical sector exerting an increasingly large environmental footprint, greater efforts to reduce its ecological impact are justified wherever possible. Methods of minimizing the production of anesthetic waste gases need not come at a steep price and can be implemented within a framework taking into account both costs and patient safety. Simple and feasible solutions applicable to everyday anesthetic practice include minimizing fresh gas flows and avoiding the use of N₂O and desflurane whenever possible^{6,16}. Methods of reducing waste gas output that would require greater changes in common anesthetic practice include more extensive use of TIVA and closed-circuit anaesthesia systems⁶. Finally, new technologies under development that may be of use in the future include systems capable of recapturing waste anesthetic gases and experimental inhalational agents such as xenon^{6,19,20}. In the field of environmentalism, no intervention is too trivial to demand consideration and measures that decrease the environmental footprint of

anaesthesia ultimately contribute to ensuring the future sustainability of our healthcare system as a whole.

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