Anaesthetic gases: environmental impact and alternatives

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Abstract

Little consideration has been given to the environmental impact of gaseous anaesthetic use. All currently used volatile anaesthetics are halogenated and chemically similar to chlorofluorocarbons (CFCs), giving them the potential to impact the environment negatively via both ozone depletion and global warming. Overall contribution to climate change is dependent on both these environmental effects, as well as the quantities released into the atmosphere. This review of the current data provides an insight into the overall ecotoxicity of volatile agents and gives alternatives which may be employed to limit environmental load. Results from the studies reveal that global warming potential and ozone depletion potential are significant for all volatiles, especially when combined with nitrous oxide use. However, because atmospheric levels are estimated to be small when compared to gaseous emissions from industrial and agricultural sources, the actual percentage contribution to climate change is small. Despite these findings, the cumulative effects of small contributors to climate change should not be underestimated, especially with increasing numbers of future anaesthetics and a decreasing CFC load. The carbon footprint of an individual anaesthetist is significantly increased by the daily use of volatile anaesthetic agents and recognised alternatives may be utilised to minimise this.

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Introduction

In recent times there has been a surge in interest in our contribution to climate change. Human activity results in increased atmospheric levels of a variety of gaseous chemicals that are able to destroy ozone and/or contribute to global warming. These effects alter the earth's thermoregulation by upsetting the balance of incoming to outgoing radiant energy, resulting in heating of the earth (Figure 1).[1] A warm earth has numerous ecological and health effects, including melting polar ice caps, rising sea levels, changing weather patterns and damage to fragile ecological systems.

The major perpetrators of climate change include known greenhouse gases carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbons (CFCs)[1] arising from, among others, deforestation, combustion of fossil fuels, agriculture and industry. Much effort has been spent assessing the environmental impact of emissions from these sources and restrictions on their use or less hazardous alternatives have been sought. Little consideration has been given to the environmental impact of anaesthetic gas use, as they are considered to be medically essential and to be used in relatively small quantities.[2] However, currently used volatile anaesthetics are halogenated and chemically similar to CFCs,[1] giving them the potential to impact the environment negatively via both ozone depletion and global warming. This is especially true in the light of these gases being exhaled with minimal metabolism, and that scavenging systems which (while keeping theatre concentrations low) transfer gases unchanged into atmosphere. The fact that volatiles are widely used in operating theatres, dentist and veterinary rooms and animal research laboratories, together with a projected increased use as the world population and operation numbers grow, warrant further consideration of the implications their use may have on the environment.

Impact on climate change

Just as an organism's ability to cause infection is based both on virulence and bacterial load, a compound's ability to impact the environment is determined by its destructiveness, together with the atmospheric levels attained.

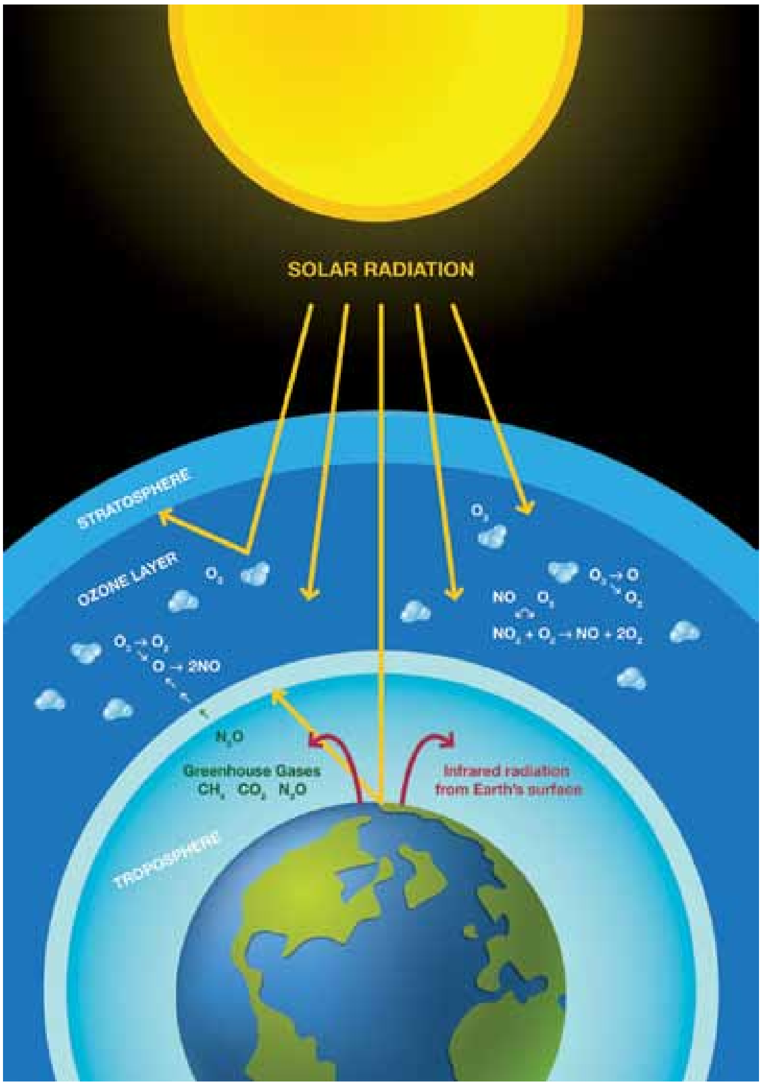

Figure 1: The two important thermoregulatory layers of the Earth are the stratosphere (ozone containing) and troposphere. The Earth absorbs approximately half of incoming solar energy, while the rest is reflected or absorbed by clouds and ozone, protecting us from damaging ultraviolet (UV) radiation from the sun. Some of this absorbed energy is emitted back into space as infrared (IR) radiation. Greenhouse gases present in the troposphere absorb this IR and re-emit it back to earth. Ozone depleters are broken down by UV in stratosphere, forming radicals that destroy ozone, allowing more solar energy in.

Destructiveness for a gaseous substance is determined by both its global warming potential (GWP) and its ozone depletion potential (ODP):

Impact on climate change = GWP (or ODP) × atmospheric levels

Atmospheric lifetimes

Both GWP and ODP are governed to a large extent by the compound's ability to resist breakdown in the stratosphere, and hence prolong its atmospheric lifetime. Stable compounds with significant atmospheric lifetimes (usually defined as more than two years[1]) will contribute longer to ozone damage and affect infrared (IR) radiation balance.[3]

Global warming potential

Global warming ability depends on both atmospheric lifetime and the gas's ability to absorb infrared radiation (trapping heat and preventing the earth from cooling).[2,4] Both are expressed singly as a derived ratio, GWP. GWP describes how many times more powerful the gas is as a heat-trapping gas than the same mass of a reference gas (either CO_2 or CFC) over a specific time period. The ratio enables direct comparison of one compound's global warming potential to another.[2]

Ozone depletion potential

The ozone-depleting ability of a gas depends on atmospheric lifetimes and its halogenations; both the number and type of halogen atoms.[1,3] Long-lived bromine- and chlorine-containing compounds are known to damage the ozone layer. Bromine contributes 35–50 times more to ozone depletion than does chlorine.[3] Fluorine ions have small ODP. Therefore halothane, isoflurane and enflurane may be more destructive to ozone than fluorinated

Table I: Experimentally determined atmospheric lifetimes and calculated global warming potential and ozone depletion potential values of some gases[2-5]

Compound	Lifetime (years)	$^{a}GWP_{100\ years}$ (Reference: CO_2)	^{b}ODP (Reference: CFC)
Chlorofluorocarbons (CFCs)	50–100	10 900	1
Carbon dioxide (CO_2)	5–200	1	–
Nitrous oxide (N_2O)	114	298	0.017
Halothane	6.6–7.0	–	1.56
Isoflurane	3.2–5.9	510–571	0.03
Sevoflurane	1.2–4.0	141–218	0.00
Desflurane	8.9–21.0	1 525–1 746	0.00

a = Reference: CO_2, b = Reference: CFC sevoflurane and desflurane.[1] Again, both are expressed singly as a ratio, ODP, which describes how many times more powerful a particular substance is as an ozone depleter than is CO_2 or CFCs.

Atmospheric levels

There are no publicly available data on the production, sales or emission of gaseous anaesthetics for health care.[2,4] Although the total amount used globally has not been thoroughly assessed,[3] the current atmospheric levels may be estimated and then used to quantify contribution to climate change.

Studies

There are four studies in the literature that have determined atmospheric lifetimes and IR absorption spectra experimentally, and then calculated GWP[2-5] and ODP[3] values from these. Some of the earlier studies[5] may be inaccurate, as IR absorption spectra of the volatiles were not accounted for in the calculation of GWP. Table I reflects the range of results obtained from existing literature values.[1-4]

Replicating complex atmospheric chemistry experimentally and the calculations used to obtain these values have their limitations, and this means that these results are, at best, coarse estimates.[2,4] However, they are the accepted method of measuring climatic impact and they still provide some useful information. A definite trend is visible.

Global warming potential

All the volatiles (except for sevoflurane in some instances) have long atmospheric lifetimes (greater than two years). Sevoflurane has the shortest lifetime and also the lowest GWP. Isoflurane and halothane are intermediate and desflurane has the greatest potential climatic impact.[1-4]

When considering the differing potencies of isoflurane and sevoflurane for a one-hour anaesthetic at 1 MAC (minimum alveolar concentration) and fresh gas flow (FGF) 2 l/minute, isoflurane is used in the smallest quantity by weight but sevoflurane still has a smaller impact. At an FGF of 0.5 l/minute (not recommended for sevoflurane), isoflurane has the lowest impact but does not differ much from sevoflurane.[2]

Ozone depletion potential

The fluorinated volatiles have no ozone-depleting ability. Despite its much shorter lifetime, halothane has an ODP value comparable to that of CFCs, showing the contribution of its bromine atom to ozone depletion.[3] Volatiles containing chlorine have low ODP when compared to CFCs, but may still have an effect.

Nitrous oxide

N_2O has a GWP of approximately 300 times that of CO_2, but an ODP lower than CFCs. The addition of 60% N_2O (but still 1 MAC) at FGF of 2 l/minute increases the GWP of sevoflurane by 590% and isoflurane by 290%, but decreases the impact of desflurane by 40%.[2]

Globally N_2O emissions from human activities are reported to be the single largest ODP-weighted emission. In 2006, the anaesthetic use of N_2O was estimated to be 3% of total N_2O emissions in the USA.[1] The declining trend in use of N_2O may see this figure decrease.

Atmospheric levels

As previously mentioned when considering the overall impact of volatiles on the environment, the atmospheric levels attained are also an important consideration. Three of the above-mentioned studies[2-4] estimate global emissions, based on annual volatile consumption at a study hospital and estimates of total anaesthetic procedures performed worldwide. The following conclusions were made regarding climatic change.

Langbein et al extrapolated data from a German hospital in the late 1980's, to estimate the contribution to total ozone depletion globally as 1% for halothane and 0.02% for isoflurane.[3] The effect on global warming of all volatiles is approximately 0.03%. Both of these are of increasing importance, as the emission of CFCs has decreased globally.

Andersen et al, using recent data from a United States hospital, reported that annual global emissions of inhaled anaesthetic have a contribution to climate change that is comparable with the emissions from one coal-fired power plant or approximately 1 million cars.[4] The use of N_2O will increase this overall impact. While this is negligible in comparison to emissions produced from industry, the cumulative effect of many small contributors cannot be overlooked.

Ryan et al did not try to quantify worldwide contribution to gas burden, in light of insufficient data. They did predict that the volatile anaesthetic agent (VAA) usage for a midsized US hospital in one year would be the equivalent to the CO_2 emissions of 100–1 200 passenger cars, depending on which gases were used. Interestingly, they also provided an estimate of an individual anaesthetist's daily contribution to gaseous emissions when using a volatile at 1 MAC at FGF rates of 1-2 l/minute and based on an average eight-hour day (or eight MAC hours). Using desflurane would equal 58 to 116 days in average auto emissions, and using sevoflurane or isoflurane would equal 4.3 or 4.8–9.6 days in average auto emissions respectively. These results reveal a significant increase in the anaesthetist's daily carbon footprint.[2]

Alternatives: eliminate, reduce, reuse, recycle

Current alternatives

Elimination of anaesthetic gases may be achieved by using regional anaesthesia or total intravenous anaesthesia. However, the environmental impact of the receptacles, drugs and equipment required for these techniques has not been measured. Proper lifecycle assessment of these options needs to be conducted, in order to allow proper comparisons with inhalational techniques.[1]

A *reduction* in volatile usage of up to 80% may be achieved with the use of the low-flow technique.[1,2] This technique is already widely available and attention to employing it routinely and as soon as possible during an anaesthetic procedure will increase conservation of gas use. Modifying our practice to select gases with a lower environmental impact is also important. Thus, avoiding or limiting the use of N_2O is of particular importance.[2] Choosing sevoflurane and isoflurane over desflurane and halothane as our primary gases would also be beneficial.

Future alternatives

A new technology is being employed to prevent wasting of anaesthetic gases into the atmosphere. It has been shown that silica zeolite (Deltazite®), when placed in the scavenging line, was able to absorb all the isoflurane (1% in exhaled gases) for a period of eight hours.[1] A Canadian company called Blue-Zone Technologies[6] produces zeolite filters (Deltasorb®) for use in scavenging lines. Each canister can adsorb approximately two bottles of halogenated anaesthetics, reducing the total amount of volatile released by 40–75%. Trapped agents are reprocessed by steam extraction and fractional distillation. The liquefied product is used as raw material for new anaesthetics. Reprocessing of the anaesthetics gases is essential, as disposal does not change the eventual fate of the gas.[1] Blue-Zone Technologies issues monthly reports to hospitals where their product is used, providing information on total anaesthetic capture in weight and the equivalent CO_2 tonnage of this capture. For example, in Sunnybrook Hospital in Canada, Deltasorb® has been installed in 21 operating rooms and one-year estimates are that 634 tonnes of CO_2 equivalent has been prevented from entering the atmosphere; approximately the same as emissions from 205 fuel-efficient cars.[6]

Xenon has been proposed as an alternative to N_2O for its advantages of providing analgesia, rapid induction and emergence, neuroprotection and haemodynamic stability, with few known detrimental effects. Its inert nature makes it a possible alternative when comparing the environmental impact of the two gases. However, xenon is unlikely to substitute N_2O, as its production is expensive and consumes enormous amounts of energy, significantly more than N_2O production.[1]

The development of newer volatiles agents that are effective, safe and environmentally benign would eliminate environmental consequences. However, there are currently none in the pipeline.[1]

Conclusion

Current evidence reveals waste anaesthetic gases (including N_2O) to have global warming and ozone-depleting properties, but makes it difficult to determine their exact contribution to climate change. Estimates of atmospheric levels suggest that it is likely to be small compared to other gaseous compounds. However, in view of cumulative effects of small contributors and the projected increasing number of anaesthetic procedures in the future, it is likely that anaesthetic gases will be targeted as an important part of the efforts to limit the production of greenhouse and ozone-depleting gases.

References

1. Yumiko Ishizawa. General Anesthetic Gases and the Global Environment. Anesth Analg. 2011;112:213–216.
2. Ryan SM, Nielsen CJ. Global warming potential of inhaled anesthetics: application to clinical use. Anesth Analg. 2010;111: 92–98.
3. Langbein T, Sonntag H, Trapp D, et al. Volatile anaesthetics and the atmosphere: atmospheric lifetimes and atmospheric effects of halothane, enflurane, isoflurane, desflurane and sevoflurane. Br J Anaesth. 1999;82:66–73.
4. Sulbaek Andersen MP, Sander SP, Nielsen OJ, et al. Inhalational anaesthesia and climate change. Br J Anaesth. 2010;105:760–766.
5. Brown AC, Canosa-Mas CE, Parr AD, et al. Tropospheric lifetimes of halogenated anaesthetics. Nature 1989;341: 635–637.
6. Deltasorb Anesthetic Collection Service [homepage on the Internet]. No date [cited 2011 Aug 15]. Available from: http://www.bluezone.ca/