

Iatrogenic greenhouse gases: the role of anaesthetic agents

The contribution of health-care activity to climate change is not negligible and is increasing. Anaesthetic greenhouse gases, in particular the fluranes, have a much more potent global warming capacity, volume for volume, than carbon dioxide, but their emissions remain completely unregulated.

The spectre of climate change continues to occupy the global political agenda. There was considerable apprehension in both the scientific and political community ahead of the December 2015 United Nations Framework Convention on Climate Change in Paris. It is likely that global targets on climate change will not be met (Geden, 2015), the most notable of which is the maximum 2°C limit in global temperature rise. Climate change is gaining increasing prominence in the medical sphere and it has tangible health ramifications in the form of cardiovascular, respiratory, zoonotic disease and even mental health conditions (McMichael, 2013; Neira et al, 2014). The World Health Organization (2014) published its quantitative projections of the effect of climate change on future mortality in 2014. It is estimated that the phenomenon will cause 250 000 extra deaths per year between 2030 and 2050, much of this toll afflicting children in developing countries. The contribution of health-care activity to climate change is not negligible, accounting for over 8% of carbon dioxide equivalent emissions in the USA (Chung and Meltzer, 2009).

Over the last decade there has been a dramatic and exponential rise in atmospheric levels of flurane anaesthetic gases. These have a potent greenhouse effect, which volume for volume is considerably greater than that of carbon dioxide. Unlike the UN conventions regulating emissions of carbon dioxide and other greenhouse gases, emissions of the fluranes remain totally unregulated. There is no concerted effort for a consensus position or for nationally or internationally agreed action plans.

In April 2015 the Vatican convened a multidisciplinary climate change meeting, comprising religious leaders and Nobel Laureates, with a view to addressing the problem, which resulted in the encyclical *Laudato si*. It is in some ways disappointing that the clergy are taking more decisive steps than clinicians in the face of this issue (Schiermeier, 2015). However, much of the problem lies in the fact that the key contributors to climate change in the medical arena are not well known and even less well quantified. This article discusses the role of iatrogenic greenhouse gases in climate change with special reference to the effect of anaesthetic agents whose role is significant but not widely appreciated.

Iatrogenic greenhouse gases

The greenhouse effect was first postulated the French physicist Joseph Fourier in 1824 and was confirmed by Swedish chemist Svante Arrhenius in 1896. In 1975 Fox et al raised concerns that halogenated anaesthetic agents could be injurious to the environment by depleting ozone levels. Similar issues were highlighted by Brown et al (1989) with regard to the effect of halogenated anaesthetic agents on global warming.

The greenhouse effect describes the phenomenon whereby incident solar radiation, in the visible and infrared spectrum, is reflected off the surface of the earth in the infrared spectrum as thermal energy, but cannot escape into space. It is trapped within the earth's atmosphere by gases which act as insulators in the troposphere (10 km high). This thermal radiation reflected from the earth's surface is absorbed by these gases and reflected back to the earth. The net effect is an increase in the temperature of the earth (Shine, 2010; Ishizawa, 2011) which has ramifications for the climate and local and global meteorological patterns. Gases responsible for this effect include carbon dioxide, methane, nitrous oxide and chlorofluorocarbons, collectively known as greenhouse gases (Held and Soden, 2000; Fox et al, 1975). Human activity, in the form of fossil fuel consumption and deforestation, affects the levels of carbon dioxide most dramatically. An undesirable milestone was reached in May 2015, where atmospheric carbon dioxide levels exceeded 400 parts per million for the first time since recording began (Earth System Research Laboratory, 2015).

Health-care systems throughout the world invariably consume resources which liberate iatrogenic greenhouse gases into the atmosphere. Carbon dioxide is the best

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characterized, but other iatrogenic emissions are also injurious to the environment. Gases such as isoflurane, desflurane, sevoflurane, halothane and nitrous oxide, which are routinely used in anaesthetic practice, also elicit a greenhouse effect. Halothane is no longer used in the developed world but is still used in significant quantities worldwide and remains on the World Health Organization's (2013a,b) list of essential medicines for both adults and children. Anaesthetic greenhouse gases have a much more potent warming effect volume for volume than carbon dioxide (Sulbaek Andersen et al, 2010). The 'atmospheric window' refers to wavelengths of infrared radiation which ordinarily would escape from the earth's atmosphere into space and hence would not heat the environment. Anaesthetic gases are highly effective at absorbing infrared radiation at these wavelengths and hence cause a potent warming effect (Ishizawa, 2011).

A number of metrics have been developed to allow comparisons of the warming effect of greenhouse gases. The first of these is radiative forcing (Held and Soden, 2000) – the rate of energy change per unit area of the globe as measured at the top of the atmosphere as a result of the greenhouse gases. This is a surrogate marker of the rate of change of temperature. The radiative forcing efficiency is the effectiveness of a given change in atmospheric concentration of greenhouse gas at causing a standard thermal increase (Held and Soden, 2000).

The second concept is the global warming potential. This compares the warming effect of a greenhouse gas to an equivalent volume of carbon dioxide (Held and Soden, 2000). This parameter not only incorporates the warming ability (radiative forcing) of a greenhouse gas relative to carbon dioxide, but also factors in the longevity of that gas in the atmosphere, hence long-

lasting greenhouse gases will tend have a greater warming effect. Over time the concentration of a greenhouse gas will decrease as a result of chemical reactions, causing its radiative forcing (global warming) effect to reduce over time. Global warming potential thus measures the cumulative radiative forcing over time, typically over 100 years, compared to an equivalent volume of carbon dioxide.

The longevity of a greenhouse gas in the atmosphere is measured in the 'atmospheric lifetime' (Held and Soden, 2000; Ishizawa, 2011). This is generally the ratio of the amount of greenhouse gas in the atmosphere to the removal rate. The anaesthetic greenhouse gases are both inert (long atmospheric lifetime) and have a high radiative forcing (warming) effect, so their global warming potential is exceptionally high. This gives them an environmental significance despite their comparatively small volume. Comparisons can be made with carbon dioxide and hence equivalent volumes of anaesthetic greenhouse gases can be calculated. *Table 1* compares these metrics for the common greenhouse gases, carbon dioxide and anaesthetic greenhouse gases (Vollmer et al, 2015). The most environmentally pernicious anaesthetic greenhouse gas is desflurane, having 2450 times the warming effect over 100 years of an equivalent volume of carbon dioxide. This is followed by some distance by isoflurane, nitrous oxide and sevoflurane.

In order to quantify the magnitude of the effect of anaesthetic greenhouse gases it is necessary to determine the production volumes of these gases. In a seminal work published in *Geophysical Research Letters* and reported in *Science* (DeMarco, 2015), Vollmer et al (2015) measured changes in the environmental concentrations of the inhalation anaesthetic gases between 2000 and 2014 in the northern hemisphere. They noted dramatic and exponential increases in ambient concentrations. The per cent increases in atmospheric concentration of isoflurane, desflurane and sevoflurane were 33%, 200% and 900% respectively over the last 10 years. Sevoflurane was essentially undetectable at the start of the study in 2000. From this, the group estimated emission levels of 880, 960 and 1200 tons annually respectively for isoflurane, desflurane and sevoflurane (*Table 2*). Their

Table 1. Features of anaesthetic greenhouse gases compared with carbon dioxide

	Clinical introduction	Atmospheric lifetime (years)	Radiative efficiency (mW/m ² /ppb)	Ozone depletion potential	Mean alveolar concentration	Global warming potential
Carbon dioxide		30–95	1.3x10 ⁵	0		1
Nitrous oxide	1844	114	0.002	0.017	104%	300
Isoflurane	1981	3.2	420	0	1.2%	510
Desflurane	1992	14	450	0	6.7%	2540
Sevoflurane	1993	1.1	370	0.01	2.2%	130
Halothane	1956	1.0	130	0.36	0.74%	50

Table 2. Production and changes in concentration of carbon dioxide and anaesthetic greenhouse gases

	Annual production (tons)	Concentration	Increase atmospheric concentration in the last decade	Equivalent CO ₂ (million tons)
Global carbon dioxide	35x10 ⁹	400 parts per million	5%	35 000
Anaesthetic nitrous oxide	44 000	328 parts per billion	2.7%	13.2
Isoflurane	880	0.097 parts per trillion	20%	0.5
Desflurane	960	0.30 parts per trillion	100%	2.44
Sevoflurane	1200	0.13 parts per trillion	900%	0.16
Halothane	250	0.0092 parts per trillion	-60%	0.125

work represents the first empirical calculation of emission levels from atmospheric calculations and as such is the first 'top down' approach. 'Bottom up' estimates project emissions from the usage of individual institutions which is then extrapolated nationally and globally, and are thus inherently inaccurate.

Vollmer et al (2015) estimated that the global use of flurane anaesthetic gases alone, excluding nitrous oxide, generates an equivalent of 3.1 million tons of carbon dioxide annually. This could double by 2050 if usage continues to rise at a similar rate. However, the most environmentally significant anaesthetic gas may be nitrous oxide given its role as a carrying agent for volatile anaesthetics. Nitrous oxide has a number of other significant sources besides health-care activity, such as agriculture, food industry and microbial activity in the soil, so it is difficult to estimate emissions exclusively resulting from anaesthetic usage. The US Environmental Protection Agency (2015) inventory estimates that 12 000 tons of nitrous oxide (equivalent to 3.6 million tons of carbon dioxide) were emitted as a result of its use for medical or dental anaesthesia in 2015. This accounts for approximately 1% of nitrous oxide emissions from the USA. EU inventory includes nitric oxide from anaesthetic sources. This category is also included in the UK data from 2013 but is not quantified (Department of Energy and Climate Change, 2015). Sherman and Cullen (1988) estimated global anaesthetic nitrous oxide emissions of 4.4 million tons by extrapolating from production from an individual institution. With the inclusion of nitrous oxide the current equivalent carbon dioxide volumes generated from use of anaesthetic greenhouse gases rise dramatically to 16.3 million tons. This is comparable to that of British Airways, whose greenhouse gas emissions in 2013 were equivalent to around 18 million tons of carbon dioxide (British Airways, 2014).

Table 2 shows the equivalent volumes of carbon dioxide liberated for each anaesthetic flurane and nitrous oxide and compares this to global carbon dioxide production. The burden of anaesthetic greenhouse gases is modest compared to the global volume of carbon dioxide, but reducing greenhouse gas emissions requires collective curtailing of emissions from each constituent source. The

relative significance of anaesthetic greenhouse gases is set to rise markedly. While globally all airlines are committed to decreasing emissions to half of their 2005 value by 2050 (Air Transport Action Group, 2014), iatrogenic greenhouse gas emission remains largely unregulated. Following the projections by Vollmer et al (2015) anaesthetic greenhouse gas volumes could be equivalent to 32.6 million tons of carbon dioxide by 2050, while the carbon dioxide emissions of British Airways are anticipated to fall to half the 2005 value, namely 8 million tons/year (British Airways, 2007, 2014).

National and international monitoring and regulation

The first international consensus on limiting greenhouse gases emission was the 1992 United Nations Framework Convention on Climate Change which came into force in 1994. This was ratified by all 196 UN member states and had the broad objective of 'stabiliz[ing] greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system' (United Nations Framework Convention on Climate Change, 1994). Signatories were also required to keep an inventory of quantities and sources of greenhouse gases. Guidance for this was provided by the Intergovernmental Panel on Climate Change (1996), which specifically included six greenhouse gases:

- Carbon dioxide
- Nitrous oxide
- Methane
- Sulfa hexafluoride
- Hydrofluorocarbons
- Perfluorocarbons.

Nitrous oxide from anaesthesia was specifically included, but the fluranes are notably excluded. The Kyoto protocol, operative from 2005 to 2012, represented a crystallisation of the objectives of the United Nations Framework Convention on Climate Change into more specific targets to reduce greenhouse gases emissions. The protocol was ratified by 55 nations, with the United States and China as notable absentees. Within the protocol, according to the Intergovernmental Panel on Climate Change guidelines, anaesthetic use of nitrous oxide falls within the category

66 With the decline in global production of chlorofluorocarbons, nitrous oxide has emerged as the principal ozone depleter. 99

of 'Solvent and other product use'. The 2010 Cancun agreement established a maximum limit of 2°C for global warming. In 2012 the Doha amendment was approved to extend the protocol to 2020 and set a date of 2015 for the development of a successor protocol to be implemented from 2020. The details of the successor Paris Agreement was crystallized in the December 2015 Climate Change Conference in Paris. The new international consensus statement did not include flurane anaesthetics as a new class of greenhouse gases.

The Kyoto protocol and its successors have some legislative force in the UK. The Climate Change Act 2008 makes it the duty of current and future Secretaries of State for Energy and Climate Change to ensure that by 2050 the UK carbon dioxide equivalent emissions of the six Kyoto greenhouse gases are at least 80% of the 1990 figure. This includes nitrous oxide but not the fluranes, which is a major omission given that the Act was predicated on the United Nations Framework Convention on Climate Change objective to stabilize 'dangerous anthropogenic interference with the climate system'. However, the Act gives the Secretary of State for Energy and Climate Change considerable latitude to add other greenhouse gases as 'targeted' gases for regulation.

The UK Sustainable Development Unit (2015) calculates the greenhouse gases produced in health-care activity in the UK, but only since 2012 have these calculations included anaesthetic agents. Each gas is translated into an equivalent volume of carbon dioxide. On this basis, UK anaesthetic agent emissions for 2012 were equivalent to 600 000 tons of carbon dioxide (Sustainable Development Unit, 2015). This represents 13% of the entire equivalent carbon dioxide emission attributable to the UK health service infrastructure and buildings. The remaining 87% is the result of electricity generation and fossil fuel usage.

Ozone damage

Nitrous oxide and the bromide- or chloride-containing fluranes halothane and isoflurane also damage the ozone layer as they react with ozone, depleting stratospheric levels. It has been estimated that fluranes account for 1% of ozone depletion (Ishizawa, 2011). Neither the fluranes nor nitrous oxide is listed as part of the Montreal Protocol on Substances That Deplete the Ozone layer, drafted following the 1987 Vienna Convention for the Protection of the Ozone Layer (U.S. Environmental Protection Agency, 2015), with the objective of phasing out gases responsible for depleting the ozone. The target was predominantly the chlorofluorocarbons but with the decline in global production of chlorofluorocarbons, nitrous oxide has

emerged as the principal ozone depleter. Drives are now in place to curb nitrous oxide production both as a result of its greenhouse and ozone depletive effects (United Nations Environment Programme, 2013).

The ozone depletion potential of a gas is the volume of ozone destroyed by the gas compared to the volume destroyed by an equivalent volume of chlorofluorocarbon CCl_2F_2 (Table 1) (Ishizawa, 2011). That for halothane is 0.36 while isoflurane and nitrous oxide are considerably weaker depleters (0.01 and 0.017 respectively) (Ishizawa, 2011). However, nitrous oxide is produced in significantly high volumes than the fluranes.

Health-care practice and mitigating the effects of anaesthetic greenhouse gases

There are ways of mitigating against anaesthetic gas effluent into the atmosphere. Anaesthetic gases can be recycled or scavenger reactions can sequester gases, preventing release into the atmosphere (Doyle et al, 2002). New efficacious scavenger compounds are being discovered in addition to new modalities such as photochemical air purification (Sherman et al, 2012). The World Health Organization in its 2011 document *Health in the Green Economy- Health Care Facilities* recommends the scavenging, capture and re-use of anaesthetic gases to address environmental concerns. The document states that 'improved recapture and reuse of waste anaesthetic gases can provide significant climate and health co-benefits'. However, there are no requirements for this for health-care institutions. Neither are there punitive measures nor incentives for environmentally irresponsible or conscientious conduct.

The lack of regulation of iatrogenic greenhouse gases and anaesthetic greenhouse gases, other than nitrous oxide, from international protocols and national statute, possibly in part reflects the primacy of individual patient care and safety over a theoretical risk. However, where there is clinical equipoise some consideration may be given to environmental impact of anaesthetic gasses. Desflurane is environmentally the most injurious as its warming potential is almost 2500 times that of carbon dioxide (Vollmer et al, 2015) and high concentrations are required to produce anaesthesia. The minimum alveolar concentration is the alveolar concentration of anaesthetic gas required to prevent a motor response in 50% of adult patients following a painful stimulus. That for desflurane is 6.7%, compared to 1.2% for isoflurane and 2.2% for sevoflurane (Table 2) (Sherman et al, 2012). However, desflurane does have some favourable clinical features such as expeditious emergence from anaesthesia as a result of its low solubility (Sherman et al, 2012). While the minimum alveolar concentration of sevoflurane is higher than that of isoflurane, the former has a lower warming potential. In some parts of the world (Canada, Australia) it is recommended that sevoflurane be administered with higher fresh gas flow rates (>2 litre/min) compared to other fluranes. This was because of concerns over the accumulation of compound A, a putative harmful

degradative product of this flurane (Nunn, 2008). Hence if sevoflurane is used in conjunction with nitrous oxide, potentially greater volumes of the latter are liberated into the atmosphere (Sherman et al, 2012).

It is estimated that 'closed circuit' anaesthesia which recycles and complements exhaled air during anaesthesia may reduce volatile and anaesthetic consumption by up to 90%. Close clinical attention is required to ensure adequate oxygenation and avoid excess concentration of volatile anaesthetics (Ishizawa, 2011). Alternatives include intravenous anaesthesia or possibly xenon volatile anaesthetic (Ishizawa, 2011), but neither is a panacea. Xenon is efficacious but its production consumes considerable amounts of energy, which indirectly results in considerable greenhouse gas emission. This makes it potentially more hazardous than routine flurane or nitrous oxide use (Ishizawa, 2011). Nitrous oxide and the fluranes are strongly indicated in paediatric anaesthesia.

Conclusions

Climate change threatens the survival of the species and planet. Environmental change has tangible health-care sequelae in the form of cardiovascular, respiratory, zoonotic disease and even mental health conditions. Clinicians should be aware of their potential role and ways in which this can be mitigated. As the Catholic Church proposes a consensus statement, the medical community could follow a similar example. This starts with the dissemination of information, so informed decisions can be made and consensus reached. **BJHM**

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KEY POINTS

- Health-care activity has a significant effect on climate change.
- There has been a precipitous rise in anaesthetic greenhouse gases over the last decade.
- Anaesthetic greenhouse gases have a much more potent global warming effect, volume for volume, compared to carbon dioxide.
- An international consensus is possibly required to monitor the use of iatrogenic greenhouse gases including anaesthetic agents.

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