Southern African Journal of Anaesthesia and Analgesia. 2021;27(6 Suppl 1):S157-161
https://doi.org/10.36303/SAJAA.2021.27.6.S1.2716

South Afr J Anaesth Analg
ISSN 2220-1181 EISSN 2220-1173

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The environmental impact of anaesthesia

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Keywords: anaesthesia, global warming, ozone depletion, life cycle assessments, waste management

Introduction

Global health care contributes an estimated 4.4–4.6% of global carbon emissions.[1-3] In most countries, the healthcare sector is the greatest service sector source of carbon emissions, with only the energy, transport and construction sectors contributing more.[1] Ozone (O_3) depletion, waste production and the use and contamination of precious resources are other ways in which health care adversely affects our environment.[4]

All inhalational anaesthetic agents are greenhouse gases (GHGs).[4-9] Sulbaek Andersen et al.[8] estimated that the cumulative release of volatile anaesthetic agents into our environment has a global warming potential (GWP) equivalent to that of the carbon dioxide (CO_2) emissions from one coal-fired power plant. Furthermore, isoflurane and nitrous oxide (N_2O) have the potential to deplete the stratospheric O_3 layer.[4,5,9] As a resource-intense speciality, anaesthesia also contributes significantly to carbon emissions through the processes involved in the manufacturing, packaging, procurement and disposal of equipment, consumables and drugs.[6,7]

Global warming overview

In early August 2021, the International Panel on Climate Change (IPCC) published the first of three working group reports, that will make up its Sixth Assessment Report (AR6).[10] AR6 will guide policy makers at the next United Nations Global Climate Summit (COP26), scheduled to take place in the United Kingdom in November 2021.[11]

According to the AR6 working group 1 report,[10] global warming is undeniably occurring due to human actions and has already caused widespread global climate change. Such changes include heatwaves, droughts, heavier precipitation, and tropical cyclones. Since the beginning of industrialisation, the earth's surface temperature has already increased by 1.1 °C and global warming is expected to exceed 1.5 to 2 °C during the 21st century. As a result of global warming, weather-related disasters will continue to become more frequent. During the period 2000 to 2018 the frequency of these events already increased by 43%.[12]

Figure 1 illustrates the basic processes involved in the earth-atmosphere energy balance and global warming. Earth's atmosphere consists of three layers: the troposphere (below 10 000 m), the stratosphere (10 000 to 50 000 m) and the mesosphere (above 50 000 m). The tropopause is the border between the troposphere and the stratosphere.[7]

Incoming solar radiation consists of ultraviolet (UV), visible and infrared (IR) light. Stratospheric ozone absorbs some of the potentially harmful UV radiation, but the remainder of the solar radiation reaches the earth's surface.[7] Outgoing radiation consists predominantly of long wave IR radiation. Between the spectral wavelengths of 8 and 14 µm an 'atmospheric window' is present, in which limited absorption of outgoing IR radiation occurs. Outside of the 'atmospheric window', IR radiation is absorbed and re-emitted by water vapour and naturally occurring greenhouse gases.[4,7,9] This regulated retention of some heat within Earth's atmosphere makes our planet inhabitable.

Global warming is occurring due to the accumulation of compounds which have IR absorption bands that overlap with the wavelength range of the 'atmospheric window'. These compounds therefore impede the natural flow of IR radiation out of Earth's atmosphere and are referred to as GHGs.[9] As part of the Kyoto Protocol of 1997, commitments were made to reduce the emissions of the following GHGs: CO_2, methane, N_2O, hydrofluorocarbons (HFCs), sulphahexafluorine and perfluorocarbons.[7] The emission of many other GHGs, including volatile anaesthetic agents, is currently not regulated.

All GHGs can variably absorb and then re-emit IR radiation (radiative efficiency). Their contribution to global warming also depends on their atmospheric lifetime. The combination of these two factors determines the GWP of GHGs. GWPs are expressed as a ratio of the absolute GWP of CO_2 and over a specific time horizon. CO_2 has an atmospheric lifetime of approximately 100 years and by convention, the GWP_{100} for CO_2 is 1.[4,7,9] Some GHGs, such as the halogenated volatile anaesthetic agents, decay more rapidly than CO_2 and their GWPs should then rather be expressed for shorter time horizons.[5,8] The atmospheric lifetime of sevoflurane is 1.1 years compared to the atmospheric lifetime of N_2O, which is 114 years.[4,9]

'Carbon footprint' is a popular and widely used, yet poorly defined term. Wiedmann and Minx[13] have proposed the following definition: 'a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused

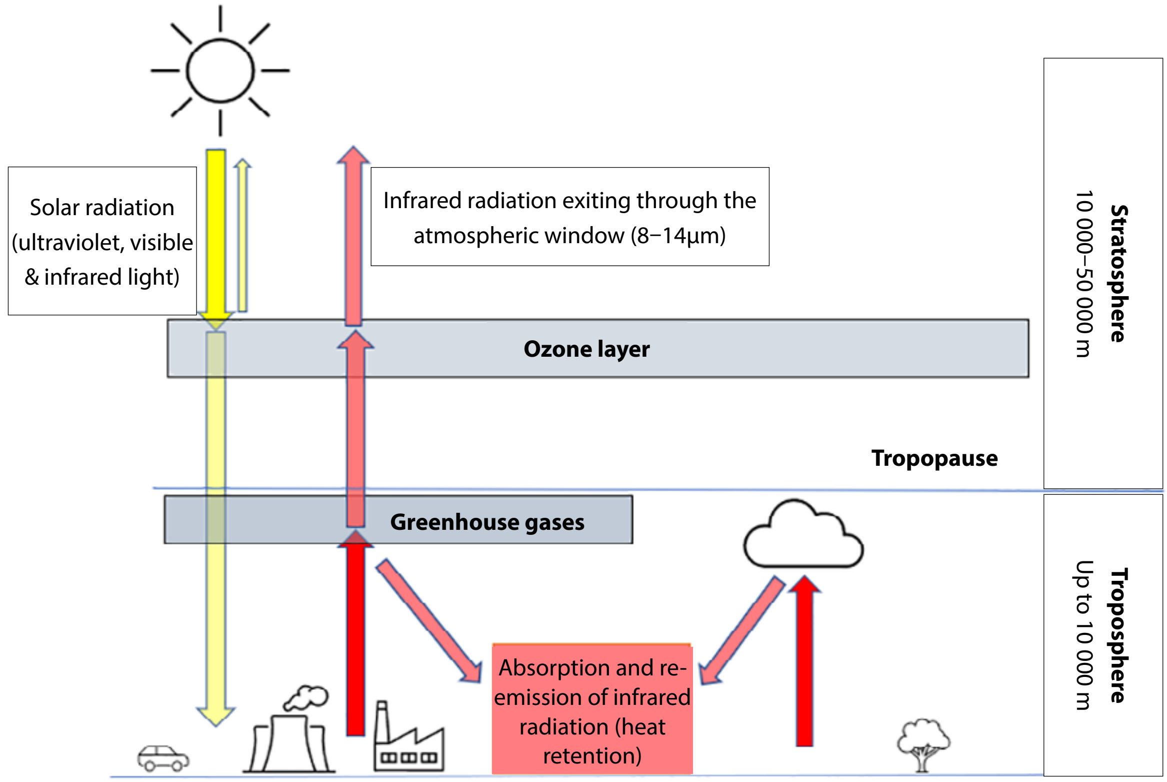

Figure 1: The basic processes involved in the earth-atmosphere energy balance and global warming. Adapted from Campbell and Pierce[7]

by an activity or is accumulated over the life stages of a product.' This definition therefore does not include the contribution to global warming of other GHGs.[13]

Carbon dioxide equivalency (CO_2e) refers to the rate at which specific GHGs are released into our atmosphere and is expressed in terms of the relative amount of CO_2 that would have the same global warming effect.[7]

O_3 is predominately found in the stratosphere, where it absorbs most of the harmful solar ultraviolet radiation. Compounds that can liberate chlorine, such as chlorofluorocarbons (CFCs), have the potential to destroy O_3. Due to this ozone depleting potential (ODP), CFCs were banned under the Montreal Protocol of 1987 and replaced by hydrochlorofluorocarbons (HCFCs), which have less ODP than CFCs. Since 2015, HCFCs are being replaced by hydrofluorocarbons (HFCs), which have no ODP.[7] However, HFCs,[7] as well as tropospheric O_3 itself, have GWP.[4]

Inhalational anaesthetic agents

All volatile anaesthetic agents and N_2O absorb IR light within the spectrum of the 'atmospheric window' and are therefore considered to be GHGs. It has been estimated that volatile anaesthetic agents account for approximately 5% of the CO_2e emissions of the United Kingdom's National Health Service.[7]

Desflurane, isoflurane and enflurane have the highest and very similar radiative efficiencies. Sevoflurane is approximately 25% less efficient and halothane approximately 65% less efficient at absorbing and re-emitting IR radiation.[4,9,14]

The atmospheric lifetime of the volatile anaesthetic agents depends on how rapidly they are broken down by hydroxyl ions in the atmosphere.[4,7,9,14] The bond between carbon and fluorine is stronger than that between carbon and hydrogen, chlorine, or bromine. Furthermore, hydroxyl ions react more strongly with halocarbon molecules in which the carbon atoms themselves are surrounded by more carbon atoms. This explains why the atmospheric lifetime of desflurane (14 years) is significantly longer than that of sevoflurane (1.1 years).[4,9,14] The atmospheric lifetimes, radiative efficiencies and corresponding GWPs of the inhalational anaesthetic agents are listed in Table I.

Table I: The atmospheric lifetimes, radiative efficiencies and GWPs of the commonly used inhalational anaesthetic agents[9]

Inhalational anaesthetic agent	Atmospheric lifetime (years)	Radiative efficiency ($W.m^{-2}.ppb^{-1}$)	GWP_{20}	GWP_{100}
Nitrous oxide	114	0.003	289	298
Halothane	1.0	0.165	190	50
Isoflurane	3.2	0.453	1800	510
Desflurane	14	0.469	6810	2540
Sevoflurane	1.1	0.351	440	130

Despite its low radiative efficiency, N_2O is a potent GHG, as it has a long atmospheric lifetime of 114 years.[9] Due to this long atmospheric lifetime, N_2O accumulates in the stratosphere, where it also contributes to O_3 destruction.[7] The vast majority of N_2O that is released into our atmosphere originates from non-medical sources, such as nitrogenous fertilisers.[6,7] This makes it difficult to quantify the amount of N_2O that is released into the environment following its use in anaesthesia and in labour wards.[15] As N_2O has low anaesthetic potency, it is usually administered at high concentrations,[6] and because of its significant alveolar uptake it is administered at relatively high flow rates.[16] The administration of 50% N_2O at 1 $l.min^{-1}$ for 1 hour therefore roughly equates to the CO_2 emissions from driving a car for 120 km.[16]

Isoflurane contains chlorine and halothane contains both chlorine and bromine. Chlorine and bromine form O_3 depleting radicals. As the atmospheric lifetimes of both isoflurane and halothane are however relatively short, their overall contributions to the destruction of O_3 are relatively minor.[4,9,15] Desflurane and sevoflurane have no ODP, as fluorine does not destroy O_3.[4,9]

Vollmer et al.[15] measured the atmospheric concentrations of the halogenated anaesthetic agents from 2000 to 2014. During this period, the atmospheric concentrations of isoflurane and desflurane increased significantly, sevoflurane concentrations showed a small increase, while halothane concentrations showed a decline. Based on their measurements, Vollmer and colleagues calculated that the total emissions from the four mentioned volatile anaesthetic agents were equivalent to 3.1±0.6 million tons of CO_2 in 2014. They also approximated that desflurane contributed 80% of the GWP of all the volatile anaesthetic agents.

Özelsel et al.[5] argue that anaesthesiologists should not only focus on GWP_{100} values when assessing the impact of inhalational anaesthetic agents on climate change. The commonly referenced GWP_{100} and GWP_{20} values would be more relevant if these agents were discontinued and would predict the future impact on our environment. When comparing the environmental effects of the different inhalational anaesthetic agents, one should also consider the potency of the agents as well as the required fresh gas flows.[6] To compare the near-term impact of releasing the different inhalational anaesthetic agents into the atmosphere, Özelsel et al.[5] calculated the driving equivalencies of the inhalational agents at 1 minimum alveolar concentration (MAC) and variable fresh gas flows (FGF) administered for seven hours. The seven-hour period was chosen to reflect a single day of surgery. The administration of 1 MAC of sevoflurane at a FGF of 1 $l.min^{-1}$ for seven hours has the same environmental impact as driving a car 1 566 km. For desflurane, the best-case scenario (1 MAC of desflurane administered at a FGF of 0.5 $l.min^{-1}$ for seven hours) equals driving 3 924 km. At a FGF of 2 $l.min^{-1}$ the desflurane driving equivalent is 15 698 km.

Reducing the use of inhalational anaesthetic agents, especially N_2O and desflurane, is the simplest way in which individual anaesthesiologists can minimise their impact on global warming. This is best achieved by minimising FGFs or by utilising total intravenous or regional anaesthesia when clinically feasible.[4,6,17]

The management of fresh gas flows

In a simple simulation experiment, Feldman[18] demonstrated that the reduction of FGF from 2 to 1 $l.min^{-1}$ during the maintenance phase of isoflurane anaesthesia prevented 18 900 l of isoflurane from being released into the environment over a 35-year career. The maintenance phase of anaesthesia is the ideal and most practical time to minimise environmental contamination. This can be achieved by avoiding circuit disconnections and incomplete seals with airway devices, while providing low maintenance FGFs through a circle (semi-closed) system.[7] This mandates the use of anaesthetic agent analysers.[17] The use of cuffed endotracheal tubes should also be considered during paediatric anaesthesia.[7] Some modern anaesthesia delivery systems are equipped with tools that guide or optimise FGFs during the maintenance phase of anaesthesia.[18]

The induction of anaesthesia requires the use of FGFs that usually exceed minute ventilation requirements (open circuit) or the use of higher concentrations of volatile anaesthetic agents during the use of overpressure techniques.[18] Immediately prior to intubation, however, the FGF should be turned off while the vapouriser setting remains unchanged. This prevents the volatile anaesthetic agent from being flushed out of the system and preserves its concentration within the circuit after intubation.[6,18] While using this technique, it is important to remember to immediately turn the FGF on again when a difficult airway is encountered.[18] During the emergence phase, FGFs should only be increased after the vapouriser has been switched off.[6,17,18]

Waste anaesthetic gas management

Anaesthetic gas scavenging systems are designed to minimise operating theatre contamination,[7] but the waste anaesthetic gases (WAGs) are eventually released into the atmosphere unchanged and the amount that is vented largely depends on FGFs.[4] WAG capture technology is being developed but is not yet routinely available. Once the WAGs have been captured, they may either be destroyed or stored and potentially reused.[6] Activated charcoal absorbers and metal organic frameworks can both capture WAGs. Ultraviolet light has the ability to destroy inhalational anaesthetic agents and membrane technologies that trap only volatile anaesthetics are being explored.[4]

Life cycle assessments

McGain et al.[4] define life cycle assessments (LCA) as: "a scientific method for analysing the 'cradle to grave' environmental 'footprint' associated with natural resource extraction, manufacturing, packaging, transport, use/reuse, and recycling/waste disposal of products or processes." LCAs can be performed for individual items or activities. For example, an LCA can assess the environmental cost of using disposable vs reusable laryngeal mask airways. LCA can however also be performed to assess the environmental impact of entire industries, such as a country's entire healthcare sector. LCAs most commonly report environmental impacts in the form of CO_2e emissions, but other reporting categories such as O_3 depletion, energy use, environmental pollution or carcinogen production may also be used.[4,6]

The predominant domestic energy source (coal vs nuclear vs renewable) significantly influences the CO_2e emissions associated with energy-consuming processes. For disposable medical consumables, most of the energy use and therefore CO_2e emissions occur during the production and packaging of large numbers of consumables. For equivalent reusable items, most of the overall energy use occurs during the repeated cleaning and sterilisation of the items.[4] LCAs have demonstrated in some instances that the use of reusable devices is environmentally more feasible than the use of single-use devices, while other LCAs have shown the opposite.[4]

Waste prevention and management

Anaesthesia is responsible for a quarter of all operating theatre waste,[19] which accounts for 20–30% of all hospital waste.[20] The popular waste hierarchy of reduce, reuse and recycle[21] should form part of any theatre waste management policy, with emphasis being placed on reduce and reuse before recycling is considered.[4,6,21] A large proportion of the medical waste that is collected as biohazard waste is not necessarily infectious.[20] Collecting and separating waste during case preparation, prior to the patient entering the operating theatre, reduces the risk of cross-contaminating recycling waste.[6]

In many healthcare sectors, concerns about transmission of infections have promoted the procurement of single-use, disposable devices.[4] The procurement of disposable devices is often perceived to be more cost-effective than the procurement and maintenance of reusable devices. However, when the cost of disposal and destruction is included in LCAs, both the financial and environmental costs often tend to favour the use of reusable devices.[6]

Eckelman et al.[22] explored the differences in the environmental impact of using disposable, single-use LMAs vs reusable LMAs. The reusable LMAs had less impact on the environment, when used a minimum of 10 times. For the reusable LMAs, the greatest environmental cost was associated with their repeated washing and sterilisation, whereas for the disposable LMAs, the greater environmental cost arose from their production, packaging, and waste management. It is important to note that this study was conducted in a large urban hospital in the United States of America (USA). Conducting the same study in a small, rural hospital in a country that relies heavily on coal as its predominant energy source, might have provided different results.

Some countries such as Japan, Spain, Germany, Canada and the USA have approved the regulated reprocessing of medical devices.[4] Many of the devices that are reprocessed are classified as single-use devices by their original manufactures.[6] Specialist companies collect, clean, performance test, re-sterilise, re-package and re-sell these devices, often at significantly reduced cost.[6] Surgical staplers, blood pressure cuffs, pulse oximeter probes, pneumatic compression stockings, endoscopic surgical equipment as well as laryngoscope blades and handles are examples of devices that can be reprocessed.[6,19,23] Unger and Landis[23] performed LCAs to access the environmental and economic impacts of varying levels of device reprocessing in their institution and demonstrated reductions in financial and environmental costs when reprocessing was performed.

Pharmaceutical waste may be toxic to the environment if not disposed of appropriately.[6,7] Drug wastage and potential environmental contamination can be minimised by avoiding drug expiration due to excess stock levels, by using appropriately sized ampoules, by accurately predicting depth and duration of required anaesthesia and by not drawing up emergency drugs for every case.[4,6,7] Pharmaceuticals should never be mixed with regular domestic waste or flushed away with wastewater. Propofol, for example, is only destroyed by high-heat incineration and residual drug should be discarded in sharps bins, never in wastewater.[6,7]

Use of valuable resources

Hospitals use large amounts of water. Routine patient care (personal hygiene), air-conditioning and heating systems, steam sterilisers as well as specialised medical services such as dialysis, require large volumes of water. Sparing and thoughtful use by patients and staff should always be encouraged and motion sensor technology could potentially reduce wastage.[4]

Energy use and energy infrastructure

Modern anaesthesia workstations are energy efficient but anaesthetic gas scavenging systems, radiant heaters and convective patient warming devices contribute more significantly to operating theatre electricity consumption. While theatres are not in use, gas scavenging systems, air-conditioning units and theatre lights should be switched off. Conductive patient warmers can be used as an alternative to convective devices.[7]

New hospitals should be built to the highest energy efficiency standards and older hospitals should undergo thermal rehabilitation to reduce energy requirements.[1] In South Africa, most hospitals rely completely on the domestic energy system, which is predominantly coal-based, instead of generating some of their own energy through sustainable and renewable processes such as solar power. Globally, the use of coal as energy source is increasing.[3] This is concerning, as domestic energy systems are the largest contributor to the CO_2 emissions of healthcare systems.[1]

Conclusion

Earth is facing an existential crisis in the form of global warming. Armed with relevant knowledge, individual anaesthetists have the power to change their own practice and to encourage their departments, healthcare institutions and governments to urgently reduce CO_2e emissions.

Conflict of interest

The author declares no conflict of interest.

Funding source

No funding sources to be declared.

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