RCoA
Royal College of Anaesthetists

e-LA
e-Learning Anaesthesia

Sustainability: **Medical gases**

Version 1.00 October 2020

Dr Pavan Raju
Dr John Hickman

Contents

Greenhouse gas effect and CO_2e 3

Main areas of use and COSHH (Control of Substances Hazardous to Health) regulations.......... 4

Medical oxygen and medical air 5

Actions to mitigate their environmental impact.......... 6

Techniques when using IAAs.......... 6

Innovative techniques 6

Lower carbon alternatives.......... 7

Alternative techniques to inhalational anaesthesia 7

Alternative techniques to Entonox® analgesia 7

National strategies and initiatives to measure and audit medical gas use and environmental impact 8

References 9

Module Learning Outcomes

- Greenhouse gas effect and CO_2e.
- Main areas of use and Control of Substances Hazardous to Health Regulations (COSHH).
- Actions to mitigate their environmental impact, including innovations such as capture (volatiles) and cracking (N_2O).
- Lower-carbon alternatives to their use.
- National strategies and initiatives to measure and audit medical gas use and their environmental impact.

Medical gases are used extensively in healthcare to provide anaesthesia and analgesia, to aid surgeries and to drive several medical devices and tools. The gases and vapours commonly used in the operating theatre are oxygen, medical air, carbon dioxide, nitrous oxide and inhalational anaesthetic agents (IAAs). Among these, IAAs and nitrous oxide are relevant both to anaesthesia and environmental sustainability. The IAAs that are currently in use in the United Kingdom are isoflurane, sevoflurane and desflurane. Along with nitrous oxide, the use of these agents in anaesthesia and their advantages are well established. However, they have some harmful effects on our environment with both direct and indirect adverse effects on our health. For more details on these deleterious effects please see the e-module in this series entitled '*Health and Climate change*'.

Greenhouse gas effect and CO_2e

Inhalational anaesthetic agents are potent greenhouse gases (GHG) and responsible for 5% of the carbon dioxide equivalence emissions of acute NHS hospitals.[1] They undergo minimal metabolism in the body and enter the environment virtually unchanged from the parent compound. The effect of a GHG is measured using carbon dioxide equivalency (CO_2e) which is based on the idea of demonstrating an individual GHG's impact over an agreed time scale (generally 100 years) in equivalent quantity of CO_2 that would produce the same global warming effect. This enables us to use a single unit to measure the global warming potential of different GHGs. So, it is the product of the mass of the GHG released multiplied by its global warming potential (GWP).[2] See '*Background science*' e-module in this series for more information.

Although nitrous oxide (N_2O) is reported in the UK GHG inventory,[3] exact data on emissions due to medical use of N_2O is not included as it is believed to be small. However, medical use has been estimated in the range of 1.3% of total UK emissions.[1] Along with its potent GHG effect (GWP_{100} 298),[4] N_2O is responsible for depletion of the ozone layer and, with an atmospheric lifetime of 114 years, this is not insignificant. The GWP is exaggerated when it is used in combination with other inhalational anaesthetic agents.

Inhalational anaesthetic agents have significant GWP due to their radiative efficiency and atmospheric lifetime. It is their difference in atmospheric persistence that explains the wide range in GWPs, as they all have a similar radiative efficiency. Desflurane has the highest GWP and sevoflurane the least (GWP_{100} of desflurane, isoflurane and sevoflurane 2540, 510, 130 respectively), as the former's atmospheric lifetime is over ten times that of the latter.[4] Given that the minimum alveolar concentration (MAC) of desflurane is three times that of sevoflurane coupled with the difference in GWP, desflurane is nearly sixty times more warming than sevoflurane per MAC hour of use. The interrogative estimate of global inhalational anaesthetic agent release was 3.1 +/- 0.6 million tonnes CO_2e in 2014, with 80% from desflurane alone.[5] See '*Background science*' e-module in this series for more information. Desflurane and sevoflurane lack the ability to deplete the ozone layer as they do not contain chlorine atoms when compared to isoflurane. The impact of isoflurane on ozone depletion is negligible as the tropospheric lifetime is short.

Main areas of use and COSHH (Control of Substances Hazardous to Health) regulations

Inhalational anaesthetic agents are mainly used in an operating theatre environment. Use is gradually increasing in remote areas involving radiology and cardiology intervention suites. N_2O is predominantly used on labour ward in the form of Entonox®. However, other areas such as the dental hospital, emergency department, acute pain services and some pre-hospital settings utilise N_2O for its analgesic property.

Apart from environmental hazards, IAAs have an impact on individuals subjected to occupational exposure. Hence, it is a legal requirement to ensure their safe removal and minimise exposure in the work area. In 1977, National Institute of Occupational Safety and Health (NIOSH) in United States set a limit of 2 parts per million (ppm) for exposure to IAAs and this was based on the lowest levels that could be detected using sampling and analysis techniques, rather than any established safe level of exposure.[5] The UK Health and Safety Commission Advisory Committee on Toxic Substances recognised 50ppm as the threshold for occupational exposure to isoflurane and 100ppm for N_2O over an 8-h time-weighted average below which there is no significant risk to health.[6] This remains the standard as recommended by the most recent COSHH guidance.[7] Unfortunately, the newer agents (desflurane and sevoflurane) are not included, possibly due to lack of evidence of direct human harm. Our veterinary colleagues have set a limit of 60ppm for sevoflurane.[8] Hence, it is prudent to employ the same standards for the newer agents. However, this recommendation is limited to the United Kingdom with other countries having their own standards.[9]

Medical oxygen and medical air

Manufacturing medical oxygen, a highly energy dependent process, is by initial compression of atmospheric air to a liquid followed by fractional distillation. The CO_2e depends on the energy source of electricity and the accepted value is 0.001 kWh energy/litre. The UK daytime CO_2 intensity is 300gCO_2e/kWh meaning that the CO_2e of Oxygen is 0.0003 kg/litre (approx. 0.3g/litre oxygen).[10]

Medical air is produced in house by compressors, filters and dryers. The CO_2e (SimaPro) is smaller than that for oxygen at 0.0003 kWh/litre equating to 0.00009kg/litre (approx. 0.1g/litre medical air).[10]

The process for both is inexpensive, oxygen from the VIE costs about £3 per hundred cubic meters (HCM at 15C) or 0.003 pence per litre. However, it is relatively more expensive (nearly 200 times) from CD cylinders at 0.5 per litre. An environmental advantage would be to use medical air as the driving gas for the ventilator instead of the standard setting where oxygen is typically used.[11]

Actions to mitigate their environmental impact

In the past two decades we have seen the evolution of a number of techniques and innovative technologies aimed at mitigating the negative environmental impact of these anaesthetic agents.

Techniques when using IAAs include:

- Avoidance of agents with high CO_2e (desflurane and nitrous oxide), selection of sevoflurane when IAA required
- Use of low flow anaesthesia (<0.5L/min)[12]
- Turn flows off, not IAA, when manipulating the airway or disconnecting from the circuit
- Over-pressuring the breathing system to allow reduced fresh gas flows, subsequently minimising the volume of IAA used
- Use of anaesthetic machines with end tidal control function have been shown to reduce IAA usage[13]
- Utilising adjuncts to reduce the mean alveolar concentration (MAC) required to maintain anaesthesia e.g. opiates, ketamine and regional techniques.

Innovative techniques:

There are a number of technologies commercially available that aim to address the issue of the venting of waste anaesthetic gases (WAGs) into the atmosphere. Broadly there are two ways in which these function, either to capture, purify and reuse the WAGs or to capture and destroy the WAGs.

Chambers containing absorptive compounds are placed within the anaesthetic gas scavenging system (AGSS) limb of the anaesthetic circuit. The absorbed WAGs are then condensed and either re-purified or destroyed. Metal organic frameworks are solid crystalline structures containing pores of varying and specific size which are able to accommodate and capture IAAs. Other absorption condensation systems also include the use of supercritical carbon dioxide and aluminosilicates[14] and are described in detail in reference by *McGain et al 2020*.[14]

Of all the anaesthetic gases 75% of the associated carbon footprint is due to nitrous oxide.[3] It is possible through the use of a heated catalyst unit to crack nitrous oxide into its constituent molecules, nitrogen and oxygen. This technology is however costly and has not gained popularity in the United Kingdom to date. In Sweden such technology has been in use since 2004, the largest of these units can be found at the Karolinska University Hospital in Stockholm.[15]

Lower carbon alternatives

Alternative techniques to inhalational anaesthesia:

- Use of Total Intravenous Anaesthesia (TIVA), which has been shown by *Sherman et al 2012* to have a significantly lower environmental impact when compared to all inhalational anaesthetic agents.[16]
- Use of regional anaesthetic techniques.

Alternative techniques to Entonox® analgesia:

- Use of alternative analgesic techniques in the obstetric setting, e.g. epidurals, remifentanil patient-controlled analgesia, transcutaneous electric nerve stimulation, oral opiates and holistic methods such as aromatherapy and hypnotherapy.
- Methoxyflurane is a short acting IAA and is gaining popularity as a substitute to Entonox® for the management of acute pain in the emergency and pre-hospital setting. With a GWP_{100} of 4 and an atmospheric lifetime of 54 days it is significantly less harmful for the environment when compared to nitrous oxide.[17] However, it does not have a license for use in children, must be avoided in patients with renal impairment and used with caution during pregnancy and in patients with liver impairment.[18]

National strategies and initiatives to measure and audit medical gas use and environmental impact

It is clear that the decisions we make as healthcare professionals have an impact on the health of the planet and subsequently our patients. The Royal College of Anaesthetists (RCoA) has published its sustainability strategy[19] and the Guidelines for the Provision of Anaesthetic Services (GPAS) now acknowledge the importance of sustainability, suggesting that departments should aspire to engage in sustainable quality improvement and academic activities within this domain.[20] The Association has also included environment and sustainability in its long-term strategic planning, with an environment and sustainability committee tasked to guide the specialty on matters of sustainability and green anaesthesia.[21]

The NHS has taken a number of steps towards sustainability in its long-term plan including the launch of 'For a Greener NHS' and publication of 'Delivering a net zero National Health Service', which have both mandated a reduction in the use of desflurane and nitrous oxide.

On an individual level, the profile of sustainability has been raised in recent years, with an emphasis being placed on the clinician to adapt their practices. Resources such as the *Anaesthetic Impact Calculator*[22], two sustainability chapters (11.1 and 11.2) in the RCoA quality improvement compendium[23] and this series of sustainability e-learning modules enable us to quantify and understand the impact our clinical choices have on the environment.

References

1. Carbon footprint from Anaesthetic gas use, Sustainable Development Unit, 2013.

2. Matt Campbell, FRCA JM, J. M. Tom Pierce, FRCP FRCA FFICM, Atmospheric science, anaesthesia, and the environment, *BJA Education*, Volume 15, Issue 4, August 2015, Pages 173–179.

3. Department of Energy and Climate Change, UK Greenhouse Gas Inventory Annual Report 1990 to 2011. Available at: gov.uk/government/publications/uk-greenhouse-gas-inventory

4. Sulbaek Andersen MP et al. Assessing the impact on global climate from general anaesthetic gases. *Anesth Analg* 2012; **114**: 1081–1085

5. Leong M. Reducing occupational exposure to volatile anaesthetics. Anaesthesia, 73 (6), 788-789.

6. Vollmer M, Rhee T, Rigby M et al. **Modern inhalation anesthetics: potent greenhouse gases in the global atmosphere.** *Geophys Res Lett.* 2015; **42**: 1606-1611

7. Health and Safety Executive. EH40/2005 Workplace Exposure limits hse.gov.uk/pubns/priced/eh40.pdf. Accessed on 25 July 2020

8. Vet-Tech. Minimise the risk of anaesthetic agents vet-tech.co.uk/contact/news/news/minimise-the-risk-of-anaesthetic-agents.aspx Accessed on 10 Aug 2020

9. Tankó B, Molnár L, Fülesdi B, Molnár C (2014) Occupational Hazards of Halogenated Volatile Anesthetics and their Prevention: Review of the Literature. J Anesth Clin Res 5: 426. doi:10.4172/2155-6148.1000426

10. Geoffrey Nunn, BA (Hons) FRCA, Low-flow anaesthesia, *Continuing Education in Anaesthesia Critical Care & Pain*, Volume 8, Issue 1, February 2008, Pages 1–4.

11. SimaPro LCA software. simapro.co.uk/simapro-9. Accessed on 25 Nov 2020.

12. Ford P, Foale M, converting gas-driven ventilators from oxygen to air. Anaesthesia, 75, 819-835.

13. End-tidal Control software for use with Aisys closed circuit anaesthesia systems for automated gas control during general anaesthesia, Medtech innovation briefing, National Institute of Clinical Excellence, 2014.

14. McGain, F., Muret, J., Lawson, C., & Sherman, J. D. (2020). Environmental sustainability within anaesthesia and critical care. *British Journal of Anaesthesia*.

15. Ek, M., & Tjus, K. (2012). Destruction of medical N2O in Sweden. Greenhouse gasses–capturing, utilization and reduction. Shanghai (China): InTech, 185-98.

16. Sherman, J., Le, C., Lamers, V., & Eckelman, M. (2012). Life cycle greenhouse gas emissions of anesthetic drugs. Anesthesia & Analgesia, 114(5), 1086-1090.

17. Hass, S. A., Andersen, S. T., Andersen, M. P. S., & Nielsen, O. J. (2019). Atmospheric Chemistry of Methoxyflurane (CH3OCF2CHCl2): Kinetics of the gas-phase reactions with OH radicals, Cl atoms and O3. Chemical Physics Letters, 722, 119-123.

18. British National Formulary, Methoxyflurane. bnf.nice.org.uk/drug/methoxyflurane.html. Accessed on 1 Dec 2020.

19. Sustainability Strategy 2019 - 2022, Royal College of Anaesthetists. rcoa.ac.uk/about-college/strategy-vision/environment-sustainability/sustainability-strategy-2019-2022. Accessed on 1 Dec 2020.

20. Chapter 1: Guidelines for the Provision of Anaesthesia Services - Introduction and next steps 2020, Royal College of Anaesthetists, 2020. rcoa.ac.uk/gpas/chapter-1. Accessed on 1 Dec 2020.

21. Long Term Strategy, Association of Anaesthetists, 2019.

22. Anaesthetic Gases Calculator, Association of Anaesthetists. anaesthetists.org/Home/Resources-publications/Environment/Guide-to-green-anaesthesia/Anaesthetic-gases-calculator. Accessed on 7th June 2020

23. Royal College of Anaesthetists quality improvement compendium, 2020. rcoa.ac.uk/media/15646. Accessed on 1 Dec 2020.

Royal College of Anaesthetists
Churchill House, 35 Red Lion Square, London WC1R 4SG
020 7092 1500 | e-LA@rcoa.ac.uk | rcoa.ac.uk/e-learning-anaesthesia
@RCoANews
RoyalCollegeofAnaesthetists
Information correct as at October 2020