THE ENVIRONMENTAL IMPACT OF ANESTHESIA AND STEPS TO MITIGATE IT

RWS

LEARNING OBJECTIVES

- Following the completion of this presentation, participants will be able to:

1. Understand current anesthesia techniques and their subsequent environmental impact
2. Compare and contrast the Global Warming Potential of current inhalational agents
3. Identify current techniques aimed at reducing anesthesia's carbon footprint

FINANCIAL DISCLOSURES

- none

SURGERY

- A 2019 study of global surgery metrics estimated that 266 million surgeries were performed worldwide in 2015, with a global median of 4171 procedures per 100,000 individuals.

- In the United States, an estimated 36 million surgeries were performed in 2015, corresponding to 11,113 surgeries per 100,000 individuals.

THE GREATEST THREAT

- The World Health Organization deemed climate change as “the greatest threat to global health in the 21st century.”

- The global environmental footprint of health care is significant; its contribution to total global greenhouse gas emissions (in carbon dioxide equivalents) is nearly 5%.

A N E S T H E S I A

- Anesthesia can be considered a “carbon hotspot.”

- The type of anesthesia used (inhalational, TIVA, regional, mixed) can have a big impact on the environment.

- In recent years, various international and national anesthesia societies have launched initiatives to minimize the environmental impact of our profession, largely focusing on the management of waste anesthetic gases

GENERAL ANESTHESIA

- General anesthesia (GA) can either be provided as inhalational anesthesia, or Total Intravenous Anesthesia (TIVA).
- GA is maintained with a volatile inhalational agent such as sevoflurane, desflurane, isoflurane, with or without N_2O as a carrier gas.
- TIVA typically is based on a continuous intravenous application of propofol, inhalational anesthesia can be delivered especially in pediatric institutions

ANESTHESIA GASES

- Along with nitrous oxide, Isoflurane, Sevoflurane, and Desflurane are potent greenhouse gases with significant global warming potentials.

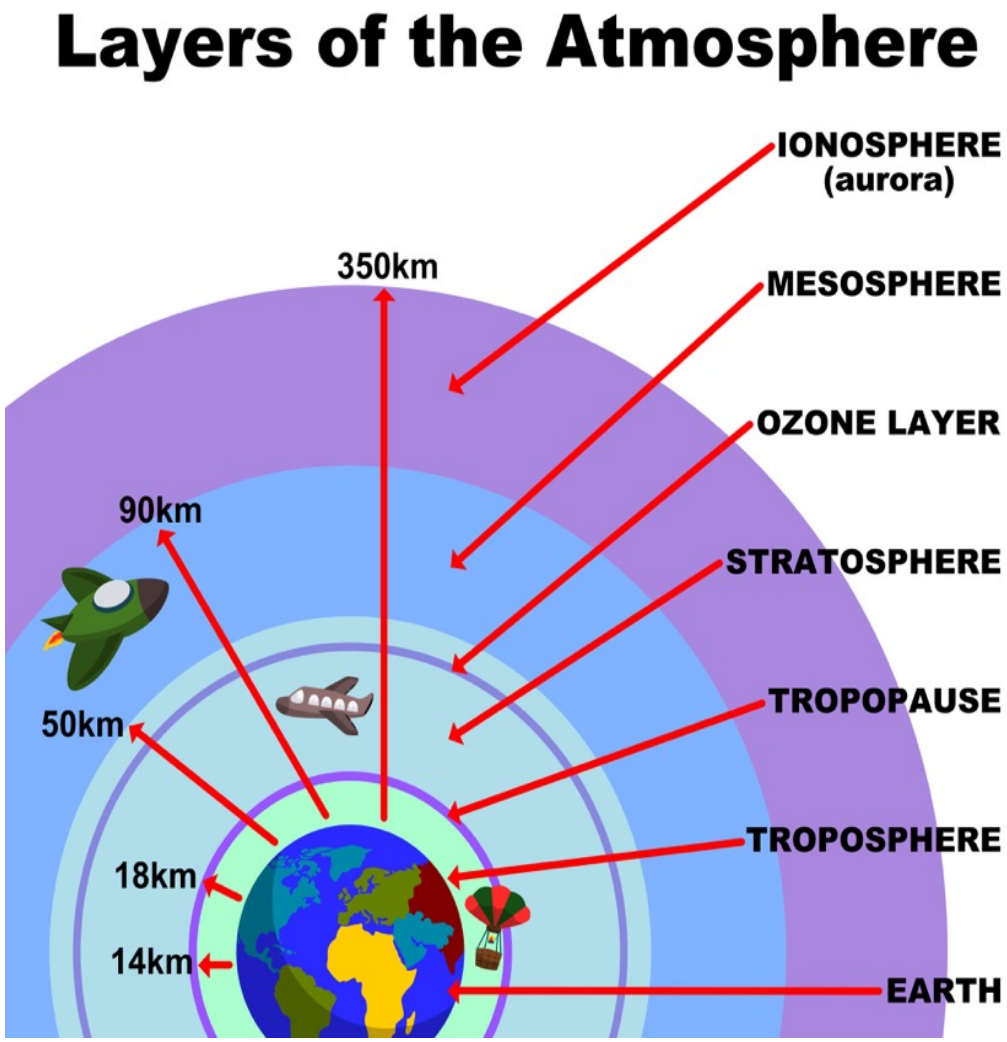
- Direct emissions are responsible for an estimated 3% of the climate footprint of national healthcare systems in industrialized countries and can account for more than 50% of greenhouse gas emissions from the perioperative chain.

GA AROUND THE WORLD

- In a 2012 French study, 72% of anesthesiologists performed GA as a combination of intravenous induction and either desflurane (48%) or sevoflurane (24%).
  - Total intravenous anesthesia was only performed in 17% of the cases.
- In a 2013 Scandinavian study, only 48.9% of anesthesiologists performed GA maintained with inhalational anesthetics, whereas 51.1% performed TIVA.
  - In 11.9% of these GAs, N_2O was used as carrier gas or coanalgesic.

GA IN THE U.S.

- A 2019 environmental survey by the American Society of Anesthesiologists' Committee on Equipment and Facilities found that sevoflurane was chosen by 66.4% of participating anesthesiologists whereas desflurane was chosen by 22.3%
- So why does this matter?



A QUICK REVIEW

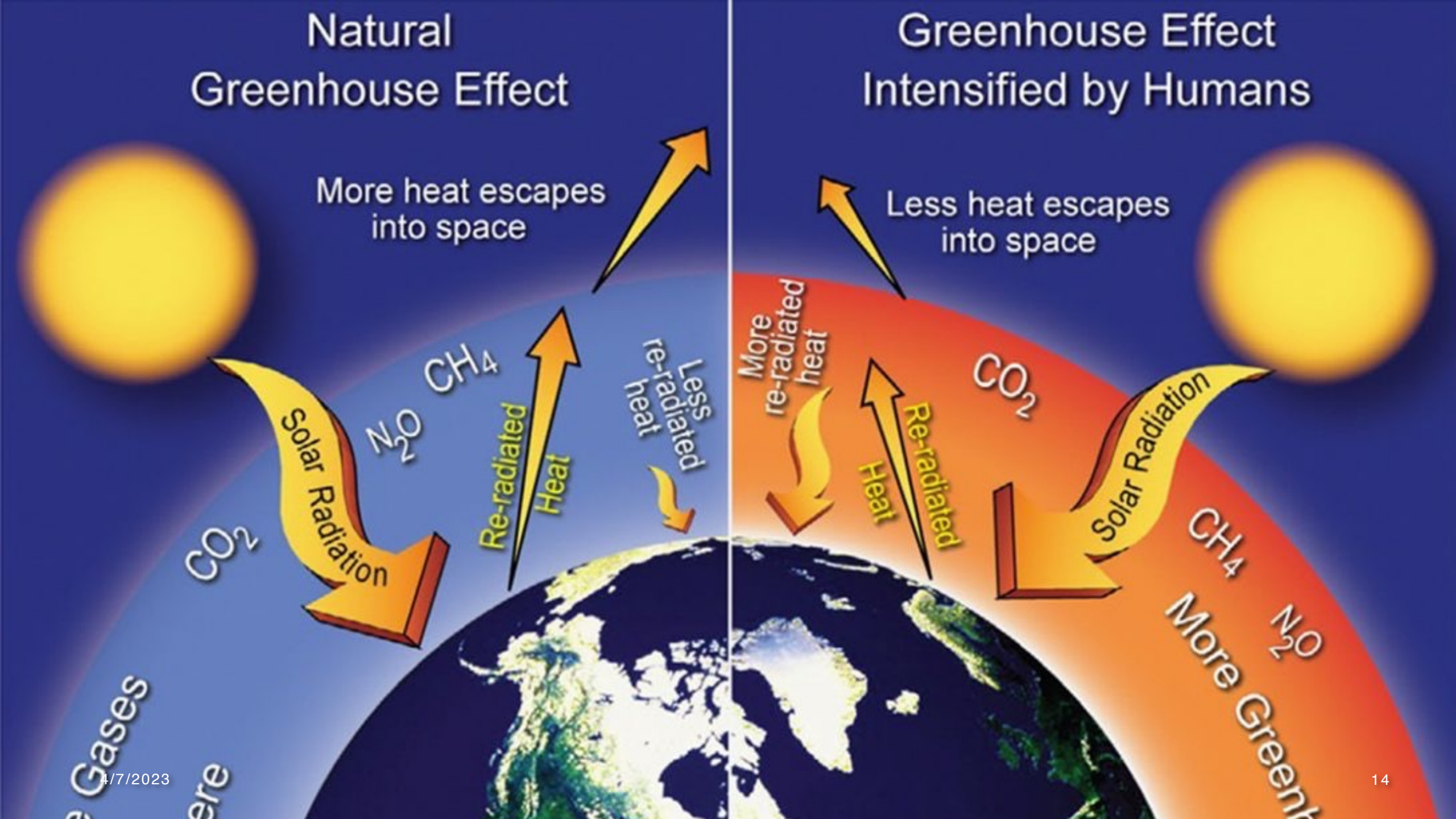
- The term “atmosphere” refers to the totality of all layers that surround our Earth's surface as a gaseous envelope.
- Atmosphere is divided into five different layers.
- For the purpose of the present discussion on the processes of global warming, we will focus on the following three layers: 1) the troposphere, up to 10,000 km; 2) the stratosphere, between 10,000 and 50,000 km; and 3) the mesosphere, beyond 50,000 km.

G R E E N H O U S E

- In the atmosphere, natural concentrations of Green house gases, clouds, water vapor, and other compounds adsorb and reflect incoming solar radiation back to space as well as outgoing infrared (IR) radiation back to the Earth.
- The equilibrium of incoming solar radiation and reflection as well as outgoing long wave IR radiation and IR reradiation creates and maintains appropriate living conditions on our planet.

GHGS

- The GHGs defined and regulated by the Kyoto Protocol 1997 are carbon dioxide (CO_2); methane (CH_4); nitrous oxide (N_2O); and fluorinated gases such as hydroxyfluorocarbon (HFC), perfluorocarbon (PFC), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3) and the commonly used inhalational anesthetics desflurane, isoflurane, and sevoflurane.


Natural
Greenhouse Effect
More heat escapes
into space
Solar Radiation
Re-radiated
Heat
Less
re-radiated
heat
CO_2
N_2O
CH_4
Greenhouse Effect
Intensified by Humans
Less heat escapes
into space
More
re-radiated
heat
Re-radiated
Heat
Solar Radiation
CO_2
CH_4
N_2O
More Greenh

WINDOW

- A range of wavelengths through which electromagnetic radiation can pass the atmosphere back into space is called the atmospheric window.

- Infrared emission through the atmospheric window ranging from 8 to 14 μm plays an important role in regulating the Earth's temperature.

- Unfortunately, inhalational anesthetics absorb mainly within this atmospheric window. Hence, they act as GHGs and influence the Earth's radiative balance by altering the IR radiation back to space. This favors the increase in global temperature.

- Widely used volatile anesthetics such as N_2O and the highly fluorinated gases sevoflurane, desflurane, and isoflurane are greenhouse gases, ozone-depleting agents, or both.

- These agents undergo minimal metabolism in the body during clinical use and are primarily (≥95%) eliminated unchanged via exhalation, waste anesthetic gases (WAGs) in operating rooms and postanesthesia care units can pose a challenge for overall elimination and occupational exposure.

GLOBAL WARMING POTENTIAL

- The global warming potential (GWP) of GHGs represents a common unit to measure absorption of energy in a defined period of time (usually 100 years).

- Enables a comparison of the greenhouse potential of different gases.

- By definition, CO_2 has a GWP of 1.

- Atmospheric lifetime is a second important determinant that influences GWP.

ATMOSPHERIC LIFETIMES OF IA

- 1–5 years for sevoflurane
- 3–6 years for isoflurane
- 9–21 years for desflurane
- 114 years for N_2O

Simple Perspective

Example

- Per hour of anesthesia with fresh gas flow rates of 0.5–2.0 L/min

Gas	Equates with driving[a]
Desflurane	235–470 miles
Isoflurane	20–40 miles
Sevoflurane	18 miles

Global Perspective

Assumptions

- ~200 million anesthetic procedures performed globally each year

Climate impact of inhaled anesthetics released

- ~0.01%[b] of CO_2 released from global fossil fuel combustion

NOT JUST GASES

- While the greatest emphasis to date in the anesthesia literature has understandably been on the carbon footprint of inhaled anesthetics,- they are just one environmental consideration within the complex system of products and services that make up anesthesia practice.
- What has been mostly lacking to date is research that analyzes the environmental impacts of health care across multiple cases so that we can understand variations, quantify uncertainty, and test whether a recommendation is generally applicable or more case dependent

A TRIP DOWN UNDER

- A prospective life cycle assessment of 10 patients in three groups undergoing knee replacements was conducted in Melbourne, Australia.
- The authors collected input data for anesthetic items, gases, and drugs, and electricity for patient warming and anesthetic machine.
- Sevoflurane or propofol was used for general anesthesia.
- Life cycle assessment software was used to convert inputs to their carbon footprint (in kilogram carbon dioxide equivalent emissions), with modeled international comparisons.

WHAT WAS MEASURED

- The composition and weights of reusable and disposable consumables: gloves, gowns, syringes, airway devices, patient warming blankets, temperature probes, intravenous fluids, drugs, and gases, and associated immediate packaging.
- Volumes of oxygen, medical air, volatiles, and nitrous oxide use were obtained from the anesthetic machine computer at the end of each case.
- For reusable items, previous data were used to estimate the environmental impacts of cleaning (sterile gowns, face masks, anesthetic breathing circuits, laryngoscope blades, and drug trays).
- The energy costs of reusable anesthetic equipment, i.e., kilowatt-hour/size of item as a proportion of washer load, and 1.9 kilowatt-hours/kg items sterilized

RESULTS

- Twenty-nine patients undergoing knee replacement were studied.
- The carbon dioxide equivalent emissions were:
  - an average 14.9 kg carbon dioxide equivalent emissions for GA
  - 16.9 kg carbon dioxide equivalent for spinal anesthesia
  - 18.5 kg carbon dioxide equivalent for combined anesthesia

SOURCES OF EMISSIONS

- Major sources of carbon dioxide emissions were:
  - electricity for the patient air warmer (average at least 2.5 kg carbon dioxide equivalent)
  - single-use items, 3.6 (general anesthesia), 3.4 (spinal), and 4.3 (combined) kg carbon dioxide equivalent emissions
  - For the general anesthesia and combined groups, sevoflurane contributed an average 4.7 kg and 3.1 kg carbon dioxide equivalent
  - For spinal and combined, washing and sterilizing reusable items contributed 4.5 kg carbon dioxide equivalent (29% total) and 4.1 kg carbon dioxide equivalent (24%) emissions, respectively.
  - Oxygen use was important to the spinal anesthetic carbon footprint (2.8 kg carbon dioxide equivalent)

Items	General Anesthesia		Spinal Anesthesia		General + Spinal Anesthesia	
	Average (Range), g/case	[Interquartile Range, 25–75%], g/case	Average (Range), g/case	[Interquartile Range, 25-75%], g/case	Average (Range), g/case	[Interquartile Range, 25-75%], g/case
Reusable items, g						
Cotton hand towel washed* and sterilized† (with sterile gown)	0	0	143	0	143	0
Plastics washed‡ (drug trays)	178 (178–178)	[178–178]	178 (178–178)	[178–178]	178 (178–178)	[178–178]
Plastics washed (anesthetic breathing circuits)§	0.1 kilowatt-hours/operation		0		0.1 kilowatt-hours/operation	
Plastics washed‡ and sterilized† (Proseal laryngeal mask, spinal tray, sterile surgical gown for spinal procedure). Note: Some spinal cases required > 1 gown (training, contamination, and so forth).	14 (0–72)	0–0	1,492 (1,227–1,828)	[1,227–1,728]	1,227 (1,227–1,227)	[1,227–1,227]
Silicone washed‡ (face mask)	78 (78–78)	[78–78]	0	0	78 (78–78)	[78–78]
Stainless steel washed‡ and sterilized§ (laryngoscope blade)‖	86 (0–123)	[31–123]	0	0	13 (0–123)	[0–0]
Single-use items,# g						
Copper**	5 (0–10)	[0–10]	1 (0–6)	[0–0]	3 (0–10)	[0–10]
Cotton	12 (0–25)	[0–23]	15 (3–28)	[6–25]	22 (11–28)	[23–25]
Glass††	161 (97–357)	[118–185]	180 (91–305)	[123–218]	186 (103–270)	[133–224]
Plastics, non–polyvinyl chloride‡‡ trash	486 (164–755)	[388–501]	451 (374–512)	[433–473]	583 (393–1040)	[482–630]
Plastics, non–polyvinyl chloride polypropylene recycled§§	0	0	42 (42–42)	[42–42]	42 (42–42)	[42–42]
Plastics, polyvinyl chloride trash	186 (89–252)	[166–222]	111 (28–236)	[92–121]	181 (98–284)	[137–250]
Plastics, polyvinyl chloride recycled‖‖	111 (91–123)	[91–123]	125 (91–151)	[123–123]	123 (91–151)	[91–123]
Rubber, latex	3 (0–29)	[0–0]	41 (28–57)	[29–57]	41 (29–57)	[29–57]
Rubber, neoprene, nitrile	30 (26–38)	[26–32]	33 (0–77)	[19–53]	42 (0–77)	[26–51]
Stainless steel##	4 (1–7)	3–6	13 (7–23)	[11–13]	13 (7–17)	[7–17]
Total, single-use items	996 (725–1,392)	[873–1,033]	997 (885–1,154)	[934–1,076]	1,237 (1,009–1,687)	[1,100–1,285]
Gases (volumes in l or ml)						
Oxygen, l	197 (75–320)	[116 – 271]	1,328 (990–1,950)	1,080–1,545	256 (53–824)	[131–332]
Compressed air, l	80 (14–273)	52–76	0	0	76 (9–193)	[42–94]
Sevoflurane,*** ml as a liquid)	24 (0–44)	0–29	0	0	16 (0–44)	[0–28]
Sevoflurane, ml/h	9.6 (6.2–14.6)	8.2–10.3	0	0	8.1 (4.8–19.0)	5.0–9.0
Sevoflurane: total intravenous anesthesia + sevoflurane: total intravenous anesthesia	8: 1: 1				5: 1: 3	

Pharmaceutical data are located in appendix 2.

*Laundered cotton data taken from Carre's Royal Melbourne Institute of Technology (Melbourne) study within Overcash.[24] †Energy required to sterilize equipment obtained from McGain *et al.*[25–27] ‡Energy required to wash (thermally disinfect trays) taken from McGain *et al.*[17]

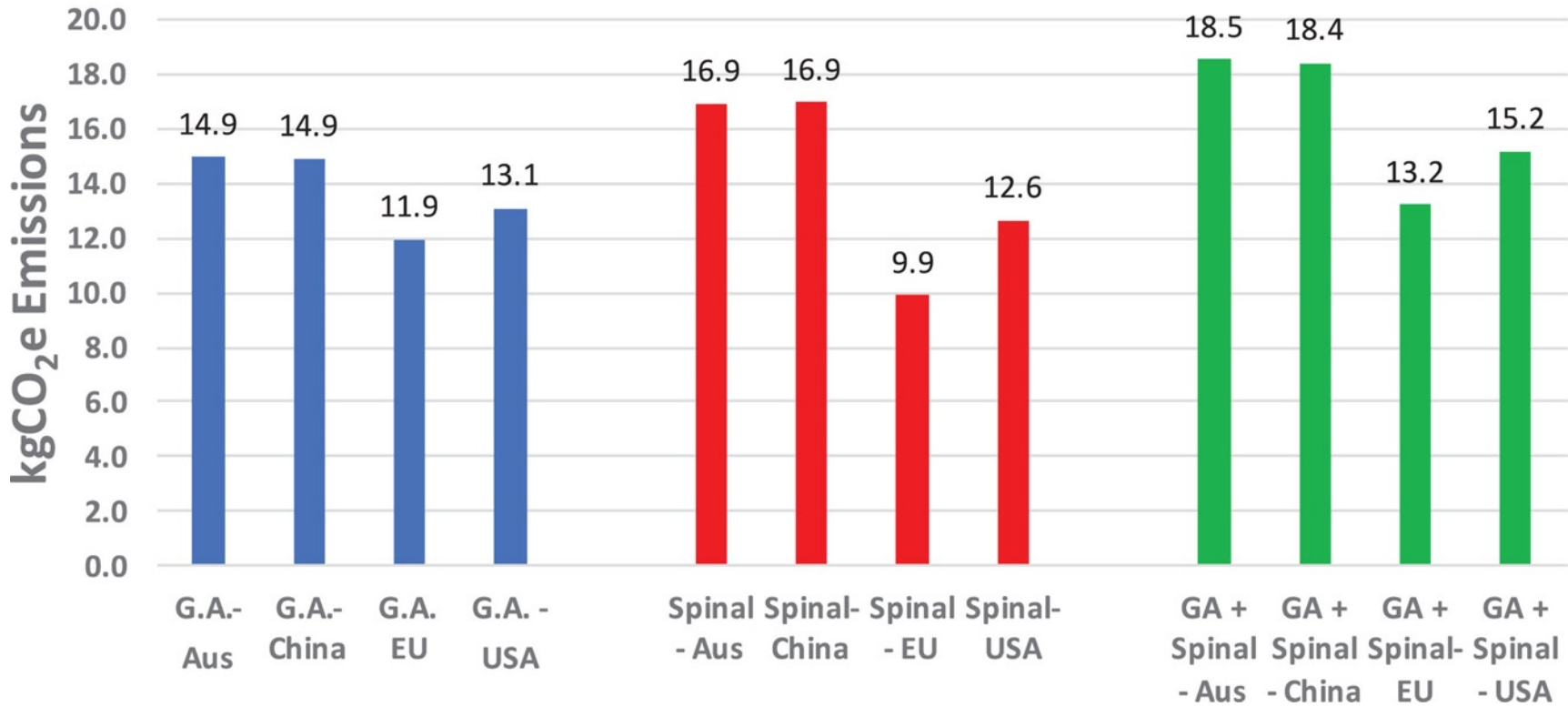
§Circuits changed weekly. Total 6.2 kilowatt-hours per wash load[17,28] with minimum of six circuits within and used for 25 operations. No energy attributed to spinal anesthetic as unused. ‖Stainless steel laryngoscope handles were wiped down with an antiseptic wipe between patient use. #Minimal paper/cardboard was disposed of within the operating room as the cardboard packets were routinely separated from the drug ampoules before entry into the operating room. No mattresses were used for heavy/obese patient transfers as most such patients are electively preferentially operated upon elsewhere in our health service. **Copper was found in the temperature probe. ††Glass arose mainly from drug ampoules. ‡‡Plastics, non–polyvinyl chloride were, from inspection and reference to our previous study of operating room plastics,[32] almost entirely polypropylene and polyethylene/polypropylene combinations (syringes). One plastic reusable ventilator circuit (436 g) was found to be leaking (thus discarded) for a general anesthesia + spinal patient, considerably increasing the maximum mass of plastics. §§Non–polyvinyl chloride recycling (of polypropylene) was occurring in the operating room.[7] ‖‖Polyvinyl chloride recycling of intravenous fluid bags was occurring in the operating room.[7] ##Stainless steel was contained within needles. ***Desflurane was not used for any cases. Nitrous oxide was used in one general anesthesia + spinal combination case, but this case was removed as the effect of nitrous oxide upon the total carbon dioxide emissions for the combination group excessively skewed the data.

Item (Equipment, Gases, Energy)	Carbon Dioxide Equivalent Emissions per Kilogram, Item, Milliliter, or Liter	General Anesthesia		Spinal		General Anesthesia + Spinal	
		Average Kilogram Carbon Dioxide Equivalent Emissions per Patient	% Total	Average Kilogram Carbon Dioxide Equivalent Emissions per Patient	% Total	Average Kilogram Carbon Dioxide Equivalent Emissions per Patient	% Total
Average anesthesia duration		161 min (2.7 h)		200 min (3.3 h)		189 min (3.2 h)	
Electricity directly associated with anesthesia (Victorian electricity = 1.12 kg carbon dioxide equivalent emissions/kilowatt-hour							
Patient air warmer (3M, USA) 0.8 kilowatt-hours/h (product information) = 0.9 kg carbon dioxide equivalent emissions/h use		2.46 kg carbon dioxide equivalent	20%	2.96	21%	2.86	19%
Anesthesia machine 0.08 kilowatt-hours/h[18] = 0.09 kg carbon dioxide equivalent/h use		0.24 kg carbon dioxide equivalent	2%	0.30	2%	0.29	2%
Reusable equipment: electricity for washing, sterilizing (Victorian electricity = 1.12 kg carbon dioxide equivalent emissions/kilowatt-hour)[29]							
Washing plastic trays[17]	0.16 kg carbon dioxide equivalent emissions/tray[17]	0.16	1%	0.16	1%	0.16	1%
Washing[17] and sterilizing plastic, cotton, silicone, and stainless steel (sterile surgical gown and towel for spinal, combined anesthesia)	3.0 kg carbon dioxide equivalent emissions/kg washed[17] and sterilized[23–25]	0.49	4%	4.52	29%	3.96	24%
Single-use Items (Australian Government National Greenhouse Accounts Factors)[29]							
Copper	11.9 kg carbon dioxide equivalent emissions/kg	0.06 kg carbon dioxide equivalent	0%	0.01 kg carbon dioxide equivalent emissions	0%	0.05 kg carbon dioxide equivalent emissions	0%
Cotton	27.2 kg carbon dioxide equivalent emissions/kg	0.35	3%	0.44	3%	0.64	4%
Glass	3.6 kg carbon dioxide equivalent emissions/kg	0.58	4%	0.65	4%	0.65	4%
Plastics, non–polyvinyl chloride	3.3 kg carbon dioxide equivalent emissions/kg	1.72	13%	1.60	10%	2.07	12%
Plastics, non–polyvinyl chloride recycled	1.8 kg carbon dioxide equivalent emissions/kg	0.12	1%	0.07	< 1%	0.07	< 1%
Plastics, polyvinyl chloride	2.6 kg carbon dioxide equivalent emissions/kg	0.49	4%	0.30	2%	0.46	3%
Plastics, polyvinyl chloride recycled	1.1 kg carbon dioxide equivalent emissions/kg	0.12	1%	0.12	1%	0.12	1%
Rubber, synthetic and natural	2.0 kg carbon dioxide equivalent emissions/kg	0.02	< 1%	0.14	1%	0.16	1%
Stainless steel	6.8 kg carbon dioxide equivalent emissions/kg	0.03	< 1%	0.09	1%	0.09	1%
Gases							
Oxygen	0.0021 kg carbon dioxide equivalent emissions/l	0.41 kg carbon dioxide equivalent	3%	2.76 kg carbon dioxide equivalent emissions	18%	0.53 kg carbon dioxide equivalent emissions	3%

C O N C L U S I O N S

- All anesthetic approaches had similar carbon footprints (desflurane and nitrous oxide were not used for general anesthesia).

- Rather than spinal being a default low carbon approach, several choices determine the final carbon footprint: using low-flow anesthesia/total intravenous anesthesia, reducing single-use plastics, reducing oxygen flows, and collaborating with engineers to augment energy efficiency/renewable electricity.


CO_2e Emissions for General, Spinal, and Combination Anesthesia (International Comparisons)
$kgCO_2e$ Emissions
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
14.9
14.9
11.9
13.1
16.9
16.9
9.9
12.6
18.5
18.4
13.2
15.2
G.A.- Aus
G.A.- China
G.A. EU
G.A. - USA
Spinal - Aus
Spinal- China
Spinal - EU
Spinal- USA
GA + Spinal - Aus
GA + Spinal - China
GA + Spinal- EU
GA + Spinal - USA

FINDINGS

- The carbon footprints of anesthesia for a knee replacement were similar for general, spinal, and combination approaches, with significant overlap between the CIs.

- The three major components of carbon dioxide equivalent emissions across all groups were single-use equipment (20 to 25%, mainly plastics), electricity for the patient air warmer (15%), and pharmaceuticals (8%).

- Carbon dioxide equivalent emissions from sevoflurane use for general anesthesia (32% total) and combination anesthesia (17% total) were considerable.

- Carbon dioxide equivalent emissions for cleaning reusable equipment were more than 25% total for spinal, and 20% for combined anesthesia.

- Oxygen use was about 15% of carbon dioxide equivalent emissions for spinal anesthesia. Importantly, the duration of anesthesia was 20% longer for spinal versus general anesthesia.

- Procedure duration contributes to carbon dioxide equivalent emissions, particularly electricity for the air warmer.

RECOMMENDATIONS TO REDUCE THE FOOTPRINT

LIFE IS A HIGHWAY…

- The fuel efficiency of the average U.S. car is 0.40 kg carbon dioxide equivalent emissions/mile, so in the Australian study, the average anesthetic carbon contribution (17 kg carbon dioxide equivalent emissions) is like driving 42 miles (without desflurane or nitrous oxide).

- For spinal anesthesia, reducing O_2 flows from 10 l to 6 l/min reduces driving by 1 mile/h.

- For general anesthesia, reducing fresh gas flow with sevoflurane by 1 l/min saves 3 miles/h.

- Replacing 1 l/min fresh gas flow sevoflurane with total intravenous anesthesia saves another 3 miles/h. Using the minimum plastic and glass use will reduce the carbon dioxide equivalent emissions 1 kg carbon dioxide equivalent emissions/h, equaling saving 3 miles/h.

THE MONTREAL PROTOCOL

- In the Montreal protocol, the medical use of inhalational anesthetics was declared as “essential” without restrictions.

- In view of global efforts to reduce the emission of greenhouse and ozone-depleting gases, it can be assumed that inhalational anesthetics will remain a significant source of emissions in the future

GLOBALLY

- The health care systems of low- and middle-income countries are confronted with a lack of health care resources and infrastructure, which challenges the provision of safe anesthesia.
- This lack of resources includes qualified anesthesiologic staff, equipment, and medication as well as basic needs such as continuous medical oxygen, power supply, and clean water
- Donated equipment cannot be readily maintained and used as expertise and material are missing.

ASA RECOMMENDS

- Avoiding N_2O as a carrier gas and minimizing fresh gas flow (FGF) rates.

- Best approximations of ideal FGF rates would be achieved by reducing FGF to 2 L/min with sevoflurane and to 0.5–1 L/min with desflurane and isoflurane.

- Use of closed-circle breathing systems and low-flow anesthesia further increases the efficiency of administration and reduces the amount of inhaled agents used and associated environmental and occupational exposure

DESFLURANE

- Comparing the global warming potential of inhalational anesthetics, desflurane is about 20 times more potent than sevoflurane and five times more potent than isoflurane.

- Anesthesia using low or minimal fresh gas flow (≤ 1 $L \cdot min^{-1}$) during the wash-in period and metabolic fresh gas flow (0.35 $L \cdot min^{-1}$) during steady-state maintenance reduces CO_2 emissions and costs by approximately 50%.

- Total intravenous anesthesia and regional anesthesia represent further options for lowering greenhouse gas emissions.

FLOW RATES

FGF	Classification
> 1.0 $L \cdot min^{-1}$	High flow
1.0 $L \cdot min^{-1}$	Low flow
0.5 $L \cdot min^{-1}$	Minimal flow
0.35 $L \cdot min^{-1}$	Metabolic flow
= $\dot{V}O_2$ ($L \cdot min^{-1}$)	Quantitative

Classification of anesthesia according to fresh gas flow for a 40-yr-old, 80-kg male patient
FGF = fresh gas flow; $\dot{V}O_2$ = total consumption of oxygen in L·

MINIMIZING WASTE GASES

- To minimize WAGs in settings that administer volatile anesthetics:
- A complete anesthesia apparatus check should be performed each day/before each use
- Face masks must fit properly and provide an effective seal
- Cuffs on tracheal tubes and laryngeal masks must be inflated adequately
- Before disconnecting a patient from a breathing system, residual gases should be eliminated through the scavenging system as much as possible
- FGF rates should be minimized as much as possible

THE FUTURE…

- New technologies are being investigated to reduce WAG release into the atmosphere.
  - Charcoal filters
- In a study comparing manual versus automated control of end-tidal anesthetic gases, automated control significantly reduced GHG emissions by 44%.
- A recent proof-of-concept study of a photochemical exhaust gas destruction system demonstrated efficient removal of desflurane and sevoflurane, although removal of N_2O requires further optimization.

ALTERNATIVES

- One alternative to volatile anesthetics may be total intravenous anesthesia (TIVA).

- While TIVA is not associated with the risks of occupational exposure or atmospheric pollution that are inherent to volatile anesthetic gases, clinical considerations should be weighed in the choice of agent.

- Appropriate procedures for the disposal of IV anesthetics must be followed to minimize any potential for negative environmental effects.

TIVA WITH PROPOFOL

- not entirely devoid of potential negative environmental effects and the total environmental impact of TIVA must be taken into account
- Studies have shown that 32%–49% of dispensed propofol is unused and disposed of as waste
- propofol has demonstrated toxicity in aquatic organisms and disposal via incineration is recommended
- not all institutions incinerate unused propofol
- improper disposal methods and subsequent release into the environment may add to the negative impact of TIVA with agents such as propofol

C O N C L U S I O N S

- Responsible anesthetic management choices should prioritize patient safety and consider all available options.
- If inhalational anesthesia is chosen, the use of minimal or metabolic fresh gas flow reduces the consumption of inhalational anesthetics significantly.
- Nitrous oxide should be avoided entirely as it contributes to depletion of the ozone layer, and desflurane should only be used in justified exceptional cases.
- Intravenous and regional techniques should be considered when appropriate


QUESTIONS

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