Review

Update in
Anaesthesia

Anaesthesiologists and the environment

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Abstract

Due to the environmental impact of human activities, the need for sustainable development has become apparent. Increasing consumption of the planet's natural resources, population growth, and waste have resulted in a serious environmental crisis, mainly represented by pollution and global warming. In light of this, many anaesthesiologists have reduced the use of inhalational anaesthetics, which include greenhouse gases. However, focusing only on anaesthetic gas emissions excludes other damaging factors. Sustainable anaesthesiology encompasses all aspects of patient care and ways to provide it with safety, quality, and environmental awareness. The objectives of this article were to understand the concept of environmental sustainability, to describe the environmental impact of medical care, to adopt strategies for sustainable anaesthesia in daily practice, and to raise public awareness about sustainability.

Key words: Anaesthesiology; environment impact; greenhouse gases; green anaesthesia; climate change.

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INTRODUCTION

In 2015, the United Nations defined 17 sustainable development goals to end poverty, protect the environment, and ensure that all people can enjoy prosperity. These goals also seek to reduce social inequality and expand access to basic rights and services.[1] This document highlights the importance of an effort between people, governments, and corporations to achieve sustainable development. Environmental sustainability is an attempt to preserve the environment and use natural resources in a balanced way to guarantee their existence for future generations.[2-4]

The intense use of natural resources, associated with population growth and waste, has resulted in a serious environmental crisis, represented mainly by pollution and global warming.[5-7] Since our current and future well-being depends on these measures, decreasing the environmental impact of human activity is a choice that must be made by all members of society, with education being the strongest means of disseminating environmental awareness.[8,9]

Health is one of the United Nations' focus areas for sustainability: medical services should be planned, financed, and provided to meet the present and future needs of the general population. This implies not only reducing the environmental impact of health care-related activities, but ensuring that health systems will adapt to climate change, fewer natural resources (water, fuel, etc.), population aging, and environmental disasters.[1,8,10] The World Health Organisation estimates that approximately 250,000 deaths related to climate change will occur each year in the coming decades.[3,7,11]

Health care produces a considerable amount of waste. Operating rooms, for example, produce 20%-30% of all hospital waste, with the U.S. health care sector alone contributing approximately 8% of greenhouse gas emissions.[5,7,10] This article describes the environmental impact of medical activities, mainly those related to anaesthesiology, and the need for sustainable anaesthesiology.

SUSTAINABLE ANAESTHESIOLOGY

Climate change poses a threat to humanity[2,5,12] and has been considered the main concern of the 21st century by the World Health Organisation, since it could contribute to 8.9 million deaths worldwide. Health care systems are facing an increasing number of pathologies linked to climate change. However, these services themselves are also a considerable source of greenhouse gas emissions[5], contributing to the increased demand.

Inhalational anaesthetics account for approximately 3% of hospital greenhouse gas emissions.[3,11,12] Many anaesthesiologists have realized the significance of this fact and have reduced their use. However, focusing only on greenhouse gas emissions overlooks other factors, such as waste management, which can contaminate water, soil, and air, indirectly contributing to global warming.[10,11,13]

In a consensus statement, the World Federation of Societies of Anaesthesiologists' Global Working Group on Environmental Sustainability in Anaesthesia lists three principles of sustainable anaesthesia:

1. patient safety should not be compromised by sustainability practices;
2. all countries must participate in these measures and support each other, and
3. health systems must reduce their contribution to global warming.[11]

In this context, anaesthesiologists must assume leadership roles, defending and encouraging environmental awareness and creating a work environment amenable to sustainable practices. To this end, management programmes have been created to foster more conscious choices about anaesthetic agents, waste disposal, and recycling, which can mitigate the negative environmental effects of anaesthesia practice.[8,11,12]

Achieving sustainable anaesthesiology requires analysis of the following topics, which will be discussed below: sustainable equipment and materials; the environmental impact of inhalational anaesthetics (IAs); fresh gas flow (FGF) management to reduce environmental contamination; conscious use of intravenous anaesthetics and other pharmaceuticals; waste disposal and recycling; conscious donation, and anaesthesiologists as leaders in sustainable change.[6,7,14]

SELECTING MORE SUSTAINABLE EQUIPMENT AND MATERIALS

Anaesthesia, a speciality involving many types of equipment and materials, produces a large amount of disposable or reusable waste.[2,5] Materials are normally selected based on cost, patient safety, effectiveness, and ease of use without considering environmental issues.[5,7,11] Disposable laryngoscope blades are a good example of how complex it can be to decide between disposable and reusable equipment. They are popular because they eliminate the risk of cross-contamination between patients and extinguish the ecological costs of cleaning, which require labour and natural resources, given that reusable items must be cleaned with disinfecting solutions that can be toxic to the environment.[2,4,6] On the other hand, reusable blades are associated with higher quality and reliability. In environmental terms, their manufacture requires fewer natural resources and they produce less waste than disposable units, which end up being incinerated. Generally, the decision to use disposable items does not consider their environmental impact and disposal/waste management costs.[4,11] Hence, there is an urgent need to plan for more sustainable materials.

The cleaning and reselling of single-use devices that are mechanically suitable for reuse is called reprocessing. Single-use devices are only designated as such by the manufacturer; in many countries they are considered reusable equipment. In the USA, reprocessing companies have begun formalizing and certifying this strategy. They accept recently used hospital equipment, such as pulse oximeters, breathing circuits for anaesthesia machines, laryngoscope handles and blades, laryngeal mask airways, sphygmomanometers, and laparoscopic trocars.[4,5,13] They clean, sterilize, and test these items, ensuring they meet U.S. Food and Drug Administration technical standards, and then resell them to hospitals. Resale prices can be 50%-60% below retail.[4,5,7]

Concerns have been raised about sterilization in equipment reprocessing, especially invasive surgical devices. The U.S. Food and Drug Administration currently requires reprocessing companies to comply with a number of rules and regulations, declaring in writing that the reprocessed medical device is "substantially equivalent" to the original. From 65%-75% of reprocessed single-use devices fall into class II (medium risk), which requires filing a report with the U.S. Food and Drug Administration prior to marketing.[3,7,10] Reprocessors must provide evidence of equivalence to the original device in terms of safety, efficacy, and intended use. Some class II devices include pulse oximetry sensors, ultrasound probes, and most laparoscopic equipment. The use of reprocessed single-use devices requires written patient consent, documentation of the reprocessed items used in treatment, and more rigorous systems for monitoring failures and injuries, in addition to attributing legal responsibility for adverse events to reprocessing companies.[5,7,11]

While reprocessing strategies seem sustainable, their costs must be considered. Reprocessing involves cleaning/autoclaving (environmental costs similar to reusable equipment), repairs, and testing (environmental costs similar to new equipment), and additional transportation. Thus, although this strategy reduces costs, it may not be actually more sustainable than others.[7,13,14]

The manufacture of anaesthesia machines and monitors also has a negative environmental impact. They contain metals, plastics, and computer parts that release toxins and heavy metals. Since these devices are manufactured in many locations, government cooperation is needed to reduce toxic emissions.[10,12,13] Improper disposal of monitoring equipment, batteries, computers, and anaesthesia machines harms the environment. This equipment usually includes recyclable metals, such as stainless steel, aluminium, brass, zinc, nickel and copper. The challenge is to separate recyclable from non-reusable material.

Conscious disposal must be achieved through proper medical waste management: independent metal recycling facilities can recover metal parts; old anaesthesia machines and monitors can be renovated and sold to laboratories, health care institutions, or veterinary clinics; medical missions may accept used equipment; contracts with environmentally committed suppliers can stipulate the return, donation, reuse of parts, or recycling of old equipment.[3,5,11,12]

THE ENVIRONMENTAL IMPACT OF INHALATIONAL ANAESTHETICS

Halogenated IAs and nitrous oxide contribute to the greenhouse effect and the depletion of the ozone layer.[6,15,16] Atmospheric emissions of IAs are unregulated, either because they are considered essential for medicine or because it is believed they contribute little to the greenhouse effect and climate change. However, IA use has increased considerably in the last 30 years, impacting the environment. Desflurane is of special concern due to its high environmental damage. Several studies have demonstrated the environmental impact of IAs and the need to minimize it.[3,17,18]

IAs contribute to the greenhouse effect by absorbing solar radiation and dissipating it as a source of heat; their long atmospheric half-life results in sustained atmospheric warming. Since IAs undergo minimal metabolism in vivo (except halothane), most of these exhaled gases remain intact and are released to the atmosphere through exhaust systems. The agent's effect will continue until the gas is degraded in the atmosphere. The atmospheric half-life of IAs ranges from 1 to 14 years, except for nitrous oxide, which has an atmospheric half-life of 114 years (Table 1).[4,16,19]

Global warming potential (GWP) is a measure of how much a given mass of gas contributes to global warming over a specific period: the Intergovernmental Panel on Climate Change, for example, uses 100 years. The GWP is a relative scale comparing the effect of a gas to that of the same mass of carbon dioxide. Thus, the GWP of CO_2, by definition, is 1. Desflurane has the highest GWP ever described (2,540), followed by isoflurane (510), and sevoflurane (130) (Table 1).[2,5,18]

The environmental impact of IAs depends on 3 factors:

1. total annual consumption (the amount used and released into the atmosphere);
2. higher vs. lower GWP, and
3. atmospheric half-life.

Annual consumption depends on FGF, nitrous oxide use, and the power of the gas. High FGFs increase the effect of volatile agents in the environment, releasing greater amounts of IAs into the atmosphere. Although nitrous oxide decreases the required amount of the volatile agent, this is more than offset by nitrous oxide's long half-life, causing prolonged damage to the ozone layer as a greenhouse gas.[2,11,16,18] Finally, higher minimum alveolar concentration (i.e., lower potency) means that higher amounts of the IA must be used in relation to other gases at similar flows, a key component that is often overlooked. For example, nitrous oxide has a relatively low GWP but is typically used in 40%-60% concentrations, thus increasing its environmental impact. Desflurane, on the other hand, has a high GWP and requires 3-6 times the amount of sevoflurane or isoflurane (assuming similar FGFs) due to its 6% minimum alveolar concentration, compared to 2% for sevoflurane and 1.2 % for isoflurane.[11,16,17,19]

Recently, a complete comparative analysis of the life cycle of IAs and propofol was conducted, with the environmental cost expressed as a carbon footprint[2,5,18] i.e., the degree to which an activity, product, etc. intensifies the greenhouse effect based on all inputs, from manufacturing and delivery to disposal. Atmospheric emission of IAs directly contributes to the greenhouse effect, being the main component of their carbon footprint; other aspects (manufacturing, delivery, and disposal) can be considered secondary.

The carbon footprint of desflurane is 15 times greater than that of isoflurane and 20 times greater than that of sevoflurane. This analysis calculated the FGF for 2L of sevoflurane vs. 1L for desflurane and isoflurane. Using nitrous oxide significantly increases the carbon footprint due to its release into the atmosphere as a residual gas, in addition to the environmental costs of manufacturing.[5,8,11,18]

Current recommendations are to avoid using desflurane and nitrous oxide whenever possible, substituting other IAs, intravenous agents, or regional anaesthesia. The carbon footprint of propofol is, on average, four times smaller than IAs, making it a more sustainable alternative.[11,17]

One way to assess the environmental impact of IAs is to compare their consumption with vehicle greenhouse gas emissions. One hour of desflurane use is equivalent to driving a gasoline-powered car for 640km, which is much higher than sevoflurane (12.8km) or isoflurane (28.8 km) (Table 1).[5,7,15]

To reduce the environmental impact of IAs, low FGFs should be used during the maintenance phase of anaesthesia and IAs should not be released into the atmosphere. Unfortunately, systems for capturing and reusing anaesthetic gases is still under development and are not yet available.[4,6,8,20]

FRESH GAS FLOW MANAGEMENT TO REDUCE ENVIRONMENTAL CONTAMINATION

Whenever the FGF exceeds the patient's needs, gases and vapors enter the exhaust system and contaminate the atmosphere. Thus, by using a minimal fresh gas flow, the environmental impact of IAs can be reduced.[2,5] Although the impact of a single surgery may seem negligible, professionals can make a difference through careful FGF management over time.[15,16.]To implement these strategies, it is important to know how to use anaesthetic agents and oxygen concentration monitors to safely determine the minimal fresh gas flow.[18,19]

Table 1 – Contribution of inhalational anesthetics to the greenhouse effect (adapted from Axelrod et al.[5])

Minimum alveolar concentration/FGF	Atmospheric half-life (years)	GWP in 100 years	Ratio of CO_2 - equivalents produced	1h of IA emissions expressed as km driven
Sevoflurane 2%/2 L	1.1	130	1.0	12.8
Isoflurane 1.2%/2 L	3.2	510	2.2	28.8
Desflurane 6%/2 L	14	2,540	49.2	640
Nitrous oxide 60%/1 L	114	298	-	97.6

FGF: fresh gas flow; GWP: global warming potential; IA: inhalational anesthetics.

Since safe anaesthesia requires continuous measurement of inspired and expired oxygen concentrations and IAs, it is possible to effectively manage FGFs.[3,5] To decrease environmental contamination, FGFs should match the patient's oxygen consumption as closely as possible.[16,17] When the vaporizer settings are adjusted or the FGF is changed, it will require more time for the gas and vapor concentrations in the circuit to change. Hence, there is a risk of inadequate concentrations, especially in the induction phase of anaesthesia, when there is a significant uptake of anaesthetic in the lungs. The concentration of expired IAs shown in the gas analyzer is the closest value to the minimum alveolar concentration and must be used to estimate it, thus ensuring adequate doses of anaesthetic.[5,15] Monitoring the oxygen concentration is essential, since decreasing the FGF below patient oxygen consumption levels will result in a progressive reduction in oxygen concentration, ultimately leading to hypoxemia.[11,15,17]

It is generally necessary to use a high FGF when a rapid change is desired in IA concentration, e.g., during the induction or awakening phases. When the desired concentration of anaesthetic vapor is in the circuit, the FGF can be reduced. Since the maintenance phase is usually the longest part of the procedure and does not require rapid changes in gas concentrations, it is the best opportunity to minimize the FGF.[16,17]

The minimum safe FGF provides enough oxygen to satisfy the patient's consumption, plus additional gas to replace leaks in the circuit and/or losses to a sidestream gas analyzer.[5,12,18] Oxygen consumption during anaesthesia varies: at an estimated 5mL/kg/minute in an adult male weighing 70kg, 350mL of oxygen will be used per minute. Thus, without considering leaks, a, FGF of 350mL/min could be considered adequate.[3,15,18] Higher FGFs will lead to excess gas, which is released into the exhaust system and the environment. If the patient's oxygen consumption is underestimated, oxygen concentration in the circuit will decrease.[2,5,18]

Therefore, measuring the inspired oxygen concentration is important for maintaining a proper FGF, ensuring safe and efficient oxygenation for the patient. If ambient air or nitrous oxide is supplied with the oxygen, environmental contamination will occur, since the nitrogen or nitrous oxide flow that exceeds the oxygen consumption rate will eventually displace a portion of the gases released through the exhaust system.[11,17]

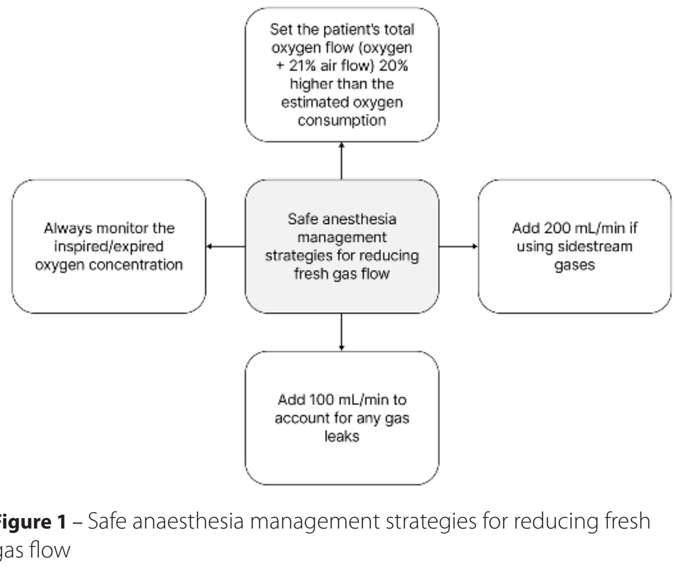

Figure 1 – Safe anaesthesia management strategies for reducing fresh gas flow

Patients with high oxygen consumption (e.g., trauma, pregnancy, or thyrotoxic crisis) require a higher FGF; in those with lower oxygen consumption, the FGF can be reduced during the maintenance phase, although the inspired oxygen concentration must still be monitored.[2,3,5,18,19]

Leakage in the circuit must be considered when determining the minimum safe FGF. It should be minimal if the anaesthesia equipment and breathing circuit have passed a leak check test. If a sidestream gas analyzer (which does not return the aspirated gas) is used, add 200mL/min to the calculated oxygen consumption; another 100mL/min must be added to offset any leaks in the circuit[4,6,19] (Figure 1).

A common practice during the induction phase is to increase the FGF during face mask ventilation and turn off the vaporizer while intubating the patient. The purpose of this is to avoid contaminating the operating theatre with anaesthetic vapor. In fact, anaesthetic vapor that accumulates in the circuit during mask ventilation is released into the room.[8,10,12] Thus, contaminating the room is unavoidable and the vapor in the circuit is wasted. Alternatively, the FGF can be turned off during intubation and the vaporizer left on. With no FGF, the IA is not released and the vapor reservoir that has accumulated in the circuit is preserved. The advantage of this strategy is that the FGF can be set to a minimum after intubation, thus preserving the concentration of anaesthetic vapor in the circuit. When the anaesthetic agent monitor indicates an adequate exhaled vapor concentration and there is a small difference between inspired and expired IA concentrations, it is then reasonable to switch to the minimum FGF.[2,4,5,18,19]

Turning off the FGF but not the vaporizer may not be a good idea in all cases, since for difficult airways the FGF must be turned on and face mask ventilation continued. Thus, anaesthesiologists must choose their own comfort level regarding airway management and FGF changes. In any case, turning off the vaporizer during intubation and leaving the FGF on contaminates the operating theater.[11,16,17]

There are techniques for reducing the concentration of IAs necessary for adequate anaesthetic depth to help reduce environmental contamination. Adjuncts, such as narcotics, regional analgesia, and infusion of local anaesthetic into the surgical field early in the procedure can reduce the required concentration of IAs. Smaller amounts of IA reduce environmental contamination. Another strategy is to use anaesthetic depth monitors to monitor exhaled IA concentrations, ensuring that the patient receives an adequate dose.[5,11,16-8]

CONSCIENTIOUS USE OF INTRAVENOUS ANESTHETICS AND OTHER PHARMACEUTICALS

Historically, anaesthesiologists have been concerned about patient safety but have neglected the effects of IAs and other medications on the environment and, thus, on the long-term health and safety of the population.[5,15] Studies have correlated IAs with the greenhouse effect, leading some to question whether the best way to reduce environmental impact would be to use intravenous anaesthesia alone. Unfortunately, this is not so simple, since intravenous anaesthesia involves solid waste (syringes, needles, vials, etc.) and the disposal of drugs that can contaminate the environment.[7]

According to pharmacokinetic principles, all administered medication is eliminated by the body, mainly through feces and urine, as active metabolites, other products of biotransformation, and/or unchanged. Thus, a portion of the drug is discarded in sewage systems, which contaminates the water since this type of waste remains untreated.[2,3] Although pharmaceutical contaminants are often below toxicity levels in the water supply, their environmental persistence is a result of a combination of high drug production and utilization rates. The effects of this are both unknown and concerning, especially for pregnant women and children, due to increased susceptibility during growth and development.[8,10]

Anaesthesiologists are trained to dilute drugs according to each case. Managing adverse outcomes is a basic principle of anaesthesia education, and obviously patient safety is paramount. However, this can lead to a staggering amount of waste: 50% of diluted drugs end up being discarded.[10,11] Decreasing medication waste helps curb the environmental impact of anaesthesiology.

In 2003, the city council of Stockholm approved an environmental risk scale for pharmaceutical products. The purpose of this 9-point index, based on persistence, bioaccumulation, and toxicity, is to decrease pharmaceutical residues in water, air, and soil. Drugs are rated according to their environmental threat, which is essentially the relationship between their expected/safe environment concentrations and environmental risk (Table 2).[5,10,15]

Propofol is the most wasted anaesthetic, with 33%-50% of the excess discarded. When used, less than 1% is excreted unchanged and 60% undergoes hepatic glucuronidation. Its improper disposal, whose half-life is >1 year, results in soil and water contamination.[3,4,7]

Antimicrobials have direct ecological effects, such as bacterial resistance, which affect health. In water, they contaminate fish by interacting with intestinal microbiota, inhibiting growth and causing infertility.[2,3,10] They affect soil microorganisms by reducing the enzymatic activity, in addition to plant protein synthesis, which limits the availability of nitrogen and CO_2, necessary for plant life. Microbial resistance is a current concern in the scientific community; a high rate of genetic alterations related to bacterial resistance has been found in environmental samples in recent years, mainly due to incorrect drug disposal in sewage, which can impact animal and human health (Table 2).[2,3,15]

WASTE DISPOSAL AND RECYCLING

Of all hospital waste, 20%-30% is produced in operating rooms. Sterile packaging systems are responsible for a large part of the waste, in addition to disposable items, which exacerbate the problem. Contaminated materials, sharps, and certain medications (dangerous for the environment) must be disposed of in special containers for regulated medical waste.[5,15]

Most operating room waste is solid and can be recycled if it has not been contaminated by body fluids. It has been estimated that anaesthesia procedures produce 25% of all operating room waste, 60% of which is recyclable. The main difficulty in recycling this waste is that infectious and clean waste are not separated.[2,3] Successful recycling programmes involve procedures to reuse materials before the patient even enters the operating room. Much recyclable waste is produced when the instruments are opened and prepared prior to the procedure. Closing containers for recyclable waste before the patient enters the room eliminates the risk of contamination.[11,12]

Recycled objects have value and can be sold to recycling facilities, which lowers the expense of solid waste disposal. Recycling in operating rooms also raises awareness about waste segregation and reduces regulated medical waste, which costs more than solid waste disposal. Several hospitals have reported cost savings after implementing effective recycling procedures in operating rooms.[5,15] According to the U.S. Centers for Disease Control and Prevention, only 2%-3% of medical waste actually requires disposal as contaminants. This is considerably lower than the 50%-70% of waste typically placed in the contaminated waste stream. Regulated medical waste can be reduced through educational programmes for the professionals involved in this process.[2,3]

Table 2 – The persistence, bioaccumulation, and toxicity of drugs used in anaesthesia (adapted from Fang et al.[10])

Medication	Persistence	Bioaccumulation	Toxicity
Propofol	High	Potential	Inhibition of algal growth and acute toxicity in small crustaceans and freshwater fish
Opioids	High	Potential I	Genetic damage to water fleas
Antibiotics (macrolides and quinolones)	High	High	Toxic to fish and amphibians
Lidocaine	High	Low	Possible carcinogen
Bupivacaine	High	Low evidence	No data
Sugammadex	No data in the literature	No data in the literature	Could affect aquatic life by binding to oestrogen and progesterone
Paracetamol	< 15 days	Potential	Highly toxic to bacteria and algae; neurotoxic to crustaceans and planarians in low doses

Responsible donation

Responsible donation involves providing the right equipment to the right facilities and care providers. Matching the supply of equipment to the demand is not merely about need, but the ability to use the donated resources. Therefore, donation plans should include operating manuals, disposable accessories, spare parts, and effective communication to ensure that recipients can operate and maintain the equipment.[4,6]

ANAESTHESIOLOGISTS AS LEADERS IN SUSTAINABLE CHANGE

Awareness is the most important part of an anaesthesiology sustainability program. Anaesthesiologists must actively participate in the selection of sustainable equipment, drugs, and anaesthetic techniques, in addition to the management of hospital waste, recycling, and operating rooms. They must also raise sustainable anaesthesia projects in interdisciplinary meetings, health events, and community events to raise awareness both inside and outside the hospital environment, thus encouraging cultural change and greater sustainability.[4,8,17]

Although most hospitals do not have a sustainability coordinator, many hospital personnel are interested in protecting the environment. Anaesthesiologists must assume leadership roles, becoming "go to" professionals regarding sustainability projects. The goals of such leadership are to identify opportunities, train personnel, monitor progress, collect, report, and analyze statistics, and develop continuing education programmes.[2,11] It is important for all areas of the hospital to participate: the anaesthesiology department, clinical staff, nursing staff, general services and hygiene, as well as the administration and hospital purchasing sectors.[12,17]

CONCLUSIONS

Sustainable anaesthesia goes beyond reducing IA use, since it aims to minimize the environmental impact of health care (Figure 2). Commitment to the environment requires the rational use of resources and a commitment to patient safety. Given that anaesthesiologists have always sought innovative care improvements, making sustainability a reality in anaesthesiology is a chance to make a difference beyond the operating room.

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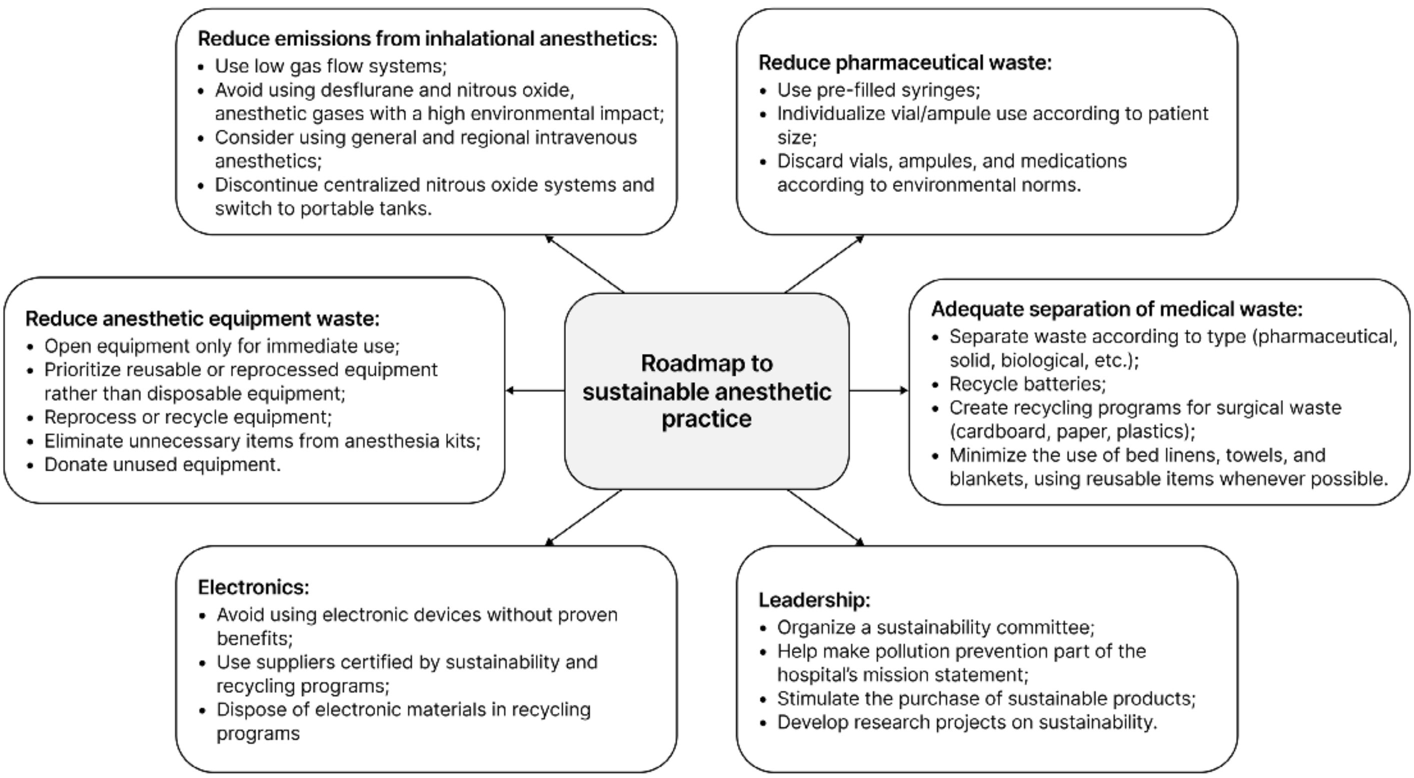

Figure 2 – Roadmap to sustainable anesthetic practice

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