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Green Anesthesia – The Impact of Anesthetic Gases on the Environment and the Application of Alternative Methods such as TIVA, LFA, and RA

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Abstract

Background. Climate change and global warming pose one of the greatest threats to public health. The medical sector, responsible for a significant percentage of global greenhouse gas (GHG) emissions, faces the necessity of reducing its carbon footprint. Among the main sources of pollution in healthcare are volatile anesthetic agents, such as desflurane, sevoflurane, and isoflurane, which exhibit a high Global Warming Potential (GWP) and are released into the atmosphere in unchanged form.

Aim. This systematic review aims to analyze the environmental impact of these anesthetic gases and present alternative, more sustainable anesthesia methods, including Total Intravenous Anesthesia (TIVA), Low-Flow Anesthesia (LFA), and Regional Anesthesia (RA).

Material and methods. A systematic review of the scientific literature was conducted using the PubMed and Google Scholar databases. Search phrases included: green anesthesia, TIVA, low-flow anesthesia, regional anesthesia, and anesthesia environmental. After initial screening, 27 articles published since 2020 were selected for detailed analysis to serve as the basis for this systematic review.

Results. The results clearly indicate that TIVA, LFA, and RA significantly reduce the carbon footprint. Furthermore, TIVA and LFA offer measurable clinical benefits, such as a reduction in postoperative cognitive dysfunction, faster recovery, and lower operational costs. The most significant environmental impact is attributed to desflurane (highest GWP), while sevoflurane is the most ecological of the inhaled agents.

Conclusions. The application of alternative methods (TIVA, LFA, RA) is crucial for significantly reducing the carbon footprint associated with anesthesia, without compromising patient comfort. Key elements for implementing these changes include educating medical staff and investing in appropriate equipment to transition towards more conscious and sustainable anesthetic practices.

Key words: Green anesthesia, TIVA, low-flow anesthesia, regional anesthesia, anesthesia environmental

1. Introduction

Climate change poses a threat to human health and life (Yeoh et al., 2020). Year by year, there is increasing discussion about pro-ecological actions aimed at protecting our planet, with popular terms including: global warming, carbon footprint, greenhouse gases, and the ozone hole. The medical sector is also a significant source of environmental pollution and greenhouse gas (GHG) emissions on a global scale. According to Skraastad et al., it is responsible for approximately 5% of global GHG production (Skraastad et al., 2025). For example, in the Netherlands, the healthcare sector accounts for 7.3% of the national carbon footprint (Kampman et al., 2025), 8.5% in the United States (Zurl et al., 2025), 7% in Australia (Barratt et al., 2022; Wang & DasSarma, 2024), and 2.7% in China (Wang & DasSarma, 2024).

A significant portion of this pollution is attributable to anesthetic gases, which, according to Kampman et al., constitute 3% of the global carbon footprint (Kampman et al., 2025). These volatile anesthetic agents (such as desflurane, sevoflurane, and isoflurane) are halogenated gases that act as potent greenhouse gases—contributing to the greenhouse effect, ozone layer depletion, and the progression of global warming (Khalil et al., 2024). Alternative methods offering environmental benefits include Total Intravenous Anesthesia (TIVA), Low-Flow Anesthesia (LFA), and Regional Anesthesia (RA) (Khalil et al., 2024; Biyani & Metta, 2023; Hammer et al., 2025). While these methods reduce the negative environmental impact, it must be noted that their use is not entirely flawless. For instance, many tools used in TIVA are disposable, which is not environmentally neutral; therefore, introducing reusable instruments is necessary for greater environmental protection (Grunert et al., 2024; Hammer et al., 2025). This paper provides a review of studies on the environmental impact of volatile anesthetic agents and presents alternative methods that can be both ecological and beneficial for the patient.

1.1. Research Objective

The objective of this research is a systematic review of the scientific literature to conduct a detailed analysis of the environmental impact of volatile anesthetic agents and present alternative, more sustainable anesthesia methods (TIVA, LFA, RA).

1.2. Research Problems

1. What is the impact of volatile anesthetic agents (desflurane, sevoflurane, isoflurane, N2O) on the environment in the context of Global Warming Potential (GWP)?
2. What are the environmental and clinical benefits resulting from the use of alternative anesthesia methods (TIVA, LFA, RA)?

1.3. Research Hypotheses

1. Volatile anesthetic agents, especially desflurane, have a significantly negative environmental impact (high GWP).
2. Total intravenous anesthesia (TIVA) and low-flow anesthesia (LFA) effectively reduce the carbon footprint while offering measurable clinical benefits compared to high-flow inhalation anesthesia.

2. Research materials and methods

A systematic review of the scientific literature was conducted using the PubMed and Google Scholar databases. The following search phrases were used: green anesthesia, TIVA, low-flow anesthesia, regional anesthesia, anesthesia environmental.

After initial relevance screening, 83 articles were selected for detailed analysis, from which 27 studies were chosen to serve as the basis for this systematic review. One of the cited publications is an article from the American Society of Anesthesiologists website. To ensure the review reflects the latest scientific evidence, only studies published since 2020 were included, with the majority—17—originating from the last 3 years.

2.1. Participants

Not applicable – literature review.

2.2. Procedure / Test protocol / Skill test trial / Measure / Instruments

Not applicable – literature review.

2.3. Data collection and analysis / Statistical analysis

Data concerning the environmental impact of anesthetic gases (GWP, atmospheric lifetime) and the clinical benefits of alternative anesthesia methods (TIVA, LFA, RA) were collected and analyzed to synthesize the results and draw conclusions.

2.3.1. Statistical Software

Not applicable – literature review.

2.3.2. AI.

Not applicable.

2.3.3. Statistical Methods

Not applicable – literature review.

3. Research results

3.1. Global Warming Potential (GWP)

Most anesthetic gases exhaled by patients are not metabolized and are released into the atmosphere in an unchanged, environmentally harmful form (Hammer et al., 2025). GWP (Global Warming Potential) is used to assess their negative impact. It is a measure of the amount of heat a given gas traps in the atmosphere compared to a similar mass of carbon dioxide (CO2) (Biyani & Metta, 2023; Wang & DasSarma, 2024; American Society of Anesthesiologists, 2024). It is calculated for a specific time interval, usually 20 or 100 years, where the GWP for CO2 is 1.

Desflurane has by far the worst impact on the environment, leading, for example, to the decision in the UK to gradually phase out the use of this drug by 2026 (Biyani & Metta, 2023). To illustrate, the carbon footprint of a single use of desflurane at a Minimum Alveolar Concentration (MAC) and Fresh Gas Flow (FGF) of 0.5 and 2 L/min, respectively, for 1 hour is equivalent to driving a car a distance of almost 380 km and 750 km, respectively (Biyani & Metta, 2023).

In the study by Kampman et al., we find another comparison of the carbon footprint calculated per kg (Kampman & Sperna Weiland, 2023). The consumption of 1kg of sevoflurane is equivalent to the emission of 440kg of CO2, while 1kg of desflurane is equivalent to 6810kg of CO2.

It is also worth noting Nitrous Oxide (N2O). Although it performs significantly better than desflurane in terms of GWP, its atmospheric lifetime is much longer (114 years), and penetrating into the stratosphere causes ozone layer depletion (Biyani & Metta, 2023).

Sevoflurane is the most ecological gas among the discussed agents, and its use should be considered during general anesthesia. According to Yeoh et al., through education and increasing staff awareness of the negative environmental impact of inhaled anesthetics in 7 hospitals in British Columbia, Canada, a 66% reduction in greenhouse gas emissions was achieved over 4 years (Yeoh et al., 2020). The change in practice involved the more frequent choice of sevoflurane over desflurane (Yeoh et al., 2020).

Table 1. Comparison of volatile anesthetic gases in terms of environmental impact

Anesthetic Gas	Atmospheric Lifetime (years) (American Society of Anesthesiologists, 2024)	GWP20 (Biyani & Metta, 2023)	GWP100 (American Society of Anesthesiologists, 2024)
Desflurane	14	6810	2540
Isoflurane	3.6	1800	539
Sevoflurane	1.9	440	144
Nitrous Oxide (N2O)	114	n.d.	278

Source: Author's own elaboration based on literature data

3.2. Alternative Anesthesia Methods

3.2.1. Total Intravenous Anesthesia (TIVA)

Total Intravenous Anesthesia (TIVA) is an excellent method for both the environment and patients. This method only uses propofol for anesthesia, whose carbon footprint is equivalent only to the energy consumed by the infusion pump used for its administration. For example, for a hysterectomy, this consumption is about 0.001kg of CO_2, while the CO_2 equivalent for desflurane for the same surgery is 505kg (Kampman & Sperna Weiland, 2023).

Setting the environment aside, it is worth looking at the outcomes of patients undergoing TIVA. Many studies emphasize that no differences were observed between anesthesia using gases like desflurane or sevoflurane and TIVA (Deng et al., 2024). Some studies, in turn, report favorable effects of TIVA over the inhalation method. Among the reported advantages, the authors mention a lower risk of postoperative cognitive dysfunction (POCD), especially in the geriatric population (Yao et al., 2024). Negrini et al. attribute this difference to the anti-inflammatory effect of propofol, which improves postoperative cognitive functions by reducing the concentration of pro-inflammatory cytokines (Negrini et al., 2022). Other advantages of TIVA highlighted in the literature include faster recovery of physical independence after surgery and reduced postoperative nausea (Kim et al., 2021). An interesting advantage of TIVA highlighted by Xiong et al. is easier perioperative glycemic control and better suppression of cortisol release in patients with type 2 diabetes mellitus (Xiong et al., 2023). In terms of financial aspects, according to Kampman et al., the use of TIVA in non-cardiac surgery patients was associated with a reduction in total costs of 11-12%, primarily due to milder and less frequent postoperative nausea and vomiting (Kampman & Sperna Weiland, 2023).

3.2.2. Low-Flow Anesthesia (LFA)

Another method mentioned earlier, which benefits both the environment and the patient, is the low-flow strategy. The premise of this method is the use of a closed circuit, in which gases exhaled by the patient are recovered back into circulation, allowing the Fresh Gas Flow (FGF) to be reduced to 0.5-1.0 L/min (Kaşıkara et al., 2022; Kutlusoy et al., 2022). This results in lower emission of anesthetic gases, reduced costs associated with their consumption, and reduced oxygen consumption (Kampman & Sperna Weiland, 2023).

Furthermore, patients are not exposed to high concentrations of anesthetic gases, and the anesthesiologist can control the humidity and temperature of the ventilated air (Kampman & Sperna Weiland, 2023; Kaşıkara et al., 2022). This action improves the mucociliary function of the airways and prevents hypothermia. According to Kampman et al., the low-flow strategy can reduce sevoflurane consumption by up to 60% when the flow is reduced from 2 L/min to 0.5 L/min (Kampman & Sperna Weiland, 2023).

This method is described as equally good (Prasad et al., 2020; Öterkuş et al., 2021) and sometimes better than the high-flow method (Öterkuş et al., 2021). Öterkuş et al. emphasize that with good oxygenation control in patients undergoing low-flow, better tissue perfusion and faster postoperative recovery can be achieved (Öterkuş et al., 2021). In turn, Kaşıkara et al. link the better postoperative effect of the low-flow strategy to lower oxidative stress following its application (Kaşıkara et al., 2022).

3.2.3. Regional Anesthesia (RA)

Where general anesthesia is not essential, the use of Regional Anesthesia (RA) also offers better outcomes for the environment and can be associated with additional benefits for the patient. In many studies, a comparison of general and regional anesthesia shows no significant differences (Li et al., 2022; Vail et al., 2024), but some report benefits, such as a reduced incidence of serious complications like myocardial infarction or acute kidney failure in total knee arthroplasty (Lee et al., 2023), or perioperative complications in chronic subdural hematoma surgery (Hestin et al., 2022).

3.3. Statistical Hypothesis Testing

Hypothesis 1 (Volatile anesthetic agents, especially desflurane, have a significantly negative environmental impact) was confirmed based on GWP data. Desflurane exhibits a GWP100 of 2540, which is many times higher than isoflurane (539) and sevoflurane (144).

Hypothesis 2 (Total intravenous anesthesia (TIVA) and low-flow anesthesia (LFA) effectively reduce the carbon footprint while offering measurable clinical benefits compared to high-flow inhalation anesthesia) was confirmed. Both methods significantly reduce gas emissions, and numerous clinical studies indicate the benefits of TIVA (lower risk of POCD, faster recovery, glycemic control) and LFA (better perfusion, lower oxidative stress).

4. Discussion

The results of the review clearly indicate that anesthesiology has a significant share in the global carbon footprint, mainly due to volatile anesthetic agents, especially desflurane. Desflurane, with a GWP100 of 2540, presents the greatest environmental challenge in this field.

In the face of growing ecological awareness, TIVA, LFA, and RA are practical and clinically justified alternatives. TIVA, utilizing propofol, has a minimal carbon footprint, and its use is also associated with a number of clinical benefits, such as better postoperative cognitive function, which is particularly important in the geriatric population (Negrini et al., 2022; Yao et al., 2024). LFA, which minimizes the consumption of inhaled gases through recirculation, proves that it is possible to combine inhalation anesthesia with environmental responsibility while also benefiting the patient, for example, through better thermal and humidity control (Kampman & Sperna Weiland, 2023).

The implementation of these "green" methods, however, requires staff education and investment in appropriate equipment (Samad et al., 2025). As Kampman et al. (2023) emphasize, switching to TIVA is also associated with measurable economic benefits for the hospital. Further research is necessary to debunk outdated myths about the superiority of high gas flows in narrow patient groups (Deng et al., 2024; Öterkuş et al., 2021).

5. Conclusions

1. The use of general anesthesia methods based on reducing the flow of anesthetic gases (low-flow strategy) or using only propofol (TIVA), as well as regional anesthesia, significantly reduces the carbon footprint without worsening patient comfort.
2. Desflurane has by far the highest Global Warming Potential (GWP) among volatile anesthetics, which should lead to its gradual phase-out.
3. Reducing N_2O consumption is crucial for limiting the depletion of the ozone layer.
4. It is necessary to increase the awareness of medical personnel about the impact of their daily work on the environment, which will contribute to promoting sustainable practices throughout the healthcare sector.

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