

Greening the Operating Room: A Narrative Review of Global Frameworks for Sustainable Surgical Practice

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AIM: Climate change is a major global health threat, and healthcare contributes 4–5% of global greenhouse gas emissions. Operating rooms (ORs) are particularly resource-intensive, producing high levels of waste and emissions. Sustainable surgical practices are essential to reduce the environmental impact of healthcare. This review aims to summarise and compare key international initiatives that promote sustainability in the OR.

METHODS: A narrative review was conducted between January and March 2025. Resources were identified through searches of PubMed, Google Scholar, and professional society websites. Inclusion criteria included publication or endorsement by recognised academic or professional bodies, availability in English, and provision of practical guidance on surgical sustainability. No formal quality assessment was performed due to the heterogeneity of sources.

RESULTS: Four major frameworks were identified: the Intercollegiate Green Theatre Checklist, which offers actionable perioperative recommendations including reusable equipment, waste reduction, and energy savings; the European Association for Endoscopic Surgery (EAES)/the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) Taskforce, which focuses on leadership, education, and international collaboration; the Harvard Climate in Obstetrics, Anaesthesia and Surgery Team (COAST) Group, which promotes equity-focused, low-cost, and scalable solutions suitable for varied healthcare settings; the World Federation of Societies of Anaesthesiologists (WFSA) Global Consensus, which outlines sustainable anaesthetic practices and education. These frameworks align with the “5R” model—Reduce, Reuse, Recycle, Rethink, and Research—and highlight the OR as a key area for intervention.

CONCLUSIONS: Despite implementation barriers, these frameworks provide practical, scalable strategies for surgical teams to reduce emissions. Embedding sustainability in surgical practice is critical for achieving healthcare decarbonisation and improving planetary health.

Keywords: sustainability; surgery; climate change

Introduction

Climate change has contributed to rising disease burden, declining air quality, and increased pressure on vital resources such as food and water [1–3]. In response, international efforts such as the United Nations’ Race to Zero initiative and the Paris Agreement have established ambitious targets; a 45% reduction in carbon emissions by 2030 and net-zero emissions by 2050 [4]. However, despite these global goals, progress remains insufficient, and healthcare must play an active role in driving environmental change.

Healthcare contributes approximately 4–5% of global greenhouse gas emissions [1]. Within hospitals, operative rooms (ORs) are particularly resource-intensive, accounting for up to one-third of total hospital waste and a significant share of energy use and carbon emissions. Up to 40% of surgical waste is generated before skin incision, most of it being non-contaminated and potentially recyclable. This has been highlighted as an area ripe for intervention [5,6].

One of the initiatives which provides evidence-based recommendations across the surgical workflow is the Royal College of Surgeons Intercollegiate Green Theatre Checklist [7]. In parallel, large-scale efforts have proposed feasible, safe, and acceptable interventions for high, low- and middle-income countries (LMICs). These include the use of reusable surgical devices, reduction of anaesthetic gases, appropriate waste segregation, and the introduction of recycling programs [8].

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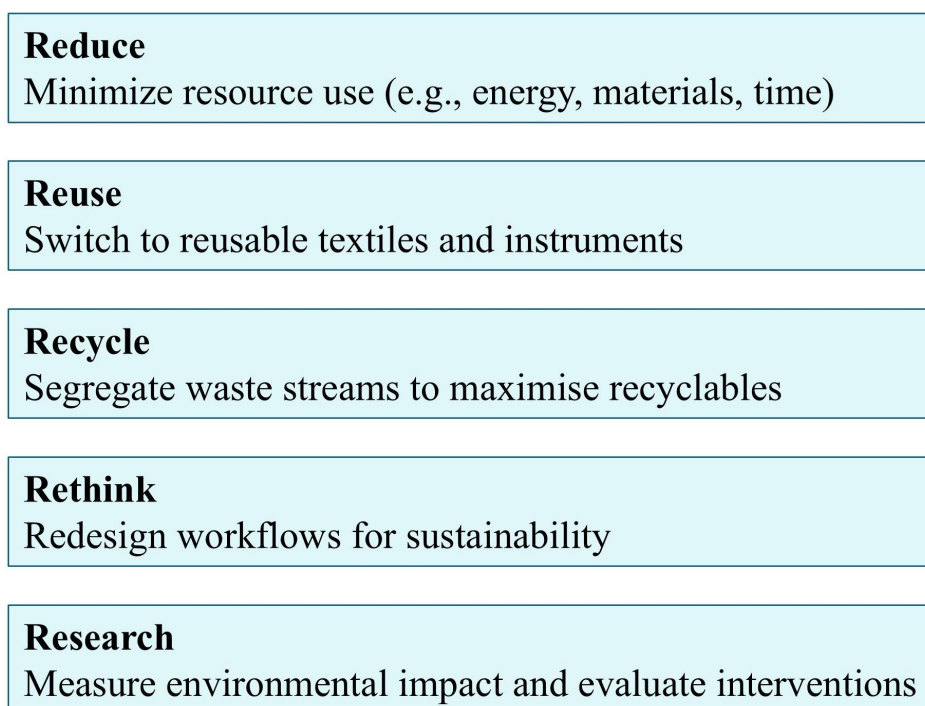


Fig. 1. The 5R framework for sustainable surgery.

Sustainability principles in the OR align with the expanded waste minimisation model - Reduce, Reuse, Recycle - now supplemented by Rethink and Research (Fig. 1). This concept resonates with the broader 10R framework of the circular economy, which prioritises interventions based on their emission-reduction potential, from refusing unnecessary materials to recovering resources at the end of their lifecycle [9].

Barriers to implementation remain significant, including procurement limitations, lack of leadership, and gaps in carbon literacy among healthcare professionals. Study emphasizes the importance of behavioural change strategies, clinician engagement, and the need for sustainability supporters within surgical teams [10]. Even small quality improvement projects, such as increasing the use of reusable gowns, recycling or reducing unnecessary glove use, can lead to measurable reductions in emissions [11,12].

Ultimately, the OR provides an ideal starting point for decarbonising healthcare, as it is a controlled environment where interdisciplinary teams can pilot, monitor, and refine sustainable practices [10].

As awareness of climate change intensifies, surgical societies, hospitals, and policy-makers are moving toward more environmentally sustainable practices [13]. In this context, tools such as checklists, global frameworks, and consensus statements have been developed to guide the transition to greener surgery. The combined insights from international checklists, implementation frameworks, and real-world audits offer a scalable path toward greener surgi-

cal systems. In doing so, surgical teams can lead by example, redesigning ORs from high-emission environments into models of sustainable innovation. This narrative review summarises and compares key initiatives aimed at improving sustainability in the OR. Together, these resources provide a roadmap for reducing the environmental impact of surgery through actionable, multidisciplinary strategies.

Materials and Methods

This review was conducted using a narrative synthesis approach. As this was a narrative review the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines were not applicable and therefore not followed. Between January and March 2025, a systematic exploration of publicly available resources and peer-reviewed literature related to sustainable surgical practice was performed.

Data Sources

Relevant checklists, frameworks, and statements were identified through the following channels: Professional Society Websites, PubMed, Google Scholar.

Search Strategy

The research strategy aimed to identify relevant frameworks, guidelines, or consensus statements related to sustainability in surgical and anaesthetic practice. Boolean operators were used to refine the search.

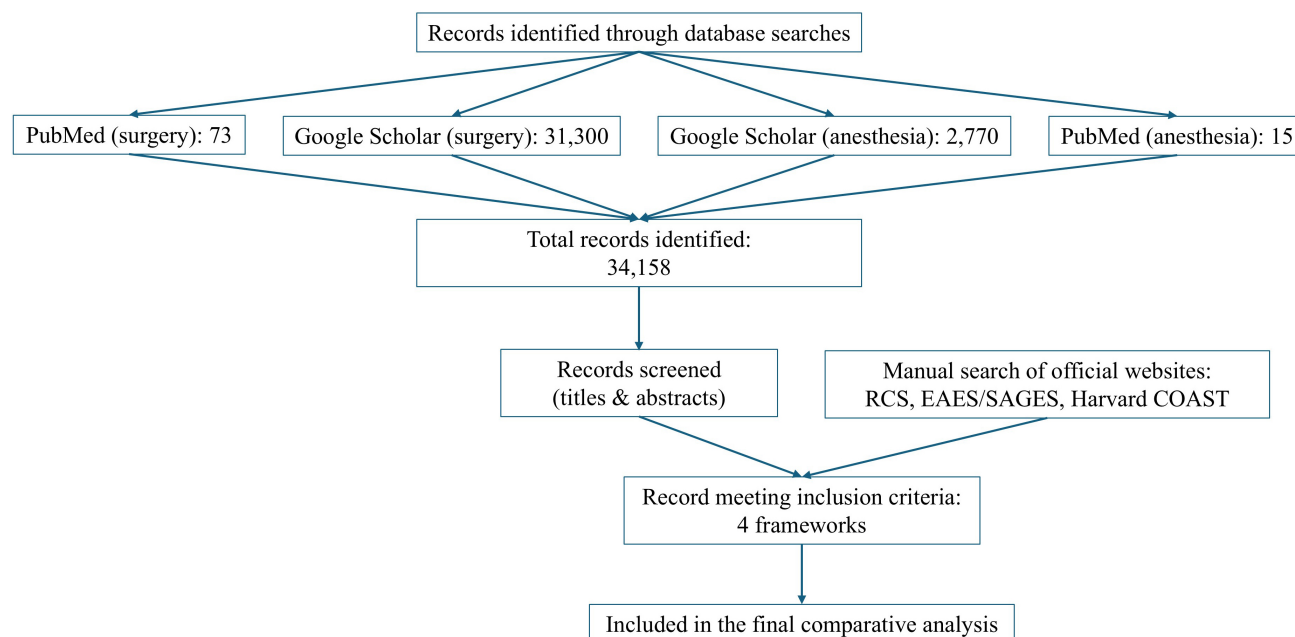


Fig. 2. Flowchart showing the identification and selection process for sustainability frameworks based on database searches and manual website review. RCS, Royal College of Surgeons; EAES, the European Association for Endoscopic Surgery; SAGES, the Society of American Gastrointestinal and Endoscopic Surgeons; COAST, Climate in Obstetrics, Anaesthesia and Surgery Team.

The following keywords were used on PubMed and Google Scholar: (“anaesthesia”) AND (“sustainability” OR “environmentally sustainable”) AND (“guidelines” OR “checklist” OR “framework” OR “consensus”) AND (“environment” OR “climate change” OR “carbon footprint”); or (“surgery” OR “surgical practice”) AND (“sustainability” OR “environmentally sustainable”) AND (“guidelines” OR “checklist” OR “framework” OR “consensus”) AND (“environment” OR “climate change” OR “carbon footprint”). Professional societies with a demonstrated interest in sustainability were identified through the literature search. Their official websites were reviewed to determine whether they had issued any guidelines, checklists, or frameworks related to environmentally sustainable surgical or anaesthetic practice.

Inclusion criteria were: (1) documents published in English; (2) issued or endorsed by recognised professional societies, academic institutions, or international healthcare bodies; and (3) containing structured guidance, recommendations, checklists, or frameworks aimed at improving environmental sustainability in the OR or surgical/anaesthetic care.

Exclusion criteria included: (1) documents unrelated to surgical or anaesthetic practice; (2) publications without actionable or implementation-oriented content (e.g., purely theoretical discussions or opinion editorials); and (3) materials focused solely on general hospital sustainability without a surgical component.

Recognizing the heterogeneity of the included sources (guidelines, checklists, toolkits, and consensus statements), a formal quality scoring system such as Grading Rec-

ommendations Assessment, Development and Evaluation (GRADE) or A Measurement Tool to Assess Systematic Reviews (AMSTAR) was not applied since they are not well suited to this type of material.

Data were extracted from each included framework or publication using a structured template designed to capture key characteristics, including developer or originating institution, publication type (e.g., checklist, consensus statement), primary focus areas, intended audience, scope of implementation, and any available evidence of impact or uptake. These characteristics were then used for a comparative summary table and thematic evaluation matrix to enable critical analysis across five dimensions: feasibility of implementation, empirical evidence, scalability, LMIC adaptability, and cross-disciplinary integration.

These criteria were chosen inductively, drawing from recurring themes in the frameworks themselves. Each framework was assessed across these dimensions through a qualitative synthesis of published materials and available documentation. Ratings represent the authors’ interpretive judgment, based on content analysis, and are intended to guide future empirical validation.

Results

The search across PubMed and Google Scholar yielded a total of 34,158 records. Despite this volume, only one relevant document met criteria as a formal international consensus statement on sustainable anaesthetic practice. To complement the database search, a manual review of the official websites of the Harvard Climate in Obstetrics, Anaesthesia

Table 1. Comparison of the different surgical sustainability frameworks.

Sustainability Framework	RCS Green Theatre Checklist	EAES/SAGES Taskforce	Harvard COAST Re-sources	WFSA Consensus Statement
Developer/Origin	Royal College of Surgeons of England (with Edinburgh & Glasgow)	EAES and SAGES	Harvard Medical School (PGSSC/COAST)	World Federation of Societies of Anaesthesiologists
Main Focus	Practical sustainability measures in the OR	Strategic leadership and global advocacy	Equity-focused sustainability in surgery	Sustainable anaesthetic practice
Target Audience	Surgical teams (all members)	Surgeons, societies, policymakers	Clinicians, trainees, hospital leadership	Anaesthesia providers and institutions
Structure	Checklist (15 items across 4 domains)	Mission-based framework (4 pillars)	Visual toolkits & educational posters	Consensus-based statement (7 principles)
Core Domains/Themes	Anaesthesia, preparation, intraoperative equipment, postoperative practices	Education, research, leadership, collaboration	Anaesthetic gases, waste, instruments, OR teams, advocacy	Minimise impact, education, research, equipment, leadership, collaboration
Implementation Level	Hospital/Department-level	International/Organisational-level	Clinical/Operational-level	Institutional/Professional-level
Geographic Scope	UK (with international applicability)	Global	Global (with LMIC emphasis)	Global
Promotes Education	Yes	Yes	Yes	Yes
Supports Research	Not directly	Yes	Yes	Yes
Policy/Leadership Focus	Moderate	High	Moderate	High

Legend: RCS, Royal College of Surgeons; EAES, the European Association for Endoscopic Surgery; SAGES, the Society of American Gastrointestinal and Endoscopic Surgeons; UK, United Kingdom; OR, Operative room; COAST, Climate in Obstetrics, Anaesthesia and Surgery Team; PGSSC, Program in Global Surgery and Social Change; WFSA, World Federation of Societies of Anaesthesiologists; LMIC, low- and middle- income countries.

and Surgery Team (COAST) Group, the Royal College of Surgeons (RCS), and the European Association for Endoscopic Surgery (EAES)/the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) joint taskforce was also conducted, as these organizations had been identified through the literature as leaders in sustainability initiatives. This triangulated approach led to the identification of four major international frameworks that were eligible for detailed comparative analysis (Fig. 2).

A descriptive comparison of the four selected sustainability frameworks across key structural and contextual features is provided by Table 1. These include their origin, primary focus areas, target audience, and implementation level. Categories were selected to distinguish structural characteristics (e.g., structure, developer, scope) from user orientation and implementation level. Efforts were made to minimize semantic overlap by separating intended audience from the system level of application.

The RCS Green Theatre Checklist is distinguished by its practical, hospital-level orientation and emphasis on OR behaviours. In contrast, the EAES/SAGES Taskforce focuses on global advocacy and high-level strategic leadership. The Harvard COAST resources take an equity-driven, operational approach, offering visual and educational tools

designed for both high income country (HIC) and LMIC settings. Finally, the World Federation of Societies of Anaesthesiologists (WFSA) Consensus Statement provides anaesthesia-specific sustainability principles with a strong global scope but less direct applicability to surgical workflow.

The Green Theatre Checklist: A Tool for Surgical Sustainability

One of the most comprehensive and actionable frameworks currently available for improving environmental sustainability in the OR is the Intercollegiate Green Theatre Checklist, developed collaboratively by the RCS of England, the RCS of Edinburgh, and the Royal College of Physicians and Surgeons of Glasgow [7]. Published in 2023, the checklist is grounded in evidence-based recommendations and is designed to be broadly applicable across institutions while allowing for local adaptation depending on available infrastructure and resources.

The checklist is structured into four key domains, encompassing the entire perioperative pathway: Anaesthesia, Preparing for Surgery, Intraoperative Equipment, and After the Operation. It includes a total of 15 recommendations, each intended to reduce waste, lower carbon emissions, and

promote resource efficiency without compromising patient safety or care quality.

Anaesthesia

The checklist recommends prioritising local or regional anaesthesia where appropriate, minimising the need for inhalational agents and allowing for targeted oxygen delivery only when necessary. When general anaesthesia is required, Total Intravenous Anaesthesia (TIVA) should be used where feasible, preferably with high fresh gas flows (5–6 L/min) and low oxygen concentrations to reduce oxygen waste. The use of nitrous oxide (N₂O), a potent greenhouse gas, should be limited to specific clinical cases. Facilities are advised to inspect piped N₂O systems for leaks and consider switching to cylinder-based supply or decommissioning them altogether. If inhalational anaesthesia is unavoidable, agents with lower global warming potential (such as sevoflurane) should be selected over isoflurane or desflurane. Removing desflurane from formularies and employing volatile gas capture technologies are also encouraged. Additionally, teams should switch to reusable anaesthetic equipment, such as laryngoscopes and warming devices, and minimize drug waste. The checklist advises minimising opened supplies and packaging, suggesting to only open items when necessary.

Preparing for Surgery

Prior to surgery, the checklist emphasizes the use of reusable textiles, including hats, sterile gowns, drapes, and trolley covers, in place of single-use items. To reduce water and energy consumption during surgical scrubbing, alcohol-based hand rubs should be used after the first scrub of the day, and automatic or pedal-operated taps should be installed to avoid unnecessary water use. The checklist also advises avoiding unnecessary preoperative interventions that do not contribute meaningfully to patient outcomes, such as prophylactic antibiotics, catheterization, or histological examinations, unless clinically indicated.

Intraoperative Equipment

During the operation, surgical teams are encouraged to critically review and rationalise the use of instruments and disposable items. This includes tailoring surgeon preference lists to distinguish between essential and optional instruments, minimizing the opening of full sets unless needed, and consolidating instrument trays where possible. The use of single-use surgical packs should be assessed to identify components that can be replaced with reusable alternatives, and suppliers should be engaged to reduce surplus. The checklist also stresses avoiding unnecessary equipment such as excess swabs and gloves, again reinforcing the principle of only open items when necessary. Reuse of remanufactured or reprocessed equipment (e.g., diathermy handles, light cords, and certain surgical tools) should be prioritised when clinically safe. Where single-use is necessary,

switching to lower carbon alternatives, such as sutures instead of clips, is recommended.

After the Operation

In this phase, waste management is a key area of focus. The checklist recommends correct segregation of waste streams; recycling packaging and materials where possible, using non-infectious offensive waste streams (e.g., yellow or black bags) when there is no infection risk, and ensuring that sharp and pharmaceutical waste is disposed of safely. Battery and metal waste collections should be arranged regularly. Equipment maintenance is also essential: damaged but reusable items should be repaired rather than replaced, and ongoing preventive maintenance should be encouraged. Finally, when ORs are not in use, staff should turn off lights, computers, ventilation systems, and temperature control to reduce unnecessary energy consumption.

The Green Theatre Checklist is not intended to serve as a certification tool but as a practical, repeatable framework for promoting sustainable surgical practices. Its strength lies in its applicability across disciplines and roles within the surgical team, fostering multidisciplinary collaboration, regular audit cycles, and ongoing quality improvement. Moreover, its flexible structure allows local teams to identify specific actions that align with their institutional capabilities and priorities.

A Critical View of the RCS Green Checklist

The RCS Green Checklist is a comprehensive guide to sustainable practices in surgery, offering numerous strengths while also presenting some limitations. One of its key merits is that it is grounded in a robust compendium of peer-reviewed evidence, guidelines, and policies, ensuring its recommendations are scientifically valid and applicable across a wide range of surgical settings. Additionally, the checklist is structured to support practical implementation by categorising actions into those that can be executed immediately and those requiring longer-term planning thereby enabling both quick wins and strategic progress. A notable strength is the multidisciplinary collaboration involved in its development, which enhances its credibility and promotes broader adoption. Furthermore, the checklist aligns with national sustainability goals, directly supporting the National Health Service (NHS)'s ambition to achieve net-zero carbon emissions by 2045.

Conversely, the checklist is not without its challenges. Some of its recommendations may be difficult to implement in resource limited environments, potentially restricting widespread uptake. As sustainability practices and technologies evolve, the checklist will also require regular updates to maintain relevance and effectiveness. Lastly, while it offers a strong framework, there is a pressing need for measurable metrics to evaluate the actual environmental impact reductions resulting from its implementation.

EAES/SAGES Taskforce: Leadership for Global Surgical Sustainability

The joint Sustainability in Surgical Practice Taskforce established by the EAES and SAGES represents a collaborative, international effort to advance environmental sustainability within surgical practice [14]. The taskforce aims not only to raise awareness but also to lead systemic change through structured, multidisciplinary strategies.

The taskforce's core vision is to support surgeons in improving the environmental sustainability of their practice through practical, evidence-based actions in four key areas:

- Education: recognizing that a fundamental step toward sustainable transformation is building awareness and understanding among surgeons, perioperative teams, and healthcare professionals. By developing and disseminating educational content, including online resources, webinars, and congress sessions, the taskforce aims to support a continuous learning process centred on the environmental impact of surgical care.
- Research: through it, the taskforce seeks to evaluate the clinical, environmental, and economic impact of sustainable surgical initiatives. It is actively working to establish the infrastructure for collaborative, multicentre studies, thereby promoting data-driven policy and practice changes. This includes assessing how specific interventions such as waste reduction, reusable instrumentation, or low-carbon surgical techniques, affect both clinical outcomes and healthcare costs.
- Leading Change: the taskforce aims to define and disseminate best practices, frameworks, and actionable guidelines to reduce the carbon footprint of surgery. These recommendations include reducing unnecessary energy use, minimising reliance on single-use products, and promoting sustainable procurement and waste disposal methods. By offering a unified and expert-driven approach, the taskforce provides institutional and individual surgical teams with practical tools to initiate change.
- Collaboration: it actively promotes partnerships between surgical societies, healthcare institutions, and international stakeholders. These efforts aim to encourage global engagement, harmonise sustainability standards, and spread successful initiatives across countries and healthcare systems.

Unlike tools such as the RCS Green Theatre Checklist, which are primarily local and operational, the EAES/SAGES Taskforce focuses on macro-level policy development, strategic alignment, and systemic transformation. By convening thought leaders, researchers, and practitioners around a unified objective, the taskforce establishes both the strategic framework and the impetus necessary to integrate sustainability into the global future of surgical practice.

A Critical View of the EAES/SAGES Sustainability in Surgical Practice Task Force

The initial work of the task force is presented in the Findings from the SAGES-EAES Sustainability in Surgical Practice Survey [15]. The study addresses the pressing issue of environmental sustainability in surgery, aligning with global efforts to reduce healthcare's carbon footprint.

It features a robust sample size, with over a thousand respondents, providing a substantial dataset for analysis and enhancing the reliability of its findings. The survey has a comprehensive scope, exploring multiple dimensions including surgeons' attitudes, knowledge of carbon footprints, concerns about sustainable interventions, willingness to change practices, and preferred educational methods.

Notably, it produced insightful findings: 63% of surgeons reported being motivated to improve sustainability, while fewer than 10% could accurately estimate the carbon footprint of surgical activities. Furthermore, most respondents were open to adopting sustainable practices, with online webinars and modules being the preferred modes of education. These findings can help spark meaningful future research and guide educational initiatives.

Conversely, the study had limited geographical representation, with the majority of respondents based in North America and Europe. This may restrict the generalisability of the results to regions with differing healthcare infrastructures and cultural attitudes toward sustainability. Additionally, it is important to note that the survey provides only a cross-sectional snapshot, without assessing longitudinal changes or the long-term impact of educational interventions on sustainable practices.

Harvard COAST Group: Bridging Sustainability and Global Equity

The Climate in Obstetrics, Anaesthesia and Surgery Team (COAST), part of the Program in Global Surgery and Social Change (PGSSC) at Harvard Medical School, provides an actionable, equity-focused framework for implementing surgical sustainability globally [16]. Their resources, structured under the "Climate Change & Surgery Hot Topics" series, focus on practical, easily implementable interventions applicable across both high-resource and low-resource settings. Through visually accessible toolkits, COAST targets clinical, behavioural, and system-level changes.

One major focus area is the reduction of anaesthetic gas emissions, noting that anaesthesia contributes to over half of the carbon footprint in the OR. COAST encourages the use of low-flow techniques, TIVA, and alternatives to desflurane and N₂O. Additionally, it promotes implementing system-based solutions (such as gas capture technology) and behavioural interventions (such as pausing before gas release) to minimise waste and emissions.

COAST also emphasises the implementation of the OR Green Teams, recommending a stepwise approach: iden-

tifying and recruiting a diverse, manageable team; engaging hospital leadership; defining sustainability goals; and ensuring transparent communication. These teams are presented not only as environmental stewards but also as potential sources of significant cost savings, with green programs shown to save up to \$56,000 per OR annually.

In terms of hospital operations, COAST highlights opportunities for local advocacy, outlining specific actions at the individual, departmental, institutional, and policy levels. These include encouraging sustainable commuting, optimizing hospital energy use, reducing packaging waste, and pushing for climate-conscious procurement policies. Clinicians are also encouraged to use their influence to drive policy changes and participate in sustainability committees. To address waste management, COAST dedicates a resource to reducing misuse of red bags, which are designated for regulated medical waste (RMW) and are significantly more expensive and environmentally damaging to dispose of. The toolkit encourages clinicians to critically assess waste classification, educate staff, and revise signage and color-coded bins to avoid overuse of RMW bags.

Another resource promotes streamlining surgical instrument use, as ORs are among the highest hospital energy consumers. COAST recommends conducting inventory checks, adopting standardized sets, reprocessing where possible, and integrating sustainability into surgical education. This not only reduces sterilisation load but also enhances operational efficiency.

In response to the widespread use of single-use items, COAST provides a roadmap for reprocessing Single Use Devices (SUDs). Hospitals are guided to identify high-volume items for reprocessing (e.g., trocars, vessel sealing devices), define goals, engage stakeholders, and draft appropriate hospital policies. Cost savings and reduced environmental burden are emphasised, alongside third-party reprocessing partnerships.

Lastly, the COAST group advocates for adopting reusable surgical gowns, offering a balanced evaluation of sustainability, barrier effectiveness, cost, and clinical usability. The resource outlines barriers (such as upfront cost and laundering logistics) but provides evidence-based arguments in favour of reusable options, showing lower carbon footprints, reduced RMW generation, and substantial financial benefits in the long term.

Collectively, these resources underscore COAST's commitment to environmentally sustainable, resource-efficient, and globally adaptable surgical practices, with a strong emphasis on equity, implementation feasibility, and education. Their toolkits serve as a bridge between policy and practice, providing frontline surgical teams with step-by-step strategies to embed sustainability into routine care.

Critical View of the Harvard COAST Group: Bridging Sustainability and Global Equity

Their approach is evidence-based and practical, with each guide grounded in peer-reviewed literature and providing step-by-step instructions for implementing sustainable practices. Topics covered include improving operating room Heating, Ventilation and Air Conditioning (HVAC) efficiency, reducing anesthetic gas emissions, and adopting reusable surgical gowns. The guides are designed to be user-friendly, featuring interactive elements such as embedded hyperlinks and quick-response (QR) codes that direct users to additional resources, thereby facilitating ease of access and implementation.

Moreover, the initiative addresses a broad range of sustainability topics—from energy consumption and waste reduction to advocacy and research—allowing healthcare providers to engage with multiple aspects of environmental sustainability. Importantly, COAST takes a global perspective, emphasising the significance of sustainable surgical practices worldwide and acknowledging the diverse challenges faced by healthcare systems in different regions.

On the other hand, the initiative shares some limitations common to similar projects. Implementing certain recommendations may be difficult in low-resource settings due to financial, infrastructural, or logistical constraints. Additionally, the lack of standardised impact metrics remains a concern, as it makes it difficult to measure the real-world effectiveness of these interventions. As with other sustainability initiatives, there is also a need for regular updates to ensure the content remains current in the face of evolving practices and technologies.

WFSA Global Consensus: Sustainability in Anaesthesia

In response to the growing climate emergency and the measurable contribution of anaesthesia to healthcare-related greenhouse gas emissions, the WFSA convened an international working group to develop the first global consensus statement on environmentally sustainable anaesthesia [17]. Published in 2022, the statement emerged from a rigorous three-stage Delphi consensus process, engaging 45 anaesthesia providers from across six continents. The initiative reflects an urgent call for internationally coordinated action and sets forth seven guiding principles for embedding sustainability into anaesthetic practice, with applicability across HICs and LMICs. The consensus is underpinned by three core assumptions:

- Patient safety must never be compromised by sustainability goals.
- Countries must support each other equitably, especially in building sustainable anaesthesia capacity in LMICs.
- Healthcare systems must be mandated, not merely encouraged, to reduce their environmental impact.

These pillars provide the ethical foundation upon which the following seven principles were developed:

Minimise the Environmental Impact of Clinical Practice

Anaesthesia providers are urged to lead by example in sustainability, both within their own practice and through institutional roles. They should participate in multidisciplinary sustainability teams, serve as department leads for environmental initiatives, and advocate publicly for sustainable healthcare. This leadership role includes measuring and actively reducing waste in medications, single-use equipment, and energy use. Given that anaesthesia practice contributes significantly to healthcare emissions, especially through waste gases and supply chains, anaesthesia professionals must become agents of change in this domain.

Use Environmentally Preferable Medications and Equipment

The choice of anaesthetic agents has major implications for climate impact. Desflurane and N₂O, for example, have global warming potentials (100 year) (GWP100) far exceeding those of sevoflurane and isoflurane [18,19]. Providers are encouraged to preferentially use agents with lower environmental impact, employ low-flow anaesthesia techniques, and regularly check N₂O delivery systems for leaks. Where possible, inhalational anaesthesia should be replaced with regional or TIVA, which are generally associated with significantly lower emissions [20]. Waste gas capture and destruction technologies should be implemented to reduce atmospheric pollution.

Minimise Waste and Overuse of Resources

The consensus emphasises applying the 5R framework—Reduce, Reuse, Recycle, Rethink, Research—to all aspects of anaesthesia. Overuse of medications, unnecessary inclusion of items in equipment packs, and inefficient energy and water use are major contributors to environmental harm. Reformulating theatre packs, using reusable rather than disposable equipment where safe, and designing low-waste cleaning and sterilisation systems are recommended. The Working Group highlights that reducing and reusing have a far greater impact than recycling alone, which remains underutilised in most OR.

Integrate Environmental Sustainability Into Anaesthesia Education

To ensure long-term change, sustainability principles must be incorporated into undergraduate curricula, postgraduate training, and continuing professional development. Despite growing interest, many experienced practitioners still lack formal education in sustainability, creating a barrier for effective teaching. The Working Group calls for sustainability to be embedded into certification, appraisal, and ongoing training pathways. Some societies, such as the Association of Anaesthetists in the United Kingdom (UK), have already begun offering fellowships and courses in this field, which serve as models for global adoption.

Embed Sustainability Into Research and Quality Improvement

The integration of environmental metrics into anaesthesia research and quality improvement (QI) programs is a priority. Projects should assess the financial, clinical, and environmental impact of interventions to align with the triple bottom line of sustainability. The consensus advocates for professional organisations, journals, and conference platforms to actively support and disseminate sustainability-focused research. Moreover, hospital-level QI initiatives should include measurable targets for reducing carbon emissions and resource use related to anaesthesia.

Lead Organisational Sustainability Efforts

Anaesthesia departments are positioned to influence hospital policy, infrastructure, and culture. Providers should contribute to the sustainable OR design, recommend “shut-down protocols” to reduce energy use, and participate in institutional decision-making around energy, procurement, and waste. Hospitals must create systems and metrics that enable the tracking and reduction of anaesthesia-related emissions. Strategic planning for new facilities and refurbishments offers critical opportunities to embed sustainability into the structural fabric of healthcare delivery.

Collaborate With Industry for Sustainable Innovation

Finally, the consensus highlights the importance of engaging with industry stakeholders to improve the sustainability profile of anaesthesia drugs, devices, and packaging. Providers should advocate for open access to environmental data from manufacturers and push for “green procurement” practices, including life-cycle assessments and total cost of ownership evaluations. A suggested “traffic-light system” for labelling the environmental impact of products could empower providers to make informed, sustainability-conscious purchasing decisions.

The WFSA consensus [17] is both a practical and visionary framework, offering guidance that is not only grounded in expert opinion but also informed by an inclusive, international process. Its adoption marks a critical step toward aligning anaesthesia with broader healthcare decarbonisation goals. While challenges in implementation remain—particularly in LMICs where infrastructure and regulation vary—the consensus offers adaptable principles that can catalyse change globally.

Critical View of the WFSA Global Consensus Statement on Environmentally Sustainable Anaesthesia

It represents a significant international effort to address the environmental impact of anaesthetic practices. Published in the journal *Anaesthesia* in 2022, this consensus outlines seven core principles aimed at guiding anaesthesia providers worldwide towards more sustainable practices. One of its greatest strengths is its global representation and inclusivity. The consensus was developed through a mod-

Table 2. Qualitative comparison of the four selected frameworks based on key dimensions derived from the literature and implementation considerations.

Framework	Feasibility of Implementation	Empirical Evidence	Scalability	LMIC Adaptability	Cross-disciplinary Integration
RCS Green Theatre Checklist	High in HICs	Low–Moderate (one UK audit study)	Moderate	Limited (infrastructure-dependent)	High (whole OR team)
EAES/SAGES Taskforce	Moderate	Moderate (4 early publications)	High (strategic and international)	Moderate–High	Moderate (surgical leadership)
Harvard COAST Resources	High	Moderate–High (multiple peer-reviewed studies)	Moderate	High (equity-focused, LMIC-relevant)	High (multidisciplinary focus)
WFSA Consensus Statement	Variable (depends on system resources)	Low (consensus, not implementation data)	High	Variable	Limited (anaesthesia-focused)

Legend: HICs, high income countries.

ified Delphi process involving 45 anaesthesia professionals from diverse regions, ensuring the recommendations are globally relevant and sensitive to varying resource settings. Moreover, it proposes comprehensive and actionable principles. The seven principles cover a wide spectrum of sustainability considerations, including clinical practice, education, research, and collaboration with industry. This holistic approach allows for integration into multiple facets of anaesthetic care.

The WFSA also places strong emphasis on equity and patient safety, with the statement underscoring that sustainability efforts must not compromise patient care. It advocates for equitable support across HICs and LMICs, promoting global solidarity in environmental stewardship. By addressing the environmental impact of anaesthesia, the consensus aligns with broader global health initiatives aimed at reducing healthcare-related carbon emissions and contributes to international climate goals.

However, there are notable limitations. There is a lack of specific implementation strategies, as the consensus does not provide detailed guidance on how to apply the principles in practice. This may pose challenges for clinicians trying to operationalise the recommendations across varied healthcare contexts.

As with similar initiatives, there is an absence of monitoring and evaluation metrics. The document does not outline specific indicators to assess the effectiveness of sustainability measures, making it difficult to track progress and outcomes.

The issue of potential resource constraints also arises, particularly in low-resource settings where financial, infrastructural, or logistical limitations may hinder adoption.

Finally, there is a clear need for regular updates, as sustainability practices and technologies are continually evolving. Keeping the framework current will be essential to its continued relevance and effectiveness.

Comparison of the Four Frameworks

To complement the descriptive comparison of the selected sustainability frameworks, a thematic evaluation matrix was developed to facilitate structured comparison across five key dimensions: feasibility of implementation, availability of supporting evidence, scalability, adaptability to LMICs, and cross-disciplinary integration (Table 2). Thematic ratings are based on interpretive synthesis, informed by available peer-reviewed publications, framework documentation, and the intended use cases described by each source. Where applicable, ratings are supported by references. Quantitative implementation data (e.g., adoption rates, emission reductions) are not yet consistently available for most frameworks, limiting the ability to include uniform scoring metrics.

The RCS Green Theatre Checklist demonstrated high feasibility in HICs and strong integration across OR team members, but more limited adaptability to LMICs due to infrastructure requirements. To date, its application has been documented in only one peer-reviewed study, which evaluated its use in UK OR and highlighted variability in implementation and staff engagement across different sites [11].

The Harvard COAST Group's sustainability framework stands out for its integration of clinical guidance, advocacy, and implementation tools specifically designed for global use. The COAST initiative is supported by a growing body of peer-reviewed literature. This includes global calls to integrate climate action into surgical system strengthening [2], educational strategies to empower OR teams in adopting environmentally conscious practices [21], and innovative models such as e-liability accounting to track surgical emissions [22]. These publications reflect the group's interdisciplinary and equity-driven approach, particularly in LMIC contexts, and provide early evidence supporting the feasibility and relevance of the framework in real-world settings.

The EAES/SAGES Taskforce provided high scalability through international strategy, though practical implementation data remain limited. The EAES/SAGES joint sustainability initiative has yielded four key publications. These include a comprehensive scoping review that establishes standard terminology and outcome measures to define the environmental footprint of surgical practices [9]; a global survey assessed surgeons' attitudes toward sustainability, revealing a strong willingness to adopt environmentally friendly practices despite limited knowledge of the carbon footprint associated with surgical procedures [15]; a collaborative call to action outlines strategic priorities for promoting sustainability in surgical practice [13]; and a commentary emphasizes the urgency of integrating sustainable practices into surgery to meet global climate goals [23]. While these publications provide a foundational framework and highlight the commitment of surgical societies to environmental sustainability, further research is needed to evaluate the practical implementation and effectiveness of these initiatives across diverse healthcare settings.

Lastly, the WFSA Consensus Statement offered strong alignment with global anaesthesia leadership but showed variable feasibility depending on system support. Overall, the matrix highlights the contextual strengths and limitations of each framework, offering insights to guide selection and adaptation based on setting-specific priorities.

Discussion

The findings of this narrative review highlight the growing recognition of the OR as a critical target for environmental sustainability within healthcare systems. The four frameworks explored—the Intercollegiate Green Theatre Checklist [7], the EAES/SAGES Taskforce [14], the Harvard COAST Group [16], and the WFSA global consensus on sustainable anaesthesia [17]—offer complementary yet distinct approaches to decarbonising surgical practice. Collectively, they provide a multifaceted roadmap for reducing the environmental impact of surgery through evidence-based, scalable, and multidisciplinary interventions.

Sustainability interventions in surgical settings can be categorised into key domains: reducing material use, transitioning to reusable equipment, implementing recycling programs, adopting lower-emission anaesthetic alternatives, and other context-specific strategies [9,11,24]. While there is strong evidence supporting the effectiveness and safety of reusable equipment, there is still a critical gap in data regarding the carbon equivalent (CO₂e) and cost impact of many other interventions, an area that warrants further investigation [24].

The joint review conducted by the SAGES-EAES task force reinforces the importance of integrating sustainability into surgical care, particularly within the OR [9]. The review echoes key strategic pillars, including the reduction of material waste, adoption of reusable instruments, recycling,

and anaesthetic material optimisation. Among these, the adoption of reusable instruments and structured recycling protocols emerged as particularly promising in reducing both greenhouse gas emissions and operational costs, aligning closely with the direction and objectives of our study.

One of the key strengths emerging from these four initiatives is their emphasis on practicality. The Intercollegiate Green Theatre Checklist [7], for instance, translates sustainability principles into specific perioperative actions, such as rationalizing instrument trays, minimising the use of high-emission anaesthetic gases, and encouraging the adoption of reusable textiles. These recommendations are not only practically applicable but also adaptable across institutions with varying levels of resources. Importantly, the checklist promotes iterative quality improvement and multidisciplinary collaboration—two essential elements for embedding sustainability into routine surgical care.

In contrast, the EAES/SAGES Taskforce adopts a broader systems-level approach, focusing on leadership, education, research, and policy engagement [14]. While less operational in nature, this initiative fills a crucial gap by offering strategic guidance and facilitating international collaboration. Its emphasis on harmonizing standards, promoting data-driven decision-making, and fostering academic inquiry is essential for long-term systemic change.

While this initiative focuses on policy and leadership, the Harvard COAST framework offers a more operational, equity-driven model. It contributes a unique perspective by integrating sustainability with global equity [16]. Their toolkits are particularly relevant for LMICs, where resource constraints may limit the feasibility of high-tech interventions. By providing low-barrier, cost-saving strategies—such as reducing biocontaminated waste, forming OR green teams, and implementing reprocessing programs—COAST bridges the gap between policy and practice, and empowers frontline teams to initiate change even in challenging contexts.

In contrast to the multidisciplinary focus of COAST, the WFSA statement concentrates specifically on anaesthetic practice [17]. As anaesthetic gases represent a major contributor to OR emissions, this global consensus underscores the urgent need to transition to low-emission alternatives, invest in gas capture technologies, and reform educational and research agendas. Moreover, the WFSA's emphasis on equitable implementation and ethical responsibility highlights that sustainability must not come at the expense of patient safety or access to care, particularly in LMICs.

Across the four frameworks, sustainability principles broadly align with the 5R model—Reduce, Reuse, Recycle, Rethink, and Research—even when not explicitly named as such. The RCS Green Theatre Checklist operationalises Reduce through minimising unnecessary equipment and consumables, Reuse via promotion of reusable textiles and instruments, and Recycle by advocating proper waste segregation and recycling protocols. Its recommendations also

reflect Rethink, encouraging teams to reassess standard practices (e.g., hand scrubbing, kit preparation), although formal research integration is limited. The EAES/SAGES Taskforce, with its focus on strategic leadership and system-level transformation, engages primarily with Research—calling for multicentre studies on environmental impact—and Rethink, through educational campaigns that shift surgical culture. The Harvard COAST Group reflects all five dimensions, particularly Reduce (low-emission anaesthesia, waste minimisation), Reuse (promotion of reprocessed SUDs and gowns), and Rethink (formation of OR Green Teams and behavioural nudges). Their toolkits actively promote Research and Recycle, with dedicated resources on red bag overuse and waste stream optimisation. The WFSA Consensus Statement most explicitly invokes the 5R model, advocating Reduce and Reuse in anaesthetic agents and equipment, Recycle through improved pack design, Rethink via clinician leadership in sustainability, and Research by embedding environmental metrics into quality improvement and academic agendas. Together, these frameworks demonstrate varying but complementary approaches to implementing the principles of sustainable surgical and anaesthetic practice.

An important distinction among the frameworks is the degree to which they foster cross-disciplinary collaboration. The WFSA Consensus Statement is predominantly anaesthesia-focused and does not directly address surgical workflow or OR-wide processes. Conversely, the RCS Green Theatre Checklist was explicitly designed for use by multidisciplinary OR teams and encourages shared responsibility across surgical, anaesthetic, and nursing staff. The Harvard COAST framework adopts a similarly integrated approach, promoting joint initiatives such as Green Teams that include surgical and anaesthetic personnel, nurses and administrators. In contrast, the EAES/SAGES Taskforce primarily targets surgical leadership, with less emphasis on interdisciplinary coordination, although its advocacy and policy strategies have the potential to influence perioperative systems more broadly. Strengthening cross-disciplinary engagement remains essential for the effective implementation of sustainable practices in the OR.

Furthermore, most frameworks offer limited quantitative data on emissions reduction, waste metrics, or life-cycle analyses. For example, the RCS Green Theatre Checklist has only been evaluated in a single UK audit without CO₂e data. The Harvard COAST group reports potential cost savings of up to \$56,000 per OR annually through green practices, but direct emissions data remain scarce. Overall, the absence of standardised life-cycle assessments or validated metrics limits the ability to compare effectiveness across frameworks. Among the four frameworks, the Harvard COAST initiative provides the most substantial peer-reviewed support, with multiple publications addressing implementation strategies and cost implications. However, none of the frameworks currently re-

port longitudinal outcomes or emissions reduction validated through independent audits or life-cycle analyses. The EAES/SAGES and WFSA frameworks represent strategic and professional consensus efforts, but their implementation impact remains largely untested. These gaps underscore the need for outcome-based research and standardised reporting of environmental indicators.

While none of the frameworks is tailored to specific surgical specialties, their general recommendations can be adapted to both elective and emergency settings, though applicability may vary depending on procedure complexity and resource availability.

Despite their strengths, the implementation of these frameworks is not without challenges. Barriers such as insufficient carbon literacy, limited institutional support, resistance to behavioural change, and inconsistent procurement policies continue to delay widespread adoption. The reviewed literature emphasises the need for sustainability supporters within clinical teams and the importance of clear, context-sensitive metrics to measure progress. Moreover, while many interventions demonstrate potential for cost savings and environmental benefits, high-quality evidence linking these changes to clinical outcomes and long-term emissions reduction is still limited. Although each framework provides structured guidance, their limitations must be critically examined. The RCS Green Theatre Checklist, for example, demonstrates strong feasibility in HICs due to its clear, actionable recommendations; however, its dependence on reusable infrastructure, sterilisation capabilities, and institutional engagement limits its transferability to low-resource settings. In contrast, the Harvard COAST framework was specifically designed with global equity and LMIC adaptability in mind, offering low-barrier toolkits and behaviourally focused strategies. Nonetheless, the framework's effectiveness remains largely inferred from descriptive accounts, with limited formal evaluation to date. The EAES/SAGES Taskforce offers high-level strategic leadership and has contributed meaningfully to standard-setting; however, it remains in the early phases of implementation and lacks robust empirical data on real-world uptake or outcomes. Similarly, the WFSA Consensus Statement provides an important foundation for advancing environmentally sustainable anaesthesia, yet its principles are based on expert agreement rather than longitudinal data, and practical guidance on implementation remains limited. Furthermore, while these initiatives collectively emphasise the potential for environmental and economic benefits, the current literature lacks high-quality evidence demonstrating measurable reductions in emissions, clinical outcomes, or cost-effectiveness. This absence of validated impact data presents a significant limitation and underscores the need for future research focused on implementation science, context-specific adaptation, and long-term evaluation, particularly within LMIC contexts. Moreover, since quantitative implementation data (e.g., adop-

tion rates, emission reductions) are not yet available for the frameworks, this limits the ability to include a scoring metrics.

These initiatives share a common foundation in the principles of waste minimisation (Reduce, Reuse, Recycle), which are now expanding to include Rethink and Research. This evolution reflects a deeper commitment to systems thinking and circular economy models, recognizing that sustainable surgical care requires a paradigm shift in how resources are valued and used.

This review provides a structured and comparative analysis of four major international sustainability frameworks in surgery and anaesthesia, highlighting their feasibility, equity, and relevance across diverse healthcare systems. By mapping each initiative to the 5R model and incorporating a thematic evaluation matrix, the study offers a unified lens for understanding their practical applications. Its global scope, focus on implementation barriers, and actionable recommendations for surgical teams and policymakers enhance its value as a tool to inform sustainable transformation in the OR. Nevertheless, it has several limitations inherent to the narrative synthesis approach. First, no formal quality appraisal tools (such as GRADE or AMSTAR) were applied, due to the heterogeneity and non-standardised nature of the included materials, which range from checklists to consensus statements and implementation toolkits. As such, the interpretation of feasibility, scalability, and cross-disciplinary integration was based on publicly available documentation and author consensus, rather than independently validated metrics. Furthermore, the lack of quantitative implementation data—such as adoption rates, emissions reduction, or cost-effectiveness—limits the ability to perform a comparative meta-analysis or assign standardised impact scores.

Conclusions

The reviewed frameworks offer synergistic pathways toward sustainable surgery. The OR, with its high resource intensity and relatively controlled environment, represents a prime setting for piloting and scaling decarbonisation efforts. The integration of practical toolkits, strategic leadership, and global equity considerations provides a robust platform for surgical teams worldwide to take meaningful action. Future work should focus on validating these interventions across diverse settings, fostering behavioural and cultural change, and embedding sustainability into surgical education, policy, and quality improvement programs. As healthcare systems strive to meet net-zero targets, the surgical community must continue to lead by example.

To support this transition, several actionable priorities based on the frameworks reviewed can be proposed. For surgical teams, the use of structured tools such as the RCS Green Theatre Checklist and the formation of multidisciplinary Green Teams can enable immediate changes in OR practices. Hospitals and healthcare administrators should

prioritise investment in reusable equipment, institutionalise waste segregation protocols, and incorporate sustainability targets into routine quality improvement initiatives. For policymakers and medical societies, promoting sustainability education, supporting implementation research, and developing adaptable, resource-sensitive guidelines are essential. Strengthening collaboration across surgical, anaesthetic, and administrative domains will be critical to embed sustainability as a core value in perioperative care.

Availability of Data and Materials

The data analyzed are available from the corresponding author upon reasonable request.

Author Contributions

MM and MY conceptualized the study, MM led the literature search, and drafted the initial manuscript. SF and EW analyzed data, contributed to define the methodology and the literature review, and critically revised the manuscript for important intellectual content. VQJN and MA assisted in data organization, reference management, and contributed to the writing and editing of the manuscript. MY provided senior supervision, reviewed the manuscript critically, and offered key revisions to strengthen the final version. All authors gave final approval of the version to be published. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

Not applicable.

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Conflict of Interest

Marina Yiasemidou is serving as one of the Editorial Board members of this journal. We declare that Marina Yiasemidou had no involvement in the peer review of this article and has no access to information regarding its peer review. Other authors declare no conflict of interest.

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