Review Article

Anaesthetic subspecialties and sustainable healthcare: a narrative review

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Summary

The principles of environmentally sustainable healthcare as applied to anaesthesia and peri-operative care are well documented. Associated recommendations focus on generic principles that can be applied to all areas of practice. These include reducing the use of inhalational anaesthetic agents and carbon dioxide equivalent emissions of modern peri-operative care. However, four areas of practice have specific patient, surgical and anaesthetic factors that present barriers to the implementation of some of these principles, namely: neuroanaesthesia; obstetric; paediatric; and cardiac anaesthesia. This narrative review describes these factors and synthesises the available evidence to highlight areas of sustainable practice clinicians can address today, as well as posing several unanswered questions for the future. In neuroanaesthesia, improvements can be made by undertaking awake surgery, moving towards more reusables and embracing telemedicine in quaternary services. Obstetric anaesthesia continues to present questions regarding how services can move away from nitrous oxide use or limit its release to the environment. The focus for paediatric anaesthesia is addressing the barriers to total intravenous and regional anaesthesia. For cardiac anaesthesia, a significant emphasis is determining how to focus the substantial resources required on those who will benefit from cardiac interventions, rather than universal implementation. Whilst the landscape of evidence-based sustainable practice is evolving, there remains an urgent need for further original evidence in healthcare sustainability targeting these four clinical areas.

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Introduction

We are living in the largest global health threat of the 21st century, namely the ecological crisis associated with climate change. The effects of this are felt by populations and healthcare systems around the world, and yet healthcare delivery also contributes towards climate change. The impact from the provision of modern anaesthesia has been well documented, with much focus on the emission of volatile inhalational anaesthetic agents. Reducing the use of these agents together with lifecycle assessments and strategies to reduce, reuse and recycle, form the basis of our understanding in this area (Table 1) [1, 2]. This narrative review aims to focus on special considerations for four subspecialty areas of peri-operative practice: neuroanaesthesia; obstetric; paediatric; and cardiac anaesthesia. Anaesthetic, surgical and patient factors in each of these areas of practice represent unique priority areas for the future of sustainable healthcare. This review aims to underline the implications for those working in peri-operative subspecialties as well as highlighting unanswered questions and future directions.

We aim to address four key areas for each specialty: peri-operative drugs and the choices faced for patients and healthcare professionals; the types of procedures performed and their comparative carbon footprint; the challenges presented by the populations of patients served by these specialties; and other areas of special consideration.

Methods

We conducted an electronic literature search of PubMed and Google Scholar for peer reviewed English articles published mainly after 2010. Study outcomes are discussed narratively to bring out key findings as well as highlight gaps in current understanding. The four anaesthetic subspecialities we chose have distinct patient, anaesthetic and surgical factors that influence the choices clinicians are faced with in terms of healthcare sustainability and environmental cost of the associated procedures.

Neurosurgical anaesthesia

Evidence on sustainable peri-operative strategies for neurosurgery and neuroanaesthesia is scarce. Neurophysiological monitoring, such as somatosensory and motor evoked potentials, can be most accurately undertaken by avoiding inhalational anaesthesia and nitrous oxide, making total intravenous anaesthesia (TIVA) the preferred technique for reasons other than environmental cost [3]. Some may argue that newer generation volatile agents are comparable with TIVA when outcomes such as speed of emergence and cerebral vascular physiology during elective craniotomies are analysed [4]. Nevertheless, TIVA has been established as the preferred anaesthetic technique in emergency cranial and spinal neurosurgical practice due to its superior profile for postoperative emergence, nausea and vomiting, better brain relaxation and reduced intracranial pressure, as well

Table 1 General principles of sustainable anaesthesia provision. Adapted from [1].

Strategy	Method	Why is it important?
Minimise the environmental impact of clinical practice.	Reduce the emission of waste anaesthetic gases to the atmosphere and reduce the use of medical supplies and pharmaceuticals.	Waste anaesthetic gases alone account for 3% of all health sector greenhouse gases in England, and the healthcare supply chain accounts for 70% of total healthcare emissions.
Use environmentally preferable medications, equipment, energy and water	Avoiding desflurane and nitrous oxide, instead choosing TIVA, regional anaesthesia, or low-flow sevoflurane anaesthesia.	Evidence exists that outline the variable environmental cost of anaesthetic techniques that have comparable clinical efficacy.
Incorporate environmental sustainability principles within formal anaesthesia education.	Anaesthesia training and continuing professional development now includes education on environmental sustainability.	Several worldwide societies have made statements about the importance of sustainability in anaesthetic practice.
Embed environmental sustainability principles within anaesthesia research and quality improvement programmes.	Considering the environmental impact of research and promotion of work in sustainable anaesthesia by organisations, conferences and journals.	There is an urgent need for education, funding and research to determine sustainable options and implement changes in clinical practice.
Anaesthetists as leaders of environmental sustainability activity within their healthcare organisations.	Incorporating clinicians in local workspace redesigns or builds and following established principles around workplace-based ergonomics and low-carbon practices.	The refurbishment of existing facilities and design of new spaces presents opportunities to implement principles of sustainable practice.
Collaborate with industry to improve environmental sustainability.	Clinicians should request data about the environmental sustainability of purchased drugs and equipment that should feed into purchasing decisions by departments and hospitals.	Decarbonisation of supply chains is crucial for achieving sustainable healthcare and circular economies.

TIVA, total intravenous anaesthesia.

as greater haemodynamic stability [5]. This has led indirectly to improved sustainability within practice.

Avoidance of general anaesthesia through undertaking awake neurosurgery with regional anaesthesia is only possible in a small subset of patients and requires a highly subspecialised peri-operative and surgical skillset. For example, a recent interest in awake spinal fusion surgery has re-emerged [6]. The concept of awake and day-case spinal surgery has been developed with the use of spinal and epidural anaesthesia, or combinations of the two [7]. However, this is far from becoming a routine and established service and would be practically applicable mostly to surgery amenable to neuraxial techniques (lower thoracic, lumbar, sacral). Some retrospective analyses have shown that the use of regional anaesthesia has the potential to reduce duration of hospitalisation, a time to ambulation, analgesic consumption and the incidence of certain complications [6, 8]. Despite these positive findings and the potential for environmental benefits by avoiding general anaesthesia and reduction in healthcare utilisation by shorter duration of hospital stay, 83% of surveyed surgeons would recommend general anaesthesia to their patients and only 41% believed spinal anaesthesia to be as safe as general anaesthesia [9]. When patients were surveyed about their willingness to participate in a randomised trial of spinal vs. general anaesthesia the results were somewhat contrasting; 60% stated they would take part in such a study [10]. Establishing an awake spinal surgery programme would require multi-professional support and sufficient education to both patients and healthcare providers of the potential benefits, including improved peri-operative outcomes and reduced financial and environmental costs [11].

Other considerations specific to neurosurgery include: the nature of a tertiary surgical service; waste management for neurosurgical procedures; and concerns regarding for the transmission of prion disease. Pre-operative assessment of patients scheduled for major neurosurgical interventions often takes place in a tertiary centre distant from patients' homes. Utilising telemedicine and designing pathways that enable patients to see specialists and undergo pre-operative investigations and optimisation locally can reduce patient travel and on-the-day cancellations [12]. Neurosurgery and neuro-interventional radiology have a substantially negative impact on the environment in terms of energy usage, water and waste pollution [13, 14]. A single neurosurgical case will generate 8.91 kg of waste which is the equivalent of 24.5 $kgCO_2$ on average [15]. Neuro-interventional procedures have similar waste accumulation as compared with neurosurgical procedures with approximately 8 kg of waste generated [16]. This waste mostly consists of single-use equipment and packaging which should prompt targeted discussions with manufacturers, moving to reusable equipment, better segregation of waste and disposal and encouraging opening equipment only when necessary. The relatively high wastage in neurosurgery has been driven in part by the potential risk of transmission of variant Creutzfeldt-Jakob disease by equipment after being in contact with cerebrospinal fluid or neural tissue [14]. However, the evidence of association between neurosurgery and spread of variant Creutzfeldt-Jakob disease remains unclear and controversial, therefore somewhat halting a simple switch to fully reusable equipment in the wider healthcare system.

Obstetric anaesthesia

The most important aspect of sustainable healthcare in obstetric anaesthesia relates to drug choice, especially the high use of nitrous oxide. This is a potent greenhouse gas and approximately one-third of carbon equivalent emissions from anaesthesia are from its use in maternity services [17]. Occupational exposure has been linked to long-term health impacts on healthcare workers, such as megaloblastic anaemia and pregnancy-related complications [18]. Reducing its environmental and occupational impact in maternity services is a priority.

Despite the lack of high-quality evidence of its consistent analgesic effects, nitrous oxide is the most common analgesic used in maternity services in the UK [19] and has been globally accepted in clinical practice [20]. Simply denying the option of inhalational analgesia to women in labour is unethical, especially in locations such as home-birthing and standalone midwifery units where alternative analgesia is not readily available [21].

There are several mitigating strategies available. As most nitrous oxide is lost from central piping systems before the point of use, these systems can be decommissioned [22] and replaced with portable cylinders [23]. In high-use areas such as maternity, a manifold supply may remain necessary, and optimising manifold efficiency by fixing leaks, auditing consumption and locating manifolds closer to the end user can improve efficiency [24]. Capture and cracking of exhaled nitrous oxide can reduce emissions following patient use [25]. Median ambient levels of nitrous oxide can be reduced by 71% when using a routine mouthpiece, and a facemask reduces these levels by a further 10% [25]. The environmental impact of intermittent inhalation (estimated as 18 $min.h^{-1}$ for 4 h) is around 237.33 $kgCO_2e$, which is the equivalent of driving 1400 km [26]. Reduction of this by 71% (or even 81% if adaptation of user technique is adopted) is a change all maternity units can make. However, adopting this technology has high associated financial costs and requires patient and staff education.

Other analgesic options have been studied less extensively regarding their environmental impact. Epidural analgesia and remifentanil patient-controlled analgesia provide more reliable and effective analgesia for a lower environmental cost [26]. However, these they are not available in all maternity settings, require additional monitoring, may restrict free movement during labour and have less favourable complication and adverse-effect profiles, making these options unsuitable for some patients. Increasing the rate of their use might be associated with higher financial costs, due to the need for more midwives and equipment. Methoxyflurane is gaining recognition as an inhaled analgesic with a much lower global warming potential than nitrous oxide (atmospheric lifetime of 54 days). It has become a recognised option for short-term control of acute pain but there is an associated risk of nephrotoxicity with repeated frequent use exceeding the recommended upper limit of 2-MAC-hours [27]. At the time of writing, methoxyflurane remains unlicensed for use in pregnancy [28].

Less than 10% of all caesarean deliveries in the developed world necessitate general anaesthesia [29, 30]. However, general anaesthesia in obstetrics often uses inhaled volatile agents and nitrous oxide [29–32]. The use of TIVA in obstetrics is not widespread despite being shown to be feasible in this setting [33]. This is perhaps due to concerns around safety, inconsistent access to essential equipment and the time-critical nature of some cases where a general anaesthetic is required [34].

Regional anaesthesia and analgesia with neuraxial techniques are common in the obstetric setting and this presents further opportunities to improve the environmental burden of healthcare. It is now accepted that single-use drapes and gowns are not required for the safe performance of neuraxial procedures [26]. This is already recommended as part of the `rapid sequence spinal´ [35], but some may take a precautionary principal standpoint and argue that despite a lack of evidence, more barrier measures confer a better safety profile [20]. Pre-prepared packs for neuraxial techniques frequently consist of unnecessary elements which get disposed of without being used. The principles of sustainable healthcare and opening equipment only when required should be employed in obstetric anaesthesia. Evaluating the level of sensory blockade after neuraxial anaesthesia is an essential measure to prevent intra-operative pain under regional anaesthesia [36]. Testing sensation to cold is used widely due to its ease to perform, reproduce and interpret. Many have substituted ethyl chloride with the more environmentally friendly and sustainable CoolSticks (Theophany Ltd, Christchurch, UK) and/or ice. There is a paucity of literature comparing these methods but emerging evidence suggests that CoolSticks provide sustainability advantages [37, 38].

Paediatric anaesthesia

Children and young people will bear the consequences of the climate crisis and are more likely to be informed about climate change. A recent international survey found that 84% of those aged 16–25 y (n = 10,000) were at least moderately worried about climate change, with 75% saying they found the future frightening as a result [39]. The principles of sustainable healthcare, such as lean service delivery, Getting It Right First Time (GIRFT) and considering the immediate patient and wider community, all apply equally to paediatric anaesthesia but may be more challenging to adopt. Some children's hospitals, such as Great Ormond Street Hospital for Children in London (UK) and SickKids in Toronto (Canada) have followed the lead of Newcastle upon Tyne Hospitals NHS Foundation Trust in declaring a climate emergency and committing to action by implementing green strategies in their peri-operative services [40, 41].

While regional anaesthesia as the sole anaesthetic technique can be employed in selected patients [42], it requires careful patient selection and preparation, as well as effective communication between the surgeon and anaesthetist. Regional anaesthesia is unlikely to be an appropriate sole technique for most children and procedures. However, non-volatile anaesthesia/sedation combined with regional techniques has been described as a suitable alternative which avoids exposure to inhalational agents and their potential neurodevelopmental effects [43].

Paediatric TIVA has gained popularity in the last decade, but there remain barriers, perceived and actual, to its wider adoption. These include: lack of training and experience; unreliable pharmacokinetic models, leading to concerns around awareness or prolonged sedation; lack of availability of essential equipment; concerns about propofol-related infusion syndrome; and the ubiquity of inhalational inductions [44, 45]. The environmental benefits of TIVA in the paediatric population have been shown using mathematical modelling and lifecycle analysis to answer several questions around the relative carbon footprints of TIVA and volatile anaesthesia in children of differing weights undergoing procedures of varying durations [46]. The calculated CO_2e benefit of TIVA over inhalational agents is applicable to the paediatric population, with the CO_2e of volatile anaesthesia overtaking TIVA (which starts as soon as the consumables are opened) within 3 min. The carbon footprint difference was found to be larger in smaller children. In addition, TIVA alone is more environmentally sustainable than inhalational maintenance or any combination of the two techniques (intravenous induction followed by inhalational maintenance and vice versa) [46]. These findings are important as they provide paediatric anaesthetists with an evidence base to change practice on sustainability grounds.

Inhalational inductions continue to be a mainstay of paediatric practice. The APRICOT study revealed that 52% of approximately 30,000 anaesthetics given to children aged ≤15 y were inhalational inductions [47]. Inhalational inductions can be perceived as less traumatic than venous cannulation when intravenous access is assessed as challenging or in patients who are needle phobic or non-compliant [48]. It is challenging to collect robust data on nitrous oxide use, but small surveys indicate that it is used frequently as part of a gaseous induction where it can provide useful anxiolysis and a smoother excitatory phase [49]. The addition of nitrous oxide during an inhalational induction predictably increases CO_2e [46]. However, optimisation or reduction of total fresh gas flow during inhalational inductions in children has been implemented successfully in individual institutions without any clinically significant sequalae, resulting in decreased anaesthetic waste and environmental impact [50, 51]. The utilisation of open circuits, such as the Jackson-Rees modification of Ayre's T-piece, remains frequent in the UK, especially in younger children. Open circuits mandate higher fresh gas flows and make scavenging difficult, if not impossible [52]. The technique of nitrous oxide-free inhalational inductions via circle anaesthetic circuits may require a more robust place in the training curriculum of future paediatric anaesthetists [48].

Pre-operative analgesic premedication is still a widespread practice in paediatric anaesthesia, perhaps more so than in adults. Simple analgesia, such as paracetamol and non-steroidal anti-inflammatory drugs, should be administered orally as this route has been shown to reduce environmental and financial costs [53]. Expanding the use of oral anxiolytic and/or sedative premedication could have a role in reducing the frequency of inhalational induction, and the perceived need for nitrous oxide as an anxiolytic. There can be institutional barriers and an efficiency cost to this approach, making it a fruitful area for quality improvement. Aiming for a reduction in inhalational inductions by developing rapport with paediatric patients, utilising effective distraction techniques and appropriate pharmacological adjuncts should be attempted in all patients.

Cardiac anaesthesia

Cardiac surgery is seldom truly elective, yet carries a relatively high risk of morbidity/mortality and requires considerable resources [54]. Considerations for cardiac anaesthesia and surgery in relation to sustainable healthcare follow other generic principles, yet at the same time encroach more than others into areas such as pre-operative preparation, patient selection, complication mitigation and enhanced recovery. A narrow focus on mode of anaesthesia A vs. B with respect to environmental impact ignores the fact that cardiac surgery waiting lists around the world are growing following the COVID-19 pandemic, with a record 349,090 people waiting for surgery in England at end of September 2022 [55]. All attempts to make cardiac surgery sustainable must focus on providing precision care by optimising every part of the patient journey.

There needs to be pre-operative pathways and processes in place to ensure the correct patient is listed for the correct procedure. This can be difficult, as there will always be a range of options for any patient with heart disease. Patients with structural heart disease should be discussed by the multidisciplinary heart team who may recommend a less invasive option that avoids a general anaesthetic altogether [56]. However, there is a dearth of evidence on lifecycle analyses of, for example, surgical aortic valve replacement vs. transcatheter approach or coronary artery surgery vs. percutaneous coronary intervention. Likewise, there is little or no evidence on the best approach to more complex procedures such as heart/lung transplantation or aortic dissection repair. Modifiable risk factor mitigation is essential and the principles underlying this are well-known [57]. Surgery must be timely following patient listing, as decompensation, heart failure, inactivity and sarcopenia due to long waits are disastrous for patients and health services. Identifying those at high risk pre-operatively provides an opportunity to ensure the substantial resources around performing cardiac surgery are used only for those who will derive a worthwhile benefit. However, it is reasonable to assume that the best approaches towards sustainable cardiac surgery are to: GIRFT; have admissions on the day of surgery; and avoid complications such as prolonged ICU stay, re-sternotomy, bleeding and need for autologous blood transfusion.

Volatile anaesthesia with isoflurane remains common for maintenance of anaesthesia in England and elsewhere. Low fresh gas flow volatile anaesthesia cannot be provided

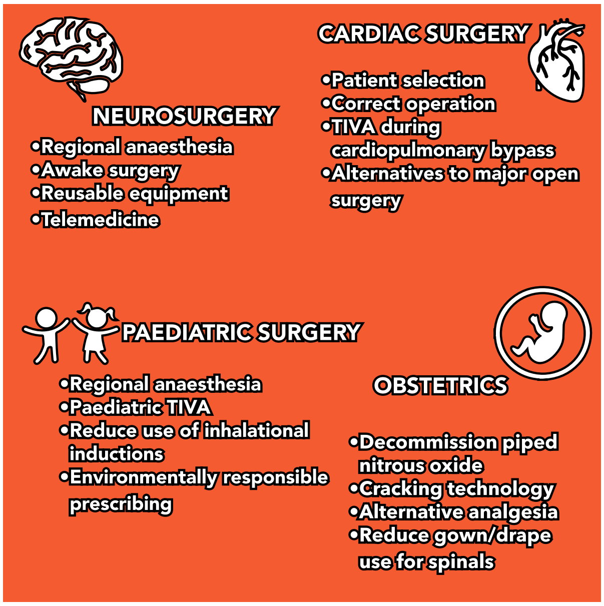

Figure 1 Target areas to reduce the environmental burden of peri-operative care in four anaesthetic subspecialties.

with cardiopulmonary bypass in the same way as an anaesthetic machine, which makes volatile expulsion to the atmosphere relatively high. Previous meta-analyses have demonstrated volatile anaesthesia to be superior for cardiac surgery [58, 59], but other recent trials and meta-analyses have not [60]. There is now reasonable evidence that mode of anaesthesia in cardiac surgery does not affect outcomes to a clinically significant degree, and with mounting evidence that TIVA is associated with less environmental costs, this is now the preferred mode in much of Europe. There are various modifications required for the use of TIVA during cardiac surgery with cardiopulmonary bypass [61]. First, haemodilution may reduce plasma concentration of drugs as compared with pharmacokinetic infusion models, but this may be offset by reduced protein binding. Second, metabolism, clearance and elimination are all reduced, which increases plasma drug concentration. Third, reduced systemic temperature during bypass reduces the elimination of remifentanil and target concentrations can be reduced by 30% for every 5°C of cooling. The most important principle, however, is the use and appropriate interpretation of processed EEG-based monitoring devices, which are essential to preventing adverse events and optimising postoperative recovery [62]. The role of regional techniques [63], minimally invasive surgery and opiate-free cardiac anaesthesia [64] also requires exploration, considering both patient outcomes and environmental impact. Sustainable healthcare aims should be incorporated in the next iteration of cardiac enhanced recovery after surgery guidelines [65] and there remains an urgent need for research in this area.

Conclusions

Despite a dearth of evidence, we have highlighted reasonable areas to target when aiming to reduce the environmental burden of four anaesthetic subspecialties (Fig. 1). The use of nitrous oxide in maternity care is the largest contributor to the carbon footprint of anaesthetic gases and mitigation should be an area for urgent focus. The use of TIVA is limited by several barriers in obstetrics, paediatrics and cardiac surgery and overcoming these to facilitate more widespread use should be a research priority. Evaluating the lifecycle carbon footprints of surgical procedures is required and information gained should be used by healthcare organisations when planning care pathways. Finally, reduction of waste at all stages of the patient journey benefits the triple bottom line of better environmental, social and financial outcomes for our patients and the planet we live on.

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