Healthcare Improvement Scotland | SHTG Advice on health technologies

SHTG Assessment
July 2024

In response to an enquiry from the National Green Theatres Programme (NGTP)

An evidence review of interventions aimed at improving the environmental sustainability of surgical operating theatres.

Key messages

1. There is limited published evidence on which to base informed decisions on interventions aimed at reducing the environmental impact of surgical operating theatres.

2. Reducing the environmental impact of surgery often requires a reduction in resource use, which in turn can lead to reduced costs. Interventions intended to improve environmental sustainability may incur an upfront cost (for example, the purchase of reusable surgical equipment), though they will likely be cost saving in the long term.

3. Primary prevention of surgical conditions, through patient education and empowerment, dietary advice and lifestyle changes, can greatly reduce the carbon footprint of surgery. When surgery is required, using environmentally sustainable approaches such as low-carbon treatments, reusables, recycling and maintaining equipment should be adopted where possible and clinically appropriate.

4. Small changes in practice can lead to environmental sustainability improvements. Examples from the literature include use of low-flow anaesthesia to reduce waste, turning off idle machines to reduce electricity use, using reusable equipment where possible and reviewing and streamlining theatre packs to reduce waste.

5. Barriers to improvements in sustainable practice include lack of leadership, limited knowledge of best practice and day-to-day workload pressures.

6. Future studies assessing the impact of different surgical approaches or models of care on sustainability should consider environmental impacts alongside other important factors such as patient outcomes and costs. Our Scottish Health Technologies Group (SHTG) Evidence Framework can be used to guide the collection of relevant data to inform decision making.

What were we asked to look at?

We were asked by the NGTP to review the published evidence on interventions or strategies designed to improve the environmental sustainability of surgical operating theatres.

Why is this important?

Operating theatres are a major contributor of greenhouse gas (GHG) emissions and waste from hospitals.[1] It has been estimated that operating theatres are three to six times more energy intensive than the rest of a hospital.[2]

The 2019 Climate Change (Emissions Reduction Targets) (Scotland) Act demonstrates Scotland's commitment to achieving a 75% reduction in GHG emissions by 2030 and net zero emissions by 2045. The Act requires public bodies, including the NHS, to act sustainably and contribute to these carbon emissions reduction targets.[3]

One of the priorities of the NHSScotland climate emergency and sustainability strategy (2022 – 2026)[4] is to reduce the carbon footprint of NHSScotland and enable more environmentally sustainable care. Achieving this net zero carbon emissions ambition, means addressing high carbon producing areas, like surgical care, by adopting environmentally sustainable strategies. These strategies should drive reductions in emissions and waste from surgery, while maintaining the highest levels of patient safety and quality of care.

What was our approach?

We conducted a review of the published evidence on the impact of interventions or strategies aimed at improving the environmental sustainability of surgical operating theatres.

More information about SHTG Assessments can be found on our website.

What next?

This report will be shared with the NGTP to inform the development of actions aimed at improving the environmental sustainability of surgical care in NHSScotland.

Key points from the evidence

1. Evidence on the effectiveness of interventions designed to reduce the environmental impact of surgery is limited in both quality and quantity. There is a lack of data on the long-term impact of these interventions including their effects on patient outcomes.

2. Primary prevention of conditions that require surgical intervention provides substantial reductions in the carbon footprint of surgery. This can be achieved through patient education and empowerment, dietary advice and lifestyle changes. In cases where surgery is needed, adopting environmentally sustainable approaches like low-carbon treatments, reusables, recycling and equipment maintenance should be considered where possible and clinically suitable.[5]

3. Interventions that lower energy consumption reduce the environmental impact of surgical care.[6] The highest proportion (90–99%) of electricity consumption comes from maintaining the operating theatre environment, particularly through heating, ventilation and air-conditioning (HVAC), though the impact this might have on infection and prevention control is not clear.[1, 5]

    a. One study reported that turning off HVAC at night, when operating theatres were not in use, saved 15–36 tonnes of carbon dioxide equivalent (CO_2e) per theatre per year. Implementing this practice across the 3000 operating theatres in NHS England could save 108,000 CO_2e annually.[5] A systematic review reported that switching off idle hospital sterilisers reduced their electricity use by 26%, and water use by 13%. The installation of operating theatre occupancy sensors reduced electricity use by 33%, for example by safely lowering lighting when the theatre is not occupied.[2]

    b. Energy consumption in operating theatres can be optimised by adopting multiple strategies including using renewable energy sources, installing occupancy sensors, switching to low-energy lighting, and switching to energy-efficient air-conditioning and water-cooling systems.[1, 2, 6]

4. Reusable equipment is more environmentally sustainable compared with single-use products, and despite upfront costs is cost saving over the long term.[1,5,2,7] One report noted that replacing single-use products with reusable items reduced overall carbon footprint by 38–56%.[5] A review that included 11 studies on single-use disposable items, stated that reusable items led to a 2.5 times lower energy consumption, three times lower water consumption and 70% reduction in waste generation.[2]

5. Studies in paediatric theatres found that streamlining and optimising surgical trays can reduce the amount of surgical instruments used by about 60%.[1]

a. One review reported that opening equipment only when necessary can lead to environmental and financial savings, as around 13% of disposable items opened for neurosurgical procedures are discarded unused.[1]

b. A second review found that establishing a minimal pack list of only essential surgical materials needed for a procedure resulted in a 13% reduction in CO_2 emissions (0.3 kg CO_2e per case). Individually wrapped items were found to generate more CO_2 emissions (38 g CO_2e per item) compared with equipment sets.[7]

6. Studies that reported costs in addition to sustainable outcomes suggested that interventions that were environmentally sustainable were also likely to reduce costs.[7]

    a. A systematic review found that strategies that rationalised the use of surgical instrument sets across a range of surgeries led to cost savings due to lower usage of single-use instruments, reduced need for waste disposal or reduced demand for instrument sterilisation.[7]

7. The environmental benefit of reusable equipment is influenced by the carbon footprint of the national energy supply.[7] Environmental benefits are greater in areas where the recycling and sterilisation processes are powered by renewable energy rather than fossil fuels.

8. The 5Rs rule of 'reduce, reuse, recycle, rethink and research' is a strategy which has been shown to optimise practical benefits while minimising waste.[8] Examples of practical changes made by following the 5Rs rule include installing recycling bins, streamlining theatre packs and using low-flow anaesthesia.[2]

9. The most common barriers to adoption of green behaviours in operating theatres include lack of leadership or organisational support, absence of suitably qualified people in key environmental sustainability leadership positions, inadequate knowledge and education of theatre staff, and lack of resources.[1 8 9 10]

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Definitions

Carbon footprint: the quantity of direct and indirect greenhouse gas (GHG) emissions associated with a sector (such as healthcare), process (such as an operation) or product (such as a surgical instrument).[1]

Climate-smart actions: strategies that prevent and reduce GHG emissions.[6]

Carbon dioxide (CO_2) emission: CO_2 that enters the atmosphere as a result of certain chemical reactions and through burning fossil fuels (oil, natural gas and coal), trees, solid waste, and other biological materials.[6] CO_2 is the main GHG emitted from healthcare and is responsible for 80–85% of the global warming potential (GWP) of the healthcare sector in the United Kingdom (UK).[1]

CO_2 equivalent (CO_2e): carbon footprint is usually expressed as a measure of weight, as in tonnes of CO_2 or CO_2e per year. CO_2e is used to standardise the effects of various GHGs on the environment or climate.[6]

Domestic waste: includes all uncontaminated non-medical and medical waste that is not at risk of infection transmission.[6]

Environmental sustainability: maintaining an ecological balance in the planet's natural environment and conserving natural resources.[6]

Greenhouse gases (GHGs): the gases that trap heat in the atmosphere, including CO_2, methane, nitrous oxide and fluorinated gases.[6]

Life-cycle assessment: a process of evaluating the effects that a product has on the environment over the entire period of its life.[6]

Low-carbon power: electricity produced with substantially lower GHG emission compared with power generated from conventional fossil fuel. This includes hydro power, nuclear power, solar power and wind power.[6]

Recycling: process of converting waste materials into new materials.[6]

Regulated medical waste (RMW): the portion of waste stream that may be contaminated by body fluids, blood or other potentially infectious materials that pose a significant risk of infection transmission. This is also known as infectious medical waste or biohazardous waste.[6]

Reprocessing medical device: processes such as sterilisation, cleaning, disinfection, testing and remanufacturing that enable a medical device to be used again.[6]

Waste segregation: the separation and sorting of different waste types to facilitate appropriate disposal and recycling.[6]

Introduction

Healthcare contributes about 4.4% of global GHG emissions.[5] The NHS accounts for 5.4% of the carbon footprint in the UK.[11] Operating theatres are one of the most energy intensive and waste-contributing areas of healthcare, where a substantial amount of medical equipment and supplies are used.[1] Operating theatres use three to six times more energy than other parts of the hospital[2] and produce 21–30% of hospital waste.[1]

In the UK, surgical care alone is estimated to produce 5.7 million tonnes CO_2e per year.[5] A typical operation emits about 146–232 kg CO_2e.[5] This is equivalent to driving 450 to 600 miles in an average petrol car.[5] Anaesthesia contributes about 5% of an acute hospital's carbon footprint or 2% of the NHS carbon footprint.[12] The gases used in anaesthesia are GHGs, and includes anaesthetic nitrous oxide (N_2O), which can remain in the atmosphere for up to 120 years.[13]

Healthcare-related waste is more likely to cause injury or infection than other types of waste.[8] Ecological concerns relate to both waste generation and incorrect disposal methods. As a result, healthcare associated waste production, collection and disposal is of critical relevance because of the potential risks to health and the environment.[8] Strategic and targeted interventions that help to reduce the environmental impact of high waste-producing areas such as operating theatres can make a meaningful difference to the environment.

Green healthcare involves the implementation of environmentally friendly practices into healthcare delivery.[8] The UK's NHS is committed to reducing its annual CO_2 emissions[7] and achieving a net zero NHS with directly controlled emissions by 2040.[14] The 2022–2026 NHSScotland climate emergency and sustainability strategy aims for NHSScotland to achieve net zero emissions by 2040 or earlier.[4] Initiatives supporting this ambition, such as the Greener NHS campaign and NHS Net Zero Report, promote more sustainable surgical care, while ensuring that patient outcomes and access to surgical interventions are not negatively impacted.[7]

This report aims to assess the evidence of the impact of strategies or interventions focused on improving the environmental sustainability of surgical operating theatres.

Health technology description

Green surgery involves providing high-value, high-quality surgical care in a way that is financially, socially and environmentally sustainable.[5] 'Green theatres' is a broader term used to describe operating theatres that use methods and materials that are less harmful to our planet.

Green theatres and green surgery recognise the value of environmentally sustainable healthcare and practices by prioritising, practising and promoting systems and processes that are less harmful to the environment and planet, without compromising patient outcomes and safety.[8] This includes reducing the environmental impact of surgical procedures by minimising carbon emissions or footprints, minimising waste, conserving energy, using energy-efficient technologies and adopting

eco-friendly materials, processes and methods for surgical procedures. The goal is to make surgical practices more environmentally responsible and reduce the healthcare sector's overall ecological footprint.[8]

National Green Theatres Programme (NGTP)

The NGTP[15] is a key element of the Scottish Government's Climate Emergency and Sustainability Strategy 2022 – 2026. The programme is led by the Centre for Sustainable Delivery (CfSD) with clinical support at NHS board level. The NGTP aims to enable and promote more environmentally sustainable care across NHSScotland, while maintaining quality of care and patient safety.

The NGTP works with clinicians across NHSScotland to develop and spread actions that reduce the carbon emissions of operating theatres. The first year of the programme has seen the release of nine carbon-saving action plans that represent an opportunity (pre-validation with health boards) for reducing carbon emission by 20,422 tonnes of CO_2 per annum.

Research question

What is the evidence on the impact of interventions or strategies aimed at improving the environmental sustainability of surgical operating theatres?

Literature search

A systematic search of primary and secondary literature was carried out between 27 October and 2 November 2023, and was updated between 28 February and 5 March 2024, to identify systematic reviews, health technology assessments and other evidence-based reports. Ovid Medline, Ovid Embase and Healthcare Management Information Consortium (HMIC), Medline, Medline in process, Epistemonikos, Embase and Cochrane databases were also searched for systematic reviews and meta-analyses.

Key websites were searched for guidelines, policy documents, clinical summaries and economic studies.

Results were limited to English language publications from 2018 onwards.

Concepts used in all searches included: *environment / carbon footprint / sustain* / climate, global warm, ecosystem, fossil fuel / natural gas, clinician, pollution, operating rooms.* A full list of resources searched and terms used is available on request.

Evidence on the effectiveness of interventions aimed at improving environmental sustainability

We identified seven studies[1, 2, 5-8, 16] evaluating the effect of interventions aimed at reducing the environmental impact of surgical theatres. Of these, six were systematic reviews[1, 2, 6-8, 16] and one was a green surgery report[5].

These studies included interventions focused on reducing energy and material consumption,[1, 2, 5-7] reusable and single-use equipment,[1, 2, 5, 7] recycling and waste management processes,[2, 7, 8, 16] and use of anaesthetic agents[2, 7]. The terminologies and methods used to define and determine environmental impact and cost savings varied among the studies. Environmental outcome measures also varied across the studies depending on the methodology used. Other outcomes included percentage energy reduction, waste reduction and CO_2 / GHG emissions. There was overlap between some of the primary studies in two of the reviewsidentified.[2, 7]

Most of the primary studies included within the reviews were observational and/or small case studies. Other studies offered untested theories based on audit findings in different settings including the UK, United States (US) and Australia.

The key findings in this report are presented under the following categories:

- operating theatre energy consumption
- heating, ventilation and air-conditioning
- single-use and reusable textile and surgical equipment
- recycling and waste management
- anaesthetic alternatives
- effect of percentage environmental weighting in procurement decisions.

Operating theatre energy consumption

We identified five articles, including four systematic reviews and the green surgery report, investigating interventions that reduce energy consumption.[1, 2, 5-7]

Interventions that reduce energy consumption are key to reducing the carbon footprint of the operating theatre.[6] Energy use is a major carbon contributor within operating theatres, with electricity accounting for 63%–78% of the carbon footprint of an operation. The amount of electricity consumed is closely linked to the duration of operations.[1] One US review found that that CO_2 emissions decreased by 234.3 metric tonnes over a one-year period as a result of routinely turning off anaesthetic and theatre equipment when not in use.[7]

Three studies found that strategies that can optimise energy consumption in operating theatres include using renewable energy rather than fossil fuel-based sources, developing and installing

occupancy sensors, and switching to low-energy lighting, energy-efficient air-conditioning systems and water-cooling systems.[1, 2, 6]

Installing solar panels and energy-efficient appliances as well as using renewable energy generated on-site can further reduce carbon impact.[5, 7] Two reviews reported that energy usage was found to reduce by one-third (33%) per operating theatre as a result of installing occupancy sensors to reduce air turnover.[2, 7]

The green surgery report recommends that energy-efficient appliances should be installed in new theatres. Prior to replacing existing systems, their age and premature obsolescence (outdatedness) should be weighed against energy savings that will be derived from new systems.[5]

Heating, ventilation and air-conditioning

Maintaining the theatre environment (that is, through HVAC) is associated with the highest (90–99%) proportion of energy consumption within theatres.[1, 5] Plug loads (that is, energy used by equipment plugged into an outlet) and lighting was estimated to consume between 1.5% and 8.4% of all the energy used.[5] Another study noted the contribution of the energy used to power anaesthetic gas scavenging systems (AGSS) and theatre ventilation, which are usually left on when theatres are not in use.[5]

Turning off idle machines was associated with reduced electricity use.[2, 5, 7] Switching HVAC off at night when theatres were not in use saved 15–36 tonnes of CO_2e per theatre per year in some hospitals in England. If rolled out across the NHS in the UK, it was estimated that this could save 108,000 tonnes of CO_2e annually in the UK[5] and 6,600 tonnes of CO_2e annually in Scotland. Hospital sterilisers still consume electricity and water when idle but turning them off reduces the electricity they consume by 26% and the water they consume by 13%.[2]

Infection prevention and control (IPC)

No studies considering the impact of alternative approaches to operating HVAC on IPC in theatres were identified.

Single-use and reusable textile and surgical equipment

We identified three systematic reviews and one report examining reusable and single-use equipment.[1, 2, 5, 7] Reusable equipment was found to be more environmentally sustainable than single-use products.[1, 2, 5, 7] There are certain items that are not appropriate for reuse, such as needles and intravenous tubing, as they are difficult to decontaminate with existing equipment.[5]

The first review reported that the use of consumable surgical items can be optimised for the environment by switching to reusable items and reducing use where clinically appropriate.[1] The green surgery report noted that switching from single-use to reusable products resulted in a surgical equipment carbon footprint reduction of 38-56%.[5] Textile are used in volume in surgical operations and shifting to reusable textiles could a bring about environmental benefits. Single-use drapes and

personal protective equipment account for about 25% of the carbon footprint of products used in common operations.[5] The use of reusable surgical drapes and gowns was associated with reductions in waste generation (750%), water footprint (25–330%) and carbon footprint (200–300%). Reusable linens and gowns were also associated with benefits beyond the environment such as higher pilling resistance, strength and water resistance.[5]

The second review[2] included 11 studies that evaluated the impact of single-use disposable items including: laparotomy mops, gowns, drapes, plastic drug trays, scissors, central venous catheter insertion kits and airway management tools. The environmental impact of disposable steel scissors was found to exceed that of reusable ones by 99%. The destruction of polyvinyl chloride (PVC) plastics by burning leads to a higher release of carcinogenic compounds from single-use items compared with reusable ones. Substantial environmental benefits can be realised by reusing items; a 2.5 times lower energy consumption, three times lower water consumption and 70% reduction in waste generation.

In a study of paediatric surgery, optimising and streamlining surgical trays reduced the amount of surgical instruments used by about 60%.[1] Opening equipment only when needed could result in financial and carbon savings; approximately 13% of disposable items opened for neurosurgical procedures are discarded without use.[1] Determining a minimal pack list that includes only the required essential surgical materials for a procedure has been reported to result in a 13% (0.3 kg CO_2e per case) reduction in CO_2 emissions. Individually wrapped items were found to produce more (38 g CO_2e per item) CO_2 emissions compared with equipment sets.[7] The impact of optimising surgical instrument packs on patient outcomes was not assessed in the studies identified.

The third review[7] included 21 studies, which described 25 interventions and analysed data from 11 studies focused on the use of reusable devices. Five studies reported 40%–66% lower emissions with reusables compared with single-use alternatives. The carbon footprint of hybrid general surgical equipment with some single-use components was lower than that of single-use equivalents because they were predominantly reusable. Six studies found that reduction in manufacturing emissions was offset by the high environmental impact of local fossil fuel-based energy required for sterilisation. Two studies found that reusable equipment generated higher CO_2 emissions compared with single-use equipment due to the use of brown coal for electricity in Australia. Reusable equipment was found to be more sustainable when the analyses were repeated using similar energy data from the UK and US, where more renewable energy sources are used.[7]

The articles highlight that the environmental impact of reusables depends on the reprocessing or sterilisation process and the electricity source of the hospital. Evidence from two reviews suggest that carbon emission due to sterilisation can be decreased by recycling sterile barrier systems, using low-carbon energy sources, integrating individually wrapped instruments into sets and having a more efficient machine loading system.[1, 7] Reprocessing surgical instruments from an entire operation was estimated to reduce GHG emissions by 9%.[1] Reusables are more environmentally sustainable if there is the equipment infrastructure to efficiently reprocess the items. One review comparing item reuse in the UK, US and Australia found a 9% increase in emissions in Australia compared with decreases observed in the UK (84%) and US (48%). This was attributed to Australia

generating 75% of its electricity from coal compared with the UK, which generates only 1% of electricity from coal.[2] The green surgery report cautioned that reusable equipment produced overall higher CO_2 emissions than single-use alternatives in Australian hospitals that use brown coal (which is particularly CO_2 emissions-intensive) to generate electricity. This does not apply in the UK, Europe and the US, where surgical products are used and reprocessed using electricity generated from more renewable energy sources.[5]

Infection prevention and control

One systematic review found no evidence of a difference in surgical site infection rates between reusable drapes and single-use drapes.[5].

Recycling and waste management

We identified three systematic reviews evaluating the impact of interventions on recycling and waste management processes.[2, 7, 8]

The first systematic review and qualitative synthesis included 19 studies on healthcare waste management.[8] The review found that operating rooms and haemodialysis activities are the areas most associated with waste production in hospitals. The review highlighted the 5Rs rule of 'reduce, reuse, recycle, rethink and research'. The 5Rs rule was the most commonly suggested strategy towards achieving practical change and minimising waste production.[8] Examples of changes made because of the 5Rs rule included using low-flow anaesthesia, streamlining theatre packs and installing recycling bins.

The second review[2] included eight studies evaluating the impact of interventions on recycling and waste management and four studies investigating waste reduction through streamlining the use of instrument packs. Installing paper and cardboard recycling bins in theatres led to the recycling of 67% of paper and cardboard generated in the operating theatre, and 50% of paper and cardboard generated in anaesthetic rooms, which would otherwise have been thrown away. Streamlining theatre packs by separating commonly used from rarely used instruments led to an annual decrease in waste of 1.48 tonnes.[2]

The third review[7] included three studies investigating waste management initiatives, including improving recycling and appropriate waste segregation. Education campaigns achieved a 75% reduction in biohazardous RMW. The studies also found a 2% decrease in GHG emissions per surgical procedure was also achieved by introducing recycling opportunities such as using reusable drapes, gowns and linen.

Anaesthetic alternatives

Anaesthetic and analgesic practices contribute approximately 5% of an acute hospital's carbon footprint or 2% of the UK's NHS carbon footprint. Use of anaesthetic gases during traditional general anaesthesia is the main contributor to this footprint. The gases that are used for anaesthetics and pain relief are GHG, and include nitrous oxide and the volatile gases desflurane, sevoflurane and isoflurane. Nitrous oxide is considered particularly polluting, partly because of its relatively long

atmospheric lifetime.[12] Desflurane has been decommissioned from use in NHSScotland. Sevoflurane and isoflurane are often reported in the literature as having high GWPs, although there is a lack of agreement on the extent to which they contribute to climate change particularly at current atmospheric concentrations.[17]

We identified two systematic reviews examining alternatives to anaesthesia.[7, 16]

The first review included four studies evaluating the impact of different approaches to anaesthesia.[7] Three of the primary studies included in the review compared the CO_2e produced per year by spinal anaesthesia (SA) versus general anaesthesia (GA), and reported an estimated saving of 12,921.51 kg CO_2e per year by converting all suitable procedures from GA to SA. In a fourth study, the source of hospital energy was primarily coal-based, and the study did not find a significant difference between GA, SA and combined approaches (14.9 versus 16.9 versus 18.5 kg CO_2e). SA produced lower CO_2e emissions than the GA and combined approaches when energy data from Europe and the US were used in the analysis.[7]

The second systematic review found that minimising the use of general anaesthesia, where clinically safe and appropriate has the potential to reduce waste. One of the included studies found that a 'wide-awake local anaesthesia no tourniquet approach', combined with minor field sterility for patients having surgery for carpal tunnel release alone, saved 2.27 kg of waste per procedure. Another study reported a marginal reduction in waste of 0.3 kg per case from performing wide-awake high-volume hand surgeries (for example, carpal tunnel releases and trigger finger) instead of under general anaesthetic.[16]

Effect of percentage environmental weighting in procurement decisions

We did not find evidence from the literature on the impact of environmental weighting in procurement decisions.

The green surgery report noted that government contracts exceeding £5 million annually are required to consider carbon reduction plans in their procurement process.[5] Since 2022, the NHS in England has applied at least a 10% weighting to net zero and social value in tender evaluations. In Scotland, public procurement contracts are required to optimise environmental benefits[5] but a percentage environmental weighting is not explicitly applied to these decisions.

Implementation of environmentally sustainable interventions

We found a number of guidelines available to support healthcare staff in adopting and implementing environmentally sustainable surgical practices, such as the green surgery report[5] and the intercollegiate green checklist.[18] The report and checklist are intended to help staff to identify, understand and prioritise the processes and strategies aimed at improving the environmental performance of theatres. Organisations such as Practice Greenhealth and Health Care Without Harm have been noted, by some studies, as useful educational and collaborative resources for the exchange of ideas.[5, 8]

The intercollegiate green checklist[18] can be applied at the start of an operating list to ensure good practice is adhered to. The checklist may also be used as a roadmap to influence any infrastructure changes required to implement good practice. The checklist can also be used as a scorecard to monitor progress or compliance.

The green surgery report[5] provides recommendations and strategies to help reduce the impact of surgical care on the environment. Beyond general recommendations to help reduce resource demand through fewer surgical complications, a reduction in post-operative critical care admissions and reduced length of hospital stay, the report proposes use of circular economy principles to reduce the carbon footprint of surgical products. For example, by implementing strategies such as switching from single-use to reusable equipment where appropriate and reducing waste (by using personal protective equipment only when necessary and streamlining single-use kits to remove unused items). In situations where reducing and reusing surgical products is not feasible, extending their lifespan can be achieved through remanufacturing, repair and recycling.[5]

The report recommends that hospitals should seek to generate energy (where possible) and use renewable energy. Proposed actions aimed at reducing energy use include:

- switching off or turning down (where appropriate) unused equipment
- installing motion sensors for lighting, and energy-efficient lighting and equipment
- using shutdown checklists
- using clinically appropriate ventilation systems with lower energy consumption and appropriate set back modes.

The reports emphasise the importance of health promotion, disease prevention and pathway optimisation as the first principle of sustainable surgery, on the basis that it reduces demand for surgery.[1, 5, 18] Primary prevention of conditions requiring surgery was noted as the biggest way to reduce the carbon footprint of surgery. This can be achieved through patient education and empowerment, dietary advice and lifestyle changes. When surgery is necessary, environmentally sustainable approaches should be considered where possible and clinically appropriate. These include using low-carbon treatment alternatives, reusables, and recycling, maintaining and repairing equipment.[5]

End-to-end surgical care pathways can be optimised through actions outside the operating theatre that ensure best use of resources and maximal patient benefit. These include using shared decision making to ensure surgery is the right option for the individual patient. For example, working with patients to streamline patient pathways by rationalising peri-operative investigations and using remote consultation supported by digital technologies. Shifting resources towards preventative public health can prevent or reduce surgical procedures and ultimately reduce the environmental impact of surgery.[5]

Engagement and a shared understanding of environmental sustainability is needed from all involved in the surgical ecosystem, including senior and trainee surgeons, anaesthetists and anaesthetic

trainees, nursing staff, operating department practitioners, and other allied health professionals, alongside colleagues in IPC, primary care, and public health practitioners.[5] Additionally, liaising with procurement teams, industry partners throughout the medical supply chain, and supporting services (including facilities and estates, instrument and linen reprocessing, and waste facilities), is important towards the overall aim of reducing the environmental impact associated with use of surgical products.[5]

Barriers and facilitators to adoption and implementation

We identified four papers, including three reviews[5, 6, 8, 10] and the green surgery report[5], that examined the beliefs and perceptions of decision makers and healthcare professionals (HCPs) on adopting environmental sustainability practices.

The green surgery report[5] noted that most NHS healthcare staff support NHS net zero targets and want to be part of the solution but do not feel well equipped to help. Surgical teams are motivated to improve sustainability but face barriers to change such as lack of leadership and guidance, lack of awareness, lack of information, inadequate facilities or resources, financial costs, feeling disempowered and lack of time.[5, 9] The report recommended that a more consistent and permissive policy is required, without compromising safety.[5]

The first review[10] included 21 studies and explored the facilitators and barriers to adopting sustainable behaviour in operating theatres. People's desire or intention to adopt sustainable practices in operating theatres was the most common facilitator, with 11 studies citing it. The most common barriers to adopting green behaviours in operating theatres included:

- a lack of knowledge of sustainable practices (n=18)
- staff shortages, full workload and inadequate recycling facilities (n=16)
- lack of leadership and lack of organisational mandate or support (n=9)
- concerns regarding safety (n=9).

The second review found that inadequate knowledge (60%) was also identified as one of the main barriers to implementing and achieving environmentally sustainable practices.[8] Although awareness around environmental sustainability is increasing, knowledge of environmentally sustainable practices remains inadequate. The review highlighted the barriers relating to healthcare waste, including inadequate training in proper waste management, a lack of awareness about the health dangers associated with it, insufficient economic and human resources and the lack of waste administration and disposal systems.[8] Common barriers associated with the implementation of greening strategies included lack of data, perceived risk of infection, lack of leadership, concerns about increased workload, staff attitudes and resistance to change. Practical steps to facilitate better environmental practice included advocating to staff that plastic devices are now often designed to be more easily recyclable, promoting awareness of recycling possibilities among healthcare workers, and a commitment to collect and recycle plastic waste.[8]

The review recommended that, in the short term, hospitals should be aware of the waste they produce (in quantitative and qualitative terms) and the resources required to improve disposal and recycling. In the middle term, the report recommended creating 'environmental greening teams' to increase knowledge, improve attitudes and facilitate the success of green initiatives across hospital sites. In the long term, the environmental impact of waste and medical procedures needs to be governed and managed at a senior level.[8]

The third review[6] identified six core climate-smart actions (that is, strategies aimed at preventing and reducing GHG emissions) from 38 studies. The review found that waste management is an area where HCPs can make the biggest difference. The climate-smart actions include:

- waste reduction by segregation
- waste reduction by recycling, reuse, and reprocessing
- sterilisation
- anaesthesia gas management
- improvement of energy use
- reducing surgical carbon footprint based on the 5Rs rule of 'reduce, reuse, recycle, rethink and research.'

Improvement of education and awareness was found to have an important impact on waste segregation and reduction. The review concluded that many climate-smart actions can be immediately implemented by HCPs in daily practice. Reducing waste production, improving waste segregation, and creating recycling protocols were noted by the authors as the easiest actions to implement.[6]

Overall, the evidence suggests that greater leadership, guidance and support is required across the health and care sector to build capability among staff to achieve and maintain improvements in sustainability. Although the creation of guidance and provision of support is the role of leadership and senior management, many practical actions could be actioned immediately by HCPs working in operating theatres.[5, 6, 10] Interventions should be co-designed with theatre staff, to help create a 'green culture' around environmentally sustainable behaviour.[6, 10]

Cost effectiveness

Systematic review

We found one systematic review that considered the financial impact of environmentally sustainable interventions in surgery.[7] The review incorporated 13 studies that reported cost outcomes for interventions which included rationalising surgical instrument sets, wrapping surgical instruments in sets, switching off equipment when unused, waterless scrub, waste segregation, multi-use/reusable equipment and alternative approaches to anaesthesia.

Generally, interventions that improved environmental impact also reduced costs in the longer-term. The exception was where using reusable equipment was associated with cost savings but greater carbon emissions than single-use equipment due to the carbon-intensive energy production in the country of the study. The authors noted that interventions focused on reducing and rationalising equipment use were cost saving in the short term, and introducing reusable equipment instead of single-use equipment often involved an upfront cost increase before cost savings were realised over the long term.

Primary studies

We found an additional 15 primary studies that included cost implications in addition to environmental outcomes that were not included in the systematic review. Studies were conducted in the US (n = 8), UK (n = 5), France (n = 1) and Germany (n = 1)). The studies are categorised and discussed below.

Operating theatre energy consumption

Twelve studies looked at the cost impact of interventions that aimed to minimise operating theatre energy expenditure or material use.

Six studies[19-24] investigated rationalising surgical packs for: midurethral sling surgery,[19] general surgery,[20, 24] paediatric surgery,[21] carpal tunnel decompression[22] and laparoscopic appendicectomy.[23] Reducing the equipment in surgical packs reduced costs and either carbon emissions or waste across all the studies. Cost savings ranged from $6 (approximately £4.75) per procedure[19] to $245,343 (approximately £194,000) per year for a single US institution.[24] Cost calculations did not include the administration of a programme to agree the necessary contents of a minimised surgical pack.

One study modelled the carbon and cost impact of switching off anaesthetic workstations overnight versus remaining on standby from the perspective of a German hospital.[25] The study estimated that if 80% of workstation devices were switched off overnight, a cost saving of €5,000 to €11,600 (approximately £4,300 to £9,900) and a carbon saving of 8.5 to 19.8 tonnes CO_2e per year could be realised. The results varied by the make and model of anaesthetic workstation. The magnitude of cost savings and environmental benefits were dependent on the unit cost of electricity and the carbon intensity of electricity generation.

A UK-based study[26] observed the impact of an education and awareness raising campaign to reduce the unnecessary opening of suture packs during laparoscopic or open surgery. A statistically significant fewer suture packs were opened during open surgery following the intervention (numerically fewer for laparoscopic surgery). If the reductions observed in the study were projected over a year, the authors estimated a carbon emission saving of 367 kg CO_2e and resource saving worth £2,799 at the site of the study.

Three studies considered the environmental and cost impact of implementing alternative surgical techniques or equipment.[27-29]

A study conducted at a UK district general hospital compared the carbon footprint and cost implications of three types of disposable pulse lavage systems used in total hip and knee arthroplasty, which varied predominantly in their source of power.[29] The analysis suggested that the device powered by the power-tool handpiece available on most arthroplasty sets was cost saving and associated with less carbon emissions when compared with devices powered by a battery pack or mains electricity. Based on a hospital purchasing 2,500 disposable pulse lavage kits per year, the study estimated a cost saving of £6,500 compared to the next cheapest option (battery-powered kit). Based on 1,800 arthroplasty cases per year, the power-tool pulse lavage system was associated with lower carbon emissions (3.0 tonnes CO_2e) than the battery-powered (7.8 tonnes CO_2e) or the alternating current (AC)-powered (5.2 tonnes CO_2e) kits. Factors that influenced both costs and environmental consequences were transportation and operating efficiencies, although a full life-cycle analysis was not conducted.

One study[27] prospectively randomised 15 consecutive adult tonsillectomy surgeries to either cold technique, monopolar electrocautery (ME) or low-temperature radiofrequency ablation (coblation). The study collected data on surgical equipment used, operating room energy expended and emissions relating to anaesthesia, sterile processing, and laundry. Life-cycle analysis was used to attribute costs and environmental outcomes to these data which were then statistically analysed. The study reported that cold process was associated with the lowest carbon emissions (157.6 kg CO_2e) compared with ME (184.5 kg CO_2e) or coblation (204.7 kg CO_2e). Cold process was also associated with the lowest costs ($472.51) (approximately £370) compared with ME ($619.10) (approximately £490) and coblation ($715.53) (approximately £560). Differences in costs and carbon emissions between the techniques were driven by quantities of disposable surgical equipment. Patient outcomes were assumed not to vary but these were not reported by the study.

Another study[28] was an audit to evaluate the feasibility of performing needle arthroscopy (NA) instead of conventional knee arthroscopy (CA) for patients with atraumatic knee pain in a Scottish high-volume national treatment centre. The study reported that per procedure NA was both less costly (£1555.20 compared with £2,351.53) and generated less non-recyclable waste by weight (1.4 kg versus 5 kg) than CA. Patient outcomes were not reported though the authors note that how patient outcomes differ between the techniques remains uncertain. If patient outcomes are different then longer-term costs and environmental consequences would be affected in the long term.

Single-use and reusable textile and surgical equipment

Three studies[30-32] investigated the environmental and cost implications of reusable equipment or textiles compared with single-use equivalents.

One study[30] compared personalised reusable cloth scrub caps with single-use polypropylene caps from the perspective of a US general hospital. The study reported that over the 6-month study period the use of reusable caps instead of single-use caps reduced carbon emissions by 11 kg CO_2e and 1.5 kg per day of polypropylene waste. Although the acquisition cost per cloth scrub cap was $11 (approximately £9) compared with $0.14 (approximately £0.11) per single-use cap, the study reported that even with daily laundry costs included reusable caps were cost saving after 26-weeks.

Another study[31] modelled the cost and environmental consequences of switching to reusable laryngoscope blades from single-use blades at a single tertiary hospital in France performing 17,200 intubations per year. Using data from life-cycle assessments, the study estimated a carbon saving of 26.5 tonnes CO_2e per year with an associated cost saving of €5,783.50 (approximately £4,900). The study reported that cost savings would be incurred after a reusable laryngoscope had been used 86 times, whereas the environmental benefits would accrue beyond only its third use.

A third study[32] modelled the cost and consequences of replacing single-use pulse oximetry sensors with reusable pulse oximetry sensors nationally across the US. Assuming approximately 26.5 million surgeries and 35,000 operating theatres, and either one single-use pulse oximeter per surgery or one reusable equivalent per operating theatre, a cost saving of $510.5 million (approximately £400 million) was estimated. Additionally, 587 tonnes of waste were estimated to be saved from landfill. The cost of reusable pulse oximeters $201.15 (approximately £160) whereas the single-use cost was $17.93 (approximately £14). The reusable pulse oximeters were cost saving after approximately 12 uses.

Recycling and waste management

A waste segregation quality improvement project at US-based hospital with 19 operating theatres reported an improvement in sharps bin use compliance and associated cost savings following an educational intervention for anaesthesia staff.[33] Sharps bin compliance improved from 50.70% pre-implementation to 58.44% post-implementation. A cost analysis that was calculated by multiplying the total weight of the sharps bins by the price per weight for their disposal suggested that the improvement in compliance could result in a cost saving of $2,964 (approximately £2,300) for the institution. The implementation costs of the quality improvement project were not reported.

Conclusion

Operating theatres have a significant impact on the environmental due to their high rate of GHG emissions, medical waste generation and resource consumption. Anaesthetic gases (such as nitrous oxide), single-use supplies, unused instruments, unnecessary electricity use and improper waste segregation are major drivers of environmental pollution and waste.

The evidence base for environmentally sustainable interventions in surgery is variable in quality and methodology, with limited data available on their long-term impact. There is limited information about fully scaled implementation projects on how to reduce the environmental impact of healthcare. There is also considerable difference in the surgical contexts where these interventions have been adopted and scaled.

Based on the information we found, modest changes in sustainability practices can lead to significant improvements within the operating theatre environment without compromising patient safety. Practical steps include reviewing and streamlining theatre packs, using of low-flow anaesthesia and turning off idle machines. Reducing resource consumption, for example by switching from single-use

supplies to reusable supplies and use of reduced surgical instrument sets, could result cost savings as well as reducing the environmental impact of operating theatres.

These changes do not need to happen in isolation. A holistic approach that drives and maintains change, across different systems, is the optimal method for reducing the environmental impact of surgical theatres. This approach should include educating HCPs and managers across the healthcare system, and the creation of environment-focused teams. Most HCPs are supportive and willing to engage in environmentally sustainable initiatives. Based on the information we found, barriers that prevent participation include lack of guidance at the hospital level, lack of awareness and education, or a lack of facilities to carry out even simple processes such a recycling. Interventions that are easily reproducible would be most beneficial in achieving uptake and spread across the operating theatre setting in NHSScotland. Interventions should be co-designed to help ensure feasibility and buy-in across all staff groups.

Identified research gaps

Future studies assessing the impact of different surgical approaches or models of care on sustainability should consider environmental impacts alongside other important factors such as patient outcomes and costs. Our SHTG Evidence Framework can be used to guide the collection of relevant data to inform decision making.

Beyond studies focusing on the aforementioned outcomes of specific changes to technology use or practice, it would be valuable to understand how quality improvement approaches could be used to support behaviour change, achieve senior management engagement and scale changes in energy supply, recycling and instrument use. A greater understanding of how sustainability is weighted within decision making will also facilitate successful implementation of effective interventions.

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Appendix 1: abbreviations

AC	alternating current
AGSS	anaesthetic gas scavenging systems
CfSD	Centre for Sustainable Delivery
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CA	conventional knee arthroscopy
GA	general anaesthesia
GHG	greenhouse gas
GS	green surgery
GWP	global warming potential
HCPs	healthcare professionals
HMIC	Healthcare Management Information Consortium
HVAC	heating, ventilation and air-conditioning
IPC	infection prevention and control
ME	monopolar electrocautery
NGTP	National Green Theatres Programme
NHS	National Health Service
NA	needle arthroscopy
N_2O	nitrous oxide
PVC	polyvinyl chloride
RMW	regulated medical waste
SA	spinal anaesthesia
SHTG	Scottish Health Technologies Group
UK	United Kingdom
US	United States
5Rs	reduce, reuse, recycle, rethink and research