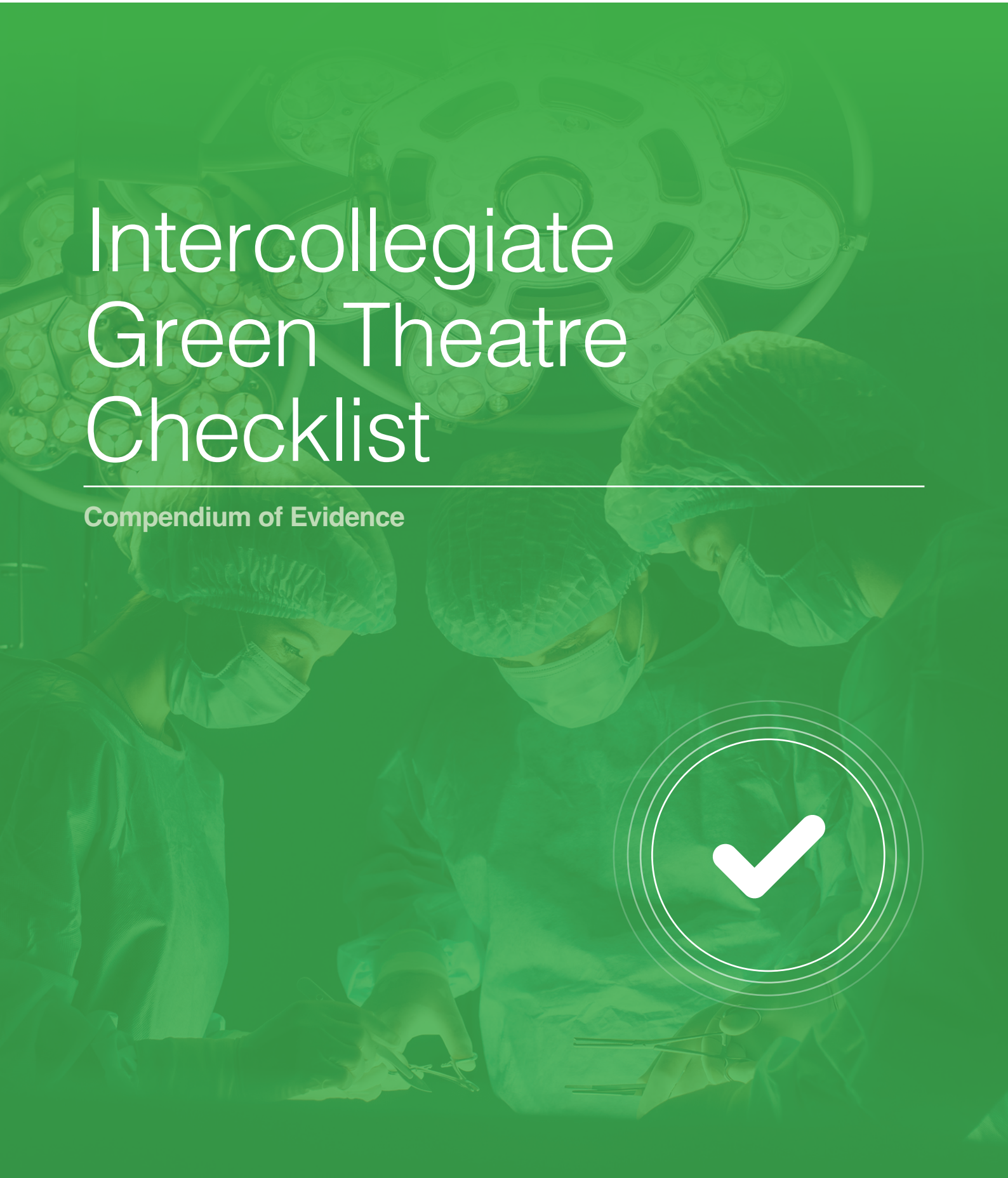
THE ROYAL COLLEGE OF SURGEONS OF EDINBURGH

Royal College of Surgeons of England
ADVANCING SURGICAL CARE

ROYAL COLLEGE OF PHYSICIANS AND SURGEONS OF GLASGOW

# Intercollegiate Green Theatre Checklist

## Compendium of Evidence



# Welcome to the Intercollegiate Green Theatre Checklist Compendium of Evidence

According to the World Health Organisation, humanity faces its greatest ever threat: the climate and ecological crisis. Health care services globally have a large carbon footprint, accounting for 4-5% of total carbon emissions.[1] Surgery is particularly carbon intensive, with a typical single operation estimated to generate between 150-170 kgCO2e, equivalent to driving 450 miles in an average petrol car.[2]

The UK and Ireland surgical colleges have recognised that it is imperative for us to act collectively and urgently to address this issue. Here we present a compendium of peer-reviewed evidence, guidelines and policies that inform the interventions included in the Intercollegiate Green Theatre Checklist. This compendium should support members of the surgical team to introduce changes in their own operating departments. Our recommendations apply the principles of sustainable quality improvement in healthcare, which aim to achieve the "triple bottom line" of environmental, social and economic impacts.[3]

This is an emerging field, and therefore this is an iterative document that will evolve with new evidence.

## How to use the checklist:

The checklist is divided into four sections, the first dedicated to anaesthetic care, and the subsequent three looking at preparation for surgery, intra-operative practice and post-operative measures.

We suggest the checklist is initially used at the daily brief at the start of an operating list, as an aide-memoire for the team of the modifications that could be applied there and then. Once these practices become embedded into practice, then the checklist may be used less frequently. At present, some theatres will lack the infrastructure required to enact all the suggested interventions and so the checklist can serve as a roadmap for discussion with management, or at departmental meetings, to guide required changes. Finally, if completed regularly, the checklist could also be used as a scorecard to monitor progress.

However you choose to use the checklist, we hope that it will be a valuable tool for staff to identify and understand interventions and considerations to decrease the environmental impact of their work.

We are grateful for feedback and any information on new research and developments, so please do contact us at sustainability@rcsed.ac.uk sustainability@rcseng.ac.uk or by using the Contact us form on the colleges' Sustainability webpages.

# General Principles for Greener Surgical Care Pathways

Although this checklist focuses on the operating theatre alone, there are a number of other interventions that can be introduced along the whole surgical patient pathway. The biggest way to reduce the carbon footprint of surgery is primary prevention of surgical disease. The first principle of sustainable surgery is therefore health promotion and disease prevention/optimisation through lifestyle changes, dietary advice, patient education and patient empowerment.[4]

It is important to note however, that surgery in itself may actually be less environmentally impactful (as well as more economical) than conservative or medical management of certain chronic conditions.[5]

When surgery is necessary, the whole pathway should be rationalised and streamlined, including utilising virtual consultations, one-stop clinics, diagnostic hubs, daycase surgery,[6] whenever possible and clinically appropriate.

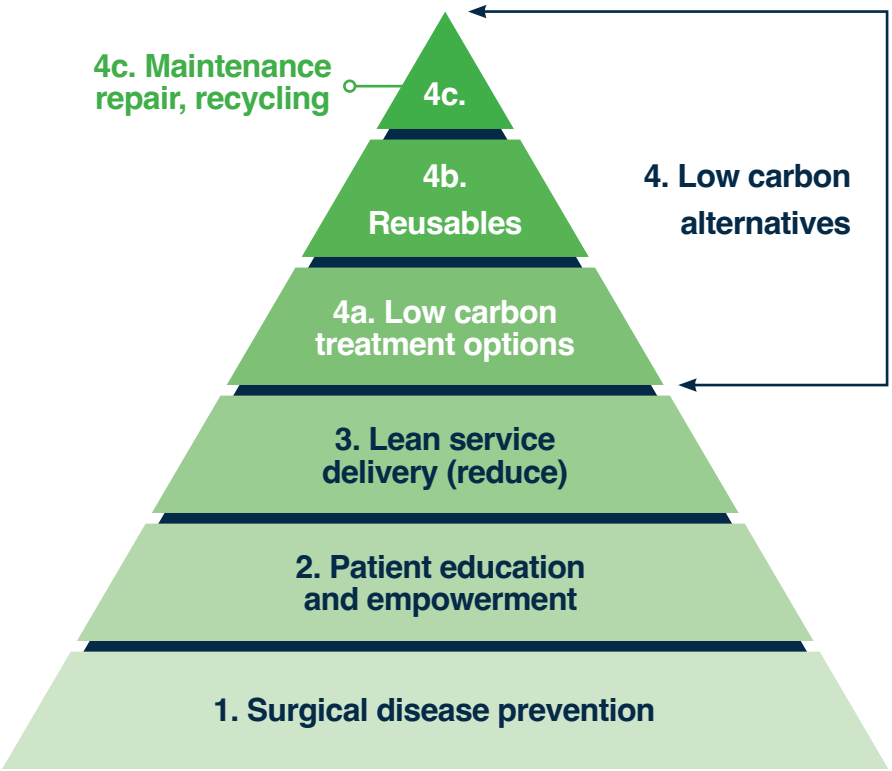



*Figure 1. Principles of sustainability in healthcare.[4]*

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# Intercollegiate Green Theatre Checklist Compendium of Evidence

**Below are a list of recommendations to reduce the environmental impact of operating theatres. All the relevant guidance and published evidence has been included in the Compendium of evidence, accessed via the QR code:**

| | | |
|---|---|---|
| **Anaesthesia** | | |
| 1 | Consider local/regional anaesthesia where appropriate (with targeted $O_2$ delivery only if necessary) | ☐ |
| 2 | Use TIVA whenever possible with high fresh gas flows (5-6 L) and, if appropriate, a low $O_2$ concentration | ☐ |
| 3 | Limit Nitrous Oxide ($N_2O$) to specific cases only and if using:<br>▸ check $N_2O$ pipes for leaks or consider decommissioning the manifold and switching to cylinders at point of use;<br>▸ introduce $N_2O$ crackers for patient-controlled delivery. | ☐ |
| 4 | If using inhalational anaesthesia:<br>▸ use lowest global warming potential (sevoflurane better than isoflurane better than desflurane);<br>▸ consider removing desflurane from formulary;<br>▸ use low-flow target controlled anaesthetic machines;<br>▸ consider Volatile Capture Technology. | ☐ |
| 5 | Switch to reusable equipment (e.g. laryngoscopes, underbody heaters, slide sheets, trays) | ☐ |
| 6 | Minimise drug waste (“*Don’t open it unless you need it”,* pre-empt propofol use) | ☐ |
| **Preparing for Surgery** | | |
| 7 | Switch to reusable textiles, including theatre hats, sterile gowns, patient drapes, and trolley covers | ☐ |
| 8 | Reduce water and energy consumption:<br>▸ rub don’t scrub: after first water scrub of day, you can use alcohol rub for subsequent cases;<br>▸ install automatic or pedal-controlled water taps. | ☐ |
| 9 | Avoid clinically unnecessary interventions (e.g. antibiotics, catheterisation, histological examinations) | ☐ |
| **Intraoperative Equipment** | | |
| 10 | REVIEW & RATIONALISE:<br>▸ surgeon preference lists for each operation - separate essential vs. optional items to have ready on side;<br>▸ single-use surgical packs - what can be reusable and added to instrument sets? what is surplus? (request suppliers remove these);<br>▸ instrument sets - open only what and when needed, integrate supplementary items into sets, and consolidate sets only if it allows smaller/fewer sets (please see guidance). | ☐ |
| 11 | REDUCE: avoid all unnecessary equipment (eg swabs, single-use gloves), “*Don’t open it unless you need it”* | ☐ |
| 12 | REUSE: opt for reusables, hybrid, or remanufactured equipment instead of single-use (e.g. diathermy, gallipots, kidney-dishes, light handles, quivers, staplers, energy devices) | ☐ |
| 13 | REPLACE: switch to low carbon alternatives (e.g. skin sutures vs. clips, loose prep in gallipots) | ☐ |
| **After the Operation** | | |
| 14 | RECYCLE or use lowest carbon appropriate waste streams as appropriate:<br>▸ use domestic or recycling waste streams for all packaging;<br>▸ use non-infectious offensive waste (yellow/black tiger), unless clear risk of infection;<br>▸ ensure only appropriate contents in sharps bins (sharps/drugs);<br>▸ arrange metals/battery collection where possible. | ☐ |
| 15 | REPAIR: ensure damaged reusable equipment is repaired, encourage active maintenance | ☐ |
| 16 | POWER OFF: lights, computers, ventilation, AGSS, temperature control when theatre empty | ☐ |

*DISCLAIMER: These suggestions are based upon current evidence and broadly generisable, however, specific environmental impacts will depend upon local infrastructure and individual Trusts’ implementation strategies.*

# Anaesthesia

Anaesthetic gases contribute an estimated 2% of the NHS's total carbon emissions.[7] All volatile anaesthetic agents are potent Greenhouse Gases, with desflurane and nitrous oxide having by far the highest global warming potential (GWP).[8] In addition to its high GWP, nitrous oxide also contributes directly to the destruction of the ozone layer.[9]

## Use of Local/Regional Anaesthesia

A range of common surgical operations, such as inguinal hernia repair, hip and knee arthroplasty, can be performed safely under local (LA) or regional anaesthesia (RA) with considerable clinical benefits for patients.[10-12] In addition, regional and local anaesthesia is usually environmentally preferable, both through negating the extra resources required for general anaesthesia (GA) (such as volatile anaesthetic agents and environmentally persistent intravenous drugs[13]) but also because of the associated shortened patient stay,[10-14] which reduces individual patient resource consumption and improves efficiency in theatres, in turn improving environmental impacts.

## Conservative Oxygen ($O_2$) Therapy

When patients are undergoing procedures under RA, or are in the recovery room, it is best to titrate $O_2$ flow rates to target appropriate saturation levels. Excess $O_2$ is detrimental to patients,[15] but also has its own carbon footprint, with 1 L medical $O_2$ equivalent to 0.7 $kgCO_2e$.[16] When utilising high flows, it is also important to note that whilst standard $O_2$ flow meters appear to have a maximum flow rate of 15 L/min, when the valve is opened fully they can deliver up to 75 L/min,[17] which wastes hospital oxygen stores with no benefit to patients.

## Use Total Intra-Venous Anaesthesia (TIVA) When Possible

TIVA has a reduced GWP compared to volatile anaesthetic agents; however the biotoxic and water contamination effects of anaesthetic compounds remain to be clarified.[18] In the absence of inhalational anaesthetic agents, remember to increase fresh gas flow (FGF) to 6 L/min in order to reduce carbon dioxide ($CO_2$) absorbent consumption, with associated environmental and financial benefits.[19,20]

## Limit Nitrous Oxide ($N_2O$) Use and Waste

$N_2O$ has a similar carbon footprint to desflurane at clinically-equivalent doses.[21] Its avoidance, both to support fresh gas flow delivery and in the form of Entonox, has been described as the "largest contribution to reducing anaesthetic greenhouse gas emissions".[22]

- *Use for specific cases only:*

  Anaesthetic use of $N_2O$ is only recommended for paediatric inductions and Caesarean Sections under GA.

- *Check $N_2O$ pipes for leaks or consider decommissioning the manifold and switching to cylinders at point of use:*

  $N_2O$ manifolds for theatres should be decommissioned and replaced with local cylinders to combat widespread issues with pipeline and manifold leakage, as well as stock control (guidance for decommissioning can be found on the Association of Anaesthetists' Nitrous Oxide project page).[23]

- *Introduce $N_2O$ crackers for patient-controlled delivery:*

  Use of Entonox or pure $N_2O$ in other areas of the hospital or healthcare services (Dental, Emergency Department, Endoscopy, Maternity, Ambulance) should be examined. Alternatives, including $N_2O$ crackers, should be sought where clinically appropriate.

# Anaesthesia
(Continued...)

## If Using Inhalation Anaesthesia

- *Use lowest global warming potential:*

  Amongst anaesthetic gases, desflurane has the highest environmental impact, followed by isoflurane, and lastly sevoflurane and halothane.[24]

| Agent | $KgCO_2e$ of vaporised bottle of the agent | $GWP_{100}$ |
|---|---|---|
| Nitrous oxide | 1013 (Size E cylinder 3.4 kg) | 298 |
| Sevoflurane | 49 (250 ml) | 130 |
| Isoflurane | 190 (250 ml) | 510 |
| Desflurane | 886 (240 ml) | 2540 |

*Table 1 - Greenhouse Warming Potential over 100 year time horizon (GWP100) and Carbon dioxide equivalency (CO2e) of anaesthetic gases.*

  At low fresh gas flows (0.5 L/min) and equipotent levels (1 MAC of agent), desflurane anaesthesia has a carbon footprint equivalent to driving 133 km; whereas sevoflurane has a carbon footprint equivalent to driving 2 km (calculated using the Association of Anaesthetists Anaesthetic gases calculator).[25] At higher fresh gas flows, these carbon footprints increase in direct proportion.[24]

- *Consider removing desflurane from formulary:*

  Although desflurane was previously associated with very limited reductions in emergence time (1-2 minutes),[26] a recent publication has suggested that these effects are not clinically significant nor do they justify the increase in financial and environmental costs.[27] The NHS has introduced guidance asking all trusts to reduce desflurane use to less than 5% of their total volume of anaesthetic gases.[28]

- *Use low flows target-controlled anaesthetic machines*

  This has been shown to help preserve resources as well as reduce the environmental impact of an anaesthetic.[29,30]

- *Consider volatile capture technology (VCT):*

  VCT utilises carbon filters to capture molecules of volatile agents after they have been expired by the patient, before they are released unmitigated into the atmosphere. VCT is connected in series to the anaesthetic machine's Anaesthetic Gas Scavenging Systems (AGSS) output and can capture between 25 to 70% of the total volatile volume administered to a patient.[16,31] Using VCT in addition to a carrier mix of $O_2$/air at the lowest flow rate is thought to have lower environmental impact when compared to propofol.[16]

## Switch to Reusable Anaesthetic Equipment where Possible

Using reusable anaesthetic equipment (such as supraglottic airways,[32] laryngoscopes,[33] direct-contact heaters, slide sheets, drug trays), can not only provide cost savings but also reduce the anaesthetic carbon footprint by as much as 84%.[34]

- *Reusable direct-contact heaters:*

  Consideration as to whether warming devices are needed routinely for all operations should be taken.[35] For brief operations, single-use warming devices may not be needed at all (similar to single-use Deep Venous Thrombosis prophylaxis stockings and air-compression devices).

  If warming is needed, then it may be more cost effective and more environmentally friendly to use reusable direct-contact heaters.

  NICE guidance from 2011 suggested that direct-body heaters are equivalent to other devices for prevention of intraoperative hypothermia.[36] Direct-contact heaters are reusable, energy efficient,[37] easily cleaned and relatively silent, and have been promoted as a more cost-effective and practical alternative to forced-air warming.[38]

# Anaesthesia
(Continued...)

## Minimise Drug Waste

Pharmaceuticals make up 20% of total NHS England emissions.[39]

- *Don't open it unless you need it!:*

  Anaesthetic drug waste was estimated to cost $185,250 (~£148,000) per year in one USA institution alone[40], approximately equivalent to 51,700 kg$CO_2$e/year. Drug waste represents up to 26% of the entire anaesthesia drug budget,[41] and includes pre-emptive emergency drugs (e.g. metaraminol, suxamethonium, atropine) which are wasted in between 39% to 91% of cases.[42]

- *Reduce propofol waste:*

  Multidose vial drugs are also a large source of waste, with propofol alone accounting for up to 50% of all anaesthetic drug waste.[40,43] Removing larger vials of propofol, accurately estimating required propofol doses (through freely available online calculators and apps), drawing up as and when required, and introducing prefilled drug syringes, have been suggested as a cost-saving and more environmentally sustainable options.[40,42-44]

# Preparing for Surgery

## Reusable Theatre Textiles

- *Theatre hats:*

  Multiple studies have demonstrated no difference in Surgical Site Infections (SSIs) with disposable bouffant caps compared to traditional, reusable cloth caps.[45-48] Reusable caps are more cost efficient in the long run.[48]

  To date no studies have compared theatre headwear from an environmental perspective, but other reusable theatre wear has been shown to be more sustainable.[49]

  Reusable hats are acceptable theatre wear according to NHS guidelines,[50,51] and can be personalised with names and roles to improve team communication.[52]

- *Reusable gowns:*

  Single-use surgical gowns produce huge amounts of waste, with over 36 million used in NHS England in 2020 alone.[53] Compared to disposable gowns, reusable gowns reduce carbon emissions by 200-300%, water usage by 250-330% and solid waste by 750%.[54,55] A Life Cycle Analysis (LCA) estimated a saving of almost 1.1 $kgCO_2e$ per gown when substituting disposable gowns with reusable gowns.[54]

  There is no evidence that reusable gowns increase SSIs,[56] and in fact reusable gowns usually offer better protection due to superior water resistance and durability.[57] Another way to make financial as well as environmental savings is to use the correct gown: reinforced gowns require more materials to produce and lead to more waste and are only needed when there is expected exposure to very high volumes of fluid.

- *Drapes:*

  When evaluating the risk of SSIs with different types of drapes, there is no evidence that single-use drapes are better than reusable.[58] Erroneous beliefs in relation to surgical drapes are often based on historical textiles (such as cotton) that are no longer in use and were not manufactured nor quality assured to modern requirements. Nowadays to meet stringent UK standards (including EN 13975 and EN ISO 13485), textiles used in surgery undergo thorough quality assessments and strict auditing of material integrity, water penetration, and sterilisation before each use, and throughout their life.[59]

## Reduce Water and Energy Consumption

- *Rub don't scrub:*

  NICE guidelines recommend that after the first water-based hand wash of the day, alcohol based hand-rub (ABHR) can be used on clean hands for subsequent antisepsis between surgical cases.[60]

  ABHR achieves hand decontamination for a wide variety of organisms,[61,62] and has been shown to have equal[63] or superior[64-66] efficacy to traditional scrub. ABHR also reduces duration of the decontamination process,[65] and has a favourable user profile,[67] attributed to lower rates of skin irritation and dryness.[68,69]

  Environmentally, studies have demonstrated many litres of water are saved when using ABHR,[70] with one hospital estimating saving 2.7 million litres of water annually by switching to waterless scrub.[71] Financial savings ensue from reduced water use as well as reduced hand towels,[72-74] although actual values will be sensitive to individual practice and local structures for procurement.

# Preparing for Surgery
(Continued...)

## Avoid Clinically Unnecessary Interventions

- *Antibiotics:*

  Pharmaceuticals contribute a fifth of NHS emissions from procurement.[39] For antibiotics, 30% of prescriptions are in secondary and tertiary care settings.[75] In 2015, 42 billion doses were used every day in the NHS, with this is expected to rise by 200% by 2030.[76] Not only is bacterial antibiotic resistance estimated to account for 1.27 million deaths worldwide per year,[77] but inappropriate disposal methods, both during production and at point of use, also pose significant ecological risks to soil microorganisms and aquatic life.[78] NICE guidance is that antibiotics should only be used in the presence of a surgical implant or where surgery is on a contaminated site.[60]

- *Catheterisation:*

  Single-use catheters have a large environmental impact.[79] It is important to consider whether the catheter is needed in the first place: for short operations, patients can be asked to empty their bladder just before anaesthesia.

  When procuring single-use catheters, consideration should also be given to their composition, with preference given to latex or newer polyolefin-based elastomer catheters with a more environmentally favourable profile compared to materials like PVC or TPU.[79,80]

- *Histological examinations:*

  Histological processing comes with a carbon cost. For example, a single gastrointestinal sample uses 0.29 kg$CO_2$e, roughly the same as driving a car one km.[81] In addition, little benefit has been found in certain routine elective procedures, such as cholecystectomy.[82] Surgeons should assess the need for histological examinations on a case-by-case basis, considering factors such as clinical uncertainty or consequences for clinical management.

# Intraoperative Equipment

## REVIEW & RATIONALISE: streamline surgeon preference lists, surgical packs and instrument sets

- *Surgeon preference lists for each operation:*

  Separate what is definitely needed and what can be listed as optional to have ready on side ("*Don't open it unless you need it!*" principle).

- *Single-use surgical pre-prepared packs:*

  Medical equipment contributes 10% of the NHS carbon footprint.[83] Reusable versions of equipment will, in almost every circumstance, reduce carbon footprint,[84] as well as plastic consumption and cost.[85]

  Under contemporary UK policy and practice, sterility of reusable items is assured. Studies from laparoscopic surgery show that disposable instruments carry no advantage for sterility,[86] but also have a 19 fold increase in costs,[87] and at least a four-fold higher carbon footprint.[88]

  Single-use packs often also contain equipment that is not used at all; contacting companies to remove these items all together will reduce financial cost, carbon, and waste.

- *Instrument sets/trays:*

  Unused instruments in an opened instrument tray, known as "overage", lead to significant and rarely justified waste. One department found they could reduce the number of instruments in each tray by 70%, (with an associated 37% reduction in setup time) and estimated institutional annual savings of $2.8 million.[89]

  Because a fixed quantity of resource is used for each sterilisation cycle, sterilisation of each tray takes up part of those resources in proportion to the amount of space it occupies in the autoclave, regardless of the number of instruments on the tray. Optimising loading of trays in the autoclave for each cycle, and optimising number of instruments in each tray, helps to divide these resources over the maximum number of instruments.

  Instruments should therefore be removed from trays but only where these are not used by any surgeons at all, and where consolidation results in a significant reduction in the size of the tray the instruments are housed in.[90] Where instruments are removed and individually wrapped as supplementary items, this significantly increases the carbon footprint (189 gCO2e per individually wrapped instrument vs. 66-77 gCO2e when part of sets).[90] The sterile barrier system (whether metal containers or tray wrap) should also be reused or recycled to confer further carbon reductions.[90]

## REDUCE: avoid ALL unnecessary single-use equipment, eg single-use gloves or single-use instruments

- *Don't open it unless you need it!:*

  Operating theatres generate large amounts of waste, compounded by opening but then not using some surgical equipment. Not only does this have financial implications (one study from the US showed an average of $653 of unused equipment per case in neurosurgery),[91] but it needlessly contributes to the surgical carbon footprint. The most common reason for unnecessarily opening supplies is the anticipation of surgeons' needs.[92] Instead of opening equipment 'just in case', it should be opened 'just in time'.

- *Non-sterile single-use gloves:*

  Billions of non-sterile gloves (NSG) are used in the NHS every year,[53] often in circumstances for which they are not required. Studies have found that use of NSG is inappropriate in more than 50% of cases,[93] and could even hinder hand hygiene in 37% of instances due to the potential for cross-contamination.[94]

  NSG are only necessary when there is anticipated contact with bodily fluid, non-intact skin, or mucus membranes, but in some settings it has become habitual to don gloves for almost all patient interactions. This is damaging both to the environment and healthcare professionals' hands. An educational campaign on appropriate use of gloves ('Gloves are Off') at Great Ormond Street hospital, led to use falling by a third.[95]

# Intraoperative Equipment
(Continued...)

## REUSE: opt for reusable, hybrid or remanufactured equivalents instead of single-use (e.g. diathermy, gallipots, kidney-dishes, quivers, light handles, staplers, energy devices)

Single-use equipment is a major hotspot in surgical operations, with consumables typically contributing 32% of carbon emissions.[83]

The increased carbon footprint of minimally invasive and robotic surgery, as exemplified for hysterectomies, the open/vaginal approach emitting 290 $kgCO_2e$, laparoscopic 560 $kgCO_2e$, and robotic >800 $kgCO_2e$, is accounted for in most part by single-use components.[96] Even hybrid reusable and disposable equipment such as laparoscopic ports, scissors and clip appliers have a carbon footprint that is 75% less than single-use alternatives.[85]

The single-use equipment culture was largely driven by uncertainty in the ability of surgical instruments to transmit the incurable variant Creutzfeldt-Jacob Disease (CJD),[97] at a time when modern decontamination and sterilisation practices did not exist.[98] There is no evidence of superior quality or safety with single-use equipment. By swapping for reusable equivalents, significant environmental savings can be easily found, as demonstrated in a systematic review of operating theatre equipment.[84]

Where reuse is not an option, remanufacture should be considered. This is an important solution for single-use medical devices (SUDs) that can contain complex mechanisms, important critical earth elements and precious metals, and are not amenable to traditional recycling. The remanufacturing process is strictly regulated and includes disassembly, component reprocessing, reassembly, sterilisation and recertification for clinical use. A review by the US Government Accountability Office (GAO) and the Food and Drug Administration (FDA) declared that reprocessed SUDs do not increase adverse events and do not present an elevated risk to patients.[99] In addition to environmental savings, remanufactured device save financial costs, including costs of medical waste disposal.[100]

One life-cycle analysis comparing remanufactured to newly-manufactured electrophysiology catheters demonstrated a >50% reduction in GWP,[101] and other studies have shown reduced GWP through remanufacture of energy devices.[100]

## REPLACE: switch for low carbon alternatives (e.g. skin sutures instead of clips, loose prep in gallipots)

- *Sutures instead of skin clips:*

  Because of their weight and complexity, single-use skin staplers have a higher embedded carbon footprint than sutures. Where appropriate, using sutures eliminates the need for staplers as well as clip removers. Using absorbable sutures, or instructing patients to remove their own sutures, eliminates the need for another appointment with a healthcare professional, saving on transport emissions and freeing up healthcare resources and time.

- *Sponge-holders and swabs instead of single-use plastic wands:*

  NICE guidance suggests that “loose” antiseptic solutions poured into reusable gallipots and applied using reusable instruments (e.g. sponge-holders) and swabs, have a reduced environmental impact.[102] A large multinational RCT found no benefit in the use of 2% alcoholic chlorhexidine skin preparation compared to 10% aqueous povidone–iodine for the prevention of SSIs.[103] For these reasons, single-use plastic wands for antisepsis are not recommended.

# After the Operation

## RECYCLE or use lowest carbon appropriate waste streams

Whilst efforts to reduce consumption and decrease reliance on single-use-item are critical, waste is inevitable. Although waste disposal is estimated to account for <0.1% of a typical operation's carbon footprint, (83) the total waste produced by the NHS is equivalent to that of European countries such as Cyprus or Luxembourg.[104]

Hospital waste in the UK is designated into multiple "waste streams" dependent on suitable methods for disposal. The highest carbon footprint for disposal is high temperature incineration (~1074 $kgCO_2e$), and the lowest is recycling (~21 $kgCO_2e$). The choice of waste stream can thus have a 50-fold impact on carbon footprint and is mirrored in financial costs, with incineration being more expensive than the less carbon intensive routes.[105]

- *Use domestic or recycling waste streams for all packaging (before any contamination):*

  Studies have suggested that less than 50% of recyclable materials are segregated appropriately prior to entering operating areas where they have potential for contamination.[106] Although recycling recovers only a fraction of embedded carbon and as a strategy is far inferior to reuse, processing of waste through recycling has the lowest carbon footprint of all waste disposal streams and therefore should be prioritised wherever possible.[105]

- *Use non-infectious offensive waste unless clear risk of infection:*

  As opposed to infectious waste (orange bag), non-infectious offensive waste (yellow and black striped bag) can be disposed of through less environmentally detrimental means, where energy is recovered from waste, and typically will have a reduced environmental impact.[105] Many theatres use an orange bag where a yellow and black striped bag would meet requirements.

- *Ensure only appropriate contents in sharps bins (sharps/drugs as per your local guidelines):*

  Waste in the sharp bin undergoes High Temperature Incineration (HTI) at 1100 degrees Celsius and is the most carbon intensive waste stream. In order to decrease the environmental impact of the incineration process, consider exploring non-plastic or reusable options for sharp bins, such as reusable metal containers or single-use cardboard sharp bins.

- *Arrange the collection of specific materials where possible:*

  There are a number of companies in the UK that specialise in the collection and recycling of healthcare waste. Examples include Guedel airways, surgical masks, any single-use metal (e.g. guidewires, drawing up needles, single-use instruments), as well as critical earth elements in the batteries of digital surgical instruments.

# After the Operation
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## REPAIR reusable surgical instruments and encourage active maintenance

Where possible reusable equipment should be preferred, and when in use actively maintained. Analyses have shown reusable equipment is often better both financially and environmentally, and repair adds to this.[107] For example, reusable steel scissors were found to have an environmental impact of only 1% of that of disposable steel scissors,[108] and repair reduces the per-use carbon footprint of reusable surgical scissors by an additional fifth (with concomitant cost savings of around one-third).[109] In another study, reusable instruments were found to cumulatively be more cost effective and to help reduce the carbon footprint of minor oculoplastic operations.[110]

## Power off lights, computers, ventilation, AGSS, temperature control when theatre empty

Heating, ventilation and air conditioning (HVAC) systems contribute to more than 90% of surgical theatres energy usage.[111] Turning off theatre spaces when unused can cut HVAC energy consumption by up to 50%.[111] Other strategies to reduce electricity usage include light-emitting diode (LED) instead of halogen lights, and adopting occupancy sensors.[112]

Anaesthetic gas scavenging systems (AGSS) and overhead radiant heaters account for 80% of the electrical energy used by anaesthetic equipment and should be switched off in unoccupied operating theatres.[113]

“Set-back” modes are able to maintain minimum background conditions, such as humidity or temperature, when the operating theatre is unoccupied, and are recommended by the Department of Health’s Health Technical Memorandum on Specialised ventilation.[114]

More information is available on the Centre for Sustainable Healthcare website: The Anaesthetic Gas Scavenging System (AGSS) project,[115] including an audit tool to help document and manage your own theatre system.

# References


1. Pichler PP, Jaccard IS, Weisz U, Weisz H. International comparison of health care carbon footprints. Environmental Research Letters. 2019;14(6):064004.
2. Rizan C, Steinbach I, Nicholson R, Lillywhite R, Reed M, Bhutta MF. The Carbon Footprint of Surgical Operations: A Systematic Review. Ann Surg. 2020;272(6):986-95.
3. Mortimer F, Isherwood J, Wilkinson A, Vaux E. Sustainability in quality improvement: redefining value. Future Healthc J. 2018;5(2):88-93.
4. Rizan CR, M.; Mortimer, F.; Jones, A.; Stancliffe, R.; Bhutta, M.F.. Using surgical sustainability principles to improve planetary health and optimise surgical services following the COVID-19 pandemic. The Bulletin of the Royal College of Surgeons of England. 2020;102(5):177-81.
5. Gatenby PA. Modelling the carbon footprint of reflux control. Int J Surg. 2011;9(1):72-4.
6. Getting it Right First Time (GIRFT). National Day Surgery Delivery Pack. Published online at: https://www.gettingitrightfirsttime.co.uk/wp-content/uploads/2021/08/National-Day-Surgery-Delivery-Pack_Aug2021_final.pdf. [Last Accessed 3 July 2022}. 2020.
7. NHS England and NHS Improvement. Delivering a 'Net Zero' national health service. Online: NHS England and NHS Improvement; 2020.
8. Campbell M, Pierce J. Atmospheric science, anaesthesia, and the environment. BJA Education. 2015;15.
9. Ravishankara AR, Daniel JS, Portmann RW. Nitrous oxide (N2O): the dominant ozone-depleting substance emitted in the 21st century. Science. 2009;326(5949):123-5.
10. Balentine CJ, Meier J, Berger M, Hogan TP, Reisch J, Cullum M, et al. Using local rather than general anesthesia for inguinal hernia repair is associated with shorter operative time and enhanced postoperative recovery. Am J Surg. 2021;221(5):902-7.
11. Sanjay P, Woodward A. Inguinal hernia repair: local or general anaesthesia? Ann R Coll Surg Engl. 2007;89(5):497-503.
12. Memtsoudis SG, Cozowicz C, Bekeris J, Bekere D, Liu J, Soffin EM, et al. Anaesthetic care of patients undergoing primary hip and knee arthroplasty: consensus recommendations from the International Consensus on Anaesthesia-Related Outcomes after Surgery group (ICAROS) based on a systematic review and meta-analysis. Br J Anaesth. 2019;123(3):269-87.
13. Lopes R, Shelton C, Charlesworth M. Inhalational anaesthetics, ozone depletion, and greenhouse warming: the basics and status of our efforts in environmental mitigation. Curr Opin Anaesthesiol. 2021;34(4):415-20.
14. Desai V, Chan PH, Prentice HA, Zohman GL, Diekmann GR, Maletis GB, et al. Is Anesthesia Technique Associated With a Higher Risk of Mortality or Complications Within 90 Days of Surgery for Geriatric Patients With Hip Fractures? Clin Orthop Relat Res. 2018;476(6):1178-88.
15. Chu DK, Kim LHY, Young PJ, Zamiri N, Almenawer SA, Jaeschke R, et al. Mortality and morbidity in acutely ill adults treated with liberal versus conservative oxygen therapy (IOTA): a systematic review and meta-analysis. The Lancet. 2018;391(10131):1693-705.
16. Hu X, Pierce JMT, Taylor T, Morrissey K. The carbon footprint of general anaesthetics: A case study in the UK. Resources, Conservation and Recycling. 2021;167:105411.
17. Arora N, Dennis A, Willson J, Norrie J, Tunstall M. Delivery of oxygen by standard oxygen flowmeters. Anaesthesia. 2021;76(11):1546-7.
18. Kostrubiak MR, Johns ZR, Vatovec CM, Malgeri MP, Tsai MH. Environmental Externalities of Switching From Inhalational to Total Intravenous Anesthesia. Anesthesia & Analgesia. 2021;132(5).
19. Zhong G, Abbas A, Jones J, Kong S, McCulloch T. Environmental and economic impact of using increased fresh gas flow to reduce carbon dioxide absorbent consumption in the absence of inhalational anaesthetics. British Journal of Anaesthesia. 2020;125(5):773-8.
20. Back M, Al-Attar A, Sutton R, Shelton C. Fresh gas flow during total intravenous anaesthesia and marginal gains in sustainable healthcare. Comment on Br J Anaesth 2020; 125: 773-8. British Journal of Anaesthesia. 2021;126(4):e143-e4.
21. Sherman J, Le C, Lamers V, Eckelman M. Life cycle greenhouse gas emissions of anesthetic drugs. Anesth Analg. 2012;114(5):1086-90.
22. Muret J, Fernandes TD, Gerlach H, Imberger G, Jörnvall H, Lawson C, et al. Environmental impacts of nitrous oxide: no laughing matter! Comment on Br J Anaesth 2019; 122: 587-604. Br J Anaesth. 2019;123(4):e481-e2.
23. Chakera A. F-WA, Allen C. Piped Nitrous Oxide Waste Reduction Strategy. . Association of Anaesthetist Nitrous Oxide Mtigation Project. 2021.
24. Ryan SM, Nielsen CJ. Global warming potential of inhaled anesthetics: application to clinical use. Anesth Analg. 2010;111(1):92-8.
25. Association of Anaesthetists. Anaesthetic gases calculator. Published online at: https://anaesthetists.org/Home/Resources-publications/Environment/Guide-to-green-anaesthesia/Anaesthetic-gases-calculator [Last accessed 5 July 2022]. [

# References
(Continued...)


26. Macario A, Dexter F, Lubarsky D. Meta-analysis of trials comparing postoperative recovery after anesthesia with sevoflurane or desflurane. American Journal of Health-System Pharmacy. 2005;62(1):63-8.
27. Shelton CL, Sutton R, White SM. Desflurane in modern anaesthetic practice: walking on thin ice(caps)? Br J Anaesth. 2020;125(6):852-6.
28. NHS England and NHS Improvement. NHS Standard Contract 2022/23 Service Conditions. Published online at: https://www.england.nhs.uk/wp-content/uploads/2022/03/03-full-length-standard-contract-22-23-service-conditions.pdf. [Last accessed 14 September 2022]. 2022.
29. Upadya M, Saneesh PJ. Low-flow anaesthesia - underused mode towards "sustainable anaesthesia". Indian J Anaesth. 2018;62(3):166-72.
30. Feldman JM. Managing fresh gas flow to reduce environmental contamination. Anesth Analg. 2012;114(5):1093-101.
31. Hinterberg J, Beffart T, Gabriel A, Holzschneider M, Tartler TM, Schaefer MS, et al. Efficiency of inhaled anaesthetic recapture in clinical practice. Br J Anaesth. 2022.
32. Eckelman M, Mosher M, Gonzalez A, Sherman J. Comparative life cycle assessment of disposable and reusable laryngeal mask airways. Anesth Analg. 2012;114(5):1067-72.
33. Sherman JD, Raibley LAt, Eckelman MJ. Life Cycle Assessment and Costing Methods for Device Procurement: Comparing Reusable and Single-Use Disposable Laryngoscopes. Anesth Analg. 2018;127(2):434-43.
34. McGain F, Story D, Lim T, McAlister S. Financial and environmental costs of reusable and single-use anaesthetic equipment. Br J Anaesth. 2017;118(6):862-9.
35. National Institute for Care and Health Excellence (NICE). Inadvertent perioperative hypothermia: The management of inadvertent perioperative hypothermia in adults (NICE CG65). Published online at: http://www.nice.org.uk/cg65 [Last accessed 21 September 2022]. 2008.
36. National Institute for Care and Health Excellence (NICE). Inditherm patient warming mattress for the prevention of inadvertent hypothermia (MTG7). Published online at: nice.org.uk/guidance/mtg7 [Last accessed 28 June 2022]2011.
37. Bayazit Y, Sparrow EM. Energy efficiency comparison of forced-air versus resistance heating devices for perioperative hypothermia management. Energy. 2010;35(3):1211-5.
38. Kimberger O, Held C, Stadelmann K, Mayer N, Hunkeler C, Sessler DI, et al. Resistive polymer versus forced-air warming: comparable heat transfer and core rewarming rates in volunteers. Anesth Analg. 2008;107(5):1621-6.
39. Tennison I, Roschnik S, Ashby B, Boyd R, Hamilton I, Oreszczyn T, et al. Health care's response to climate change: a carbon footprint assessment of the NHS in England. The Lancet Planetary Health. 2021;5(2):e84-e92.
40. Atcheson CL, Spivack J, Williams R, Bryson EO. Preventable drug waste among anesthesia providers: opportunities for efficiency. J Clin Anesth. 2016;30:24-32.
41. Gillerman RG, Browning RA. Drug use inefficiency: a hidden source of wasted health care dollars. Anesth Analg. 2000;91(4):921-4.
42. Lejus C, Blanloeil Y, Oudot M, Le Teurnier Y, Lepage JY, Loutrel O, et al. Atropine and ephedrine: a significant waste in the operating theatre. Anaesthesia. 2012;67(3):300-1.
43. Mankes R.F. Propofol wastage in anesthesia. Anesth Analg. 2012;114(5):1091-2.
44. Petre MA, Malherbe S. Environmentally sustainable perioperative medicine: simple strategies for anesthetic practice. Can J Anaesth. 2020;67(8):1044-63.
45. Haskins IN, Prabhu AS, Krpata DM, Perez AJ, Tastaldi L, Tu C, et al. Is there an association between surgeon hat type and 30-day wound events following ventral hernia repair? Hernia. 2017;21(4):495-503.
46. Markel TA, Gormley T, Greeley D, Ostojic J, Wise A, Rajala J, et al. Hats Off: A Study of Different Operating Room Headgear Assessed by Environmental Quality Indicators. J Am Coll Surg. 2017;225(5):573-81.
47. Shallwani H, Shakir HJ, Aldridge AM, Donovan MT, Levy EI, Gibbons KJ. Mandatory Change From Surgical Skull Caps to Bouffant Caps Among Operating Room Personnel Does Not Reduce Surgical Site Infections in Class I Surgical Cases: A Single-Center Experience With More Than 15 000 Patients. Neurosurgery. 2018;82(4):548-54.
48. Kothari SN, Anderson MJ, Borgert AJ, Kallies KJ, Kowalski TJ. Bouffant vs Skull Cap and Impact on Surgical Site Infection: Does Operating Room Headwear Really Matter? J Am Coll Surg. 2018;227(2):198-202.
49. Elmously A, Gray KD, Michelassi F, Afaneh C, Kluger MD, Salemi A, et al. Operating Room Attire Policy and Healthcare Cost: Favoring Evidence over Action for Prevention of Surgical Site Infections. J Am Coll Surg. 2019;228(1):98-106.
50. Woodhead K, Taylor EW, Bannister G, Chesworth T, Hoffman P, Humphreys H. Behaviours and rituals in the operating theatre. A report from the Hospital Infection Society Working Party on Infection Control in Operating Theatres. J Hosp Infect. 2002;51(4):241-55.

# References
(Continued...)


51. NHS Services Scotland. Antimicrobial Resistance and Healthcare Associated Infection Scotland. Scotland Infection Control team. Standard Infection Control Precautions literature review. Personal Protective Equipment (PPE): Headwear. Published online at: https://www.nipcm.hps.scot.nhs.uk/media/1669/2021-08-18-sicp-lr-headwear-v3.pdf. [Last accessed 18 June 2022]2021.
52. Dougherty J, Slowey C, Hermon A, Wolpaw J. Simple budget-neutral tool to improve intraoperative communication. Postgraduate Medical Journal. 2020;96(1141):703.
53. Department of Health and Social Care. Experimental statistics – personal protective equipment distributed for use by health and social care services in England: 10 May to 30 May 2021. Published online at: www.gov.uk/government/statistics/ppe-distribution-england-10-may-to-30-may-2021/experimental-statistics-personal-protective-equipment-distributed-for-use-by-health-and-social-care-services-in-england-10-may-to-30-may-2021> [Last accessed 22 March 2022]2022.
54. Vozzola E, Overcash M, Griffing E. An Environmental Analysis of Reusable and Disposable Surgical Gowns. Aorn j. 2020;111(3):315-25.
55. Overcash M. A comparison of reusable and disposable perioperative textiles: sustainability state-of-the-art 2012. Anesth Analg. 2012;114(5):1055-66.
56. Overcash MR, Sehulster LM. Estimated incidence rate of healthcare-associated infections (HAIs) linked to laundered reusable healthcare textiles (HCTs) in the United States and United Kingdom over a 50-year period: Do the data support the efficacy of approved laundry practices? Infect Control Hosp Epidemiol. 2021:1-2.
57. McQuerry M, Easter E, Cao A. Disposable versus reusable medical gowns: A performance comparison. Am J Infect Control. 2021;49(5):563-70.
58. Kieser DC, Wyatt MC, Beswick A, Kunutsor S, Hooper GJ. Does the type of surgical drape (disposable versus non-disposable) affect the risk of subsequent surgical site infection? J Orthop. 2018;15(2):566-70.
59. NHS England and NHS Improvement. Decontamination of linen for health and social care: Management and provision (HTM 01-04). In: Care. DoHaS, editor. Published online at: https://www.england.nhs.uk/publication/decontamination-of-linen-for-health-and-social-care-htm-01-04/. [Last accessed 28 June 2022]. 2016.
60. National institute for health and clinical excellence (NICE). Surgical Site Infections: prevention and treatment (NG125). Published online at: https://www.nice.org.uk/guidance/ng125/resources/surgical-site-infections-prevention-and-treatment-pdf-66141660564421. [Last Accessed 7 April 2022]: NICE; 2019.
61. Boyce JM. Using Alcohol for Hand Antisepsis: Dispelling Old Myths. Infection Control & Hospital Epidemiology. 2000;21(7):438-41.
62. Pratt RJ, Pellowe C, Loveday HP, Robinson N, Smith GW, Barrett S, et al. The epic project: developing national evidence-based guidelines for preventing healthcare associated infections. Phase I: Guidelines for preventing hospital-acquired infections. Department of Health (England). J Hosp Infect. 2001;47 Suppl:S3-82.
63. Global Guidelines for the Prevention of Surgical Site Infection. Web Appendix 10, Summary of a systematic review on surgical hand preparation., (2018).
64. Boyce JM, Pittet D. Guideline for Hand Hygiene in Health-Care Settings. Recommendations of the Healthcare Infection Control Practices Advisory Committee and the HICPAC/SHEA/APIC/IDSA Hand Hygiene Task Force. Society for Healthcare Epidemiology of America/Association for Professionals in Infection Control/Infectious Diseases Society of America. MMWR Recomm Rep. 2002;51(Rr-16):1-45, quiz CE1-4.
65. Gaspar GG, Menegueti MG, Lopes AER, Santos ROC, de Araújo TR, Nassiff A, et al. Alcohol-based surgical hand preparation: translating scientific evidence into clinical practice. Antimicrob Resist Infect Control. 2018;7:80.
66. Tanner J, Dumville JC, Norman G, Fortnam M. Surgical hand antisepsis to reduce surgical site infection. Cochrane Database Syst Rev. 2016;2016(1):Cd004288.
67. Lopes AER, Menegueti MG, Gaspar GG, Tartari E, da Silva Canini SRM, Pittet D, et al. Comparing surgeon's skin tolerance and acceptability to alcohol-based surgical hand preparation vs traditional surgical scrub: A matched quasi-experimental study. American Journal of Infection Control. 2022;50(10):1091 - 7.
68. Parienti JJ, Thibon P, Heller R, Le Roux Y, von Theobald P, Bensadoun H, et al. Hand-rubbing with an aqueous alcoholic solution vs traditional surgical hand-scrubbing and 30-day surgical site infection rates: a randomized equivalence study. Jama. 2002;288(6):722-7.
69. Kampf G, Muscatiello M. Dermal tolerance of Sterillium, a propanol-based hand rub. J Hosp Infect. 2003;55(4):295-8.
70. Jehle K, Jarrett N, Matthews S. Clean and Green: Saving Water in the Operating Theatre. The Annals of The Royal College of Surgeons of England. 2008;90(1):22-4.
71. Wormer BA, Augenstein VA, Carpenter CL, Burton PV, Yokeley WT, Prabhu AS, et al. The green operating room: simple changes to reduce cost and our carbon footprint. Am Surg. 2013;79(7):666-71.

# References
(Continued...)


72. Marchand R, Theoret S, Dion D, Pellerin M. Clinical implementation of a scrubless chlorhexidine/ethanol pre-operative surgical hand rub. Can Oper Room Nurs J. 2008;26(2):21-2, 6, 9-31.

73. Javitt MJ, Grossman A, Grajewski A, Javitt JC. Association Between Eliminating Water From Surgical Hand Antisepsis at a Large Ophthalmic Surgical Hospital and Cost. JAMA Ophthalmol. 2020;138(4):382-6.

74. Weight CJ, Lee MC, Palmer JS. Avagard hand antisepsis vs. traditional scrub in 3600 pediatric urologic procedures. Urology. 2010;76(1):15-7.

75. Nuffield Trust. Antibiotic prescribing. Published online at: https://www.nuffieldtrust.org.uk/resource/antibiotic-prescribing [Last accessed 4th July 2022]: Nuffield Trust.; 2020.

76. Klein EY, Boeckel TPV, Martinez EM, Pant S, Gandra S, Levin SA, et al. Global increase and geographic convergence in antibiotic consumption between 2000 and 2015. Proceedings of the National Academy of Sciences. 2018;115(15):E3463-E70.

77. Murray CJL, Ikuta KS, Sharara F, Swetschinski L, Robles Aguilar G, Gray A, et al. Global burden of bacterial antimicrobial resistance in 2019: a systematic analysis. The Lancet. 2022;399(10325):629-55.

78. Apreja M, Sharma A, Balda S, Kataria K, Capalash N, Sharma P. Antibiotic residues in environment: antimicrobial resistance development, ecological risks, and bioremediation. Environ Sci Pollut Res Int. 2022;29(3):3355-71.

79. Sun AJ, Comiter CV, Elliott CS. The cost of a catheter: An environmental perspective on single use clean intermittent catheterization. Neurourol Urodyn. 2018;37(7):2204-8.

80. Stripple H, Westman R, Holm D. Development and environmental improvements of plastics for hydrophilic catheters in medical care: an environmental evaluation. Journal of Cleaner Production. 2008;16(16):1764-76.

81. Gordon IO, Sherman JD, Leapman M, Overcash M, Thiel CL. Life Cycle Greenhouse Gas Emissions of Gastrointestinal Biopsies in a Surgical Pathology Laboratory. Am J Clin Pathol. 2021;156(4):540-9.

82. Darmas B, Mahmud S, Abbas A, Baker AL. Is there any justification for the routine histological examination of straightforward cholecystectomy specimens? Annals of the Royal College of Surgeons of England. 2007;89(3):238-41.

83. Whiting A TI, Roschnik S, Collins M. Surgery and the NHS carbon footprint. The Bulletin of the Royal College of Surgeons of England. 2020;102(5):182-5.

84. Drew J, Christie SD, Tyedmers P, Smith-Forrester J, Rainham D. Operating in a Climate Crisis: A State-of-the-Science Review of Life Cycle Assessment within Surgical and Anesthetic Care. Environ Health Perspect. 2021;129(7):76001.

85. Rizan C, Bhutta MF. Environmental impact and life cycle financial cost of hybrid (reusable/single-use) instruments versus single-use equivalents in laparoscopic cholecystectomy. Surg Endosc. 2021.

86. Siu J, Hill AG, MacCormick AD. Systematic review of reusable versus disposable laparoscopic instruments: costs and safety. ANZ J Surg. 2017;87(1-2):28-33.

87. Adler S, Scherrer M, Rückauer KD, Daschner FD. Comparison of economic and environmental impacts between disposable and reusable instruments used for laparoscopic cholecystectomy. Surg Endosc. 2005;19(2):268-72.

88. Rizan C, Bhutta MF. Environmental impact and life cycle financial cost of hybrid (reusable/single-use) instruments versus single-use equivalents in laparoscopic cholecystectomy. Surg Endosc. 2022;36(6):4067-78.

89. Farrokhi FR, Gunther M, Williams B, Blackmore CC. Application of Lean Methodology for Improved Quality and Efficiency in Operating Room Instrument Availability. The Journal for Healthcare Quality (JHQ). 2015;37(5):277-86.

90. Rizan C, Lillywhite R, Reed M, Bhutta MF. Minimising carbon and financial costs of steam sterilisation and packaging of reusable surgical instruments. Br J Surg. 2022;109(2):200-10.

91. Zygourakis CC, Yoon S, Valencia V, Boscardin C, Moriates C, Gonzales R, et al. Operating room waste: disposable supply utilization in neurosurgical procedures. J Neurosurg. 2017;126(2):620-5.

92. Chasseigne V, Leguelinel-Blache G, Nguyen TL, de Tayrac R, Prudhomme M, Kinowski JM, et al. Assessing the costs of disposable and reusable supplies wasted during surgeries. Int J Surg. 2018;53:18-23.

93. Wilson J, Prieto J, Singleton J, O'Connor V, Lynam S, Loveday H. The misuse and overuse of non-sterile gloves: application of an audit tool to define the problem. Journal of Infection Prevention. 2015;16(1):24-31.

94. Loveday HP, Lynam S, Singleton J, Wilson J. Clinical glove use: healthcare workers' actions and perceptions. J Hosp Infect. 2014;86(2):110-6.

95. GOSH. Great Ormond Street Hospital for Children NHS Foundation Trust: News [Internet]. Published online at: https://www.gosh.nhs.uk/news/gloves-are-off/ [Last Accessed 3 July 2022].

# References
(Continued...)


96. Thiel CL, Eckelman M, Guido R, Huddleston M, Landis AE, Sherman J, et al. Environmental impacts of surgical procedures: life cycle assessment of hysterectomy in the United States. Environ Sci Technol. 2015;49(3):1779-86.

97. Coulter WA, Chew-Graham CA, Cheung SW, Burke FJ. Autoclave performance and operator knowledge of autoclave use in primary care: a survey of UK practices. J Hosp Infect. 2001;48(3):180-5.

98. Health Technical Memorandum 01-01: Management and decontamination of surgical instruments., (2016).

99. Reprocessed Single-use Medical Devices: FDA Oversight Has Increased, and Available Information Does Not Indicate that Use Presents an Elevated Health Risk: Report to the Committee on Oversight and Government Reform, House of Representatives, (2008).

100. Unger S, Landis A. Assessing the environmental, human health, and economic impacts of reprocessed medical devices in a Phoenix hospital's supply chain. Journal of Cleaner Production. 2016;112:1995-2003.

101. Schulte A, Maga D, Thonemann N. Combining Life Cycle Assessment and Circularity Assessment to Analyze Environmental Impacts of the Medical Remanufacturing of Electrophysiology Catheters. Sustainability. 2021;13(2):898.

102. Excellence. NIfHaC. Evidence review for the effectiveness of skin antiseptics in the prevention of surgical site infection: Surgical site infections: prevention and treatment: Evidence review B. . In: (NICE). NIfHaCE, editor. (NICE Guideline, No 125). Published online at: https://www.ncbi.nlm.nih.gov/books/NBK569835/. [Last accessed 4th July 2022]2019.

103. Ademuyiwa AO, Hardy P, Runigamugabo E, Sodonougbo P, Behanzin H, Kangni S, et al. Reducing surgical site infections in low-income and middle-income countries (FALCON): a pragmatic, multicentre, stratified, randomised controlled trial. The Lancet. 2021;398(10312):1687-99.

104. Pencheon D. DA. Pollution from the health and care System. Published online at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/690846/CMO_Annual_Report_2017_Health_Impacts_of_All_Pollution_what_do_we_know.pdf [Last accessed 4th July 2022]: Department of Health and Social Care; 2017.

105. Rizan C, Bhutta MF, Reed M, Lillywhite R. The carbon footprint of waste streams in a UK hospital. Journal of Cleaner Production. 2021;286:125446.

106. Pegg M, Rawson R, Okere U. Operating room waste management: A case study of primary hip operations at a leading national health service hospital in the United Kingdom. J Health Serv Res Policy. 2022:13558196221094488.

107. van Straten B, Dankelman J, van der Eijk A, Horeman T. A Circular Healthcare Economy; a feasibility study to reduce surgical stainless steel waste. Sustainable Production and Consumption. 2021;27:169-75.

108. Ibbotson S, Dettmer T, Kara S, Herrmann C. Eco-efficiency of disposable and reusable surgical instruments—a scissors case. The International Journal of Life Cycle Assessment. 2013;18(5):1137-48.

109. Rizan C, Brophy T, Lillywhite R, Reed M, Bhutta MF. Life cycle assessment and life cycle cost of repairing surgical scissors. The International Journal of Life Cycle Assessment. 2022;27(6):780-95.

110. Putri CA, Rezai P, Currie Z. Cost analysis of disposable versus non-disposable instruments for oculoplastics minor operations. Investigative Ophthalmology & Visual Science. 2019;60(9):5456-.

111. MacNeill AJ, Lillywhite R, Brown CJ. The impact of surgery on global climate: a carbon footprinting study of operating theatres in three health systems. The Lancet Planetary Health. 2017;1(9):e381-e8.

112. Kaplan S, Sadler B, Little K, Franz C, Orris P. Can sustainable hospitals help bend the health care cost curve? Issue Brief (Commonw Fund). 2012;29:1-14.

113. Pierce J, Morris G, Parker B. Reducing theatre energy consumption. Health estate. 2014;68:58-62.

114. Health Technical Memorandum 03-01 Specialised ventilation for healthcare premises Part B., (2021).

115. Gandhi J. HJ, Shinde S.,. The Anaesthetic Gas Scavenging System (AGSS) Project. Published online at: https://sustainablehealthcare.org.uk/what-we-do/sustainable-specialties/anaesthetics/anaesthetic-gas-scavenging-system.: Centre for Sustainable Healthcare [Last accessed 8 September 2022]. 2022 [