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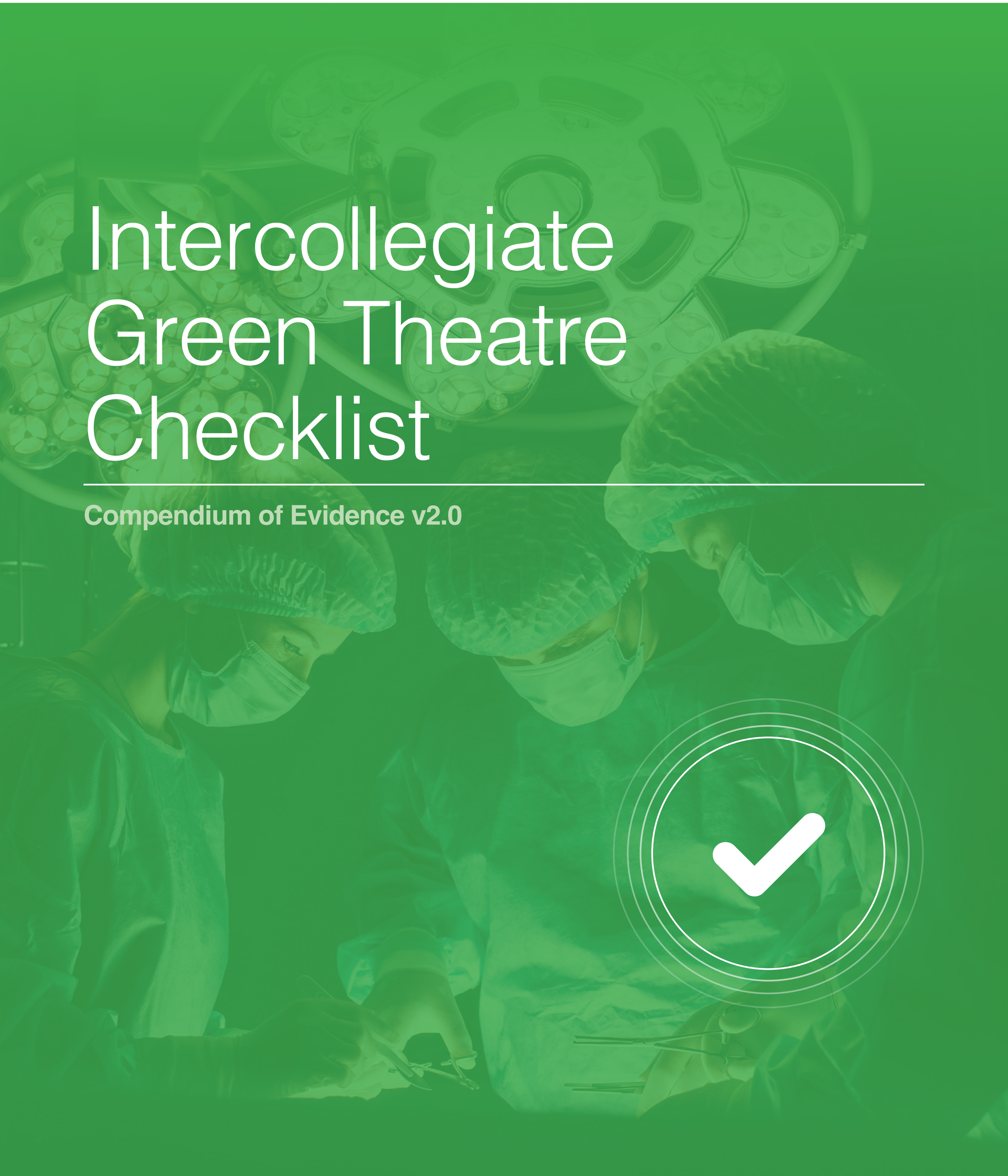
Intercollegiate Green Theatre Checklist

Compendium of Evidence v2.0



Welcome to the Intercollegiate Green Theatre Checklist Compendium of Evidence v2.0

According to the World Health Organization, 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 kgCO_2e (carbon dioxide equivalents),[2] similar to the carbon footprint of driving 644 miles in an average petrol car.[3]

The UK and Ireland Surgical Colleges, The Association of Anaesthetists, The Royal College of Anaesthetists and the Association for Perioperative Practice have all 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,[4] whilst ensuring clinical standards of care are maintained, if not improved.

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 anaesthesia, and the subsequent three looking at preparation for surgery, intra-operative practice and post-operative measures.

Based on feedback, we have modified the checklist so that it now highlights the interventions that can be applied on the day – in the green rows– and separates below those interventions that will require more time to be implemented – in the white rows.

Using the green rows only makes the checklist amenable to use at the brief at the start of an operating list, as an aide-memoire for the team.

The extended checklist remains as a roadmap to guide transformation towards sustainable practice at a departmental level, including interventions that require discussion and planning with relevant stakeholders, including management, procurement, infection control and prevention, estates, etc.

On a day-to-day basis, opting for reusable equipment, avoiding opening unnecessary equipment, as well as administering an anaesthetic technique which balances patient needs, surgical requirements and environmental emissions, are changes associated with high environmental impact.

In the longer term, interventions with the most significant environmental gains are expected to be the decommissioning of nitrous oxide (N_2O) centralised delivery systems as well as the implementation of energy saving strategies for "powering off" (with accompanying safety protocols). Both of these require some departmental engagement but are relatively simple to introduce and are associated with significant financial incentives for trusts.

In particular, due to the relative simplicity of the task and the reduction in environmental impacts immediately attained, all trusts should proceed to urgently decommission centralised N_2O delivery systems (and substitution by portable cylinders) as the single most effective measure to significantly reduce their environmental impact with no effects on patient care (whilst securing financial savings).[5]

If completed regularly, the checklist can be used as a scorecard to monitor progress and demonstrate achievements made towards establishing a greener surgical practice.

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 and we refer you to the recent Green Surgery Report (published by UK Health Alliance on Climate Change, Brighton & Sussex Medical School and the Centre for Sustainable Healthcare) for a comprehensive review.[6]

The biggest way to reduce the carbon footprint of surgery is primary prevention of surgical disease. The first principle of surgery is therefore health promotion and disease prevention/optimisation through lifestyle changes, dietary advice, patient education and patient empowerment.[7]

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.[8]

When surgery is necessary, the whole pathway should be rationalised and streamlined, including utilising virtual consultations, one-stop clinics, diagnostic hubs, daycase surgery,[9] and ambulatory or office surgery whenever possible and clinically appropriate.

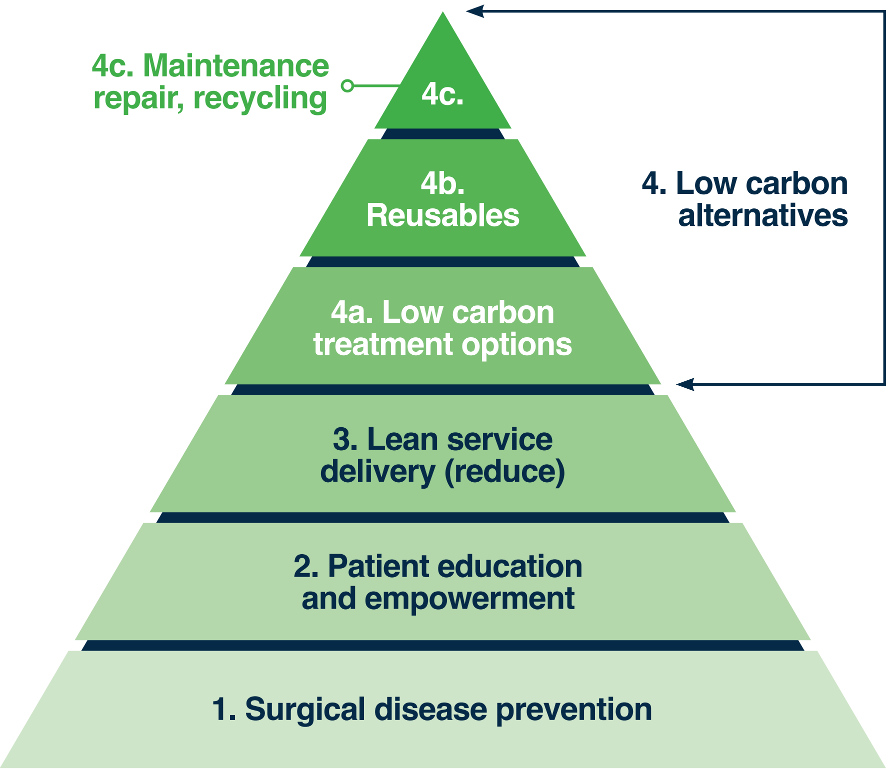


Figure 1. Principles of sustainability in healthcare.[7]

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Authors

Lead Author

Miss Jasmine Winter Beatty MBBS BSc(Hons) MRCS DMCC *- General Surgery Specialist Registrar, NW London Deanery. Clinical Research Fellow, Imperial College London. Sustainability Champion, Royal College of Surgeons of Edinburgh.*

Collaborating Authors

Mr Henry Douglas Robb MBChB BSc(Hons) MSc MRCS *- General Surgery Specialist Registrar NW London Deanery, Academic Clinical Fellow, Imperial College London.*

Mr James Chu Bsc(Hons) *- Foundation year 1 trainee, University Hospitals Sussex. Affiliate and Sustainability Champion Royal College of Surgeons of Edinburgh.*

Miss Victoria Pegna MSc FRCS *- Consultant Colorectal Surgeon, University Hospital Sussex. Founding Chair of the Sustainability in Surgery Committee at the Royal College of Surgeons of England.*

Miss Alyss Vaughan Robinson MBChB(Hons) MRes MRCS *- Core Surgical Trainee KSS Deanery.*

Dr Francesca Testa MBBS BSc(Hons) *- Foundation Doctor, University Hospitals Sussex. NHS Clinical Entrepreneur.*

Miss Katherine Hurst MB BCh BSc(Hons) MRCS *- General Surgery Specialist Registrar, Thames Valley Deanery. Chair of Sustainability Champions, Royal College of Surgeons of Edinburgh and RCSEd council member.*

Anaesthetic Advisors

Dr Cliff Shelton MBChB PhD FRCA *– Consultant Anaesthetist, Wythenshawe Hospital, Manchester University NHS Foundation Trust. Senior Clinical Lecturer in Anaesthesia, Lancaster Medical School, Lancaster University. Co-opted member of the Environment and Sustainability Committee, Association of Anaesthetists.*

Dr Kenneth Barker MBChB, FRCA *- Consultant Anaesthetist, Clinical Lead for Sustainability NHSH, Raigmore Hospital. Chair of Environment and Sustainability Committee, Association of Anaesthetists. Clinical Lead, National Green Theatres Project, Centre for Sustainable Delivery, NHS Scotland.*

Dr Jason Gandhi MBChB *- Specialist registrar in Anaesthesia, Association of Anaesthetists and Centre for Sustainable Healthcare National Fellow in Environmentally Sustainable Anaesthesia.*

Assoc. Professor Dr Forbes McGain MBBS FANZCA FCICM PhD - *Anaesthetist and ICU Physician, Western Health, Melbourne. Associate Professor, Critical Care, University of Melbourne.*

RCOA Environmental Advisors

Senior Advisors

Assoc. Professor Chantelle Rizan BSc(Hons) MBBCh MRes MRCS(ENT) – *Associate Professor, Center for Sustainable Medicine, National University of Singapore.*

Professor Mahmood Bhutta DPhil FRCS *- Chair in ENT and Sustainable Healthcare, Brighton & Sussex Medical School. ENT Consultant and Clinical Green Lead, University Hospitals Sussex.*

On behalf of:

The Royal College of Surgeons of Edinburgh, The Royal College of Surgeons of England, the Royal College of Physicians and Surgeons of Glasgow, the Royal College of Surgeons of Ireland, the Association of Anaesthetists, the Royal College of Anaesthetists and the Association For Perioperative Practice.

Intercollegiate Green Theatre Checklist v2.0

Below is a list of recommendations to reduce the environmental impact of operating theatres. Interventions in the **green** rows can be implemented on the day without prior preparation and can be used as part of a daily pre-operative checklist. Interventions in the **white** rows are those requiring wider stakeholder engagement and planning and may be suitable for monthly review or to help identify areas for quality improvement projects. Relevant guidance and academic literature supporting this checklist is included in the Compendium of Evidence, available at this link:

Anaesthesia

1 Limit Nitrous Oxide (N_2O) to specific cases where there is evidence of clinical benefit ☐

Decommission manifolds and switch to N_2O cylinders at point of use (or repair pipe leaks if centralized delivery still used)

2 Consider TIVA and ensure that all drug waste and giving sets are disposed of through the pharmaceutical waste stream ☐

3 If using inhalational anaesthesia:
- use low-flow anaesthesia (via end-tidal anaesthetic gas control, if available) ☐

Remove desflurane from formulary

4 Reduce waste:
- avoid unnecessary equipment and opt for reusables (e.g. laryngoscopes, body warmers, slide sheets, trays, soda lime canisters) ☐
- transfer single-use objects with the patient if still needed (e.g. facemasks, suction) ☐

Review and rationalise pre-prepared single-use equipment packs and PPE requirements for standard procedures

5 Minimise drug waste (“*Don’t open unless needed*”, pre-empt propofol use, titrate O_2) and dispose in correct pharmaceutical waste stream ☐

Use air instead of oxygen as the ventilator drive gas

Preparing for Surgery

6 Evaluate PPE and sterile field requirements:
- rationalise use of non-sterile single-use gloves and PPE and opt for reusables when possible ☐
- limit sterile field to necessary areas only ☐

Ensure availability of reusable textiles, including theatre hats, sterile gowns, patient drapes, and trolley covers

7 Reduce water and energy consumption:
- *‘rub don’t scrub’*: after first water scrub of day, you can use alcohol rub for subsequent cases ☐

Install automatic or pedal-controlled water taps

8 Avoid clinically unnecessary interventions (e.g. antibiotics, urinary catheterisation, histology examinations) ☐

Intraoperative Equipment

9 REVIEW AND RATIONALISE:
- clarify necessary kit for case and specify what should be available to open only if needed: “Just in time” ☐
- take the opportunity to review instrument sets and identify any targets for overage reduction ☐

- Review pre-prepared single-use surgical packs and engage with suppliers to remove surplus items and identify those that can be replaced with reusable options (to be included in instrument sets)
- Review reusable instrument sets, remove overage, integrate supplementary items into sets, consolidate sets only if it allows smaller/fewer sets (please see guidance)

10 REDUCE: unnecessary waste and single-use equipment, “*don’t open it unless you need it*”, limit CO_2 insufflation ☐

11 REUSE: opt for reusables, hybrid, or remanufactured equipment instead of single-use (e.g. gallipots, light handles, staplers, energy devices) ☐

Consider sourcing reusable, hybrid or remanufactured alternatives for single-use equipment

12 REPLACE: switch to low carbon alternatives (e.g. skin sutures vs. clips, “loose” antiseptic solutions in reusable gallipots) ☐

After the Operation

13 POWER OFF: Heating, Ventilation, Air conditioning (HVAC), AGSS, lights, computers and equipment out-of-hours ☐

- Switch off AGSS when theatres are not in use or volatile anaesthesia is not being utilised
- Introduce “shut-down” and “power on” checklists
- Install occupancy sensors and automatise “set-back” modes HVAC systems

14 RECYCLE/use lowest carbon appropriate waste streams:
- use recycling waste streams for packaging or, if not available, domestic waste stream (prior to patient entering the room) ☐
- use non-infectious offensive waste streams (yellow/black tiger) unless clear risk of infection (orange) ☐
- ensure only appropriate contents in sharps bins (sharps/drugs) ☐

- Switch to low impact sharp bins e.g. reusable or cardboard boxes
- Arrange metals/battery collection where possible

15 REPAIR: ensure damaged reusable equipment is repaired, encourage active maintenance ☐

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

A number of simple changes to clinical practice can be taken to minimise the environmental impacts of anaesthesia. Tackling pre-utilisation waste (e.g., drugs / equipment that are prepared but never used), and wasteful clinical practices (e.g., excessive fresh gas flows with inhalation anaesthesia) are obvious mitigation targets. Whilst concern has existed for some time regarding the climate impact of the volatile anaesthetic agents, it is acknowledged that they represent a small overall proportion of radiative forcing (the process that can lead to global warming).[10] As such, the most important target for mitigation in UK anaesthetic practice at the present time is nitrous oxide (N_2O).

Globally, the radiative forcing from anaesthetic emissions of N_2O is estimated to be around 0.1% of the climate effect due to CO_2 increases resulting from human activity[11]. In addition to having long-term greenhouse gas effect,[12] N_2O contributes directly to the destruction of the ozone layer.[13] Of note, the clinical use of nitrous oxide currently represents the minority of nitrous oxide emissions, whereas the largest proportion of gas is wasted from centralised delivery systems.

When administrating inhalational anaesthesia, the routine use of N_2O in general anaesthesia should be abandoned and good volatile husbandry should be adopted,[14] including minimising fresh gas flows and avoiding anaesthetic drug waste. Further measures requiring capital investment should also be introduced, such as decommissioning centralised N_2O delivery, automating shutdown systems for equipment, air handling and Anaesthetic Gas Scavenging Systems (AGSS), as well as using end-tidal target control of volatile concentration, if available, to minimise volatile waste. Concomitantly, other measures applying the general principles of sustainability should be adopted, including: waste prevention, reducing consumption of resources, in particular by avoiding single-use products, and switching to reusable options whenever possible.

Use of local/regional anaesthesia

Where possible and appropriate, it is important to discuss anaesthetic options with the patient and the anaesthetic team prior to the day of surgery, ideally at the time of first agreeing to surgical intervention, in order to ensure patients, receive information on all treatment options for an informed consent. For this reason, this point has been removed from the checklist itself but remains an important consideration and thus useful information is included here.

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.[15-17] Wide-awake Local Anaesthesia Without Tourniquet (WALANT) is used ubiquitously for hand and upper limb surgery, in many centres being performed in ambulatory settings.[18]

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[19] but also because of the associated shortened patient stay,[15, 20] which reduces individual patient resource consumption and improves efficiency in theatres, as well as the possibility of being performed outside of resource-intense operating theatres.

Limit Nitrous Oxide (N_2O) use and waste

Nitrous oxide (N_2O) is an important long-lived anthropogenic greenhouse gas with obvious mitigation opportunities.[12] A recent consensus statement from the Royal College of Anaesthetists, the Association of Anaesthetists, the College of Anaesthesiologists of Ireland, the Obstetric Anaesthetists' Association and the Association of Paediatric Anaesthetists of Great Britain and Ireland has recommended that nitrous oxide no longer be considered an essential drug, and that nitrous oxide manifolds be decommissioned by the end of 2026/27 financial year.[21]

The use of N_2O in anaesthesia should be limited to only those specific cases where there is evidence of clinical benefit, as its use is not mandatory for any form of anaesthesia, including paediatric anaesthesia.[22]

Importantly it must be noted that, although N_2O has a similar carbon footprint to desflurane at clinically-equivalent doses,[23] its use in practice has reduced significantly, and most of its impact is due to waste though leaks from centralised hospital delivery systems.[24] Reports have shown that over 90% of piped N_2O leaks from hospital central delivery systems and can enter the atmosphere prior to any clinical use with millions of litres wasted in this way every year.[24-26]

Faulty equipment and infrastructure, poor stock management (all cylinders returned to the manufacturers after use are vented into the atmosphere, irrespective of remaining quantity contained) and theft are also recognised contributing factors. [24]

NHS Scotland has launched a comprehensive strategy to mitigate Nitrous Oxide emissions from system loss and mismanagement, centred on three core objectives:

- *The removal of anaesthetic nitrous oxide where not clinically necessary,*
- *The establishment of the leanest physical supply system,*
- *The introduction of continuous system monitoring and reporting.[5]*

As mentioned above, the relative simplicity of decommissioning centralised piping and the significant environmental savings immediately attained, should drive all trusts to urgently decommission centralised delivery systems as a single most highly effective measure to significantly reduce their environmental impact, with no effects on patient care, whilst securing financial savings.[5]

- *Decommission manifolds and switch to N_2O cylinders at point of use (or repair pipe leaks if centralized delivery still used).*

  If possible, proceed directly to decommissioning N_2O manifolds and replace 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).[24] If use of centralised delivery systems is unavoidable, then it is imperative to immediately check pipes for leaks and repair as soon as possible and to ensure regular close monitoring is maintained thereafter.

  Consider N_2O catalytic destruction for patient-controlled use:

  Use of "gas and air" or pure N_2O in other areas of the hospital or healthcare services (Dental, Emergency Department, Endoscopy, Maternity, Ambulance) should be examined and alternatives sought where clinically appropriate. If need for N_2O persists, and mitigating actions to lean supply and prevent wastage have been implemented, then catalytic destroyers should be considered for patient-controlled delivery, with care given to educate patients on the technique for optimal expired gas capture.

Consider total intravenous anaesthesia (TIVA) and correctly dispose of drug waste and giving sets

All anaesthetic compounds have the potential to cause biotoxic and water contamination effects.[27] To date the environmental concentration of propofol has been calculated to be below levels considered harmful to humans or other lifeforms.[28] However with the increasing usage of TIVA in the UK, this analysis should be periodically updated. Correct disposal of drug waste and contaminated giving sets is essential to minimise these environmental effects (see later section on pharmaceutical waste disposal).

In the absence of inhalational anaesthetic agents, using the lowest FiO_2 possible during the maintenance of anaesthesia is associated with the lowest environmental impact. Increasing the fresh gas flows (FGF) increases the associated CO_2e, though the difference is modest when a low FiO_2 (e.g. 30%) is used, compared to when a high FiO_2 (e.g. over 60%) is used, where the CO_2e doubles.[29] However, using higher FGF reduces CO_2 absorbent consumption, which confers financial benefits and reduces the amount of plastic and absorbent material disposed of though hospital waste streams. It is also worth remembering that opting for medical air as a fresh gas carrier offers environmental savings, as its production requires approximately only 1/10th of the energy required to produce liquified O_2.[30, 31]

If using inhalation anaesthesia:

Sevoflurane currently represents the overwhelming majority volatile anaesthetic agent use (e.g., in NHS England: Sevoflurane ~95%, Isoflurane ~4.5%, desflurane ~0.5%, by volume supplied). Sevoflurane is appropriate

Anaesthesia
(Continued...)

for most circumstances where volatile anaesthesia is used and is considered to have the lowest environmental impacts of the modern volatile anaesthetic agents.[32] Nevertheless, it should be administered in a way that minimises waste while maintaining high-quality clinical care; this generally involves using low-flow anaesthesia.

- *Use low-flow anaesthesia (via end-tidal anaesthetic gas control, if available)*

  Low flow anaesthesia via end-tidal anaesthetic gas control (ETAG) has been shown to help preserve resources as well as reduce the environmental impact of an anaesthetic.[33, 34] This should be used when available, and when procuring new anaesthetic machines, departments should consider purchasing those with ETAG functionality.

- *Volatile capture technology (VCT):*

  We previously recommended considering the use of VCT, a technology that captures molecules of volatile agents after they have been expired by the patient, before they are released unmitigated into the atmosphere through the AGSS. However, further research and development on the clinical application of VCT is necessary before wide-spread adoption can be advocated.

  VCT has the potential to allow an almost circular system for anaesthetic gas usage and may even offer advantages over TIVA due to reduced environmental permanence and potential biotoxicity. When used in addition to a carrier mix of O_2/air at the lowest flow rate, it has been estimated to have lower environmental impact compared to propofol based anaesthesia (if a 70% capture rate is assumed).[35]

  However, a large proportion of the volatile agent may be lost when patients are disconnected from the anaesthetic circuit, either during transfer or, more significantly, during the postoperative period. Real-life research has so far shown disparate results and relatively low yields, with capture rates between 25 to 70% of the total volatile volume administered to a patient.[35, 36] In addition, there is as yet uncertainty regarding potential for reuse of the captured gases in human clinical practice, with legislation in many countries still awaited. Unless and until extraction and re-use are permitted, the environmental benefits of VCT canisters will go unrealised, and VCT may even lead to environmental harms if capture canisters are disposed of by incineration.

- *Remove desflurane from formulary:*

  Clinical use of desflurane has fallen dramatically and ongoing phasing-out efforts mean NHS Scotland was the first healthcare system to formally remove desflurane from its supply chain in March 2023.[37, 38] Desflurane was also decommissioned from routine practice by NHS England in 2024,[39] with clinical exceptions for specified neurosurgical cases as defined by the Neuro Anaesthesia and Critical Care Society, while more evidence is sought.[40] Of note, desflurane is the first medicine to be decommissioned by NHS England because of its environmental effects.[39]

  The recent NICE evidence review has shown no therapeutic or service provision advantages for patients undergoing neurological procedures or with a body mass index (BMI) of at least 30 kg/m^2.[39]

  Although desflurane was previously associated with very limited reductions in emergence time (1-2 minutes), research has suggested that these effects are not clinically significant.[41]

  Continued routine use of desflurane could not be justified due to increased greenhouse gas emissions (both in terms of CO_2 production and administration,[23] and point of care emissions of desflurane), the lack of evidenced clinical benefit and increased financial cost.[42]

Anaesthesia
(Continued...)

Minimise waste

- *Avoid unnecessary equipment and disposables, opting for reusable equipment where possible:*

  Rationalise the contents of equipment packs and avoid unnecessary use of personal protective equipment where use not supported by evidence.

  Reusable anaesthetic equipment (such as supraglottic airways,[43] laryngoscopes,[44, 45] face masks,[45] anaesthetic circuits,[46] direct-contact heaters, slide sheets, drug trays,[47] cold sticks[48-50], can not only provide cost savings but also reduce the anaesthetic carbon footprint by as much as 84% in the UK (48% in the USA).[45] If still needed, remember to transfer single-use objects with the patient (e.g. facemasks, Yankauer suckers).

  Reusable body warmers:

  Consideration as to whether warming devices are needed routinely for all operations should be taken.[51] For brief operations (surgery expected to last less than 30 mins and no increased risk of inadvertent perioperative hypothermia), warming devices may not be needed at all (similar to single-use Deep Venous Thrombosis prophylaxis stockings and intermittent compression devices).[51]

  If warming is needed, NICE guidance recommends the use of forced-air warming (FAW) devices and, if not available, direct-contact heaters (DCH).[51] It has been suggested that DCH have an equivalent efficacy to FAW in terms of preventing patient hypothermia[51-57], but more quality evidence is needed.

  Currently all FAW devices are single use and have a less energy efficient profile in comparison to DCH[53]. DCH are also easily cleaned and relatively silent,[54, 56] and have been promoted as a more cost-effective (lower running costs, reduced supply maintenance efforts) and practical alternative to FAW.[57]

  Conversely it should be noted that DCH may take longer to apply than FAW alternatives and are not transferable "in situ" on the patient. DCHs therefore may represent an alternative to single use FAW heaters in elective situations.

  In addition, many DCH devices have a limited lifespan (2-5 years depending on product), and therefore a formal life cycle assessment is needed to substantiate claims that DCH are environmentally and financially preferable.

  NICE suggests trials are required to determine the compared efficacy and safety profile of FAW and DCH[51], and we advocate this should also consider the environmental and cost implications of each modality.

Minimise drug waste and dispose of correctly in pharmaceutical waste streams

Pharmaceuticals make up 20% of total NHS England emissions,[58] and are causing growing concerns regarding environmental contamination and the resulting effects on human and other lifeforms. Numerous strategies have been described to tackle the huge amount of pharmaceuticals wasted globally and we strongly encourage these to be considered at local, departmental and national levels. Measures suggested include drawing up "as and when required", recycling schemes for patient delivery systems, reusing/refilling delivery equipment, as well as prefilled drug syringes.[59, 60]

Don't open unless needed!

Anaesthetic drug waste was estimated to cost USD $185,250 (~£148,000) per year in one USA institution alone,[61] equivalent to 51,700 kgCO_2e/year. Drug waste represents up to 26% of the entire anaesthesia drug budget,[62] and includes emergency drugs which are wasted in between 39% to 91% of cases.[60]

Reduce propofol waste:

Multidose vial drugs are a large source of waste, with one French study suggesting up to 16% of propofol is wasted due to this.[63] Rationalising propofol concentrations (1% vs. 2%), accurately estimating required propofol doses (based on operative duration estimates and freely available online calculators and apps), splitting of vials across patients (with a formal pharmacy approved solution), and drawing up as and when required, have been suggested as cost-saving and more environmentally sustainable options.[59, 61, 64, 65]

Anaesthesia
(Continued...)

Conservative oxygen (O_2) therapy:

When patients are undergoing procedures under regional anaesthesia, 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,[66] but also has its own carbon footprint, with 1 L medical O_2 equivalent to between 0.62 (EU) and 1.17 (worldwide) $kgCO_2e/L$.[67]

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,[68] wasting hospital oxygen stores with no benefit to patient care.

Dispose in correct pharmaceutical waste streams:

The biotoxicity of pharmaceuticals is known to affect many lifeforms,[69] including significant consequences for human health, most notably through the promotion of antimicrobial resistance,[70, 71] a rapidly evolving public health crisis.[72]

Worryingly, research has shown that, in some hospitals, significant amounts of propofol are being disposed of incorrectly in sharp bins and in general waste streams.[73] It is essential that all pharmaceuticals are disposed of in the correct waste stream ('blue bin' pharmaceutical waste) in order to be incinerated and thus minimise the effects on our ecosystem.

- *Use air instead of oxygen as the ventilator drive gas*

  Because medical O_2 has a carbon equivalent footprint approximately 10 times that of air,[31] changing ventilator drive gas should also be considered. If possible, converting machines will lead to long-term financial savings, and when purchasing new anaesthetic machines, opting for those able to utilise air as a driving agent should be favoured.[30]

Preparing for Surgery

Evaluate sterile field and Personal Protective Equipment (PPE) requirements

Consideration should be taken as to whether all procedures require the same level of sterility, including use of patient draping and extent of the sterile field, as well as PPE requirements. More importantly, reusable textiles should always be chosen over single-use equipment, and efforts made to ensure their availability in surgical departments.

- *Single-use non-sterile gloves:*

  Billions of non-sterile gloves (NSG) are used in the NHS every year,[74] often in circumstances for which they are not required. Studies have found that use of NSG is inappropriate in more than 50% of cases,[75] and could even hinder hand hygiene in 37% of instances due to the potential for cross-contamination.[76] This overuse of gloves increases the carbon footprint of healthcare and can increase the risk that microorganisms will be transmitted between equipment and patients.

  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 most patient interactions. An educational campaign on appropriate use of gloves ('Gloves are Off') at Great Ormond Street hospital, led to use falling by a third.[77]

- *PPE requirements:*

  As per above, numerous studies have shown that full sterile gowning of surgeons is not linked with reduced SSI rates for certain minor operations, including skin, upper limb surgery as well as perianal surgery.[78-82]

  One study looking at closed pinning of paediatric humeral fractures, estimated that eliminating unnecessary gowns and masks in the United States would save between 18,612 and 22,162 gowns and masks respectively, with costs savings of USD $3.7 million to $4.4 million annually.[78]

  Investigating the requirement for asepsis in perianal surgery, another study found that there was no significant difference in regard to SSI or re-intervention rates between sterile and non-sterile set-ups.[82] It also estimated financial savings of approximately £106 per case attained by using non-sterile gloves and abandoning use of sterile drapes, sterile gowns and aseptic skin preparation (instruments were still sterilised).[82]

  Another way to make environmental savings is to use the correct gown: reinforced gowns should only be used when there is expected exposure to very high volumes of bodily or contaminated fluids, as they require more materials to produce and lead to more waste (as well as being more expensive).

- *Field sterility:*

  Cases centred over small body areas, or those involving contaminated (dirty) areas, could be performed without full sterile gowning and patient draping, by applying the concept of "field sterility". This has been found to adequately preserve sterility in minor procedures including k-wiring of hand fractures,[79, 81, 83, 84] dental surgery,[85] minor skin and hand surgery,[80] and even closed pinning of paediatric humeral fractures.[78]

  Draping of patients should be minimised as far as possible, to prevent excess waste and laundry. Small fenestrated drapes are preferable to whole patient draping whenever possible.

- *Reusable surgical textiles:*

  Theatre hats

  Multiple studies have demonstrated no difference in Surgical Site Infections (SSIs) with disposable bouffant caps compared to traditional, reusable cloth caps.[86-90]

  Reusable hats are officially approved part of theatre wear according to NHS guidelines,[91, 92] and have been shown to improve team communication when personalised with names and roles.[93]

  Like other reusable theatre wear,[94] theatre headwear has also been found to be more environmentally sustainable. A small 2023 economic and environmental burden analysis found that supplying 92 surgical trainees with reusable caps led to a 76-100% reduction in their use of disposable hats at 6 months.[95] For this group alone, they projected improvements in energy consumption, carbon footprint, air and water toxicity, including 540kg of solid waste savings at one year.[95]

Confirming previous work demonstrating reusable caps to be more cost efficient in the long run,[89] this study showed an economic breakeven point between 15-26 weeks of use dependent on frequency of use and laundry.[95] Taken in parallel, these findings suggest that reusable scrub caps are an economically and environmentally favourable alternative to their disposable counterparts.

Reusable gowns:

Single-use surgical gowns produce huge amounts of waste, with over 36 million used in NHS England in 2020 alone.[74] Compared to disposable gowns, reusable gowns reduce carbon emissions by 200-300%, water usage by 250-330% and solid waste by 750%.[96, 97] A Life Cycle Analysis (LCA) estimated a saving of almost 1.1 $kgCO_2e$ per gown when substituting disposable gowns with reusable gowns.[96]

There is no evidence that reusable gowns increase SSIs,[98] and both are considered equal for their prevention according to WHO guidance.[99] Reusable gowns are thought to offer better protection due to superior water resistance and durability,[100] and were felt to be superior to disposables in terms of comfort, ease of use and protective properties by surgical staff.[101]

Drapes:

When evaluating the risk of SSIs with different types of drapes, there is no evidence that single-use drapes are better than reusable.[102] 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. To meet current 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 throughout their life.[103]

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.[104]

ABHR achieves hand decontamination for a wide variety of organisms,[105, 106] and has been shown to have equal,[99,107] if not superior,[108-111] efficacy to traditional scrub. ABHR also reduces duration of the decontamination process,[109] and has a favourable user profile,[112] attributed to lower rates of skin irritation and dryness.[113,114]

Environmentally, studies have demonstrated many litres of water are saved when using ABHR, with each wash requiring around 18-21 L of water.[115,116] One recent study demonstrated a reduction in water consumption between 57%-70% when using ABHR after the first scrub of the day.[116]

A single hospital in the USA estimated savings of 2.7 million litres of water annually by switching to waterless scrub.[117] Financial savings ensue from reduced water use, including energy for water heating, as well as reduced hand towels,[118-120] although actual values will be sensitive to individual practice and local structures for procurement.

Simple measures that can be taken to further limit water waste include turning the taps off when scrubbing, where possible. The instalment of programmable sensor-operated or pedal-operated taps should be introduced if the opportunity arises at the theatre design stage.

Preparing for Surgery
(Continued...)

Avoid clinically unnecessary interventions:

Antibiotics:

Pharmaceuticals contribute a fifth of NHS emissions from procurement.[58] 30% of antibiotic prescriptions are in secondary and tertiary care settings.[121] In 2015, 42 billion doses were used every day across the globe, with this is expected to rise by 200% by 2030.[122] Not only is bacterial antibiotic resistance estimated to account for 1·27 million deaths worldwide per year,[123] but inappropriate disposal methods, both during production and at point of use, also pose significant ecological risks to soil microorganisms and aquatic life.[124] NICE guidance is that antibiotics should only be used in the presence of a surgical implant or where surgery is on a contaminated site.[104]

Catheterisation:

Single-use catheters have a large environmental impact.[125] 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.[125, 126]

Histological examinations:

Histological examinations come with a carbon cost. A single gastrointestinal specimen uses 0.29 kgCO_2e, roughly the same as driving a car one km.[127] Often there is little benefit for sending samples for routine histological examinations. For example, a study auditing 1,452 routine cholecystectomy specimens found just 4 cases of malignancy. Each of these had high index of suspicion pre-operatively and intra-operatively.[128] 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:

At the morning brief, it is essential to clarify necessary equipment, specifying in particular what should be available to open only if needed, "Just in time", and can thus be kept ready on the side. In addition, at the end of the operation, it might be useful to review instrument sets and observe what is never or very rarely used and could be a suitable target to reduce the excess of unnecessary instruments known as "overage".

Surgeon preference lists:

It is useful to review surgeon preference lists and separate clearly what is definitely needed for each case and what instead can be listed as optional to have ready on the side, adopting the "just in time" principle.

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

  Medical equipment contributes 10% of the NHS carbon footprint.[129] Reusable versions of equipment will, in almost every circumstance, reduce carbon footprint,[130] with average reductions of 38-56% carbon dioxide equivalents,[131] as well as plastic consumption and cost.[132]

  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,[133] but also have a 19 fold increase in costs,[134] and at least a four-fold higher carbon footprint.[132]

  Single-use packs often also contain equipment that is not used at all and disposed of on being opening the pack; engaging with suppliers to remove these items all together will reduce financial cost, carbon, and waste.[101]

- *Instrument sets/trays:*

  Unused instruments in an opened instrument tray, known as "overage", lead to significant and rarely justified waste of resources and associated carbon emissions. An American study of vascular surgery sets found that on average only 30 of 131 (22.9%) and 19 of 152 (12.5%) instruments were used.[135]

A plastic surgery department achieved savings of USD $163 800 (£130 500) annually by reducing the number of instruments in two sets by 45.1% and 36.7%,[136] whereas a neurosurgery department reduced the number of instruments in trays by 70%, (with an associated 37% reduction in setup time) and estimated institutional annual savings of USD $2.8 million.[137]

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.[138]

Where instruments are removed and individually wrapped as supplementary items, this significantly increases their carbon footprint due to the space taken up in the autoclave (189 gCO_2e per individually wrapped instrument vs. 66-77 gCO_2e when part of sets), alongside the use of single-use (often double) packaging.[139] Instruments should therefore be removed from trays only where they are not used at all or extremely rarely, and where consolidation results in a significant reduction in the size or number of trays that will need to be opened.[139]

Through a process of audit, focus groups, surveys, intervention, re-audit and monitoring, working groups can engage relevant stakeholders to coordinate the optimisation of surgical instrument trays. Other important interventions to consider integrating in the process at this time include introducing reusable alternatives whenever possible, and switching sterile barrier system to single-use tray wraps with an appropriate recycling pathway.[139] Further discussions should also look at how autoclave loading can be optimised, reducing autoclave stand-by and idle time[140, 141], ensuring appropriate repair pathways are in place,[142] and that low carbon energy is utilised for decontamination processes.[143]

Intraoperative Equipment
(Continued...)

REDUCE: avoid unnecessary waste and single-use equipment.

Don't open it unless you need it:

Operating theatres generate large amounts of waste, compounded by frequently opening and then not using equipment. For instance, a study in ENT found 12 out of 40 single-use products in a pre-packaged tonsillectomy kit were unnecessary.[144] Not only does this have substantial financial implications (one study from the US showed an average of USD $653 of unused equipment per case in neurosurgery),[145] but it needlessly exacerbates the surgical carbon footprint. The most common reason for unnecessarily opening equipment is the anticipation of surgeons' needs.[146] Instead of opening equipment 'just in case', our culture must shift to opening 'just in time'.

As low as reasonable insufflation (ALARI):

Use as low as reasonable pneumoperitoneum insufflation pressures to reduce CO_2 used and consequent contributions to the greenhouse effect. This is in line with the European Association for Endoscopic Surgery consensus guidelines which recommend using the lowest insufflation pressures that allow adequate visualisation of the surgical field, rather than just routine settings.[147]

In addition, there are clinical benefits for patients, as demonstrated by a large systematic review of 7349 patients: this study found that lower intrabdominal pressures were associated with a lower incidence of minor complications, lower pain scores and postoperative nausea and vomiting (PONV), as well as a reduced length of stay. Low insufflation pressures were not associated with an increase in intraoperative complications.[148]

REUSE: opt for reusable instead of single-use products (or hybrid or remanufactured equivalents if fully reusable not available)

Single-use surgical equipment generates an average of 68% of the carbon footprint of the 5 most common operations in England.[149] Despite this, there continues to be a rapid rise in the prevalence of single-use instruments and devices within surgical theatres.

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),[150] at a time when modern decontamination and sterilisation practices did not exist.[151] However, there is no evidence of superior quality or safety with single-use equipment.[152]

Of particular concern, single-use devices contribute significantly to the carbon footprint of minimally invasive and robotic surgical approaches. As exemplified in hysterectomies, the rising carbon emissions from open (290 $kgCO_2e$) to laparoscopic (560 $kgCo_2e$) and robotic approaches (>800 $KgCo_2e$) can largely be attributed to single-use equipment.[153]

Importantly, in almost all cases, switching from single-use to reusable equivalents reduces the carbon footprint of the product by 38-50% on average.[131] Promisingly, these carbon savings are often associated with significant financial benefits, both for purchasing,[130, 132, 154] as well as waste disposal.[101] Where it is not feasible to use fully reusable products, there may be potential to increase the proportion of reusable components through adopting 'hybrid' reusable/disposable equipment such as laparoscopic ports, scissors and clip appliers, estimated to reduce the carbon footprint by 75% compared with single-use alternatives.[132]

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

Intraoperative Equipment
(Continued...)

(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.[155] In addition to environmental savings, remanufactured device save financial costs, including costs of medical waste disposal.[156]

One life-cycle analysis comparing remanufactured to newly-manufactured electrophysiology catheters, demonstrated a >50% reduction in GWP,[157] and other studies have shown reduced GWP through remanufacture of energy devices.[156]

Aside from requesting reusable versions of single-use products whenever possible, surgical staff can also engage industry by asking about carbon reduction strategies and targets, as well as by asking whether sustainable frameworks, such as "Design for the Environment", are being utilised in manufacturing, distribution and waste management processes (e.g. utilising renewable energy sources and eliminating air freight).[6]

REPLACE: switch for low carbon alternatives

Numerous small changes in the operating theatre intuitively represent greener options without affecting patient care. Examples include using pillowcases instead of single-use absorbent pads to wrap patient arms, not throwing away the patient's newly donned anti slip socks, not using sterile surgical gowns to keep warm but appropriate reusable theatre attire. Some interventions, such as choosing dissolvable subcuticular skin sutures, can also have a small but significant ripple effect on the patient journey and are worth thinking about where the chance arises.

Sutures instead of skin staples:

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 staple removers. Using absorbable sutures or instructing patients on how to remove their own sutures[158, 159] 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.[160] 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.[161] For these reasons, single-use plastic wands for antisepsis are not recommended.

After the Operation

Power off: Heating, Ventilation, Air conditioning (HVAC), AGSS, lights, computers, equipment

Energy use typically accounts for 60% of the carbon footprint of an operation;[129] of this, more than 90% is used for heating, ventilation and air conditioning (HVAC) systems.[162] Because operating theatres are mostly unoccupied, turning off theatre spaces when unused with appropriate set back modes is estimated to cut HVAC energy consumption by at least 50%.[162]

Powering off HVAC systems, theatre equipment and computers has been found to lead to savings of 44,774 $kgCO_2e$ per year and at least £30,000 pounds per theatre per year.[163] The National Green Theatres Programme estimates that this intervention alone applied across the whole of Scotland will save almost £5.5 million and almost 3.3 tonnes CO_2e per year.[164]

According to the Department of Health's Health Technical Memorandum on Specialised ventilation, all theatres, including emergency theatres, should have ventilation switched off when not in use and set to automatically start when required to maintain a minimum of 18°C.[165] The guidance is clear that all ventilation and air handling systems only require 20-30 minutes to achieve full operating conditions, negating the need to leave the ventilation on "just in case".[165]

Other strategies to reduce electricity usage include shutting down all electrical systems and equipment when not in use, which can be supported by the use of powering on and off checklists,[6] as well as adopting automated occupancy sensors, and the installation of light-emitting diode (LED) instead of halogen lights.[166]

- *Switch off AGSS when theatres are not in use or volatile anaesthesia is not being utilised.*

  Anaesthetic gas scavenging systems (AGSS) in particular, account for almost 78% of the electrical energy used by anaesthetic equipment and should be switched off in unoccupied operating theatres, and when volatile anaesthesia is not in use.[167]

  More information is available on the Centre for Sustainable Healthcare website: The Anaesthetic Gas Scavenging System (AGSS) project,[168] including an audit tool to help document and manage your own theatre system.

- *Introduce "shut-down" and "power on" checklists:*

  Introducing "shut down" and "power on" checklists can help ensure necessary safety precautions are embedded in the process.[163]

- *Install occupancy sensors and automate "set-back" modes HVAC systems:*

  Consider occupancy-based ventilation strategies to shut down HVAC in unused theatres and automate the system to "set-back mode" in order to maintain temperatures above 18°C.[165]

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,[129] the total waste produced by the NHS is equivalent to that of European countries such as Cyprus or Luxembourg.[169]

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.[170]

After the Operation
(Continued...)

- *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.[171] 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.[170]

- *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.[170] Many theatres use an orange bag where a yellow and black striped bag would meet requirements. Clinical waste (yellow bag) should be reserved for infectious waste contaminated with chemicals or pharmaceuticals/ medicinal waste.

- *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°C and is the most carbon intensive waste stream.

- *Switch to low impact sharp bins:*

  The introduction of reusable sharps containers (RSC) in place of single-use sharps containers (SSC) in 40 trusts in the NHS found the RSC to have an impact that was almost a sixth of the SSC (50.7 vs 313.0 kgCO_2e) with an overall reduction of the annual GWP of 84%.[172] Similar studies in the USA have reported reductions in GWP of 65-84%.[173, 174], diverting 50.2 tons of plastic and 8.1 tons of cardboard from landfill, and modelled savings of up to 64,000 metric tons of CO_2 equivalent annually across the USA.[173]

- *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.

REPAIR reusable surgical instruments and encourage active maintenance

Where possible reusable equipment should be preferred, and when in use actively maintained to maximise the number of uses. When reusable equipment is damaged there is often opportunity to repair this, rather than purchasing a new reusable piece of equipment, enabling further uses. Analyses have shown reusable equipment is often better both financially and environmentally, and repair adds to this.[142] For example, reusable steel scissors were found to have an environmental impact of only 1% of that of disposable steel scissors,[175] and repair reduces the per-use carbon footprint of reusable surgical scissors by an additional fifth (with concomitant cost savings of around one-third) compared with purchasing new reusable surgical scissors.[176] In another study, reusable instruments were found to cumulatively be more cost effective and to help reduce the carbon footprint of minor oculoplastic operations.[177]

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