Greening ORs: A guidance document for improving the environmental sustainability of operating rooms

A Clinical Practice Guideline developed by the University of Toronto's Best Practice in Surgery and Centre for Sustainable Health Systems

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Section 1. General information

Aim

The aim of this guideline is to provide recommendations to assist hospitals in improving the environmental sustainability of operating rooms.

Outcomes of interest

Overall, the outcomes of interest are to reduce waste and expenditure, while ensuring sterility and patient safety. To assist with implementation, the working group, with assistance from key stakeholders from the Toronto Academic Health Science Network Sustainable Health System Community of Practice, developed a scorecard with 4 key areas of environmental impact: anesthetic gases, reusables, waste management and energy management. To learn more about this initiative, please click here.

Target population

These recommendations apply to operating rooms in hospitals.

Intended users

This guideline is intended for use by any hospital staff who are interested in increasing the environmental sustainability of operating rooms. These persons may include, but are not limited to nurses, surgeons, anesthesiologists, OR managers, environmental professionals, quality improvement professionals, caretaking staff, and senior leadership.

Rationale

Climate change is one of the world's most pressing challenges with global impacts on health.(1) In the Canadian context, both the immediate impacts of climate change, such as increased extreme weather events, and downstream impacts, such as displacement, will yield far-ranging health impacts from increased incidence of cardiorespiratory disease to exacerbation of mental health conditions.(2) Canada, especially the north west, is particularly vulnerable to the impact of climate change, with a projected mean temperature rise twice as great compared to the global average.(3) Paradoxically, while climate change will negatively impact public health, health systems have been shown to unintentionally contribute to climate change.(4)

The healthcare system is responsible for approximately 4.6% of Canada's greenhouse gas (GHG) emissions and 200,000 tons of other pollutants - impacts that appear to be rising. (5)Healthcare emissions stem from a variety of activities including high-energy use, anesthetic gases, waste and the emissions embedded in the production, transportation use and disposal of the large number of clinical and non-clinical products and services consumed in the delivery of care.(5,6)

Operating rooms (ORs), specifically, have been shown to have a negative impact on the environment. (7) A range of tools have been used to establish these impacts, including simpler tools such as a waste audit or footprint analysis, to the more complex Life Cycle Assessment (LCA), which assess all the inputs into the production and disposal of a product. The evidence demonstrates that ORs are energy intensive, consuming 6-fold more energy per square meter than the hospital as a whole. Moreover, ORs generate up to a third of total hospital waste, including biohazardous medical waste such as fluids and contaminated materials. Last, surgical procedures are resource-intensive with high levels of material consumption; for example, a LCA of surgical hysterectomy demonstrated that the majority of environmental impacts stemmed from the production and manufacture of single-use supplies.(8)

Given the environmental footprint of ORs, it is an opportune site for sustainable interventions. Thus, the objective of this document is to create an evidence-based guidance document to help hospitals improve the environmental sustainability of OR. A recent systematic review highlights potential interventions based upon LCAs across surgical and anesthetic services, however this guideline provides evidence-based recommendations that synthesizes evidence from clinical and implementation science.(9)Prior recommendations developed with a similar methodology in an American context have highlighted the following as areas of priority: (1) operating room waste reduction and segregation, (2) reprocessing of single-use medical devices (SUMD), (3)environmentally preferable purchasing, (4) energy consumption management, and (5) pharmaceutical waste management.(10)

Moreover, while guidelines specific to a profession exist, this is the first comprehensive Canadian guideline for any hospital staff who are interested in improving the environmental sustainability of their operating rooms.(10)

Implementation of these recommendations will be contingent upon the legal and regulatory landscape given the provincial and territorial administration of healthcare in Canada. Furthermore, the feasibility of such efforts is also dependent upon the existing capacity of hospitals and service providers, both with regards to capital and human resources. As such, these recommendations vary in terms of their ease of implementation; its breadth spans interventions requiring major capital investments for construction or re-design of infrastructure to operational modifications that can be accomplished by clinicians.

Overview of process

The AGREE Health Services (AGREE-HS) tool was used to guide the development of this document.(11) The AGREE-HS provides a methodological framework for developing, reporting and implementing guidance documents on health services challenges (e.g. environmental sustainability) based on best-evidence. However, the AGREE-HS tool differs from the traditional AGREE-II tool used for clinical practice guidelines in that the recommendations and supporting evidence will differ as the information used to create the HS documents are not as straightforward (e.g. strictly clinical evidence and recommendations to inform clinical decision making) as they often are for clinical practice guidelines.

Guidance development team

This document was developed collaboratively by the Centre for Sustainable Health Systems and the Best Practice in Surgery. The working group includes key stakeholders including clinicians, knowledge translation specialists, administrators and environmental specialists from the University of Toronto affiliated hospitals. Supplemental information was sought from local waste haulers and recycling companies.

Literature reviews

Initially, a scoping review was undertaken to identify interventions to increase the environmental sustainability of operating rooms. Based on these findings, 31 potential interventions were selected for further review. Each intervention was further evaluated with a rapid review (refer to Appendix A). Based on these reviews, it was determined that 16 interventions had enough published information for a rapid review, 6 interventions did not have any published data, so grey literature searches were undertaken, and 9 interventions did not have enough information available to be included in the review.

For the 16 interventions where rapid reviews were undertaken, they were conducted in Medline and Cochrane Database for Systematic Reviews. All study designs were included. Only publications written in English and concerned with humans were included. Searches were run between January 1, 2000 and June 1, 2020. Three independent reviewers conducted the searches and met regularly with each other and other authors to discuss and edit search strategies and search terms. Titles and abstracts were independently reviewed prior to determining eligibility. Full text articles were independently reviewed and findings were discussed with the other authors prior to inclusion.(12) For the 6 interventions where only grey literature was used, the reviewers conducted a search using keywords in Google. All sources of information were included (e.g. blog posts, websites). Saturation was reached by the 10th search page. Additional sources of information were also obtained from the authors files.

Development of recommendations

All relevant information for each intervention was then summarized and presented to University of Toronto affiliated stakeholders and local experts for discussion and development of recommendations. Based upon the wide variety of information used to determine recommendations, the summary of evidence for each recommendation will include the following subtopics where available: environmental impacts, clinical effectiveness and safety, feasibility, and financial implications. A final iteration was circulated to all potential end-users at the University of Toronto teaching hospitals to provide feedback. The original stakeholder group was sent the penultimate document to come to consensus.

Scope of the document

The users of this guideline include all hospital staff who are interested in improving the environmental sustainability of their operating rooms by decreasing greenhouse gas emissions and other pollutants while maintaining a high quality of care based on best evidence.

This document focuses on interventions pertaining directly to the operating room. Interventions that do not relate directly to the operating room, such as paper charting and virtual follow-ups, were not included. In addition, Environmentally Preferable Purchasing (EPP), defined as the "act of purchasing products/services whose environmental impacts have been considered and found to be less damaging to the environment and human health when compared to competing products/services", was also beyond the scope of this document.

In the sustainable healthcare literature, greening initiatives are often discussed in terms of reduce, reuse, recycle, rethink and research((6–8). The first three categories identify a hierarchy of interventions in pursuit of environmental sustainability. The first priority is to "reduce" – that is, to avoid the use of materials wherever possible. The second priority is to pursue opportunities to "reuse" materials. The least favoured option is to "recycle"- that is to divert used materials from waste so that their constituent parts can serve as inputs to the production of other useful goods. The categories of "rethink" and "research" supplement this hierarchy. The "rethink" category identifies the need for the reorganization of usual practices, to make efforts to reduce, reuse or recycle more efficient or effective. The "research" category serves to acknowledge the need for new evidence and insight; research is beyond scope for this project. Thus, the recommendations in this document are presented across the four main categories.

Section 2. Guideline Recommendations

1. Reduce

1.1 Reduce energy use in operating rooms

- **1.1.1 Reduce energy use from HVAC systems by implementing a setback program, reducing air circulation when not in use and/or installing occupancy sensors**
- **1.1.2 Reduce energy use from OR lights by switching to LED surgical lights, and/or implementing a lighting setback program and/or installing occupancy sensors**

1.2 Reduce waste in operating rooms

- **1.2.1 Reduce water waste by using alcohol hand rub in place of a traditional surgical scrub**
- **1.2.2 Reduce pharmaceutical drug waste**
- **1.2.3 Reduce waste from surgical trays by using specialized trays**

2. Reuse

2.1 Use reusable products in lieu of disposable products (or extend the use of disposable products) wherever possible. The following are commonly used disposable products that can safely be switched to reusable:

- **2.1.1 Use reusable anesthesia breathing circuits or extend the use of disposable breathing circuits**
- **2.1.2 Use reusable laryngeal mask airways**
- **2.1.3 Use reusable laryngoscopes**
- **2.1.4 Use reusable linens (gowns, drapes, scrub caps)**
- **2.1.5 Use reusable sharps containers**

2.2 Use remanufactured single use medical devices (SUMD) wherever possible

3. Recycle

3.1. Develop and implement an effective recycling program in the OR

4. Rethink

4.1 Rethink the use of anesthetic gases, carrier gases and capturing systems

- **4.1.1 Use sevoflurane for surgical procedures requiring general anesthesia**
- **4.1.2 Use air as a carrier gas when using halogenated anesthetic gases**
- **4.1.3 Use low fresh gas flows wherever possible**
- **4.1.4 Use anesthetic techniques other than inhalational anesthesia wherever possible**

4.2 Rethink the management of waste and unused supplies

- **4.2.1 Rethink waste management practices**
- **4.2.2 Rethink the management of unused supplies, older machines and devices through donation where appropriate**

4.3 Rethink the use of blue sterile wrap and consider the use of reusable hard cases wherever possible

Section 3. Guideline Recommendations and Summary of Evidence

1. Reduce

1.1 Reduce energy use in operating rooms

The most energy intensive part of a hospital is the operating room.(10) A study conducted by MacNeill et al. comparing 3 hospitals in Canada, the US and the UK, found that ORs used three to six times more energy per square foot than the hospital as a whole.(13)

1.1.1 Reduce energy use from HVAC systems by implementing a setback program, reducing air circulation when not in use and/or installing occupancy sensors

The energy intensity of the OR is attributed to the strict heating, ventilation, and air conditioning (HVAC) requirements of an OR.(13) Within the OR, the HVAC system may account for as much as 90 to 99 percent of the OR's energy use per square foot and 36 percent of its direct greenhouse gas (GHG) emissions. The literature suggests two ways to minimize the amount of unnecessary energy use related to HVAC systems: turn down systems when not in use via setback programs for temperature and ventilation rate or use occupancy sensors.

Canadian ORs have strict requirements for air changes per hour, temperature, pressure and humidity parameters, as outlined in the CSA 315.(14) Opportunities exist, though, to reduce energy use even while observing these requirements. Of note, HVAC systems are often turned on, even when the OR is unoccupied. MacNeill et al found that by turning down HVAC systems in unused ORs in the middle of the night and on weekends, while still leaving a subset of ORs online for emergencies, HVAC energy consumption was reduced by half.(13) In addition to having a positive environmental impact, HVAC setback programs have been shown to provide major savings for the hospitals that have implemented them. A modelling project from the Greening Healthcare team projected that a total of 81,491 kW/yr and 72,731 M3/yr could be saved in a 25,000 cfm reference system with no heat recovery in typical Toronto weather conditions. This would translate to an annual cost savings of $27, 962.(15)

Second, HVAC occupancy sensors appear to provide similar benefits by reducing energy use. HVAC occupancy sensors, which work by automatically turning the HVAC system into setback mode after no detection of movement for a programmed length of time. A benefit of occupancy sensors compared to automatic setback programs is that there is more flexibility in the case that an OR is required to be occupied during a time that is normally scheduled for a setback. Providence St. Peter Hospital in Olympia, WA reduced its energy use by 25,000 kilowatt/hour (kWh) and is saving $4,000USD per year after installing HVAC occupancy sensors in two of their ORs.(16)

1.1.2 Reduce energy use from OR lights by switching to LED surgical lights, and/or implementing a lighting setback program and/or installing occupancy sensors

Surgical lighting adheres to strict standards for quality, illuminance, diameter and colour. Transitioning to light-emitting diode (LED) surgical lights can reduce the environmental footprint associated with achieving these standards. LED lights use 49% less energy than traditional lighting, such as halogen bulbs.(17) Moreover, traditional lighting is heat generating. (18) In contrast, LED lights generate less heat, and thus, reduce the HVAC cooling load, even further reducing energy expenditure in the OR.(17,18)Furthermore, their longer lifespan equates to less consumption of resources for production and less waste products.(18,19) From a waste disposal perspective, the benefit between lighting choices depends on the capacity of the waste hauler to recycle either product since both are theoretically recyclable. In addition, LED lights do not contain toxic elements like their traditional counterparts, which need to be properly disposed of to prevent contamination. (18) Along with their smaller carbon footprint, clinicians report a general preference for LEDs as they provide better colour retention as well as reduced overhead heat.(19) In addition to environmental benefits, replacing traditional lighting with LED surgical lighting in the OR has been shown to offer a financial savings.(19) The Biomedical Engineering Team at University Health Network, for example, has undertaken a LED retrofit initiative. This involves replacing halogen lights in 8 ORs at Toronto General Hospital. The LED retrofit initiative reduced electric consumption by 28,000 kWh/year and peak demand by 9kW. Cost savings amounted to approximately $3,500/year.

Another method to reduce the vast energy consumption that results from lighting usage in ORs is to implement a "lighting setback" program. Similar to the HVAC program, this program entails setting back lighting when the OR is unoccupied.(19) A group from the Duke Medical Centre placed occupancy sensors in just five areas throughout the Ambulatory Surgical Centre (ASC) and conducted an audit to evaluate the unnecessary use of lighting in the building. In less than a year, the ASC saw a 30-megawatt hour energy saving. Each sensor costs between $100 and $200, but annual cost-savings in electricity was over $2,000 USD.(20)

1.2 Reduce waste in operating rooms

The OR is a major source of the substantial amount of waste produced by hospitals, estimated to be greater than 7000 tonnes of waste per day in the US.(21) It is estimated that around 40% of the waste generated by hospitals is from ORs, despite the proportionally small physical area that they occupy.(22)Studies have shown that longer surgical cases can generate up to 50 pounds of waste, with cardiac and orthopaedic cases generating upwards of 100-200 pounds of waste per case.(23) Some portion of the waste generated in the OR can be reduced through efforts to rationalize and reduce the materials used in the OR. (N.B. The improved management of remaining waste is discussed in section 2; recycling opportunities are discussed in section 3.1)

1.2.1 Reduce water waste by using alcohol hand rub in place of a traditional surgical scrub

Traditional surgical hand scrubbing involves scrubbing hands and nails with brushes and antimicrobial solution for 5 minutes. Recently, alcohol-based hand rub has gained popularity; it involves a 1-minute hand wash with non-antiseptic soap and water, followed by 2 minutes of hand rubbing with an alcohol solution. Studies have assessed the different methods of hand washing based on environmental impact, clinical safety, and feasibility.

With regards to the environmental impact of traditional hand scrub, Weiss et al noted that one hospital in the UK found that scrubbing before an procedure utilizes 18.5 litres (L) of water per episode.(20) The centre performed approximately 15,500 operations per year, which equates to 931,938 L of water use per year for scrubbing.(24) Similarly, Wormer et al assessed 100 consecutive scrub cycles of physicians, nurses, residents, and technicians prior to an operation at the Carolinas Medical Centre in Charlotte, NC. They found that the water ran non-stop 98% of the time while they were scrubbing and occasionally was left on after they entered the OR. Based on flow meters, they found that it was possible to save 2.7 million litres of water annually by switching to an alcohol rub.(21) It should be noted that both studies focused on the conservation of water as a primary objective, which is a greater priority in water-scarce contexts. However, alcohol-based rubs also have a deleterious environmental impact when considering its life cycle. Alternative methods for water conservation during traditional surgical scrub, including turning off taps throughout the scrub or alternative mechanisms of controlling water supply, could be considered.(25,26)

With regards to the clinical safety of alcohol rub, Tanner at al published a Cochrane Review in 2016 on the effects of surgical hand antisepsis on preventing surgical site infection prevention (SSIs) and the overall numbers of colony-forming unit (CFUs) on clinicians' hands.(27)Fourteen trials were included in the review with four reporting on SSIs and ten reporting on CFUs. The authors found that there was no clear evidence that one type of anti-sepsis was better at reducing SSI rates. With regards to CFUs, when comparing alcohol rubs with traditional scrubs, three studies found fewer CFUs with alcohol scrub with additional active ingredients. Only one study found traditional scrubs to be more effective; however, that study was of very low quality. The authors concluded that SSI rates appear to be the same between different types of antiseptics. The authors also found that alcohol rubs appear to have the lowest CFUs, followed by chlorhexidine gluconate and povidone iodine scrubs, in order. The authors also noted that most of the evidence used was of low quality. More recent meta-analyses and randomized controlled trial (RCTS) found similar results.(28–30)

To assess the acceptability of alcohol rub, Liu et al conducted a review to assess skin integrity of different surgical scrub methods.(31) The review included 8 RCTs and two non-randomized controlled trials. Five of these studies compared traditional scrubbing with alcohol rub and found better skin condition in the alcohol group, although only one study reported a statistically significant difference. One trial reported no difference in skin damage. Three trials reported a preference for the alcohol rub.

A study of ophthalmologic surgeries found that cost-savings were accrued from water conservation and cheaper cost of alcohol scrub compared to aqueous soap.(32) However, several studies have documented the increased cost of alcohol rub over traditional scrubbing techniques. Notably, these studies did not account for the cost savings of a) using less alcohol gel, b) using less water, and c) using less towels to dry hands after scrubbing.(24)

1.2.2 Reduce pharmaceutical drug waste

Pharmaceutical waste, particularly through partial use of packaged drugs used for anesthesia, represents another source of unnecessary waste generated in the operating room. Mechanisms of pharmaceutical waste production include drawing excess drugs and disposal of drugs due to poor storage. Studies document that between 20-50% of drugs drawn during surgery are wasted.(33)In addition, waste is created from plastic syringes which are often disposed of as biohazardous waste, which is more costly and resource-intensive to process. (34)

One strategy to reduce pharmaceutical waste is to use prefilled syringes. It is recommended to have prefilled appropriate dose aliquots in syringes to maximize yield from high-concentration drug vials that need to be diluted.(34) This circumvents situations where the diluted solution of the high-concentration drug ends up discarded after the case. For example, phenylephrine or remifentanil can be pre-prepared by pharmacy into diluted syringes stored in the refrigerator giving them a reasonable shelf-life. While commercially prepared medication syringes are also available, they tend to be expensive. A prospective observational study in a French university obstetrical unit compared the consumption and cost of ephedrine available in two forms: ampoules and prefilled syringes. The study, which included 113 patients, assessed consumption and cost of ephedrine during two consecutive time periods of 14 days. In time period one, ampoules were used and in time period two, prefilled syringes were used. The study found that, in time period one, 155 ampoules were used compared to 45 pre-filled syringes in time period two. The authors concluded that pre-filled syringes of ephedrine reduced wastage and yielded cost savings (in this instance, of EUR 0.5 per patient).(35)

Another strategy to reduce pharmaceutical waste is to implement better storage documentation for refrigerated medications. A study conducted in cardiovascular operating rooms (CVOR) of an American hospital created a storage system for commonly-used refrigerated medications in mini refrigerators placed in each CVOR.(36) Specifically, norepinephrine intravenous piggyback (IVPB), norepinephrine syringes, nitroglycerin 2 mg vials, and epinephrine IVPB were put in the mini-fridges. Other medication storage changes include the following: vasopressin vials were loaded into automated anesthesia cabinets and labeled with a room temperature expiration of 12 months (undiluted expiration date), and phenylephrine push dose syringes and vials to make a phenylephrine IVPB at bedside were also loaded into the automated anesthesia cabinets. After implementing these changes there was a significant reduction in monetary waste - pre-intervention medication waste averaged $1,188.59USD per week, which was reduced to $322.96USD per week post-intervention ($P < .001$). This is a weekly savings of $865.63USD, or an annual savings of over $45,000USD, achieved despite a consistent weekly CVOR caseload.

Lastly, it is recommended to avoid the traditional practice of drawing 'emergency' drugs in advance but rather have the necessary vials and materials ready at hand.(34)

1.2.3 Reduce waste from surgical trays by using specialized trays

In some countries, such as the United States, Ireland and Canada, surgical tray redundancy is a known and costly source of unnecessary waste for surgical units. Several studies have documented that up to 80% of instruments on surgical trays remain unused.(37–39) This creates a financial and environmental issue as all instruments on the tray must be resterilized or disposed of after the operation, whether or not they are used.

Lower consumption of surgical tools reduces the environmental impact due to the use of less blue sterile wrap, natural gas, electricity and water required for resterilization.(40) Life cycle analyses of both single use medical devices (SUMDs) or reusable medical devices demonstrate significant GHG associated with the raw material consumption or sterilization processes, respectively.(40,41) A life cycle assessment comparing reusable and disposable surgical scissors demonstrated that even the production of a single instrument had significant environmental impact associated with extracting the raw materials and manufacturing the product.(42)

John-Baptiste et al conducted a cost analysis to determine the potential savings of surgical trays with redundant instruments compared to surgical trays with reduced instruments.(39) The study included 5 otolaryngology procedures at an Ontario hospital over a 1-year period. Overall, the study found that redundant trays cost $21,806 CAD whereas the reduced trays cost $8,803CAD which equated to a cost savings of $13,003CAD per year. The authors also note that there could be further savings as they did not assess other processes such as faster set-up, easier retrieval of instruments and faster clean up.

Implementation studies have shown that a reduction of instruments would be both feasible and agreeable to most surgeons. Capra et al conducted a before-after study to evaluate the results of a quality improvement project aimed to increase the efficiency of total knee arthroplasty (TKA) and total hip arthroplasty (THA) by implementing surgical tray optimization.(43) The study compared 96 procedures, 38 pre-implementation and 58 post-implementation, across two surgeons at an American hospital. In the post-implementation period, the number of instruments was reduced by 43.6% for TKA and 17.5% for THA. The authors also found that the average set up time decreased by 3 minutes ($p=.06$) for THA, but found a 23% time reduction of 6 minutes for TKA($p=.01$). There appeared to be a slightly longer clean-up time of 2.4 minutes post implementation ($p=.36$).

2. Reuse

2.1 Use reusable products or extend the use of disposable products wherever possible. The following are commonly used disposable products that can safely be switched to reusable:

2.1.1 Use reusable anesthesia breathing circuits or extend the use of disposable breathing circuits

Many operating rooms rely on single-use high efficiency microbiological filters to reduce the risk of cross-contamination mediated by breathing circuits and anesthesia machines. Multiple studies have found that it is more environmentally sustainable and cost-effective to employ reusable circuits or at least extend the use of disposable circuits with no apparent increase in clinical risk. (44,45) A life cycle assessment completed in the Australian context comparing the use of disposable to reusable anesthetic equipment, including breathing circuits, projected that the carbon dioxide emissions would be decreased approximately 50% in the US. (46)

With regards to the clinical safety of reusable circuits, several studies have demonstrated that either extending the use of circuits or reusing circuits did not increase contamination. An experimental observational study on extended use done by evaluating microbiological samples taken from 112 parts of the ventilator circuit noted no significant increase in contamination rates between 24 to 72 hours of use.(47) Another prospective longitudinal clinical study found that extending breathing circuit systems (BCSs) for seven days, in combination with heat moisture exchanging filters (HMEF) did not result in transmission of respiratory flora or colonizing pathogens.(48)Last, an Australian study extended the use of reusable breathing circuits from 24 hours to 7 days and found no significant difference in the proportion of contaminated circuits.(49) The study also reported cost savings of $4,846USD and a 57% decrease in anaesthesia circuit steriliser loads associated with a yearly saving of 2760 kWh of electricity and 48,000L of water.

2.1.2 Use reusable laryngeal mask airways

A life cycle assessment comparing reusable and disposable laryngeal mask airways (LMAs) found reusable masks were environmentally preferable to disposable masks if used at least 10 times, and more cost effective if used at least 20 times.(5) The most important sources of impacts for the disposable LMA were the production of polymers, packaging, and waste management, whereas for the reusable LMA, washing and sterilization were the biggest sources of environmental impact.

In terms of clinical efficacy, a randomized control trial at a hospital in the United Kingdom sought to compare insertion rates of single-use polyvinyl chloride LMAs vs reusable silicone LMAs in 72 anaesthetised patients.(50) The study found no difference between single-use polyvinyl chloride LMAs and reusable silicone LMAs.

Benefits of reuse must be weighed against risk of infection, as some studies have shown 'proteinaceous material' on routinely cleaned reusable LMAs which may put patients at risk of prion-related disease; however no such cases have been reported since 1976.((5,51)

2.1.3 Use reusable laryngoscopes

A cradle-to-grave life cycle assessment was conducted to compare environmental impacts and total cost of ownership among laryngoscope options.(52)The investigators found that the plastic handle on single-use laryngoscopes generates ~16-18 times more life cycle carbon dioxide equivalents than traditional low-level disinfection of the reusable steel handle. The authors also report that the single use plastic tongue generates ~5-6 times more carbon dioxide equivalents than the reusable steel blade treated with high level disinfection. Further, reusable handles would be more economical if used at least 4-5 times, and reusable blades if used 5-7 times.

2.1.4 Use reusable linens (gowns, drapes, scrub caps)

Several life-cycle analyses have been conducted to assess the environmental impact of reusable linens vs disposable linens in the operating room, with a particular focus on gowns. Vozzola et al compared the use of 1,000 gowns (16.7 reusable gowns that were reprocessed 60 times each).(53)The lifecycle analysis included 6 steps: gown manufacture and supply chain, packaging manufacture and supply chain, laundry, sterilization, use phase transport, and end-of-life. Reusable gowns are more environmentally preferable;43 they reduced natural resource energy consumption (64%), greenhouse gas emissions (66%), blue water consumption (83%), and solid waste generation (84%) as compared with disposable gowns. The results of this study are consistent with other previously published life cycle analyses comparing these two gowns.(54,55)

Overcash conducted a state-of-the-art review of the literature comparing reusable and disposable perioperative gowns and drapes between 1993-2012.(55) In the review, reusable and disposable gowns were compared based upon surgical site infection prevention, comfort, economics, and environmental life cycle analysis. Five life cycle analyses estimated that disposable gowns increased energy use and carbon footprint by 200% to 300%, increased the water footprint by 250% to 330%, and increased solid waste from 38 kg to 320 kg per 1000 gown uses (a 750% increase). Other factors were equal or more favourable for reusable gowns. Overall, there is a clear preference toward reusable gowns noting that more information is needed on economic comparisons.(55)

2.1.5 Use reusable sharps containers

With regards to the environmental implications, McPherson et al conducted a cradle to grave life-cycle carbon footprint analysis over a 1-year period at a US hospital system that includes 1100 beds and 5 hospitals that are geographically distant from manufacturing and processing plants.(56) The annual GHG emissions for each container was expressed in metric tonnes of carbon dioxide equivalents (MTCO2eq). When looking at the specific aspects of the life-cycle analysis, the MTCO2eq for manufacturing was 148.6 for disposable sharps containers as compared to 3.1 for reusable sharps containers. The MTCO2eq for washing was minimal for the reusable sharps' containers at 4.9 MTCO2eq as compared to none for the disposal containers. To treat and dispose of disposable containers had 30.2 MTCO2eq as compared to 0.6 MTCO2eq for reusable. Overall, disposable sharps containers account for 248.6 MTCO2eq as compared to 86.2 MTCO2eq for reusable. This accounted for a 162.4 MTCO2eq reduction in carbon footprint (65.3%, $p < 0.001$, RR 2.27-3.71). In addition to GHG reduction, the hospital system eliminated 50.2 tonnes of plastic waste and 8.1 tonnes of cardboard.

A barrier to reusable sharps containers is the concern for potential transmission of bacteria. Grimmond et al conducted a microbiological study to assess the transmission-potential of Clostridium Difficile (C diff).(57) The study was conducted at 7 US hospitals and included 197 reusable sharps containers to assess whether processing can remove C. diff. The authors found that processing completely removed C. diff. In the study assessing the difference between reusable sharps containers and disposable sharps containers, 4 of 50 reusable sharps containers (8.0%) and 8 of 50 disposable sharps containers (16.0%) had sub-infective counts of C. diff ($P = .27$). The authors concluded that sharps containers pose no increased risk for C. diff transmission.

2.2 Use remanufactured single use medical devices (SUMD) wherever possible

In 2016, Health Canada established a regulatory pathway for remanufactured SUMD, whereby devices are processed to meet the same requirements as new medical devices to be licensed for sale in Canada. Several studies on numerous different surgical devices have shown that remanufactured SUMD have the potential to reduce costs and are better for the environment with no impact on patient care.(58) For some devices, the reprocessing of SUMDs is a temporizing measure with a goal is to replace SUMD with reusable alternatives. For example, a life cycle assessment from an American hospital found that reprocessing various surgical instruments was only advantageous if reprocessing inputs could be minimized.(59) This is consistent with the current body of literature on reprocessing non-surgical SUMDs, which demonstrates that not all SUMD have a lower environmental impact when re-processed.(60)

In clinical practice, assessments of clinical safety and efficacy are specific to the remanufactured device as challenges to re-processing may be specific to the complexity and design of the device. For example, a 2018 study on the use of a remanufactured circular mapping catheter used in 100 consecutive patients undergoing an atrial fibrillation ablation found no health risk, only one device malfunction, and a reported cost savings of £30,444.(61)

3. Recycle

3.1 Develop and implement an effective recycling program in the OR

There are opportunities to enhance recycling in the OR, as part of a comprehensive waste management program (see Section 3.1). According to US-based Practice Greenhealth, operating rooms "have not historically been a target for large scale recycling efforts" due to the high level of complexity associated with implementing such programs.(62) However, studies have shown that various recycling programs can be implemented, including those for medical plastics, other materials, and SUMDs. It should be noted that implementation of recycling for different types of materials will be contingent upon jurisdictional regulation and capacity of the waste hauler.

Medical plastics have attracted particular attention as a focus of OR recycling efforts, due to the volume of plastics produced and the complexity of plastic recycling. An article by Wyssusek et al highlights that based on the fact that three commonly-used plastics (Polypropylene, polyethylene and PVC) are recyclable, up to 84% OR plastics are theoretically recyclable.(63,64) However, plastic recycling is challenging due to: (1) the significant variation in shape, size, volume, and plastic type within the OR, (2) the identification of recycling streams from healthcare facilities as posing occupational risks, especially where manual sortation is used, thus necessitating decontamination, which can be costly, and (3) the limited recycling hauling capacity or markets for the kinds of plastics generated in the OR. Two Toronto hospitals have started a PVC recycling program that is projected to divert 80,000 pounds from landfills in partnership with their local waste hauler. Beyond plastics, there is a role for recycling program for other materials including cardboard, paper, and aluminum.(21) Moreover, glass from anesthetic vials can be recycled; for example, a Toronto hospital has identified 2 waste haulers accepting these vials.

Furthermore, SUMD can be diverted for recycling. For example, the Grand River Hospital implemented a waste diversion program that has diverted 1,302 lbs. of garbage from landfill and reduced their waste costs by $1,990 and established $1,000 in company credits towards the purchase of equipment.(65) This equipment includes repurchasing SUDs or an option to purchase other products i.e. mattresses/beds.

Finally, there is potential for financial savings along with environmental benefits from recycling. According to Practice Greenhealth's Sustainability Benchmarking report from 2010, a conservative estimate is that 25% of plastics end up in the medical waste container rather than recycling. Financial savings may be realized from the reduction of waste hauling costs.(62) The process of starting up a novel recycling program in the OR comes with a cost, but there have been instances where capital funds that are spent implementing a program of this type are paid back within three to four years after the implementation.(66) To address logistic barriers to implementation, Practice Greenhealth has also developed several steps to aid organizations in implementing successful medical plastic recycling programs in the OR.(62)

4. Rethink

4.1 Rethink the use of anesthetic gases, carrier gases and capturing systems

4.1.1 Use sevoflurane for surgical procedures requiring general anesthesia

The majority of anaesthetic gases used during surgery are ultimately exhaled, as they undergo minimal metabolism during respiration.(67) Despite mitigation measures, these gases eventually end up in the external environment where, due to their chemical composition, they remain in the lower atmosphere and contribute to global climate change.(68) Anesthetic gases thus represent a major source of environmental pollution and emissions from the operating room. One life cycle assessment study of abdominal and vaginal hysterectomies found that the average greenhouse gas impacts of inhaled anesthetic gases account for approximately 70% of the total emissions for these surgeries.(8)

Desflurane is regarded as the most problematic of the commonly used halogenated anesthetic gases. Globally, desflurane constitutes 80% of the equivalent 3.1 million tons of carbon dioxide released by all anesthetic gases (69). A LCA of desflurane, sevoflurane, isoflurane, nitrous oxide, and propofol found that desflurane had the largest greenhouse gas impact compared to the other drugs examined, with greenhouse gas emissions 20 times that of sevoflurane on a per minimum alveolar concentration-hour basis when an oxygen/air mix is used as a carrier gas, with similar results when nitrous oxide was used as a carrier gas.(70) The Global Warming Potential over 20 years (GWP20) of anesthetic gases is a relative scale, which measures a gas's capacity to trap heat in the atmosphere compared to a similar amount of carbon dioxide. Amongst commonly used halogenated anesthetic gases, desflurane has an estimated GWP20 of 6810, compared to sevoflurane which only has a GWP20 of 440.(71) There is also the issue of atmospheric persistence; sevoflurane persists for 1.1 yr, desflurane for 14 years and nitrous oxide persists for more than a 100 years.(72) Additionally, nitrous oxide not only contributes to global warming but also depletes the ozone. As such, desflurane and nitrous oxide should be avoided, and sevoflurane should be the anesthetic gas of choice. (73)

A quality assurance study from The Department of Anesthesiology at the University of British Columbia intended to raise awareness about the environmental impact of anesthetic gases and change the department's preference to using anesthetics with the lowest GWP20 values. The project used provider education to influence choice of anesthetic gas. As sevoflurane (GWP20 = 440) replaced desflurane (GWP20= 6810) across the 5-year measurement period, the department noted an 8.9 million kg decrease in total carbon footprint or a 66% reduction in greenhouse gas emissions.

4.1.2 Use air as a carrier gas when using halogenated anesthetic gases

Nitrous oxide (NO2) is effective at trapping heat and has an atmospheric lifetime estimated to be over 100 years, with a GWP20 of 289.(74) A study using infrared absorption techniques for desflurane, sevoflurane and isoflurane compared the GWP for these gases when using air/oxygen mix as a carrier gas, and when using nitrous oxide/oxygen mix as a carrier gas.(69) When a mix of N2O/oxygen replaced air/oxygen as a carrier gas combination, the carbon dioxide equivalent of sevoflurane was 5.9 times higher. Accordingly, air/oxygen is recommended as a carrier gas. The elimination of nitrous oxide as a carrier gas has been implemented in Yale New Haven hospital since 2013.(70)

4.1.3 Use low fresh gas flows wherever possible

Choosing lower maintenance flows reduces the total volume of anesthetic gases used during the procedure and in doing so reduces the environmental impact of the gas. A clinical study of 32 patients in Sweden undergoing elective day surgery at a tertiary hospital aimed to evaluate drug consumption and direct costs related to variations in the fresh gas flow and use of nitrous oxide at a 1 minimum alveolar concentration (MAC) sevoflurane end-tidal anaesthesia.(75) The investigators found that the amount of sevoflurane consumed, vaporized, and subsequently released into the atmosphere at 1 MAC decreased from 0.66 (0.07) to 0.48 (0.05) grams per minute−1, a 27% reduction by reducing fresh gas flow from 2 to 1 litres per minute. In practice, using flows of less than 1lpm and down to 0.5lpm with sevoflurane is common in many jurisdictions.(76) The maintenance phase of anaesthesia is the best opportunity to reduce fresh gas flow because circuit gas concentrations are relatively stable and it is often the longest phase of the procedure.(77) In a 2012 literature review of low fresh gas flows, Brattwall et al. reported that using low fresh gas flows has several co-benefits beyond reducing the environmental impact of anesthetic gases including enhanced temperature and humidity preservation and cost savings through more efficient use of anesthetic gases.(78)

A quality improvement project at a tertiary hospital in London, United Kingdom, aimed to reduce costs and provide environmental benefits by promoting the use of low-flow anaesthesia.(80) The project activities included an email to staff explaining the project, initial questionnaire and spot audits of behaviours, as well as a 'low flow board' in the department, which highlighted the project aims alongside pictorial and graphical representations of monthly progression. The project reported an increasing trend in use of low-flow anaesthesia within the department, as well as a decrease in the number of bottles of volatile agent ordered - 18% fewer bottles ordered compared with the same period the previous year, which represented a 25% decrease in total departmental expenditure on volatile agents despite an increase in OR activity.(79)

4.1.4 Use anesthetic techniques other than inhalational anesthesia wherever possible

Regional anesthesia techniques including central neuraxial blocks such as spinal, epidural, and caudal anesthesia, and other peripheral nerve blocks, as well as total intravenous anesthesia (TIVA) use a combination of agents to achieve anesthesia without the use of inhalational agents.(80) The American Society of Anesthesiologists recommends the use of intravenous and regional techniques for its clinical safety and environmental co-benefits.(34) Indeed, despite the use of syringes, pumps and infusion lines associated with TIVA, a life cycle assessment found that TIVA with propofol has approximately 1% the GWP of sevoflurane and far lower life cycle carbon impact than inhalational anesthesia.(68) However, questions remain on the risk of environmental contamination if intravenous pharmaceuticals enter the water supply through disposal of unused drugs or indirectly through human excretion. Early studies into the environmental persistence of these agents shows that propofol has a high Persistence, Bioaccumulation, and Toxicity (PBT) index value which warrants further study.

The research on alternative anesthetic techniques is constantly evolving, and consultations with local experts in the field have mentioned that 'recent articles have questioned the environmental superiority of TIVA based on plastic and pharmaceutical pollution' (81) and there are few studies on regional anesthesia and GHG. A recent study by McGain, Sheridan, Wickramarachchi, et al., (2021) in Australia showed a similar GHG from general anesthesia and spinal (regional technique) anesthesia for knee replacement, whereas they suggest that there are 60% less GHG in the US with renewables.(82). Thus, according to an expert consultant, there may not be 'enough data to categorically say TIVA and regional anesthesia should be prioritized over low flow sevoflurane anesthesia'. As a result of this emerging research, it may be best to not include these anesthetic techniques as suggested alternatives, until more evidence to support their use is shown.

4.2 Rethink the management of waste and unused supplies

4.2.1 Rethink waste management practices

Water and materials waste are estimated to comprise 5% of the total climate footprint (direct and indirect emissions) of the English National Health Service.(6)Opportunities to reduce waste exist by reducing the use of single-use items, avoiding the creation of unnecessary waste (Section 2.2), and through diverting recyclable items from the waste stream (Section 3.1). Where reduction opportunities have been maximized, well organized waste management is needed to ensure appropriate waste sorting, to minimize environmental contamination (e.g., of pharmaceuticals) and the quantity of waste unnecessarily disposed of as hazardous/biomedical waste; this reduces the cost of disposal and may yield some environmental benefits through the reduction of incineration.

With regards to the optimal waste segregation strategies, it appears that it is up to individual centres to determine what works best for them. Canadian waste is commonly sorted into: general waste, yellow bag waste, yellow sharps waste, red cytotoxic sharps waste, recycling (regular, PVC, SUMD) and pharmaceutical waste. A primary issue for proper waste management concerns reducing the amount of unnecessary waste labelled as biomedical waste. Studies have found that up to 90% of the waste in biohazardous bags does not meet the criteria. Beyond the environmental burden of disposing of biohazardous waste, the cost of disposal is often 8-10 times more than regular waste. For example, through education, and making the regular waste bin larger than the biomedical waste bin, Wormer et al created an initiative to reduce saw a 75% reduction in biomedical waste which equated to a cost savings of approximately $60,000.(21)

A second waste management issue relates to reducing the environmental burden of unused pharmaceuticals.(83) In Section 1.2.2 the environmentally conscious use of pharmaceuticals is discussed, however it is anticipated that there will still be situations in which excess pharmaceuticals must be disposed of. It is recommended that all unused non-cytotoxic IV medication, which is essentially all routine medication used in an OR, be expelled from the syringe or vial and the container should be disposed of as waste or recycling depending on local policies. Medication syringes should be emptied and thrown into general waste as no recycling program currently exists. Unused medication should be expelled into a pharmaceutical waste container for incineration, which though not currently mandated by provincial or federal regulations, is considered best practice to avoid medication getting into the water supply and persisting in the environment. If pharmaceutical waste containers are not available, medication can be expelled into general waste (not the sink and not the yellow sharps container).(84)

4.2.2 Rethink the management of unused supplies, older machines and devices through donation where appropriate

Donating surplus medical supplies may be an impactful, cost-effective and environmentally friendly way for hospitals to dispose of supplies and equipment that are no longer of use to them. However, prior to donating, it is essential to be aware of the guidelines and regulations surrounding donations to ensure that the supplies and/or equipment being donated is going to good use rather than being a burden on the receivers.

Marks et al conducted a literature review to assess the current literature on guidelines for medical equipment donations in low- and medium-income countries.(85) The authors found 33 guidelines from different governments, the World Health Organization (WHO), academia and non-governmental organizations (NGOs). The themes that emerged from all of these guidelines included the importance of considering all aspects of the donation process including planning, sourcing, transporting, training, maintaining, and evaluating equipment donations. Donors are encouraged to consult national guidelines to ensure that the donations are appropriate, desirable, and non-costly to both parties as well as ensure that the relationship between the donor and receiver is equitable and collaborative.

Organizations exist to help hospitals donate supplies. Not Just Tourists is one such organization that will assist with donations.(86) On a practical level, it is important to partner with these charitable organizations, and form a Donations Subcommittee with representation from stores/supplies manager (surplus supplies), biomedical engineering (decommissioned equipment), OR Inventory manager and others to ensure comprehensive access to eligible items.

4.3 Rethink the use of blue sterile wrap and consider the use of reusable hard cases wherever possible

Blue wrap is a sterilization wrap composed of polypropylene plastic, which contains and protects surgical instruments. It is used to cover surgical instruments during sterilization and maintain sterility during storage. This wrap is estimated to contribute 19% of the total waste from ORs.(87) Since blue wrap is covered in petroleum-based plastics that are not biodegradable,(88)when it is incorrectly disposed of it can find its way into incinerator bound waste as well and release harmful toxins as it is burned.(20) Another issue with blue wrap is that it is easily torn or is often compromised. When this occurs, it may delay surgical start time, result in cancelled cases, require tray re-sterilization, increase anaesthesia times, and most importantly, it may compromise patient care.(89)

To reduce blue wrap usage, Practice Greenhealth recommends using reusable rigid sterilization containers for surgical instrumentation as opposed to blue wrap.(90)These hard cases, which are typically made of anodized aluminium or stainless steel, must meet the following criteria: (1) allow for sterilant penetration during the sterilization process, (2) prevent microbial penetration during storage and transport as a means of maintaining sterility of processed items, and (3) facilitate aseptic presentation of contents.(89) Based upon a life cycle assessment from the Mayo Clinic, comparing disposable polypropylene blue wrap and reusable aluminum hard cases, the total GHG emissions associated with reusable hard cases was half that of blue wrap when used daily for 10 years.(91)

A potential barrier to implementation of rigid containers in replacement of blue wrap for medical devices sterilization is the significant initial cost. However, since they can be reused, the cost of blue wrap and related waste disposal costs are eventually driven down significantly.(90)According to Practice Greenhealth, utilizing reusable sterilization containers in replacement of blue wrap derives average annual savings of $7,575 per OR.(19) Mills-Peninsula Medical Center, a 413-bed hospital in Burlingame, CA purchased rigid sterilization containers for $34,987 in 2006. Over 8.2 months, the costs broke even as there was a cost savings of $25,173 from blue wrap purchasing and $26,000 from rewrapping costs for torn blue wrap sets. An annual cost-savings of $16,186 in one year was achieved without factoring in waste avoidance costs.(90)

Although some institutions have replaced blue sterile wrap with reusable rigid containers, the view that "blue wrap will likely always have a place in the OR" still persists. This is based on the belief that the hard containers are more expensive, take up space, and that some smaller items necessitate the use of blue wrap.(22) Thus, an alternative to making the switch to hard cases, or in conditions where this switch is not appropriate, recycling blue wrap is another option. Since blue wrap is made from a "speciality plastic", it cannot be sorted into a regular recycling bin.(92) However, when teamed up with the right hauling partner, recycling blue wrap is sometimes possible. Blue wrap can be recycled and transformed into hospital curtains, tote bags, carpeting, rope, and even thermal underwear, when captured correctly.(92)According to Eduarda Calada, head of St.Michael's Hospital's greening initiative, the hospital recycles about 57% of the blue sterile wrap and packaging used in its 22 ORs.(93)

Appendix A: List of potential interventions

Suggested Intervention	Reviewer	Notes
Use anaesthetic gases with lower environmental impact	VH	
Use a lower impact carrier gas	VH	
Use low fresh gas flows	VH	
Use anaesthetic gas capturing systems	VH	
Prepare drugs only when needed	VH	
Ensure proper disposal of pharmaceutical waste	VH	
Reuse anaesthesia breathing circuits	VH	
HEPA filters	VH	
Avoiding spillage upon refilling the anesthesia machine's vaporizer	VH	Excluded from the review
Use of cuffed endotracheal tubes when possible	VH	Excluded from the review
Ongoing checks and maintenance of the anesthesia circuit and anesthesia machines	VH	Excluded from the review
Use of appropriate anaesthetic scavenging and recycling technology	VH	
Update fluid management systems	VH	Excluded from the review
Proper waste segregation (e.g., general, pharmaceutical, biomedical, cytotoxic)	EP	
Recycle medical plastics	JG	Gray literature
Recycle batteries	JG	Excluded from the review
Recycle ampoules or switch packaging	JG	Gray literature
Reduce OR kit overage	EP	
HVAC (e.g. turning off/down OR air exchangers when not in use)	JG	Gray literature
OR Lighting	JG	Gray literature
Reduce use of blue sterile wrap	JG	Gray literature
Reduce use of foam padding	JG	Excluded from the review

Suggested Intervention	Reviewer	Notes
Modify inconsistencies that lead to unnecessary waste	EP	Excluded from the review
Repurpose single use medical devices	EP	
Use of reusable products (e.g. surgical linens, scrub hats)	EP	
Reusable sharps containers	EP	
Waterless hand scrub	EP	
Unnecessary surgeries (e.g. arthroscopic surgery for patients with osteoarthritis)	EP	Excluded from the review
Surplus donations (e.g. donate unused/unopened supplies)	EP	
Scrubbing team management	EP	Excluded from the review
Modification of packaging from external suppliers	EP	

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