Increasing the Environmental Sustainably of Canadian Operating Rooms:
An Evidence Informed Guideline for Policy

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The following Organizations endorse this guideline:

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Introduction

The Canadian healthcare system is responsible for 4.6% of Canada's greenhouse gas (GHG) emissions and 200,000 tons of other pollutants (1). Within hospitals, operating rooms (ORs) have a particularly negative environmental impact (2,3) as they are extremely energy-intensive, consuming six times more energy per square meter than the rest of the hospital (4). They also generate up to a third of total hospital waste (2,5,6). Given the substantial environmental footprint of ORs, they present opportune sites for environmentally sustainable interventions. This guideline highlights the opportunities for sustainable practices in the OR that save time and money while maintaining high quality care and patient safety.

This is an update of a guideline released in 2020. The guidelines were developed by the Best Practice in Surgery Group from the Department of Surgery at the University of Toronto (www.bestpracticeinsurgery.ca), with the update including input from experts from across Ontario, endorsements from national organizations (e.g. Choosing Wisely Canada, Canadian Anesthesiologists' Society, Canadian Association of General Surgeons, CASCADES, and the Canadian Coalition for Green Health Care) and feedback from a broad range of potential end-users from across Canada. Since 2020, several systematic reviews and guidance documents have further evaluated the evidence for "green" interventions in the OR (2,7–12). The objective of this guideline is to provide actionable, evidence-informed recommendations to increase the environmental sustainability of ORs.

Scope

The scope of this guideline is limited to interventions related directly to the OR. The end-users include, but are not limited to, persons working in the ORs (e.g. surgeons, anesthesiologists, nurses, OR managers, trainees, assistants), housekeeping and patient service staff (e.g. laundry and waste services), medical device reprocessing departments, administrators (e.g. environmental and quality improvement (QI) managers, procurement teams), hospital executives and policy makers (e.g. provincial hospital associations or health authorities).

Recommendations

A total of 21 recommendations are provided and presented byway of the 4Rs (reduce, reuse, recycle, and rethink) (Table 1) , which are commonly used categories for sustainability efforts in healthcare (9,13,14).

Reduce refers to interventions that decrease waste of resources (e.g. energy use) and/or physical waste. Reuse is substituting reusable items for disposable ones and/or reusing or remanufacturing single-use items. Recycling relates to converting waste into reusable materials. Rethink refers to interventions that require more research or consideration for change (13,14).

A unique grading matrix was developed based on the hierarchy of evidence of included studies and the triple bottom line (15,16) (Box 1). The triple bottom line is a conceptual framework, originating from the business literature, that assesses the social, environmental, and financial impacts of an activity (16). In this guideline, the terms people, planet, and profits are used to indicate the social, environmental, and financial impact of each recommendation. The matrix provides a visual snapshot of the type of studies that inform each aspect of the triple bottom line so that the reader can critically appraise the evidence themselves. The matrix is based on a modified hierarchy of evidence that includes studies relevant to environmental sustainability, (15,17). The evidence is presented this way so that end-users can use different types of information to better understand the impact of the intervention and assist with implementation (e.g. "profit" information for administrators, "planet" information to increase user buy-in, "people" information to understand potential barriers).

The strength of each recommendation is provided for each recommendation (Box 2). The determination of a strong, conditional, or for consideration recommendation was based on the balancing and synthesis of evidence according to the triple bottom line and guideline development tools (18–20). For example, "Profit" was assessed by the resource use, cost-benefit, cost-savings, and upfront costs reported; "People" was assessed based on desirable and consequences such as healthcare team preferences, feasibility, implementability, and safety of the intervention, and "planet" was assessed for its reported environmental impact. The steering committee adjudicated this balance.

Methods

This is an update to a guideline that was developed in 2020 by the Best Practice in Surgery Group from the University of Toronto, Department of Surgery. The development of the guideline was funded by the Department of Surgery and Collaborative Centre for Climate, Health and Sustainable Care, University of Toronto. The AGREE Health Services tool was used as the methodological framework as it provides guidance on developing, reporting and implementing health services challenges based on best-evidence (19,21). The GIN-McMaster Checklist was also utilized (22). ADAPTE was used to create the recommendations for inhalational anesthesia (23). Lastly, a modified Delphi was undertaken to gain expert agreement on the recommendations (24).

Composition of Participating Groups

This guideline was developed by a multidisciplinary team of 17 members including clinicians, administrators, environmental specialists, and patients (n=2). Members were invited to participate based on authoring the 2020 version, being a known expert or being a member of the Patient Advisors Network (www.patientadvisors.ca). This group served as the Delphi panel (henceforth referred to as the guideline panel) who took part in all aspects of the guideline development including the determination of priority topics, voting on recommendations, reviewing summaries of evidence, and development of the grading matrix. The steering committee was tasked with the majority of writing of the guideline (JG, EP, SW). To ensure broad applicability, an end-user group was formed for external review with participants from ON-SQIN (www.hqontario.ca/Quality-Improvement/Quality-Improvement-in-Action/Ontario-Surgical-Quality-Improvement-Network) , CASCADES (www.cascadescanada.ca) , and the Patient Advisors Network.

Selection of Priority Topics

To determine all possible interventions on increasing the environmental sustainability of ORs, a scoping review was undertaken in PubMed, Medline, and Embase by a librarian (CDC) as well as a search of the grey literature (JG, EP) in Google Advance in Summer 2023. Three reviewers (JG, KL, EP) independently reviewed titles, abstracts and full-text articles to generate a comprehensive list of reported possible interventions. The guideline panel then voted on whether or not to include the intervention for further review based on pre-determined inclusion criteria (e.g. OR specific, relatable to the Canadian context, implementable). Anonymous voting took place during an online meeting in November, 2023. An 80% threshold for agreement was selected a priori as there is no gold standard for Delphi studies, however 80% is noted as the most rigorous (25). Of the 39 interventions presented, 24 were selected to undergo further review.

Literature Review and Quality Assessment

All 24 rapid reviews were conducted using the Rapid Review Guidebook (26). Searches for each intervention, framed by the triple bottom line, were performed by a librarian (CDC) in PubMed (www.pubmed.ncbi.nlm.nih.gov) , Medline (www.nlm.nih.gov) , and Cochrane (www.cochrane.org)) in August 2023 and February 2024, using the PRESS Checklist (27). Grey literature searches were conducted in Summer 2024 in Google Advance, supplemented by the HealthcareLCA database (https://healthcarelca.com/) and reference list screening. Two reviewers independently screened titles and abstracts in Covidence (JG, KL), with discrepancies resolved by a third reviewer (EP). A total of 7,768 titles and abstracts were screened, yielding 344 full-text articles; 405 documents were added from grey literature and hand-searching, for a total of 749 data sources. Full text articles and grey literature sources were imported into Zotero. Data were extracted using a standardized form addressing the triple bottom line and implementation strategies, and synthesized narratively.

During this process, several recent anesthesia guidelines were identified from reputable organizations (8–11,28–31) most of which recommended similar interventions. Thus, the authors opted to summarize the guidelines using ADAPTE methodology (23) rather than undertake new reviews for each intervention related to inhalational anesthesia.

Traditional quality assessments were not possible given the types of studies included in this review. Although several quality assessment tools exist for various types of study designs (20,32–36), only 30% of the included studies allowed for quality assessment and the authors determined that assessing the quality of those studies would not add value to the recommendations. Additionally, there is currently no validated way to include quality assessment of environmental studies into healthcare related guidelines (37).

Development of Recommendations

The grading matrix was developed as no known framework or quality assessment exists relevant to the triple bottom line and the types of studies referenced in this paper (20,38,39). The triple bottom line is increasingly utilized in healthcare to provide a more comprehensive, holistic assessment of the impact of an intervention/activity (18,40). As the objective of this guideline is to increase environmental sustainability, the summary of evidence needed to include sustainability studies in addition to studies reporting traditional outcomes (i.e. profits and people). As noted above, quality assessments were not undertaken. However, the authors wanted readers to be able to assess the type of evidence included. Thus, the traditional hierarchy of evidence was used to map where the types of studies used for the triple bottom line fit (15,17). For example, LCAs and CFAs are the most robust types of environmental studies, which would be similar to a Randomized Controlled Trial for a clinical intervention (high quality). Similarly, many QI studies are similar to traditional observational studies (moderate quality). The authors reviewed each included reference to determine the type of study and mapped each study design to a ranking (High, Moderate, Low) (See Box 1). The guideline panel approved the matrix.

A modified approach to the ADAPTE process was utilized with the "set-up" and "finalization" phases omitted as these were undertaken in accordance with the AGREE-HS toolkit. The authors followed the Adaptation phase, which included: determining the health questions, searching and screening guidelines, assessing the quality, currency, content, consistency and applicability and acceptability of the recommendations, reviewing assessments and selections for adapted recommendations. PubMed and Google Advance were searched for relevant guidelines using terms such as "Inhalational Anesthesia", "Guidelines", and "Environmental Sustainability". Two authors independently reviewed the Guidelines using the AGREE instrument and ADAPTE evaluation sheets. Overall, most of the included guidelines lacked transparency regarding the methods for creating the recommendations and searching and summarizing the related the evidence. Additionally, quality assessments were omitted. Despite this, the recommendations and summaries of evidence for all of the recommendations assessed were similar. The recommendations provided here are the result of the synthesis of the ADAPTE process and input from the guideline panel as part of the modified Delphi.

Following data extraction, the steering committee drafted summaries of evidence based on the triple bottom line and suggested recommendations based on the available evidence, noting recommendations from the 2020 version, and in accordance with AGREE-HS and GIN-McMaster guidance documents (19,22). The draft recommendations and summaries of evidence were sent to the guideline panelists as part of the Delphi process for a round of anonymous voting in September 2024. Panelists had the opportunity to vote whether they agreed/disagreed with the recommendation, had suggestions for wording, or whether it required further discission. The guideline panelists discussed the results in an online meeting in October 2024. The threshold for agreement was 80%.

External Review

Following revisions, the updated recommendations and evidence summaries underwent external review (November–December 2024). An online, anonymous national survey was distributed via ON-SQIN and CASCADES mailing lists. Respondents represented a range of participants: surgeons (27%), anesthesiologists (14%), nurses, trainees, administrators, managers, patients, and researchers from academic (41%), community (34%), and mixed settings (21%) across rural (10%) and urban (85%) areas in seven provinces and territories. Feedback was reviewed by the steering committee, leading to further refinements. The recommendations were circulated to the guideline panel as part of the Delphi for a second, final round of voting. Over 80% agreement was achieved for all recommendations, with most exceeding 90%.

Management of Competing Interests

The Guidelines International Network Principles for Conflicts of Interest in Guidelines were adhered to (41). Each member of the guideline panel was asked to indicate if they had any financial and nonfinancial competing interests at the beginning of the project and again at the end. As no members had any conflicts to declare, no further action was required. Funding was received from the Collaborative Centre for Climate, Health & Sustainable Care and Department of Surgery at the University of Toronto, to assist with the preparation of this guideline, yet had no direct role in its development.

Table 1. Summary of Recommendations

Recommendations	Triple Bottom Line: Hierarchy of Evidence			Strength of Recommendation
	Planet	Profit	People	
1. Reduce				
1.1 Reduce energy use by turning off lights and equipment at the end of the day, using HVAC setback systems and/or occupancy sensors	✓✓✓	✓✓	✓✓	Strong
1.2 Reduce unnecessary waste by ensuring appropriate waste segregation	✓✓✓	✓✓	✓✓	Strong
1.3 Reduce pharmaceutical drug waste (e.g. use prefilled syringes, refrigerate unused drugs, use drugs that are close to expiry first)	✓✓	✓✓	✓✓	Strong
1.4 Reduce redundant items on surgical trays	✓✓	✓✓	✓✓	Strong
1.5 Reduce redundant items in custom packs	✓✓✓	✓✓	✓	Strong
1.6 Reduce the use of blue wrap	✓✓✓	✓✓	✓✓✓	Strong
1.7 Reduce greenhouse gas emissions from inhalational anesthesia				
1.7.1 Do not use desflurane	✓✓✓	NR	NR	Strong
1.7.2 Avoid the use of nitrous oxide if possible	✓✓✓	NR	NR	Strong
1.7.3 Decommission the use of nitrous oxide through central piping systems and use portable canisters instead	✓✓	NR	NR	Strong
1.7.4 Minimize fresh gas flows (≤ 1L/min)	✓✓	NR	NR	Strong
2. Reuse				
2.1 Use reusable medical devices	✓✓✓	✓✓✓	✓✓✓	Strong
2.2 Use reusable textiles (e.g. surgical gowns)	✓✓✓	✓✓	✓✓✓	Strong
2.3 Use reusable sharps containers	✓✓✓	✓	✓✓✓	Strong
2.4 Collect single-use medical devices for remanufacturing and reuse whenever possible	✓✓✓	✓✓✓	✓✓✓	Strong
3. Recycle				
3.1 Develop and implement an effective recycling program in the OR. To ensure effectiveness, assess recycling procedures at your hospital (e.g. downstream processes and recycling hauler regulations) prior to implementation.	✓✓	✓	✓✓✓	Weak
3.2 Develop and implement specialized recycling programs if feasible (i.e. PVC, blue wrap, batteries, copper)	✓	✓	✓	Weak
4. Rethink				
4.1 Rethink disposal of unused supplies, older machines and devices and consider donation where appropriate	NR	NR	NR	For consideration
4.2 Rethink all procurement decisions by implementing an Environmentally Preferrable Purchasing policy	NR	NR	NR	For consideration
4.3 Rethink traditional hand scrub and consider the use of alcohol hand rub	✓✓✓	NR	✓✓	For consideration
4.4 Rethink anaesthetic techniques other than inhalational anaesthesia	NR	NR	NR	For consideration

*NR- not reported

Box 1. Grading Matrix based on the Hierarchy of Evidence of Study Designs

Low (✓): Supporting evidence comes from survey studies, review articles (unspecified), grey literature, and/or expert opinion
Moderate (✓✓): Supporting evidence comes from comparative studies, waste audits, literature/narrative/scoping reviews, cost-analyses, quality improvement studies and/or guidelines
High (✓✓✓): Supporting evidence comes from systematic reviews, randomized controlled trials, life-cycle analyses (LCA) or carbon foot printing analyses (CFA).

Box 2. Strength of Recommendations

Strong recommendation: The recommendation can be adapted as policy in most situations. Adherence to this recommendation could be used as a quality indictor for the environmental impact of ORs.

Conditional recommendation: Policy-making will require substantial debate and involvement of various stakeholders. An appropriately documented decision-making process could be used as quality indicator for the environmental impact of this recommendation.

For consideration: There is insufficient evidence to support a decision for or against a recommendation. However, the intervention is thought to have the potential to increase the environmental sustainability of ORs.

Summaries of Evidence

1. Reduce

1.1 Reduce energy use by turning off lights and equipment at the end of the day, using HVAC setback systems and/or occupancy sensors

Summary

Despite occupying a relatively small portion of the hospital footprint, ORs are the most energy-intensive areas, consuming 3-6 times more energy than the rest of the hospital (11,42). The majority (90-99%) of energy consumption in the OR relates to HVAC (heating, ventilation and air conditioning) systems and the remainder of energy usage comes from plug-loads and lighting (11). ORs in North America are typically unoccupied 40% of the time, in

dicating that some of this energy usage may be unnecessary (14). It is essential that health care systems work to reduce the energy consumption of ORs. Key recommendations include: the implementation of HVAC and lighting setback programs or occupancy sensors; turning off lights and equipment during downtime; replacing traditional lighting with energy-efficient LED lights; as well as upgrading electrical equipment to "low power hardware" (computer hardware such as monitors and processing units). By adopting these strategies, healthcare facilities can significantly mitigate their environmental impact and generate cost savings, while maintaining high standards of patient care. Many hospitals have successfully implemented HVAC set-back systems and reduced energy consumption by up to 50% (4,14).

People

Environment Canada states that "a typical operating room ventilation system delivers 20 to 25 air changes per hour in occupied mode with 4 air changes per hour of outside air; many older designs have air changes in excess of 30 air changes per hour" (43). Recent evidence recommends ORs have a minimum of 20 air changes per hour while in use and allows for this to be safely reduced by up to 90% when the OR is unoccupied and the minimum number of air exchanges required can be re-established by the time the OR becomes reoccupied. With regard to the safety of reducing energy use, Dettekofer et al. conducted a study to assess the safety of HVAC setback protocols. The ventilation system was switched off and restarted after 10 hours. Particles suspended in the air near the operating table were counted, OR temperature was measured, and settle plates were exposed and incubated. The study found particle and microbial counts remained at a safe level following this measure if adequate ventilation was restarted within 30 minutes of surgery (44). Implementing an HVAC setback program or occupancy sensors has little impact on staff and patients using the ORs (44,45).

Perioperative staff recognize the importance of implementing energy-saving measures and are willing to engage in such activities. In a cross-sectional survey by Ho and Naseem, 75% of perioperative staff acknowledged healthcare's significant environmental impact, and 97% were willing to participate in sustainable activities (46). Key energy-saving strategies identified included using energy-efficient appliances (97%), switching off lights (94%), conducting energy audits (86%), using low-energy lighting (81%), and unplugging equipment (58%). These findings are widely supported in the literature (47). Despite the agreement on the importance of energy-saving activities in the OR, there are barriers to implementing them. Ho and Naseem's survey noted lack of recycling facilities as the great perceived barrier (92%), followed by staff attitudes (78%), time (72%), lack of leadership (69%), lack of support from colleagues (58%), and cost (58%) as the main barriers to achieving more sustainable practices (46).

Planet

MacNeill et al. found that using a HVAC set-back system, which included reducing air flow rates in 19 of 22 theatres overnight and on weekends and leaving three theatres online for emergencies, reduced

HVAC energy consumption by 50% (4). 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 (48). Providence St. Peter Hospital in Washington reduced use of energy in its operating room by reducing its ventilation system output by 60% during unoccupied times (14). HVAC occupancy sensors offer similar environmental benefits to a setback program which is estimated to reduce energy consumption by 40% (Environment Canada). Lin et al. conducted a pilot study where they implemented a radiofrequency identification system to automatically control high-efficiency particulate air (HEPA) ventilation. The system activated and adjusted itself according to the number of individuals in the operating room. The system was able to achieve 50% energy savings 60 (7,49). It is also possible to use occupancy sensors for OR lights. Duke Medical Centre installed occupancy sensors in five areas throughout the Ambulatory Surgical Centre (ASC) and conducted an audit to evaluate unnecessary lighting usage. Within a year, the ASC achieved a 30-megawatt-hour energy saving (50). Green Surgery Automation highlights that using passive infrared (PIR) sensors to control lights, HVAC systems, and temperature can help reduce energy consumption if located appropriately, and can eliminate human error (11).

The Centre for Sustainable Healthcare in the UK recommends turning HVAC systems completely off when unoccupied, as opposed to a setback setting (11). The article states that turning off OR ventilation overnight or when unoccupied is appropriate and quickly reversible as an OR can achieve safe operating conditions after 20 (laminar air flow) to 30 minutes (temperature-controlled air flow) of full-power ventilation. When Nuffield Health Centre piloted a program when switching OR ventilation from a low powered 'set back mode' to off overnight, CO_2 emissions decreased by 15-36 tonnes of CO_2e/year per room. This initiative also led to cost savings of £30,000 per room per year (11).

Many studies have documented the positive environmental impact of powering down ORs when not in use (6,11,51). Wormer et al. included a "power down" initiative as part of their Green OR initiative, which involved turning off all anesthesia and OR equipment, lights, computers, and radios each evening and on weekends while leaving a subset of ORs ready for immediate use (6). This resulted in a reduction of 234.3 metric tons of CO_2 emissions per year. Similarly, an initiative implemented by Barts Health NHS Trust, "Operation TLC" (Turn off equipment, Lights out, Control temperatures), reduced annual carbon emissions by 2200 tonnes and energy costs by £500,000 (52). Additionally, a clinical team at an NHS hospital implemented a shutdown initiative that encouraged staff to turn off devices in elective operating theatres at the end of the day, including computers, anaesthetic machines, and anaesthetic gas scavenging (11). The team anticipates that this initiative could save 44,774 kg CO_2e per year, along with significant economic savings.

Lastly, the environmental impact of ORs can be reduced by switching to more environmentally friendly options for OR equipment and machines. For example, LED lights use 49% less energy than traditional lighting and generate less heat. In turn, this lowers the HVAC cooling load, further decreasing energy expenditure in the OR (53) Furthermore, their longer lifespan equates to less consumption of resources for production and less waste products (54,55). In addition to switching to LED, when purchasing newer equipment, it is essential to keep in the mind the environmental impact when possible and choose machines that allow for more sustainable practices like anesthetic machines that allow for minimal fresh-gas flows or choosing equipment that requires less energy to run.

Profit

HVAC setback programs have been shown to provide major cost savings. The Greening OR Program at the Cleveland Clinic implemented an HVAC setback program which decreased the hourly exchange rate from 35 exchanges per hour 24/hours a day to 20 exchanges per hour when the OR is in use and 4 when unoccupied. This change resulted in $6 million USD in total energy savings. In addition to reducing energy consumption, establishing HVAC setbacks that decrease OR air exchange rates while maintaining positive pressure when facilities are unoccupied also extends the life of HVAC equipment, contributing to even more cost savings in the future. (56). Other studies have also documented significant savings from implementing HVAC setback programs (11,44,48). The modelling project from Greening Healthcare found that an HVAC setback program would translate to an annual cost savings of $27,962 CAD (6,57). Dettenkofer et al documented that shutting down HVAC systems during idle hours led to an estimated annual savings of $6105 Euro per OR (44). The American Hospital Association's Guidelines for HVAC Setback indicate that while adopting an HVAC setback strategy yields notable savings in any climate, the savings are especially substantial in extreme climates (58).

In terms of occupancy sensors, 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 (14). Power-down initiatives are also associated with significant cost savings (6,11,52). Wormer et al.'s power-down initiative resulted in estimated annual cost savings of $33,000 USD based on 30 ORs (6). Duke's installation of occupancy sensors, which cost between $100 and $200 USD each, led to annual electricity cost savings of over $2,000 USD (50).

Replacing traditional lights with LED lights in the OR has been shown to offer financial savings (59). The Biomedical Engineering Team at University Health Network, for example, undertook an LED retrofit initiative. This involved replacing halogen lights in 8 ORs. The LED retrofit initiative reduced electric consumption by 28,000 kWh/year and peak demand by 9kW. Cost savings amounted to approximately $3,500CAD/year(60). Although an initial investment is required for these upgrades, the financial returns are substantial and quick. NY Presbyterian Hospital invested $1.1 million USD in updating their 11,000 light fixtures and saves $400,000 USD per year. This investment had a payback period of only 2.5 years (50). As part of the Cleveland Clinic's Greening OR Program for energy improvement, surgical field and peripheral lighting in Cleveland Clinic ORs was standardized to LEDs, replacing halogen fixtures. LEDs' reduced heat output has lessened the demand on HVAC systems (56). Cleveland Clinic's overall energy efficiency improvements have saved the health system more than $100 million USD since 2010.

Lastly, ORs should invest in "low power" hardware (computer hardware, such as monitors and processing units). Weiss et al. estimate that using low-power hardware for just 100 computers can save approximately $6,000 USD annually in electricity cost (61).

Implementation

Below are the most commonly reported implementation strategies to assist with successful uptake of this recommendation:

- Staff education (47,50)
- Energy audits (47,50)
- Visual reminders (11,51,56)
- Shutdown checklists (11,51,56)
- Ensuring that the setback schedule matches the actual occupancy (43)

1.2 Reduce unnecessary waste by ensuring appropriate waste segregation

Summary

There is an abundance of literature suggesting that up to 90% of OR waste is not appropriately disposed of in ORs, leading to regular waste being treated as biohazardous or sharps waste, which is both costlier and more environmentally harmful (5). Biohazardous waste is treated with energy-intensive processes like incineration or autoclaving which produce harmful emissions, including carcinogens such as dioxins and mercury (14,62). Many quality improvement studies show that proper segregation of waste can minimize the amount of waste requiring such high-energy processing, thereby reducing the carbon footprint of ORs. Financially, improper waste segregation increases costs as removing biohazardous waste is 8-10 times more expensive than disposing of general waste (6,14,63). Several systematic reviews and multiple implementation projects have shown that educational interventions on OR waste segregation are an unmet need. These interventions have proven effective in enhancing staff knowledge and participation in waste segregation (7,64–68).

Person

Biohazardous waste is particularly concerning due to its potential to harm to both human health and the environment. Included in the Health Canada definition of biomedical waste is human anatomical waste (i.e. human tissues, organs, body parts excluding hair, nails and teeth; human blood and body fluid waste (items saturated with blood, body fluid contaminated with blood) and sharps waste (69). Improper disposal of biohazardous waste can contribute to the spread of infectious diseases. Additionally, the treatment and disposal of biohazardous waste involves energy-intensive processes, like incineration or autoclaving, which release harmful emissions, including carcinogens like dioxins and mercury, into the atmosphere (14,62). These harmful emissions pose significant risks to human health, contributing to respiratory problems and other health issues**.**

Reducing unnecessary and improperly streamed waste in the OR requires the commitment and active participation of healthcare professionals. The attitudes and behaviors of staff are critical to the success of waste segregation programs. A 2023 systematic review by Pradere et al. highlights that, of all climate-smart actions identified, waste management is where healthcare workers can have the strongest impact (7). OR staff are generally supportive of efforts to reduce OR waste production. Thiel et al. conducted a survey at the University of Pittsburgh Medical Center and found that 95% of obstetricians and gynecologists supported efforts to reduce surgical waste (70). The available literature found that OR staff perceive inadequate knowledge and lack of infrastructure as the main barriers to improving waste management in the OR (46,64,71). These findings underscore the necessity for improved infrastructure and comprehensive education on waste segregation practices to ensure staff engagement and compliance**.**

Planet

The environmental impact of OR waste is substantial due to its large volume and the frequent misclassification of non-hazardous waste as biohazardous. Biohazardous waste or regulated medical waste requires high-energy processing (14). Techniques like autoclaving and incineration, used for this purpose, have adverse environmental effects. One kilogram of biohazardous waste produces three kilograms of CO2 emissions, and each OR is estimated to produce approximately 2300 kilograms of waste a year (18,72). Proper waste segregation ensures that biohazardous waste is minimized, and that only genuinely biohazardous materials are subjected to high-cost and high-impact disposal methods. A systematic review identified nine studies and two guidelines emphasizing the importance of waste segregation in the OR, with eleven studies noting the need to recycle or reuse waste (7). Many studies have documented the improper disposable of non-hazardous waste into the biohazardous stream in the OR. One case study reported that up to 92% of discarded biohazardous waste may be nonhazardous (14,73,74). Another case study found that the average volume of waste per surgical procedure was 10.9 kg, consisting of clinical (84.4%), recyclable (12.8%), and bio-bin (2.8%) waste (75). Given that experts suggest biohazardous waste should make up no more than 15% of an institution's total waste stream (14,76), these studies highlight the issue of improper waste segregation in the OR**.** Furthermore, up to 80% of OR waste is generated before surgery begins, during the preparation phase, and is not biohazardous (42,45).

Proper segregation practices can significantly reduce the volume of biohazardous waste generated in the OR, and thus, mitigate some of the environmental impacts. A study by Wormer et al. at Carolinas Medical Center showed that educating staff on proper waste segregation significantly reduced biohazardous waste (6). Staff were instructed to place only materials heavily soiled with blood or potentially containing bloodborne pathogens in red bags, and infrastructural changes such as larger general waste bins and smaller red biohazard bins were implemented to encourage proper segregation. These interventions lead to a 75% reduction in red bag waste. Hubbard et al. investigated whether using standard waste receptacles for anesthesia-related waste before patient entry would reduce biohazardous waste (77). Standard waste bags were used until the patient entered the room, then replaced with biohazard bags. This approach resulted in a median waste collection of 0.35 kg per case, suggesting a potential annual reduction of 13,800 kg of biohazardous waste and cost savings of $2200USD.

Profit

Proper waste segregation can lead to significant cost savings. Experts state that proper waste segregation in the OR may have the single greatest impact on costs related to waste disposal. (14). The removal of biohazardous waste is 8-10 times more expensive than regular waste (6,14,63,78). Inova Fairfax Hospital in Virginia, USA, implemented an educational program to help reduce their "red bag waste" by appropriately segregating waste. They achieved an annual reduction of 14% in biohazardous waste, equating to a 100,000-pound reduction and over $200,000 in cost savings (79). Similarly, Wormer et al. reported a 75% reduction in biohazardous waste after an educational intervention, resulting in $60,000 in annual savings (6). Southorn et al. found that appropriate waste segregation in knee operations could yield potential savings of £420,000 per year for two operations alone, excluding additional savings from recycling (72). Fraifeld et al. instituted a waste segregation initiative in 35 ORs at a tertiary care center, which resulted in a decrease in the overall weight of biohazardous waste from 0.33 kg/case to 0.09 kg/case, saving $28,392 annually (65). Magee-Women's Hospital of the University of Pittsburgh Medical Center in Pennsylvania targeted proper waste segregation and, in 2010, decreased biohazard waste from operating rooms by 47%, achieving savings of more than $89,000.22 (14,80).

Implementation

Below are the most commonly reported implementation strategies to assist with successful uptake of this recommendation:

- Staff education (7) (64–68)
- Increasing team familiarity (81)
- Interventions to reduce cognitive load (i.e. having appropriate bins available; appropriate signage) (2).

1.3. Reduce pharmaceutical drug waste (i.e. use prefilled syringes, refrigerate unused drugs, use drugs that are close to expiry first)

Summary

Pharmaceutical waste represents another source of unnecessary waste generated operating rooms. Most pharmaceutical waste is produced when excess drugs are drawn or from drugs being left unrefrigerated and subsequently discarded per protocol. Studies document that between 20-50% of drugs drawn by anesthesiologists during surgery are wasted (82). Several observational studies have quantified the amount of drug waste generated in ORs as well as the associated financial costs. Barbariol et al. conducted a prospective observational multicenter study tracking drug wastage in ORs and ICUs across 12 hospitals in northeastern Italy over a one-month period (83). The study collected data on 13,078 prepared syringes, revealing an overall wastage rate of 38% and a financial loss of €78,060. Additionally, 4968kg of preventable medical waste was generated annually. Similarly, Atcheson et al. analyzed which drugs were used, wasted, or discarded for the first surgical case each day over 12 months at an academic medical center (84). The average cost of wasted drugs was $1011.94CAD per day, totaling $252,983.88CAD annually. In addition to the financial burden, improper disposal of unused pharmaceuticals poses a serious threat to the environment as wasted medications often end up contaminating air, soil, and water, including tap water, leading to long-term negative impacts, such as unintended consumption by humans and animals (10,85). For instance, waste from propofol, a common drug used in ORs, contaminates the environment extensively due to its non-biodegradability, leading to rapid accumulation and toxicity in aquatic settings (28,83). Since managing pharmaceutical waste is costly environmentally and financially, strategies should be used to decrease medication waste including the use of prefilled syringes, splitting of vials (especially in pediatric anesthesia) to accommodate smaller dose volumes, and avoiding drawing up medications that may not be used (86).

People

Since managing pharmaceutical waste is environmentally and financially costly, strategies that help prevent waste from being generated in the first place should be explored (86). Strategies to decrease medication waste include the use of prefilled syringes, splitting of vials (especially in pediatric anesthesia) to accommodate smaller dose volumes, and avoiding drawing up medications that may not be used (86). Several studies have highlighted clinical benefits of using prefilled syringes of pharmaceuticals to help reduce waste in the ORs which include reducing clinician error and the consequent risk of harm to patients and enhanced workflow (87). It is recommended to have prefilled appropriate dose aliquots in syringes to maximize yield from high-concentration drug vials that need to be diluted. 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 the pharmacy into diluted syringes stored in the refrigerator giving them a reasonable shelf-life. However, Atcheson et al., notes that the potential savings of using prefilled syringes could be offset by their expiration and disposal, hidden costs within the hospital pharmacy, and challenges in providing certain medications in prefilled syringes due to stability or manufacturing limitations (84).

Planet

Medications often end up contaminating air, soil, and water, including tap water, leading to long-term negative impacts, such as unintended consumption by humans and animals (10,85). For instance, waste from propofol, a common drug used in ORs, contaminates the environment extensively due to its non-biodegradability, leading to rapid accumulation and toxicity in aquatic settings (28,83).

Profit

Several observational studies have quantified the amount of drug waste generated in ORs as well as the associated financial costs. Barbariol et al. conducted a prospective observational multicenter study tracking drug wastage in ORs and ICUs across 12 hospitals in northeastern Italy over a one-month period (83). The study collected data on 13,078 prepared syringes, revealing an overall wastage rate of 38% and a financial loss of €78,060. Additionally, 4968 kg of preventable medical waste was generated annually. Similarly, Atcheson et al. analyzed which drugs were used, wasted, or discarded for the first surgical case each day over 12 months at an academic medical center (84). The average cost of wasted drugs was $1011.94CAD per day, totaling $252,983.88 CAD annually. The highest amount of preventable waste was recorded for ephedrine at 59.5%, associated with an annual cost of $75,246CAD. Kaniyil et al. investigated the wastage of IV anesthetic drugs and estimated associated financial losses in major ORs at a tertiary care hospital in Kerala, India over five non-consecutive weeks (89). Significant quantities of drugs like propofol, thiopentone sodium, vecuronium, mephentermine, lignocaine, midazolam, and atropine were wasted daily. The total financial loss during the study was Rs. 59,631, with an average daily loss of Rs. 1987.

The literature emphasizes using prefilled syringes as an effective strategy to reduce pharmaceutical waste (86). A cost-analysis was conducted in France comparing atropine ampoules that were prepared by providers at the point of care versus pre-filled syringes and found that prefilled syringes reduced the total annual cost by $ 7,746,894CAD despite the unit cost of a pre-filled syringe being a $7.89CAD higher (90). These savings were achieved as drug waste was eliminated and the costs from medication error and waste disposal had been reduced by 77% and 70% respectively.

A significant portion of medication waste results from drugs being left unrefrigerated and subsequently discarded per protocol. With this in mind, Tsang et al. conducted a prospective quality improvement study aimed at reducing waste from unused refrigerated medications in cardiovascular operating rooms (CVORs) at Tampa General Hospital in Florida. The authors identified the most frequently used medications and implemented changes, such as relocating norepinephrine, epinephrine, and nitroglycerin to mini-refrigerators within each CVOR and placing other medications like vasopressin in automated anesthesia cabinets. The intervention led to a substantial reduction in weekly waste costs, dropping from $1,188.59USD to $322.96USD, resulting in annual savings of over $45,000USD (91) .

Implementation

Below are the most commonly reported implementation strategies to assist with successful uptake of this recommendation:

- Using prefilled syringes (86)
- Splitting of vials (especially in pediatric anesthesia) to accommodate smaller dose volumes (86)
- Avoiding drawing up medications that may not be used (86)

1.4 Reduce redundant items on surgical trays

Summary

Several studies have documented the large number of surgical instruments that enter the OR for procedures but remain unused. Research from various surgical specialties highlights the benefits of reducing the number of instruments on surgical trays, which includes reductions in operating time, instrument error rates (broken or missing instruments), waste, and costs. (92–94) While most of the data comes from case studies and quality improvement initiatives, the consistent and significant benefits reported underscore the importance of this intervention. Reducing the number of instruments on surgical trays enhances workflow efficiency, reduces the rate of instrument errors, and increases satisfaction among stakeholders (95). These changes do not compromise patient safety. The financial implications of optimizing surgical trays are also substantial. Wasted supplies, particularly unused instruments, represent a significant financial burden in the OR. Numerous studies have found that reducing instruments in surgical trays is associated with cost savings (93,94,96,97). Although there is less information available on the environmental benefits, removing underutilized and redundant instruments from surgical trays reduces the need for unnecessary re-sterilization and the amount of waste generated. This can be safely assumed to contribute positively to environmental sustainability.

People

Optimizing surgical trays by reducing the number of instruments enhances workflow efficiency, reduces errors, and increases satisfaction among stakeholders. Numerous studies have documented time savings from removing underutilized and redundant instruments from surgical trays. For example, Lonner et al. conducted a prospective pilot study to assess the economic impact of instrument tray optimization in total joint arthroplasty (THA). Instrument utilization in THA procedures was observed and recorded, and then redundant or underutilized instruments were identified. Based on these findings, surgeons agreed upon the fewest number needed for each tray and removed 32.2% of instruments from trays (92). Mean setup time decreased from 20.7 to 14.2 minutes, while 40-75 minutes were saved during the sterilization process. Schneider et al. conducted a mixed-methods study to optimize ophthalmic surgical instrument management at a Brazilian university hospital (93). Initially, they conducted brainstorming sessions and field observations to understand how instruments were used during surgeries and identified key themes. Using these insights, they applied matrix arrangements and linear programming to reorganize surgical trays more efficiently. This method reduced the number of instruments per tray by 13.10% and increased surgical production by 17.88%, allowing more surgeries to be performed in the same timeframe. Lastly, Knowles et al. analyzed vascular surgery instruments on aortic and vascular trays to optimize usage (94). They monitored 168 vascular surgeries over three months, collecting data on which instruments were used. They found that only 22.9% of instruments in the vascular tray and 12.5% in the aortic tray were used. Consequently, they removed 45.8% of instruments from the vascular tray and 62.5% from the aortic tray, leading to improved efficiency. This led to a reduction in setup time from 7:44 to 5:02 minutes for the vascular tray and from 8:53 to 4:56 minutes for the aortic tray, saving 316.2 hours of personnel time annually.

Reducing the number of instruments may also reduce the instrument error rate. Stockert and Langerman conducted a single-site prospective observational study which involved analyzing at the relationship between instrument tray size and the number of errors per tray (missing or broken instruments) (95). Instrumentation issues were observed to dramatically increase by tray size, with an error rate of 49% for trays with greater than 40 instruments, contrasted against an error rate of 13% for trays with 40 instruments or less. They found that an increasing number of instruments per tray was associated with decreased use and a higher rate of instrument errors, such as broken or missing instruments.

Numerous implementation studies have shown that a reduction in surgical instruments is agreeable to most surgeons. Capra et al. conducted a before-after study to evaluate surgical tray optimization for 96 total knee arthroplasty (TKA) and/or total hip arthroplasty (THA) procedures and found the number of instruments could be reduced by 43.6% for TKA and 17.5% for THA (97). In addition, the authors found that the average setup time decreased by 3 minutes for THA and 6 minutes for TKA. Furthermore, when surveyed, surgeons and hospital staff reported positive feedback on the intervention. Wannemuehler et al. used Lean Six Sigma to reduce adenotonsillectomy instruments from 52 to 24, moving 28 less-used items to a supplemental set (98). The supplemental set was needed in only 3.6% of cases, proving the effectiveness and acceptance of the reduction. This cut median assembly time by 44% and setup time from 97.6 to 76.1 seconds, without affecting operative times. Satisfaction surveys revealed that over 90% of scrub personnel and surgeons were pleased with the changes, agreeing that the reduced sets did not negatively impact surgical procedures or patient care. A similar quality improvement initiative that focused on neck surgical optimization found 100% surgeon satisfaction with the reformulated trays (99). Lastly, a Canadian quality improvement initiative, which aimed to optimize surgical trays for common otolaryngology procedures, reduced the number of instruments per tray by 26% (100). This resulted in significant time savings in tray setup (2.5 minutes) and rebuilding (1.4 minutes). The study also included a survey that revealed overall satisfaction with the tray optimization intervention was high, with 92% of respondents rating it as "good" or "very good." The quality improvement initiative conducted by Fu et al. also monitored other balancing measures such as the frequency of instrument recall and any adverse impacts on patient outcomes (100). The study's findings suggest that surgical tray optimization did not compromise patient safety, as there were no negative impacts reported in terms of patient outcomes or procedural safety.

Different studies have examined various methodologies that can be used to streamline surgical tray instrumentation. Belhouari et al. conducted a quality improvement study in which three methodologies to reduce the size of surgical trays were compared: (1) clinician review, (2) mathematical programming, and (3) a novel hybrid model (101). They found that mathematical programming was the most accurate methodology, but savings were similar across all three methods. Clinical review and the hybrid model are significantly less laborious and thus are practical alternatives. Toor et al. conducted an observational study to compare whether the use of a customized mathematical inventory optimization model would result in a greater reduction in the number of instruments on a surgical tray than clinician review of the tray (102). The mathematical model yielded an additional 22% instrument reduction and $14,230 in savings compared with clinician review alone.

Planet

Several studies have documented that up to 80% of instruments on surgical trays remain unused (103). This creates both financial and environmental issues, as all instruments on the tray must be re-sterilized or disposed of after the operation, regardless of usage**.** Reducing the consumption of surgical tools lessens the environmental impact due to the decreased need for blue sterile wrap, natural gas, electricity, and water required for re-sterilization (97,104). A study focusing on laparoscopic gynecological surgery minimized packs to essential items only, resulting in a waste reduction of 400 grams per case, or 280 kilograms per year (105). A prospective quality improvement initiative by Capra et al. reduced the total weight of THA and TKA trays by an average of 47.4% (97). The authors highlight that these trays have a lesser environmental impact due to reduced use of blue wrap, natural gas, electricity, and water. Findings from a study conducted by Schmidt et al. emphasize the significant environmental benefits achievable through instrument reduction in surgical trays (106). By employing LCA and Integer Linear Programming methods, the study optimized tray compositions to include only frequently used instruments, potentially leading to a 46% reduction in annual carbon emissions by decreasing the number and size of trays**.**

Profit

Numerous studies have found that reducing instruments on surgical trays is associated with financial savings. Practice Green Health reported that the University of Minnesota Medical Center Fairview reformulated OR kits which reduced their total waste by 5,332 pounds per year and led to more than $81,000USD in cost savings (107). A cost analysis was conducted to determine the potential savings of surgical trays with redundant instruments compared to surgical trays with reduced instruments (103). 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.

Over the past 5 years, several quality improvement projects have been undertaken that highlight the cost savings associated with a reduction in surgical instruments from most surgical specialties. The plethora of studies along with the significant cost savings realized, indicates the importance of this intervention, as well as the financial benefits of doing so. For example, in 2022, Yalamanchi et al. conducted a prospective quality improvement initiative to assess the cost savings from optimizing head and neck surgical trays (99). Over a 3-year postintervention period, streamlined surgical trays were used 9284 times with direct cost savings of $228,338USD. As well, a Canadian-based quality improvement initiative by Fu et al. aimed to optimize surgical trays for common otolaryngology procedures, and examined the impact on costs, OR efficiency, and patient safety (100). After observing a total of 238 procedures by six surgeons were observed, the project achieved an average instrument reduction of 26%, resulting in 1-year cost savings of $9,010 CAD and 10-year cost savings of $69,576 CAD. Yoon et al. decreased otolaryngology–head and neck surgery (OHNS) surgical instrument sets by 10% which resulted in an estimated savings of $35,665USD (108). A prospective quality improvement initiative conducted by Holland et al. reduced the standard surgical tray used for lumpectomies and mastectomies by removing 17 underutilized instruments to create a breast-specific tray (109). This instrument reduction resulted in $18,847USD in instrument reprocessing and $680USD in maintenance savings, with total annual cost savings of $19,527USD. Wood et al. conducted a comprehensive review of 40 major instrument trays at UNC Rex Hospital and then removed underutilized or redundant instruments based on data collected (96). The removal of the instruments yielded an estimated cost avoidance of $163,800USD for instrument repurchase and $69,441USD in annual resterilization savings. The pilot study by Knowles et al. that removed 45.8% of the instruments from vascular trays and 62.5% from the aortic trays found that the instrument reduction from these two trays alone yielded an estimated cost savings of $97,781USD for repurchase and $97,444USD in annual resterilization savings (94) The instrument reduction initiative for TKA and THA trays, which was carried out by Capra et al., estimated that optimized instrumentation configuration could provide an annual savings of $159,600USD in sterile processing costs (97). As mentioned under "person", the study also documented that the optimized trays resulted in decreased assembly and set-up times. The reduction in total OR turnover time that results from these time savings translates to a projected financial savings of $99,000USD. Lonner et al. also conducted a prospective pilot study to assess the economic impact of instrument tray optimization in THA (92). After reviewing instrument utilization in the original trays, the authors removed 32.2% of instruments from the TKA trays, and 41.1% of instruments from the THA trays. Average annual savings amounted to $281,298USD. Schneider et al's. reduction of ophthalmologic trays by an average of 13.10% in the number of pieces per tray estimated a reduction in institutional costs by R$420,000 (93). Lastly, a quality improvement study conducted by Sanchez et al. decreased the number of laparoscopic/thoracoscopy instruments in the trays by 63 and 87% for bariatric and thoracic surgery, respectively (110). This represented a decrease in costs of 58.99 and 78.28% for each bariatric and thoracic tray, respectively and an estimated annual savings of $100,846USD.

Eiferman et al. highlighted that surgeons traditionally lack incentives to reduce costs, as savings typically benefit the hospital and not the practitioners (111). The authors implemented a shared-savings program where 50% of the cost savings were returned to the surgery divisions. Standardization of surgical supplies and competitive bidding from suppliers led to $893,865 in savings, illustrating that alignment of hospital and surgeon incentives is an effective strategy for driving significant change.

Implementation

Below are the most commonly reported implementation strategies to assist with successful uptake of this recommendation:

- Each surgical specialty within a hospital should identify at least one high-volume procedure for which to produce a leaner surgical tray (112)
- For each surgical procedure in which a lean surgical tray are going to be created, perform an audit of the instruments and tools used during these procedures (51). If an instrument is not used 80% of the time, it should be removed (107,113)
- After determining redundant instruments, it is essential to speak to all end-users reach an agreement on the removal of these instruments (107,113)
- Ensure a feedback mechanism so that the OR team can report on what is working and what needs to change (107,113)
- Communication between surgeons is vital to ensure successful implementation (51)

1.5 Reduce redundant items in custom packs

Summary

Disposable custom packs are a set of sterile, disposable products that come prepackaged for specific medical and surgical procedures (114). While custom packs were created to streamline effectiveness by reducing time, errors and contamination risks, they have proven to also be environmentally and financially detrimental as once the packs are opened, all items must be discarded, whether used or not. Several studies have documented substantial reductions in waste and cost savings resulting from leaning of custom packs. One study projected that removing unused items from custom packs could prevent over 6000 tons of tons of waste in the US each year (115). Several studies have noted annual savings exceeding $10,000 due to removing unused items. (116–118). In terms of implementation, reports state that it is often relatively easy for clinicians to have items added to the packs, but that it is challenging and can take up to a year to have redundant items removed (116).

People

Most studies assessing utilization of custom packs specify the importance of having stakeholder involvement in determining the items that should be included. It is essential to have all end users of lean custom packs have their input into the instruments that they use. Once input has been received, there is reported high satisfaction with lean custom packs from all stakeholders (116).

Planet

It is well known that many items in custom packs remain unused which leads to unnecessary waste in the OR. Two recent studies evaluated the use of minimal customized packs for wide-awake hand surgery; one study found a decreased of 2.8 tons of waste from 1,099 hand procedures using minimal custom packs compared to conventional packs. The other study reported 13% less waste per case (116). Campion et al conducted a LCA to assess the impact of disposable custom packs designed for traditional vaginal birth from 15 different hospitals. The authors found that reducing the size of custom packs by regular evaluation of necessary items can save money, reduce waste and improve environmental impacts (119). Braschi et al conducted a pre-post study to assess which items were not used in two single-use surgical packs for general surgery cases. The authors noted which items remained unused over a 3-month period, shared the list with key stakeholders and then modified the packs. This resulted in 2437 pounds of less waste per year based on 1048 cases. (118). A similar study was carried out in a large academic children's centre in the US which decided to exclude all items that were discarded 85% of the time during the study period (115). The authors found 46 items to be removed from the surgical packs which resulted in diverting 2 tons of plastic from landfill waste over 1 year The authors estimated that if this process was applied nationally, it could prevent over 6000 tons of waste in the US every year (115).

Profit

Several studies have noted cost savings for switching to lean custom packs. Van Demark and colleagues undertook a project to make hand surgery at their US hospital, "lean and green" (120). One major component of their project was to decrease surgical waste by reviewing and minimizing the supplies in their pre-packed surgical packs. They found a cost savings of $10.64USD per case for their "green packs" as well as a decrease of 5 pounds of waste per case. Over approximately 2 years and 1,099 hand cases, they saved $13,250 USD and 5,561 pounds of waste (120). Thiel et al also conducted a study for hand surgeries assessing the difference in cost and waste for using a "minimal pack" versus a "standard pack". Data were analyzed for 178 procedures. The authors found a 13% reduction in waste for the minimal packs as well as a 55% decrease in cost ($125USD/case) (116). Lastly, a Canadian-based cross-sectional study by Punch et al compared the impact of using generic commodity packs (no proprietary equipment-specific supplies) to full utilization of Custom-Pak®, a comprehensive pack (disposables plus equipment-specific supplies) in cataract and retina surgeries (117). The authors found that switching to the comprehensive Custom-Pak in 1000 retina cases saves (CA)$10,650 annually. Additionally, the authors found that switching from generic to comprehensive packs at a community hospital that conducted 2500 cataract procedures per year could save 287 labor hours per year. Surgery preparation (OR) hours saved allow for an additional 196 potential procedures annually. The pre-post by Braschi et al also noted estimated cost savings of over $40CAD per pack which resulted in a cost savings of $45,719CAD annually based on 1048 cases (118). The study conducted by Cunningham et al which removed 46 items from 113 different surgical packs resulted in significant cost savings of an estimated $27,503USD in acquisition costs, prevented a loss of $13,824 in wasted supplies, and an estimated $70,000 of savings through supply chain streamlining (115).

Implementation

Below are the most commonly reported implementation strategies to assist with successful uptake of this recommendation:

- Hospital specific guidelines should be put in place for streamlining of custom packs (119)
- Review teams should include procurement personnel, clinicians, environmental services, and central services (119)
- Practice Greenhealth provides in-depth recommendations to assist with implementation (113).
- Have a process in place to review the packs regularly (annually) to ensure that the items in the packs are still regularly used (121).

1.6 Reduce the use of blue wrap

Summary

The use of polypropene blue wrap (commonly referred to as "blue wrap" although it actually comes in several different colours) in ORs has become a widespread practice for packaging sterilized surgical equipment. However, this practice is a significant environmental sustainability concern, as the sheer volume of blue wrap that is used and discarded can be a large contributor to waste generated in the OR. It is estimated that blue wrap constitutes 19% of the total waste from ORs and that approximately 255 million pounds of blue wrap is thrown away each year (122,123). Moreover, its non-biodegradable nature adds to the environmental burden, as it takes hundreds of years to break down and may never decompose. (123). The recurring cost of both purchasing and disposing of blue wrap also imposes a financial burden on healthcare facilities. Specialized recycling programs for blue wrap, as well as upcycling initiatives where blue wrap is repurposed into functional items, have been shown to reduce the environmental burden. There is robust and multifaceted evidence to supporting switching from blue wrap to rigid reusable sterilization containers, with several LCAs highlighting that the containers have a significantly lower carbon footprint (82% reduction in total CO2e/GHG emissions) (124). As well, case studies from hospitals that have adopted rigid sterilized containers confirm substantial financial savings and reduced waste.(125).

People

Despite its widespread use, single-use blue wrap is not be the best product to use for sterilized surgical equipment. In addition to its substantial environmental footprint, blue wrap is easily torn which can compromise sterilization and lead to delays in surgical start times, canceled cases, the need for tray re-sterilization, increased anesthesia times, and compromised patient care (126). Rigid sterilized containers are a sustainable and safe alternative to blue wrap for sterile OR equipment. Beside the environmental benefits, the containers provide superior protection to instruments from damage caused by drops, enable better organization of instrument sets, and prevent breakthrough issues that necessitate re-sterilization (125). Furthermore, Practice Greenhealth emphasizes that switching to rigid sterilized containers can significantly reduce the workload of the sterile processing department and the need for flash sterilization when the wrap is accidentally torn (125). These benefits can lead to increased efficiency, reduced stress for healthcare workers, and better overall patient care.

Planet

The U.S. Environmental Protection Agency estimates that blue wrap contributes 19% of the total waste from ORs and Practice Greenhealth estimates that 255 million pounds of blue wrap is thrown away each year (122,123). In Toronto, the University Health Network (UHN) reports that an average of 60-70 bags of blue wrap, each weighing 18-20 lbs, are generated weekly (127). Furthermore, blue wrap is covered in petroleum-based plastics that are not biodegradable (50,128).

The best way to minimize the environmental impact from blue wrap is to minimize its use and use rigid sterilized containers or reusable linens in its place. Several LCAs have documented that replacing blue wrap with rigid sterilized containers has significant environmental benefits. Friedericy et al. conducted an LCA to compare the environmental implications of disposable polypropylene blue wrap to reusable rigid sterilized containers for instrument sterilization (124). Results showed that rigid sterilized containers have a significantly lower carbon footprint (82% reduction in total CO2e/GHG emissions) and environmental impact (52% reduction according to ReCiPe, a comprehensive environmental impact assessment method considering damage to human health, ecosystems, and resource depletion) compared to blue wrap. The analysis included break-even points, indicating that rigid sterilized containers become environmentally advantageous after 98 cycles in terms of carbon emissions and 228 cycles for ReCiPe points. In addition, rigid sterilized containers may be indefinitely, which only increases its environmentally preferability. Thus, switching to rigid sterilization containers, particularly for hospitals with high usage, can significantly reduce the environmental burden from traditional blue wrap. Based upon a life cycle assessment comparing 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 (129). According to Practice Greenhealth, MetroWest Medical Center Natick and Framingham now use rigid sterilization containers for two-thirds of their surgical instrumentation, reducing surgical waste by 40% (125). Through this initiative, MetroWest Medical centre generated an estimated cost savings of $29,843 in less than one year. If it is not possible to switch to rigid containers at your center, there have been some success stories in specialized blue wrap recycling programs (see recommendation 3.2).

Profit

The recurring costs of purchasing and disposing of blue wrap impose a financial burden on healthcare facilities. The disposal of large amounts of blue wrap is expensive. A quality improvement initiative conducted by Rooney et al. estimated that disposing of blue wrap in the general waste stream costs over three times more than disposing of the same quantity of wrap in the recycling stream over the course of a year (130). The financial burden of blue wrap is largely due to purchasing costs (80). In addition to the environmental benefits of rigid sterilized containers, the literature documents that making the switch can generate substantial financial savings. Practice Greenhealth highlights that since the cases can be reused continuously, the cost of both blue wrap purchasing and disposal is driven down (80). Krohn et al. compared the costs of four different packaging alternatives: (1) non-woven sterilization wrap with two sheets, (2) one-step wrap, (3) sterilization container with inner wrap, and (4) sterilization container without inner wrap (131). The authors found that the sterilization container without inner wrap was generally the most cost-effective option across various scenarios, costing 2.05€ per use. The options "sterile container with inner wrap" (3.24€), "one-step sterilization wrap" (3.44€), and "two sheets sterilization wrap" (3.87€) were more expensive. The wraps used in this study are single-use and are noted to lead to a high volume of waste, which creates increased cost environmental challenges,. some hospitals have opted to use reusable linens instead. Case studies from Practice Greenhealth also illustrate the significant cost savings achieved by hospitals that have switched to rigid sterilized containers. For example, Mills-Peninsula Medical Center, a 413-bed hospital in Burlingame, CA, purchased rigid sterilized containers for $34,987 in 2006 (80). Over 8.2 months, the costs broke even, resulting in a cost savings of $25,173 from blue wrap purchasing and $26,000 from rewrapping costs for torn blue wrap. An annual cost-saving of $16,186 was achieved in one year, without factoring in waste avoidance costs, which could be substantial. Similarly, Boulder Community Hospital invested $150,000 in rigid containers for their operating rooms in 2003 (80). Within two years, this investment allowed them to reduce their annual blue wrap expenses from $250,000 to $60,000, achieving a payback period of under two years. In addition to the cost-savings from reducing the amount of blue wrap, Practice Greenhealth highlights that additional cost-savings can come from reducing the need for other single-use sterilization materials, like sterile indicator tape, which may require special disposal if lead-based (125).

Implementation

Below are the most commonly reported implementation strategies to assist with successful uptake of this recommendation:

- Use rigid sterilized containers if finances and storage space are available (132)
- Use reusable cotton wrap / linens in lieu of single-use blue wrap (112)
- Practice Greenhealth provide step-by-step processes for hospitals to follow when transitioning to rigid sterilized containers (125)
- Set up a specialized recycling program if other options are not feasible (see recommendation 3.2)

1.7 Reduce greenhouse gas emissions from inhalational anesthesia

As noted in the Methods section, the following recommendations and summaries of evidence are based on recently published Guidelines and thus it was not feasible to provide the evidence synthesis in terms of the triple bottom line (people, planet, profits) (9–11,28,31,133,134).

1.7.1 Do not use desflurane

When assessing which inhalational anesthetic to use, the guidelines recommend choosing an inhalational anesthetic with the lowest global warming potential, when all other clinical indications are equal. (10,28). In terms of routinely used anesthetics, desflurane is consistently noted to have the highest global warming potential of all inhaled anesthetics with an estimated impact of 80% of greenhouse gas emissions from all volatile anesthetics pollution. (10,28). Many studies looking at the environmental impact of inhalational anesthetics all reached the same conclusion, nitrous oxide and desflurane have the greatest negative impact on the environment and should be avoided whenever possible. The ASA suggests that the best strategy to minimize the environmental impact of anesthesia is to avoid desflurane and nitrous oxide unless there are clear clinical indications. (10). The SFAR guideline recommends the use of sevoflurane over desflurane or isoflurane, when there is equal benefit to the patient, based on reducing the environmental impact of anesthesia. (28).

In terms of the global warming potential (GWP), desflurane has the highest GWP of approximately 2,540, followed by isoflurane 510-539, nitrous oxide 130-273, and sevoflurane 130-144.(10,12,28). Another way to look at it, is that by mass, desflurane has a GWP 20x that of sevoflurane, 5x that of isoflurane, and 10 times that of nitrous oxide (9,12) The GWP measures, by mass, how much a greenhouse gas contributes to global warming over 100 years to an equivalent mass of carbon dioxide. The GWP of carbon dioxide is one and is always the unit of comparison. Most of the exhaled anesthetic agents are released from hospitals fully intact, which increases its global warming potential as studies have shown that the metabolism of these vapours is very weak (sevflorane 5%, 0.2%-0.5% isoflourane, and 0.005% desfourne) (28). Additionally, studies have shown that the atmospheric lifetimes of desflurane is approximately 14 years, isoflurane is 3 years and sevoflurane is -1-2 years, with nitrous oxide having the greatest impact with a atmospheric lifetime of 114 years (10,28). The Intercollegiate guideline provides a layperson's summary of the impact of the most commonly used inhalational anesthetics. "With fresh gas flows (0.5 L/min) and equipotent levels (1 MAC of agent), desflurane anaesthesia has a carbon footprint equivalent to driving 133 km; whereas sevoflurane has a carbon footprint equivalent to driving 2 km (calculated using the Association of Anaesthetists Anaesthetic gases calculator). At higher fresh gas flows, these carbon footprints increase in direct proportion." Further to this, they recommend removing desflourane from the formulary and if it must remain, the suggest using it less than 5% of the total anesthetic gases. (8)

1.7.2 Avoid the use of nitrous oxide if possible

All current guidelines recommend avoiding the use of nitrous oxide when it is clinically safe to do. (10,28). It is well-known that nitrous oxide has the largest negative impact on global warming of all inhalational anesthetics due to its GWP of 265 and an atmospheric lifetime of 114 years. (10,28). In addition, nitrous oxide has been shown to contribute to ozone depletion. (10,28). Nitrous oxide from anesthesia is estimated to represent 1-3% of the worldwide nitrous emission. (9,28). When used as a carrier gas, nitrous oxide increases the environmental impact of sevoflurane and desflurane by 3-6 times vs when used with air. (28). Despite the strong evidence of the negative environmental impacts, several local stakeholders still strongly believe that there is still use for it in specific cases such as pediatric surgery, some ear surgeries, and in the labour and delivery setting (112).

1.7.3 Decommission the use of nitrous oxide through central piping systems and use portable canisters instead

Although some guidelines suggest completely removing nitrous oxide from formularies, it may not be possible to do so. If nitrous oxide must be used, it should be administered through portable canisters due to the well-known risk of leaks. There is a plethora of evidence available to support hospitals switching from central piping systems for nitrous oxide to the use of portable canisters. The ASA highlights studies from around the world all indicating that significant losses of nitrous oxide (77-95%) occurs prior to clinical use due to central pipeline leaks (10). In addition to the negative environmental impact of these leaks, several studies have also shown a financial loss as one hospital noted that the leaks accounted for 38,400 hours of anesthesia over one year (28). The Intercollegiate guidelines also recommendations that nitrous oxide manifolds should be decommissioned and replaced with cylinders (8). Several stakeholders have noted great success in decommissioning the central piping systems, however it is essential to have all stakeholders onboard, including engineering and building facilities personnel (112).

1.7.4 Minimize fresh gas flows (≤ 1L/min)

The ASA and SFAR both recommend using low fresh gas flow to minimize the environmental impact of inhalational anesthetics (10,28). Pauchard et al note that "As much as the choice of anaesthetic agent, fresh gas flow has a direct effect on climate change and its worldwide economic repercussions". Reduced fresh gas flows directly reduces the impact of associated with the halogenated agents by reducing GHG emissions. (28). The evidence clearly supports the use of low gas flows for a positive environmental impact as well as cost savings due to use of less anesthetic agents. One study found that the carbon equivalent over 20 years of desflurane decreased from 26.8 with a fresh gas flow of 2 L/min to 6.7 with fresh gas flows at 0.5 L/min. Another study found that environmental impact of desflurane with fresh gas flows at 1 L/min was 13x higher than sevoflurane at twice the fresh gas flow are (2 L/min). (28). Pauchard et al also note that several studies have documented cost savings when minimizing fresh gas flows. Fresh gas flows are an essential part of minimizing the impact of inhaled anesthetics, as the amount of anesthetics used, directly relates to fresh gas flows as well as the clinical potency (measured as mean alveolar concentration (MAC)) of the anesthetic. (10). Desflurane is also the greatest contributor to emissions in terms of clinical potency as it has the lowest clinical potency (MAC 6.7%) of the other agents like sevoflurane (MAC 2.2%) and isoflurane (MAC 1.2%) to achieve an equivalent clinical effect at similar fresh gas flow rates. (10). While there is some discrepancy in the guidelines as to whether the fresh gas flows should be 1L/min or 0.5L/min, all of the guidelines agree that a minimum fresh gas flow of ≤ 1L/min is a safe and efficient way to minimize the environmental impact of inhalational anesthesia while still providing safe patient care (12).

2. Reuse

2.1 Use reusable medical devices

Summary

There is a considerable amount of literature on the use of disposable versus reusable medical devices in the OR (135). In terms of patient care and safety, several reviews have been conducted on this topic and found no significant difference between reusable and disposable instruments in preventing surgical site infections (SSIs) (135–137) nor in the quality and performance of reusable instruments (138,139). Furthermore, studies on perioperative staff preferences have shown a general preference for reusable instruments (135,139,140). From an environmental perspective, several studies including a recent systematic review (141) as well as multiple LCAs (142–147) have all demonstrated environmental benefits of switching to reusable medical devices. Keil et al's systematic review of comparative LCAs of single-use and reusable healthcare products found a mean reduction of 47% in GHG emissions for most invasive medical devices (141). Similarly, an LCA by McGain et al., which assessed the environmental and economic impact of reusable versus single-use anesthesia equipment, found that in the USA, converting to reusables would reduce CO2 emissions by 50% (144). Moreover, the literature also suggests financial advantages of using reusable instruments over disposable ones. For example, an LCA by Boberg et al. found that single-use trocar systems are approximately twice as expensive as reusable and mixed systems (143). Despite the benefits of switching to reusable devices, widespread adoption of reusable instruments is hindered by the lack of awareness among surgeons about their proven safety, environmental and economic benefits, as well as the challenges in changing established practices (135). Another potential barrier is that some surgeons and anesthesiologists may prefer instruments that are only available in single-use form (135). Therefore, when implementing this recommendation, it is essential make all staff aware of the benefits of reusable medical devices in terms of environmental, financial, and overall performance.

Person

According to three systematic reviews, there do not appear to be significant differences between reusable and disposable instruments in preventing SSIs (135–137). Bolten et al. conducted a scoping review to synthesize the evidence on the carbon footprint of commonly used infection prevention measures in the operating room (136). The review did not find any data indicating differences between reusable and disposable instruments in terms of SSI prevention. Disposable devices, perceived to carry a lower contamination risk, have become standard practice. However, when reusable devices undergo validated sterilization processes, their contamination risk is minimal. From a risk-based perspective, the environmental impact of the increased CO2 emissions from disposable devices might outweigh the negligible contamination risk of properly sterilized reusable devices. A systematic review by Siu et al. notes that theoretical advantages of single-use instruments in quality, safety, sterility, ease of use and patient outcomes have rarely been examined (135). The authors note that this, in combination with the environmental and economic benefits of reusable instruments that have been documented, shows there is lack of evidence to support the use of single-use instruments. However, some studies have reported infections associated with reusable devices. In 2014, Southworth reviewed incidents of unsuccessful decontamination of reusable surgical instruments and found that while there were reported incidents, the overall risk of cross-infection was low when proper cleaning and sterilization procedures are followed (137).

The literature on the quality and performance of reusable instruments generally supports their use (138,139). A randomized controlled trial by Buleon et al. compared the rates of intubation failure at first laryngoscopy using metallic single-use, plastic single-use, and metallic reusable laryngoscope blades (138). The study included 1863 adults requiring general anesthesia. Results indicated that plastic single-use blades were associated with higher intubation failure rates and poorer glottic exposure compared to metallic reusable and single-use blades in the OR. Furthermore, a single-centre prospective study that compared the radiological outcomes of patients who underwent distal radius fracture fixation with locking volar plates with single use instruments and reusable instruments found no significant difference between the two study groups (139). Siu et al. highlight that reusable instruments undergo rigorous inspection cycles by sterilization teams, OR staff, and surgeons (135). However, the study also notes that while reusable devices are subject to wear and tear, their fitness depends on various factors such as precision handling during surgery, safe transport, disassembly, cleanability, and material quality.

In terms of perioperative staff preference, the literature reveals that staff generally prefer using reusable instruments (135,139,140). Siu et al., note that this preference is related to the predictable performance and familiarity of reusable instruments (135). Jegastheeswaran et al., conducted a cross-sectional survey to assess ENT surgical trainees' preferences for the qualities of disposable and reusable fibre-optic nasendoscopes (140). The survey found no difference in trainees' satisfaction with disposable and reusable fibre-optic nasendoscopes, and the majority (79.2%) were supportive of climate-friendly initiatives. Similarly, Desclée et al compared the satisfaction of OR staff between single use instrumentation kits and reusable instrumentation kits the context of distal radius fracture fixation with volar locking plates and found that surgeons and scrub nurses preferred the reusable instrumentation kits (139).

The literature suggests that physicians recognize the importance of climate change and are generally supportive of efforts to mitigate the environmental impact of operating rooms. Thiel et al., conducted a survey on 236 obstetricians and gynaecologists at a hospital in the United States that found that physicians in obstetrics and gynaecology were more likely than the public (84% vs. 54%) to believe that global warming is occurring (70). Two-thirds of physicians felt the amount of surgical waste generated is excessive and increasing, and the majority (95%) would support efforts to reduce waste, with 66% favoring the use of reusable surgical tools over disposable ones where clinically equivalent. Although physicians in obstetrics and gynaecology expressed a preference for reusable surgical instruments in general, only 20% preferred the reusable devices available to them, possibly due to concerns about the safety or reliability of reusing devices (70). Jegastheeswaran et al., conducted a cross-sectional survey to assess ENT surgical trainees' preferences for the qualities of disposable and reusable fibre-optic nasendoscopes (140). The survey found no difference in trainees' satisfaction with disposable and reusable fibre-optic nasendoscopes, and the majority (79.2%) were supportive of climate-friendly initiatives. Hence, acceptability of reusable instruments and devices likely varies by specialty and by device, with some reusable devices being more acceptable to clinicians than others.

Planet

There is substantial evidence indicating that reusable medical devices are more environmentally friendly than their disposable counterparts. Several studies, including a recent systematic review (141) and multiple LCAs (142–147) have demonstrated the environmental benefits of using reusable medical devices.

Keil et al. conducted a systematic review of comparative LCAs of single-use and reusable healthcare products, assessing changes in the environmental impact after switching from single-use to reusable products as their main outcome measure (141). The study found significant reductions in GHG emissions for most invasive medical devices, with a mean reduction of 47%. These findings are supported by several LCAs that have evaluated the environmental impact of different instruments in the operating room. Rizan and Bhutta conducted an LCA to evaluate the environmental impact of hybrid laparoscopic clip appliers, scissors, and ports used for laparoscopic cholecystectomy, comparing these with single-use equivalents (146). They found that the carbon footprint of using hybrid instruments for laparoscopic cholecystectomy is about a quarter of that for single-use equivalents, with the financial cost being around half. The environmental benefits of reusable instruments extend beyond carbon footprint reductions; they also significantly lower waste generation and resource consumption. Other LCAs have reported similar findings regarding the environmental benefits of reusable instruments (142–144,147). For example, Boberg et al. assessed single-use, reusable, and mixed trocar systems used for laparoscopic cholecystectomies and found that reusable trocar systems had a reduced environmental impact compared to single-use systems (143). The single-use system had a higher impact on resources (182%), ecosystem quality (83%), and human health (240%) than the reusable system. Meissner et al. assessed single-use and multi-use staplers and found that multi-use staplers resulted in a reduction of waste (40%), material consumption (90%), and greenhouse gas emissions related to the lithium in the batteries (99.7%)(148). An LCA by McGain et al., which assessed the environmental and economic impact of reusable versus single-use anesthesia equipment, found that in the USA, converting to reusables would reduce CO2 emissions by 50% (144).

Rizan et al. conducted a carbon footprint analysis of products used within five common operations to identify the biggest contributors. The study found that around two-thirds of the carbon footprint were related to single-use products and one-third to reusable products. They estimate that by switching to reusable products, optimizing decontamination processes, and reducing waste, the carbon footprint of these operations could theoretically be reduced by 23%-42% (145). The environmental benefits of switching to reusable devices are further highlighted in a prospective pilot study by Rouvière et al. (149). The authors assessed the impact of 13 sustainable actions implemented in ORs at a hospital over one year. Of the 13 actions, switching from disposable to reusable laryngoscope blades had the highest annual impact on several environmental categories, including land occupation (58.5%), mineral resources (94.9%), and fossil resources.

Profit

Half of all OR costs are attributed to equipment, with 84% of this amount allocated to disposable equipment (135). Therefore, transitioning to reusable devices presents a significant opportunity for cost reduction, as documented in the literature. LCAs consistently conclude that reusable devices are economically favorable. The LCA by Boberg et al. found that single-use trocar systems are approximately twice as expensive as reusable and mixed systems (143). The study highlights that the major costs for single-use systems are purchase expenses, while for reusable and mixed systems, costs also include labor and sterilization processes but still result in overall savings. Similarly, Rizan and Bhutta also found cost savings when hybrid laparoscopic clip appliers, scissors, and ports used for a laparoscopic cholecystectomy were compared with single-use equivalents (146). McGain et al. reported substantial cost savings, with a switch from single-use to reusable anesthetic equipment saving more than AUD$30,000 (approx. $26,765CAD/year) (144).

A prospective study by Rouvière et al., which implemented 13 sustainable actions and assessed their environmental and economic impacts, found that switching to reusable laryngoscopes yielded the largest cost savings of all actions (149). This switch generated an annual financial gain of €7,787.40, primarily through reduced material and waste management costs. Adler et al. compared the economic and environmental effects of disposable and reusable instruments for cholecystectomy and found that disposable instruments were 19 times more expensive than reusable ones, primarily due to purchase price (142). The authors emphasized that the higher cost of using disposable instruments is mainly attributable to the purchase price, while the processing of reusable instruments has little significance in terms of cost. A study by Jegatheeswaran et al. The authors highlight that the higher cost of using disposable instruments is mainly attributable to the purchase price, while the processing of reusable instruments has little significance in terms of cost. (140).

Implementation

Below are the most commonly reported implementation strategies to assist with successful uptake of this recommendation:

- Staff education (135)
- Opportunity for staff to trial reusable options (112)

2.2 Use reusable textiles (e.g. surgical gowns)

Summary

Over the past 20 years the environmental impact of single-use surgical textiles has become increasingly evident. Disposable surgical linens are discarded into the waste, or sometimes biohazardous waste after a single use, whereas reusable textiles produce less packaging waste and can be reused 75 times or more (150). Extensive evidence, mainly from LCAs, indicates that reusable textiles have a lower environmental impact compared to disposable ones (151–157). For example, Vozzola et al. conducted a LCA comparing the environmental impact of reusable and disposable gowns, including the gown and packaging manufacturing, processing, laundry and sterilization, transportation, and disposal of the gowns in a North American context (157)**.** The comparisons were based on 1,000 uses of a gown in the OR, equating to 16.7 reusable gowns reused 60 times each and 1,000 disposable gowns**.** The authors found reusable gowns to be more environmentally preferable as they had reduced natural resource energy consumption (64%), greenhouse gas emissions (66%), blue water (i.e. fresh surface or groundwater) consumption (83%), and solid waste generation (84%). The results of this study are consistent with other previously published LCAs (152,154–156). Beyond the environmental benefits, the literature also suggests that reusable textiles are superior to disposable ones from clinical and financial perspectives (18,151–153,158,159). The majority of the literature suggests that reusable surgical linens are equivalent or superior to disposable gowns in terms of sterility and infection prevention durability, water resistance, and comfort (152,158,159). While there is limited literature on the financial benefit of reusable vs disposable linens, the available literature suggests potential cost savings for the use of reusable linens. Erbay et al conducted a cost-benefit analysis that compared disposable and reusable surgical drapes, which found that reusable drapes were approximately 5-6x more cost-beneficial compared to disposable ones**.** The total cost decreased as the number of uses of reusable surgical drapes increased (153).

Person

The majority of the literature suggests that reusable surgical linens are equivalent or superior to disposable gowns in terms of sterility and infection prevention durability, water resistance comfort (152,158,159). McQuerry et al. conducted an LCA to assess the protection, durability and comfort of disposable vs reusable isolation and surgical gowns over the products lifespan (158). The authors found that reusable gowns met all requirements for impact penetration, while disposable gowns did not. In terms of durability, reusable gowns were superior regarding breaking, tears, and seam strength. A 2024 cross-sectional survey by van Nieuwenhuizen et al. supported these findings, with perioperative staff rating the functionality of reusable gowns as equal to or better than that of disposable gowns (159). These results are further confirmed by a meta-analysis conducted for the 2018 WHO guidelines on the prevention of surgical site infection**,** which concluded that the protection offered by reusable surgical gowns is likely equivalent to that of disposable ones (160).

While there is a plethora of support for gowns, drapes are a bit more nuanced because there is some evidence to the contrary and there is also less availability of various draping configurations for certain procedures. Acceptable drapes exist for square-draping a simple surgical site, but complex draping systems (e.g. for arthroscopic shoulder surgery) do not currently exist in acceptable reusable formats. In 2014, Showalter et al. conducted a prospective randomized trial to assess whether disposable draping systems are superior to reusable draping materials in preventing infection during implant-based breast reconstruction (161). Results indicated that disposable draping material is superior to reusable draping systems in preventing clinical infection within the immediate postoperative period. Reusable drapes are an emerging area of interest related to operating room sustainability and current options for drape configurations are dfairly limited. Additional research will be needed as newer and more varied reusable drape options become available, to update the evidence related to drape performance.

The available data on the comfort of reusable gowns are mixed. Conrardy et al. conducted a survey to assess surgeons' attitudes towards reusable and disposable gowns (152). Surgeons were asked to rate the comfort, ease of use, and protective properties of reusable compared to disposable gowns. Overall, surgeons clearly preferred reusable gowns based on assessments of comfort, ease of use, and protection (152). Similarly, a cross-sectional survey study by van Nieuwenhuizen et al. found that the majority of perioperative staff rated the comfort of reusable sterile surgical gowns as equal to or better than that of conventional disposable sterile surgical gowns.(159). However, McQuerry et al reported that clinicians found the disposable gowns to be more comfortable due to increased breathability and permeability (158). These attributes, however, come at the cost of lower levels of protection, durability, and water resistance. Additionally, some first-hand reports claim that reusable gowns do not come in all necessary sizes, particularly very large sizes. Single-use gowns could be made available on a limited as-needed basis to accommodate special sizes or the requirements of individuals who cannot tolerate reusable gowns.

Planet

Several LCAs have shown that reusable linens have a reduced environmental impact compared to disposable ones (145,154–157). **V**ozzola et al. conducted a LCA comparing the environmental impact of reusable and disposable gowns, including the gown and packaging manufacturing, processing, laundry and sterilization, transportation, and disposal of the gowns in a North American context (157)**.** The comparisons were based on 1,000 uses of a gown in the OR, equating to 16.7 reusable gowns reused 60 times each and 1,000 disposable gowns**.** The authors found reusable gowns to be more environmentally preferable as they had reduced natural resource energy consumption (64%), greenhouse gas emissions (66%), blue water (i.e. fresh surface or groundwater) consumption (83%), and solid waste generation (84%). The results of this study are consistent with other previously published LCAs (152,154–156).

In terms of other surgical linens, Agarwal et al. conducted a pilot study to examine the impact of using reusable scrub caps versus disposable single-use scrub caps (151). Perioperative staff were each provided with one reusable scrub cap and laundered it on average once a week. Consistent with other textile items, the authors found reusable scrub caps were significantly better than disposable in all categories of environmental impacts. Reusable scrub cap adoption by a small number of participants at the institution where the study took place decreased the solid polypropylene waste generated by nearly 1.5 kg per day (equivalent to 540 kg per year). Findings from another study that focused on surgical drapes were consistent with the findings for caps (153). As well, a state-of-the-art review of the literature comparing reusable and disposable perioperative gowns and drapes 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 1,000 gown uses (a 750% increase). Other factors were equal or more favorable for reusable gowns. Overall, there is a clear preference for reusable gowns, though more information is needed on economic comparisons (154).

Profit

While there is limited literature on the cost-benefits of reusable vs disposable linens, the available literature suggests potential cost savings for the use of reusable linens. Erbay et al conducted a cost-benefit analysis that compared disposable and reusable surgical drapes, which found that reusable drapes were approximately 5-6x more cost-beneficial compared to disposable ones**.** The total cost decreased as the number of uses of reusable surgical drapes increased (153). Additionally, a pilot study by Agarwal et al.

found that reusable scrub caps had both environmental and economic benefits during the study period (151). Reusable scrub caps achieved an economic breakeven point between 15 and 26 weeks, depending on laundry frequency. Furthermore, there were substantial cost savings with continued use beyond the breakeven point, highlighting the long-term economic benefits. Lastly, a North American narrative review by Choi and Chen highlights the significant cost savings associated with using reusable gowns compared to disposable ones (18). A case study from Carilion Clinic in Virginia also found that reusable gowns cost significantly less per use ($0.39USD) compared to disposable gowns ($0.79USD), resulting in nearly 50% savings (18). Additionally, the review discusses the spike in gown prices during the COVID-19 pandemic, which, coupled with the healthcare industry's economic losses, further emphasizes the cost-effectiveness of reusable gowns.

Implementation

Below are the most commonly reported implementation strategies to assist with successful uptake of this recommendation:

- Securing internal support from administration and clinical teams (162)
- Establishing local baseline data (162)
- Determining local laundry services (162)
- Determining providers of reusable gowns (162)
- Having local champions host events to provide education on the proposed change and address concerns (162,163)
- Include all key stakeholders, including housekeeping and laundering staff, to ensure that protocols are in place for appropriate usage (e.g. 100 uses) and end-of-life disposal (e.g. recycling) (162)
- Conducting carbon impact and financial analyses to highlight the benefits of the change to the staff (150,162,163)

2.3 Use reusable sharps containers

Summary

Proper disposal of surgical sharps waste is crucial to prevent injuries and infections (61). Traditionally, single-use sharps containers have been used to dispose of these items, with the containers typically being incinerated or autoclaved and then sent to landfills (164). However, the environmental and economic burden associated with the production, transportation, and disposal of single-use sharps containers has led to growing interest in reusable sharps containers. Reusable sharps containers offer a safe and sustainable alternative, mitigating some of the environmental and economic burdens associated with traditional sharps disposal systems. Grimmond et al. conducted a microbiological study to assess the decontamination process for reusable sharps containers in the US and (165,166) and found that all traces of *C. diff* were completely removed post-decontamination. Additionally, reusable sharps containers can be reused up to 600 times (167). This reuse reduces the need for the continuous manufacture of new containers, thereby conserving natural resources and minimizing waste (167). McPherson et al conducted a cradle-to-grave life-cycle carbon footprint analysis comparing the two containers and found a 65.3% reduction in carbon footprint ($p < 0.001$) when switching to reusable sharps containers in addition to eliminating 50.2 tonnes of plastic waste and 8.1 tonnes of cardboard, further underscoring the environmental benefits of reusable sharps containers. These environmental benefits translate into financial savings by lowering costs associated with infectious waste disposal and reducing the recurring expense of repurchasing and replacing single-use containers (80). Given the substantial environmental and economic advantages of reusable containers, along with strong evidence supporting their safety, reusable sharps containers are a viable and responsible choice for healthcare institutions.

People

One potential barrier to reusable sharps containers is the concern for bacterial transmission. To address this concern, Grimmond et al. conducted a microbiological study across seven U.S. hospitals (165,166). The study aimed to assess whether the decontamination process for reusable sharps containers effectively eliminates *C. difficile (C. Diff)* spores. Out of 197 sampled containers, all traces of *C. diff* were completely removed post-decontamination. Moreover, when comparing reusable and disposable sharps containers, 8.0% of reusable and 16.0% of disposable containers harbored sub-infective levels of *C. diff,* with no statistically significant difference between them. The authors concluded that, with proper decontamination, reusable sharps containers do not increase the risk of *C. diff* transmission. In contrast, Pogorzelska-Maziarz examined the relationship between sharps container type and *C. diff* infection rates across a sample of 539 U.S. hospitals, using a survey-based approach (168). This study found that hospitals using single-use sharps containers reported significantly lower rates of *C. diff* infections compared to those using reusable containers. However, this study's observational nature and reliance on self-reported data introduce potential biases. The authors acknowledged the possibility of selection bias, in that the hospitals which responded to the survey may differ from those that did not, potentially skewing the results. Additionally, the study did not directly measure bacterial contamination on the sharps containers themselves, unlike the microbiological testing conducted by Grimmond et al. When weighed against the robust microbiological data provided by Grimmond et al., the case for reusable sharps containers remains strong, particularly when proper decontamination protocols are followed. Hospital decisions regarding sharps container use should be informed by risk assessments that consider both the latest scientific evidence and the specific context of each facility.

Planet

The available literature emphasizes the environmental benefits from transitioning from single-use sharps containers to reusable ones (164,166,169). Stericycle reports that using one reusable container can keep 600 disposable sharps containers out of landfills (167). This reuse eliminates the need to continuously manufacture new containers, thereby conserving natural resources and reducing waste (167). A before-and-after study by Grimmond et al. evaluated the environmental impact of transitioning from single-use to reusable sharps containers across 40 NHS hospital trusts in the UK (166). The study revealed that this switch led to a significant reduction in global warming potential (GWP), with annual greenhouse gas (GHG) emissions dropping by 83.9%, equivalent to 3267.4 tonnes of CO2e. Additionally, the transition to reusable sharps containers eliminated the need to incinerate 900.8 tonnes of plastic and significantly reduced the disposal or recycling of 132.5 tonnes of cardboard. The study also noted a 61.1% reduction in the number of container exchanges required, further minimizing the environmental footprint. Similarly, McPherson et al conducted a cradle-to-grave life-cycle carbon footprint analysis over a one-year period at a large US hospital system consisting of 1100 beds and five hospitals located far from manufacturing and processing plants (169). The annual GHG emissions for each container were expressed in metric tonnes of carbon dioxide equivalents (MTCO2eq). The study found that the annual GHG emissions for disposable sharps containers (DSC) amounted to 248.6 metric tonnes of MTCO2eq, while reusable sharps containers resulted in only 86.2 MTCO2eq. This represents a 65.3% reduction in carbon footprint ($p < 0.001$) when switching to reusable sharps containers. The hospital system also eliminated 50.2 tonnes of plastic waste and 8.1 tonnes of cardboard, further underscoring the environmental benefits of reusable sharps containers. A 2012 LCA by Grimmond and Reiner, using a method similar to McPherson et al., further supports reusable sharps containers as the environmentally superior option (164). Overall, documented reductions in GHG emissions, plastic waste, and cardboard use, along with the overall decrease in the environmental footprint, highlight the role that reusable sharps containers can play in sustainable practices.

Profit

Practice Greenhealth discusses the financial gains of hospitals that have implemented reusable container systems for sharps disposal (80). By reusing containers hundreds of times, hospitals can reduce both waste and the costs associated with replacement supplies. The reusable sharps container program at

Illinois Masonic Hospital reduced its biohazardous waste by 10 tons and saved the organization $13,000 USD in 2010. Similarly, Borgess Medical Center made the switch to reusable sharps containers, which enabled the center to reduce its biohazardous waste by 10.5 tons and, save $11,000 USD annually. The McGill University Health Centre successfully transitioned to reusable sharps containers across all of their sites which led to more than $1 million CAD worth of single-use plastic sharps containers ending up in landfills every year from Montreal area hospitals alone. The article explains that making the switch could save "tens of thousands of dollars." (170) .

Implementation

Below are the most commonly reported implementation strategies to assist with successful uptake of this recommendation:

- Visual audit of ORs to assess current sharps containers to ensure they are reusable (112)
- Speak with manufacturers to request reusable sharps containers (112)

2.4 Collect single-use medical devices for remanufacturing and reuse whenever possible

Summary

A major source of OR waste comes from single use medical devices (SUMD). Many hospitals have opted to collect and send SUMD for remanufacturing to mitigate waste production and extend the devices' life-spans. Remanufacturing SUMDs entails a series of procedures: dismantling, decontaminating, cleaning, inspecting, testing, repackaging, relabeling, and sterilizing these devices (171). Studies have shown that remanufactured SUMDs can reduce costs and benefit the environment without compromising patient safety or care (172). A 2024 CADTH rapid review including eight studies evaluating remanufacturing SUMDs compared to new ones found no statistically significant differences in patient outcomes (173). As well, many studies comparing the safety and efficacy of remanufactured versus disposable SUMDs have concluded that there is minimal or no increased risk of infection or device failure when remanufacturing is done correctly (18,174). An LCA by Unger and Landis, which assessed seven types of remanufactured SUMD at a US hospital, found that remanufacturing devices led to substantial cost savings for the hospital which ranged from $182,000USD to $520,000USD annually, depending on the extent of remanufacturing (147). Lastly, a 2021 review by Yates et al. indicated that in 2018 alone, hospitals participating in SUMD remanufacturing saved $471 billion USD and diverted 7,000 tons of medical waste from landfills (175).

Person

Some healthcare professionals have expressed concerns regarding the potential safety and efficacy of using remanufactured SUMDs (176,177). These apprehensions likely come from findings from older studies or those from low- and middle-income countries where remanufacturing procedures lack advanced technology and regulatory standards or where devices intended as single use were simply sterilized and reused against the manufacturers' instructions. It is important to note that over the past four decades, there have been significant advancements and standardization in many regions. While, remanufacturing procedures vary by country (42,177), concerns are less relevant in North America, where stringent standards are enforced (176,177). In Canada, there are regulatory standards enforced by Health Canada as well as provincial policies (176,177). In 2016, Health Canada established regulations for companies remanufacturing SUMDs that indicate that remanufactured devices must meet the same standards as new devices. While hospital-based remanufacturing remains under provincial oversight, commercial remanufacturers must comply with federal regulations. (173). Similar regulations exist for low- and middle-income countries. In 2019, the FDA and the European Commission developed regulations to control in-hospital remanufacturing and there is a growing trend towards outsourcing commercial reprocessing that aligns with these standards.(42). With regards to the safety and efficacy of remanufacturing SUMDs, the literature suggests that while there is a possibility of contamination or adverse effects, these risks can be mitigated by appropriate remanufacturing (147). A 2024 CADTH rapid review including eight studies evaluating remanufacturing SUMDs compared to new ones found no statistically significant differences in patient outcomes (173). A study showing that reprocessed single-use bipolar and ultrasound diathermy devices had a lower rate of defects compared to non-reprocessed devices, further supporting the safety and reliability of reprocessed SUMDs (18).

Planet

Remanufacturing SUMDs can reduce the environmental impact by decreasing medical waste and conserving resources and energy needed to produce new devices (147,175,178,179). The literature provides strong evidence to support the environmental benefits of remanufacturing SUMD, often identifying it as a key strategy to reduce the carbon footprint of ORs. A consensus document by Kapoor et al. lists remanufacturing of SUMD as a best practice for its environmental benefits and as a top green purchasing practice (174). Similarly, findings from a Canadian literature review from 2024, which aimed to identify changes that can be made to make hand surgery more environmentally sustainable, identified remanufacturing SUMDs as a useful technique (51). The review also highlights that remanufacturing has been shown to divert 2,150 tons of medical waste from landfills (51,180). Several LCAs have also noted a decreased carbon footprint from remanufacturing SUMDs. An LCA by the manufacturing company Stryker assessed the carbon footprint of five remanufactured SUMDs and their original manufacturing SUMD scenarios (178). The study found that all remanufactured SUMDs have a lower carbon footprint than originals, with emissions ranging from 23% to 51% lower than manufacturing the original device. This reduction is attributed to the fact that the primary contributors to the carbon footprint of SUMDs are the production of components and raw materials. Remanufacturing avoids the need for new virgin plastic and metal materials. Furthermore, GHG emissions from disposal are lower in the remanufacture system compared to the original devices because only the equivalent of the remanufacturing waste, which is less than one device, is sent to disposal. Another LCA, conducted in the United States by Unger and Landis, found an environmental impact that follows a similar trend to what was reported by Stryker (147).

Profit

In addition to the environmental benefits, there is consensus that remanufacturing SUMD also has profound economic benefits. A consensus document by Kapoor et al., references cost savings as the single most important reason for remanufacturing medical devices (174). An LCA by Unger and Landis, which assessed seven types of remanufactured SUMD at a US hospital, found that remanufacturing devices led to substantial cost savings for the hospital (147). Total savings ranged from $182,000USD to $520,000USD annually, depending on the extent of remanufacturing. The largest savings were noted in devices with the highest original equipment manufacturer costs. Renton et al note that purchasing remanufactured SUMDs is often a fraction of the price of purchasing "new" instruments. Renton et al. found that the use of remanufactured SUMDs resulted in an estimated savings of $12.04USD per procedure which resulted in savings of $2.7 billion USD over 5 years at their institution (179). Similarly, a 2021 review by Yates et al. indicated that in 2018 alone, hospitals participating in SUMD remanufacturing saved $471 billion USD and diverted 7,000 tons of medical waste from landfills (175).

Implementation

Below are the most commonly reported implementation strategies to assist with successful uptake of this recommendation:

- Speak to manufacturers of medical devices about their remanufacturing programs (112)
- Engage hospital procurement and finance leaders (112)

3. Recycle

3.1 Develop and implement an effective recycling program in the OR. To ensure effectiveness, assess recycling procedures at your hospital (i.e. downstream processes and recycling hauler regulations) prior to implementation.

Summary

It is well documented that recycling in the OR is not often done despite waste audits showing a significant portion of OR waste is potentially recyclable. One prospective waste audit found that 40% of the total waste was recyclable (62) and a Canadian study found that almost 90% of preoperative waste in otolaryngology is recyclable (181). Diverting recyclable waste from solid waste streams to recycling streams presents an opportunity for significant financial savings as the hauling costs for recyclable plastics are nearly half that of solid waste disposal ($68USD vs. $121USD per ton) (14). A waste audit by Sullivan et al. estimated that establishing a recycling program in the ORs at a children's hospital could result in annual avoidance of 58,500 to 91,500 kg of carbon dioxide equivalent emissions (182). While recycling is often a cornerstone of environmentally sustainable programs, there are several known barriers such as inadequate recycling facilities, lack of education, and negative staff attitudes (7,62,71). Additionally, first hand accounts have noted that despite efforts made in the OR to recycle, downstream processes are often inadequate to ensure that recyclable materials are in fact diverted from landfill. Therefore, it is essential to assess local recycling capacity including recycling hauler regulations and availability of appropriate recycling facilities to ensure that proposed recycling programs can be effective.

People

McGain et al conducted a survey to assess Anesthesiologists' views of recycling in ORs. Of the 780 Anesthesiologists that responded, 93% responded that they would like to increase recycling in the OR and dedicate their time to do so, but not their money. However, they highlighted several barriers to recycling including inadequate recycling facilities (49%), negative staff attitudes (17%) and inadequate information on how to reliably identify recyclable materials (16%)(71). Similarly, Pradere et al.'s systematic review found that education was both lacking for healthcare workers and highly effective in improving waste management (7). The authors concluded that to improve recycling and reduce waste production in the OR, educational programmes should be carried out in line with the implementation of dedicated recycling facilities**.** Numerous quality improvement projects have demonstrated that addressing knowledge gaps through education can significantly improve waste management, supporting the conclusions of Pradere et al.'s systematic review (64–68). Martin et al. also found significant improvements in waste segregation practices and a notable increase in recycling rates following an extensive educational campaign (67). This approach involved educating staff through modules, printed materials, and interactive sessions, which significantly decreased domestic waste and increased recyclable waste. During the intervention period, the percentage of staff correctly disposing of glass bottles increased from 33% to 58%, and the overall commitment to recycling rose from 54% to 92%. First hand accounts from various staff from Canadian hospitals have noted that despite efforts made in the OR to recycle, the downstream processes often undo the work that done, as recycling infrastructure within hospitals is often poor and sorted "recyclable" waste often ends up mixed with general waste and sent to landfill. Therefore, it is essential to assess the local recycling practices including recycling hauler regulations and recycling facilities to ensure that the recycling program being implemented can be effective.

Planet

Proper waste segregation includes recycling. Most OR waste is solid and a significant portion can be recycled if not contaminated by bodily fluids (183). A prospective waste audit was conducted at a university-affiliated hospital in Melbourne, Australia found that 40% of the total waste was recyclable (62). A Canadian study found that almost 90% of preoperative waste in otolaryngology is recyclable (181). However, many hospitals are not recycling to the extent that they could. A study in six Australian ORs found that in 237 operations during one week, 1,265 kg of waste was produced (45% general waste, 32% infectious waste, and 23% recyclables). However, only 55% of the recyclable materials were recycled (184). Recycling initiatives can reduce the environmental burden of biohazardous waste produced by ORs. Kagoma et al. highlight that preoperatively, a large volume of recyclable plastics is generated, which can be easily recycled by installing collection containers (14). Installing paper and cardboard recycling bins in anesthetic rooms and ORs resulted in 50% and 67% of the waste being recycled, respectively (45). Martin et al. implemented a recycling initiative that led to a substantial decrease in solid waste (12% by weight and 6% by bags) and biohazardous waste (59% by weight and 61% by bags), and an increase in recycled waste (19% by weight and 45% by bags) (67). A waste audit by Sullivan et al. estimated that establishing a recycling program in the ORs at a children's hospital could result in annual avoidance of 58,500 to 91,500 kg of carbon dioxide equivalent emissions (or 6,583 to 10,296 gallons of gasoline) (182). However, despite the documented environmental benefits of waste segregation and recycling, an LCA by Thiel et al. found that common greening efforts, such as recycling, do not significantly impact overall emissions for a single procedure (70). The authors suggest focusing on other interventions, such as minimizing overall material use in each surgery, to effectively reduce carbon emissions in the OR.

Profit

The hauling costs for recyclable plastics are nearly half that of solid waste disposal ($68USD vs. $121USD per ton) (14). Diverting recyclable waste from solid waste streams to recycling streams presents an opportunity for significant financial savings. Paper, cardboard, and metal products can be easily collected for recycling in the OR (14). Some hospitals have achieved recycling rates as high as 40% of total waste, with substantial savings through reduced hauling costs and revenues from industrial recyclers (14). McKendrick et al. evaluated the impact of introducing paper and cardboard recycling at Dr. Gray's Hospital during the surgical setup period, resulting in a mean cost saving of sho£0.51 per case (185). This translates to a potential annual saving of £4,251 based on their 8,407 surgical cases in 2013-2014. Sullivan et al. conducted a waste audit and found more modest cost savings from the introduction of a recycling program, estimating potential waste-related cost savings ranging from 0.26% to 0.33% per case (182).

Implementation

Below are the most commonly reported implementation strategies to assist with successful uptake of this recommendation:

- Assess the downstream recycling processes at your hospital (engage environmental services and waste management teams) (112)
- Speak to your local recycling haulers to understand their policies, including what specific materials are locally recyclable and how recyclables must be collected in order to be streamed to recycling instead of landfill (112)
- Staff education to ensure proper waste sorting and avoid inadvertent contamination of recycling (6)

3.2 Develop and implement specialized recycling programs if feasible (e.g. PVC, blue wrap, batteries, copper)

Summary

Creating, implementing and sustaining specialized recycling programs in the ORs have been widely documented as essential yet challenging aspects of sustainability programs. Once established, specialized recycling programs have been shown to result in environmental benefits and cost-savings. However, it often requires the dedication and passion of a local champion to implement such programs as they can be work-intensive and may require coordination with recyclers not typically engaged with hospital systems (e.g. scrap metal dealers for copper recycling). There have been several instances of hospitals successfully setting up PVC recycling programs, battery recycling programs, SUMD programs and blue wrap (6,78,186).

People

While there is no published information on the personal impact of specialized recycled programs, the authors received a lot of feedback from collaborators and end users. Several sources indicated that specialized recycling programs increased multidisciplinary collaboration in the OR due to creating, implementing and sustaining a specialized recycling program. In addition, some teams used any profits (i.e. from copper collection) to go towards group pizza parties. Although there are potential upsides, many noted that starting and maintaining these programs can be time-consuming and at times difficult to maintain if you do not have champions leading the project (112).

Planet

Most of the literature for specialty recycling programs comes from case studies and local examples of hospitals successfully implementing programs. Two Toronto hospitals started a PVC recycling program projected to divert 80,000 pounds from landfills in partnership with their local waste hauler (186). Wormer et al. implemented a battery recycling program which resulted in 500 pounds of alkaline waste being diverted from landfill annually (6). There are several accounts of hospitals recycling SUMD and the environmental and financial benefits associated with it (6,187). Wormer et al placed SUMD recycling bins in every OR and diverted 12,860 pounds of medical waste (6). Similarly, the Grand River Hospital implemented an SUMD recycling program that diverted 1,302 lbs. of garbage from landfill as well as generated cost savings (187) (See recommendation 3.4 for more information on reprocessing SUMD)

Sterile blue wrap is estimated to make up 20-30% of surgical waste and is not traditionally recyclable due to contamination risks (50,188). Hospitals have worked with recycling companies to develop a way to divert some of this blue wrap from the landfill. Although we recommend not using blue wrap altogether (see recommendation 1.6), if it must be used, upcycling is a good option to reducing waste. Cheng et al. conducted an implementation study at The Duke Ambulatory Surgery Center which revealed that one OR generates eight 30-gallon bags of blue wrap waste from just three surgeries (50). This is approximately 67% of the centre's outgoing solid waste stream. Thus, the implementation of a blue wrap recycling program could divert significant amounts of waste from landfills. Many hospitals have successfully created and implemented specialized recycling programs for blue wrap. The literature consistently reports environmental and financial benefits of employing these programs. By diverting significant amounts of blue wrap from landfills, these programs help reduce waste and promote resource conservation. In addition to recycling, many hospitals have implemented blue wrap repurposing initiatives. This helps to alleviate the environmental burden of its waste. For example, UHN has donated blue wrap (that would have otherwise been discarded) to a local community center, where it is used in sewing training sessions (127). They also donated to the Bloor Improvement Group, which used blue wrap as insulation for art production spaces, offering a lower carbon footprint alternative to traditional insulation (127). Flagstaff Medical Center has upcycled blue wrap into reusable bags for patients to store their personal belongings before surgery, replacing the typical plastic bags (123). This initiative has saved roughly 60,000 pounds of blue wrap waste from landfills and $17,000 in medical waste disposal fees. Similarly, Overlook Medical Centre has had success in piloting a project to upcycle blue wrap into bags (189).

Another type of plastic that is commonly found in OR waste is polyethylene terephthalate (PET). Wyssusek et al. discusses the results of a PET waste audit that was conducted at the Royal Brisbane and Women's Hospital (RBWH) (190). The goal of the study was to reduce PET waste by measuring the volume of PET accumulated across all ORs at the RBWH over a one-month period. The total weight of PET at the end of the audit was 141 kg. Wyssusek suggests that developing a recycling program for PET could divert a lot of unnecessary plastic waste from landfills.

Profits

In addition to the environmental benefits, specialized recycling programs can also lead to significant financial savings. Wormer et al. found a cost saving of $9,238USD by repurposing and reusing batteries from the OR and saved $4,372USD by recycling SUMD (6). The Grand River Hospital's new SUMD recycling program, which diverted 1,302 lbs. of garbage from the landfill, reduced waste costs by $1,990CAD and established $1,000CAD in company credits towards equipment purchases(187). The Mayo clinic reported a 10.3% cost savings after implementing a recycling program aimed at sharps waste disposal (64). To assess the financial viability of recycling blue wrap, Cheng et al. examined two potential recycling services (50). Orange Recycling offered waste-to-energy incineration at $200USD per ton, while Waste Management proposed converting blue wrap into plastic pellets at $0.11USD per pound, with potential returns of $0.20USD to $0.25USD per pound. Considering the hospital's estimated annual blue wrap production and accounting for service fees and returns, the projected net financial benefit of a blue wrap recycling program was approximately $19,802.50USD per year. Hospitals that have implemented specialized recycling programs and reprocessing initiatives for blue wrap have documented significant cost savings in disposal costs (123,130,189). For example, the upcycling of blue wrap into bags at both Flagstaff Medical Centre and Overlook Medical Centre has generated an estimated $17,000USD and $30,000USD in cost savings, respectively, annually (123,189)

Implementation

Below are the most commonly reported implementation strategies to assist with successful uptake of this recommendation:

- Practice Greenhealth has developed several steps to aid organizations in implementing successful medical plastic recycling programs in the OR (188).
- Implementation of recycling for different types of materials will be contingent upon jurisdictional regulation and capacity of the waste hauler. (112)
- Staff education (7)
- Engage hospital administrators (7)

4. Rethink

4.1 Rethink disposal of unused supplies, older machines and devices and consider donation where appropriate

Systematic reviews and quality improvement projects addressing OR sustainability highlight donations of medical supplies as a key strategy for reducing the carbon footprint of ORs (6,10,13,177). By extending the lifespan of older machines and equipment and repurposing unused or nearly expired supplies, these initiatives not only reduce waste but also provide financial savings by decreasing the need for new supplies and equipment and lowering disposal costs (191) The primary objective of donations should be to benefit the recipient, with environmental considerations being secondary. The concept of "responsible donating" is emphasized, underscoring that recipient countries do not want items that are expired, of poor quality, or require additional resources that are unavailable. Responsible donating means providing the right equipment to the appropriate facilities and caregivers, ensuring that the donations align with both the needs and the capacities of the recipients (10). Several other articles share similar warnings that while donations can serve as a sustainability tool, their impact must be carefully evaluated to avoid creating new problems in recipient countries. Ensuring that donations are genuinely useful to recipients is crucial to maximizing their positive impact. Despite good intentions, donors' lack of awareness of local realities or political dynamics can lead to unforeseen consequences for recipients (13,177,192). The World Health Organization (WHO) has developed guidelines for medicine donations, intended to form the basis of donation policies and to be adapted and implemented by governments and organizations (193). These guidelines not only outline best practices but also define specific roles and responsibilities for both donors and recipients, emphasizing active involvement and accountability.

4.2 Rethink all procurement decisions by implementing an Environmentally Preferrable Purchasing (EPP) policy

Environmentally preferable purchasing (EPP) refers to the procurement of products and services that have a lesser or reduced effect on human health and the environment (194). More specifically, it includes taking into account the life-cycle of the goods and/or services when compared to competing ones with the same purpose. This approach evaluates products based on multiple factors including raw material acquisition, manufacturing processes, packaging, distribution, usage, and disposal (194). By addressing potential problems at the onset of the purchasing process, EPP acts as a proactive strategy – reducing concerns regarding the management of hazardous waste, toxic exposures, or energy inefficiency right from the start (195). An essential part of an EPP policy is to engage with manufacturers to reduce packaging and to employ more environmentally friendly manufacturing and packaging methods. First hand accounts as well as case studies have noted the excessive and often unnecessary amount of packaging for many surgical instruments and supplies in the OR. The reviewed literature highlights the multi-faceted benefits of employing EPP practices. Choosing to purchase products and services that are more sustainable reduces waste, GHG emissions, and resource depletion. Financial benefits of EPP practices include cost savings from reduced waste disposal fees and energy use. Additional long-term savings can be realized through life cycle cost analyses and reduced occupational health risks. As major purchasers of goods and services, hospitals have a lot of choice and the ability to make an environmental difference when it comes to procurement. Moreover, large organizations can serve as models for successfully implementing EPP and inspire other institutions to adopt similar practices (196). Utilizing these "green" products and services can lead to better health outcomes for workers and patients, potential cost savings, and an enhanced public image for the facility. (195). There are several resources available to help hospitals transition toward more environmentally conscious purchasing practices. Yates et al. conducted a comprehensive narrative review synthesizing research on environmentally sustainable surgical practices and identified four key resources offering strategies for implementing EPP in surgical settings (175): 1) Practice Greenhealth's Sustainable Procurement Guide; 2) Total Cost of Ownership Calculator; 3) EPEAT Registry for selecting environmentally certified electronics and 4) Healthcare Without Harm's guidelines for sustainable purchasing policies. In Canada, the Children's Hospital of Eastern Ontario partnered with the Canadian Coalition for Green Health Care to develop a Green Hospital Procurement Policy and Procedure Manual, and Implementation Guide (197). The Canadian-based documents provide an excellent guide to help hospitals implement a Green Procurement Policy which includes obtaining support from management, involving all relevant staff, and creating formal policies and procedures. Adopting EPP practices may be among the most impactful "greening" strategies, especially when considering the well-being of patients and healthcare workers**.**

4.3 Rethink traditional hand scrub and consider the use of alcohol hand rub

While it is well established that pre-operative hand anti-sepsis is critical in preventing surgical site infections (SSIs), the optimal method that staff should be using to disinfect their hands is often debated. Traditional hand antisepsis involves scrubbing the hands with water and surgical handwash containing an antiseptic liquid soap, such as chlorhexidine, povidone-iodine, or triclosan (198). More recently, the use of alcohol-based hand rub for surgical hand preparation has gained popularity. Several systematic reviews and RCTs indicate that alcohol-based hand rubs are as effective or superior to antimicrobial scrub agents in terms of efficacy (199–211). Many studies also document the environmental benefits of alcohol-based hand rub compared to traditional hand scrubbing due to significant water savings from using a waterless alternative (6,42,212,213). However, at this time, there are no LCAs that document the difference between traditional hand scrub and alcohol-based hand scrub. Cost evaluations show that alcohol-based hand scrubs are generally more cost-effective than traditional scrubbing methods due to lower water usage and reduced application time (205,212). The literature also demonstrates a preference for alcohol-based hand rub due to its efficacy, environmental benefits, and cost savings. However, there is conflicting evidence on physician preference for tradition hand scrub vs alcohol hand rub due to irritation. Guidelines from major health organizations state that alcohol-based hand rub is an appropriate alternative to surgical scrubbing with an antimicrobial scrub product (214,215). In Canada, both IPAC Canada and Public Health Ontario recommend using alcohol-based hand rub or an antimicrobial soap (surgical hand scrub) with persistent antimicrobial activity, with a preference for alcohol-based hand rub due to its superior efficacy (216,217). Public Health Ontario's Hand Hygiene guideline also recommends this practice (217). Based on current evidence, it is recommended to have both options currently available for use for surgical scrubs.

4.4 Rethink anaesthetic techniques other than inhalational anaesthesia

All of the recently published guidelines recommend using anesthesia techniques other than inhalational anesthesia whenever possible due to the well-known negative environmental impact of the volatile gases. While the environmental impact of inhalational anesthesia has been studied over the past few years, the environmental impact of other forms of anesthesia has not received the same attention. Pauchard et al and White et al note that while IV drugs are not greenhouse gases, they are polluters of soil and water due to the ways in which they are discarded. Studies have shown that approximately 1% of propofol is excreted by the patient in the form of urine unmetabolized (unchanged) and from 14-49% of propofol is never used and is wasted (28). This wastage is problematic as it is highly toxic for aquatic organisms and also presents a high potential for bioaccumulation or mobility in soil. Additionally, there is no evidence to show that that it biodegraded in water nor under anaerobic conditions. The only way known to destroy it is to incinerate it as 1000 degrees Celsius for at least two seconds. (28,28). While many guidelines recommend the use of IV anesthesia with Propofol, they all note that the environmental impacts of Propofol need to be studied further before a definitive recommendation can made (8,10,28,29,218). For example, the SFAR Guideline notes that "From the standpoint of environmental impact, the experts suggest that, with equal clinical benefit for the patient, anaesthesia professionals utilize either maintained general anaesthesia by inhaled vapours, or total intravenous general anaesthesia by propofol injection; while the former have an environmental impact through greenhouse gas emission, the latter are ecotoxic for water and soils.". Aside from using IV Propofol, the Intercollegiate Guideline recommends the use of local and regional anesthesia for common surgical operations such as inguinal hernia repair and hip and knee arthroplasty. (8). Local and regional anesthesia is environmentally preferrable to both inhalational anesthesia as well as Propofol. In addition, local and regional anesthesia provides clinical benefits for patients and allows for shortened length of stay. (8). Due to the limited amount of evidence currently available on the environmental impact of different anesthetic techniques, we are currently recommending to consider the environment when making decisions on the type of anesthetic to use.

Implementation

Successful implementation will require tailored strategies, and not all recommendations will be feasible for every hospital. It is well documented several barriers to implementation of these recommendations exist including limited resources (financial, time, and personnel), staff buy-in, site-specific restrictions (e.g. access to reusable sharps containers, portable nitrous oxide canisters) and/or administrative restrictions (e.g. OR occupancy sensors, current purchase agreements, space restrictions). Due to these, and other barriers, the authors strongly suggest that the first step in implementation should be the development of a multidisciplinary Green OR team to determine which recommendations may be feasible for your site as well as having interdisciplinary champions to lead and oversee the changes to be made. CASCADES (www.cascadescanada.ca) modified its Perioperative Scorecard to align with our recommendations to assist with national implementation via their Dashboard. The Canadian Coalition for Green Healthcare (www.greenhealthcare.ca) also offers tools to support tracking and progress. Additional resources, such as webinars and toolkits, are available through Choosing Wisely Canada (www.choosingwiselycanada.org) and international groups like Practice Greenhealth (www.practicegreenhealth.org). Many studies also highlight effective implementation strategies, as are shown in Table 1. The Best Practice in Surgery group intends to update this guideline every five years, incorporating emerging evidence and best practices.

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