An Analysis of the Feasibility of Circular Economies as a Method of Reducing Waste from Hospital Operating Rooms

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Abstract

Operating room (OR) waste accounts for a large proportion of total hospital waste. Current consumption, use and disposal techniques are highly standardized and regulated. This thesis investigates the possibility of reuse and recycling as feasible methods of reducing OR waste without negatively affecting the standard and quality of care. Data was collected from interviews with healthcare providers (HCPs) and through observational analysis in the OR at Kingston General Hospital. The data was used to identify the barriers preventing a classical or typical response to the waste hierarchy, a tool used for assessing waste management solutions. Analysis revealed that infection control is the most pressing issue, which restricts the amount of recycling and reuse initiatives that can be implemented. Additional factors identified include cost reduction, reliability, and administrative structures. Most healthcare professionals working in ORs are aware that surgeries create a large volume of waste; however, waste remains a low-priority issue. Results demonstrate that hospitals are an institution where responses to the waste hierarchy are restricted to reuse and disposal methods. Additional expansions to reuse or recycling, while possible, are limited in their magnitude and may result in adverse effects and increased risks to patients.

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This thesis is dedicated to Steph Maunder, who always believed in me.

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List of Abbreviations

APC – air pollution control

BSW – blue sterile wrap

CCME – Canadian Council of Ministers of the Environment

CO_2 – carbon dioxide

CWS – Canada-Wide Standards

GWP – global warming potential

H_2O_2 – hydrogen peroxide

HCP – healthcare provider

HDH – Hotel Dieu Hospital

HIV – human immunodeficiency virus

KGH – Kingston General Hospital

KHSC – Kingston Health Sciences Centre

MSW – municipal standard waste

N_2O – nitrous oxide

OR – operating room

PAH – polycyclic aromatic hydrocarbon

PPE - personal protective equipment

PCDD/Fs – polychlorinated dibenzodioxins, polychlorinated dibenzofurans

SARS – severe acute respiratory syndrome

SARS-CoV-2 – severe acute respiratory syndrome coronavirus 2

SUD – single use device

Introduction

Hospitals are institutions that generate many types of wastes. From the cafeteria and food services to the provision of patient care, nearly every facet necessary to the successful functioning of a hospital generates some type of waste. Specifically, hospital operating rooms (ORs) generate an abundant volume of waste, sometimes totalling up to a third of all hospital waste (Stall et al., 2013). Much of the waste generated through surgeries can be attributed to the use of single-use devices (SUDs); this can include equipment, linens, tools and anatomical wastes (Dempsey & Thirucote, 1989). Examples of SUDs include drapes, gowns, gloves, sponges, saw blades and other instrumentation (Cortese, 2005). Some items can be sterilized and used again, through the practice of reprocessing. Reprocessing a medical device entails sterilizing and cleaning the device such that it can be used again. Reprocessed devices are common to most surgical specialties, including but not limited to cardiology, orthopedics, neurology, and urology (Unger & Landis, 2016). Reducing surgical waste may not be as simple as reducing waste in other industries, as the frequency of illness cannot be controlled and access to life-saving medical procedures cannot be denied. Therefore, I aim to answer: Is reusability a feasible and safe method for reducing OR waste? Can this waste be reduced without compromising safety?

This thesis project examines Kingston General Hospital (KGH), a teaching university hospital in Kingston, Ontario. The objective of this work is to analyze OR waste from various perspectives of healthcare providers (HCPs) in order to identify issues or barriers that prevent extensive reusability and recycling in hospital ORs. In a broader sense, this work will indicate whether hospitals can transition to become closed loops with their resources. It is important to acknowledge that some waste generation is inevitable and deemed necessary for an OR to function appropriately. Hospitals may be institutions where responses to waste management tools, such as the waste hierarchy, are restricted. That is, disposal may be more appropriate for OR waste than reducing, reusing and recycling due to challenges that prevent a classical response to the waste hierarchy.

Literature Review

History of Single-Use Devices

The practice of surgery is as old as mankind (Haeger, 2014, The Beginnings of Medicine section, para. 1). The earliest surgeries involved boring holes into the skull in a practice called trephining (Haeger, 2014, The Beginnings of Medicine section, para. 2). Over the years, civilizations recognized the importance of cleaning a wound, though the concept of disease was poorly understood (Haeger, 2014, The Beginnings of Medicine section, para. 5; Goodrich, 2004). Mortality from surgical procedures remained high throughout the 1500s-1800s (Chamberland, 2009). Up to 80% of all surgeries resulted in post-operative gangrene infections, and nearly half of all surgical patients died after a procedure (Alexander, 1985). In 1867, Joseph Lister introduced the practice of antisepsis into clinical surgery when he treated suppuration (pus formation) with carbolic acid (Lister, 1870). The newly-termed aseptic era concluded with the creation of gowns and caps in the 1880s, to prevent the surgeons from getting blood on themselves, and gloves in the 1890s (Alexander, 1985). This new era of cleanliness was complimented by hospitals beginning to process and sterilize dressings, glassware, and sutures in-house (Greene, 1986). In the 1900s, surgeons began adopting the principle of asepsis (Alexander, 1985); this principle focuses on preventing bacteria from gaining access to a wound, thereby avoiding the need for antisepsis. To date, asepsis remains a primary factor in surgical success (Alexander, 1985).

In the 1890s, many medical supply houses began to provide hospitals with pre-packaged and pre-sterilized dressings, plasters and ligatures (Greene, 1986). The hospital supply industry began to cheaply and efficiently synthesize disposable plastic alternatives to devices that were traditionally made of glass, metal, rubber or textiles (Greene, 1986). Production of plastics increased exponentially during the Second World War, with 818 million pounds being produced in 1945 (Freinkel, 2011, p. 25). The significantly lower market prices of disposable items compared to their reusable counterparts and their reliability has made them ideal for mass-use (Ibbotson et al., 2013). In the 1960s, the incorporation of high- and low-density polyethylene into medical products allowed them to be manufactured, used and disposed of without being cost prohibitive (Unger & Landis, 2016). Single use devices became more common. By the 1970s, many hospitals had switched to using mostly disposable items because it was more cost-effective to buy and discard the disposables than to buy and sterilize the reusables (Greene, 1986). Manufacturers developed more heat-tolerant plastics, meaning they could be autoclaved in-house, presenting another cost-saving measure on top of the cheaper up-front cost of disposable items (Greene, 1986). However, it was not long before disposables became a major expense, due in part to the volume of items required, so hospitals then attempted to reprocess some of the less critical disposables, such as plastic bedpans, urinals and thermometers (Greene, 1986).

In the 1980s and 1990s, concern arose about the spread of bloodborne diseases, mainly human immunodeficiency virus (HIV) and Hepatitis B (Rastogi et al., 2011). These diseases only reinforced the use of disposable items to reduce the risk of cross-contamination. Furthermore, the lack of knowledge regarding transmission of these diseases, particularly HIV, resulted in increased pressure on healthcare providers (HCPs) to ensure the safety of their patients (Rutala &

Mayhall, 2012). The consumption of single-use gloves and syringes were critical in the wake of AIDS (Freinkel, 2011, p.82).

Types of Waste in the Operating Room

There are multiple types of waste from surgery in the operating room (OR). General waste comprises up to 85% of the waste volume (Melamed, 2003). Recyclable materials, such as paper, glass and cardboard account for a large portion of general waste (Tieszen & Gruenberg, 1992). It is estimated that waste per person per procedure can average 13.3kg (Stall et al., 2013). One surgery can produce more waste than a family of four would create in a week ("Greening the OR", 2011). Biohazardous medical waste comprises the remaining 15% of waste and must be disposed of in certain ways that reduce the potential for infection transmission (Melamed, 2003). Biohazardous waste can include bodily fluids, pathological wastes such as tissue samples, anatomical wastes such as whole organs or limbs, sharps such as syringes and needles, and any equipment that has had contact with the patient (Melamed, 2003). Disposal costs for biohazardous wastes are estimated to be eight times higher than general waste, at CAD$963 per tonne (Kagoma et al., 2012). Issues with respect to disposal arise because up to 85% of OR waste that should be disposed as general waste is placed into the biohazardous stream (Melamed, 2003; Laustsen, 2007), thereby increasing the volume of waste entering a more costly disposal stream.

Blue sterile wrap (BSW), which is made of polypropylene, is a large source of non-recyclable general waste in hospitals, accounting for up to 25% of medical waste (Shinn et al., 2016) and 5% of total hospital waste (Babu et al., 2018). Many reprocessed instruments return to the OR wrapped in BSW (Shinn et al., 2016). The use of pre-packaged surgical kits, often referred to as custom packs, are used in the OR to maintain efficiency. These packs contain everything required to complete a procedure, and often more than one pack is necessary. For example, a total knee arthroplasty (knee replacement) needs three packs – one for the knee replacement, which includes the cement and other relevant equipment, one for anesthesia, and one for the catheter (Stall et al., 2013). Often, more than a dozen items from these packs are opened but never consumed (Albert & Rothkopf, 2015). These cannot be used in another procedure as they are no longer sterile and end up in the general waste stream.

Anesthesia-related waste includes syringes, needles, bottles, airway equipment and tubing (Esaki & Macario, 2009). Less than 5% of administered anesthetic gases are metabolized by a patient (Malekirad et al., 2005); the majority are exhaled and vented into the atmosphere. Anesthetic gases are potent greenhouse gases and account for 0.03% of all warming from volatile gases (Langbein et al., 1999). While this may appear insignificant, these emissions are of increasing concern. Isoflurane, sevoflurane and desflurane are the most common general anesthetics used in surgery (Yasny & White, 2012). The majority of environmental impacts from anesthetic gases are attributed to desflurane, whose global warming potential (GWP) is 26 times greater than the GWP of sevoflurane, the next most potent compound (Yasny & White, 2012). This creates a significant heat-trapping effect (Sherman et al., 2012) and can result in ozone depletion in the stratosphere and greenhouse warming in the troposphere (Langbein et al., 1999). The resulting lifetimes of these drugs are 21 years for desflurane and 4 years for sevoflurane (Langbein et al., 1999).

Disposal Techniques

The two main methods of disposal for operating room waste are incineration and sterilization via autoclave or sterrad. Incineration is an effective technique because it reduces the mass of waste by 70% and the volume by 90% (Singh & Prakash, 2006). However, these advantages are outweighed by negative environmental impacts. Incineration releases nitrous oxide (N_2O), polycyclic aromatic hydrocarbons (PAHs), and dioxins, which can adversely affect human health (Kagoma et al., 2012). Dioxin emissions from incineration account for 22.5% of Canada's total dioxin emissions ("Management of toxic substances: incineration sector," 2015). Atmospheric emissions and solid residues from bottom ash, fly ash and air pollution control (APC) systems all contribute to the total concentration of polychlorinated dibenzodioxins and polychlorinated dibenzofurans (PCDD/Fs) from incinerators (Canadian Council of Ministers of the Environment [CCME], 2007). Because medical waste often contains high amounts of plastic, incinerator ash usually contains high quantities of PAHs and PCDD/Fs (Lee et al., 2002). Ash is moved to a landfill for final disposal, where it is buried (Walkinshaw, 2011).

Autoclaving treats infectious waste with dry heat or steam (Windfield & Brooks, 2015), whereas the sterrad uses hydrogen peroxide (H_2O_2) vapour and high-pressure gas to sterilize items. To ensure that bacteria and microbes are killed, the temperature of the autoclave must reach a minimum of 121°C (250°F) and must be maintained for a minimal amount of time (Centers for Disease Control and Prevention [CDC], 2016). The time will vary depending on the composition of the items to be sterilized and the type of autoclave (CDC, 2016). This technique is advantageous because there is no release of dioxins or PAHs and it allows waste to be disposed of in a general municipal solid waste (MSW) landfill (Klangsin & Harding, 1998). However, autoclaved waste can be mistaken for untreated infectious waste, so autoclaved waste is often incinerated, making the sterilization process redundant (Windfield & Brooks, 2015). As a result, sterilization processes often include the use of chemical and bioindicators that signal effective sterilization with each run of the machine, such as a colour change (Serp et al., 2002). However, defects in the use of bioindicators have been noted (Jabbari et al., 2012). Some studies have cited false positives affirming sterilization when bacterial spores were in fact growing

(Kelkar et al., 2004). A common challenge in sterilization is inconsistency in reprocessing information from device manufacturers. For example, fine statinsky clamps had always been sterilized at 270°C for four minutes, but new clamps arriving from the manufacturer indicated sterilization should occur at 270°C for five minutes (Stephens & Assang, 2010). This contributes to an overall sense of frustration in sterilization as a reprocessing technique.

Regulation

The Canadian Council of Ministers of the Environment (CCME) is a government organization composed of federal, provincial and territorial ministers that focuses on national issues requiring interjurisdictional or intergovernmental action (CCME, 2007). The CCME has developed directives for medical waste, including Canada-Wide Standards (CWS) to minimize environmental risk and standardize environmental quality across the country (CCME, 2007). However, each province has the authority to regulate medical waste as they see fit (Windfield & Brooks, 2015). In Ontario, biohazardous wastes are required to be sterilized prior to disposal in a landfill (Walkinshaw, 2011). Waste must be sorted into colour-coded and clearly marked bags and bins, indicating the pathogenicity of its contents (that is, the ability to cause disease), in order to determine the appropriate waste disposal stream (Windfield & Brooks, 2015). For example, at Kingston General Hospital, biohazardous wastes are coded by a vibrant yellow bag, and general wastes are placed into clear industrial sized garbage bags.

The CCME has also imposed directives on incineration. CWS are applicable to incineration facilities that handle municipal, medical and hazardous wastes ("Management of toxic substances: incineration sector," 2015). Operating an incineration facility often necessitates testing of the stack (chimney) to establish emission performance (CCME, 2007). Additionally, in Ontario, the CWS for emission limits from incineration have been adopted as conditions of operation (CCME, 2009). Ontario requires annual testing of all incinerators, even if the facility reports low levels (CCME, 2006). There are also regulations with respect to the storage, containment and transportation of medical wastes ("C-4: The Management of Biomedical Waste in Ontario", 2016). Additionally, the Spaulding classification system is used to organize medical devices into one of three categories based on the risk of infection involved with their use; each requires its own level of disinfection (Nelson et al., 2003). The three types are: critical, having come into contact with blood or sterile tissue; semi-critical, having come into contact with mucous membranes; and non-critical, having come into contact with unbroken skin (Nelson et al., 2003).

At the federal level, Health Canada has imposed regulations on reprocessing of SUDs. These include clear labelling of the device as 'reprocessed,' giving the reprocessed device a new license number, and including reprocessing instructions on the device's label (Cowling & de Leseleuc, 2015). At the provincial level, Public Health Ontario has described some requirements for reprocessing. These include a centralized area for reprocessing, such as a medical device reprocessing centre with defined cleaning procedures and adequate access to personal protective equipment (PPE) for all reprocessing activities (Public Health Ontario, 2013). Public Health Ontario (2013) has also recommended that Ontario hospitals source reprocessing from a third party to reduce concerns over legal liability, adverse events, and ethical considerations.

Currently, the lack of a standardized definition of medical waste and infectious objects (that is, classifying which objects have the most potential to cause harm) has contributed to an increase in medical waste and volume of disposable waste (Mbongwe et al., 2008). This makes it difficult to perform comparative analyses between regions and countries (Windfield & Brooks, 2015). Many find it safer to dispose of most items than to risk transmitting infection or cause injury to healthcare personnel. Part of this is attributable to many infection-related studies citing inconclusive results. A study from 1995 found that infection rates from using reprocessed laparoscopic instruments such as trocars, scissors and staplers, increased by 1.8% (DesCoteaux et al., 1995b); however, it was noted that they lacked sufficient data to perform a complete assessment. Other studies comparing infection rates have found extremely low prevalence of skin infections and bacteremia from the use of reprocessed catheters (O'Donoghue & Platia, 1988). Most hospitals do not keep statistics on the number of adverse events and device malfunctions attributable to reprocessing (Polisena et al., 2008). The lack of documentation on hospital waste incinerators is also challenging (CCME, 2007). There is also high variation between studies which contributes to an overall sense of unease.

Recycling and Reusability

There are hundreds of studies examining the feasibility of recycling initiatives in hospital ORs. Cost-reducing methods include reusing single-use devices (SUDs), modifying surgical techniques to need less disposables, increasing recycling availability, and altering custom packs (Siu et al., 2016). Identifying and removing items from custom packs that are commonly opened and never used can decrease the cost per pack, saving an estimated US$41 844 (Albert & Rothkopf, 2015). Recycling streams for BSW were found to save over 31.2 cubic feet of landfill space (Babu et al., 2018). A study by Stall et al. (2013) found that failure to maximize recycling efforts in operating rooms resulted in increased landfilled waste and increased disposal costs. The use of anesthetic gases can also be modified to be more environmentally conscious. Implementing gas flow reduction programs, which reduce the flow of anesthetic gases from 4-6L/min to 1-2L/min, was found to minimize environmental impacts (Yasny & White, 2012). New gas recovery methods are also in development; these techniques allow for selective capture of gases before they enter the atmosphere, and can be sold back to pharmaceutical companies at a cheaper cost than what it costs companies to synthesize them (Yasny & White, 2012).

Studies examining reusability and reprocessing are less common. One study found that the use of reusable objects was found to decrease medical waste by 65% (Conrardy et al., 2010). A study from 2008 showed that 28% of Canadian hospitals reprocess their SUDs, with larger hospitals being more likely to reprocess (Polisena et al., 2008). Furthermore, 70% of the hospitals mentioned they used to reprocess but ceased between 2002 and 2004 (Polisena et al., 2008). It is worth noting that this coincides with the outbreak of severe acute respiratory syndrome (SARS) in Canada (Poutanen et al., 2003). The SUDs most commonly reprocessed in Canada include breast pump kits, ventilator circuits and burrs (drill bits) (Hailey et al., 2008).

Hospital Supply Chain and the Waste Hierarchy

The waste hierarchy is a tool used to describe best practices for waste management and is used as a guideline to formulate waste policy (Rasmussen et al., 2005). The hierarchy is organized into levels in the shape of an inverted triangle, with the preference for each level increasing as one moves up the hierarchy (that is, the most preferable options are at the top) (See Figure 1 in Appendix A). The waste hierarchy expands upon the traditional “3 Rs”: reduce, reuse, and recycle, to encourage more preventative actions, such as rethinking of waste generation and redesign of systems to promote these types of changes (Rasmussen et al., 2005). These are preferable to landfilling, incineration and resource extraction techniques such as material recovery (“The International Zero Waste Definition & Hierarchy,” 2018). Much of the current effort focuses on recycling programs; though important, they are not as effective as prevention strategies with respect to sustainability (Gertsakis & Lewis, 2003). It is more effective to avoid or prevent the causes of environmental problems from the onset than to manage the impacts, wastes and emissions arising later (Gertsakis & Lewis, 2003).

Solutions like incineration and disposal do not address the problem of waste generation and unsustainable consumption of resources. Despite technological advancement in waste management, there are still unwanted consequences (Rasmussen et al., 2005). Mass-production has made waste a pressing environmental problem, especially with the increased availability of materials and energy (Hultman & Corvellec, 2012), global transportation, communication, and cheap mechanized labour (Hird, 2012). The presence of waste in society and the ways in which it is dealt with is characterized by dissociation (Hultman & Corvellec, 2012). Waste producers want to be physically and psychologically separate from waste, and do not engage with the fate of materials past their consumption (Corvellec & Hultman, 2013, pg. 142). Most things spend little time within the realm of human production and consumption (Hird, 2012). Rasmussen et al. (2005) describe it well: it is not a question of whether to recycle or landfill or not, but rather how much to recycle or landfill, as to minimize the environmental, social or economic costs that exist. There needs to be an organizational shift with respect to waste that moves from a resource recovery-based hierarchy to a prevention-based hierarchy (Gertsakis & Lewis, 2003). In certain instances, disposal routes, such as landfilling, might be more preferable to disposal (Price & Joseph, 2000). This is due, in part, to the fact that a hierarchy of prevention requires systematic change that is not always compatible or appealing to companies or industries with investments in conventional environmental management systems (Gertsakis & Lewis, 2003). The best environmental option may be disposal rather than any form of recycling or reuse because of the environmental or economic costs of these options (Price & Joseph, 2000).

Hospital supply chains are unique in that they are composed of both external (from the manufacturers to distributors) and internal (from the storerooms to the nursing units to the points of care) loops (Landry & Beaulieu, 2013). The current linear healthcare supply chain parallels an industrial supply chain but is more complex due to the integration of care (see Figure 2 in Appendix A, adapted from Phalange, 2017). Improving hospital supply chains can provide many benefits, such as reduced supply costs, increased quality of care (Landry & Beaulieu, 2013). Hospitals may be an institution that can benefit from the implementation of programs that promote reuse, reduction and redesign (Suarez-Eiroa et al., 2019). This could contribute to the circularization of hospital supply chains, effectively creating a closed loop of resources. The circular economy presents several environmental and economic benefits, such as material recycling, sharing economies (Scavarda et al., 2019), and the decoupling of economic activity from resource use (Wijkman & Skanberg, 2015). However, when applying this model to hospitals, it becomes clear that there are areas of the hospital where it may be harder to implement (Suarez-Eiroa et al., 2019). Operating rooms may be a type of institution that presents a restricted response to the waste hierarchy due to various barriers, making a transition to a circular economy more challenging than in other institutions.

Methods

Study Area and Participants

Kingston General Hospital (KGH) is a teaching university hospital in Kingston, Ontario. It is a 1.228 million square foot facility with 440 beds and several operating rooms (ORs) that perform approximately 9000 surgical procedures each year ("KGH Site Quick Facts", 2019). As of April 2017, KGH is a member of the Kingston Health Sciences Centre (KHSC), a hospital corporation that joined together KGH with other Kingston-area healthcare facilities, including Hotel Dieu Hospital (HDH) and the Cancer Centre of Southeastern Ontario (Kingston Health Sciences Centre, 2018). Additionally, it works with a variety of regional partners to service most of Southeastern Ontario; these partners include Providence Care, Kingston, Frontenac and Lennox & Addington Public Health, Brockville General Hospital, Lennox and Addington General Hospital, Perth and Smiths Falls District Hospital, and Quinte Health Care (Kingston Health Sciences Centre, 2018). KGH is unique in that it is the only acute-care teaching hospital serving Southeastern Ontario that also conducts patient-oriented research and trains post-graduate students ("KGH Quick Facts," 2019), making this an interesting facility to analyze for research purposes. (See Figure 3 in Appendix A for a map of the facility.)

I collected interview data from healthcare professionals (HCPs) that work in the operating rooms at KGH. In order to recruit participants, I sent emails to members of the Department of Surgery and the Department of Anesthesiology and Perioperative Medicine. If I did not receive a response after one week, I sent a reminder. I requested that the email be forwarded to anyone assumed to have interest in the study. I conducted five interviews in person. The interviewees varied in age, gender, role, and OR experience, providing me with various perspectives on waste issues in the OR (See Table 1 in Appendix B for details on the interviewees). Because I used snowballing network techniques, the study information was passed to HDH. As a result, I conducted four (80%) of the interviews with members of KGH, and one (20%) interview with a member from HDH. Though the original call was for LGH personnel, I did not exclude the HDH respondent due to their occupation and relevancy to the project. I assigned each interviewee an alphanumeric code (A1-A5, for "Anonymous 1," "Anonymous 2," and so on), by which they are referred to for the duration of the paper. This thesis is part of Dr. Myra Hird's overall study: "Canada's Waste Future: Uncertainty, Futurity, and Democratic Engagement" (grant number 435-2013-0560), with approval from Queen's University General Ethics Review Board (Ref. #: GENSC-057-13).

Data Collection

I conducted semi-structured interviews with respondents A1-A5. This method was ideal as it allowed me to interact personally with each interviewee, making it possible to obtain relevant knowledge from those who perform surgeries every day. The general format followed for the semi-structured interviews can be found in Appendix C. I asked interviewees about operating room waste, how recycling and reprocessing worked, and the possibility of expanding reuse and recycling circuits. I stored the audio files from the interviews on a secured (password-protected, fingerprint-sensitive) device, and transcribed them two weeks later. With the exception of one interview that occurred in the participant's office, all interviews occurred in neutral locations, such as local coffee shops or libraries. In addition to the interviews, I also obtained key observational data when my supervisor and I observed a surgery at KGH on February 13th, 2020. We observed firsthand the quantities of waste generated from a single procedure.

Analysis

After transcribing the audio files from each interview, I then interpreted the data using a thematic approach. I noted relevant themes and prevalent issues to assess if this type of waste is a pressing sustainability issue and if reusability and recycling were safe and effective means of reducing OR waste. For the observational data, I noted by hand the amounts and types of waste generated, and then later, cross-referenced that information with the recurrent themes noted in the interview data. This was done to see if pressing issues among members of KHSC correlated with the generation of waste.

Limitations

One of the major limitations in this study was low participant response. Specifically, the Department of Surgery garnered no responses. I received a total of nine responses. Of those, five further initiated to set up an interview. It is uncertain how many people actually saw the email containing the study details. Furthermore, departments deemed important to the research were unavailable to participate. Specifically, equipment managerial services for the OR and Environmental Health Services were unavailable. I received replies to my emails that potential participants were on vacation or were concerned about repercussion from their supervisors. I reached out to supervisors for permission, but it was never granted, further limiting the participant pool. Time was also a constricting factor; more time would have allowed for a deeper inquiry and additional analysis of waste generation. Finally, emails coming from external users (that is, people who do not have a KHSC email account) have a warning attached to them indicating the email is coming from outside the KHSC user database. This may have turned some potential participants away as they may have assumed it was junk mail.

Results and Discussion

Interview Data

Recurrent themes and prevalent issues noted in the interviews are summarized in Table 2 of Appendix B. When asked, interviewees had difficulty quantifying the waste that comes from the operating room (OR). It is interesting to note this, because throughout the observational analysis, strict counting and organization is done by the circulating nurse. Waste volume from the OR is dependent upon a multitude of factors, including numbers of surgeries per day, type of surgery, length of each case, and turnover rate of the OR – that is, how fast the OR can be cleaned and reset for the next procedure. Therefore, the difficulty in quantifying was more or less a reflection of the sheer volume of waste being generated, and not that the healthcare providers (HCPs) are not paying attention. Each interviewee stated that most things are thrown out and incinerated, with a small percentage of items being sent for reprocessing. Thousands of items are used each month, creating enormous volumes of waste as a result of each procedure. Other university-affiliated teaching hospitals were found to make similarly large volumes of waste: waste tracking at a teaching hospital in Brazil resulted in a total of 21.1 tonnes of biological and sharps waste and 113.9 tonnes of solid waste per month (Martini et al., 2017).

Factors affecting circular model implementation in the OR vary from the administrative to HCP level. A2, an anesthesiologist, described administrative structures as challenging to overcome, resulting in slow implementation of changes. A1, who is also an anesthesiologist, and A3, a medical student, noted the primary issue at the administrative level is cost and cost reduction. They stated this limits the response to environmental issues and is a critical factor in decision making. Often, the marketed cost-effectiveness of single-use devices (SUDs) makes them more attractive as an option (Ibbotson et al., 2013). A5, a scrub nurse, also stated that the lack of change in the OR is likely attributable to the cost of reprocessing compared with the cost of buying disposables. They also stated that the first thing done when changes are proposed is to assess if the idea is "financially appropriate."

At the HCP level, all interviewees indicated infection control as the primary issue, followed by cost and a multitude of other factors, including education, engagement and corporate responsibility. The shift to disposables in the ORs at Kingston General Hospital (KGH) began in the 1990s due to the spread of AIDS. A4, who was an OR nurse at the time, indicated that the number of items that could be reprocessed was higher in the 1990s than it is currently. Items that were traditionally reprocessed were replaced by single-use clones, meaning less items were being reprocessed. "I don't think anything was disposable. Not in my time," said A4. Many interviewees believed the shift was primarily a cost-driven decision, but it is likely there were considerations for infection control as well. A5 also mentioned that reliability is a contributing factor; disposable devices will always be sharp and sterile out of the package, whereas a reusable device of the same nature may become dull or crack over time. Some studies have found that as few as four instances of reprocessing may introduce micro-cracks into reusable devices, increasing the surface area available for oxidative processes and inducing mechanical failure (Lucas et al., 2010). A1 believed that there may have been considerations for the carbon emissions from reprocessing. A study by Unger and Landis (2016) showed that kilograms of carbon dioxide (CO_2) equivalent emitted by commonly reprocessed devices, such as ligasures and trocars, increased with each instance of reprocessing. That is, the more you reprocess an instrument, the more carbon it emits. HCPs were surprised by the fact that "each time something new comes in, it seems to be disposable." This speaks to the increased volume of waste that is being created with each procedure, and demonstrates shifts down the waste hierarchy, towards the least preferable options of disposal and incineration.

KGH uses a mix of autoclaving and sterrad techniques for reprocessing. The items with high heat tolerance are steam-autoclaved, whereas more delicate items that may be damaged by steam are reprocessed in the sterrad. Items that are opened but unused, such as in the case of an emergency, are usually thrown out. These items cannot be used on another patient because they are no longer sterile. However, A1, A4 and A5 discussed repurposing efforts for some of these items. This included donating items such as endotracheal tubes to a simulation lab or to medical students and residents who want to practice their technique with these items. They also describe at-home use of things like drapes and plastic tubs, for purposes such as cat litter containers and paint drop cloths.

Additionally, commonly used anesthetic gases were noted by A1 and A2 (the anesthesiologists) to be potent greenhouse gases and a source of concern among many in the same profession. Specifically, the trapping of heat by CO_2 and the potency of nitrous oxide (N_2O) were mentioned. Attempts to reduce the quantities used of N_2O and other greenhouse gases were believed to be cost-effective techniques. N_2O is used as a carrier gas in conjunction with desflurane or sevoflurane, but can be safely excluded from surgery (Thiel et al., 2018). A2 mentioned that most people in the department have switched from desflurane, a potent greenhouse gas used as a general anesthetic, to sevoflurane, a very similar compound with a far better emission profile. Switching from desflurane to sevoflurane can reduce greenhouse gas emissions by up to 64%; most of this reduction is attributable to the volatility of desflurane (Zuegge et al., 2019).

As was previously mentioned, infection control was the most important factor with respect to implementing extensive reuse and recycle programs for OR equipment and tools; this was common to all interviewees. Any items in contact with the patient are incinerated as a safety precaution. Concerns surrounding transmission of diseases, viruses and prions were described as "justified" by A2 due to the inability of modern sterilization technology to remove persistent infectious agents. A4 stated that instruments with very small diameters and lengths are particularly troublesome with respect to reprocessing. For example, a cannula the size of a pen tip or a tool with an immovable part would be difficult to sterilize with high degrees of confidence, so it is easier to discard it. Residual debris can be found in articulations, furrows, junctions and grooves of reprocessed instruments, despite them appearing to be clean at a macroscopic level (DesCoteaux et al., 1995a). This would understandably make it difficult to reuse these items on another patient. A3 also spoke about confidence in reprocessing, stating that "there is a fear that if something is not brand new, it's not sterile." This displays the hesitance that some HCPs at KGH feel towards the reuse of tools and equipment. A3 also stated that if newly-introduced reusable items could be reprocessed to a point where their sterility matches or exceeds that of a new disposable item, then more of these items would likely be incorporated into OR supply chains based on demand and improved confidence in the sterility.

Because of the focus on creating and maintaining a sterile environment, and the fact that safety is a critical issue, environmental issues such as waste are simply low priority. This, combined with the importance of infection control, makes reusability and any other levels of the waste hierarchy above it, more difficult to implement. However, many of the interviewees discussed recycling as a current initiative that was making the ORs more environmentally conscious places without compromising patient safety and sterility. Recycling bins do exist in the

ORs but are usually filled to capacity prior to the first incision being made, as nurses are opening relevant packs and equipment. Each item that is reprocessed returns to the OR in a plastic sleeve with a paper backing, which can be separated and recycled. Many interviewees describe the setup by nurses as diligent and the initial effort to sort recyclables as strong. As the procedure begins, there is less effort to recycle and sort because personnel are focused on the procedure. When the turnover of the OR is tight, many interviewees stated that recycling is not a priority, and everything is simply thrown out. This may limit the capacity of the OR to sustain long-term environmentally conscious changes.

Despite being the most visible form of the environmental impacts of healthcare (Thiel et al., 2015), and that most interviewees agree it is a significant issue, waste is not treated as such. Although personnel who work in the ORs describe the waste volume as substantial, there lacks a complementary policy with respect to waste. No interviewee was aware of any initiatives in place at KGH that may contribute to making OR waste a priority or to increasing reusability in the OR. Despite the fact that no initiatives appear to be planned for the operating rooms, the importance of implementing environmental policies was noted. It was acknowledged that these types of policies could encourage the development of preventative based healthcare models and long-term environmental sustainability in hospital settings. Preventative healthcare models aim to avoid clinical manifestations of illness and to decrease the number of people requiring treatment (Sadkovsky et al., 2014). Interestingly, the only interviewee to mention this was A3, who was the interviewee with the least experience in the OR. The interviewees also described how departments are not notified of environmentally related changes when they occur. A4 noted that changes occur quickly, and employees are expected to adapt. For example, the hospital began offering their scrub tops and bottoms in individual disposable plastic bags about a year ago. The reasoning behind this change was not shared with HCPs, and A4 continues to question the motives behind these decisions, labelling them as unnecessary and problematic changes. A2 stated that when it comes to disposal and reprocessing, "someone takes [the dirty item] away; it gets cleaned and appears again." This indicates a dissociation from waste at the HCP level.

A4 indicated that nurses are more in tune to the waste generated in surgery because they are the ones unwrapping and prepping materials and equipment throughout the procedure. Additionally, the provision of patient care, which is also done by nurses, involves waste generation as well, such as changing bandages or placing IVs. Surgeons and anesthesiologists were described as being more focused on their own niches and tasks. It is interesting to note the intersection of gender, profession and waste here. Over 90% of nurses in Canada are female (Canadian Institute for Health Information, 2018). Additionally, females in healthcare tend to be associated with patient care (Waugaman & Lohrer, 2000). In terms of municipal or household waste, women are more likely to be involved with recycling activities than men (Sidique et al., 2010). Societal roles that have been traditionally attributed to women, such as food provisioner, frontline primary healthcare provider and cleaner (Buckingham et al., 2005) have inherently placed responsibility for waste management onto women. This reflects the notion that women have always been held more accountable for waste and implies that traditional gender roles have expanded from the homestead to the workplace. Therefore, it is unsurprising that the interviewees described nurses as being more in tune to the waste generated and responsible for ensuring the accurate sorting of recyclable materials in the OR. They were also described by A5 as being more receptive to environmentally-related changes and often, the group pushing for the implementation of improved recycling streams.

Observational Analysis

My supervisor and I had the opportunity to observe a surgical procedure through observational analysis. Observational analysis is a fairly uncommon opportunity in research, and I extend great thanks to the staff at KGH for allowing us to observe a procedure. The procedure observed was a heart valve replacement and a coronary bypass graft on a 75-year-old male. We observed that sterility begins outside the OR. Prior to entering, we received our scrub tops and bottoms in individual plastic bags, just as A4 had described in the interviews. These bags were discarded into specified garbage bins in the locker room. As we entered the OR, the scrub and circulating nurses were arranging instruments on equipment tables, opening relevant tools and separating the paper and plastic backings for recycling. Two recycling bins were located in the far corner of the OR, near the supply storage. There were also several general waste garbage bags and several biohazardous bags ready. The scrub nurse stated that most of the waste is generated right at the beginning of the procedure as things are being opened and prepared, and as surgeons gain access to the site of operation, which aligns with the literature (Kagoma et al., 2012; Shinn et al., 2016).

In terms of anesthetics, the patient could not be administered the standard gases, such as desflurane or sevoflurane, due to a condition called malignant hyperthermia. This condition is characterized by hyperthermia, muscle rigidity and hyperkalemia (elevated potassium) when given the standard anesthetic gases and can be life-threatening (Litman et al., 2018). As such, the patient was given propofol instead. Propofol is an alternative anesthetic induction agent that, when used as appropriate in a clinical setting, can reduce greenhouse gas emissions by 28% (Thiel et al., 2018). As the surgery commenced, the circulating nurse was closest to the recycling bins and was supplying the scrub nurse with equipment throughout the procedure. They were, understandably, more focused on ensuring the scrub nurse was prepared at all times rather than focusing on proper recycling. Additionally, the recycling bins were quite full by this point as well. When an item in blue sterile wrap (BSW) was opened, the item was handed to the scrub nurse and the BSW was thrown away in the general waste bags. The number of towels used was tracked through the use of bag counters, which have slots for a certain number of towels. Once all the slots were filled, the bag counter was rolled up and placed in the biohazardous bag. Over a dozen bag counters were used throughout the five-hour procedure.

Sterility was critical throughout the entire procedure. In addition to donning personal protective equipment, such as shoe covers, caps and face masks, we were also instructed to maintain a certain distance from the equipment tables, to prevent contact and contamination of the sterile field. Waste is generated in the process of creating and maintaining a sterile environment. For example, a floor mat had to be moved at one point to wheel a piece of equipment closer to where the anesthesiologists needed it. For this to be done, the circulating nurse donned a new glove, moved the mat, then discarded the glove. Furthermore, an instrument requested by the scrub nurse was acquired by the circulating nurse, only for them to realize the sleeve was not sealed, and the item could not be used. The item was thrown away because it was not considered sterile, and a new item was requested. The circulating nurse mentioned this was common.

I was shown the excised aortic valve in a plastic specimen cup. The circulating nurse said that it would be sent to pathology to confirm that the valve was calcified, and it would then be incinerated. Cleanup of the OR and setup for the next procedure occur simultaneously. This includes wiping down the OR table, blood pressure cuff and anesthesia carts. Three biohazardous bags were filled with the majority of the items used, including the perfusion tubing, valve insertion equipment, large plastic containers filled with suction fluid, plastic basins, sponges and towels. Additionally, most of the valve replacement equipment, including the tools used to load the valve and insert it into the heart, were thrown away. Three to four industrial sized garbage bags were filled with general waste, including some items that could have been reprocessed had the recycling bins not been filled to capacity earlier in the procedure. All the garbage bags were taken into the hall and placed into a large bin to be wheeled away. A large metal box that resembled a fridge was wheeled into the OR. Everything that was scheduled to be reprocessed was placed into large metal bins on the shelves of the fridge. This was comprised mostly of the metal items, such as the saw, retractor and all the clamps. Additionally, the scope was also sent for reprocessing on a tray with a reprocessing checklist for the cleaning crew to follow to ensure the device was thoroughly cleaned.

In both observational analysis and interviews, everyone was aware of the volume of waste and that it was problematic. One person even referred to the OR as "waste central." It is worth noting that these HCPs were aware of our project and thus there is a chance they were more diligent with their recycling than usual. OR waste is arguably one of the most justifiable forms of waste that exists because it is created in the process of saving a life. This may be due to the fact that many Canadians view the risk associated with medicine and hospitals to be low, reflecting a sense of trust in these institutions (Krewski et al., 1995). Though outsiders may justify it, the same cannot be said for HCPs. There appears to be some internalized guilt and shame among HCPs in the OR, often referring to the volume of waste as "unbelievable" and "so wrong." Any further reductions in waste could end up causing undue harm, which goes against the Hippocratic Oath. Even when confronted with the aforementioned justification for this type of waste, many HCPs did not agree with it and expressed frustration over not having the power to enact meaningful change outside of what has already been done without increasing the risk to the patient. Surgeon-led initiatives tend to be most effective for implementing change in a hospital setting (Allen et al., 2003). This is in stark contrast to the fact that the scrub and circulating nurses did the sorting and recycling.

Conclusions

Hospital operating rooms generate a large volume of waste. Much of this waste is necessary for adequate functioning of the operating room. Therefore, in providing an expected standard of care and being prepared for emergency situations, waste will always be generated. Though this issue is prevalent and concerning, it is important to consider the implications of attempting to fully mitigate waste generation in an operating room. Significant reductions in waste could come at the expense of the patient or the healthcare worker. It is more critical that surgeons and nurses have access to as many supplies and equipment they deem necessary to provide appropriate care, making waste a low-priority issue. Every regulation in place serves a purpose and stems from very legitimate concerns surrounding infection, sterility, hygiene and efficacy. The integration of these components makes the issue more complex than anticipated. These concerns are exacerbated by a lack of data on adverse events from reprocessed devices and the designation of devices as single use. Therefore, the waste hierarchy is altered to accommodate for sterility, infection control and quality of care.

Operating rooms have a restricted capacity to change; the waste hierarchy can only focus on reuse and recycling to a certain extent. This restricted response prevents significant movements up the hierarchy, as safety and hygiene remain uncompromised. Reuse, rethink and redesign of supply chains are not as appropriate here as they are in other industries or institutions, presenting an interesting situation where operating rooms would not benefit from more extensive reuse and recycling circuits. The issue lies in implementing policy that affects change in a positive way while maintaining safety. This renders reusability initiatives and any higher positions on the waste hierarchy less effective than in other institutions. It is important to note that, at the time of completion of this thesis, the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pandemic has compromised healthcare standards. A limited supply of personal protective equipment for healthcare providers and sanitation workers has resulted in reuse of items such as sterile masks that would normally be discarded during care of patients with a contagious disease.

Because waste is not a prioritized topic in hospital operating rooms, it is recommended that future initiatives focus on safely reducing waste as much as possible. However, this must proceed with extreme caution and observation at each step to ensure that any initiatives are not resulting in adverse effects. Hospitals should attempt to convert as many aspects of their supply chain as possible to ones that focus on redesign of current systems. However, in places such as the OR, a focus on recycling should be more prevalent. Additionally, future work should focus on comparing the infection rates of reusable items and their disposable counterparts. Potential recommendations for future use involve a take-back program, where manufacturers can take back their packaging and reusable items such as plastics or cardboard boxes, to introduce methods of distribution that better align with the top of the hierarchy. This can introduce a new facet of reusability to hospital supply chains while also maintaining the standard of care. Additionally, a "just-in-time" approach for non-emergency supplies can reduce the number of items opened and unused. However, I noted this system is already in place between the scrub nurse and the other OR nurses in observational analysis. This approach could be effective if in combination with other approaches to reduce OR waste.

Overall, operating room waste remains a concerning and prevalent issue with respect to environmental sustainability. Sterility and infection control are crucial to maintaining a safe and efficient operating room. The need to safely dispose of infectious or biohazardous waste is met through incineration, which has many negative environmental effects. Recycling and reusability do exist in operating rooms and their supply chains, but they are limited in their capacity. Any further expansions to reuse may increase the risk of adverse events and pose risks to both patients and healthcare workers. Future goals should focus on limiting the volume of waste produced to minimize the environmental impacts of healthcare, while also ensuring that critical elements of surgery, such as sterility, are maintained.

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Appendix A: Figures

Figure 1: The Zero Waste Hierarchy

Figure 1: The waste hierarchy, which shows various management options for waste. The most preferable options are at the top. Hospitals may be an institution where one can only go so high. Photo from the Zero Waste Alliance Canada website (https://zerowastecanada.ca/zero-waste-hierarchy/)

Figure 2: The Linear Hospital Supply Chain

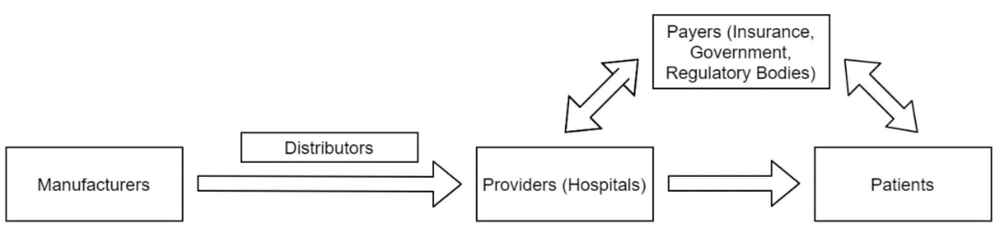

Figure 2: Traditional linear hospital supply chain. Figure adapted from "The Impact of Digitization on Healthcare," by Phalange, R., (2017, November 14). Retrieved from: https://digital.hbs.edu/platform-rctom/submission/impact-of-digitalization-on-healthcare/

Figure 3: Map of KHSC – KGH Site

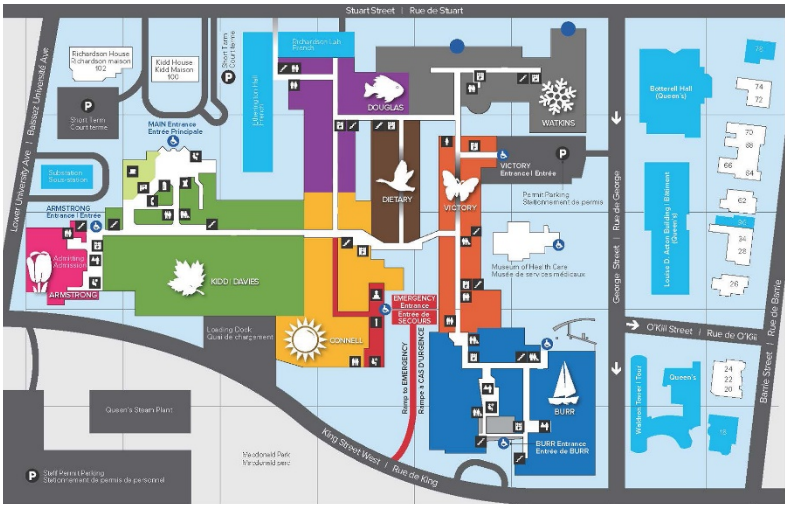

Figure 1: Map of Kingston General Hospital (KGH), which spans 1.228 million square feet and is fully affiliated with Queen's University as a teaching hospital. Photo from Kingston Health Sciences Centre (https://kingstonhsc.ca/file/kgh-mapjpg)

Appendix B: Tables

Table 1: Participant Occupations

Table 1: Table showing the general occupation of the participants in the study and their primary site of operation within KHSC. Note that "A1" refers to Anonymous 1, "A2" to Anonymous 2, and so on.

Participant Identification Code	**Role or Occupation**	**Site Within KHSC**
A1	Anesthesiologist	KGH
A2	Anesthesiologist	KGH
A3	Medical Student (Queen's University School of Medicine)	KGH
A4	Operating room nurse (retired)	KGH
A5	Operating room nurse (current)	HDH

Table 2: Primary Themes from Healthcare Professional Interviews and Relevant Subthemes

Table 2: Table depicting the relevant major themes and common subthemes from interviews with healthcare providers at KHSC.

Primary Themes	**Relevant Subthemes**
Volume of Waste Created	a. Baseline waste per procedure b. Complexity of situation; various factors involved c. Majority of items are disposable & thrown out d. Waste anesthetic gases and emissions
Infection Control and Safety	a. Human contact as catalyst for disposal b. Various sterilization techniques and infection control methods (eg. PPE) c. Risks associated with reuse d. Fear of resulting infections e. Cleanliness
Cost	a. Limiting factor b. Cost of carbon emissions c. Cost of recycling and repurposing vs disposal
Priority of environmental issues	a. Safety and standard of care b. Norms and standardized procedures c. High interest among some groups, but low priority issue overall d. Apathy
Green Infrastructure	a. Lack of recycling infrastructure b. Lack of integration between departments c. Limited engagement of members d. Poor direction e. Feeling out of the loop
Responsibility for Waste	a. Corporations and quality control b. Dissociation from waste c. Conscious of contributions d. Role and responsibility of nurses e. Multiple stakeholders

Appendix C: Semi-Structured Interview Format

The following questions were used as a guide when speaking with participants of the study.

- Has waste or waste management ever been at the forefront of environmental or green discussions in the hospital?
- What kinds of waste are made in operating rooms at KHSC? In your opinion, are there any items that produce a particularly large volume of waste?
- Is the amount of waste dependent on the type of surgery?
- Which items are designated as single-use? Which can be sterilized or reprocessed to be reused?
- Has KHSC done anything, that you are aware of, to make the operating rooms greener?
- What happens to items from pre-packaged surgical kits that are not used during an operation?
- Are patients notified if a procedure is done with a reprocessed item?
- Has reusing items had an impact on the standard of care or the quality of treatment?
- Is there a difference in quality between a disposable/single-use device and a reusable device?
- Are you aware of any additional green policies planned for the future? If so, what are they (to the best of your knowledge)?