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Original Research

An Audit of Recyclable and Contaminated Waste From Invasive Cardiac Procedures

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ABSTRACT

Background: Waste generation from health care facilities is significant. Quantifying and minimizing waste from cardiac catheterization laboratories (CCL) and cardiac operating theaters (COT) has received little attention in an effort to lessen its environmental impact. The purpose of this study was to assess the quantity of contaminated and recyclable waste resulting from invasive cardiac procedures.

Methods: To assess the potential impact of recycling, quantify the amount of waste that ends up in landfills, and determine how much contaminated material needs to be managed, we audited the amount of hazardous and nonhazardous medical waste produced from CCL and COT in our cardiac center.

Results: Every year, our cardiac center performs 350 cardiac surgeries and 2900 interventional cases. We estimated that annually 11,000 kg of recyclable waste and 30,000 kg of contaminated waste are generated. If this is extrapolated to all the CCL and COT globally, the anticipated annual waste production from invasive cardiac procedures is 150 million kg (150,000 metric tons).

Conclusions: Cardiologists and cardiac surgeons must embrace sustainability as a critical need and join the effort to prevent global warming. One tiny action that each of us can take to improve the environment is to try to decrease waste while encouraging recycling.

Introduction

Health care globally produces 2 gigatons (2×10^9 tons) of carbon dioxide equivalent (CO_2e) greenhouse gases (GHG), with a predicted 3-fold increase in this environmental footprint by 2050.[1] In addition, land, water, and air pollution from waste landfills and emissions from hazardous medical waste (HMW) treatment lead to climate change, chronic diseases, and premature deaths. An estimated 3 million disability-adjusted life-years are lost because of health care's GHG emissions.[2]

Health care facilities (HCF) produce a substantial amount of waste, that is second only to the food industry.[3] In the United States, 5.9 million tons of waste are generated annually from HCF.[4] Energy and resource-intensive departments, such as radiology suites, operating rooms, and cardiac catheterization laboratories (CCL), leave a substantial carbon footprint, including medical waste (MW).[4,5] Limiting material consumption and waste generation is a critical step toward CCL sustainability, and there are quality initiatives proposed to audit and track waste management as an unmet key performance indicator.

Scare attention has been given to quantifying and reducing waste from CCL and cardiac operating theaters (COT) to help lower the environmental footprint.[4]

We sought to audit the amount of nonhazardous medical waste (NHMW) and HMW generated from the CCL and COT, identify the potential impact of recycling, and measure the volume of waste that goes to landfills and the contaminated material that will require waste management from Mohammed Bin Khalifa Specialist Cardiac Centre, a tertiary cardiac care center in the Kingdom of Bahrain.

"Go Green" protocol implementation

We set out to quantify the amount of NHMW and HMW in our CCL and COT. The NHMW contained potentially recyclable material that comprised uncontaminated paper (mainly from package inserts), plastic

Abbreviations: CABG, coronary artery bypass graft surgery; CCL, cardiac catheterization laboratories; CO_2e, carbon dioxide equivalent; COT, cardiac operating theaters; CTO, chronic total occlusion; GHG, greenhouse gases; HCF, health care facilities; HMW, hazardous medical waste; NHMW, nonhazardous medical waste; PCI, percutaneous coronary interventions.

Keywords: carbon footprint; cardiac surgery; catheterization laboratory; greenhouse gas emissions; recycling; sustainability; waste.

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packing, and cardboard boxes (the latter from balloon catheters, stents, diagnostic catheters, guides, and structural devices) that were collected during the procedure. This waste was disposed of in landfills with no recycling program available in our center. HMW included all the contaminated materials in contact with bodily fluids and blood and single-use items (drapes, gowns, gloves, syringes, manifolds, catheters and guides, angioplasty balloons, electrophysiology [EP] diagnostic and ablation catheters, wires, disposable towels, and gauze, etc) used during the procedure that required special waste management. The nursing staff were instructed to check the final contents in the designated "NHMW green bags" and avoid all contaminated contents. The HMW was collected in the "contaminated yellow bags." A similar "Go Green Protocol" was observed in the COT. This indicated that every procedural case would have 2 categories of waste, weighed in kilograms: uncontaminated, potentially recyclable waste (green bags) and contaminated hazardous waste (yellow bags), each labeled with respect to the procedure performed. We evaluated all the invasive cardiac procedures performed in our center starting with a diagnostic angiogram, percutaneous coronary interventions (PCI), to more complex PCI involving intravascular imaging, plaque modification techniques, and chronic total occlusion PCI. Structural interventions, both adult and pediatric, as well as electrophysiological procedures, were evaluated. Finally, coronary artery bypass graft surgery (CABG), with and without valve repair or replacement, was also included. Data from 248 elective, consecutive cases were collected over a 2-month period, and average weights from at least 6 cases for each designated procedure were tabulated.

Recyclable and contaminated waste from cardiac procedures

NHMW and HMW from various cardiac procedures are shown in Table 1. Diagnostic coronary angiography and right heart studies (RHS) produced the least amount of waste. A standard PCI produces an average of 7 kg of waste. Complex PCI, including chronic total occlusion interventions and rotational atherectomy, produced double the waste. Structural interventions produced even higher waste volumes as would be expected from the increasing procedural complexity, producing triple the waste of a standard PCI. Finally, CABG, with valve replacement or repair, produced the highest amount of waste out of all invasive cardiac procedures amounting to an average of 35 kg per case. As observed, the amount of waste generated increases with procedural complexity and is dictated by patient characteristics and comorbidities. Surgical procedures predictably produced more waste, especially HMW, with a 3- to 4-fold increase compared to CCL waste. Combined CABG and valve surgery produced the highest amount of HMW (30 kg) and NHMW (9 kg) among all the procedures. TAVR produced half the HMW compared to isolated surgical aortic valve replacement (12 kg vs 24 kg).

NHMW or potentially recyclable waste, is 25% of the total waste produced per case across all categories. We discovered that most of the NHMW, comprising paper, cardboard boxes, and selected plastics, can be easily recycled by waste management companies if initially sorted correctly in our hospital.

Two thousand nine hundred interventional cases and 350 surgical procedures are performed annually in our center. We estimated that 11,000 kg of potentially recyclable waste and 30,000 kg of contaminated waste are produced every year. All our NHMW is disposed of in landfills with the general hospital waste with no recycling program available. All our HMW gets shredded, autoclaved, and then disposed of in landfills, with incineration in special cases.

Extrapolating this to all CCL and COT worldwide (approximately 5 million CCL procedures, including 250,000 TAVR, and 1.3 million COT procedures annually)[6] an estimated 150 million kg, or 150,000 metric tons, of waste is produced annually. In context, this is equivalent to the weight of 15 Eiffel Towers. A quarter of this waste is potentially recyclable (see Central Illustration).

Table 1. Recyclable and contaminated waste per procedure.

Procedure	No. of procedures	Recyclable waste, kg	Contaminated waste, kg
Coronary angiogram	40	1.4	4.2
Coronary angiogram + RHS	6	1.4	4.4
PCI	49	2.2	5.5
PCI + intravascular imaging	31	3.9	6.9
PCI + FFR	6	2.4	5.3
PCI + rotablation	6	3.7	8.7
CTO PCI	6	3.8	8.8
Peripheral intervention	6	2	6.9
PPM	11	2.3	4.6
EPS ablation	6	3.5	6.3
Pediatric structural[a]	8	2.6	6.8
TAVR	6	5.6	12.9
TMVR/TTVR	7	8.9	14.7
CABG surgery	20	7.1	26.9
Valve surgery	30	5.8	23.7
CABG + valve surgery	10	9.4	31

CABG, coronary artery bypass graft; CTO, chronic total occlusion; EPS, electrophysiology study; FFR, fractional flow reserve; PCI, percutaneous coronary interventions; PPM, permanent pacemaker implantation; RHS, right heart study; TAVR, transcatheter aortic valve replacement; TMVR, transcatheter mitral valve replacement; TTVR, transcatheter tricuspid valve replacement.

[a] Pediatric cases including atrial septal defect and patent ductus arteriosus closures and percutaneous pulmonic valve implantation.

Discussion

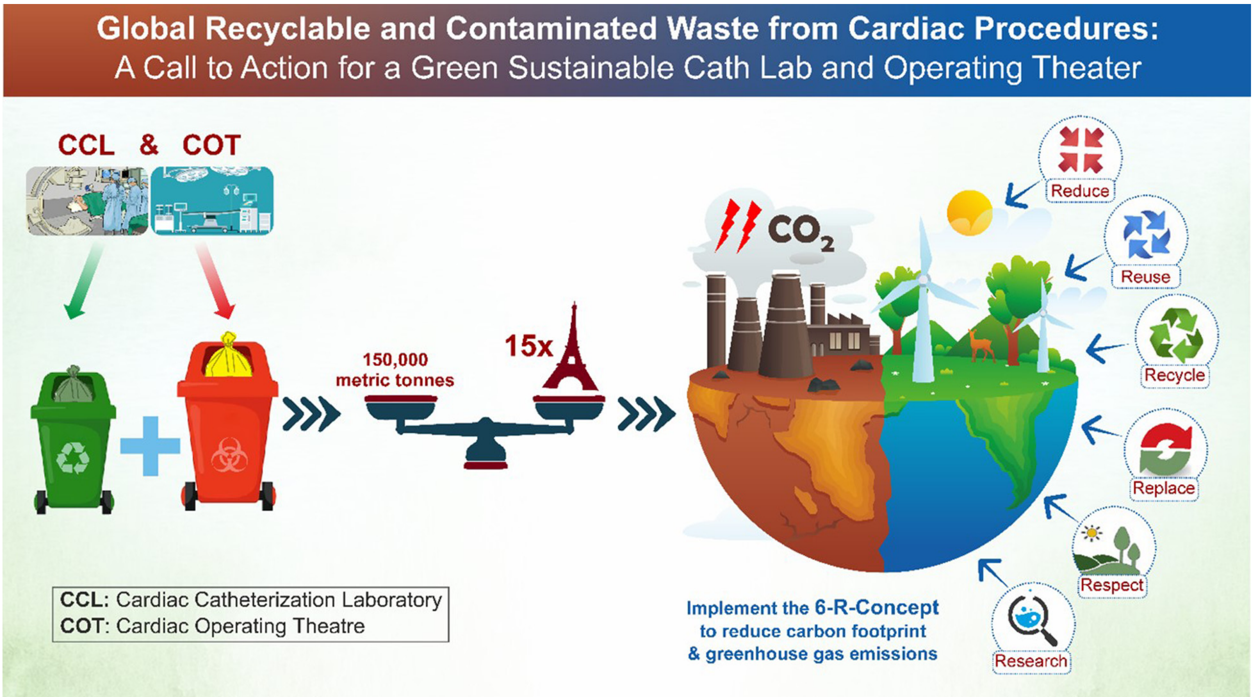
Medical waste is defined as any waste or by-product from HCF that was used for diagnosis, treatment, or immunization of patients.[7] One-fifth of MW is classified as hazardous due to infective, toxic, or radioactive contamination,[7,8] whereas the remaining 80% is nonhazardous and treated similarly to municipal waste. High-income countries usually produce 0.5 kg per hospital bed of HMW.[7] Of the MW, 20% to 30% is plastics, with most, but not all, being potentially recyclable.

Few studies have attempted to quantify the amount of waste that is produced from cardiac procedures. Doshi et al[4] quantified the amount of recyclable waste and noted higher recyclable waste with PCI (1.4 kg) compared to the diagnostic right heart study (0.7 kg). A Stanford team noted 15% recyclable waste per procedure, amounting to 12 tons of material diverted from landfills annually.[3]

Medical waste management employs steps where MW generated is handled from its production until its safe disposal. All invasive cardiac procedures will produce hazardous, contaminated waste that will require treatment with either incineration or autoclaving. HMW incineration releases 1074 kg CO_2e per ton of waste, releasing heavy metals, dioxins, acid gases, and organic compounds.[7,8] There is a carbon footprint associated with the transport and treatment of hazardous waste itself. Three percent of global GHG emissions are related to health care waste management.[1] The NHMW is treated like municipal waste and usually finds its way to landfills for disposal. If no recycling is performed, the opportunity to decrease the growth of landfills and its impact on the environment is lost.

An important step in recycling is waste segregation at the source, with the sorting of paper, plastics, and cardboard into well-demarcated individual bags, with buy-in from the CCL and COT staff. Recycling helps to divert waste from landfills with maximal reuse of materials as part of a circular economy. This has shown itself to be cost-effective and may garner self-sustaining profits.[9]

The pillars of sustainability are "reduce, reuse and recycle," and form the foundational basis for greener invasive cardiac procedures:



Central Illustration.
Global waste production from cardiac procedures (the Eiffel Tower weighs 10,100 metric tons).

1. Reduce: reducing material consumption via "lean" cath laboratory and surgical kits devoid of redundant or unused materials. "Open-only-when-required" materials to avoid wastage of single-use items. Auditing case inventory with preset targets. Finally, monitoring expiry dates of items with preferred utilization before product expiration.
2. Reuse: reutilization of sterilized medical equipment deemed safe by infection control. This excludes most single-use items that usually form HMW. Plastic bowls, surgical metallic equipment, and BP cuffs/pulse oximeters are commonly resterilized and reused. Reprocessing of some single-use devices is being performed in some countries.
3. Recycle: recycling of plastics, paper, cardboard, and metals is essential to prevent landfill disposal. Segregation into different MW categories in separate designated bins or bags is essential to streamline recycling. The goal is for 100% recycling of NHMW.

Recycling, defined as destroying a product, separating its components, and using them to make new products,[10] may be a financially and environmentally viable activity if it is carried out efficiently and in compliance with current regulations.[9] The following variables may have an impact on the cost of recycling in the CCL and COT:

1. Initial setup costs: implementing a recycling program may require an initial investment in equipment, bins, signage, and training for staff. These setup costs can vary depending on the size of the facility and the scope of the recycling program.
2. Sorting and collection: proper sorting or segregation and collection of recyclable materials can incur additional labor costs. Staff may need to be trained in how to separate recyclable materials from general waste and ensure that materials are disposed of correctly.
3. Recycling services: some HCF may choose to work with third-party recycling services or vendors to handle the collection, processing, and recycling of materials. These services may charge fees based on the volume of waste generated or the specific materials being recycled.
4. Transportation and processing costs: transporting recyclable materials to recycling facilities and the costs involved in recycling can impact the overall expense incurred by the institution. These costs can vary based on the distance to recycling facilities and the specific recycling processes used.
5. Regulatory compliance: compliance with regulations governing the handling and disposal of MW, including recycling, may involve additional costs related to reporting, documentation, and monitoring to ensure that recycling practices meet legal requirements.
6. Potential savings: although there are costs associated with implementing a recycling program in the cath laboratory, there may also be potential cost savings in terms of reduced waste disposal fees and other efficiency gains that result from recycling efforts.
   Overall, the cost of recycling in a cath laboratory is a complex issue that depends on various factors specific to the health care facility and its recycling practices. By carefully evaluating the costs and benefits of recycling, HCF can make informed decisions about implementing sustainable waste management practices.

Reprocessing, defined as reusing single-use medical devices after they are cleaned, tested, and resterilized,[10] has previously existed in some countries across the globe but without rules or regulations to ensure safety and quality. In recent years, the Food and Drug Administration and the European Union have allowed and set rules for reprocessing single-use devices. Reprocessing is allowed in Belgium, Germany, Spain, and the Netherlands, whereas it is illegal in other European countries.[10] Reprocessors, either internally in the same hospital or by external third parties, should demonstrate that their products are safe, effective, and of high quality and should remove all concerns about potential health risks. Reprocessed devices lower costs, reduce waste, save raw materials, and decrease the carbon footprint. Out of all the reused devices, EP diagnostic and ablation catheters appear to be the most appropriate as they maintain their efficacy for up to 5 reuses. Precious metals (platinum and gold) from catheter electrodes should be recycled when the catheter cannot be reprocessed. Copper from cables and patches can also be recycled. Other devices, including cardiovascular implantable electronic devices, are approved for use only in some countries where patients may be unable to afford a device in the first place. India has approved the reuse of explanted cardiovascular implantable electronic devices if they have no malfunction and a remaining battery life of at least 5 years.[10,11] Diagnostic and guide catheters for coronary interventions have been reused in some countries, although their performance may be affected with time. Balloon catheters are not recommended for reuse because of altered mechanics and issues with sterilization.[11] In summary, reprocessing of single-use devices, especially from the EP domain, needs stringent regulatory standards with collaboration between physicians, policymakers, and manufacturers to mitigate the environmental carbon footprint and foster sustainable practices.

Even contaminated waste can be converted to municipal waste if treated correctly. Heart bypass circuits have been successfully rinsed with normal saline to salvage 240 mL of blood for transfusion and convert HMW to solid municipal waste that will not require special waste treatment. This diverts 7.5 kg of plastic tubing to landfills, avoiding the carbon footprint of incineration.[2] CABG itself produces 124 to 505 kg CO_2e GHG per case, equivalent to the environmental footprint of a 10-day routine consumption of an individual in a European country.[9] Any attempt to decrease that footprint is commendable.

Reducing waste production in the CCL and COT can be achieved through the implementation of the above strategies to reinforce recycling and reprocessing of single-use devices. Waste should be properly sorted into categories such as general, recyclable, and reusable to help ensure that materials are disposed of appropriately, recycled, or repurposed. Additionally, minimizing overstocking through inventory management helps lessen the chance of expired supplies, which can result in waste. Furthermore, a culture of accountability and understanding can be promoted through sustainable procurement, which involves selecting suppliers who emphasize sustainable materials and teaching employees on these topics. Reducing waste may also be achieved by working with manufacturers and vendors to provide items with minimum or reduced packaging. Lastly, moving to electronic records may help decrease paper waste related to patient documentation and reporting.[5] Undertaking waste audits to identify areas of waste production and guide focused initiatives for reduction can also prove useful. By putting these measures in place, waste generation may be decreased overall, and invasive cardiac procedures can become more sustainable.

Replacing invasive coronary angiography with ischemia testing or CT angiography will also decrease waste production. Up to one-third of our interventional cases are diagnostic angiograms, leaving room for improvement.

Research in health care sustainability, especially as it pertains to GHG emissions, waste management, and recycling, is essential as we strive to respect and protect our environment.

The main limitation of our study is the fact that weight-based waste assessment reflects only 1 facet of modern sustainability for several key reasons. First, different materials have varying impacts, and weight alone does not account for factors like recyclability, environmental toxicity, or resource intensity. Second, lightweight materials may take up significant space, leading to inefficiencies in waste management that weight alone does not capture (volume considerations). Furthermore, modern sustainability emphasizes the entire lifecycle of products, including production, use, and disposal. Weight assessments typically focus only on disposal weight, missing the impact of the carbon-intensive supply chain and fossil fuel consumption. Lastly, waste comprises various materials, both hazardous and nonhazardous, with different environmental implications; hence, a weight-based approach may oversimplify these differences, requiring different management strategies. We believe that incorporating a more holistic approach that includes environmental impact assessments, lifecycle analyses, and a focus on reducing waste generation would provide a more accurate reflection of sustainability.

Cardiac catheterization laboratory sustainability awareness should start during interventional fellowship training as an important concept that is implicitly learned when you practice in a "green cath lab." Formal training would be an added boon, similar to training in radiation safety, that is distinct from the knowledge and technical skills that all fellows acquire. Setting up a CCL "Green Team," comprised doctors, nurses, and waste management personnel, who should audit and implement greener practices, is an important first milestone. CCL sustainability should find a place in cardiology conferences, best practice guidelines, and interventional cardiology discussions. Sustainability quality metrics need to be determined and should be endorsed by interventional societies as a means to greener CCL services.[5] The GHG emissions of our practices need to be determined, as has been done for CABG and EP procedures,[9,10] with the goal of decreasing this carbon footprint. All scopes of GHG emissions, including the health care supply chain and fossil fuel consumption, should be factored into the overall environmental impact of our procedures. The Paris Agreement has undertaken to lower health care net emissions to 0 by 2050.[1] Our contribution at the CCL level would be to decrease material consumption, reuse and reprocess devices, recycle 100% of nonhazardous waste, and conserve energy and water. Waste management needs to be a central tenet of any sustainability plan. To help in this endeavor, the WHO has developed training modules in best practices of health care waste management, from identification to classification, and to safe disposal.[8] A similar path should be taken by our cardiovascular surgical colleagues.

Conclusion

We attempted to quantify both recyclable and contaminated waste over a wide range of cardiac procedures. The more complex the cardiac intervention is, the more the waste that is produced. Extrapolating this to the global stage, 150 million kgs of estimated waste is produced annually from invasive cardiac procedures. A quarter of this waste is potentially recyclable, necessitating appropriate recycling and waste management strategies.

Sustainability is a vital necessity that all cardiologists and cardiac surgeons need to heed and join in the race to save the planet from global warming. Striving to reduce waste and help recycle is 1 small step that we can all take to help our environment.

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Declaration of competing interest

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Ethics statement and patient consent

This manuscript does not report on patients or patient data; hence, patient consent was not required.

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