Environmental Impacts of Kidney Replacement Therapies: A Comparative Lifecycle Assessment

Saba Saleem, Caroline Stigant, Tasleem Rajan, Kasun Hewage, Rehan Sadiq, Andrea J. MacNeill, and Christopher Nguan

Rationale & Objective: Health care delivery is associated with considerable emissions of greenhouse gases and other pollutants. Although the relative health and economic impacts of kidney replacement therapies (KRTs) have been examined, their comparative environmental impacts have been poorly described. This study sought to characterize these impacts, comparing them across types of KRT.

Study Design: A comparative lifecycle assessment (LCA).

Setting & Participants: Data collection implemented at Vancouver General Hospital in Vancouver, British Columbia, Canada.

Exposure: Three KRTs: deceased-donor kidney transplant (KT), automated/cycler peritoneal dialysis (PD), or in-center hemodialysis (HD).

Outcome: Environmental impacts of KRTs over 1 year were evaluated using the World ReCiPe (H) 2016 method.

Analytical Approach: Lifecycle inventory results were transformed into 3 end-point and 18 midpoint environmental impact categories including climate change, air pollution, human toxicity, and water depletion.

Results: Across the majority of environmental impact categories, including climate change, air pollution, human toxicity, and water depletion, HD had the highest environmental impact and KT the lowest. The climate impact from a patient receiving HD was 74% and 46% more than from patients receiving KT and PD, respectively. Similarly, HD accounted for 65% of total air pollution impacts, 54% of human toxicity, and 44% of water depletion. The highest impact of PD was on water depletion (41%) and metal depletion (81%). KT demonstrated the lowest impact across all categories except terrestrial ecotoxicity. Within each therapy, patient and staff travel and consumables were the largest contributors to greenhouse gas emissions.

Limitations: Pharmaceuticals were excluded from this study because of a lack of publicly available data.

Conclusions: KT is the most environmentally preferred KRT. PD had fewer environmental impacts than HD. Understanding the relative environmental impacts of KRTs can help inform clinical decision-making in the management of kidney failure.

Visual Abstract online

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Climate change and pollution are contributing to dual epidemics of acute and chronic kidney diseases (CKDs).[1,2] CKD affects 850 million individuals worldwide[3] and is the third fastest growing cause of global mortality.[4] Most recent global estimates suggest that at least 3.9 million people with kidney failure are treated with a kidney replacement therapy (KRT),[5] which include kidney transplant (KT), hemodialysis (HD), and peritoneal dialysis (PD). The ability of health systems to deliver uninterrupted quality kidney care is threatened by climate risks that impact infrastructure and supply chains. Extreme weather events have already restricted patient access to HD[6] and necessitated innovative strategies to provide uninterrupted PD care.[7]

Delivery of KRTs is resource-intensive, and, with increasing recognition of the environmental impacts of perioperative care and dialysis therapies,[8,9] there is a need for rigorous environmental impact assessments to inform clinical decision-making and policy. There have been no direct comparisons between KRTs in a single region to date. Estimates of per-patient, per-year greenhouse gas (GHG) emissions from HD vary from 3.3 to 10.2 tons of carbon dioxide equivalents (tCO_2e).[9,10] GHG emissions from PD are described in a single-center study of continuous ambulatory PD that estimated per-patient, per-year emissions of 1.4 tCO_2e,[11] and a study of PD in Australia reported average per-patient, per-year emissions of 1.5-2.7 tCO_2e for continuous ambulatory PD and 2.4-4.5 tCO_2e for automated PD.[12] More recently, Garcia Sanchez et al, using previously published data, modeled PD emissions in more than 10 countries and reported per-annum continuous ambulatory PD and automated PD emissions ranging from 1.3 to 1.8 tCO_2e and from 4.3 to 5.5 tCO_2e, respectively.[13] This is the only study to date that has also estimated the GHG emissions of KT across different regions, reported as 0.3-2.2 tCO_2e per patient per year.[13]

Lifecycle assessment (LCA) is an internationally standardized approach that assesses a broad range of environmental impacts throughout the lifecycle of a product, process, or service, accounting for all energy and material inputs and outputs at each stage.[14] In the present study, we employ LCA to rigorously compare the environmental

PLAIN-LANGUAGE SUMMARY

The environmental impacts of health care are gaining attention, yet kidney care, and especially kidney replacement therapies (KRTs), have been underexamined. This study was inspired by growing concerns about the environmental consequences of KRTs like hemodialysis, peritoneal dialysis, and transplantation. We used environmental assessment tools to measure emissions and resource use across different KRTs in a clinical setting in Vancouver, Canada. We found that these therapies vary widely in their environmental impacts, with in-center hemodialysis having the greatest negative impact and kidney transplant the least impact. This study also explored the sources of these impacts and can inform health systems and health care policymakers regarding opportunities for more environmentally informed practices in kidney care.

performance of KRTs in one health region and to identify opportunities to develop sustainable kidney care delivery across all therapeutic strategies. This work aims to surface opportunities for changes in procurement, equipment use, disposal, and reuse or recycling to reduce the environmental footprint of prototypical KRTs and to enable review of systems-level resource deployment including consideration of environmental impacts.

Methods

Process-based LCAs were conducted according to international standards (ISO 14040 and 14044)[14] for the following KRTs: locally procured deceased-donor KT, in-center HD, and automated/cycler PD. These modalities are the most common KRTs in British Columbia, Canada (http://www.bcrenal.ca). The functional unit of comparison was defined as kidney replacement for 1 patient for 1 year. For KT, this included one transplant consisting of a deceased-donor nephrectomy procurement operation and recipient implant procedure with protocolized 1-year ambulatory follow-up. For HD, this comprised three 4-hour sessions weekly for a total of 156 sessions. For PD, 8 hours of cycler time and 12 L of solution over 365 treatment days were included. Only processes directly related to KRT delivery were included; medical complications including prolonged hospital stays were excluded. All relevant stages of KRTs, material flows, and processes are shown in the system boundary diagrams (Figs 1 and 2). A lifecycle approach was used, including raw material extraction, manufacturing, and transportation of supplies to the hospital or patient's home through the processes of therapy and waste disposal.

Lifecycle inventories were constructed for KRTs (Table S1). Data collection was specific to Vancouver General Hospital (VGH) in Vancouver, British Columbia. HD recipients receive in-center dialysis at VGH, and PD recipients are managed through a dialysis clinic. Inputs and outputs relating to the production and disposal of capital equipment including surgical infrastructure, anesthetic machines, the reverse osmosis (RO) unit, HD machines, and PD cyclers were excluded. Operative procedures for dialysis access, pharmaceuticals, and laboratory testing were also excluded. The transport of consumables from manufacturing to distribution sites was excluded because of unobtainable supply network data. All data were collected from primary sources under University of British Columbia Research Ethics Board study protocol (approval H22-02433).

Processes

KT

Transplant recipients are admitted to the hospital 12 hours before surgery and remain in the hospital for 5 days postoperatively, including 5 hours in the postanesthesia care unit. A base scenario was modeled in which organ transportation is excluded, with deceased-donor procurement and transplant operations taking place at the same hospital. This reflects common practice in British Columbia. Average operative times of 4 hours were used for procurement and implant procedures. Among a total of 28 posttransplant annual follow-up visits, 17 occur in person and 11 are conducted virtually. Only in-person ambulatory clinic appointments were included in the analysis.

PD

The automated PD prescription assumed 8 hours of cycler time on a Baxter Amia 98 machine with a 16-hour day dwell. Two 5-L bags of 1.5% glucose and a 2-L bag of 7.5% icodextrin solution are used. In-center training for PD recipients takes place over 4 hours per day for 5 days. Follow-up during the first year of therapy includes 3 in-person and 3 virtual visits. The latter were excluded from analysis.

HD

HD is carried out using Fresenius 5008s dialysis machines with Fx-1000-HDF dialyzers. Four-hour treatments use a 1-L bag of saline solution with 4.5 L of acid concentrate. Vascular access is assumed to be a mix of arteriovenous fistula (60%) and central venous catheter (40%) based on published global practice patterns.[15] The RO unit included is manufactured by Canadian Water Technologies (CWTROHDH2-806) with a 40% rejection rate, and water consumption was calculated based on flow rates of 0.5 L/min plus 40 minutes of machine rinsing before and after each session.

Parameters

Consumables Manufacture and Transport

Primary activity data were collected for all consumables used (Tables S1 and S2). Transportation distances from local distribution centers to VGH were estimated for KT and HD with mean one-way distances of 45 km and 17

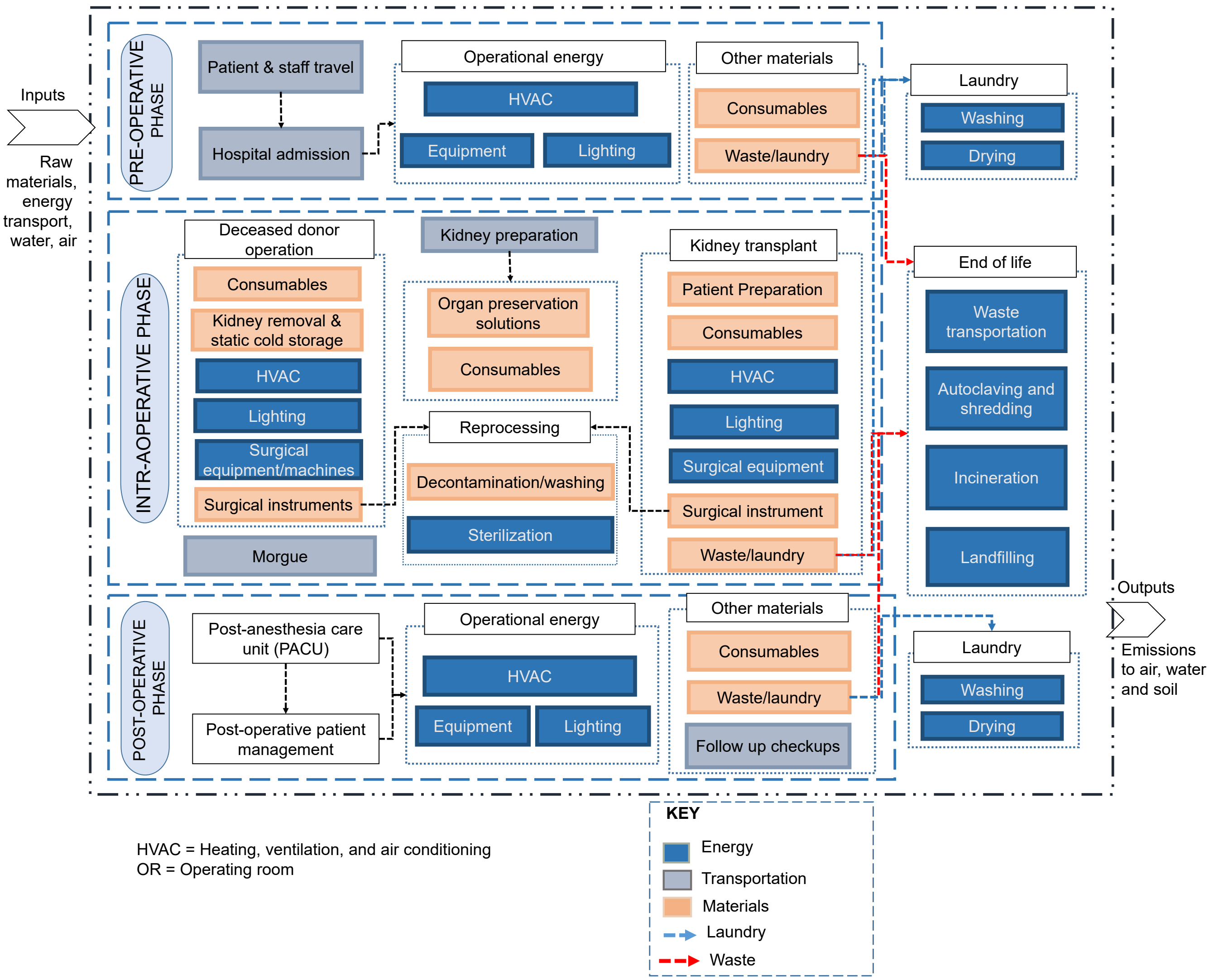

Figure 1. Illustration of the system boundary for a kidney transplant defines the included processes such as organ procurement, transplant, postoperative care, and related resource flows. Abbreviations: HVAC, heating, ventilation, and air conditioning.

km, respectively. For delivery of PD supplies, a mean distance of 930 km was used from the regional distribution center to patient homes based on geographic distribution data provided by the Provincial Renal Agency. Provenance of supplies was unable to be determined for all consumables; thus, transportation distances from manufacturers to distribution centers were excluded.

Patient and Staff Travel

Average one-way travel distances from patient homes to VGH were 46 km for KT, 9.5 km for HD, and 39 km for PD, based on provincial data. Average one-way staff travel was estimated to be 10 km.[16]

Energy Consumption

Thermal and electrical energy requirements of the operating rooms, dialysis facility, central sterilization department, and morgue were directly measured or calculated. Space heating, ventilation, and air conditioning requirements and electricity consumption from lighting were calculated using the VGH building management system, and electricity consumption from plug loads was measured using Kill-a-Watt meters.

Laundry

Laundry from VGH is processed by a third-party service provider, K-Bro Linen Systems, at a local facility powered by natural gas. Thermal and electrical energy requirements were provided by K-Bro based on a recent energy audit (Table S1).

Waste Management

In-hospital KRTs generate biohazardous and municipal solid waste. Waste from VGH (for KT and HD processes) is incinerated at a waste-to-energy facility and the ash is landfilled, with travel distances of 17 km and 28 km,

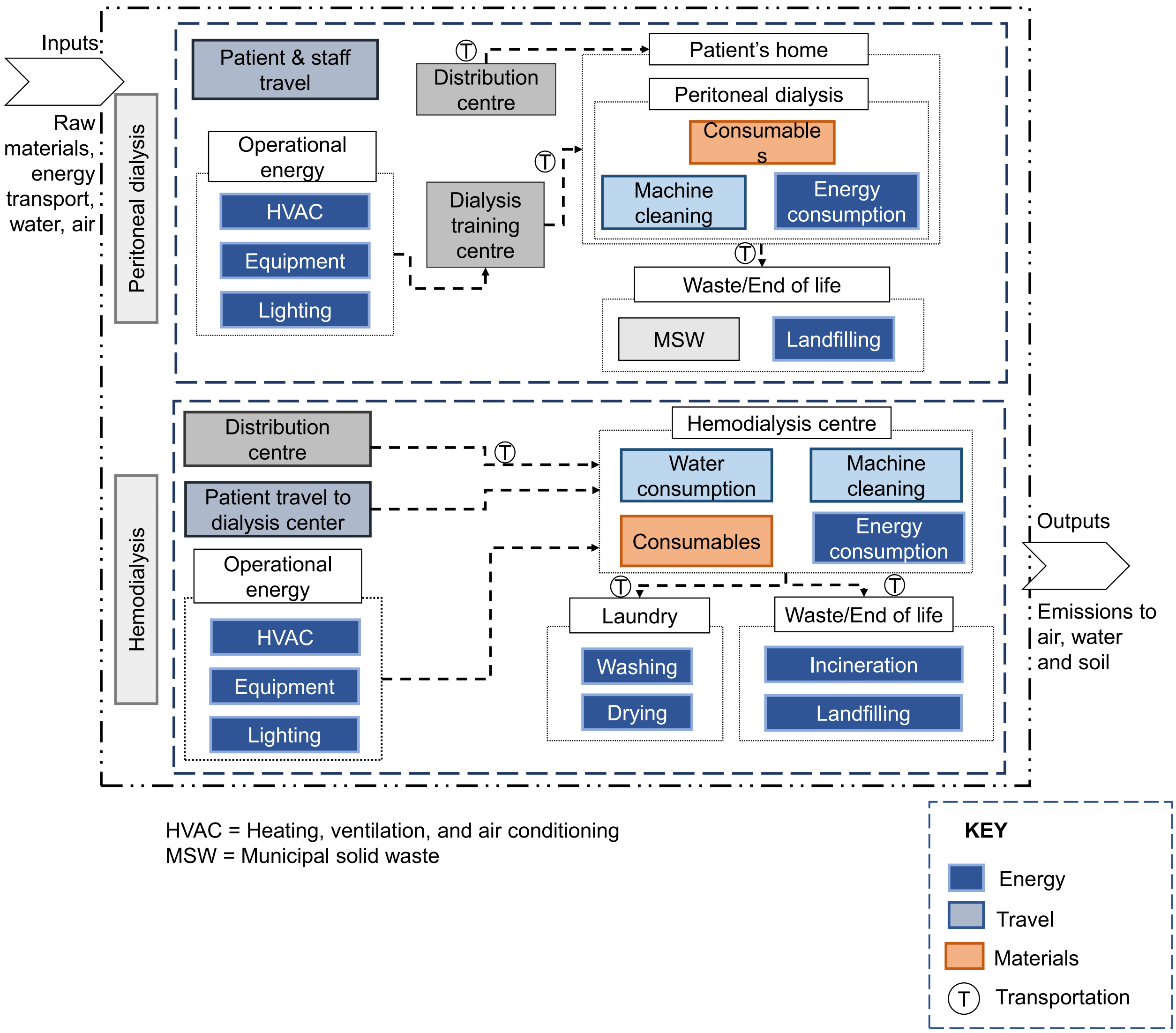

Figure 2. System boundary for hemodialysis and peritoneal dialysis. The figure shows what is included in the system for hemodialysis and peritoneal dialysis, covering resource use, treatment processes, and waste generation. Abbreviations: HVAC, heating, ventilation, and air conditioning; MSW, municipal solid waste.

respectively. Biohazardous waste is transported 63 km to a health care waste management facility for autoclaving and shredding and a further 548 km to a landfill. For PD, an average one-way distance of 27 km from patient home to landfill site was estimated using a weighted average method. The total number of round trips per year required to dispose of the estimated annual volume of each waste type was calculated and aggregated based on vehicle capacity.

Lifecycle Impact Assessment

Lifecycle impact assessments of selected KRTs were performed using SimaPro (version 8.3.0.0).[17] Background data for materials, chemicals, and modes of transportation were sourced from the Ecoinvent 3.8-unit process database.[18] Impact assessments were performed using the World ReCiPe (H) 2016[19] method, which transforms the lifecycle inventory results (Tables S3-S7) into 3 end-point and 18 midpoint environmental impact categories.[20]

Results

HD has the highest environmental impacts across nearly all impact categories, whereas KT has the lowest (Fig 3). The climate impact of a patient receiving HD is 2.7 tCO2e annually, compared with 0.7 tCO_2e for KT and 1.4 tCO_2e for PD. Ozone depletion was one of the highest impact categories across all 3 modalities, with the effect of HD (0.0006 kg of trichlorofluoromethane equivalent over the course of follow-up) being 45% higher than that of KT (0.0001 kg) and 18% higher than that of PD (0.0004 kg). Air pollution attributable to HD is 47% more than that from KT and PD (8.11 kg of ≤10-μm-diameter particulate matter equivalent over the course of follow-up, compared

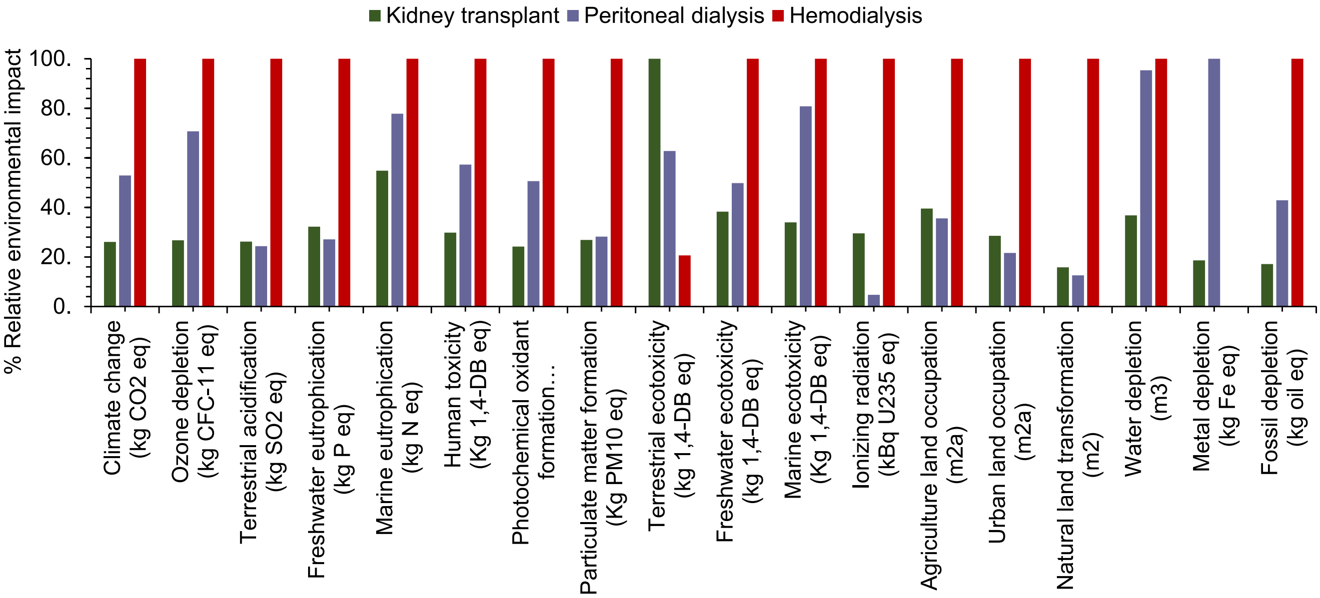

Figure 3. Illustration of lifecycle environmental impacts of kidney replacement therapies (midpoint impact categories) measured for different environmental categories in addition to carbon emissions.

with 2.08 kg and 2.3 kg, respectively). Compared with HD, PD has considerably lower impacts (9%-41% of those for HD), with highest impacts on water depletion (41%), ozone depletion (36%), human toxicity (30%), and climate change (29%). The environmental impacts of KT are <35% of those of HD across all categories except terrestrial ecotoxicity, on which KT has a greater impact (54%) than HD (10%) and PD (34%).

The impact of KRTs on climate change varies significantly because of their travel requirements and consumables used. KT entails the least climate impact (26% of HD), most of which (81%) is attributable to patient and staff travel associated with perioperative care (Fig 5). Conversely, HD demonstrates the highest climate impact, accounting for 56% of total GHG emissions from KRTs, with patient and staff travel to repetitive dialysis sessions being the primary contributor (75%), followed by single-use consumables (17%) and energy consumption (5.4%). The climate impact of PD (52% of HD) was largely attributable to consumables (85% of PD GHG emissions).

When individual environmental impact categories are aggregated into damage categories, HD is responsible for considerably more damage to human health (0.006 disability-adjusted life years per year), ecosystems (2.93×10^{-5} species extinctions per year), and natural resources (US $264) than other KRTs (Fig 4). KT has the best performance, with only 14% of human health impacts, 16% of ecosystem damages, and 10% of natural resource depletion compared with HD. PD causes moderately more damage than KT but still performs considerably better than HD, with 26% of human health, 28% of ecosystem, and 27% of natural resource impacts.

KT

Contributors to the lifecycle environmental impacts of KT are shown in Fig 5 (select impact categories shown; full results are provided in Figures S1-S3). For most impact categories, patient and staff travel were the primary contributors, followed by consumables. Patient and staff travel were most impactful to air pollution (84%), climate

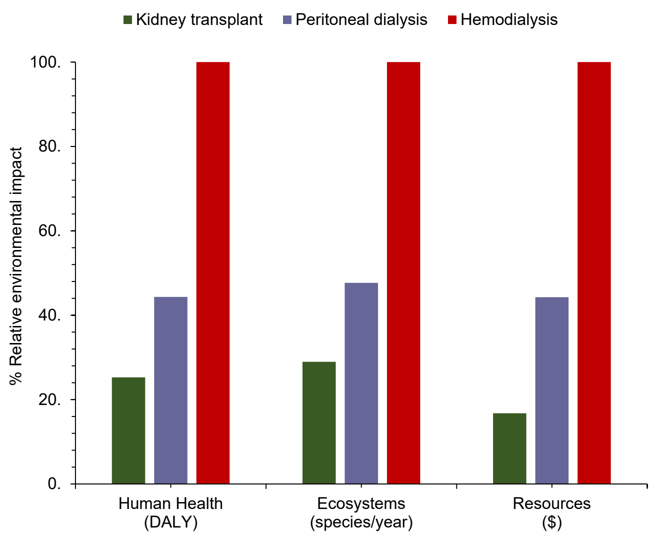

Figure 4. Lifecycle environmental impacts of kidney replacement therapies (end point/damage impact categories). The figure shows the environmental impacts of kidney replacement therapies on 3 major categories, including effects on human health, ecosystems, and resource use. Abbreviation: DALY, disability adjusted life-year.

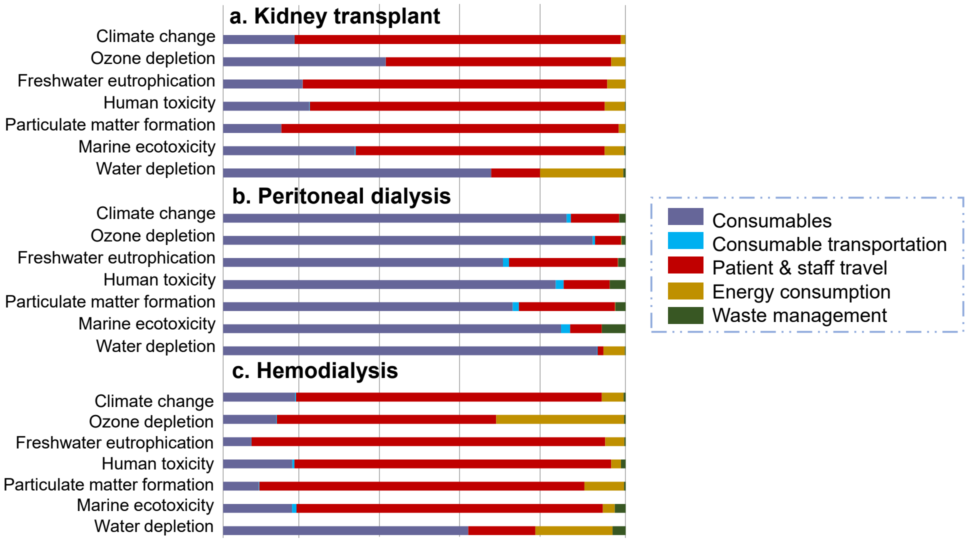

Figure 5. Contributors to select environmental impacts of kidney replacement therapies. The figure illustrates the main factors/hotspots of high emissions within each kidney replacement therapy on selective environmental impact categories.

change (81%), freshwater eutrophication (75%), and human toxicity (73%) and least impactful to water depletion (12%). Consumables including surgical supplies, gowns, drapes, and all other disposable materials were the second largest contributor with the highest impacts to water depletion (66%), ozone depletion (40%), and marine ecotoxicity (32%). The smallest contributors to KT environmental impacts were waste management and consumables transportation (<1%). Energy consumption is responsible for <5% of all impacts except water depletion.

PD

PD consumables accounted for the highest impacts across all categories, most notably water depletion (92%), ozone depletion (91%), marine ecotoxicity (83%), climate change (85%), and human toxicity (82%). Consumables consisted largely of dialysate bags, tubing, cassettes, and their plastic packaging. Patient and staff travel was the second-highest contributor to PD environmental impacts, resulting in 23% of air pollution and 11% of impacts to climate change and human toxicity. All other processes including energy consumption, consumables transportation, and waste management contributed <10% of overall PD environmental impacts.

HD

Patient and staff travel for HD was responsible for >70% of impacts across all categories except water depletion (16%). Consumables contribute primarily to climate change, marine ecotoxicity, and human toxicity (>17%), and, much like PD, these impacts were due to plastics used in the HD circuit. Water depletion was significantly impacted by RO water (60%) and energy consumption (19%; Fig 5), to which the high water requirements of as much as 300 L per dialysis session and power generation for heating, ventilation, and air conditioning requirements of dialysis units were the main contributors.

Discussion

Management of the growing global population living with kidney failure presents a significant challenge for health care systems. KRTs are resource-intensive, and estimation of their environmental impacts is still in its infancy. This study is the first to investigate KT via LCA using primary data sources and the first comparative analysis between KT, HD, and PD. Our setting is a high-volume kidney care center involved in the direct delivery of the range of treatments for kidney failure, and our therapy-focused study design enables users to apply these data to their own regional transport and supply-chain features to inform local processes.

HD accounted for 2.7 tCO_2e per patient per year, which is less than the published range of 3.7-10.2 tCO_2e. Correspondingly, per-treatment GHG emissions were 0.01 tCO_2e, compared with 0.02-0.06 tCO_2e reported in previous studies.[9,13,21,22] Despite being on the lower end, these emissions remain substantial, equivalent to 13%-18% of an average Canadian's annual carbon footprint and comparable to emissions from driving a gasoline-powered vehicle approximately 12,000 km.[23,24] The lower emissions for HD in our study are likely due to differences in energy supply (with abundant hydroelectricity in British Columbia), our exclusion of proximal supply-chain transport, and regional practice efficiencies compared with other published studies, most of which were conducted at a facility level and exhibit high variability.

Between dialysis modalities, PD is environmentally preferable to HD. In our study, PD's annual per-patient GHG emissions of 1.4 tCO_2e were less than those described in Australia (2.4-4.5 tons)[12] or other national settings (4.3-5.5 tons).[13] Higher reported Australian PD emissions are likely attributable to more extensive supply distribution networks and higher electricity grid carbon intensity. Thus, important PD process improvement opportunities include using virtual assessments when appropriate and systematically reducing supply network emissions, such as through low-emissions transport or innovations such as regional or home dialysate production.

In contrast, the climate impact of KT was calculated to be only 0.67 tCO_2e per patient per year, 2 times less than PD and 4 times less than HD. Our results confirm that KT is the environmentally preferred option among the 3 studied KRTs, primarily because of the resources required for repeated dialysis sessions versus a one-time surgical procedure with follow-up visits. Because median allograft survival times of deceased-donor KTs are approximately 12 years or longer[25] and our study modeled only the first year of treatment, the considerable difference in environmental performance shown in this study is necessarily an underestimate. That said, our study assumed that donor and recipient operations occurred at the same center, which is likely the lowest-impact scenario for KT. Although this reflects prevalent local practice within our health region, in some jurisdictions, substantial travel emissions could be incurred from more distant organ retrieval. The extent to which organ or donor transport logistics affects overall KT impacts is informed by specific regional and national transplant system policies, which is to be explored in future analysis.

KRT emissions are comparable to those reported from another abdominal surgery (laparoscopic hysterectomy, ~0.5 tCO_2e).[26] Compared with other repetitive treatments, dialysis emissions are higher than those associated with well-controlled type 2 diabetes on first-line treatment (0.67 tCO_2e per year)[27] but lower than emissions arising from the treatment of a patient with septic shock in an intensive care in the United States (0.17-0.29 tCO_2e per day).[28]

The environmental superiority of KT aligns with existing data on patient outcomes, including lower mortality rates,[25] improved patient experience[29] and quality of life,[30] and cost-effectiveness,[31-33] supporting transplantation whenever possible. Improving KT adoption may require many strategies, including streamlining donor assessments, improving system coordination and education, investing in living-related donation programs, and/or enhancing deceased organ donation.

Our study also highlights environmental "hotspots" within modalities and opportunities for mitigation. Patient and staff travel emerged as a substantial contributor to the environmental impact of KRTs, most notably in HD, in which it accounted for >80% of total impacts. This finding agrees with other studies emphasizing the clinical advantages of reducing patient travel emissions.[34] Home HD, satellite dialysis clinics, and mobile dialysis units could reduce patient travel requirements, but emissions thereby avoided must be weighed against those generated by increased resource requirements from service replication (eg, producing dialysis machines for individual patients' homes instead of achieving economies of scale in center-based units).[6] Increasing adoption of telehealth consultations and other remote monitoring tools for the follow-up of home dialysis and transplant patients may further mitigate travel-related emissions.[8] Our findings also highlight the essential role health care planning agencies play in the geographic allocation of KRT resources, whereby population health care needs are considered in conjunction with sustainability goals.

Consumables are a driver of climate-change impacts in all 3 modalities (17% in KT, 85% in PD, and 18% in HD). The impact of consumables can be reduced by minimizing resource use as appropriate, such as through incremental or decremental dialysis prescriptions, reprocessing of surgical instruments, or recycling materials like dialysate bags and outer packaging.[12] Innovation in design of dialysis systems to require fewer consumables, and in materials engineering to replace the polyvinyl chloride and polypropylene in consumables and packaging with environmentally preferable alternatives, could substantially reduce dialysis-related impacts.

The global annual water consumption of HD is estimated at 26.5 billion liters: dramatic consumption considering that, in 2021, more than 700 million people lived in countries with high or critical levels of water stress.[35] RO systems used for HD are highly specialized, expensive systems that often work continuously and can generate nearly 60% wastewater for every liter used. Newer technologies in RO systems may reduce the proportion of wastewater generated, and measures to reuse "gray water" from RO systems have been implemented for agriculture, laundry services, steam sterilization, and more.[1] Dramatic reductions in water use may be achieved with HD system innovation, such as has been proposed with sorbent systems, which may use as little as 6 L of water for a single HD session.[36] In contrast to the direct water consumption of HD, PD water intensity is predominantly indirect, arising upstream from the point of care from the manufacture of dialysate solutions and the plastics in which they are packaged.

In the present study, energy consumption was not a significant contributor to environmental damage, accounting for <3% of HD and KT emissions, respectively, and <4% of air pollution. This finding reflects the clean energy sources, primarily hydroelectric, used in British Columbia. In contrast, a study of HD in Mexico revealed higher overall energy-sourced emissions (5.1 tCO_2e) due to the use of natural gas as a primary electricity source.[21] Societal transition to renewable energy, optimized according to geographic attributes, is a key system strategy to reduce GHG emissions from health care.[37]

There are increasing calls for high-quality environmental impact assessment in health care, and the present data can be used to improve environmental performance of kidney care at sectoral, regional, and program levels, in addition to supporting informed decision-making for patients who are anticipated to increasingly expect stewardship of their health care resources.

Sustainable health care delivery must consider not only environmental impacts of care but also resilience of populations and systems to disruption. Although these 2 elements of health system sustainability ("mitigation" and "adaptation") are typically considered separately, this study reveals a convergence, in that the lowest-polluting care (KT) also supports the most resilient population. In-center HD recipients rely on continual access to acute services, with the potential for life-threatening consequences in the event of disruption.[38] In contrast, PD recipients typically receive monthly supply shipments and are therefore more resilient to disruptions in access to care, whereas KT recipients rely only on pharmaceutical supply chains for immunosuppressive agents, which can typically be secured for months. To our knowledge, there are no other documented instances of health services design that offer this integrated mitigation and adaptation solution.

Pharmaceuticals were excluded from this study because of a lack of publicly available data. Given that pharmaceuticals are estimated to contribute substantially to emissions from health care activities, and antimetabolite and cytotoxic drugs specifically may have unique toxicities to humans and ecosystems, our findings likely underestimate the overall environmental impacts of patients receiving KRTs.

This estimation of the relative environmental impacts of KRTs contributes an additional dimension of health care quality to existing knowledge of patient outcomes, experience, and costs of kidney care. Although KT is well recognized to confer improved clinical outcomes and health economic benefits over dialysis, its significantly lower environmental impacts further support systematic efforts to maximize transplantation. Among dialysis modalities, PD is environmentally preferable to HD, and methods to increase its uptake should be continually sought. These results can also guide efforts to optimize the environmental performance of KRTs, such as exploring low-emission transportation options, alternative energy sources in infrastructure, and selective materials acquisition throughout the spectrum of care. The low-carbon, sustainable hierarchy of KRTs established here aligns with the relative resilience of these populations, offering one of the first examples of an integrated mitigation and adaptation solution in health services design.

Supplementary Material

Supplementary File (PDF)

Figure S1: Lifecycle environmental midpoint impacts of kidney transplant.

Figure S2: Lifecycle environmental midpoint impacts of peritoneal dialysis.

Figure S3: Lifecycle environmental midpoint impacts of hemodialysis.

Table S1: Lifecycle inventory for kidney replacement therapies per patient per session.

Table S2: Per-patient consumables used during kidney replacement therapies.

Table S3: Midpoint and end-point environmental impacts of kidney replacement therapies.

Table S4: Environmental impacts of kidney transplant.

Table S5: Environmental impacts of peritoneal dialysis.

Table S6: Environmental impacts of hemodialysis.

Table S7: Overview of lifecycle assessment midpoint indicators and their description.

Article Information

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Environmental Impacts of Kidney Replacement Therapies

Setting & Participants

Comparative lifecycle assessment

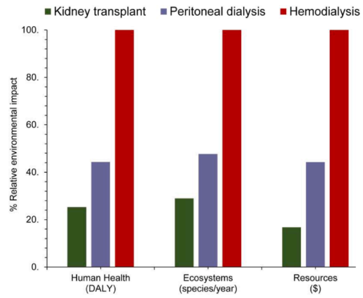
Single-center in Vancouver, Canada

Exposure: Kidney replacement therapies (KRTs)
- Kidney transplantation (KT)
- Hemodialysis (HD)
- Peritoneal dialysis (PD)

Outcome: Environmental impacts of KRTs over one year

Findings

Environmental Impact	KT	PD	HD
Climate Change *(tCO2e)*	0.7	1.4	2.7
Ozone Depletion *(kg CFC-11 eq/FU)*	0.0001	0.0004	0.0006
Air Pollution *(kg PM10 eq/FU)*	2.08	2.3	8.11



Largest Contributors to Greenhouse Gas Emissions (Across All KRTs)

Patient & Staff Travel **Consumables**

CONCLUSION: KT is the most environmentally preferred KRT. PD had fewer environmental impacts than HD. Understanding the relative environmental impacts of KRTs can help inform clinical decision-making in the management of kidney failure.

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