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Climate change and cardiovascular health: Recent updates and actions for healthcare

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ABSTRACT

Climate change is a public health crisis predominantly due to fossil fuel combustion, that challenges planetary and human health. Considerable evidence exists to demonstrate the impact climate change has on cardiovascular disease primarily through air pollution, and non-optimal temperature. Conversely, healthcare systems themselves contribute substantially to climate change. Many clinicians personally report a sense of responsibility to reduce the detrimental impact of parts of our healthcare system on the environment. Roadmaps exist to guide decarbonization and reduce pollution in the healthcare sector. The first step in minimizing the climate impact of the provision of cardiovascular care is to determine the carbon footprint of highly resource dependent sectors such as critical care cardiology as well as the cardiac catheterization and electrophysiology laboratories. This should be followed by sustainable changes to address healthcare waste and energy use. Engagement from healthcare leadership, governmental organizations and major cardiac societies will be necessary to impact meaningful change.

1. Introduction

Anthropomorphic fossil fuel combustion, and the production of greenhouse gases (GHG) has warmed the Earth by 1.1 °C, compared with pre-industrial temperatures over a century ago. This has resulted in rising sea levels, frequent droughts, heatwaves and other weather hazards, biodiversity loss, ocean warming and acidification, among many other climate risks. Climate change impacts global health through a number of pathways including weather and heat exposure, food and water insecurity, and transmission of infectious disease as outlined in the Lancet Countdown [1–3]. Specific to the cardiovascular system, climate change effects pathological processes predominately through air pollution and extremes in temperature [4].

Furthermore, the relationship between climate change and human health is bidirectional. Specifically, healthcare systems can contribute substantially to climate change. For example, if the US healthcare system were a country it would rank 13th in the world for GHG emissions [5]. The Intergovernmental Panel on Climate Change (IPCC) is a United Nations group that assesses the science of climate change and outlines "mitigation" actions that limit the GHG in the atmosphere, and "adaptation" strategies to adjust to the effects of climate change [6–8]. To tackle the climate impact of healthcare, accurate quantification of GHG production by each sector of healthcare must be followed by intensive mitigation strategies.

This paper reviews some recent updates on studies involving climate change and cardiovascular disease, and discusses the impact of the healthcare system on climate change. We also summarize the limited literature that exists to describe the climate impact of components of the healthcare system pertinent to the management of cardiovascular disease. We conclude with suggestions for necessary next steps to address the climate impact of contemporary cardiovascular disease management (Fig. 1).

2. Climate change and cardiovascular disease – recent updates

Over recent years, there has been increased research on the health impacts of climate change, including cardiovascular disease [9]. A *pubmed* search for "climate change AND cardiovascular disease" returned 162 results in 2023 as compared with 131 and 107 in the two prior years respectively. However, these studies are predominantly

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impact studies, outlining the health effect of non-optimal temperature and air pollution, with few evaluating mitigation and adaptation strategies. In this section, we discuss pertinent recent publications as they relate to the cardiovascular system; with an emphasis on new findings, or those evaluating mitigation or adaptation strategies.

2.1. Acute coronary syndrome

A team from Italy studied the mechanism of acute coronary syndrome in 139 participants exposed to short term air pollution who subsequently had an acute coronary syndrome [10]. Particulate matter (PM) 2.5 levels on the day of event and 6 days prior was determined based on the patient's home address and the lesion was classified as plaque rupture (i.e. type 1 MI) or intact fibrous cap (type 2 MI), through intracoronary optical coherence tomography (OCT). Patients with plaque rupture had an average of $3.7\ \mu g/m^3$ higher PM2.5 levels on the day of ACS, without difference in the immediate 6 days before index ACS. It is well known that air pollution contributes to atherosclerosis and that demand ischemia can result from high temperatures [7] however, this study adds to the literature by demonstrating that acute short-term exposure to PM2.5 is associated with coronary plaque instability.

A time-stratified case-crossover study in China investigated the association of exposure to both extreme temperature events and PM2.5 levels with MI mortality [11]. Using multiple definitions of extreme temperature events, both hot and cold spells were associated with increased odds of MI mortality. Furthermore, heat waves and PM2.5 levels act synergistically to trigger MI deaths; with women and older adults appearing to be more vulnerable to these events and elevated PM2.5 levels. It is well recognized that older adults are more vulnerable to non-optimal temperature and pollution; however, the finding that women are more prone to extreme weather events is less well accepted-with conflicting results in the literature. One theory for this finding is that women may tend to have poorer thermoregulation, lower sweating capacity, and greater airway reactivity than men [12].

2.2. *Atherosclerosis and carotid plaque*

Plastics manufacturing has increased exponentially, and single use plastics comprise about 35–40% of all plastics. They are responsible for approximately 3.7% of global GHG and are projected to increase to 4.5% by 2060. To date, the effect of plastics on human health has not been well defined; however, plastics recycling workers have higher rates of CVD [13].

Building on the concept that plastics exposure may be a cardiovascular risk factor, a widely publicized Italian observational study found microplastics and nanoplastics in atheromatous plaque from 58.4% of 304 individuals undergoing asymptomatic carotid endarterectomy [14]. Furthermore, those with evidence of plastics in carotid plaque were found to have a higher risk of the primary composite endpoint of MI, stroke, or death from any cause (hazard ratio 4.53; 95% confidence interval 2.00–10.27; $P < 0.001$), when compared with individuals who had no evidence of plastics in the excised plaque. The implications of this powerful study are not yet clear and further study of plastics is essential.

2.3. *Hypertension*

A multitude of systematic reviews and meta-analyses have reinforced the association between blood pressure (BP) and various pollutants, including levels of PM1, PM2.5, PM10 and SO [15,16,17]. Non-optimal temperature has also been associated with hypertensive disorders of pregnancy [18]. In a large cohort of 129,009 pregnancies from Israel, exposure to high temperatures during gestation was associated with an increased risk of preeclampsia during pregnancy, with a hazard ratio (HR) of 1.12 when comparing 37 °C to the reference temperature of 22.4 °C [19].

The relationship between traffic-related air pollution and cardiovascular disease was explored in a US-based randomized blinded crossover trial of 16 normotensive middle-aged persons over 2 days. On 2 days chosen at random, road air was entrained into the vehicle used by study participants over a 2-h drive. On other days the vehicle was equipped with a high-efficiency particular air (HEPA) filter. Mean DBP and SBP was 4.7 mmHg and 4.5 mmHg higher for the unfiltered drives compared with the filtered drives, and the changes in DBP was sustained for at least 24 h [20]. This study provides much needed randomized data to support the use of air filters. In areas with high air pollution or wildfire events, high efficiency air cleaners and N95 masks when going

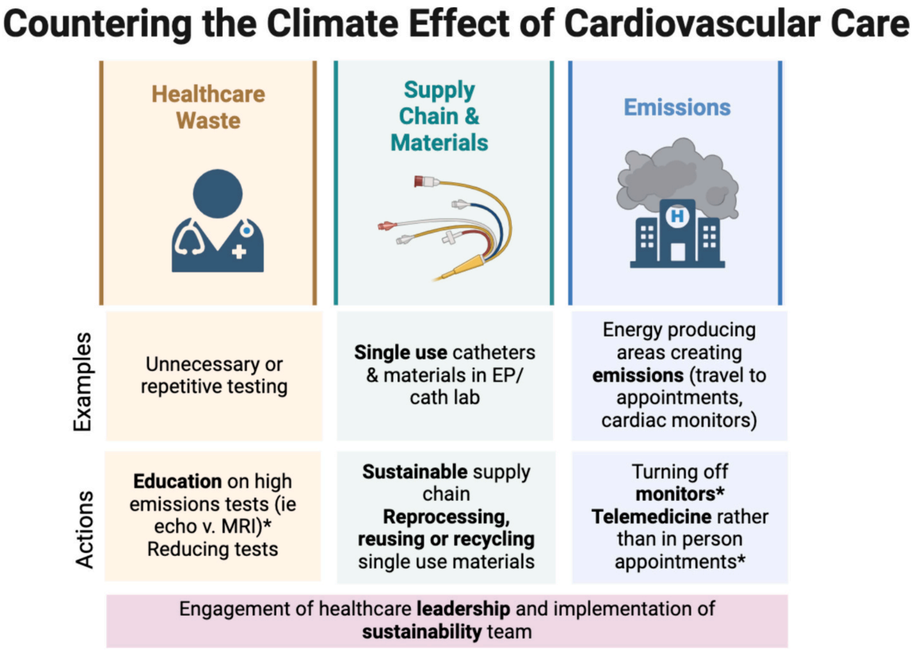

Fig. 1. Countering the climate effect of cardiovascular care.
*Only if clinically appropriate for the patient care
Echo = Echocardiogram, MRI = Magnetic Resonance Imaging, EP = Electrophysiology, Cath = Catherization.

outdoors may help patients at high risk of cardiopulmonary disease [21].

2.4. Dyslipidemia, diabetes mellitus, cardiometabolic health and pregnancy. A number of studies reaffirmed the deleterious association between air pollution and dyslipidemia [22,23]. Similarly, extreme high temperatures were associated with elevated fasting glucose, insulin resistance, diabetes, and metabolic syndrome. [24,25] In pregnancy, exposure to air pollution is associated with gestational diabetes; however, whether critical windows of exposure exist and whether other environmental factors modify the associations remains unclear. Investigators from Ontario, Canada showed that exposure to PM2.5 in early pregnancy and ozone exposure during the late first trimester and over the second trimester of pregnancy were associated with gestational diabetes, but exposure to green space may confer a protective relationship. [26]

3. Climate and healthcare

3.1. Contribution of healthcare to climate change

Fossil fuel combustion to support facility operations such as electricity in hospitals and clinics, the production of pharmaceuticals and medical devices, transport, and food production for health systems generates approximately 8.5% of all GHGs in the US, and 4.6% of all global GHG emissions [7]. These emissions stem from direct operations of health care facilities (scope 1), indirectly from purchased sources of energy, heating and cooling (scope 2), and supply chain of health care services and goods (scope 3) [27]. Each year the United Nations Framework Convention on Climate Change meet at the Conference of the Parties (COP) to discuss and implement national communications, goals, and emission inventories. The 28th of these meetings (COP28), held in Dubai in 2023, included an official Health Day where 123 countries committed to curb emissions in the healthcare sector and develop decarbonization targets for healthcare [28]. This was the first COP to address the impact of healthcare driven climate change on public health.

Most healthcare workers appear to be aware of this issue. Four in five clinicians in the US believe that it is important for their hospital to address climate change, and three out of four felt personal responsibility to pursue this mission [29]. As health is a major motivator for climate action, health professionals are well positioned to advance decarbonization policies. Medical organizations from the US, Europe, and Australia have developed roadmaps for a sustainable low-emission health sector [30,31].

The first step in decarbonizing the healthcare system is determining the carbon footprint of each healthcare facility, which provides targets for decarbonization [32]. The National Academy of Medicine (NAM) has launched the Action Collaborative on Decarbonizing the U.S. Health Sector to intervene upon these targets [33]. The NAM Action Collaborative recommends that healthcare systems should establish an executive level sustainability team with broad representation from both operational and clinical lines. The sustainability team should then conduct a GHG inventory and specific decarbonization goals should be established. To achieve these decarbonization goals, an implementation plan should be developed to document milestones and track progress. This implementation plan should include high impact decarbonization interventions, such as reducing building emissions, emissions from anesthetic gases, physical waste and single use plastics, and emissions from food and transport.

Roadmaps similar to the NAM Action Collaborative have been presented at the 2023 European Healthcare summit and in The Medical Journal of Australia-Lancet Countdown 2023 report [13,30]. These initiatives provide neutral platforms for their participants to align around collective goals and actions for decarbonization, based on evidence, shared solutions, and a commitment to improve health equity [34].

Particularly in developed countries, the use of digital infrastructure and telemedicine services may reduce healthcare emissions. During the COVID-19 pandemic, telemedicine services were widely employed. A retrospective observational study found that the use of telemedicine during the years 2021–2022 resulted in an estimated saving of 1,443,800 metric tons of CO2, when accounting for patient travel as well as the emissions of telemedicine electricity [35]. This equates to the energy saved by having 380 wind turbines running for 1 year [36]. A Stanford Healthcare study similarly found GHG emission reduction from the use of telemedicine [37]. Though all appointments are not appropriate for telemedicine, shifting feasible patient encounters to telemedicine clearly improves GHG emissions.

However, global energy consumption due to digital health is increasing, driven in part by precision medicine and Internet of things devices e.g., smartwatches which contribute increased data traffic and storage [38]. Global information and technology accounts for about 3.5% of global carbon emissions, while healthcare data accounts for 30% of the world's total data [39]. The sourcing of important metals involved in the production of digital hardware results in substantial environmental and ethical issues [40]. Furthermore, both the training and inference phases of artificial intelligence models are highly energy intensive [41]. Therefore, guiding principles and recommendations for a more sustainable digital health system, directed towards researchers and clinicians have been proposed and include [38]:

1) Digital temperance instead of overconsumption and overpromotion – refers to restraint in production, use and promotion.
2) As with all medical devices, digital healthcare products and infrastructure should sustainable throughout their lifecycle.
3) Use of a complex systems approach, for example, to estimate the direct and indirect effects of digitalization of the health sector.

The third of these points is crucial for predicting potential rebound effects such as “Jevons paradox”, wherein technological progress increases the efficiency of resource use, but the falling cost of use induces an increase in resource consumption, rather than a decrease [42]. For example, the use of artificial intelligence is theorized to improve healthcare efficiency and reduce GHGs associated with existing healthcare facilities, however, this technology may be implemented in ways that do not lead to the expected reductions [43].

Storing data requires significant amounts of electricity, as does copying and sending data to the cloud [43]. Such requirements can be reduced by eliminating data storage and flows that are no longer required [44]. Less frequently visited data may be migrated to less sophisticated tape storage systems [45]. Global cloud infrastructure can be migrated to more temperate climates that rely on natural cooling to reduce heat rather than using high-powered cooling equipment. Personal actions that an individual can implement in their daily life to reduce the carbon footprint of data storage includes the use of cloud file sharing solutions, using links rather than attachments in emails, setting up automatic deletions and unsubscribing from unwanted newsletters [39,40].

Healthcare organizations in some countries have been able to generate their own energy via rooftop solar and solar microgrids, resulting in decreased reliance on fossil fuels and greater energy security. For example, in Puerto Rico, Federally Qualified Health Centers that were solarized after Hurricane Maria remained operational during an island-wide power outage in April 2022. Similarly, in Uganda, a randomized controlled trial among hospitals with limited or unreliable access to oxygen demonstrated a pediatric mortality benefit following the installation of solar-powered O2 systems [46]. Such approaches may be of greater benefit in low- or middle-income countries located in particularly sunny climates and may provide increased energy security in these areas [34].

3.2. The carbon footprint of cardiovascular disease management

The limited literature that exists to evaluate the environmental impact of cardiovascular healthcare was recently summarized by Barratt et al. [47] Measurement of the environmental impact of products involved in healthcare is an emerging research field, but the assessment of these products is best quantified by an internationally standardized life cycle assessment (LCA). [48] An LCA measures the diverse range of environmental emission and their impacts, including water, land and air pollution, along with the carbon emissions over the full life of the product from raw material acquisition through manufacturing, packaging, distribution, use, and disposal.

Examples of strategies to reduce the carbon footprint of cardiovascular disease management that are currently supported by data include:

1) Use of echocardiography over other imaging modalities as a first line imaging modality, as clinically appropriate. Indeed, echocardiography has favorable environmental impacts on human health, ecosystems, and resource usage, which were 1%–20% of that of cardiac magnetic resonance (CMR) or single photon emission tomography (SPECT) based on LCA. [49]
2) Remote monitoring of pacemakers and telephone consultations over in-person evaluation. [50]
3) Use of stretchable cardiac monitoring devices rather than rigid electronic devices, as less printed circuit boards are used. [51]
4) Use of virtual cardiology conference webinars over traditional in person conferences. [52]

In contrast to outpatient settings like in Preventive Cardiology, inpatient aspects of the management of cardiovascular disease such as cardiac operating rooms, cardiac catheterization and electrophysiology laboratories and cardiovascular critical care units can be highly resource dependent. [53] Energy use data for inpatient medical devices such as a cardiac monitors or ventilators is scarce, and no data exists to describe the likely substantial carbon foot print of implantable cardiac devices or mechanical circulatory support devices [54].

Investigators from France performed an eco-audit LCA for an atrial fibrillation ablation procedure, which was found to involve a mean of 76.9 kg of CO2 equivalents [55]. Given the 600,000 annual worldwide procedures, the environmental impact of atrial fibrillation activity equates to 700,000 km of car rides each day. Notably, the electrophysiology procedure itself accounted for 75% of the CO2 equivalents, whereas anesthesia (predominantly anesthetic gases) contributed the remaining 25%. The production of single use electrophysiology catheters and patches were the main contributors to the carbon footprint, particularly the use of precious metals like platinum and gold. This builds on prior surveys, which identified single use mapping and ablation catheters as the most commonly cited potential sustainable solution including reusing and re-sterilizing catheters or external re-processing of catheters to make them multi-use. Frameworks to reduce, reuse and recycle these items have been proposed [56] A position paper from the Working Group of Cardiac Pacing and Electrophysiology of the French Society of Cardiology described how the reprocessing of single-use devices could mitigate the environmental impact of these procedures but noted that it remained unauthorized (primarily due to the theoretical concern of prion disease) in certain countries [57].

Some cardiac catheterization labs have also taken the first steps to address energy use and reduce waste but more widespread traction has been limited [53,58]. Therefore, significant work in quantifying the energy use of a cardiac catheterization lab, with, for example, the Greenhouse Gas Protocol tool is a necessary first step [59]. As outlined in more detail above, subsequent steps will require the establishment of a sustainability team and sustainability plan with engagement from scientific society leadership, industry and federal regulation [53,60].

On an individual level, a simple step that healthcare team members can easily implement is to not leave cardiac monitors or ventilators in standby mode as this uses almost as much electricity as when they are in clinical use. As with all components of climate change mitigation and adaptation, personal actions are useful for short term reductions in the climate impact of healthcare; however, no individual action will be sufficient without larger policy change [61].

4. Conclusions

Climate change related CVD is an important consideration for all clinicians and patients as the earth continues to warm. CVD remains the leading cause of death globally and literature documenting the impact of climate change on cardiovascular health with substantial social inequity continues to grow. The effect of climate change on cardiovascular health must be addressed at many levels including through the lens of healthcare systems, which contribute substantially to climate change, particularly in the US. Advocacy for policy and system-level changes, in addition to personal actions, are essential to mitigate and adapt to climate change. Healthcare systems have the potential and the roadmap to lead these decarbonization efforts. Further work, particularly in the cardiac critical care, cardiac catheterization, and electrophysiology laboratories is clearly warranted. Individual clinicians should ensure that addressing climate change is aligned with their healthcare organization's mission.

CRediT authorship contribution statement

Jasmine K. Malhi: Writing – review & editing, Writing – original draft, Visualization, Validation. **John W. McEvoy:** Writing – review & editing, Visualization, Supervision. **Roger S. Blumenthal:** Writing – review & editing, Supervision. **Alan P. Jacobsen:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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