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Carbon emissions and air pollution savings among telehealth visits for cardiology appointments

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ABSTRACT

Background: Climate change has been associated with adverse cardiovascular health, prompting interest in climate mitigation strategies while improving access for cardiovascular patients. We estimated greenhouse gas and air pollution savings from telehealth use in cardiology.

Methods: Using cardiology telehealth visits at a large academic medical center from July 2020 to March 2024, carbon dioxide (CO_2), nitrogen oxides (NO_x), carbon monoxide (CO), and particulate matter ($PM_{2.5}$) emissions saved were calculated using U.S. Environmental Protection Agency modeling software. Savings were converted into real-world comparators and differences were assessed by cardiology subspecialty and patient insurance status.

Results: Over 45 months, 14,828 telehealth visits among 9942 patients resulted in savings of 484,152 kg of CO_2, 5225 kg of CO, 243,491 g of NO_x, and 9091 g of $PM_{2.5}$ with the total carbon saved equivalent to planting 9070 tree saplings over ten years. CO_2 emissions saved per visit (kg) differed significantly by payor (Self-pay 24.99, Medicare 19.67, Medicaid 19.54, Private 17.85, Other 17.37, $p = 0.004$) and by subspecialty (Interventional 23.79, General 19.08, Heart Failure 18.86, Electrophysiology 17.81, Adult Congenital 16.59, $p < 0.001$).

Conclusions: Carbon emission and air pollution savings from telehealth in cardiology were substantial, with an estimated 19.06 kg of CO_2 saved per visit and total savings over 45 months equivalent to planting over nine thousand trees.

1. Introduction

Contemporary estimates suggest that the healthcare sector contributes 8.5 % of all United States (US) greenhouse gas emissions. (1) Greenhouse gases, including carbon dioxide (CO_2) and nitrogen oxides (NO_x), have direct and indirect effects on heat energy emission and absorption, leading to temperature fluctuations and global climate change. (2) Identifying opportunities to reduce greenhouse gas emissions and air pollution is of particular significance for cardiovascular care, as growing evidence has linked climate change to cardiovascular health. Specifically, previous research has demonstrated that exposure to high and low temperatures, extreme weather events, and other climate change-related phenomena precipitates worse cardiovascular outcomes, including hospitalizations and death. (2–4) Similarly, air pollution exposures, such as fine particulate matter ($PM_{2.5}$) and carbon monoxide (CO), are risk factors in the development and exacerbation of cardiovascular diseases (CVD). (2–4) Even short-term variation in $PM_{2.5}$ levels is associated with increased risk of myocardial infarction, stroke, heart failure (HF) exacerbation, atrial fibrillation, and death from CVD. (2–4) Proposed mechanisms for this include oxidative stress and inflammation associated with pollutant exposure and hemoconcentration and hypercoagulability associated with higher temperatures. (2,4)

Telehealth, or delivery of health services via telecommunications and digital communication technologies, presents an opportunity to support mitigation efforts as carbon emissions saved from reduced vehicle use may be substantial, while increasing health care access for those with less resources. Further, virtual appointments may be protective for patients with increased sensitivity to environmental

Abbreviations: CO2, Carbon dioxide; NOx, nitrogen oxides; CO, carbon monoxide; PM2.5, fine particulate matter; CVD, cardiovascular disease; HF, heart failure; EP, electrophysiology; ACHD, adult congenital heart disease.

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exposures and high risk of adverse cardiovascular outcomes (e.g. avoid unnecessary travel for appointments on days when $PM_{2.5}$ or temperature is elevated). (5) While previous studies have estimated greenhouse gas emissions saved from telehealth use in other specialties, (5–7) data for cardiology visits across subspecialties are limited. Moreover, to our knowledge no prior studies have estimated reduction in $PM_{2.5}$ and other pollutants from use of telehealth services. We aim to fill this gap by estimating carbon emissions and air pollution saved from telehealth use for cardiology appointments at a large academic medical center.

2. Methods

This retrospective study included adult patients with telehealth visits within the Division of Cardiology at Duke University Health System (Durham, NC). Only patients with home addresses in North Carolina were included in line with state telehealth regulations. The study period was from July 1, 2020 to March 31, 2024, corresponding with the start of standardized reporting for telehealth visits within the electronic health record. Cardiology visits were defined as any visit with a provider in the Division of Cardiology. Individual cardiology visits were categorized into general cardiology, electrophysiology (EP), HF, interventional cardiology, and adult congenital heart disease (ACHD) based on primary area of expertise of the attending physician associated with the encounter. Home addresses of patients at time of the encounter were converted to latitude and longitude locations, and roundtrip driving distance was calculated in miles to the ambulatory clinic sites using ArcGIS Pro software (version 3.2). $PM_{2.5}$, CO, and greenhouse gas emissions, including CO_2 and NO_x, were modeled using Environmental Protection Agency's (EPA) Motor Vehicle Emissions Simulator, which is a validated modeling system to estimate emissions from mobile sources. (8) Emissions were estimated using light-duty passenger vehicles, which includes personal vehicles that are <8500 lbs. Insurance status of patients were collected from each encounter and categorized into Private (commercial insurance plans), Medicare (traditional Medicare and Medicare Advantage), Medicaid (Medicaid, pending Medicaid application, and Medicaid managed care), Self-Pay, and Other (Worker's compensation and other governmental insurance).

Descriptive statistics and analysis of variance along with Kruskal-Wallis tests were used to assess differences in emissions by payor and cardiology subspecialty. In order to compare rates among subspecialties, estimates of emissions were calculated per telehealth visit as well as per hundred total visits, including both in-person and telehealth visits, to account for relative use of telehealth. The EPA Greenhouse Gas Equivalences calculator was used to convert emission estimates into other real world comparators (e.g., trees planted). (9,10) This calculator uses industry standard estimates for carbon sequestration and survival factors, such that approximately 53 kg of CO_2 are sequestered from a tree sapling planted over ten years. (10) All statistical analyses were conducted using RStudio Desktop Pro (version 2023.12.1).

3. Results

During the 45-month study period, 14,828 cardiology telehealth visits occurred (3.8 % of all cardiology visits) among 9942 patients. These telehealth visits included 6757 general visits, 3891 EP visits, 1768 HF visits, 1934 interventional visits, and 478 ACHD visits (Table 1). In total, 484,152 kg of CO_2, 5225 kg of CO, 243,491 g of NO_x, and 9091 g of $PM_{2.5}$ were estimated to be saved during the study interval. CO_2 emissions saved varied over the study period, and total CO_2 emissions are estimated to be equivalent to carbon saved from planting 9070 tree saplings over ten years or recycling 23,827 trash bags instead of sending them to a landfill (Fig. 1). (9) Total $PM_{2.5}$ emissions saved are estimated to be equivalent to the air pollution from 757,583 cigarettes.

Median CO_2 emissions saved per telehealth visit was 19.06 kg [Interquartile range (IQR) 9.75–41.34]. This differed significantly by specialty, ranging from median of 16.59 kg (IQR 7.52–35.47) among ACHD visits up to 23.79 kg (IQR 11.17–44.06) for interventional visits ($p < 0.001$) (Table 2). Similarly, median CO_2 emissions saved per visit differed significantly by payor with private insurance having lower emissions saved per visit (17.85 kg, IQR 9.53–40.20) compared to Medicare (19.67 kg, IQR 10.02–42.04) and Medicaid (19.54 kg, IQR 9.70–41.31) ($p = 0.004$). Patients who were Self-pay had the highest emissions saved per visit at 24.99 kg (IQR 9.98–49.72).

Overall, telehealth visits for general cardiology saved the highest amount of carbon, accounting for 215,529 kg of or 44.5 % of total CO_2 emissions saved during the study period (Fig. 2a). This was followed by EP (118,294 kg of CO_2, 24.4 %), interventional (74,880 kg of CO_2, 15.5 %), HF (58,656 kg of CO_2, 12.2 %), and ACHD (16,793 kg of CO_2, 3.5 %). When CO_2 emissions were examined in relation to total visits (including both in-person and telehealth), a median of 84.11 kg were saved per hundred total cardiology visits. The rate of CO_2 emissions saved per hundred total visits also differed significantly by subspecialty with 139.45 kg saved per hundred EP visits, 123.47 kg saved per hundred interventional visits, 89.19 kg saved per hundred HF visits, 62.40 kg saved per hundred ACHD visits, and 51.52 kg saved per hundred general visits ($p < 0.001$) (Fig. 2b).

4. Discussion

This retrospective analysis of carbon and air pollution savings from telehealth use for cardiology appointments at a large academic medical center contributes to the growing body of work linking climate change, CVD, and healthcare. First, we identify that carbon emission and air pollution savings from telehealth use in cardiology over a four-year period is substantial, equivalent to planting nearly ten thousand trees. Second, we identified differences in CO_2 emissions saved per telehealth visit by both payor and by subspecialty. Moreover, differences in CO_2 emissions saved by subspecialty became even more substantial when relative rate of telehealth visits to in-person visits was considered. Taken together, this work highlights an under recognized benefit of telehealth, as well as an opportunity to further reduce the carbon footprint in cardiovascular care, which is critical to mitigating negative health

Table 1
Estimated greenhouse gas and air pollution savings from patients using telehealth for cardiology appointments.

Characteristic	Total	General	EP	HF	Interventional	ACHD
Number of telehealth visits	14,828	6757	3891	1768	1934	478
Per hundred total visits	3.83	2.70	7.83	4.73	5.19	3.76
Round-trip distance saved (miles)	1,363,223	605,861	334,620	164,863	210,607	47,272
CO_2 emissions saved (kg)	484,152	215,529	118,294	58,656	74,880	16,793
NO_x emissions saved (g)	243,491	109,156	57,968	29,722	38,161	8484
CO saved (kg)	5224	2326	1275	633	809	181
PM2.5 saved (g)	9091	4035	2217	1112	1415	312
Tire wear	1364	606	335	165	211	47
Brake wear	4090	1818	1004	495	631	142
Exhaust	3640	1612	879	453	573	123

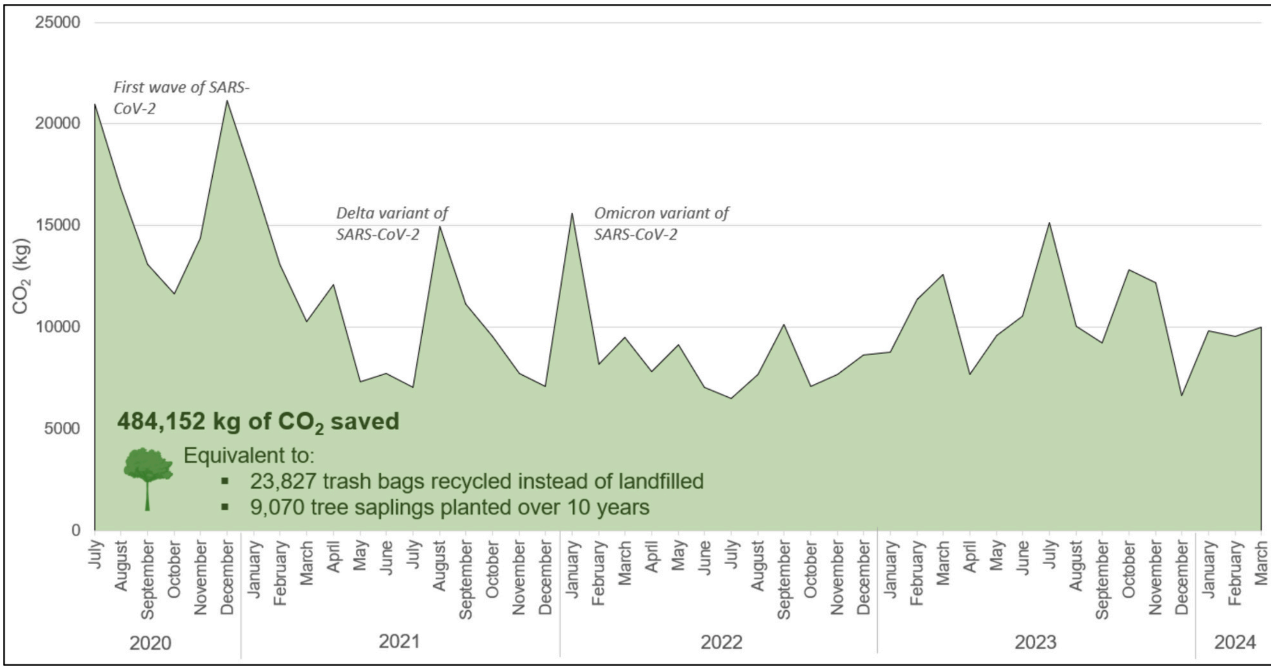

Fig. 1. Estimated carbon emissions savings among patients using telehealth for cardiology visits.

Table 2
Comparison of carbon emission savings per visit by specialty and payor.

Characteristic	CO_2 savings per telehealth visit, kg, median (25th percentile, 75th percentile)	p-value
Subspecialty		<0.001
General ($n = 6757$)	19.08 (9.92, 40.99)	
Electrophysiology ($n = 3891$)	17.81 (9.25, 40.54)	
Heart Failure ($n = 1768$)	18.86 (9.75, 43.22)	
Interventional ($n = 1934$)	23.79 (11.17, 44.06)	
Adult Congenital Heart Disease ($n = 478$)	16.59 (7.52, 35.47)	
Payor		0.004
Private ($n = 5327$)	17.85 (9.53, 40.20)	
Medicare ($n = 8331$)	19.67 (10.02, 42.04)	
Medicaid ($n = 574$)	19.54 (9.70,41.31)	
Self-pay ($n = 186$)	24.99 (9.98, 49.72)	
Other ($n = 401$)	17.37 (7.92, 41.52)	

consequences of climate change.

CO_2 emissions varied significantly by both subspecialty and by payor. Among subspecialists, telehealth appointments with interventional cardiologists saved the largest amount of CO_2 per visit. This likely reflects differences in catchment areas for subspecialties and that patients typically travel further distances for interventional appointments. Similarly, differences in CO_2 emissions by payor represent the variation in travel distances for in-person appointments, such that patients who are self-pay had the largest amount of savings per visit. Both patients with Medicare and Medicaid had higher CO_2 emissions savings per visit than those with private insurance. As such, in addition to convenience and time saved for patients, which is particularly significant for those without paid leave for appointments, telehealth use within these populations may lead to greater CO_2 emissions savings.

The pattern of differences in CO_2 emissions savings by subspecialty changes when examined by relative rate of telehealth use. EP had the highest rate of telehealth visits and highest CO_2 emissions savings per hundred total visits. One facilitator of this is the availability and infrastructure for remote device monitoring within EP. Specifically, the ability to remotely monitor cardiac implantable electronic devices enables access to robust objective data without necessitating an in-person visit, which has previously been estimated to reduce net greenhouse gas emissions. (7,11) Looking forward, as the ecosystem of digital health devices continues to expand, there are opportunities for similar telehealth uptake and carbon emissions savings across other cardiology subspecialties. For example, use of pulmonary artery pressure monitoring through implantable devices allows for home monitoring of patients with HF. (11) Adjunct technologies such as digital scales and pill boxes also offer opportunities for remote monitoring at lower costs, including tracking medication adherence to antiplatelet therapy after a coronary intervention.

Finally, the temporal pattern of carbon emissions saved reflects the use of telehealth for cardiology within the health system. Months with the highest emission savings track with the relative increased burden of SARS-CoV-2, including the initial wave, Delta variant, and Omicron variant. More recently, monthly levels of CO_2 emissions savings from cardiology telehealth visits are less than half of peak levels. While this temporal variation suggests that there is opportunity and capability for more CO_2 emissions savings through increased telehealth use, more information is needed to understand how relative use of telehealth ultimately affects health outcomes. Further work is needed to determine the cadence and optimal outcomes for chronic cardiovascular care that utilizes telehealth as a key component of care.

Key limitations of the present study should be considered. First, we assumed that all patients traveled round-trip by light-duty passenger vehicles to the clinic site of their visit. It is possible that patients used alternative means of transport or used heavy-duty passenger vehicles. Second, we assumed that patients who attended a telehealth appointment would have otherwise attended an in-person appointment and that they did not complete the trip for other reasons, such as additional healthcare appointments or errands. Finally, we did not account for carbon emissions that may be generated from electricity used during telehealth visits. Taken together, despite use of state-of-the-science modeling methods, the value of the present study is not the specificity of estimates of greenhouse gas and air pollution savings, but establishing these savings as a co-benefit of telehealth use in cardiovascular care.

In addition to examining ultimate CVD outcomes from telehealth

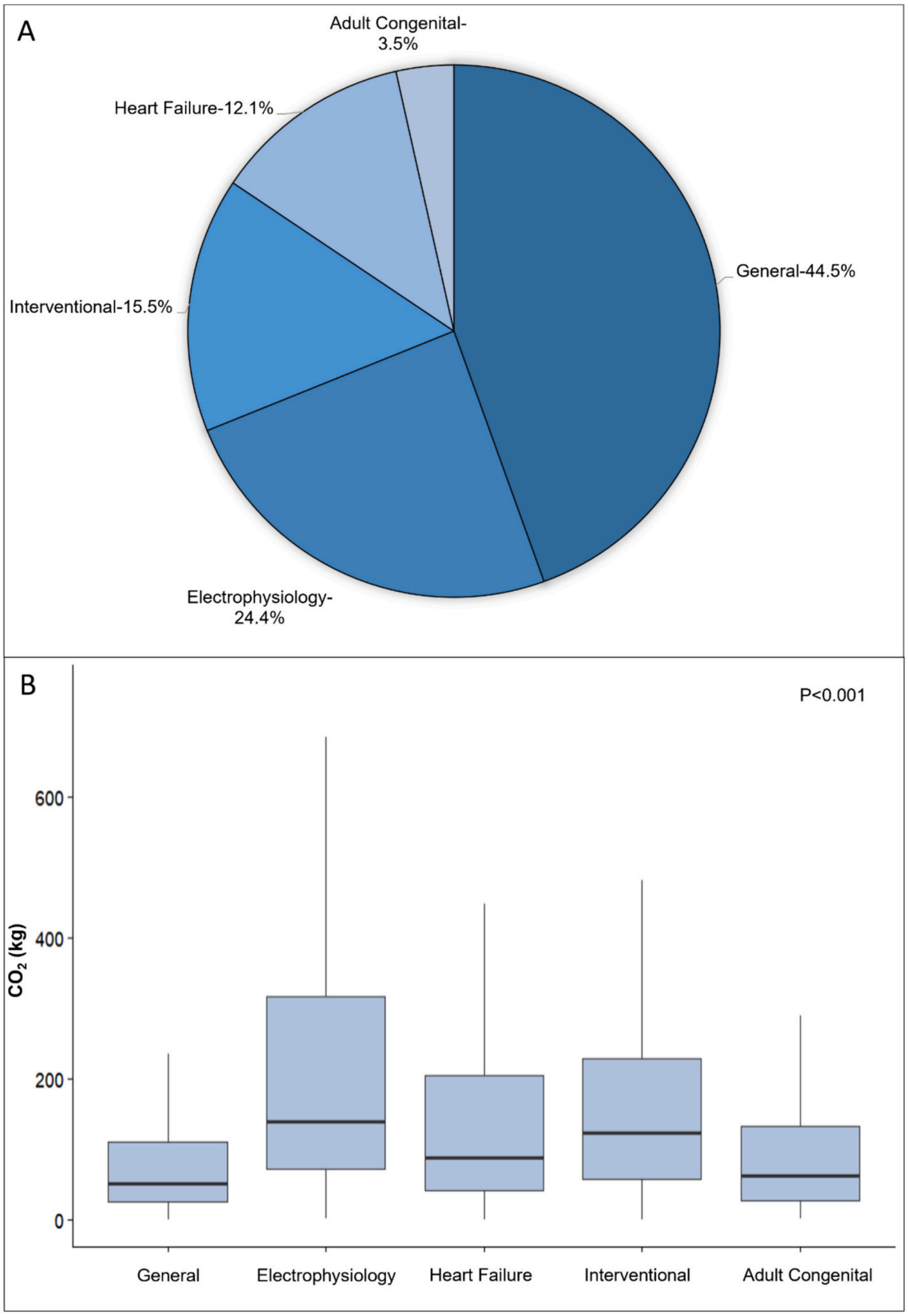

Fig. 2. Total carbon emissions and carbon emissions saved per hundred visits by subspecialty.

use, future work should explore how telehealth use reduces exposure of patients to traffic-related air pollution associated with driving to and from appointments. Additionally, future research could examine the relative effects of access to telehealth and burden of environmental exposures on health disparities in order to identify best telehealth practices to promote equity within cardiovascular care.

5. Conclusion

Carbon emission and air pollution savings from telehealth use in cardiology was substantial—equivalent to the greenhouse gas reductions of planting 9070 tree saplings over ten years. The highest rate of savings observed were among electrophysiology visits, which may stem from availability and use of medical devices with remote data monitoring. Finally, looking forward, if 4 % of in-person visits were converted to telehealth, the rate of carbon emission and air pollution savings would be expected to double.

CRediT authorship contribution statement

Alexander H. Gunn: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis. **Evan M. Murray:** Writing – review & editing, Methodology. **Manesh R. Patel:** Writing – review & editing. **Robert J. Mentz:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Dr. Robert J. Mentz received research support and honoraria from Abbott, American Regent, Amgen, AstraZeneca, Bayer, Boehringer Ingelheim, Boston Scientific, Cytokinetics, Fast BioMedical, Gilead, Innolife, Eli Lilly and Company, Medtronic, Medable, Merck, Novartis, Novo Nordisk, Pharmacosmos, Relypsa, Respicardia, Roche, Sanofi, Vifor, Windtree Therapeutics, and ZOLL. Dr. Manesh R. Patel received research support and honoraria from Bayer, Janssen, Novartis, Esperion, and Research Grants from NHBLI, Idorsia, and Heartflow.

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