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Research Letter

# Effect of Radiation Schedule on Transportation-Related Carbon Emissions: A Case Study in Rectal Cancer

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**Purpose:** The health care sector is a major contributor of worldwide greenhouse gas (GHG) emissions. Indirect emissions, including those associated with transportation, make up 82% of the US health care sector's environmental footprint. Radiation therapy (RT) treatment regimens present an opportunity for environmental health care−based stewardship owing to the high incidence of cancer diagnosis, significant utilization of RT, and myriad treatment days required for curative regimens. Because the use of short-course RT (SCRT) in the treatment of rectal cancer has demonstrated noninferior clinical outcomes compared with conventional, long-course RT (LCRT), we investigate the environmental and health equity−related outcomes.

**Methods and Materials:** Patients treated with curative, preoperative RT for newly diagnosed rectal cancer at our institution between 2004 and 2022 and living in-state were included. Travel distance was estimated using patients' reported home address. Associated GHG emissions were calculated and reported in carbon dioxide equivalents ($CO_2e$).

**Results:** Of 334 patients included, the total distance traveled for the treatment course was significantly greater in patients treated with LCRT versus SCRT (median, 1417 vs 319 miles; $P < .001$). Total $CO_2e$ emissions for those undergoing LCRT (n = 261) and SCRT (n = 73) were 665.3 kg $CO_2e$ and 149.9 kg $CO_2e$, respectively, per treatment course ($P < .001$), with a net difference of 515.4 kg $CO_2e$. Relatively, this suggests that LCRT is associated with 4.5 times greater GHG emissions from patient transportation.

**Conclusions:** Using treatment of rectal cancer as proof-of-principle, we advocate for the inclusion of environmental considerations in the creation of climate-resilient oncologic RT practices, especially in the context of equivocal clinical outcomes between RT fractionation schedules.



## Introduction

The global health care sector, if it were a country, would be the fifth largest emitter of greenhouse gas (GHG) emissions worldwide.[1] The US health sector is considered the world's number 1 emitter of GHG emissions, in regard to both absolute and per capita terms.[1] Indirect emissions—known as Scope 3 emissions—are those primarily derived from the production, transport, use, and disposal of goods and services and make up 82% of the US health care sector's environmental footprint.[2] Patient-related transportation GHG emissions accounted for the largest proportion (32%) of inventoried GHG emissions in 2020 at our institution—a large tertiary medical center.[3]

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Research data are stored in an institutional repository and will be shared upon request to the corresponding author.

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Altering the transportation behavior of the population of patients with cancer would have measurable effects on reducing health care GHG emissions, not only because cancer is a leading cause of national morbidity and mortality but also because cancer care requires myriad visits for evaluation and treatment. Radiation therapy (RT) is an integral part of oncologic care, with most patients with cancer requiring RT at some point during their lifetime.[4] Accumulating data support hypofractionated RT schedules in cancer care, for which rectal cancer is a prime example because short-course RT (SCRT) has been shown to be a cost-effective, efficacious, and safe alternative to long-course RT (LCRT).[5] We herein characterize the outcomes of a hypofractionated radiation schedule for transportation-associated GHG emissions using rectal cancer as a case study.

## Methods and Materials

Patients treated with preoperative RT for newly diagnosed rectal cancer at our institution between 2004 and 2022 were included in this institutional review board −approved study. Patients living out of state were excluded. Travel distance and travel time to radiation were estimated with the Google Maps directions feature using patients' reported home address. When multiple routes were offered, the route with the shortest travel time was selected. Associated GHG emissions were calculated in proportion to vehicle type (gas, hybrid, electric, or plug-in hybrid) and defined by published statewide vehicle registration statistics using a published well-to-wheel model,[6] which accounts for all emissions related to fuel (ie, gas, electricity) production and use (Table 1) (calculation method available from GHG [https://docs.google.com/spreadsheets/d/1clhXip02wgZ9KGQyueh81x89TyImImGU61J7PVwauwg/edit#gid=0][7]). GHG emissions were converted into carbon dioxide equivalents ($CO_2e$) using global warming potentials, a measure of how much energy 1 ton of an emitted gas will absorb relative to 1 ton of emitted $CO_2$; they provide a common unit of measure ($CO_2e$) and enable comparisons of emissions across sectors and gases.[8] Travel-related costs were determined by the 2022 Internal Revenue Service mileage reimbursement rate of 58.5 cents per mile traveled, accounting for gas, insurance, and vehicle depreciation. Comparative analyses between variables were performed using *t* test comparisons with Stata, version 14.2.

## Results

A total of 334 patients treated with preoperative, definitive chemoradiation were evaluable, with 73 and 261 having received SCRT and LCRT, respectively. The median dose delivered for SCRT was 25 Gy in 5 fractions and for LCRT, 50.4 Gy in 28 fractions.

Total distance traveled for the treatment course was significantly greater in patients treated with LCRT in comparison with patients who received SCRT (median for LCRT, 1417 miles; median for SCRT, 319 miles; $P < .001$). Similarly, total time spent traveling was significantly higher in the LCRT versus SCRT group (median for LCRT, 30.6 hours; median for SCRT, 6.5 hours; $P < .001$). Cost projections quantifying dollars spent per treatment course additionally attributed higher transportation-associated costs to LCRT (median for LCRT, $892; median for SCRT, $187; $P < .001$) (Table 1).

Over the total treatment course, LCRT was associated with nearly 4.5 times greater GHG emissions than SCRT. Total $CO_2e$ emissions for LCRT and SCRT were 665.3 kg $CO_2e$ and 149.9 kg $CO_2e$ per patient treatment course, respectively ($P < .001$), with a net difference of 515.4 kg $CO_2e$ (Table 2).

## Discussion

Radiation treatment is an integral component of cancer care and presents an opportunity to reduce health care's environmental effects due to the large number of visits requiring transportation. In the example of rectal cancer, we found that for a single patient undergoing

**Table 1** Distance traveled, time spent in transit, and transportation-related costs associated with short-course and long-course radiation therapy treatment, by daily round trip and total treatment course

| | Daily round trip | | | | Total treatment course | | | |
|---|---|---|---|---|---|---|---|---|
| | Entire cohort | Short course | Long course | *P* value | Entire cohort | Short course | Long course | *P* value |
| Distance, median (IQR), miles | 55 (32-134) | 61.4 (36-169) | 53 (32-119) | .10 | 1193 (455-2436) | 319 (179-874) | 1417 (869-3030) | <.01 |
| Time, median (IQR), min | 68 (50-138) | 78 (52-182) | 68 (50-128) | .22 | 1610 (896-2912) | 390 (260-960) | 1836 (1344-3234) | <.01 |
| Cost, median (IQR), US$ | 32 (19-79) | 36 (21-97) | 31 (19-70) | .12 | 698 (266-1425) | 187 (105-511) | 829 (509-1773) | <.01 |

**Table 2 Transportation-related greenhouse gas emissions associated with total short-course versus long-course radiation therapy treatment by primary emission gas and vehicle type and converted to $CO_2$ equivalents by global warming potential**

| Emission | Gas | Hybrid | PHEV | Electric | Emissions, kg | GWP | Emissions, $CO_2$e, kg |
|---|---|---|---|---|---|---|---|
| Short course | | | | | | | |
| VOCs | 0.08 | 0.00 | 0.00 | 0.01 | 0.09 | Not defined | - |
| CO | 0.79 | 0.06 | 0.01 | 3.09 | 3.94 | Not defined | - |
| $N_2O$ | 0.11 | 0.01 | 0.00 | 0.00 | 0.11 | Not defined | - |
| $CH_4$ | 0.13 | 0.01 | 0.00 | 0.01 | 0.14 | 28.00 | 3.9 |
| $CO_2$ | 122.94 | 7.13 | 1.33 | 3.09 | 134.49 | 1.00 | 134.5 |
| $NO_2$ | 0.04 | 0.00 | 0.00 | 0.00 | 0.04 | 298.00 | 11.4 |
| Total $CO_2$e emissions | - | - | - | - | - | - | 149.9 |
| Long course | | | | | | | |
| VOCs | 0.35 | 0.02 | 0.00 | 0.03 | 0.40 | Not defined | - |
| CO | 3.49 | 0.27 | 0.03 | 13.71 | 17.51 | Not defined | - |
| $N_2O$ | 0.48 | 0.03 | 0.00 | 0.00 | 0.51 | Not defined | - |
| $CH_4$ | 0.56 | 0.03 | 0.01 | 0.03 | 0.63 | 28.00 | 17.6 |
| $CO_2$ | 545.71 | 31.66 | 5.92 | 13.71 | 597.00 | 1.00 | 597.0 |
| $NO_2$ | 0.16 | 0.01 | 0.00 | 0.00 | 0.17 | 298.00 | 50.7 |
| Total $CO_2$e emissions | - | - | - | - | - | - | 665.3 |

*Abbreviations:* $CH_4$ = methane; CO = carbon monoxide; $CO_2$ = carbon dioxide; $CO_2$e = carbon dioxide equivalents; GWP = global warming potential; $N_2O$ = nitrous oxide; $NO_2$ = nitrogen dioxide; PHEV = plug-in-hybrid electric vehicle; VOCs = volatile organic compounds.

SCRT instead of LCRT, the nearly 80% reduction in GHG emissions amounted to 515.4 kg of $CO_2$e—the same GHG emissions associated with electrifying an American home for 37 days.[9]

Short-course neoadjuvant RT remains severely underused for treatment of rectal cancer in the United States, with a National Cancer Database analysis showing that less than 1% of eligible patients are treated with SCRT.[10] Even a modest increase in SCRT utilization would impart large savings in GHG emissions and patient-facing costs, particularly because colorectal cancer is the third most commonly diagnosed cancer in the United States.[11]

There have been recent calls to action directed at physicians—especially oncologists—to adopt strategies that minimize the environmental effects of care.[12] Although our study did not aim to be a comprehensive life-cycle analysis of the carbon footprint of RT for treatment of rectal cancer, we provide new information regarding transportation-related carbon emissions during radiation treatment. Our study strongly complements a recent report that estimates $CO_2$ emissions associated with linear accelerator energy use during external beam RT for the most common cancer diagnoses.[13] The authors calculated that linear accelerator $CO_2$ emissions associated with LCRT and SCRT for rectal cancer were 11.32 and 4.36 kg $CO_2$ per treatment course, the GHG-equivalent of 28.1 and 10.8 miles driven. Immediately apparent is that patient transportation far overshadows linear accelerator energy use in its contribution to treatment-related GHG emissions and highlights the patient commute as a high-yield intervention when considering strategies to reduce the environmental impact of care.

There are several limitations to our analysis that warrant future investigation. We were unable to identify patients who used local housing during treatment and therefore may have overestimated commute distances, particularly for patients who traveled from afar. One approach in mitigating this bias was excluding patients who lived out of state. However, by following this exclusion principle, we could not rationally define a threshold that assumed patients were unwilling to commute. Our analysis additionally did not factor in patients who might have walked or used public transportation; given our location in a densely populated, suburban environment, we assumed patients traveled by personal motor vehicle. We also did not know the specific vehicle type that our patients commuted in, which is why we extrapolated vehicle type from published statewide statistics. Consideration of a future travel audit of our patients may provide more granular information regarding all of these aforementioned details. Although we describe here only patients with rectal cancer treated at a single institution, these findings can be more broadly applied to compare any hypofractionated treatment regimen against conventional fractionation, regardless of disease site.

## Conclusion

In summary, hypofractionated RT can reduce patient transportation-related carbon emissions. We additionally provide a publicly accessible tool for providers to estimate transportation-related $CO_2$ emissions and compare across fractionation schedules. We advocate for the inclusion of these environmental considerations in the creation of climate-resilient oncologic practices, especially in the context of equivocal clinical outcomes between treatment regimens.

## Disclosures

All authors declare that they have no conflicts of interest.

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