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EDITORIAL

Transitioning to Environmentally Sustainable, Climate-Smart Radiation Oncology Care

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Introduction

Climate change is among the most pressing global threats. Action now and in the coming decades is critical. Rising temperatures exacerbate the frequency and intensity of extreme weather events, including wildfires, hurricanes, floods, and droughts. Such events threaten not only our ecosystems, but also our health. Climate change's negative effects on human health are slowly becoming better understood and are projected to increase if emissions mitigation remains inadequate.[1,2,3] Emerging research notes a disproportionate effect of climate change on vulnerable populations (eg, older populations, children, low-income populations, ethnic minorities, and patients with chronic conditions, including cancer) who are the least equipped to deal with these outsized effects.[4-9]

Climate change has been an issue in the public discourse for decades, but collective action remains inadequate. We are just beginning to understand the effect climate change has on oncology and the cancer control continuum.[10-15] These effects span a wide range, from increasing causal factors of certain cancers to disruption of the complex health care systems required for cancer prevention, screening, diagnosis, treatment, and survivorship (Fig. 1). Unlike infectious

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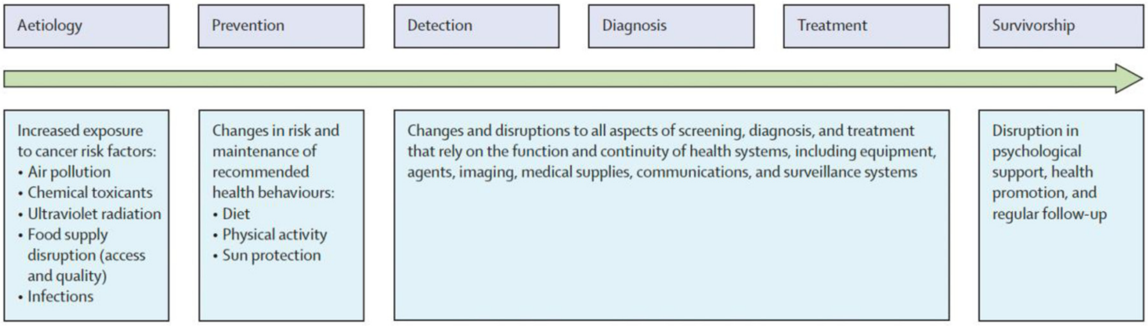

Fig. 1. Climate change impact across the cancer control continuum.[10]

diseases, which have direct temporal proximity to the exposure brought on by climate change, cancer incidence rates are affected through climate-affected causal pathways involving air pollution, exposure to ultraviolet radiation, disruptions in food and water supply, exposure to industrial toxins, and possibly infectious causes[10,16-18] (Fig. 2). For example, diminished air quality and pollution will exacerbate and increase the prevalence of other health conditions, including respiratory disease and cancers including lung and skin.[1,5,16,19-21] Beyond such causal factors, climate change and extreme weather events cause major disruptions to the infrastructure of health care systems required for prevention, screening, diagnosis, treatment, and cancer care follow-up.

More than half of cancer patients will require radiation therapy (RT) during the course of their illness.[22,23] As most RT courses are delivered using fractionated external beam radiation (EBRT), patients undergoing EBRT are vulnerable to treatment disruptions from climate events. Notably, disruption of RT treatments due to severe weather events has been shown to affect patient treatment and survival.[15,24,25] As radiation oncologists, it is imperative to recognize and further investigate the effects of climate change on health and cancer outcomes and understand the specific vulnerabilities of patients receiving RT to the effects of climate change. We must also advance our understanding of the contribution of radiation oncology as a specialty to greenhouse gas (GHG) emissions, and what measures may be taken in our daily practices to join the international efforts in reducing our negative environmental impact.

Taking Action to Transition to Climate-Smart Radiation Oncology Practice

In the United States (US), the health care sector accounts for approximately 8.5% of GHG emissions and 9% of air pollutants,[26] with a significant portion attributed to hospital care and physician services (47%).[27] Thus, resource consumption and emissions generated by medical care activities have a negative effect on our climate, and thus our health and well-being. For example, single-use supplies are often sterilized using ethylene oxide (ETO), a known carcinogen.[28] As a localized example of the adverse public health effects of medical care, Sterigenics, a medical supply sterilization facility north of Chicago, was forced to close in 2019 due to public outcry of the use of ETO gas. A recent report by the Environmental Protection Agency showed increased cancer rates in that community, validating these concerns.[29-32] Although the plant was closed, ETO remains the primary sterilizing agent for single use, sterile medical supplies,

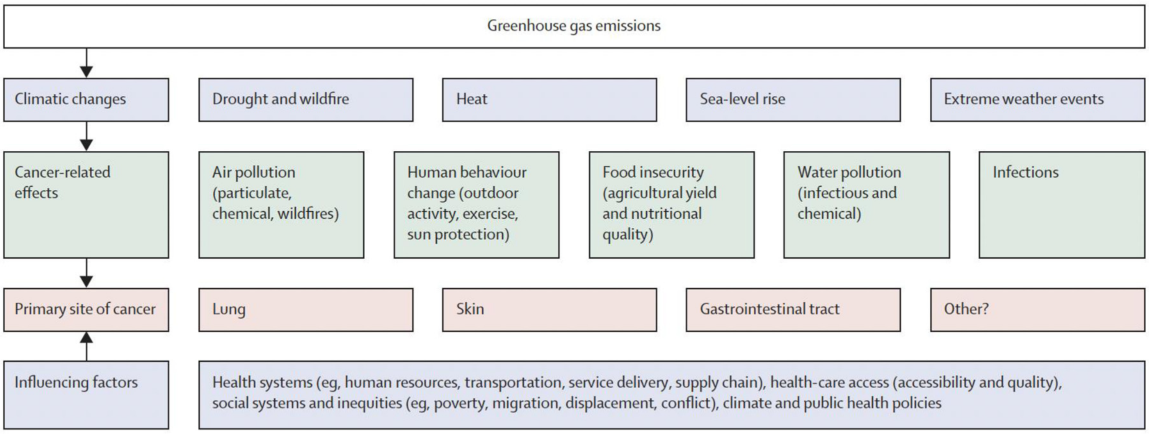

Fig. 2. Pathways from climate change to cancer outcomes.[9]

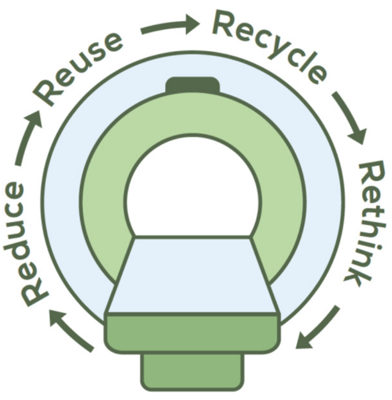

Fig. 3. The 4 Rs to address environmental impact of radiation oncology care: reduce, reuse, recycle, rethink.

highlighting the need for health care facilities and professionals to investigate the environmental and health effects of current practices.[33-36]

Understanding the environmental effect and measuring the GHG contribution of daily radiation delivery in the US and globally remain a priority, as this enables us to focus efforts to reduce the environmental impact of our specialty. To our knowledge, this has not been investigated rigorously before. Radiation oncologists must take steps to understand our contribution to the climate crisis and initiate changes to create sustainable, climate-smart health care practices. Climate-smart health care refers to an approach that bridges the divide between adaptation and mitigation to prioritize both low-carbon and resiliency strategies.[37] In an effort to transition to such, we encourage all members in the field of radiation oncology to actively engage in this transition. Herein, we present points-of-action presented in the framework of the 4 Rs: reduce, reuse, recycle, and rethink (Fig. 3).

Reduce

Reduce consumption of equipment energy

Despite manufacturers' claims of energy efficiency, little data exists describing and comparing the energy consumption of different radiation therapy treatments and/or machines. Energy consumption of different diagnostic imaging modalities is better defined in the radiology literature than therapeutic machines within radiation oncology. Imaging is known to be a large contributor to health care energy use and many radiology departments have invested time and resources to better characterize this use.[38] For example, the University of California, San Francisco has partnered with Siemens Health and is working to meter diagnostic imaging machines to help measure real-world use.[39] Computed tomography (CT) and magnetic resonance imaging account for approximately 4% (615,000 kWh) of a hospitals' yearly energy consumption.[40] In one study, the annual energy consumption of a single CT scanner in a hospital is equivalent to that of 5 households (78,679 kWh) and an MR scanner is equivalent to that of 26 households.[40] Furthermore, emerging research and efforts in radiology demonstrate a reduction in energy expenditure without reducing the number of patient scans performed.[40-42] Specifically, imaging technology most commonly has several distinct modes of operation: scanning, idle or "ready-to-scan," and "off." Surprisingly, the amount of energy in the idle and off states is significant due to the need for cooling.[40] Thus, users could optimize the degree of utilization per period, and manufacturers could decrease energy consumption during nonproductive idle and system-off states.

Radiation therapy machines and other capital equipment likely consume similarly high amounts of energy; however, the exact data are limited to date. Radiation oncologists should engage in similar efforts to measure energy use of our radiation and capital equipment and improve the efficiency of these machines both during treatment and idle periods. We could partner with vendors to emphasize the value of more efficient machines, which could also lead to financial savings with a decreased monthly electric bill.[43] Such information could be used by the Environmental Protection Agency and manufacturers to develop metrics for establishing energy-efficient ratings for radiation therapy machines similar to ENERGY STAR ratings under development for medical imaging equipment and hospitals.[44]

To achieve these goals, an essential initial step will be an analytical evaluation of the different radiation oncology practices/processes with life-cycle assessments (LCA). LCA is an internationally standardized (ISO 14040) modeling tool used to quantify the environmental effect of a product or process across its "life cycle" including extraction of raw materials, manufacturing, and disposal.[45] LCA is the first step toward a better understanding of the environmental effect of radiation oncology delivery before suggesting steps to reduce our carbon footprint.

Reduce consumption of energy broadly

In addition to imaging equipment, lighting, computers, electronics, and picture archiving and communications systems stations significantly contribute to energy use within radiology departments. A radiology department at a university teaching hospital in Dublin, Ireland measured energy use of computers, electronics, and picture archiving and communications systems stations left "on" overnight and/or during weekends and found that the 78% of systems left on resulted in CO_2 emissions equivalent to the annual emissions of over 10 passenger cars.[46] If this rough estimate from a single radiology center was multiplied across the estimated 2313 radiation oncology facilities reported in 2020 in the US,[47] this would result in a reduction of emissions equivalent to the annual emissions of over 23,130 passenger cars (assuming radiation oncology has similar energy use as radiology departments). To better understand this environmental effect, the annual emissions of a typical car in the US assumes 11,500 miles are driven per year for an average vehicle with a fuel economy of 22.0 miles per gallon.

Radiation oncology departments and clinics should encourage habits of regularly turning off lights and powering down electronics and other systems at night and over the weekend when they are not needed for patient care. Such initiatives can reduce energy costs and simultaneously reduce GHG emissions.

Decarbonize energy sources

Decarbonizing energy sources aims to replace fossil fuel (such as coal, oil, or natural gas) with energy sources with significantly less GHG emissions, such as wind, solar, and nuclear energy. Decarbonizing the energy system is a major step in the global efforts to mitigate our carbon footprint. Although this is a bigger task involving hospital-wide systems, radiation oncology departments along with cancer centers should be involved with local, national, and international advocacy groups to pursue green energy options to power the energy needs of our specialty. Increased utilization of renewable energy sources such as wind and solar or more carbon-neutral solutions of nuclear energy can help mitigate the envionrmental impact of our specialty. Physicians and health systems should actively engage in framing local/federal policies and international initiatives (ie, International Energy Agency's pledge for carbon neutrality by 2050) that will help us achieve cleaner energy. For example, the National Health Service in the United Kingdom is aiming to become net carbon zero by 2040. Each hospital or group of hospitals must create a board approved sustainability plans[48] to enable this to happen. As part of this, all National Health Service hospitals are required to switch to renewable energy.

Reduce medical waste

Hospitals are a major source of waste generation with many medical supplies disposed after a single use.[49-51] Ultimately, waste produced in hospitals and clinics ends up in landfills, oceans, or is incinerated.[52] Not only do incinerators and landfills emit gases such as methane into the atmosphere, but the transportation of waste requires fossil fuel-burning trucks and is financially costly.[53] Reducing, or preventing waste, is key to transitioning to climate-smart care. Performing departmental, procedural, or clinical waste-audits can identify areas for waste diversion or waste management improvement.[53] Past audits have noted improper sorting of medical waste (eg, hazardous waste versus solid waste) and disposal of unused products that were opened but ultimately not used.[54-56] Improper hazardous waste disposal increases both the footprint and cost of transporting and treating normal solid waste. Avoiding disposal of unused products can decrease financial and environmental costs associated with product manufacturing, transportation, and disposal. The University of California, San Francisco and Stanford University have collaborated to design a 6-minute waste audit toolkit for brachytherapy that could be used by radiation oncologists globally to analyze clinical processes and reduce financial and environmental costs. Additionally, waste can be reduced through climate-smart procurement and supply decisions. We can choose products with limited or zero packaging waste or encourage suppliers to consider packaging that is recyclable or compostable. Numerous sustainable procurement guides exist such as that published by Practice Greenhealth,[57] which could guide leaders within radiation oncology to establish department- or nation-wide processes to reduce medical waste within the field.

Reuse

Numerous LCAs have highlighted the environmental and economic benefits of moving toward reusable products and away from single-use disposable items. In 2014, University of California Los Angeles Health implemented a program to switch to reusable surgical and isolation gowns. Since then, University of California Los Angeles Health has reported an estimated annual waste reduction of 234 tons and costs savings of over $450,000 each year. Additionally, a recent pandemic-focused study from Stanford University has found reusable gowns use 28% less total energy compared with disposable gowns in the product life cycle leading to a 30% reduction in GHG emissions and a 93% to 99% reduction in solid waste generation.[58]

Within radiation therapy, working to ensure the use of reusable products, operative supplies (eg, applicators, surgical gowns, packs, drapes), and treatment supplies such as patient immobilization devices (eg, reusable Vac-loc systems) has the potential to reduce waste, cost, and the environmental impact. We should prefer reusable products over recycling given the additional energy required in the process of recycling.[59] Further efforts can be made within radiation oncology to collaborate with supply chain leaders, regulatory agencies (eg, the Food and Drug Administration),[60] and industry/original equipment manufacturers to reduce single-use products and favor reusable supplies throughout the scope of our practice. Additionally, radiation oncologists could advocate for environmental impact to be considered within current single-use reprocessing legislation[60] and regulations (21 C.F.R. § 807.20 et seq. [2021]) and support the expansion of the number of supplies that may be reprocessed. Organizations such as Practice Greenhealth and Health Care Without Harm have created sustainable supply chain procurement guides and solutions to address waste. Efforts could be initiated to tailor such recommendations to radiation oncology.

Recycle

Although action steps to "reduce" and "reuse" should be preferred, recycling can reduce overall waste from single-use products, inspire resource-conservative behaviors, and even raise morale.[61] Similar to most clinics and specialties, radiation oncology departments and clinics have the potential to increase recycling globally. A waste-audit of an urban, tertiary care academic medical center estimated 38% of all the department's waste could be recycled and diverted from landfills with improved accessibility to bins, and education to improve appropriate waste allocation.[56] Today, the solid waste accounts for approximately two-thirds of the health care waste stream, with recycling and regulated waste accounting for 26% and 6.3%, respectively.[62] By ensuring appropriate recycling programs are in place, we can divert waste from landfills reducing costs and harm. Numerous examples exist of interprofessional waste reduction "teams" established to improve clinical waste and recycling management practices. As previously discussed, providers can work with suppliers to buy recycled products which can stimulate the market for recycled medical supply materials.

Rethink

Rethinking quality of care, incorporating sustainability research, metrics, and innovation

Environmental sustainability is an underappreciated dimension of health care quality.[63] Data collected from multi-institutional LCAs, and individual practice waste audits can highlight excessive or inappropriate resource use that if reduced may contribute to improved patient care quality and population health. However, the support of the oncology community will be necessary for changes to be implemented. For this reason, clinicians' and patients' understanding and attitudes toward climate change and health care should continue to be assessed across departments.[64]

Numerous LCAs have been applied to entire health sectors at national levels[26,65] and across various clinical services including computed tomography (CT) scans,[66] anesthetic drugs,[67] surgeries,[49,68-70] and inpatient care.[71] The development of such assessments specific to oncology and radiation therapy will be crucial in elucidating and reducing the environmental impact of our practices. LCAs could span the breadth of oncologic services or focus on different aspects of care such as quantifying environmental emissions from diagnostic and treatment machine energy use,[40,72,74] energy sources,[73] anesthetic gas,[67] operating room (OR) and procedural waste management,[40,64,71,74] and data storage (yet to be quantified). With more robust analyses, the environmental effect of each radiation modality (external beam radiation therapy compared with brachytherapy or proton therapy; or conventionally fractionated RT compared with hypofractionation) could be used as an additional metric when cancer outcomes are equivalent.[75]

Furthermore, radiation oncologists could advocate for incorporating sustainability metrics into the methodology for specialty rankings (US News & World Report's "Best Hospitals: Specialty Rankings"), or in Joint Commission Standards to encourage the development of sustainability evaluations and reports by hospitals nationwide.

Low-carbon, climate-smart practices

Outpatient care accounts for a portion of the calculated "inpatient or other care delivery venues" contributing to health care's effect on climate.[26,76] The category "Outpatient Care" is expansive and groups together nonhospital services including medical doctors, dentists, home care, public health departments, and other professional services. Given that many radiation oncologists practice in outpatient settings, radiation oncologists have the opportunity to implement climate-smart practices across numerous free-standing clinics and satellites. My Green Doctor is a free practice management service for outpatient offices that was launched by physicians in 2010. The service guides practices to save money as they transition toward environmental sustainability. To date, 15 health professional societies have chosen to offer My Green Doctor to their members as a free member benefit and is currently used by thousands of practices in more than 43 US states and 80 countries. Practice Greenhealth also offers support and membership for outpatient centers.

Additionally, advocacy for further expansion of telemedicine within radiation oncology has many possible benefits, including reducing the carbon footprint of outpatient care. Telemedicine can broadly be defined as the practice of medicine using technology to deliver care at a distance and can include virtual visits, home monitoring devices, e-mail, and phone communication. Although McKinsey reports have noted physician hesitation to adopt telehealth services,[77] previous studies, including a 2019 survey of radiation oncologists and patients, have described numerous benefits of telemedicine including decreased travel time, personal/financial burdens, travel emissions, and increased communication, access to care, and both patient and provider satisfaction.[78-81] Replacing physical visits with telemedicine appointments, when appropriate, can result in an estimated 40% to 70% decrease in carbon emissions.[82]

In the US, an estimated 575,000 patients are treated annually with daily radiation therapy over the course of 4 to 6 weeks and on average live 12.5 miles from the closest radiation therapy center.[83,84] In the United Kingdom, an estimated 120,000 patients are treated annually with radiation therapy with patients living approximately 12 miles from the closest radiation therapy center.[85-87] Using these data, patient transportation alone would account for an estimated 3546 metric tons of carbon dioxide emissions. Whereas in-person visits are essential for daily treatments, the ability to expand telemedicine for consults and follow-up visits (when clinically appropriate) holds significant potential to reduce resource utilization and emissions. However, it is not without shortcomings and legal considerations, including, but not limited to state licensure, originating sites, and disparate reimbursement.[88] To date, several legislative efforts exist to permanently expand telehealth outside the confines of a global pandemic, and to maintain payment parity between telehealth and in-person services.[89-91] Additional considerations of telehealth will be required such as equity and accessibility, financial and environmental costs of setting up associated infrastructure, increased data usage, and issues arising from performing limited physical examinations. Further research is required to understand the feasibility of telehealth within oncology and the numerous effects of adoption and expansion of telemedicine within radiation oncology specifically.

Furthermore, hypofractionated treatments requiring fewer treatment days compared with conventionally fractionated treatments will presumably be associated with reduced environmental impact due to reduced patient/staff travel, total operating energy, and resource utilization. Hypofractionation has been incorporated into treatment guidelines of many disease sites including breast, and prostate, among many others.[92,93] For example, an analysis of the environmental effect of data from the UK TARGET-A trial and 2 UK NHS hospitals offering TARGIT intraoperative radiation therapy[94] found women treated for breast cancer were able to omit 15 to 30 subsequent care visits when treated with a single intraoperative radiation therapy fraction after lumpectomy compared with EBRT. Women living in urban and semiurban areas were spared traveling 305 and 753 miles, respectively. This averaged to a reduction of 86.7 kg of carbon dioxide per patient randomized to TARGIT. Similar analyses comparing the environmental effect of other hypofractionated regimens will be essential given hypofractionated treatments encompass numerous factors that, when reduced, may ultimately contribute to improved patient care quality (eg, total treatment days, cost, travel) and environmental health.

Additionally, efforts to "rethink" in-person visits in clinical trial design may increase access to care for patients who have historically been underrepresented in clinical trials.[82] Many in-person patient visits are required for clinical trial participation, and adherence to strict schedules presents difficulty to patient groups with limited access to transportation.[95,96] We advocate for clinical trial designs that considers incorporation of telehealth for follow-up and surveillance.[97] This may increase the inclusion of historically neglected groups[96] while simultaneously reducing associated costs,[98,99] burdens,[96,100,101] and carbon emissions associated with transportation. Furthermore, we invite investigators to consider partnership with local oncologists in the delivery of chemotherapy or radiation on clinical trials. By allowing for a telehealth consultation with the sponsoring institution and treatment to be delivered locally, we propose access to care would similarly be expanded, enrollment of diverse populations would increase, and environmental impact would decrease. Parameters would thoughtfully be designed to ensure adherence to clinical trial protocols, and treatment specifics (such as treatment volumes or chemotherapy schedules) should be shared for centralized review and collaboration. We challenge investigators to consider environmental impact in the design of clinical trials so that as we consider the future of cancer treatment, we also work toward a sustainable future.

Additional low-carbon approaches

Radiation oncologists and our professional societies have an obligation to investigate and promote greater sustainability of our meetings and conferences. Since the onset of the COVID-19 pandemic, the use of teleconferencing for international and national conferences, such as American Society for Radiation Oncology (ASTRO), has risen steeply. Like telemedicine, teleconferencing is associated with reduced travel emissions, as well as increased accessibility and equity for individuals with financial, personal, professional, medical, and/or geographic constraints.[102-105] However, teleconferencing (similar to remote work) is not without limitations such as reduced engagement and collaboration.[106]

Radiation oncologists are not unique in their desire to network and collaborate. A 2020 Nature briefing[107] found that total travel for 28,000 attendees to a scientific conference in San Francisco, California accounted for 177 million travel miles and 80,000 tons of carbon dioxide emitted. By comparison, ASTRO attendance in 2019 consisted of 12,000 attendees. The following year when the conference was online-only, attendance increased by 62%. The same study evaluated a scenario in which the meeting was held in a more central location of Chicago, Illinois, and found emissions would be reduced by 12%. If the conference were held biennially, rather than annually, and if conference organizers encouraged the 36% of participants who in this study traveled the furthest to instead participate virtually, this would reduce the travel footprint by 90%. However, it is unlikely that virtual networking will be able to replace in-person interactions, particularly for early-career attendees. Potential options to reduce travel-associated conference emissions include (1) offering hybrid in-person and online attendance options, (2) alternating in-person and online conferences, (3) hosting biannual or less frequent in-person meetings, and (4) establishing a decentralized hub-and-spoke model with multiple conference venues. Such interventions would require an analysis of costs, engagement, accessibility, and associated emissions from alternative non-travel related activities.

Similarly, opportunities exist to advocate for low-carbon education opportunities. The COVID-19 pandemic has encouraged the expansion of teleconferencing and its use for education (eg, didactic lectures, tumor boards, and chart rounds). To date, a variety of low-carbon, tele-education opportunities exist within radiation oncology such as Rayos Contra Cancer, eContour, and Radiation Oncology Virtual Education Rotation. Many carbon-friendly, virtual opportunities have flourished for networking and mentoring such as American Brachytherapy Society (ABS) #NextGenbrachy program, the Association of Residents in Radiation Oncology (ARRO) *Contour Connections* programming, and the Society for Women in Radiation Oncology Mentorship Program. Relatedly, radiation oncology residency training programs can support a 2022 initiative titled Interview Without Harm, calling for a permanent shift to virtual residency interviews with the focus of creating a sustainable, equitable, and efficient interview system.[108] Opportunities exist for further expansion of such programs, the investigation into the total carbon emission mitigation of such efforts, and innovative training programs such as ABS's virtual reality brachytherapy online training.

Address health equity

Climate change directly affects upstream determinants of health, such as geographic location, socioeconomic status, access to food, housing, transportation, and care that contribute to health care inequities.[109] The effects of climate change on health is amplified for vulnerable patients with pre-existing health conditions and limited community resources.[110,111] This is especially relevant for cancer patients, for whom inequities are rooted in a long history of structural, racial, and socioeconomic barriers to access and treatment.[112,113] Specific challenges cancer patients face include, but are not limited to, access to appropriate screening and care, geographic access to cancer centers, dependence on emergency care facilities and public transportation, medical distrust, and food and housing insecurities.[96,114-116] Environmental exposures,[117-119] climate disasters,[15] and environmental injustices[120-125] further amplify many of these factors. Advocacy for resilient, climate-smart health systems addresses both access to care and the upstream determinants of health. We seek to further normalize the inclusion of environmental factors of health and environmental justice within discussions of health equity as these concepts are closely intertwined and promotion of one will directly address the other.[9]

Physicians as advocates

A collective effort between physicians, scientists, advocacy groups, professional associations, local, state, and federal governments, financial institutions, and industry is needed to investigate and invent new solutions to delivering radiation therapy at a decreased cost to the environment. Modeling successful climate endeavors in other specialties, partnering with business corporations, software developers, and professional associations such as ASTRO and ARRO, and improving involvement with local, state, and federal governments are important places to start in addressing the climate crisis.

Professional societies like ASTRO can be leaders in addressing our current climate crisis by prioritizing environmental sustainability in their endeavors. The ARRO Global Health Subcommittee has created a Climate Health, Equity, and Sustainability Task Force to assist with advocacy and to address the overlap between climate change, global health, and oncology. ASTRO and other professional organizations can form similar initiatives to bring together passionate individuals motivated to address and improve the ecological effects of our treatments.

We call on physicians and scientists within the field of radiation oncology and beyond to identify novel solutions to measure and reduce our specialty's contributions to climate change. Health care professionals and radiation oncologists are well-positioned to be advocates for change within our practices and the health care system at large to not only join in recognizing how climate change affects health but also proactively aid in the transition to sustainable care. Health Care Without Harm seeks to transform health care worldwide so the sector reduces its environmental footprint and becomes a leader in the global movement for environmental health and justice.[126] Working closely with Health Care Without Harm, Practice Greenhealth[127] is the leading membership and networking organization for sustainable health care, delivering environmental solutions to more than 1400 US hospitals and health systems.

To date, 180 organizations in the US, including the AMA, have declared climate change a health emergency.[128] In 2019, the AMA passed a resolution supporting the inclusion of climate change education into medical and patient education and encouraged physicians to serve as role models for promoting environmental sustainability. Medical Students for a Sustainable Future has encouraged students and schools across the nation to pilot and implement climate education into their curricula and host virtual elective courses.[129] Similar educational opportunities exist for residents and physicians.[130] Profession-wide efforts continue to be essential in creating a fairer and healthier world.

Conclusions

The health care system contributes significantly to today's climate health crisis. All efforts addressing the crisis are important due to their direct emissions reduction potential, and the example they set for the health care system and the patients who need the care. Although the effects of increasing global temperatures on human health are well studied, the effects of health care, and specifically oncology and radiation treatments, on contributing to climate change are not. The radiation oncology community has a unique opportunity to use our technological expertise and awareness to assess and minimize the environmental impact of our care and set the standard for sustainable health care practices for other specialties to emulate.

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