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Scientific Article

Measuring Global Inequity in Radiation Therapy: Resource Deficits in Low- and Middle-Income Countries Without Radiation Therapy Facilities

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Abstract

Purpose: Although radiation therapy (RT) is an effective and inexpensive pillar of multidisciplinary cancer care, access to RT facilities remains highly inequitable globally. Numerous studies have documented this resource gap, yet many countries continue facing their raging cancer epidemics ill-equipped. In this study, we present an estimation of resource deficits in low- and middle-income countries (LMICs) without any RT facilities at all.

Methods and Materials: This study builds on publicly available data on country classification, population, cancer incidence, and RT requirements provided by the World Bank Group, the World Health Organization, and the International Atomic Energy Agency. Leveraging these data, we developed a capacity-planning model to estimate the current deficit of fundamental RT resources for LMICs with more than 1 million inhabitants and no active RT facilities.

Results: There were 23 LMICs with a population of more than 1 million inhabitants and without any active RT facilities, 78% of which were located in sub-Saharan Africa. The aggregate population of these countries was 197.3 million people. The largest countries without RT facilities were Afghanistan and Malawi, with a population of 38.0 million and 18.6 million inhabitants, respectively. Estimated cancer incidence for all countries under study totaled at 134,783 new cases per year, 84,239 (62.5%) of which would have required RT. There was an aggregate deficit of 188 megavoltage machines and 85 brachytherapy afterloaders, along with simulation equipment and human capital in the magnitude of approximately 3363 trained radiation oncology staff.

Conclusions: Hundreds of thousands of patients with cancer in LMICs continue to live in countries without access to RT in their own country. This extreme form of global health inequity requires urgent and decisive action, the success of which depends on the integration of international and local efforts.

Introduction

Access to radiation therapy (RT) facilities remains highly inequitable globally. Although high-income countries share in an abundance of RT facilities, many low- and middle-income countries (LMICs) continue to struggle with severe undersupply.[1-3] The World Health Organization identified health equity as an important vision long ago.[4] Yet, it is over the past 2 decades that "health

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inequalities," that is, the unequal distribution of health care resources and consequently health outcomes, have arguably become "health inequities," that is, "unfair, avoidable and remediable differences in health status between countries."[5] Although many root causes have been identified for lack of decisive action, we now need to seize the renewed sense of urgency instilled in the international radiation oncology community. The goal should be to more fiercely tackle global health inequity, as LMICs find themselves in the midst of their long-prognosticated cancer epidemics⍰still without the required resources to combat cancer.[3,6]

Over the past 2 decades, there have been numerous studies documenting the lack of radio-oncological health care resources in LMICs. In 2003, the International Atomic Energy Agency (IAEA) issued the report "A Silent Crisis: Cancer Treatment in Developing Countries," highlighting a gap of 5000 megavoltage machines (MVMs) in developing countries.[7] In a *Lancet Oncology* series on cancer control in Africa published in 2013, Abdel-Wahab et al[8] reported that only 23 and 20 of 52 African countries have tele- and brachytherapy facilities, respectively. Zubizarreta et al,[1] in a comprehensive assessment of the need for RT in LMICs, found that more than one-half of patients in need of RT in LMICs lack access, and they estimated that the infrastructure gap in LMICs continues to lie in the range of 4300 to 7000 MVMs. In an updated RT capacity assessment for Africa published in *Lancet Oncology*, Elmore et al[3] concluded that no single African country has sufficient RT resources. Last year, Gospodarowicz[9] published an editorial on the global access of RT in *JCO Global Oncology*. In it, Gospodarowicz highlighted that although the global RT resource gap is widely documented and the field of radiation oncology well-positioned to substantially narrow it, addressing these extreme health inequities remains a highly complex "work in progress."[9]

RT has been documented to be a safe, effective, and affordable pillar in modern oncologic therapy.[10] For many of the most common cancer types in LMICs, curative or palliative RT is essential for effective treatment. However, as building a successful RT facility requires a high upfront investment, RT resources in particular are neglected when planning and building cancer treatment facilities in LMICs.[11] There have been other original research studies, older and more recent ones, that have analyzed capacity, economics, and governing principles of RT in high-income countries[12-15]; estimated RT resource gaps in LIMCs with existing RT facilities mostly[1,16-18]; and addressed subsets of LMICs or subgroups of underserved populations, for example, those located on the African continent or indigenous populations.[8,19,20] To the best of our knowledge, no published study has focused exclusively on countries that have continuously received the least attention: LMICs, which continue to operate without any RT facilities to date. In an effort to document and analyze the most extreme form of health inequity in radiation oncology today, we focus our capacity estimation analysis on these countries and also conduct an in-depth analysis of the identified LMICs to detect uniting features and analyze structural factors that help sustain these health inequities.

Methods and Materials

Modeling approach

This project has been conceptualized as a resource capacity assessment in global radiation oncology. We develop a simple capacity planning model to estimate minimum infrastructure and human capital requirements in some of the most resource-constrained countries in the world (Fig. E1a, E1b). In following previously published studies focusing on gap analyses of RT resources in LMICs, we draw on publicly available data and employ a forecasting methodology that is well-established and has been used in other studies to ensure comparability of findings.

The estimates of the deficient RT resources comprise both infrastructure and human capital. For the purposes of this study, we confined the analysis to the fundamental RT resources set out by the IAEA in their "Human Health Report No. 13 on Staffing in Radiotherapy: An Activity Based Approach," which was published in 2015.[21] RT infrastructure includes linear accelerators, brachytherapy afterloaders, computed tomography (CT) simulators, orthovoltage machines, and CT scanners. Human capital consists of radiation oncologists, medical physicists, RT technicians, and nurses.[21]

Sources of data

The World Bank Group (WBG) country classification by income level was used to screen for today's LMICs. This classification is published by the WBG on a yearly basis and categorizes countries into 4 income buckets based on gross national income (GNI) per capita in US dollars. The 4 income buckets comprise low-, lower-middle, upper-middle, and high-income countries, with cutoff points and economic indicators being reviewed whenever the classification is updated. For the 2021 and 2022 iteration, the categories were low (<$1046), lower-middle ($1046-$4095), upper-middle ($4096-$12,695), and high (>$12,695). The data can be downloaded directly from the WBG website.[22]

The WBG's Databank on World Development Indicators (WDI) was used to fetch the latest population figures for all countries under study. The WBG describes its WDI as a "compilation of relevant, high-quality, and internationally comparable statistics about development and the fight against poverty."[23] Under the data theme "people," the WDI offers population estimates for countries. The obtained population figures were last updated by the WBG on February 17, 2021. They are downloadable from the WBG's databank website.[23]

For the purposes of this study, we used the cancer incidence estimates provided by the Global Cancer Observatory of the World Health Organization's International Agency for Research on Cancer. The online database GLOBOCAN 2020 includes national incidence and mortality estimates for 185 countries and is accessible via the website *Cancer Today*. The incidence and mortality estimates are available online, and Annex A details the sources and methodologies for all estimates per country.[21] The latest available estimates exist for the year 2020, which we employed for our analysis.[24]

The Directory of Radiotherapy Centers (DIRAC) database of the IAEA represents "the world's most comprehensive database on radiotherapy resources."[25] It compiles up-to-date and historical data starting in 1959 on hardware in radiation oncology centers, including "teletherapy machines, brachytherapy units, treatment planning systems, computed tomography systems and simulators."[25] According to the website, the DIRAC database is updated on a daily basis, fulfilling the ambition of integrating any breaking news on the opening of RT centers around the world. The data are available via the DIRAC website, which also provides maps and publications. The database was used to screen for countries without any RT equipment.[25]

In the "Human Health Report No. 13 on Staffing in Radiotherapy: An Activity Based Approach," the IAEA aimed at providing an evidence-based algorithm on how to build and sustain RT facilities. In laying out their staffing algorithm, the IAEA differentiates between (1) basic RT service; (2) large academic facility in a middle-income country; and (3) large academic facility in a high-income country. For each facility, assumptions on the staffing of the facility are provided[21] (Table E1).

Important model specifications and assumptions

We opted for estimating RT resource deficits based on the assumption that only basic RT services as per the IAEA nomenclature would be built.[21] This simplification is justified, as (1) none of the analyzed LMICs currently has any RT facilities and the basic RT services would be the first to be built; (2) some analyzed LMICs have only small populations; and (3) others are quite vast, most likely requiring RT facilities in different parts of the country.

To render the RT resource estimates of our model more meaningful, we chose a population cutoff of 1 million for a country to be included in the analysis. The IAEA recommends a MVM for every 250,000 inhabitants.[20] Although the availability of a MVM per 250,000 inhabitants, as is usually the case in high-income countries, might be regarded as the ultimately desirable target, the availability of a MVM per every 1 million inhabitants already helps to significantly reduce the cancer burden in LMICs.[1]

Following Rosenblatt et al,[26] whose team assessed the optimal RT utilization (RTU) rates in high-income countries, we assumed a RTU of 62.5% throughout our analysis. An RTU of 62.5% means that RT is employed in the disease course of almost two-thirds of cancer cases, either in a curative or palliative intent as well as for a reirradiation.[26]

Results

Countries in focus

The 2021 and 2022 country classification of the WBG lists 218 countries, 137 (63%) of which are categorized as LMICs. According to the DIRAC database, 43 (31%) of these countries do not possess any RT facilities. Per the WBG's WDIs, 20 (47%) of these countries had fewer than 1 million inhabitants in 2021, many of which are island states in the East Asia and Pacific Region. The remaining 23 (53%) LMICs all had more than 1 million inhabitants in 2021 and were therefore included into our analysis. A total of 78% (18/23) of identified LMICs are located in sub-Saharan Africa, with each of the remaining 5 countries located in a different geographic world region (East Asia and Pacific, Europe and Central Asia, Latin America and Caribbean, Middle East and North Africa, and South Asia). The large majority of these LMICs were low-income countries (15/23; 65%), with 6 countries (26%) being classified as lower-middle-income and 2 countries (9%) as upper-middle-income countries (Kosovo and Equatorial Guinea) (Table 1, Fig. 1).

Underserved population

According to the WBG's WDIs, the median population of the selected LMICs was 5.4 (interquartile range [IQR], 2.2-11.7) million inhabitants in 2021. Taken together, the population of the selected LMICs amounted to 197.3 million people, which constituted 2.5% (197.3 million/7875 million) of the world population in 2021. The largest LMIC without RT facilities was Afghanistan, with a population of 38.0 million inhabitants. The second- and third-largest LMICs without RT facilities were Malawi (18.6

Table 1 Population figures, cancer incidence, and estimate of annual cases requiring RT in LMICs without any RT facilities and more than 1 million inhabitants

Country	Region	Country classification	Population	Cancer incidence	Cases per year requiring RT
Afghanistan	South Asia	Low income	38,041,754	22,817	14,261
Malawi	Sub-Saharan Africa	Low income	18,628,747	17,936	11,210
Chad	Sub-Saharan Africa	Low income	15,946,876	8575	5359
Somalia	Sub-Saharan Africa	Low income	15,442,905	10,134	6334
Guinea	Sub-Saharan Africa	Low income	12,771,246	7871	4919
Benin	Sub-Saharan Africa	Lower-middle income	11,801,151	6747	4217
Burundi	Sub-Saharan Africa	Low income	11,530,580	7929	4956
Haiti	Latin America and Caribbean	Low income	11,263,077	12,404	7753
South Sudan	Sub-Saharan Africa	Low income	11,062,113	6312	3945
Togo	Sub-Saharan Africa	Low income	8,082,366	5208	3255
Sierra Leone	Sub-Saharan Africa	Low income	7,813,215	4708	2943
Republic of the Congo	Sub-Saharan Africa	Lower-middle income	5,380,508	2478	1549
Liberia	Sub-Saharan Africa	Low income	4,937,374	3552	2220
Central African Republic	Sub-Saharan Africa	Low income	4,745,185	2675	1672
West Bank and Gaza	Middle East and North Africa	Lower-middle income	4,685,306	4779	2987
Eritrea	Sub-Saharan Africa	Low income	3,213,972	2408	1505
The Gambia	Sub-Saharan Africa	Low income	2,347,706	1035	647
Lesotho	Sub-Saharan Africa	Lower-middle income	2,125,268	1876	1173
Guinea-Bissau	Sub-Saharan Africa	Low income	1,920,922	1127	704
Kosovo	Europe and Central Asia	Upper-middle income	1,794,248	1479	924
Equatorial Guinea	Sub-Saharan Africa	Upper-middle income	1,355,986	927	579
Timor-Leste	East Asia and Pacific	Lower-middle income	1,293,119	814	509
Eswatini	Sub-Saharan Africa	Lower-middle income	1,148,130	992	620
Total	Mixed	Mixed	197,331,754	134,783	84,239

Abbreviations: LMIC = low- and middle-income country; RT = radiation therapy.

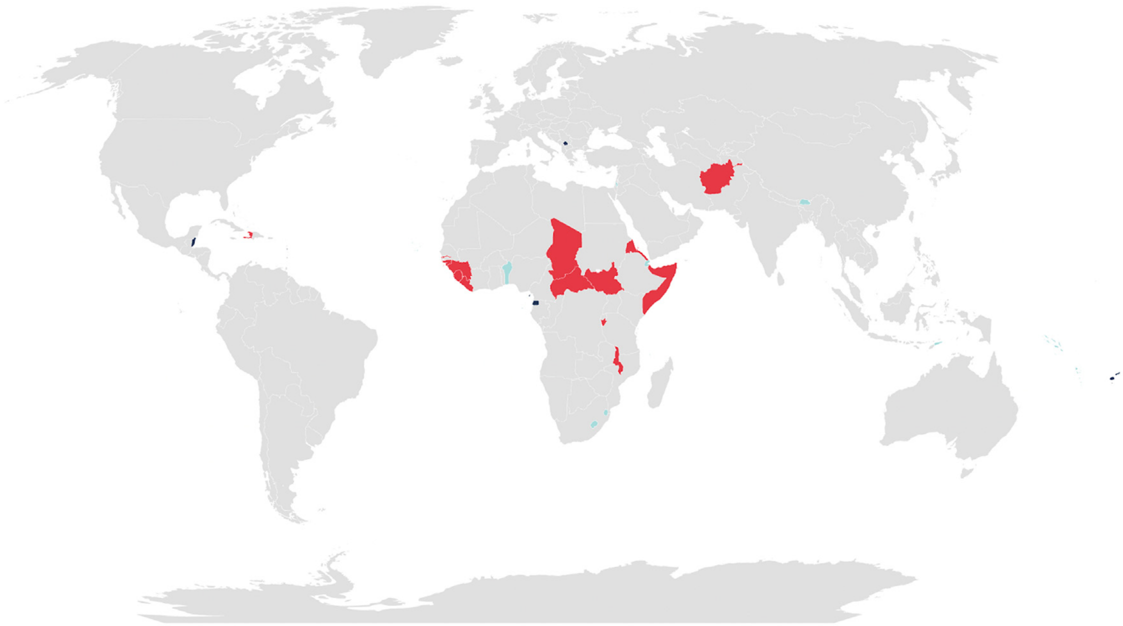

Figure 1 World map showing low- and middle-income countries without radiation therapy facilities. Red = low-income country; light blue = lower-middle−income country; dark blue = upper-middle−income country.

million) and Chad (15.9 million). The 3 smallest LMIC without RT facilities and a population of more than 1 million inhabitants in 2021 were Equatorial Guinea (1.4 million), Timor-Leste (1.3 million), and Eswatini (1.1 million) (Table 1).

The median cancer incidence for the LMICs under study was 4708 (IQR, 1678-7900) new cases for the year 2020, according to the data available in the online database GLOBOCAN. The total estimated cancer incidence amounted to 134,783 new cases across all assessed countries. The estimated cancer incidence for each county largely followed the population figures, with several notable exceptions such as Somalia, Haiti, and West Bank and Gaza, where cancer incidence estimates were greater than the ones for similarly sized peer countries. As per an RTU of 62.5%, the annual new cancer cases requiring either curative or palliative RT were 84,239 across all selected LMICs. The median number of new cases requiring RT per country was 2943 (IQR, 1048-4938) (Table 1).

Estimated resource deficits

Based on our basic capacity estimation model, a median of 7 (IQR, 3-11) linear accelerators were lacking per analyzed LMIC, amounting to a total MVM deficit of 188. In terms of brachytherapy equipment, a median of 3 (IQR, 1-5) afterloaders were missing per LMIC, totaling at a shortage of 85 machines. Moreover, for the countries under study, there was a corresponding median deficit of 7 (IQR, 3-11) CT simulators, orthovoltage units, and CT scanners, respectively, to prepare and plan individual cancer treatments at each basic RT service facility.

There also was a human capital shortage corresponding to the RT infrastructure deficit. A median of 27 (IQR, 11-50) radiation oncologists was lacking per LMIC analyzed, totaling 836 specialist radiation oncologists. In addition, 655 medical physicists were missing, which equated to a median of 23 (IQR, 8-39) per LMIC. The human capital requirement for RT technicians was largest, with a median of 46 (IQR, 16-77) per country and totaling 1310. Lastly, a median of 20 (IQR, 7-33) nurses was lacking, which amounted to a total of 562 certified nursing staff (Table 2).

Discussion

The majority of assessed LMICs were located in Central and Eastern sub-Saharan Africa. By the nature of this study, they ranked among the poorest countries globally by GNI. According to the United Nations' Human Development Index, which is a broader metric for human development than the GNI and includes "a long and healthy life, being knowledgeable and hav[ing] a decent standard of living," only 4 countries (Equatorial Guinea, Eswatini, Liberia, and Timor-Leste) featured in the "medium" bucket of countries in 2019.[27] The remainder of LMICs assessed in this study held ranks between 157 and 189 and thus belonged to the least-developed counties in the world.[27] Further uniting features between some of these LMICs was that they recently faced wars or armed conflicts, for example, Afghanistan, Benin, or Somalia,[28]

Table 2 Estimated resource needs of LMICs without any RT facilities with more than 1 million inhabitants

Country	Linacs	After-loaders	CT simulators	Orthovoltage units	CT scanners	Radiation oncologists	Medical physicists	RTTs	Nurses
Afghanistan	32	14	32	32	32	143	111	222	95
Malawi	25	11	25	25	25	112	87	174	75
Chad	12	5	12	12	12	54	42	83	36
Somalia	14	6	14	14	14	63	49	99	42
Guinea	11	5	11	11	11	49	38	77	33
Benin	9	4	9	9	9	42	33	66	28
Burundi	11	5	11	11	11	50	39	77	33
Haiti	17	8	17	17	17	78	60	121	52
South Sudan	9	4	9	9	9	39	31	61	26
Togo	8	3	8	8	8	27	25	50	22
Sierra Leone	7	3	7	7	7	29	23	46	20
Republic of the Congo	3	2	3	3	3	15	12	24	10
Liberia	5	2	5	5	5	22	17	35	15
Central African Republic	4	2	4	4	4	17	13	26	11
West Bank and Gaza	7	3	7	7	7	30	23	46	20
Eritrea	3	1	3	3	3	15	12	23	10
The Gambia	1	1	1	1	1	6	5	10	4
Lesotho	3	1	3	3	3	12	9	18	8
Guinea-Bissau	2	1	2	2	2	7	5	11	5
Kosovo	2	1	2	2	2	9	7	14	6
Equatorial Guinea	1	1	1	1	1	6	5	9	4
Timor-Leste	1	1	1	1	1	5	4	8	3
Eswatini	1	1	1	1	1	6	5	10	4
Total	188	85	188	188	188	836	655	1310	562

Abbreviations: CT = computed tomography; linacs = linear accelerators; LMICs = low- and middle-income countries; RT = radiation therapy; RTT = radiation therapy technician.

and that they had younger populations, for example, the population of Malawi and Haiti had median ages of 18 and 24 years, respectively.[29]

Our assessment showed that 31% (43/137) of LMICs still lack RT facilities. Compared with figures from a capacity estimation exercise that Datta et al[18] conducted in 2014, according to which 40% (55/139) of LMICs were without RT facilities, this constitutes only a small improvement in almost a decade. Especially in Africa, the situation remains complex: Levin et al[20] reported that of 56 African countries, 22 had MVMs in 1999, which amounted to a proportion of 61% (34/56) of countries without RT facilities. According to an analysis by Abdel-Wahab et al,[8] this proportion stood at 54% (29/52) by 2013. In the most recent IAEA update on RT resources in Africa by Elmore et al,[3] the share of countries without RT facilities in Africa was 52% (28/54). Per our assessment, 18 African LMICs with a population of more than 1 million inhabitants remain without RT facilities, which suggests that the deficit in Africa has further narrowed, yet highlights the persisting global health inequities, which proved very hard to overcome during the past 3 decades. Elmore et al[3] hypothesize that although significant progress has been made in recent years, Africa will never close its RT resource gap at the current rate of improvements.

According to our analysis, an aggregate deficit of 188 MVMs and 85 afterloaders existed for the LMICs included into our study. RT resource gap estimates are difficult to compare between studies, as lists of countries and time horizons for predictions vary greatly. Datta et al[18] estimated that countries without RT facilities in 2014 would require 390 MVMs by 2020, which equates to a rate of 65 MVMs per year. Elmore et al[3] estimated that by 2030, between 1500 and 2000 MVMs would be required to completely close Africa's gap. Although the authors did not provide an aggregate estimate for countries in Africa without any RT facilities, the forecasted deficit was the range of about 150 to 200 MVMs per year, with approximately 50% of countries in Africa remaining without any RT facilities to date. In relation to the underserved population, our estimate of 188 MVMs for 197.3 million people amounts to a ratio of 1 MVM per 1.01 million inhabitants. These figures can be understood as a starting point for the development of an RT facilities ecosystem in the assessed countries. According to the high-level IAEA recommendations or compared with the MVM density found in high-income countries, the figure should be 4 to 6 times as high.[30] As we followed common assumptions such as an RTU of 62.5% and a case load per MVM of 450, reasons for our lower-end estimate might lie in erroneous, lower-than-actual cancer incidence figures or in the fact that many of the assessed LMICs have young populations, where higher cancer rates manifest in the future.

Given the limited progress of recent years and the commonalities of the LMICs analyzed in this study, our study underscores the notion that systemic and structural problems for global health inequity weigh heavily, especially for the provision of RT resources. In 2014, Atun et al[11] advocated a "change in approach" to tackle RT resource deficits in LMICs. They argued that as countries become richer and extreme poverty is eliminated within our lifetime, the most important task for the global radiation oncology community is to make sure that RT is widely recognized as an efficacious tool to fight cancer, so that RT would feature high on essential resource lists when investment decision will be made.[11] Although the authors acknowledged the many small initiatives and nongovernmental organizations that work toward narrowing the RT resource gap, they argued that this local, grassroots-type approach alone, paired with the perception that the IAEA is lastly responsible to solve the global health inequity with respect to RT resources, will fail.[11] However, money alone will not solve the global health inequity—quite to the contrary, it has been argued that efforts to reduce the global cancer burden have long been too narrowly conceived, with the matter having been viewed through a Western lens, not taking into account local complexities like political realities, human rights, and governance issues, to just name a few.[31]

The solution of the global health inequity in radiation oncology will require an integration of international and local efforts. In an article on improving global collaboration in radiation oncology published in *Lancet Oncology* in 2021, Kassick and Abdel-Wahab[32] described recent efforts by the global oncology community to come together and act decisively. In 2 working meetings spearheaded by the IAEA, which took place in 2020 and 2021, the global oncologic community identified 5 urgent priorities: (1) creation of the ORION database, where information on global initiatives in radiation oncology is to be found; (2) launch of the comprehensive e-learning platform to globally disseminate educational material; (3) identification of the International Research Integration System to facilitate exchanges regarding research projects in global cancer care; (4) development of key messages on RT to spread the news; and (5) creation of an international society of radiation oncology.[32] As these initiatives are launched, particular attention should remain on LMICs without any RT facilities, as chances are high that they might again not been reached by these efforts.

This study is the first to exclusively focus on LMICs without any RT facilities in an attempt to document the extremes of global health inequity in radiation oncology in the 21st century. The easy-to-follow, rigorous modeling methodology is a strength of our study, which allowed for coming up with estimates of the minimum RT requirements for some of the world's poorest, underdeveloped and most neglected countries. Although the leveraged population estimates can generally be regarded as proficient, the cancer incidence data need to be highlighted as the model's weakest link. When erroneous, they tend to underestimate the number of annual cancer cases, thus resulting in downward-biased RT resource estimates. Given this limitation, we confined our analysis to the current period rather than making additional assumptions about the future.

Conclusion

Although RT is known to be a safe, efficacious, and cost-effective pillar in modern cancer care, hundreds of thousands of patients with cancer in LMICs do not have access to basic RT facilities in their country. This global inequity in radiation oncology developed long ago and has persisted for decades. It requires urgent and decisive action, the success of which more than ever depends on the integration of international and local efforts alike.

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.adro.2023.101175.

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