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Radiation Oncology in Global Health

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Introduction

Radiation oncology is one of the three main therapeutic disciplines of clinical oncology, along with medical and surgical oncology [1]. As in radiology, the team members in radiation oncology work together in patient care. Radiation oncologists are physicians who work closely with a multidisciplinary team of oncologists and radiation therapy staff to treat mostly cancer (and some benign conditions) using ionizing radiation.

At the time of consultation, a radiation oncologist assesses the need for additional diagnostic evaluation or clinical interventions. Then, they integrate their knowledge of the patient's diagnosis, diagnostic studies, natural history of disease, and general medical condition with their understanding of medical physics, radiobiology, and radiation safety to answer the following questions to guide therapy [1]:

1. Indication for treatment: local control, symptom relief, improving quality of life or cure in

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D. J. Mollura et al. (eds.), *Radiology in Global Health*,
https://doi.org/10.1007/978-3-319-98485-8_25

the context of available data, the patient's clinical condition, and personal goals
2. Intent of treatment: palliative vs. definitive with use of single or combined therapies (e.g., systemic agents, surgery, oxygen, heat)
3. Target delineation: identifying the volume of tissue to be irradiated using understanding of anatomy, radiology (i.e., X-rays, CT, MRI), knowledge of disease
4. Method of delivery and treatment techniques: teletherapy vs. brachytherapy, 3D conformal vs. intensity-modulated radiation therapy, radiosurgery, stereotactic body radiation therapy, and particle/energy used for treatment delivery (e.g., photons, electrons, protons)
5. Prescription: total dose to target, fractionation (number of treatments), and dose per fraction
6. Normal tissue tolerance/toxicity: balancing treatment benefit with acute and chronic toxicity to maximize the effect of local treatment while minimizing the risk of damage to normal tissues

Treatment duration may range from 1 day to over 8 weeks; during this time, the radiation oncologist manages treatment-related adverse effects and coordinates care of the patient with other involved disciplines. He or she serves as leader of the radiation oncology team, working closely with all members.

While patients rarely meet medical physicists, their work is critical for safe, accurate delivery of the highest quality radiation therapy and monitoring staff safety. Their work requires close partnership with physicians, dosimetrists, and therapists while applying knowledge of radiation physics, radiobiology, and radiation safety. Physicists perform routine quality assurance (QA), investigating equipment and imaging system performance as well as quality for treatment; they work closely with IT and engineering staff ensuring that all equipment (machines, computers, software) functions optimally and is compliant with international/national standards. They perform accurate measurements of radiation output from radiation treatment machines as well as output from radioactive sources used during therapy, confirming that the planned dose is actually delivered to the planned target during treatment.

For new machines and equipment, they perform calibration, commissioning, and installation of radiotherapy equipment ensuring accurate delivery of radiation therapy. Research is a vital role of physicists; their fields of study include but are not limited to the application of new technology, high-energy machines, and development of new methods of treatment delivery and radiation measurements [2, 3].

The medical dosimetrist is a member of the radiation oncology team that works closely with radiation oncologists, medical physicists, and therapists to design radiation treatment plans applying knowledge of radiation treatment machines, physics, radiology, anatomy, and radiobiology.

Prior to treatment planning, dosimetrists assist during simulations (e.g., clinical setups, CT, PET, MRI) to ensure optimal immobilization for the patient and treatment delivery. Plan design requires use of computer software planning systems or manual computations to optimize beam geometry such that dose to the target is maximized and dose to critical structures is minimized as per the radiation oncologist's prescription; they also use beam-modifying devices (such as wedges or blocks) to manipulate the beam and achieve this goal. For cases that require the use of PET scans or MRIs, the dosimetrist registers these images to the treatment planning software so that these images can be used to delineate the treatment target. For brachytherapy cases, dosimetrists perform planning and dose calculations needed prior to treatment delivery. Once planning is complete with approval from the physician, dosimetrists perform calculations for accurate delivery of the prescribed dose and verify calculations prior to treatment delivery [4].

A patient referred for radiotherapy first meets radiation therapists during the time of treatment simulation when the patient undergoes imaging (clinical setup, CT, MRI, PET) in the treatment position. Therapists assist in choosing this position and designing an immobilization device that would be most comfortable for the patient as well as most reproducible for daily treatment delivery.

Therapists see the patient daily during the course of treatment. They are trained in administering therapeutic doses of ionizing radiation to a target via teletherapy (typically linear accelerators or Cobalt machines), using their knowledge of physics, radiology, patient anatomy, patient care, and radiation safety [5–7]. They must accurately reproduce the patient's position for treatment by lining up the patient using a system similar to coordinates on a grid system; this process often requires evaluation of imaging (X-ray, CBCT, MRI) and changing patient position such that treatment position closely resembles position at the time of simulation. Therapists monitor patients while operating the teletherapy unit to accurately and safely deliver treatment [5–7].

Radiation oncology nurses play a critical role in patient care and advocacy; they have daily interactions with patients and their families while working closely with the radiation oncologists, therapists, and clinical social workers [8]. Prior to the start of treatment, nurses assist with patient assessment in multiple domains (health, physical, mental, emotional) at the time of consultation and teach patients and family members about treatment-related adverse effects and management.

Nurses assist with procedures such as brachytherapy, invasive examinations, drug administration, and the simulation process. During the course of treatment, nursing staff are critical providers of patient support, helping patients and their family members navigate through complex medical systems while coordinating care with other specialties (oncologic and nononcologic) and coordinating any additional work-up. They also manage treatment-related toxicities closely with patients [8].

Radiation oncology nurses serve as essential intermediaries for patients and physicians, while building their own rapport with patients. They often inform physicians of the patient's current condition and need for additional management; for patients, they answer many questions while providing physical and emotional support before, during, and after treatment.

To provide comprehensive medical, physical, emotional, and psychological care for radiation oncology patients before, during, and after treatment, there are additional members of the radiation oncology team. Patient care is enhanced by a number of other individuals including but not limited to clinical social workers, psychologists/psychiatrists, nutritionists, speech-language pathologists, dentists, nurse practitioners, physician assistants, and research staff [1].

Gaps in Radiotherapy

The global demographic and epidemiological transitions predict an increase in the cancer burden in the next few decades [9, 10]. A 53% increase is predicted from 2014 to 2030 with more than 20 million new cancer cases expected annually [10].

Radiotherapy is an essential component in the management of cancer that can be used with a curative intent, either alone or in combination with surgery and/or systemic treatments. Also, it can be used with a palliative intent to alleviate symptoms in patients with incurable disease. Radiotherapy is estimated to be required in 50% to 60% of newly diagnosed cases [11].

In recent years, a large body of evidence has emerged on the demand and supply of radiotherapy worldwide [12–19]. Gaps to radiotherapy access have been identified, but in particular in low- and middle-income countries (LMICs). Initiatives that address the gaps must take into consideration quality and safety of radiotherapy [20]. Resources, including those from the International Atomic Energy Agency (IAEA), are needed to support radiotherapy activities; careful planning is essential to avoid compromising safety and quality [21, 22]. Financial resources for equipment must be coupled with an understanding of the advantages, disadvantages, and limitations of available technologies [23, 24]. In addition, an accurate assessment of the radiotherapy condition on the ground and in-depth knowledge of the unique local needs is essential to make appropriate equipment recommendations.

Radiotherapy is cost-effective as a key treatment modality for cancer with substantial positive economic returns associated with the expansion of access to radiation oncology in LMICs [17]. Bridging the gap in global access to radiotherapy is both affordable and feasible. Disparities to meet the demand for radiotherapy arise from gaps in access to equipment and gaps in health workforce.

Gaps in Access to Equipment

The status and the total needs to provide full access to radiotherapy by region are detailed in Table 25.1. It shows the currently available resources and the related costs (annual operational costs and average cost per course) calculated for the status of equipment to date. In addition, it presents an estimate of the total number of courses needed to obtain full access, with the related projection of total resources needed. Finally, it gives the total investment costs, based on capital investment and training, needed to optimize access, as well as the operational costs and cost per course projected for this optimal situation. As can be observed, the coverage in Africa is only about one-third of the optimal, whereas coverage nearly reaches two-thirds in Asia Pacific. In Europe and Latin America, coverage hovers around 90%. Conversely, North America seems to be significantly over-resourced, when using the same operational model of 12 h/day that is commonly used when calculating needs in other regions. Thus, this finding is likely due to a combined effect of real excess in available equipment together with different operational models used in clinical practice.

Figure 25.1 shows the current number and additional needs of megavoltage units by region and income group. By absolute numbers, the needs of Asia Pacific are clearly the greatest. However, as a percentage of what is already available, Africa needs additional resources in the order of 200%, and Asia Pacific around 40–70%. Figure 25.2 shows the additional investment needed to close this gap by region and income group, in absolute numbers. Half of the additional investment needed in low-income countries is needed in Africa.

There are around 40 countries without radiotherapy services. Focusing on LMICs, there are 4221 teletherapy machines installed, representing between 38% and 49% of the machines

Table 25.1 Actual status and total needs to provide full access to radiotherapy

	North America	Latin America	Africa	Asia Pacific	Europe
Population and RT courses					
Population (million)	350	601	1070	4108	893
Total RT courses needed	934,746	573,385	437,624	3,277,387	1,884,893
Resources					
Actual MV machines	4243	968	277	3894	3751
Total MV machines needed for full access	2175	1106	813	6406	4098
Actual coverage of the needs	195%	88%	34%	61%	92%
Costs					
Additional investment needed to reach full access (million USD)	1558	918	2118	10,497	2573
Actual operational costs/y (million USD)	6151	975	182	4638	5868
Total operational costs/y (million USD), assuming full access	6588	1192	571	6968	6573
Actual cost per RT course (USD)	6581	1939	1226	2423	3428
Total cost per RT course (USD), assuming full access	7048	2079	1306	2126	3487

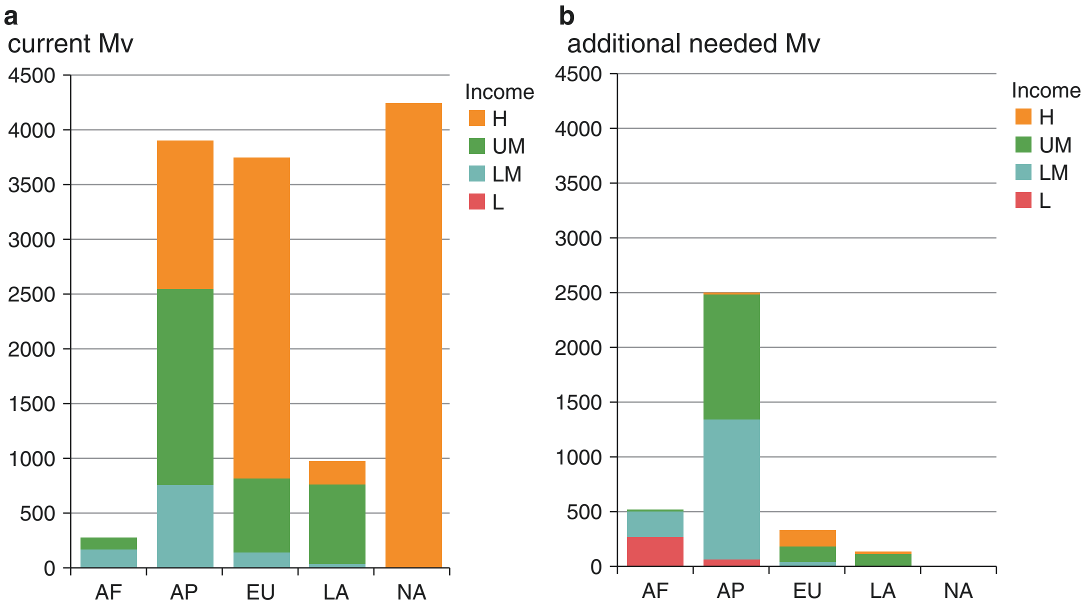

Fig. 25.1 Current (**a**) and needed (**b**) equipment, by region and income group

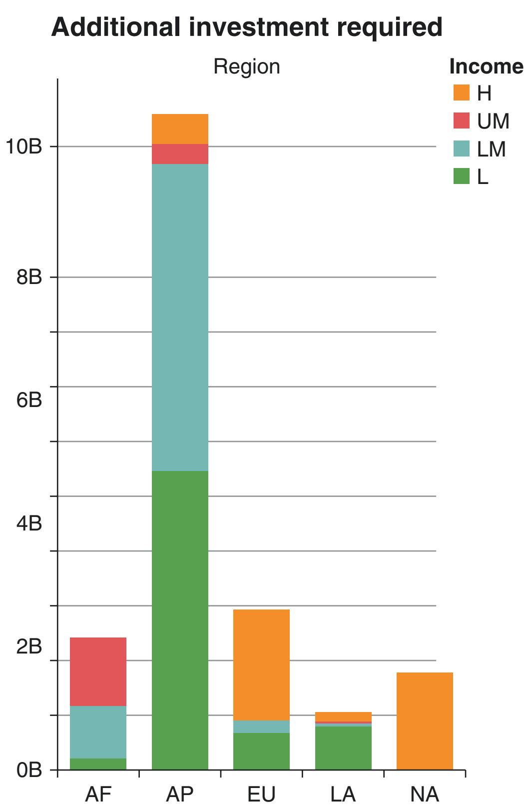

Fig. 25.2 Additional investment needed to close the gap by region and income group

needed, depending on the benchmark used. Between 4320 and 6958 additional units are required to meet these needs [18]. The Global Task Force on Radiotherapy for Cancer Control (GTFRCC) has proposed a call for action to increase by 25% the 2015 radiotherapy treatment capacity in LMICs by 2025 [17].

Gaps in Human Resources and Education

While the radiotherapy gap in low- and middle-income countries (LMICs) is usually measured in terms of equipment, human capacity for treatment delivery is in severely short supply also [16]. Meeting the demands for radiotherapy depends not only on the supply of radiotherapy equipment but also on the availability of qualified professionals to run this equipment. Furthermore, competency-based educational programs should be considered for capacity building activities [25]. In addition, novel approaches need to be used to continue to close the gap in the availability of skilled personnel that has been identified by several authors [16–18].

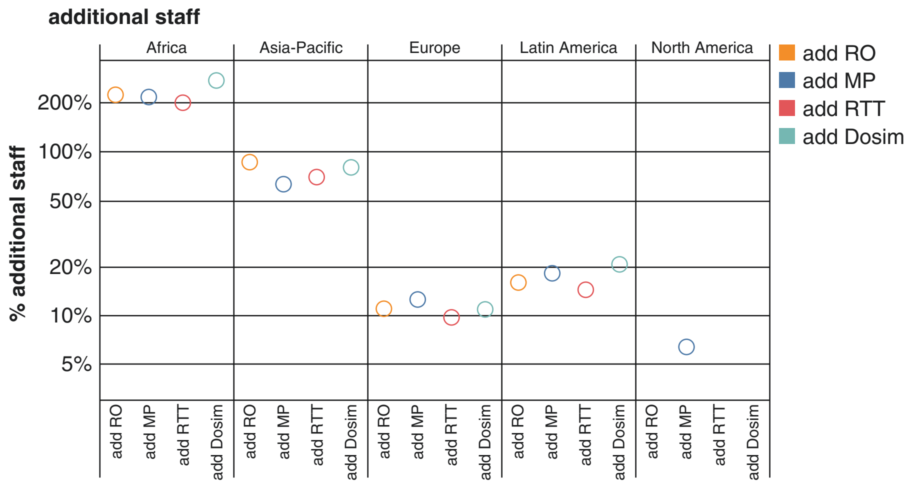

Fig. 25.3 Additional staff needed by region

To fill the gap in human resources required in LMICs, a total number of additional professionals needed will be 12,960 radiation oncologists, 6480 medical physicists, 3240 dosimetrists, and 20,520 radiation therapists [18]. In this regard, the GTFRCC has proposed a call for action to train 7500 radiation oncologists, 20,000 radiation therapists, and 6000 medical physicists in LMICs by 2025 [17].

With regard to additional staff needed by region, Africa's additional need in human resources is around 200%, and Asia Pacific around 70% (Fig. 25.3).

Because of the increasing disease burden and the gap in trained personnel, it is critical that LMICs develop adequate training programs [26]. Traditionally, high-level trainees from LMICs commonly emigrate to high-income countries for specialized oncology training but then choose not to return to their home country. This has led to "brain drain," an unfortunate phenomenon that propagates imbalances in the global cancer workforce.

Multiple stakeholders are required to engage if there is hope to make significant progress in training the necessary workforce. Established in 1957, the IAEA is the multilateral international organization with the longest track record for developing human capacity for radiotherapy in LMICs. As part of any Technical Cooperation (TC) project to establish radiotherapy services, the IAEA always includes the training of a full team, including radiation oncologists, medical physicists, radiation therapists, and occasionally maintenance engineers and nurses [11]. Typically, training options in the home country are limited, so training is sponsored abroad on a country-specific basis. The first choice for a partner training site is typically within the same world region.

To supplement international training efforts, there is growing interest from radiation oncologists in high-income countries to support colleagues in LMICs. Such assistance can prove vitally important to developing sustainable human capacity and infrastructure for clinical care, research, and education. Presently, there are successful examples of "twinning" partnerships, such as those between the University of Pennsylvania and Massachusetts General Hospital in Botswana, the University of California at San Diego in Senegal, and Duke University in Tanzania, among others [27–30]. These partnerships are challenging to sustain, and there is no established pathway for trainees interested in global oncology to become global oncologists [31–33]. For radiation oncology trainees interested in global health, there are opportunities for rotations abroad to gain exposure and to develop partnerships to enhance human capacity. Some current examples of training options include the American Society for Radiation Oncology's (ASTRO)/Association of Residents in Radiation Oncology's (ARRO)'s Global Health Scholar Program and the American College of Radiology Foundation's Goldberg-Reeder Resident Travel Grant.

To attempt to bridge the human capacity gap in a more transformative fashion, the International Cancer Expert Corps (ICEC) is developing a novel global mentorship–partnership model to address workforce capability and capacity [34]. The ICEC twinning program is a collaborative relationship between a university department or cancer program (or private practice) in an upper-income country (an ICEC Hub with ICEC Experts) and a cancer program/facility in an LMIC (an ICEC Center with ICEC Associates). The ultimate aim is for the ICEC Centers and Associates to progress to become ICEC Hubs and Experts for their specific regions.

Clearly, the human capacity gap for radiotherapy in LMICs is profound, and it will take a tremendous effort to close the gap. As roughly 50% of cancer cases can be prevented, investing in prevention programs could reduce the required human capacity for radiotherapy services [35]. The creation of effective radiotherapy treatment programs in LMICs requires a multipronged approach. Such an approach could include the following:

- Individual LMICs dedicating efforts and investments towards comprehensive cancer control plans
- The IAEA's continued investment in human capacity for LMICs to develop a sustainable local workforce
- International societies (e.g., ASTRO, ESTRO) providing consensus guidelines on best radiation therapy practices that are stratified for available resources [36]
- Radiotherapy device manufacturers developing radiotherapy equipment that requires fewer man-hours, reduced QA requirements, and reduced maintenance demands

Novel Approaches

Novel approaches are needed to fill the gaps in access to radiotherapy worldwide. These novel approaches fall into three different categories: alternate models for radiotherapy centers, use of new technologies, and new tools for scaling-up the human workforce.

The traditional model of a fully independent stand-alone radiotherapy facility is unlikely to expand to meet the demands in large regions of the world. The implementation of alternate models could reduce the current shortfall. Alternate models include (1) central/satellite configuration, where satellite centers rely on support and direction from a central institution; (2) networks of small departments that share some processes or equipment; and (3) small departments that outsource complex activities such as contouring, planning, or quality assurance.

Automation in radiotherapy will play a major role in the future and will help fill the gaps in equipment and process management. Automated contouring and treatment planning and automated QA will streamline the radiotherapy process, especially in low-resource environments. Enhancing the use of internet and communication technologies (i.e., the internet of things) to routine radiotherapy workflow will enable remote equipment diagnosis and assistance, presumably reducing downtime and increasing cost-efficiency, safety, and efficacy.

The human workforce should benefit from novel approaches. Virtual tumor boards for peer review of clinical cases, radiotherapy indications, and plans are one example. The development of sophisticated e-learning tools and the creation of virtual communities or hubs for discussion and twinning partnerships are other examples of novel solutions. New models of education are also needed, as the demand for health professionals is unlikely to be filled through traditional models. The redefinition of traditional roles in radiotherapy and task shifting can also promote a more efficient use of the available human resources. This approach should only be done after extensive consultations, study, and evaluation of the effect on patient care to ensure that quality is not compromised.

Mobilizing Resources to Finance Global Access to Radiotherapy

Full access to radiotherapy could be achieved for all patients in LMICs by 2035 for as little as US $97 billion [17]. Despite this "investment case" for the global expansion of radiotherapy and the growing political commitment to reducing global mortality from noncommunicable diseases (NCDs) reflected in the UN Sustainable Development Goals (SDGs), programs aimed at increasing access to quality cancer services in developing countries remain woefully underfunded.

Whereas high-income countries devote an average of 3–7% of total health spending to cancer control, most LMICs allocate far less; cancer accounts for about 1% of domestic health spending in Brazil and India, and only 2% in China and Mexico [37]. The majority of low-income countries in Africa and Asia are spending much lower amounts. Achieving adequate and sustainable funding levels for the expansion of radiotherapy in developing countries will require blending multiple sources of financing and applying innovative investment approaches.

Major Financing Sources

Domestic Funding

In all LMICs, most of the financing for cancer care and control will continue to be from domestic spending on health. Sources for this funding consist of government allocations and social health insurance schemes, and out-of-pocket spending by patients, including through private health insurance.

Overall, domestic funding for health is expected to increase rapidly in the next decades, driven by continued economic development and higher rates of government social spending. If current trends continue, overall global health expenditures will grow from US $9.2 trillion in 2014 to US $24.5 trillion in 2040. The rate of increase, however, will vary greatly across countries, with health spending in low-income countries (LICs) expected to remain low at US $195 per capita in 2040 [38].

Out-of-pocket (OOP) spending, on the other hand, is the least equitable and efficient means of financing health systems and often leads to impoverishment. OOP payments are highest in low-income countries representing more than 50% of total health expenditures [39]. A diagnosis of cancer is associated with some of the highest rates of out-of-pocket expenditure of any health intervention, with the poor and disenfranchised at greatest risk. State spending on health and in particular on cancer care should be boosted. This can also be achieved through the reallocation of existing funds and raising new revenue by enhancing the tax base and improving tax compliance.

Another very promising avenue for raising additional funds is the introduction of excise taxes on unhealthy products, that is, on tobacco, alcohol, and certain foods and beverages. Raising taxes on tobacco, for instance, is seen as the most important single cancer prevention intervention, and a tripling of the excise tax on tobacco would mobilize an extra US $100 billion worldwide in annual revenue, which, in turn, could be invested in expanding cancer diagnosis and treatment services [40].

In addition, a major target of the Sustainable Development Goals aims at achieving Universal Health Coverage (UHC) by 2030. As more and more countries adopt UHC policies, it will be important to ensure that high-impact, cost-effective cancer treatments, including radiotherapy, are included in all iterations of any UHC coverage plan to expand affordable and equitable access for patients in need.

Development Assistance for Health

Although domestic resources are the primary means of closing the financing gap globally over time, significant additional resources are needed to meet, by 2030, the SDG target to achieve a third reduction in premature NCD deaths, including from cancer. It will be important that high-income countries provide more and higher quality resources to the countries in need to complement domestic resources. A potential funding source is international development assistance for health (DAH). However, noncommunicable diseases (NCDs), including cancer, receive only 1.7% (or US $643.8 million) of an estimated total US $37.6 billion DAH spent by international funders in 2016 [41]. DAH, development bonds, and concessional loans can be leveraged to build capacity and catalyze cancer service delivery in resource-poor settings.

Major global health financing institutions have identified opportunities for stronger synergies and investment opportunities linking programs geared towards infectious diseases with NCD interventions.

The Global Fund to Fight AIDS, Tuberculosis and Malaria (GFATM), for instance, is collaborating with beneficiary countries to integrate human papillomavirus (HPV) screening and early treatment into well-resourced HIV programs. The Global Alliance for Vaccines and Immunization (GAVI) has spent US $39 million for HPV vaccinations to prevent cervical cancer in LMICs in 2011–2015 and is further expanding these activities [42].

The IAEA has for many years provided support in setting up and upgrading radiation oncology infrastructure and training the necessary professionals. Between 1980 and 2016, it has spent €305 million on cancer-related technical cooperation projects in LMICs.

Development banks are playing an important role in making substantial funding available to expand cancer diagnosis and treatment capacities in LMICs. In 2016, over 20 NCD-related loans worth hundreds of millions of dollars have been supplied by lenders such as the World Bank and the Inter-American Development Bank [43].

Also, the IAEA has partnered with the Islamic Development Bank (IsDB) to jointly support countries in accessing cancer-related funding. Since 2013, the IsDB has committed US $100 million to strengthen cancer diagnostic and treatment services in several common member states, including Côte d'Ivoire, Djibouti, Niger, Sudan, and Uzbekistan [44].

In addition to providing access to much-needed financing, international development assistance also provides ample opportunities to build much-needed cancer control capacity in LMICs through offering mechanisms for sharing experts, expertise, and approaches that are suitable to bolster national cancer control efforts in resource-limited settings.

Private Sector and Innovative Financing Mechanisms

The final element of the financing agenda for expanding cancer control services, including through investments in radiation oncology, is the contribution of private sector solutions and ways to align private capital with national health priorities, including through public-private partnerships and innovative financing.

Private sector entities are key players in the national cancer control arena. They provide goods and services that have a profound impact on health outcomes and inequalities and in many countries are major healthcare providers. The private sector brings to the table innovative methods and strengthened mechanisms for research and development partnerships, knowledge-sharing platforms, technology and skills transfer, and infrastructure investment.

Future Steps in Global Radiation Oncology

Future steps in global radiation oncology are as diverse as the "gaps in care" are wide. These efforts will continue to be guided by multiple goals centered on tackling the many limitations to advancing global radiation oncology care in low-resource settings. Advocacy by organizations to increase awareness about the global burden of cancer and the staggering conditions of cancer care is critical; this step will mobilize radiation oncology resources (human, equipment, monetary, etc.) to tackle these limitations.

Partnerships between developed programs, developing programs, international organizations, industry, local healthcare workers, and governments can continue to provide avenues for training physicians, physicists, and therapists to create self-sustaining treatment, education, and research programs while respecting cultural sensitivity. While a variety of initiatives exist to advance safe use of equipment, few initiatives exist to provide radiation therapy units in low-resource settings; this limitation is an enormous roadblock to increasing access to radiation therapy care. Lack of electrical/technological infrastructure to sustain technical radiation treatment equipment is a huge impediment to providing radiation therapy in LMICs; understanding local government and customs is the cornerstone to establishing infrastructure suitable to foster radiation therapy. The shortage of trained individuals, shortage of equipment, and lack of infrastructure can be addressed by novel approaches and "thinking outside the box" by designing software that would automate treatment planning/quality assurance steps or by creating a quality teletherapy unit that is affordable, user friendly, "reliable, self-diagnosing, is insensitive to power interruptions and has low power requirements," as was designed by an ICEC-hosted workshop at CERN [45].

Numerous organizations have invested in advancing oncology care worldwide – AMPATH, GlobalRT, IAEA Expert Group on Increasing Access to Radiation Therapy, ICEC, industry, International Organization for Medical Physics, Istituto Scientifico Romagnolo per lo Studio e la Cura dei Tumori, Medical Physics for World Benefit, RAD-AID, Radiating Hope, UICC, and so on. Global Oncology Map has created a website to form a directory and create a platform to unify current global oncology efforts and continues to make this resource more robust. All of the abovementioned limitations, steps, projects, and organizations will continue to need financing through the multitude of methods listed previously. While manuscripts and task forces on global radiation oncology identify the need of a number of teletherapy units or human resources by a specific time, the question of how to meet this need as a global community remains to be answered. Many organizations are answering this question and working to meet the global need in cancer care, individually. Formulating this response and creating a paradigm for the future will require global collaborations to align together and focus on a common goal of advancing radiation oncology care worldwide.

References

1. Halperin EC, Wazer DE, Perez CA. The discipline of radiation oncology. In: Halperin EC, Brady LW, Perez CA, Wazer DE, editors. Perez and Brady's principles and practice of radiation oncology. 6th ed. Philadelphia: Lippincott Williams & Williams; 2013. p. 2–75.
2. The American Association of Physicists in Medicine. Available at: www.AAPM.org. Accessed 27 Dec 2017.
3. Radiation Oncology Targeting Cancer. Available at: https://www.targetingcancer.com.au/radiation-oncology-team/radiation-oncology-medical-physicists/. Accessed 27 Dec 2017.
4. Medical Dosimetrist Certification Board. Available at: https://mdcb.org. Accessed 27 Dec 2017.
5. American Society of Radiologic Technologists. Available at: www.asrt.org. Accessed 27 Dec 2017.
6. American Registry of Radiologic Technologists. Available at: www.arrt.org. Accessed 27 Dec 2017.
7. Radiation Oncology Targeting Cancer. Available at: https://www.targetingcancer.com.au/radiation-oncology-team/radiation-therapists/. Accessed 27 Dec 2017.
8. Radiation Oncology Targeting Cancer. Available at: https://www.targetingcancer.com.au/radiation-oncology-team/radiation-oncology-nurses/. Accessed 27 Dec 2017.
9. Bray F, Jemal A, Grey N, Ferlay J, Forman D. Global cancer transitions according to the Human Development Index (2008–2030): a population-based study. Lancet Oncol. 2012;13:790–801.
10. Ferlay J, Soerjomataram I, Dikshit R, et al. Cancer incidence and mortality worldwide: sources, methods and major patterns in GLOBOCAN 2012. Int J Cancer. 2015;136:E359–86.
11. Rosenblatt E, Acuna O, Abdel-Wahab M. The challenge of global radiation therapy: an IAEA perspective. Int J Radiat Oncol Biol Phys. 2015;91(4):687–9.
12. Yap ML, Zubizarreta E, Bray F, Ferlay J, Barton M. Global access to radiotherapy services: have we made progress during the past decade. J Glob Oncol. 2016;2:207–15.
13. Zubizarreta E, Van Dyk J, Lievens Y. Analysis of global radiotherapy needs and costs by geographic

region and income level. Clin Oncol (R Coll Radiol). 2017;29:84–92.
14. Rosenblatt E, Barton M, Mackillop W, et al. Optimal radiotherapy utilisation rate in developing countries: an IAEA study. Radiother Oncol. 2015;116:35–7.
15. Abdel-Wahab M, Bourque JM, Pynda Y, et al. Status of radiotherapy resources in Africa: an International Atomic Energy Agency analysis. Lancet Oncol. 2013;14:e168–75.
16. Datta NR, Samiei M, Bodis S. Radiation therapy infrastructure and human resources in low- and middle-income countries: present status and projections for 2020. Int J Radiat Oncol Biol Phys. 2014;89(3):448–57.
17. Atun R, Jaffray DA, Barton MB, et al. Expanding global access to radiotherapy. Lancet Oncol. 2015;16:1153–86.
18. Zubizarreta EH, Fidarova E, Healy B, Rosenblatt E. Need for radiotherapy in low and middle income countries – the silent crisis continues. Clin Oncol (R Coll Radiol). 2015;27:107–14.
19. Barton MB, Frommer M, Shafiq J. Role of radiotherapy in cancer control in low-income and middle-income countries. Lancet Oncol. 2006;7:584–95.
20. Abdel-Wahab M, Fidarova E, Polo A. Global access to radiotherapy in low and middle income countries. Clin Oncol (R Coll Radiol). 2017;29(2):99–104.
21. Abdel-Wahab M, Zubizarreta E, Polo A, Meghzifene A. Improving quality and access to radiation therapy- an IAEA perspective. Semin Radiat Oncol. 2017;27:109–17.
22. Abdel-Wahab M, Rosenblatt E, Homberg O, Meghzifene A. Safety in radiation oncology-the role of International initiatives by IAEA. J Am Coll Radiol. 2011;8(11):789–94.
23. Page B, Hudson A, Brown DW, Shulman AC, Abdel-Wahab M, Fisher BJ, Patel S. Cobalt, linac, or other: what is the best solution for radiotherapy in developing countries? Int J Radiat Oncol Biol Phys. 2014;89(3):476–80. In reply to Page BR and Abdel-Wahab M. Revisiting Cobalt 60 teletherapy. Cobalt, linac, or other: what is the best solution for radiation therapy in developing countries? In Reply to Ravichandran R and Ravikumar. Int J Radiat Oncol Biol Phys. 2015;91(5):111.
24. Rosenblatt E, Meghzifene A, Belyakov O, Abdel-Wahab M. The relevance of particle therapy to developing countries. Int J Radiat Oncol Biol Phys. 2015;95(1):25–9.
25. Rosenblatt E, Prajogi GB, Barton M, Fidarova E, Ericksen J, Haffty B, et al. The need for competency based radiation oncology education in developing countries. Creative Educ. 2017;8(1):66–80.
26. Chite Asirwa F, Greist A, Busakhala N, Rosen B, Loehrer PJ Sr. Medical education and training: building in-country capacity at all levels. J Clin Oncol. 2016;34(1):36–42.
27. Efstathiou JA, Heunis M, Karumekayi T, et al. Establishing and delivering quality radiation therapy in resource-constrained settings: the story of Botswana. J Clin Oncol. 2015;34(1):27–35.
28. Chabner BA, Efstathiou J, Dryden-Peterson S. visiting team from the Massachusetts General Hospital Cancer Center and our partners at the Medical School of the University of Botswana, the Princess Marina Hospital, the Gaborone Private Hospital, and the Botswana Ministry of Health. Cancer in Botswana: the second wave of AIDS in Sub-Saharan Africa. Oncologist. 2013;18(7):777–8.
29. Einck JP, Hudson A, Shulman AC, et al. Implementation of a high-dose-rate brachytherapy program for carcinoma of the cervix in Senegal: a pragmatic model for the developing world. Int J Radiat Oncol Biol Phys. 2014;89(3):462–7.
30. Schroeder K, Olson AC, Ackerson B, et al. Radiation needs in pediatric oncology in the lake region of Tanzania. JGO. 2016;2(3_suppl):64s–64s.
31. Grover S, Balogun OD, Yamoah K, et al. Training global oncologists: addressing the global cancer control problem. Front Oncol. 2015;5:80.
32. Dad L, Shah MM, Mutter R, et al. Why target the globe?: 4-year report (2009–2013) of the Association of Residents in Radiation Oncology Global Health Initiative. Int J Radiat Oncol Biol Phys. 2014;89(3):485–91.
33. Yamoah K, Beecham K, Hegarty SE, Hyslop T, Showalter T, Yarney J. Early results of prostate cancer radiation therapy: an analysis with emphasis on research strategies to improve treatment delivery and outcomes. BMC Cancer. 2013;13:23.
34. Coleman CN, Formenti SC, Williams TR, et al. The international cancer expert corps: a unique approach for sustainable cancer care in low and lower-middle income countries. Front Oncol. 2014;4:333.
35. Stewart BW, Wild CP, editors. World cancer report. Geneva: WHO Press; 2014. http://publications.iarc.fr/Non-Series-Publications/World-Cancer-Reports/World-Cancer-Report-2014.
36. Suneja G, Brown D, Chang A, et al. American Brachytherapy Society: brachytherapy treatment recommendations for locally advanced cervix cancer for low-income and middle-income countries. Brachytherapy. 2017;16(1):85–94.
37. Gelband H, Sankaranarayanan R, Gauvreau CL, Horton S, Anderson BO, et al. Costs, affordability, and feasibility of an essential package of cancer control interventions in low-income and middle-income countries: key messages from Disease Control Priorities, 3rd edition. Lancet. 2016;387(10033):2133–44. p. 2140.
38. Global Burden of Disease Health Financing Collaborator Network. Future and potential spending on health 2015–2040: development assistance for health, and government, prepaid private, and out-of-pocket health spending in 184 countries. Lancet. 2017;389(10083):2005–30.
39. Asante A, Price J, Hayen A, Jan S, Wiseman V. Equity in health care financing in low- and middle-income countries: a systematic review of evidence from stud-

ies using benefit and financing incidence analyses. PLoS One. 2016;11(4):e0152866.
40. Jha P, Peto R. Global effects of smoking, of quitting, and of taxing tobacco. N Engl J Med. 2014;370:60–8.
41. Institute for Health Metrics and Evaluation (IHME). Financing global health 2016: development assistance, public and private health spending for the pursuit of universal health coverage. Seattle: IHME; 2017.
42. GAVI. The 2016–2020 investment opportunity. Geneva; 2016.
43. Allen LN. Financing national non-communicable disease responses. Glob Health Action. 2017;10(1):1326687.
44. International Atomic Energy Agency. Available at: https://www.iaea.org/newscenter/pressreleases/iaea-meeting-aims-to-help-fund-cancer-care-in-low-and-middle-income-countries. Accessed 27 Dec 2017.
45. Pistenmaa D, Coleman N. Developing medical linacs for challenging regions. Int J High Energy Phys. Available at: http://cerncourier.com/cws/article/cern/67710. Accessed 27 Dec 2017.