

## Expanding global access to radiotherapy



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Radiotherapy is a critical and inseparable component of comprehensive cancer treatment and care. For many of the most common cancers in low-income and middle-income countries, radiotherapy is essential for effective treatment. In high-income countries, radiotherapy is used in more than half of all cases of cancer to cure localised disease, palliate symptoms, and control disease in incurable cancers. Yet, in planning and building treatment capacity for cancer, radiotherapy is frequently the last resource to be considered. Consequently, worldwide access to radiotherapy is unacceptably low. We present a new body of evidence that quantifies the worldwide coverage of radiotherapy services by country. We show the shortfall in access to radiotherapy by country and globally for 2015–35 based on current and projected need, and show substantial health and economic benefits to investing in radiotherapy. The cost of scaling up radiotherapy in the nominal model in 2015–35 is US\$26·6 billion in low-income countries, \$62·6 billion in lower-middle-income countries, and \$94·8 billion in upper-middle-income countries, which amounts to \$184·0 billion across all low-income and middle-income countries. In the efficiency model the costs were lower: \$14·1 billion in low-income, \$33·3 billion in lower-middle-income, and \$49·4 billion in upper-middle-income countries—a total of \$96·8 billion. Scale-up of radiotherapy capacity in 2015–35 from current levels could lead to saving of 26·9 million life-years in low-income and middle-income countries over the lifetime of the patients who received treatment. The economic benefits of investment in radiotherapy are very substantial. Using the nominal cost model could produce a net benefit of \$278·1 billion in 2015–35 (\$265·2 million in low-income countries, \$38·5 billion in lower-middle-income countries, and \$239·3 billion in upper-middle-income countries). Investment in the efficiency model would produce in the same period an even greater total benefit of \$365·4 billion (\$12·8 billion in low-income countries, \$67·7 billion in lower-middle-income countries, and \$284·7 billion in upper-middle-income countries). The returns, by the human-capital approach, are projected to be less with the nominal cost model, amounting to \$16·9 billion in 2015–35 (–\$14·9 billion in low-income countries; –\$18·7 billion in lower-middle-income countries, and \$50·5 billion in upper-middle-income countries). The returns with the efficiency model were projected to be greater, however, amounting to \$104·2 billion (–\$2·4 billion in low-income countries, \$10·7 billion in lower-middle-income countries, and \$95·9 billion in upper-middle-income countries). Our results provide compelling evidence that investment in radiotherapy not only enables treatment of large numbers of cancer cases to save lives, but also brings positive economic benefits.

### Introduction

In 2012, 14·1 million new cases of cancer were reported worldwide (figure 1A), and this number is projected to reach 24·6 million by 2030.<sup>1</sup> 8·2 million cancer deaths were recorded in 2012, and this figure is projected to rise to 13·0 million by 2030, when most of the deaths will occur in low-income and middle-income countries,<sup>2</sup> (where, in 2012, cancer became a leading cause of death and disability).<sup>3</sup> Beyond the human suffering, cancer imposes an enormous economic burden worldwide—US\$2 trillion in 2010.<sup>4</sup>

Radiotherapy is a fundamental component of effective cancer treatment and control.<sup>5</sup> It is estimated that about half of cancer patients would benefit from radiotherapy for treatment of localised disease, local control, and palliation.<sup>6</sup> Yet this crucial component of the response to cancer has been largely absent from global health discourse, and has received limited domestic and international funding. Even in high-income countries, radiotherapy has frequently been used suboptimally despite facilities being available. As a result, there is a worldwide shortfall of radiotherapy services, with more than 90% of the population in low-income countries

lacking access to radiotherapy.<sup>7</sup> The growing burden of cancer will place increased demand on the already-scarce radiotherapy services worldwide.

Much has been written about the need for a comprehensive approach to population-based cancer control. In 2011, the UN General Assembly committed to prevention and control of non-communicable diseases (NCDs).<sup>8</sup> In 2013, WHO member states agreed at the World Health Assembly to develop comprehensive NCD global monitoring framework targets to reduce by 2025 premature mortality from cardiovascular and chronic respiratory diseases, cancers, and diabetes by 25% relative to their 2010 levels.<sup>9,10</sup> At least 1·5 million deaths from cancer will need to be prevented each year to achieve the so-called 25 by 25 target,<sup>11</sup> but global efforts to control cancer are woefully inadequate so far,<sup>12,13</sup> especially in low-income and middle-income countries, which have only 5% of the resources but 80% of the global cancer burden.<sup>14</sup> The 25 by 25 target cannot be achieved by prevention alone. Managing cancer requires both effective preventive measures to reduce future burden of disease, and health-care systems that provide accurate diagnosis and high-quality multimodality

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treatment. Such multimodality treatment should include radiotherapy, surgery, drugs, and access to palliative and supportive care. However, persistent underinvestment in radiotherapy resources with resulting unnecessary deaths shows that this clinical service is frequently forgotten when planning cancer control systems. Investment in radiotherapy is crucial and an imperative in low-income and middle-income countries<sup>15</sup> if unnecessary cancer deaths and suffering are to be avoided. Thus, with WHO's focus on access to cancer drugs,<sup>16</sup> global access to surgery,<sup>17</sup> and access to palliative care,<sup>18</sup> we thought it timely to be concerned about the gap in access to radiotherapy, and consider the economic case for investment in radiotherapy.

Radiotherapy is perceived as a complex treatment. A misleading assumption is that its deployment in poorer nations is not feasible, but nothing could be further from the truth. Radiotherapy can be effectively standardised and delivered irrespective of socioeconomic, political, and cultural context.<sup>19–22</sup> Here, we present new evidence to show that radiotherapy is affordable and feasible, and can be safely and consistently deployed in low-income and middle-income countries. Our report will show the health and economic benefits of investing in radiotherapy in these nations. Investment in radiotherapy is timely for many reasons, including evidence from The Lancet Commission on Investing in Health<sup>23</sup> showing the benefits of investing in health to achieve convergence in health outcomes between low-income countries and upper-middle-income countries, the momentum for investing in low-income and middle-

income countries to expand surgery,<sup>24</sup> and the UN resolution on sustainable development, which recognises that “universal health coverage is a key instrument to enhancing health, social cohesion and sustainable human and economic development”.<sup>25</sup>

This Commission presents new analyses that quantify coverage of radiotherapy services worldwide and by country. It also includes new estimates for the future burden of cancer to 2035 and the projected demand for radiotherapy services by country and globally from 2015 to 2035, to ascertain the scale-up of radiotherapy services needed. Provision of high-quality, safe, effective, timely, efficient, equitable, and patient-centred<sup>26</sup> radiotherapy services is particularly important because service quality critically affects cancer outcomes.<sup>27–29</sup> Our analysis also includes health systems investments needed to create an enabling environment for delivery of high-quality radiotherapy services in low-income and middle-income countries.

Investment in radiotherapy necessitates an important set of skills and resources. We project the financial, human, and physical resources needed to address the worldwide shortfall in radiotherapy services. Here, we calculate the financial resources and investment needed to expand coverage of radiotherapy in low-income and middle-income countries between 2015 and 2035, and estimate health and economic benefits of investing in radiotherapy. Finally, we describe the opportunities that could be created by innovations in science, human resources, and financing, and discuss the importance of leadership that could help to develop an inclusive response.

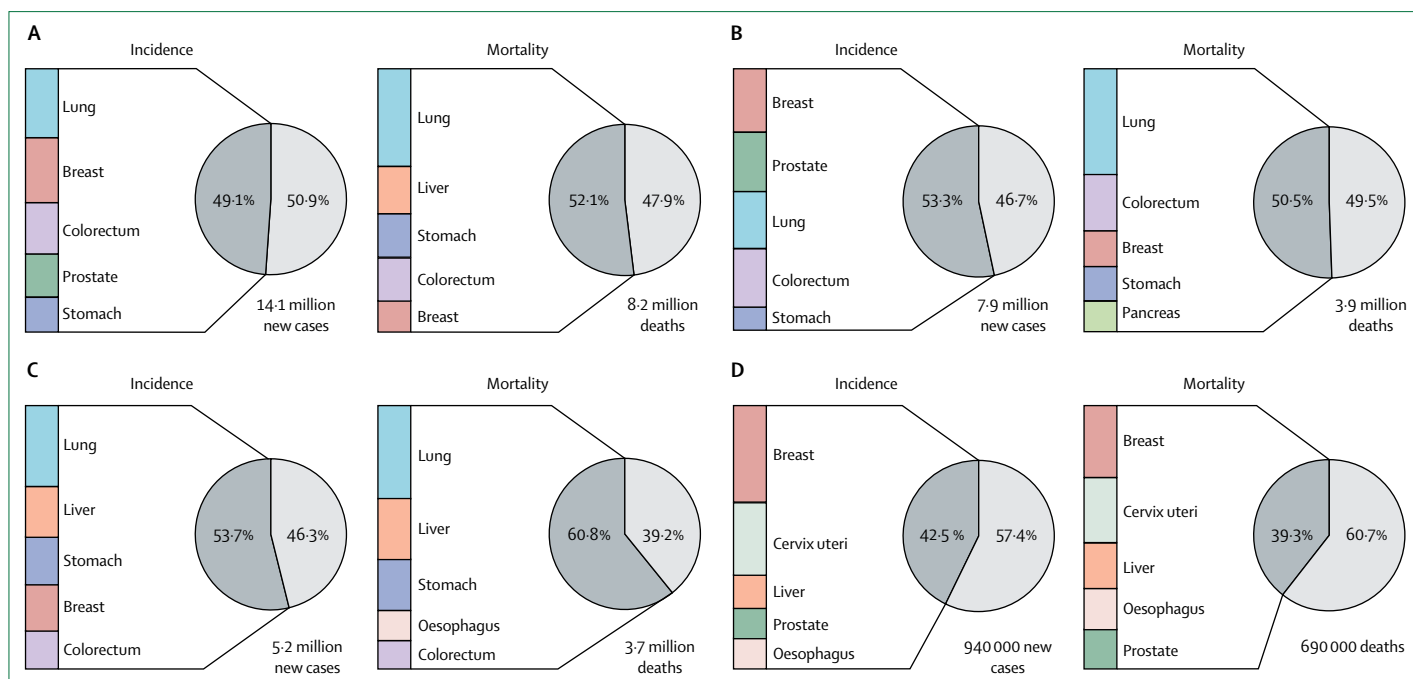


Figure 1: Total incidence of, and mortality from, cancer in 2012 worldwide (A), in high and very high HDI countries (B), in medium HDI countries (C), and in low HDI countries (D). The top five cancers are shown in the dark grey portion of the pie chart. HDI=Human Development Index.

We conclude by identifying a series of actions that should underpin the global efforts to scale up coverage of radiotherapy in low-income and middle-income countries.

### Part 1: Magnitude and distribution of cancers worldwide

In 2012, five cancers—lung (1·8 million cases), breast (1·7 million), colorectal (1·4 million), prostate (1·1 million), and stomach (0·95 million)—comprised almost half the total incidence of cancer worldwide,<sup>1</sup> and caused 53% of the 8·2 million cancer deaths (figure 1A). However, there is variation in the scale and profile of cancer between and within countries. Type and incidence of cancers vary according to levels of the Human Development Index (HDI)<sup>30</sup>—a measure of education, life expectancy, and income level that provides an all-encompassing measure of socioeconomic development of a country.<sup>31</sup> Around 56% (7·9 million) of new cancer cases in 2012 occurred in high or very high HDI countries (figure 1B), which account for less than a third of the global population. The cancer incidence and mortality profiles in medium HDI (figure 1C) and low HDI (figure 1D) countries are substantially different from those in high HDI countries.

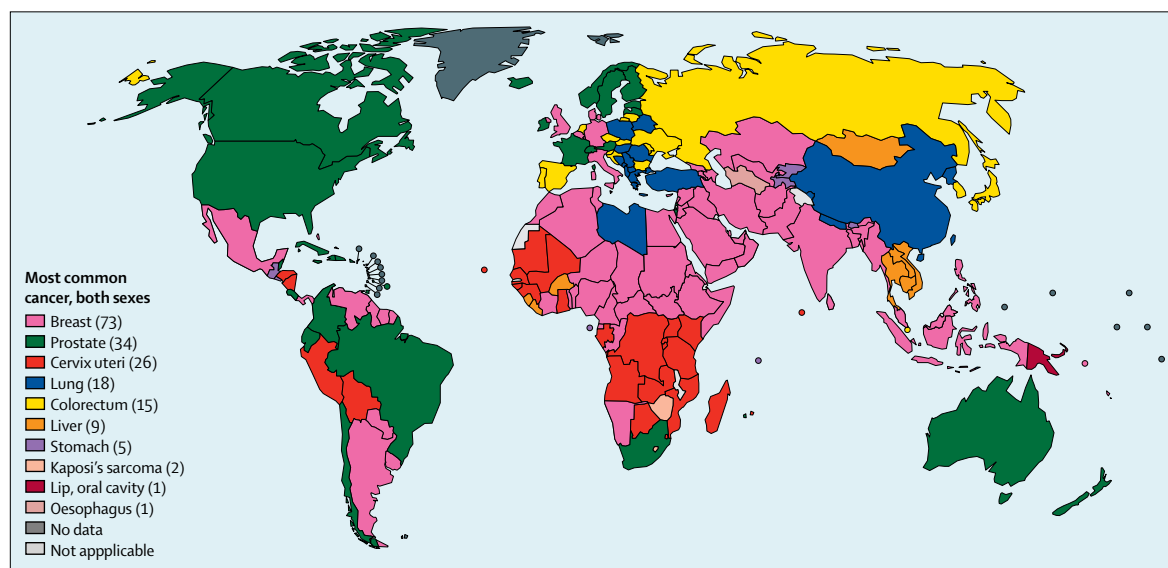
In medium HDI countries, lung cancer is the leading cancer by incidence and mortality, followed by liver and stomach cancer in both measures. Breast and colorectal cancers are the fourth and fifth most common by incidence, and oesophageal and colorectal cancers the fourth and fifth in terms of mortality. By contrast, breast (147 500 cases) and cervical cancers (110 000 cases) are the predominant cancers in low HDI countries, and account for close to a quarter of all new cases and deaths.

Figure 2 shows the country-specific variability in the most common cancer types in terms of frequency of

new cases in both sexes, as estimated in 184 countries worldwide. It shows breast cancer as the leading cause of cancer in 73 countries, including parts of Central and South America, Africa, and across Asia. Prostate cancer is the most frequent cancer in 34 countries—largely those where life expectancy is high and testing for prostate surface antigen has been highly prevalent (eg, the Americas, northern and western Europe, Oceania) but also where incidence might be increased because of increased underlying risk, such as in the predominantly black populations in South Africa and the Caribbean. Cervical cancer is most common in 26 countries, mainly within sub-Saharan Africa but also in parts of South America. Lung cancer is the most frequent cancer in 18 countries, including parts of eastern Europe, western Asia, northern Africa, and eastern Asia (including China). Colorectal cancer incidence is highest in an almost equivalent number of countries, mainly in Europe and in eastern Asia. Radiotherapy is needed to treat most of these cancers as part of a course of evidenced-based, effective care.<sup>30</sup>

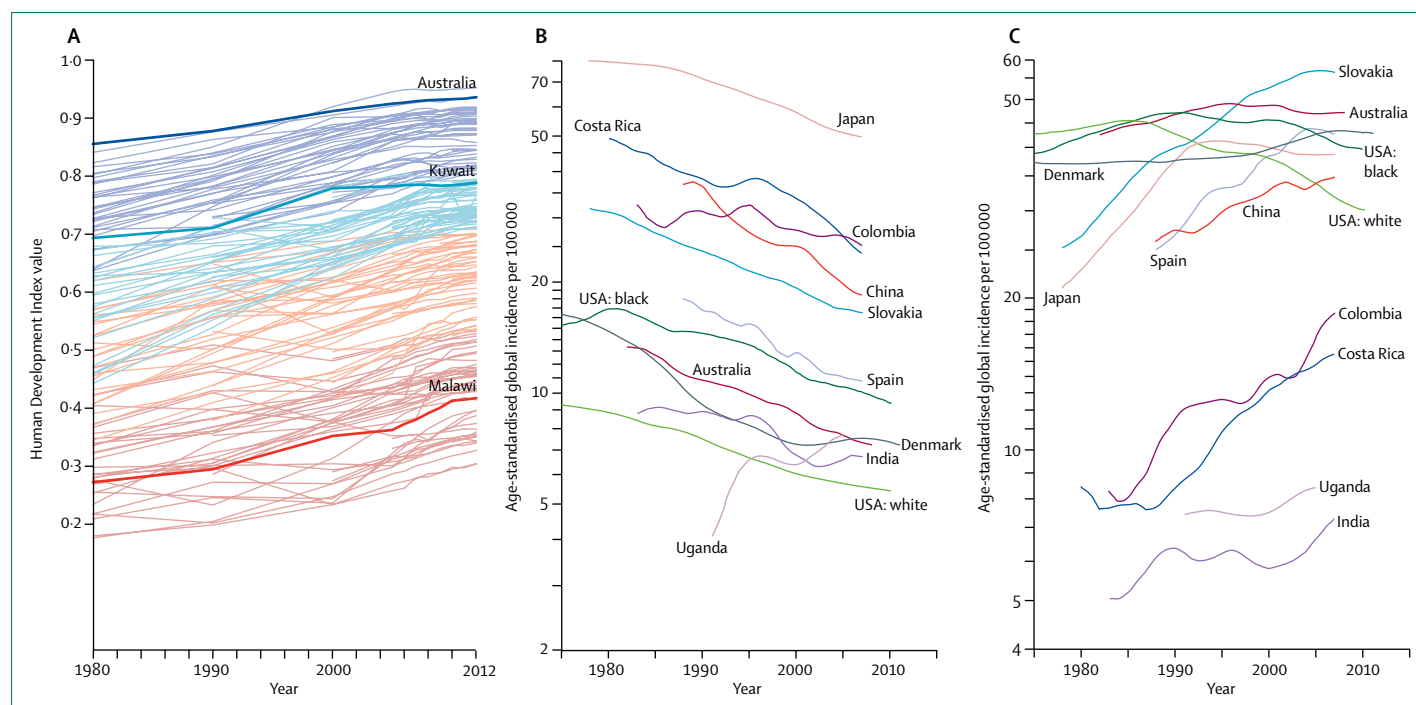
### Part 2: The changing profile of cancer and the burden in 2030

When levels of socioeconomic development increase, cancer emerges along with other NCDs as a major source of morbidity and mortality as part of a late-stage epidemiological transition, displacing infectious diseases and malnutrition.<sup>2,32</sup> Cancer is now the leading cause of early death worldwide.<sup>33</sup> Societal and economic transitions have partly brought about the increasing risk of several common cancers, via changes in reproductive patterns (a risk factor for breast cancer), tobacco consumption (major cause of lung and other



**Figure 2: Estimated most frequent cancer type in 184 countries for both sexes, 2012**

Data are from GLOBOCAN 2012. Data in parentheses are the number of countries in which that cancer is the most common. The map was produced by the International Agency for Research on Cancer (Lyon, France), and reproduced with permission.



**Figure 3:** Trends in the Human Development Index in 184 countries (A), stomach cancer age-standardised global incidence in selected registry populations (B), and colorectal cancer age-standardised global incidence in selected registry populations (C), 1980–2012

In (A), Australia, Kuwait, and Malawi are examples of countries in different Human Development Index groups.

tobacco-related cancers, such as head and neck cancers), and other nutrition-related factors that include an unhealthy diet, sedentary lifestyle, and obesity (which are all either established or putative risk factors for colorectal, breast, and—possibly—prostate cancer).

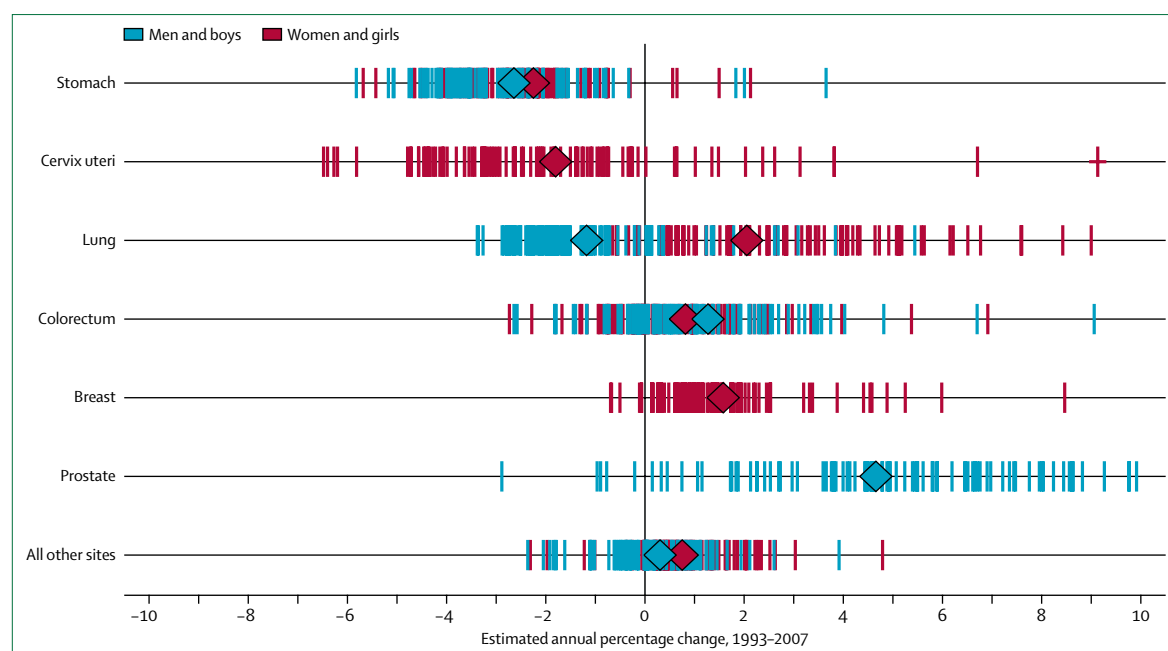
The cancer picture is not static or uniform as countries transition towards higher levels of human development. Figure 3 shows trends in the past 40 years or so of the HDI, by country, and corresponding incidences of stomach and colorectal cancers, both of which increase in incidence as countries develop economically. The decline in the incidence of stomach cancer (figure 3B) in most countries shows that, whereas reductions in *Helicobacter pylori* and improvements in diet can be attributed to average socioeconomic gains and associated with a lowering of risk within countries over time, incidence continues to rise in some low HDI populations (eg, Uganda).<sup>34</sup> The rising incidence of colorectal cancer (figure 3C) can be interpreted as a more direct link to westernisation in societies undergoing rapid transition, with both changing lifestyle choices (linked to disposable income), and changing (enforced) built environment impeding physical exercise (linked to national income and policy). Thus such data show that countries' cancer profiles evolve in response to socioeconomic changes, but the net burden continues to increase.

Figure 4 presents estimated changes from 1993 to 2007 in sex-specific incidence of six common cancers, based on available data<sup>35</sup> from high-quality registry populations in

medium, high, and very high HDI countries worldwide. In keeping with the epidemiological transition, mean declines in stomach (in both sexes) and cervical cancer are offset by respective mean increases in colorectal (in both sexes), breast, and prostate cancer incidences each year.

Incidence of cervical cancer (beyond in-situ stage) has been decreasing in many countries worldwide because of effective cytological screening in many Western countries and socioeconomic improvements in low and medium HDI countries. However, there are notable exceptions—including the rapid rises in cervical cancer in very high-risk populations (women who engage in frequent unprotected intercourse with different male partners, women living with HIV) in Uganda<sup>34</sup> and Zimbabwe,<sup>36</sup> and in several high HDI countries in eastern Europe and the former Soviet Union.<sup>37</sup>

The effects of population ageing and growth are the key drivers of the growing cancer burden globally. Slow decreases in high fertility levels in Africa and India, coupled with increasing life expectancy have brought about a worldwide demographic transition, with the global population projected to reach 8.4 billion by 2030, from around 7 billion in 2012. The biggest demographic changes will be in low or medium HDI countries (figure 5A). Taking into account population forecasts and assuming that trends in cancer will continue, we estimate that there will be 24.6 million new cancer cases by 2030 (figure 5B), which will affect all countries except those with very high HDI.



**Figure 4: Estimated annual percentage change for six common cancers and all other cancer sites, by sex, in selected registry populations**  
Diamonds represent the mean estimated annual percentage change. Data are from the C15plus registries.

The growing burden of cancer places substantial pressure on health systems to provide effective cancer services. Radiotherapy, surgery, and drug treatment in an integrated approach are necessary for cancer care. The current and growing demand for these services necessitates investment if lives are to be saved. The complexity and changing patterns of cancer merit investment in registration and monitoring of cancer burden at a local level. The Global Initiative on Cancer Registry Development, an international partnership coordinated by the International Agency for Research on Cancer (Lyon, France), is an international effort to reduce disparities in cancer information in low-income and middle-income countries, with six regional hubs providing the necessary technical support, training, advocacy, and networking to targeted countries.

An accurate assessment of the available health-care resources and demand for treatment services, including radiotherapy, is essential for an effective response to cancer. Here, we estimate the need for radiotherapy and the elements that need be considered to prevent unnecessary deaths due to the lack of access to treatment.

### Part 3: Shortfall in radiotherapy services

Estimation of the exact proportion of new cancer cases that will need radiotherapy is complex, in view of the variable patterns of cancer presentation and limited information on the current proportion of patients receiving radiotherapy. During the past 20 years, several investigators<sup>6,38–40</sup> have developed evidence-based estimates of desirable radiotherapy use on the basis of the indications for radiotherapy in clinical practice

guidelines and the distribution of cancers and different stages of disease at presentation. These estimates suggest that 50–60% of all patients with cancer will need radiotherapy. Optimum allocation of radiotherapy resources within the framework of a national cancer control plan necessitates monitoring of both the national cancer burden and the population's cancer staging, as well as determination of radiotherapy use by cancer type. Only then can resource requirements be estimated to align radiotherapy-intervention need to cancer burden effectively over time.

The shortfall in radiotherapy refers to the difference between currently available radiotherapy resources and what would be needed worldwide to optimally deliver necessary radiotherapy services to patients with cancer. Accurate estimation of the magnitude of the need for radiotherapy services worldwide is challenging. Although epidemiological data for worldwide incidence and distribution of cancer are available, the relations between cancer burden and radiotherapy resources (services, equipment, and personnel) needed to address this burden are affected by factors including access, levels of use, cancer stage distribution, and the nature of the required radiation treatment. We adopted a stepwise approach to estimate the required global level of radiotherapy services and the shortfall in meeting current and future need.

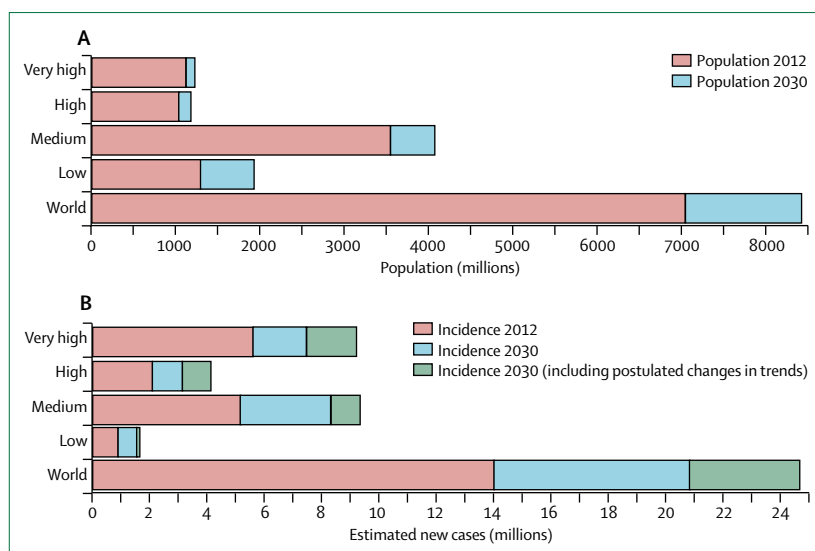
#### Step 1: Estimation of the volume of radiotherapy treatment needed by cancer burden

The first step in defining the relation between patients with cancer in need of radiotherapy and the radiation treatment resources needed is to estimate the number of

For the Global Initiative on Cancer Registry Development see <http://gicr.iarc.fr>

For more on the epidemiological data for worldwide incidence and distribution of cancer see <http://globocan.iarc.fr>





**Figure 5: Population increases (A) and predicted increases in cancer burden based on demographic and risk changes (B) by HDI level, 2012–30**

Demographics are based on UN projections. Risk changes for low HDI countries are based on application of mean registry EAPC in medium HDI countries to national incidence estimates in GLOBOCAN 2012. For medium HDI countries, they are based on mean registry EAPC in medium and high HDI countries, for high HDI countries they are based on mean registry EAPC in high and very high HDI countries, and for very high HDI countries, they are based on mean registry EAPC in very high HDI countries. HDI=Human Development Index. EAPC=estimated annual percentage change.

individual radiotherapy treatment visits or fractions that should be made available to the population in need of care. There are two approaches that have been used to estimate appropriate radiotherapy use.

Criterion-based benchmarking<sup>41</sup> is an empirical approach, which measures the use of radiotherapy services in population groups privileged enough to have optimum access to services, delivered under optimum conditions. The rate of use in these privileged communities is used as the benchmark for optimum rate of use.<sup>42</sup> The second approach is an epidemiological, evidence-based estimation approach, in which the appropriate level of radiotherapy use is estimated for radiotherapy services by using decision models—underpinned by evidence-based guidelines, cancer type, and disease stage—to allocate patients to radiotherapy or no treatment.<sup>6,38</sup>

Comparison of the two methods shows that the latter approach typically predicts higher rates of use than criterion-based benchmarking, raising questions about which approach is more reliable.<sup>41,43</sup> A challenge with the criterion-based benchmarking approach is that privileged communities are very difficult to define in low-income and middle-income countries because of the lack of appropriately resourced regions and long-term follow-up data. Therefore we opted to use the epidemiological, evidence-based estimation approach, because this method allows the estimation of the proportion of patients needing radiotherapy and the number of courses and fractions needed for a given population for curative and palliative indications.<sup>44</sup>

The difference between evidence-based and observation-based approaches is a topic of investigation, and is not unexpected in view of the many factors that affect clinical decision making and access to care. Taken together, the two approaches provide insight into the complexities of designing and ultimately achieving access to radiotherapy.

## Step 2: Estimation of radiotherapy resources required from treatment volume

The second step in characterisation of the relation is to translate the number of radiotherapy fractions or courses needed into resources needed to provide radiotherapy services. Several rules of thumb define the number of patients or courses that can be served by one megavoltage machine or per radiotherapy professional.<sup>45,46</sup>

A benchmark of 400–500 patients per radiotherapy treatment unit per year has been suggested for suitable machine throughput, whereas annual numbers of 200–300 patients per radiation oncologist, 300–500 per medical physicist, and 100–150 per radiation technologist have been suggested.<sup>46,47</sup> There are fewer recommendations, however, for the resources needed to deliver several fractions. Although various studies<sup>48,49</sup> have been done to forecast the number of radiotherapy units and personnel needed on the basis of these figures, other factors affecting resource needs should be considered when estimating required resources. The proportion of long-course versus short-course treatments will affect the number of fractions needed, which, in combination with the level of complexity of radiotherapy used, will affect the resources needed.<sup>50</sup>

Thus, when determining global investment in radiotherapy, there are many benefits associated with characterising the demand and the work to be done in terms of delivered fractions rather than courses. To overcome the shortcomings of the guidelines used to estimate resource needs, we used an activity-based costing model<sup>51</sup> (appendix) derived from previously reported methods, not only to estimate operational and upfront capital investment costs, but also to compute the resources needed to deliver the required number of fractions for defined global populations of patients.

To populate the activity-based costing model, we made assumptions in relation to facility size and level of complexity, equipment chosen, construction costs, personnel costs, and details of the operating model (ie, working hours and time needed by staff to do various activities; appendix). The value of these variables is affected by economic standards, work regulations, and the costs associated with the distance that patients need to travel to treatment facilities. We defined an infrastructure and operational model that combines a set of resource variables (equipment and human resources) and an operational paradigm. The model takes into account prevailing radiotherapy service needs in low-income and middle-income

See Online for appendix

countries and the operational approaches in use both there and in high-income countries (appendix). For the resource inputs, in numbers and costs, and the operational variables for the nominal model, please see the appendix.

### Step 3: Comparison of available resources to optimum resources

The third step consisted of comparing currently available radiotherapy resources to the optimum levels that we estimated would be required in different settings. Accurate data for radiotherapy staffing levels are available for high-income countries,<sup>52</sup> but not for low-income or middle-income countries. Therefore, we estimated the shortfall in radiotherapy personnel in low-income and middle-income countries on the basis of the shortfall between the number of radiotherapy units available and the optimum number of radiotherapy units needed to serve the worldwide cancer population. We used the 2013 figures for worldwide equipment levels available from the International Atomic Energy Agency's (IAEA) Directory of Radiotherapy Centres (DIRAC), a voluntary global registry.<sup>53</sup>

### Step 4: Mapping resources

Only 40–60% of patients with cancer are estimated to have access to radiotherapy services. There is no mandatory global registry of radiotherapy treatment resources, nor is there information on the patients who receive treatment through them. Although DIRAC gives an indication of worldwide equipment levels, it is a voluntary registry only and no information is available on whether the equipment is used, how it is used, by whom, and for whom. In some areas, equipment has not been deployed or cannot be used because of a lack of maintenance. In others, the equipment might be used continually, or for several shifts to treat large numbers of patients, or could be underused in areas with sparse populations. Thus it is difficult to accurately estimate what proportion of the world's population has access to radiotherapy facilities. However, strong evidence shows serious limitations in worldwide availability of radiotherapy services.<sup>54</sup> Therefore, scarce data for current radiotherapy resources should not overshadow what is a continuous crisis in access to radiotherapy, resulting in unnecessary deaths and suffering.

## Part 4: Barriers to access for radiotherapy services

Worldwide, a lack of investment has led to severe limitations in access to radiotherapy. Even in high-income countries, such as Canada,<sup>55</sup> Australia,<sup>56</sup> and the UK,<sup>57</sup> numbers of radiotherapy facilities, equipment, and trained staff are inadequate. There is an almost-complete absence of radiotherapy facilities in most countries in sub-Saharan Africa.<sup>7,54,58,59</sup> In countries with adequate or

almost-adequate treatment capacity, facilities tend to be centralised in large urban centres, creating geographical barriers to equitable access. This set-up is especially the case in large countries, such as Brazil, where health services in rural areas are lacking in parts of the country,<sup>60</sup> and Australia and Canada, which have sparsely populated remote areas where the low population density does not justify investment in complex health-care facilities.

A serious long-term commitment to cancer treatment and care is needed to develop radiotherapy services, which necessitate a large upfront investment in facilities.<sup>61</sup> As parallel investments in surgery, chemotherapy, and diagnostic services—particularly imaging, laboratory medicine, and pathology—can be shared and used for health services beyond cancer, these are often taken up by governments before such investment in radiotherapy. Radiotherapy, even more than other modern cancer treatments, necessitates a supportive technology ecosystem and is uniquely used for cancer treatment, and therefore is frequently the last service to be implemented for cancer care despite its central role in cure and care. Several cancer treatment facilities have been created without any radiotherapy facilities—eg, the Butaro Cancer Centre in Rwanda<sup>62</sup> and Moi University cancer facility in Kenya. Concerns about costs and lack of confidence in the ability to adequately staff and maintain services create reluctance to invest in radiotherapy facilities.

Additionally, financial constraints deter implementation of radiotherapy programmes, even when the initial costs of construction and equipment can be met, because of concerns about securing funding for operational costs and the affordability of services.<sup>63</sup> Countries with apparently acceptable levels of radiotherapy facilities might have equipment that limits modern practice; such outdated facilities risk causing worse adverse effects, and, in some cases (eg, patients with nasopharyngeal cancer), are associated with higher death rates than more modern equipment.<sup>64,65</sup>

Establishment of new radiotherapy facilities in low-income countries might be especially difficult because of limited resources in the health system, a lack of reliable electricity, poor transport links, variable security, and geopolitical instability.<sup>66</sup> Furthermore, radiotherapy facilities need highly specialised staff, and training, recruitment, and retention of a suitable health workforce can be major challenges, in view of the high cost and time commitment of training assumed by the country and the increasing mobility of the health workforce (eg, skilled physicians, nurses, technicians, physicists) who could be attracted into this specialised field.<sup>67</sup> Moreover, other health-care professionals must be aware of the benefits of radiotherapy to ensure that patients are referred for the treatment when appropriate. Maintaining effective routine radiotherapy operations is essential for continuous access; thus service contracts are needed to

plan for the maintenance needs. Without a service contract, radiotherapy equipment might cease to function and repairs might not be affordable.<sup>68</sup>

Barriers to acquisition of equipment with sufficient capabilities can also include so-called analysis paralysis, whereby decision makers endlessly debate the merits of competing technologies and solutions. The IAEA recommends <sup>60</sup>Co devices for radiotherapy in low-to-middle-income countries,<sup>47</sup> which can effectively be used to treat many of the cancers facing populations that have no access to treatment at low cost and with a high level of robustness.<sup>69</sup> Even for cancer types for which linear accelerators might provide better treatment, a cobalt system is still a vast improvement over no radiotherapy at all. However, because linear accelerators are more prevalent and can treat a wider range of cancers, a case to spend more to get more is sometimes proposed. This can lead to an unfruitful debate, which in many settings has produced years-long delays at the expense of patients who are left with no treatment options. A universal bunker design could help to accelerate a decision: a bunker can be constructed without detailed equipment specifications while the debate progresses to agree a solution. Thus, installing <sup>60</sup>Co machines and building universal bunkers (capable of housing linear accelerators) could provide the foundations for sustainable radiotherapy services.

High expectations can present a barrier to implementation of a radiotherapy programme. Many vendors have created lower-cost therapy units specifically designed for developing markets, including single-energy linear accelerators and <sup>60</sup>Co units. However, to a large extent, these low-cost models have been rejected by countries, which do not want perceived second-class equipment. For example, in 2014, the Ethiopian health ministry, which aims to provide radiotherapy in the country for the first time by establishing six new radiotherapy centres for cancer treatment, launched a call for proposals for linear accelerators, specifying the latest models with multiple energies and suitable for use in various specialised treatment techniques. The proposal stipulated that the “offered model shall be sold throughout the world”.

Cultural factors can also create barriers to radiotherapy. At the individual level, stigma associated with cancer<sup>70,71</sup> and fears associated with radiation<sup>72</sup> create barriers to uptake of radiotherapy services. At the government level, politics can interfere with prioritisation and efficiency of allocation, when investment is made for electoral influence rather than population benefit, imposing, in effect, a corruption tax.

## Part 5: Role of radiotherapy for cancer treatment and palliative care

Radiotherapy has been used for treatment of cancer for more than 100 years.<sup>73,74</sup> Shortly after the discovery of x-rays, both low-energy x-rays and radium sources were

used for treatment of superficial tumours.<sup>73</sup> Regression of tumours was often noted, but so were radiation side-effects or toxic effects. With growing experience and knowledge of the effects of radiation on normal tissues and tumours—which led to the use of fractionation, careful dose calculation, and better targeting—radiotherapy secured its place as indispensable for cancer treatment and control.<sup>74</sup> The invention of high energy radiotherapy, delivered by <sup>60</sup>Co machines or linear accelerators, scientific advances, and better clinical care have led to improved outcomes and significantly fewer side-effects.

Radiotherapy is integral to the management of most cancers, including breast, lung, prostate, head and neck, and cervical cancers, which together account for more than two-fifths of cases worldwide. Radiotherapy provides excellent local tumour control, which is not always achievable with surgery, and preserves normal form and function. For example, radiotherapy for larynx cancer allows laryngeal conservation, an important factor contributing to quality of life and ability to return to work after treatment. Incorporation of radiotherapy into multimodal management of breast cancer or limb sarcomas makes mastectomy or amputation unnecessary.

Radiotherapy can be used alone—as in early-stage prostate cancer, in which most patients are cured—or in combination with surgery, as in breast cancer and lung cancer. Radiotherapy can be used preoperatively to shrink tumours to improve their resectability, or postoperatively to eradicate residual microscopic cancer deposits in tissues surrounding the resected area. Radiotherapy is also frequently used in combination with chemotherapy. Neoadjuvant chemotherapy can be given before radiotherapy to reduce tumour volume and improve the effectiveness of radiotherapy. Concurrent chemotherapy is given in a wide range of indications to enhance the radiotherapy. Adjuvant chemotherapy is used to eradicate occult distant cancer spread after radiotherapy has achieved control of the local tumour mass.

In an era of personalised medicine, progress means that radiotherapy beams can be shaped and modulated to conform to the exact shape of tumours, maximising radiation dose deposition in the cancer while sparing normal tissues from high doses—ie, those most likely to evoke normal tissue toxic effects.<sup>75,76</sup> Radiotherapy is also a powerful instrument in palliation of symptoms associated with cancer. Modern approaches to cancer treatment frequently rely on all treatment modalities—surgery, radiotherapy, and chemotherapy—to achieve the best results with least damage. With improvement in control of metastatic disease, local tumour control is more important than ever.

## Radiotherapy utilisation

In view of the role of radiotherapy in cancer control, the case for investment is paramount. Quantification of the investment needed to provide radiotherapy services



worldwide requires a reliable estimate of the global demand for radiotherapy. We used a well described model of the optimum radiotherapy utilisation rate (RTU),<sup>38</sup> which is based on the epidemiological evidence-based estimation method, to estimate global demand for radiotherapy. The RTU represents the proportion of new cases of cancer that have an indication for treatment by radiotherapy according to evidence-based guidelines.<sup>6</sup>

We defined an indication for radiotherapy as a clinical situation for which radiotherapy was recommended as the treatment of choice, on the basis of evidence that it was associated with better outcomes than alternative treatment modalities and that the patient could undergo radiotherapy. Better outcomes could mean improved survival, quality of life, or local control, or fewer or less severe toxic effects. We included palliative indications if they were the treatment of choice for a clinical presentation. For situations in which there were guideline-supported alternatives to radiotherapy, the effect of these alternatives on the use of radiation was modelled in the sensitivity analysis.

The model was not adjusted for the differing distribution of stages at presentation in countries of different income groups because of the absence of population-based data on stage. In low-income and middle-income countries, a higher proportion of patients present in the advanced stages of cancer than in high-income countries,<sup>77</sup> because of a lack of effective screening programmes, poor access to health care, and low levels of health education. To determine the effect of stage, all early-stage disease was removed and modelled; we found a median increase of 4% of early-stage cancers in the RTU model in low-income countries. In view of this small difference in RTU, we applied the unadjusted RTU model to all countries, which means that estimates of RTU are conservative for low-income countries.

Additionally, non-notifiable cancers (ie, those not included in cancer registries) for which radiotherapy is indicated were not included in the RTU model—eg, non-melanomatous skin cancers and non-malignant neoplasms—because population-based data were not available for their incidence. These cancers accounted for roughly 10% of radiotherapy courses in Australia, but this proportion could differ among countries.

RTUs per cancer site for the ten most frequent cancers are listed in table 1. We calculated the RTU for each country in the world by applying the cancer-site-specific RTU to each country's unique proportional cancer case-mix, as reported by GLOBOCAN 2012.<sup>1,78</sup> RTU by country ranged from 32% in Mongolia to 63% in the Comoros (figure 6). Overall, the RTU for the world was 50% in 2012 (appendix).

We estimated that there were 7 million cancer cases globally for which radiotherapy treatment was indicated in 2012. Using the GLOBOCAN incidence projection data to 2035,<sup>1,78</sup> and proportions from the RTU demand

	Radiotherapy utilisation rate (%)	Mean radiotherapy fractions per course	5-year local control benefit (%)	5-year overall survival benefit (%)
Breast	87	16	15	2
Cervix	71	21	35	20
Colorectal	19	23	5	2
Haematological	48	8	7	4
Head and neck	74	22	34	20
Liver	0	0	0	0
Lung	77	16	9	6
Oesophagus	71	15	5	2
Prostate	58	28	25*	1
Stomach	27	19	2	1
Total	50	18	10	4

Radiotherapy utilisation rate is the number of patients for whom radiotherapy is the treatment of choice according to guidelines and evidence, divided by the number of new cases in one year. Haematological cancers include leukaemia, Hodgkin's lymphoma, non-Hodgkin lymphoma, and multiple myeloma. \*5-year biochemical disease-free survival for curative cases only.

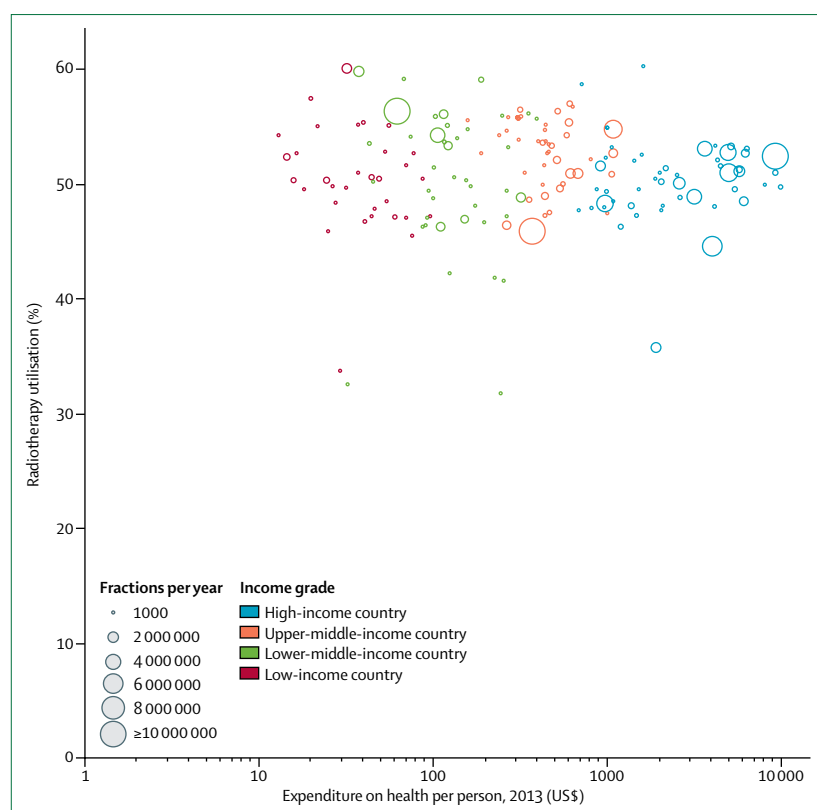
**Table 1: Radiotherapy utilisation rate, mean fractions, and outcome benefits (absolute proportional) for top ten cancers globally by incidence**

model, we projected the estimated number of patients globally needing radiotherapy as part of their cancer treatment to 2035. We estimated that, in 2035, 12 million patients will get diagnosed with a cancer for which radiotherapy treatment has been indicated.

### Radiotherapy fractions required per year

We used the RTU model to estimate in three steps the total number of radiotherapy fractions (specific to the first course of radiotherapy) needed globally to treat all cancer cases per year.<sup>79</sup> First, for each tumour type, we estimated the mean number of fractions per treatment course for each radiotherapy indication by determining the optimum number of fractions for each radiotherapy indication from the highest level of evidence reported globally.<sup>79</sup> If there were two regimens of equal efficacy then we used the lower number in the model and did sensitivity analysis to explore the effect of using more fractions. Retreatment was not included in our estimates, because only 10–25% of patients receive a second or subsequent course of radiotherapy,<sup>80</sup> and retreatment courses typically have a small fraction number (mean 3.1 fractions) and so overall retreatment does not significantly change the mean number of fractions per radiotherapy course.<sup>80</sup>

Second, we estimated the mean number of radiotherapy fractions per cancer type by multiplying the optimum number of fractions for each radiotherapy indication with the proportion of patients with that indication and summing all amounts for each cancer type. Finally, we estimated the number of radiotherapy fractions each country would have to deliver per year to treat all patients with indications for radiotherapy, by



**Figure 6: Radiotherapy utilisation versus health expenditure per person, 2013, by income level**  
Each circle represents a distinct country. The diameter of the circle is the actual yearly number of fractions delivered. Evidence-based estimates of appropriate levels of radiotherapy utilisation are independent of a country's health-care expenditure status.

using the GLOBOCAN 2012 national cancer incidence for each cancer type and data for the mean number of fractions for each cancer type. We also estimated the mean number of fractions per radiotherapy case in each country.

The total number of fractions needed per country in 2012 ranged from 996 in Samoa to 23·5 million in China. The mean number of fractions per radiotherapy case ranged from 17 in Egypt to 22·4 in Martinique. The mean number of fractions per radiotherapy case globally was 18·4. The total number of fractions necessary for all patients with cancer worldwide to receive full access to guideline-based radiotherapy in 2012 was 119 million fractions. When applying the GLOBOCAN incidence projections, the projected number of fractions for the world in 2035 was estimated to be more than 204 million (appendix).

#### Population radiotherapy benefits

We used previously described methods<sup>81</sup> (which build on the RTU demand model) to estimate the population benefits of guideline-based radiotherapy. 5-year overall survival and 5-year local control benefit of radiotherapy were estimated for the ten cancers with the highest global incidence according to GLOBOCAN 2012.<sup>178</sup> For radical indications, the radiotherapy indication benefit

was defined as the absolute proportional benefit of radiotherapy over no treatment. For adjuvant indications, the radiotherapy indication benefit was defined as the absolute proportional benefit of radiation together with surgery compared with surgery alone. If concurrent chemotherapy was indicated, it was included as part of the radiotherapy benefit.

We systematically reviewed citation databases to identify the highest level of evidence defining each indication benefit. Searches were limited to data published in or after 1990, and were completed between 2011 and Aug 2, 2014. We did meta-analyses when two or more sources of the same level of evidence were available. For most radical indications, 5-year overall survival and local tumour control was deemed to be 0% without radiotherapy. This assumption was not made for adjuvant indications. The main exceptions to this were indolent cancers, such as prostate cancer, for which comparative clinical studies formed the basis of estimates of benefit. Deterministic and probabilistic sensitivity analyses were done and confirmed the robustness of the benefit model.

To estimate population benefit, we multiplied the proportion of patients with each radiotherapy indication by the associated benefit for that indication. These benefits were then summed to determine the radiotherapy population benefit, which described the absolute proportion of the population achieving a benefit from radiotherapy delivered according to guidelines compared with those receiving no radiotherapy (table 1). These benefits were thus distinct from the contribution of other modalities to cancer outcomes and did not describe the mean survival or local control of a patient treated with radiotherapy. The population local control benefit per country at 5 years ranged from 6% in Mongolia to 15% in Tanzania. Overall survival at 5 years ranged from 2% in Sweden to 7% in Mozambique. The world population benefit at 5 years was 10% for local control and 4% for overall survival.

We estimated the number of patients globally who would benefit from radiotherapy in the future, up to 2035 on the basis of GLOBOCAN projections of incidence<sup>178</sup> and by applying the population outcomes model. In 2012, an estimated 1·5 million people globally would derive a local control benefit and more than 580 000 people would derive a survival benefit from radiotherapy if all patients needing radiotherapy had access. By 2035, however, the estimates suggest substantial growth to roughly 2·5 million people who would have a local control benefit and 950 000 people who would have an overall survival benefit from global access to radiotherapy.

#### Benefits of palliative radiotherapy

Most resource planning incorporates the need for radiotherapy to increase survival and cure cancer. The palliative value of radiotherapy in reducing the suffering

associated with cancer is frequently overlooked in terms of both resources needed and geographical accessibility. Radiotherapy not only contributes to years of life gained and lives saved in the curative setting, but also provides immense value for pain relief in the palliative setting.<sup>82–84</sup> It can relieve symptoms due to either primary or metastatic tumours, including common manifestations of cancer, such as pain, bleeding, obstruction, and compression. Palliative radiotherapy is often easier to plan and deliver than radiotherapy with curative intent. Small doses of radiotherapy (8–30 Gy in one to ten fractions) alleviate the pain associated with cancer, and can be used to stop bleeding, relieve airway obstruction, and alleviate neurological tissue compression caused by cancer progression.

Patients who need palliative radiotherapy are often very ill and would benefit from immediate access. Many radiotherapy facilities have developed specialised palliative radiotherapy teams and rapid access programmes to identify, assess, and treat these patients as soon as possible, or at least after no longer than a few days' wait.<sup>85,86</sup>

## Part 6: Existing capacity and nature of investment needed

### Elements of radiotherapy

Delivering radiotherapy involves several steps that involve various technologies (figure 7). These steps are not always in the same order or done by the same professionals. They include assessment of the patient (by a radiation oncologist), imaging for treatment preparation (by a radiation technologist), target volume delineation (by a radiation oncologist) and critical structure determination (by a radiation technologist or radiation oncologist), treatment plan development (by a dosimetrist or medical physicist), pretreatment review and quality-control checks (by all radiation professionals), transfer of patients' data to the treatment machine (when pretreatment quality-control testing is undertaken by a radiation technologist or medical physicist, or both), image guidance just before dose application (by a radiation technologist), which is often provided to ensure constancy and accuracy of set-up for the patient, and delivery of radiation dose (by a radiation technologist).

Preparing a patient for a specific treatment course is usually done once, whereas treatment delivery at the therapy machine is done multiple times, depending on the prescription provided by the radiation oncologist. Once the treatment course is completed, follow-up occurs at various times after treatment and involves a radiation oncologist and a nurse. In addition to individual treatments, medical physicists are also involved in all the steps associated with the departmental design, technology acceptance testing, commissioning, quality assurance, and all aspects of radiation protection and radiation safety. Appropriate staffing with well-trained professionals is crucial for the provision of safe and effective radiation treatment.

	Process	Technology	Personnel
Preparation	Assessment and prescription		Radiation oncologist
	Imaging for treatment planning	CT simulator	Radiation technologist
	Treatment volume determination	Planning system	Radiation oncologist
	Treatment planning	Planning system	Dosimetrist
	Pretreatment review and quality-control checks	Recording and verification	Radiation oncologist
	Data transfer		Medical physicist
Treatment Xn fractions	Treatment-related quality control	Guidance technology	Radiation technologist
	Pretreatment image guidance	Linear accelerate	Medical physicist
	Dose delivery	<sup>60</sup> Co unit	Service engineer
	On-treatment care		Radiation oncologist
			Nurse
Follow-up	Ongoing follow-up		Radiation oncologist
			Nurse

Figure 7: Processes, technologies, and professionals involved in radiotherapy

A course of radiotherapy is typically divided into a series of 1–40 fractions depending on the type of cancer and the clinical objective.

When planning new facilities, trained staff should be identified before the clinic is opened. For example, medical physicists should be in place before the construction of the clinic so that they can participate in the shielding design and technology acquisition. Furthermore, basic staff training requires an average educational lead time of about 4–5 years after a medical degree for radiation oncologists,<sup>87,88</sup> about 4 years after an undergraduate degree for medical physicists,<sup>89</sup> and 2–4 years after secondary school for radiation technologists and dosimetrists.<sup>88,90</sup>

Advances in three-dimensional (3D) CT imaging and computer technology have enabled the transition from basic two-dimensional radiotherapy to a more sophisticated approach with 3D conformal radiotherapy. The development of computer-controlled radiation field shaping technology (multileaf collimators) has supported 3D conformal radiotherapy and enabled intensity-modulated radiotherapy. These advances, combined with treatment machine on-board image guidance technologies allowing image-guided radiotherapy, have made delivery of highly conformal and accurate radiation doses to the most complex tumour volumes while sparing nearby critical tissues, possible. However, safe application of these precise treatments requires appropriate staff training and seamless teamwork within the radiation treatment environment.

### Estimation of radiotherapy costs

Radiotherapy costs can be divided into two major components: upfront costs to develop a new facility, including building, equipment, and training of new staff; and operating costs to deliver treatments once the facility is established. These costs are affected by various factors, including facility size, level of treatment complexity, equipment, construction and personnel costs, and the clinical operating conditions (such as the length of the working day and the time needed by staff for various activities).

### Panel 1: Activity-based cost estimation for quality radiotherapy

#### Capital and construction costs (facilities and equipment) for the nominal model of radiotherapy facility

When determining capital costs of both facilities and equipment, specific assumptions have to be made about the size and composition of a nominal model of a radiotherapy facility that has essential equipment and elements. In the nominal model, the facility consists of a department with two megavoltage treatment units (assuming an overall proportion of 50% monoenergetic and 50% multimodality capabilities), each of which is equipped with multileaf collimators and electronic portal imaging systems. Additionally, a CT simulator is included, although we assumed that it is used only half the time for radiotherapy, with the other half allocated to diagnostic radiology. Each department also has a three-dimensional-conformal-radiotherapy-capable radiation treatment planning system, an oncology information management system, and appropriate dosimetry, quality-assurance, and radiation protection equipment. For comparison and validation purposes, we also made cost estimations for high-income settings, in which we assumed that 50% of the patients are treated with three-dimensional-conformal radiotherapy and 50% receive intensity-modulated radiotherapy or image-guided radiotherapy. Brachytherapy is assumed for some departments, depending on the regional needs.

Facility layout and size were taken from the International Atomic Energy Agency (IAEA) guidance documents.<sup>66</sup> The construction cost per square metre is drawn from the IAEA's construction documents and global construction reports.<sup>92,93</sup> These costs were adjusted for the radiotherapy-specific construction costs by an additional 20% to account for medical

construction requirements. An additional 50% was applied for the construction of the radiation treatment rooms to accommodate shielding and air-handling costs—eg, in low-income countries, the general construction cost is US\$1000/m<sup>2</sup>, which is adjusted to \$1200/m<sup>2</sup> for a radiotherapy facility; a shielded treatment room would cost \$1800/m<sup>2</sup>.

#### Personnel costs

The data for mean salaries and working days were gathered partly through questionnaires distributed to the members of the Global Task Force for Radiotherapy for Cancer Control and partly from public databases, such as LABORSTA (International Labour Office database on labour statistics operated by the International Labour Office Department of Statistics). We compared various closely related professions between countries with different per-person income levels to determine mean salary levels.

#### Educational costs

Training costs are the additional costs to train an individual to become a radiotherapy professional and do not include the base training costs associated with completion, for example, of an undergraduate degree. Training costs were limited to radiotherapy professionals only—ie, radiation oncologists, medical physicists, dosimetrists, and radiation technologists. Continuing education has not been included as part of the training costs. The cost per trainee varies according to per-person gross national income and has been estimated from the Global Task Force on Radiotherapy for Cancer Control survey results and training resources used by the IAEA. The list of the operational parameters and quantities for the activity-based costing model used in this Commission are listed in the appendix.

An activity-based costing model<sup>51</sup> can be used to generate practice-specific estimates of the staffing levels required to deliver every aspect of radiotherapy, ranging from doctors' interactions with patients through to quality assurance of the equipment (figure 7). Thus, an activity-based model allows estimation of human resources needed for all steps in the radiotherapy process to achieve a certain treatment capacity, for a given department and treatment type. Similarly, capital needs for buildings and equipment can be estimated by modelling for different levels of treatment capacity. These models for staffing levels and capital needs can be combined to determine the cost (of buildings, equipment, and human resources) given the number of fractions to be delivered, or alternatively they can be used to determine the number of fractions that can be delivered given the available resources. The activity-based costing calculator used in this study draws on previous work of the IAEA (Vienna, Austria), which has developed a good understanding of the staff needed to operate radiotherapy facilities through their worldwide work.<sup>91</sup> The IAEA has also relied on an activity-based costing model (panel 1) to

help with decision making in countries establishing new radiotherapy facilities.<sup>94</sup> We adapted and merged these models to estimate the capital and operating costs in each of the World-Bank-defined regions of low income, lower middle income, upper middle income, and high income (appendix).<sup>95</sup>

#### Estimation of capital and operating expenses for scale-up of coverage

Investment calculations require an understanding of both future operational costs and the upfront costs to establish new capacity. Capacity is measured in fractions of radiotherapy that can be delivered in a year. Operational costs include human resources, maintenance, consumables, overheads—which include costs of consumables, such as immobilisation devices, other nursing supplies, cleaning, facility maintenance, heating, cooling, and general administration, but do not include additional services to provide cancer care, such as pathology and diagnostic imaging—and the amortisation costs of equipment and facilities, such that the fraction delivery capacity can be renewed from operational funds and

For more on LABORSTA see  
<http://laborsta.ilo.org/>

therefore available in perpetuity. This operational cost per fraction can be quantified as follows:

$$\text{Operational cost per fraction} = \left( \frac{\text{Oper} + \text{Equip} (\text{mnt} + \text{amort})}{\text{Number of fractions per year}} \right) \times 1.2 (\text{overhead})$$

*Oper* is the operational cost per year (excluding equipment and building costs), *Equip* (*mnt* + *amort*) is the cost of equipment per year including maintenance and a 12-year amortisation period, and *Blndg* (*mnt* + *amort*) is the cost of the building per year including structural maintenance and a 30-year amortisation period. The factor of 1.2 accounts for overhead. Operational cost per fraction is measured in US dollars.

The upfront cost to establish new capacity to deliver an additional fraction of radiotherapy includes the investment in construction and equipment and human-resource training costs. Upfront cost is a one-off cost required to create the capacity, after which expenditure on operating costs is incurred. The cost of building additional capacity is quantified as:

$$\text{Total capital expense} = \frac{\text{Building costs} + \text{equipment costs} + \text{training costs}}{\text{Number of fractions per year}}$$

The costs include the total capital cost of the building and equipment in addition to the cost of training the radiotherapy professionals who will be providing the service. For example, if a country needs to increase its delivery capacity by *n* fractions per year to accommodate the increased cancer burden, it would need to invest a quantity equal to the *n* fractions per year that is needed times the capital expense, which is quantified as investment cost per fraction per year of capacity. Both operational cost per fraction and capital expense are needed as input data for the investment framework to estimate investment costs and economic benefits (table 2).

### Cost of alternative operating models

We did a sensitivity analysis by adjusting selected input parameters in the nominal activity-based model to test three scenarios to assess more efficient ways of using available resources or decreasing upfront investment costs, or both: increased efficiency, by increasing the number of fractions per hour from four to five in low-income and middle-income countries by reducing treatment-planning time by 50% and quality-assurance time by 50%; extending daily operating hours from 12 to 16; and using bulk purchasing for equipment acquisition with potential savings of 30% in capital costs, as estimated by the members of the Global Task Force on Radiotherapy for Cancer Control (GTFRCC).

	High-income countries	Upper-middle-income countries	Lower-middle-income countries	Low-income countries
Operating cost per fraction	235	86	65	60
Upfront cost per fraction	803	357	349	352

Estimated on the basis of the activity-based model. Data are cost in US\$.  
Operating cost=cost / fractions delivered. Upfront cost=one-off cost required to create the capacity, after which operating costs are incurred.

**Table 2: Operating and upfront costs per radiation fraction per year**

These three scenarios were applied either alone or in combination, giving seven alternative combinations. There was no change in fractionation for these scenarios, although fewer fractions per course are increasingly used in practice. The result of the sensitivity analysis for operating expenses suggests a combination of efficiency gains, longer hours, and bulk purchasing could lead to a 50% reduction in costs, especially in low-income settings (table 3). In this Commission, we refer to the simultaneous application of all three scenarios (ie, efficiency gains, longer hours, and bulk purchasing) as the efficiency model.

In high-income countries, the costs of equipment, building, and salaries are 30%, 6%, and 64%, respectively, whereas in low-income countries these costs are 81%, 9%, and 10%, respectively (figure 8). Capital costs of equipment are the major cost component for radiotherapy in low-income and middle-income countries; salaries dominate in high-income countries. Our results for high-income countries are consistent with those from previous studies,<sup>96</sup> in which capital equipment costs were estimated to be around 30% of total cost.

### Estimation of current treatment capacity

The capital and operating costs for radiotherapy scale-up and additional future requirements will depend on the incidence of cancer, types of cancers treated, corresponding number of fractions for each treatment course, and existing capacity. Although many country-based repositories detail available capital and human radiotherapy resources, data for regional or worldwide resources are limited. The two main sources of information are the DIRAC<sup>47,54</sup> and the European Society for Radiotherapy and Oncology's Health Economics in Radiation Oncology (HERO) databases (panel 2).<sup>97,98</sup>

We used the DIRAC data<sup>53</sup> to provide a worldwide estimate of available radiotherapy facilities and equipment, and the HERO data as a form of validity check for countries where the data were available. For the number of departments and equipment, there was good concordance between the two datasets. As data for a given country could have been gathered in different years for the two sets, some variance between the DIRAC and HERO data was deemed acceptable. Table 4 lists available



	Operating cost per fraction: sensitivity analysis			Cost savings relative to base scenario			
	Automation: efficiency	Longer hours	Bulk purchase	High-income countries	Upper-middle-income countries	Lower-middle-income countries	Low-income countries
Combination 1	X	..	..	25%	21%	21%	21%
Combination 2	..	X	..	13%	18%	23%	25%
Combination 3	..	..	X	8%	16%	21%	23%
Combination 4	X	X	..	33%	34%	39%	40%
Combination 5	..	X	X	19%	34%	38%	42%
Combination 6	X	..	X	31%	34%	38%	39%
Combination 7	X	X	X	37%	43%	51%	53%

The operating cost model allows for improved efficiency, longer treatment hours per day, and bulk purchasing savings. These factors can occur alone or in combination, resulting in seven different combinations. X shows the inclusion of a factor in the sensitivity analysis.

**Table 3: Sensitivity analysis to determine operational costs**

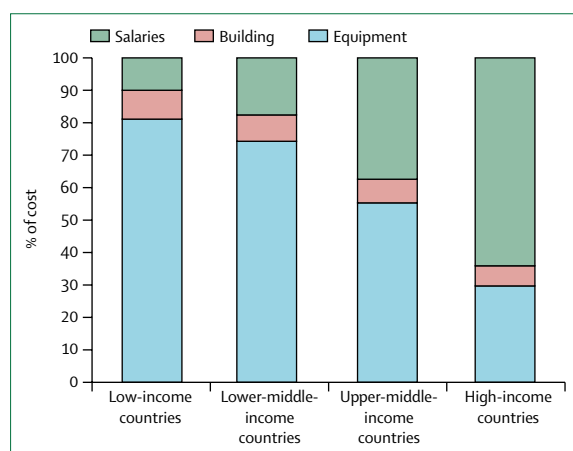


Figure 8: Cost breakdown for salaries, buildings, and equipment needed for radiotherapy, by gross-national-income region

resources in 2013 in terms of number of radiotherapy departments, linear accelerators, and  $^{60}\text{Co}$  machines.

The difference between the two datasets was substantial for human resources. Whereas the data for HERO were cautiously gathered and validated with representatives from each country's national societies,<sup>52</sup> the DIRAC database is based on voluntary reporting by a facility's contact person, creating uncertainties about the number of full-time equivalent staff because of dual jobs in private and public hospitals, potential double accountability for personnel working in satellites and primary departments, and larger fluctuation of the human resources related to the needs, retirement, and training. Thus, we did not use DIRAC data as the basis for human-resources availability. Similarly, no reliable data for actual worldwide fraction capacity were available. To overcome this lack of data on the number of worldwide fraction capacity and personnel, we adopted a pragmatic approach. We assumed that the

current number of professionals working in radiation oncology services worldwide and the number of fractions delivered were in line with the available equipment as estimated by the nominal model, and that the available equipment would be used at optimum capacity, and inferred the number of delivered fractions and of personnel needed for radiotherapy machines from the quantity of radiotherapy equipment.

Figure 9 shows regional variation in radiotherapy treatment capacity, in the form of the coverage metric, and figure 10 plots coverage against gross national income. We define coverage as the current capacity, determined by the equipment and the nominal model, divided by the estimated demand for radiotherapy fractions based on the cancer burden and evidence-based practice. Coverage is affected by several factors, including countries with small populations, the discrete nature of an individual treatment machine and its corresponding treatment capacity, and organisation of palliative versus curative services in different countries. Additionally, installation of redundant capacity for high availability and future growth is not uncommon. Unfortunately, the data sources used for these estimates do not show the operational status of the equipment reported.

### Estimation of future facility, equipment, and staff needs

To determine future needs in terms of facility and operational requirements, we used incidence and fractionation data per country and divided these into four gross-national-income groups (low income, lower middle income, upper middle income, and high income). Then, on the basis of the assumptions described previously (eg, two treatment machines per department, 12 treatment hours per day, and four fractions per h), we determined the number of facilities, equipment, staff, and operations needed to deliver effective radiotherapy (table 5).

These projections are based on the conservative assumption that cancer treatment practices—radiotherapy specifically—will not change substantially in the next 20 years. Given that these investments have a 20-year lifetime and novel therapeutics take 10–15 years to transfer to routine clinical use, this assumption is reasonable.

### Part 7: Return on investment

Investment frameworks have been used to make a case for investing in HIV,<sup>99–101</sup> maternal and child health,<sup>102</sup> and, more broadly, in public health and health care.<sup>23</sup> They typically provide a conceptual outline for estimation of health, economic, and social benefits of health investments, with a defined timescale, evidence on cost-effective interventions, and contextual factors that determine the realisation of the full impact of benefits.<sup>99–102</sup>

In the investment framework for radiotherapy, it is implicit that effective delivery of radiotherapy services depends on the successful functioning of a comprehensive

### Panel 2: Databases of radiotherapy capacity

The International Atomic Energy Agency (IAEA) has maintained a registry of radiotherapy centres since 1959. The Directory of Radiotherapy Centres (DIRAC), the current web-based version, was launched in 1995 and is a database of radiotherapy infrastructure worldwide that draws on voluntary contributions of information by countries.<sup>53</sup> DIRAC includes data for teletherapy machines, sources and devices used in brachytherapy, and equipment for dosimetry, imaging, dose calculation, and quality assurance. It provides information about type of machine and energy, but has limited information on additional functionality. The database equipment also contains reported numbers of radiation oncologists, medical physicists, and radiation technologists working in the facilities.

Reliable data for human resources are more difficult to obtain than data on equipment because in some regions professionals work simultaneously in more than one place (public-private) and, although DIRAC's questionnaires specifically request information on full-time equivalence, institutions do not always provide these figures, resulting in a possible overestimation of the final numbers. The growing number of satellite centres sharing staff with a main centre also makes interpretation of the data difficult. Because of training of new professionals in some regions, the numbers can change substantially quite quickly. DIRAC is continuously updated on the basis of questionnaires available from the IAEA and additional information from audit networks.<sup>53</sup>

The Health Economics in Radiation Oncology (HERO) project, which was initiated by the European Society for Radiotherapy and Oncology, aimed to develop a knowledge base and a model for health economic evaluation of radiation treatments at the level of individual European countries,<sup>97</sup> by availability, needs, cost, and cost-effectiveness of radiotherapy. The availability of resources was assessed through a web-based questionnaire relating to population and cancer incidence and radiotherapy activity, resources, guidelines, and reimbursement. The data capture and validation was closed in early 2014 and the dataset now provides a comprehensive overview of available radiotherapy resources across Europe, with data mostly pertaining to radiotherapy availability after 2010.

28 European countries provided data about facilities and equipment.<sup>98</sup> Facilities were classified as departments. Equipment was classified as the number of megavoltage units (linear accelerators, <sup>60</sup>Co machines, and dedicated stereotactic machines), along with the intensity-modulated and image-guided radiotherapy capability of the units. Furthermore, the availability of orthovoltage machines and hadron equipment was recorded. Simulators were classified as conventional simulators, CT simulators, or simulators with a cone-beam CT option. 24 countries were able to provide information about human resources.<sup>98</sup> Data were gathered for radiation oncologists, medical physicists, dosimetrists, radiation technologists, nurses, and radiobiologists, both for the public and the private sectors, in absolute numbers and full-time equivalents.

cancer system and presence of enabling services that include adequate diagnostic imaging, pathology, surgery, systemic therapy, and primary care. Additionally, contextual readiness is important, including infrastructure (panel 3), financing mechanisms, and awareness building, to create an enabling environment for investment and scale-up.

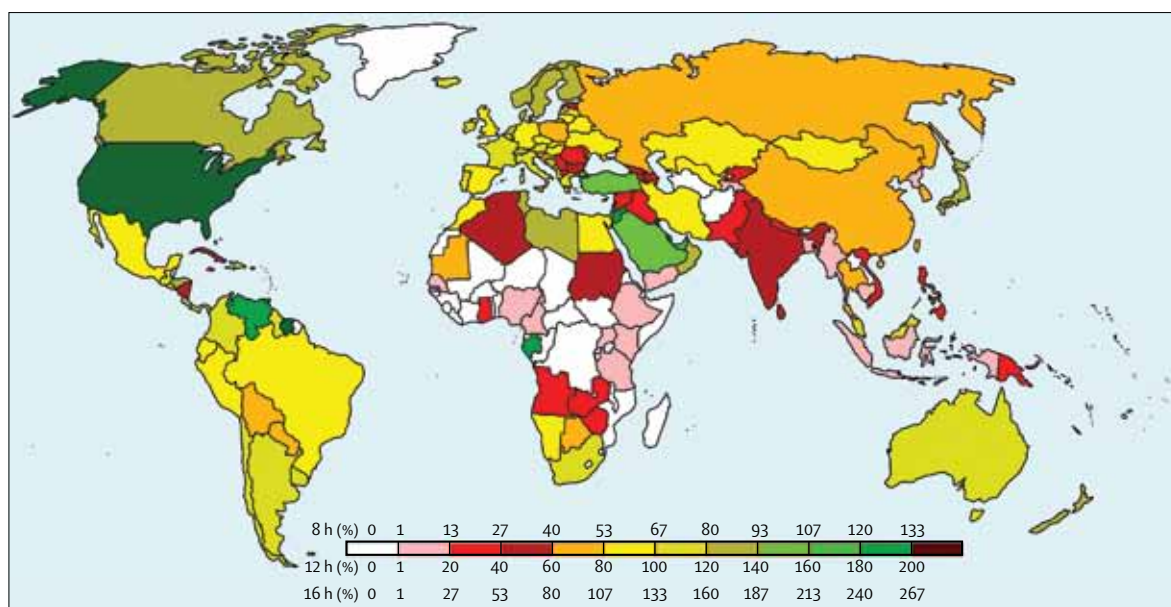
### Analytic approach

We estimated potential health and economic returns on investment to scale up radiotherapy capacity in 2015–35. Using a parsimonious model, with conservative estimates that assumed no efficiency improvements in costs in the period of analysis, we estimated returns for the ten cancers with highest worldwide incidence, which collectively represent 75–80% of the global burden of cancer. The period 2015–35 was chosen on the basis of data availability (the projections of the burden of cancer, which were obtained from the IARC, extended to 2035).

We stratified the analysis by World Bank income-group region, and did it separately for 35 low-income, 42 lower-middle-income, and 44 upper-middle-income countries (table 6). Net monetary benefits were calculated for two radiotherapy packages—the nominal model and the efficiency model—recognising that a singular approach might not be feasible or appropriate. All costs and benefits were discounted at 3%, as recommended by WHO.<sup>104</sup>

	High-income countries	Upper-middle-income countries	Lower-middle-income countries	Low-income countries
Radiotherapy departments	5075	1972	590	40
Total megavoltage machines	8911	3115	1014	62
Linear accelerators	8300	2371	523	25
<sup>60</sup> Co units	611	744	491	37
Modelled capacity (fractions per year)	75 879 000	32 995 000	10 660 000	650 000
Data are n, unless otherwise specified. The number of fractions that can be delivered with this equipment each year was modelled according to the nominal activity-based model.				
<b>Table 4: Radiotherapy resources and modelled capacity, 2013</b>				

Cancer-site-specific Markov models were developed for each of the top ten cancers to simulate remaining lifetime after diagnosis. The total population in whom a given cancer was diagnosed in each year from 2015 to 2035 was defined as a cohort, and simulated in a scenario of radiotherapy scale-up or no scale-up. In the no-scale-up scenarios, a baseline radiotherapy coverage level was defined to estimate the proportion of radiotherapy fractions required for the population who need treatment, and we assumed a linear scale-up to 100% of known radiotherapy fraction demand for the study period. We assumed that sufficient societal and health infrastructure



**Figure 9: Coverage of radiotherapy services according to country as determined by global equipment databases, an activity-based operations model, cancer incidence, and evidence-based estimates of radiotherapy need**

Estimates depend on the nature of equipment use. The colour bar shows the operational model: 12 h operation was used as the feasible case, but 8 h and 16 h were also modelled to capture typical and potential capacity, respectively.

would be in place to enable scale-up and delivery of radiotherapy services (panel 3).

Health benefits were measured as the additional discounted life-years gained through scaled-up radiotherapy capacity. In each simulated scenario, we measured the probability of survival with radiotherapy against the counterfactual of survival without radiotherapy. The indications for radiotherapy, the corresponding survival benefits, and the background mortality rate of a population were assumed to be constant throughout the study period. We modelled excess mortality on the basis of representative life tables published by WHO for low-income, lower-middle-income, and upper-middle-income countries. Median age was modelled on the basis of data from the Surveillance, Epidemiology, and End Results Program and adapted to the demographic patterns of low-income and middle-income countries.<sup>105–108</sup>

Economic benefits were estimated with both the human-capital and the value-of-life-years methods—the so-called full-income approach. Both methods rely on gross domestic product to estimate the effects of radiotherapy investment. In the human-capital approach, the economic value of life according to a person's economic contribution to the gross domestic product is calculated—ie, the contribution that a working individual is expected to make through the extra life-years provided by radiotherapy for her or his cancer. In this analysis, we assume that life-years gained after age 70 years do not add to gross domestic product.

The full-income approach, in which a multidimensional view of human welfare beyond an individual's capacity to generate a sufficient livelihood is taken,<sup>109</sup> takes into

account societal benefits of radiotherapy investment. It recognises the intrinsic personal or societal value of a life-saving intervention, even if the recipient is no longer able to contribute to the workforce. It is rooted in analyses of willingness to pay by a society or individual to avoid potential reduction in life expectancy, which was estimated in The Lancet Commission Global Health 2035 to be 2.3 times the gross domestic product per person in a given year.<sup>23</sup>

### Pace of investment

The term scale-up does not have a universally accepted definition. A Commission on Macroeconomics and Health has defined scaling up as expansion of priority health services so that they are universally available.<sup>110</sup> Others have described going to scale as when “at least 60% of a target population receives a program from which they could potentially benefit”.<sup>111</sup> Inadequate diagnostics and lack of accurate disease reporting have limited our ability to estimate demand for radiotherapy accurately. Population-based cancer registries—a key means of cancer planning—are established in less than a fifth of low-income and middle-income countries.

We have estimated a linear scale-up to 100% of known radiotherapy fraction demand for the study period. Investment levels were modelled at 4.3% per year in low-income countries, 2.7% per year in lower-middle-income countries, and 1.5% per year in upper-middle-income countries, accounting for projected increases in cancer incidence. The investment levels were similar to the projections in The Lancet Global Surgery Commission, in which a historical scale-up rate of 5.1% per year from

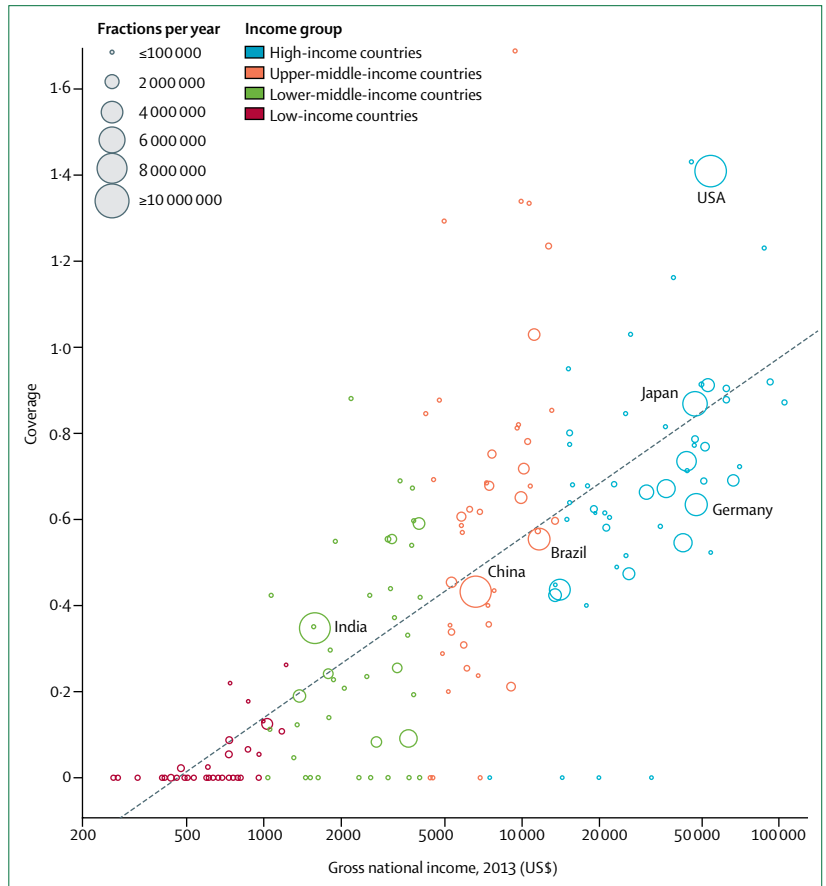
2012 to 2030 was calculated with data for surgical volumes and gross national income per person.<sup>112</sup> We also assumed that in a given year 20% of patients with a potential survival benefit from radiotherapy would not receive treatment. This estimate is based on the expectation that communicating the indications and appropriate use of radiotherapy to patients and the medical community—effectively changing practice—might not proceed at the same pace as the installation of physical infrastructure.<sup>113</sup>

### Monetary benefit and returns on investment

Through a linear scale-up of radiotherapy capacity from 2015 to 2035, 6·3 million discounted life-years would be gained in low-income countries, 9·9 million in lower-middle-income countries, and 10·7 million in upper-middle-income countries over the lifetime of the patients who received treatment. The cost of scaling up radiotherapy in the nominal model in 2015–35 is \$26·6 billion in low-income countries, \$62·6 billion in lower-middle-income countries, and \$94·8 billion in upper-middle-income countries, which amounts to \$184·0 billion across all low-income and middle-income countries. In the efficiency model the costs were lower: \$14·1 billion in low-income, \$33·3 billion in lower-middle-income, and \$49·4 billion in upper-middle-income countries—a total of \$96·8 billion.

With a full-income approach, a positive return on investment was calculated across the income group regions with investment in radiotherapy. The nominal cost model resulted in a net benefit of \$265·2 million in low-income countries, \$38·5 billion in lower-middle-income countries, and \$239·3 billion in upper-middle-income countries in the 20-year period of projections (table 6). Investment by the efficiency model also yielded substantial gains in all income group regions (table 6). Such modifications to the technology package, based on the circumstances of specific countries and regions, allow important health and economic benefits to be achieved in regions with varying resources.

Application of the human-capital approach led to more conservative monetary benefits and returns, and a substantial improvement in the investment plan was noted with the efficiency model (table 6). With the nominal cost model, there was a net deficit during the study period in low-income countries (–\$14·9 billion) and lower-middle-income countries (–\$18·7 billion), but positive returns of \$50·5 billion were noted in upper-middle-income countries (table 6). The efficiency model showed net monetary benefit in lower-middle-income and upper-middle-income countries. In lower-middle-income countries, benefits began to outweigh the costs by 2021, and net benefits were achieved after a year of scale-up in upper-middle-income countries. In low-income countries, a net deficit of \$2·4 billion over the study period was noted, but a net benefit was achieved in the final year of investment, emphasising the long-term perspective that is needed (figure 11).



**Figure 10: Radiotherapy coverage as a function of gross national income**

Each circle represents a distinct country. The diameter of the circle is the actual yearly number of fractions delivered. Coverage is reported for an assumed 8 h operating day.

	High-income countries	Upper-middle-income countries	Lower-middle-income countries	Low-income countries
Fractions	76 424 000	77 014 000	40 974 000	13 268 000
Radiotherapy departments	4600	3700	2000	600
Megavoltage machines	9200	7400	3900	1300
CT scanners	4600	3700	2000	600
Radiation oncologists to be trained	15 500	16 800	9900	3300
Medical physicists to be trained	17 200	12 500	7200	2400
Radiation technologists to be trained	51 900	45 300	24 900	8100

Data are n. The appendix contains more information about the CT scanner shared-use model.

**Table 5: Projected fractions and related resources needed in 2035**

Scientific advances, which are incorporated into the efficiency model, mean that radiotherapy is affordable and its scale-up is feasible. The estimates suggest that returns on investment in radiotherapy are positive and substantial. In addition to the estimated health and economic benefits of using radiotherapy for treating cancer, additional benefits are to be gained from palliation of symptoms of advanced disease, such as pain

### Panel 3: Structural investments for radiotherapy

#### Regulatory investments

Several institutions identify standards for safety and quality assurance in radiotherapy delivery. The International Atomic Energy Agency, International Commission on Radiation Units and Measurements, and National Council on Radiation Protection and Measurements (a US national association) are involved in setting industry standards. However, enforcement of safety and quality standards is the responsibility of regional and national governments, which should establish regulatory bodies with sufficient authority and independence to undertake assessments and inspections, enforce minimum standards, provide authorisation, and issue licences.

Regulation of occupational, medical, and public exposure to ionising radiation requires adherence to dose constraints, guideline-based therapy, and a commitment to maintaining exposures as low as reasonably achievable. Trained personnel in medical physics and physicians with medical specialisation in radiation oncology must oversee this system and participate in organised quality-assurance review.<sup>103</sup> Radiotherapy that is not delivered safely can cause substantially more harm than can lack of access to radiotherapy.

#### Technical investments

Technical investments vary substantially with the technological package that is purchased. Treatment machines and simulators typically need a reliable power supply and some degree of environmental control, including specific air-handling requirements. Treatment units that have reduced energy demands, such as <sup>60</sup>Co units, address these issues but can present other challenges, including transporting and replacing the radioactive source amid increased international security and transportation concerns.

#### Societal investments

Radiotherapy is typically delivered as a daily outpatient treatment modality, which means that patients have to find accommodation near the treatment facility or travel back and forth from home each day. Adequate roads, transportation, and financial support for the cost of receiving treatment away from home must be available to encourage adherence to treatment. Furthermore, access to nursing and hospital services to manage complications of treatment is essential.

from bony metastases, spinal cord compression, cognitive or neurological impairment from brain metastases, or bleeding. In high-income countries, more than half the workload of radiotherapy departments is palliation.<sup>114</sup> In countries without cancer screening programmes, most patients present late with advanced disease and poor performance status, and thus the availability of appropriate palliative care—including radiotherapy—is of utmost importance. A study<sup>115</sup> in 2008 of 23 radiotherapy centres in Africa showed that, on average, only 22% of patients presented with early-stage disease. In our analysis, the estimated costs include palliative fractions, but no benefit is assigned to these fractions, since they contribute to improved quality, but not quantity, of life-years. In this way, it might be reasonable to assume that our cost–benefit ratio for fractions contributing to life expectancy could be greater if palliative care benefits were taken into account.

Several other factors affect the estimated return on investment. Over time, centres will become more efficient at delivering treatments as teams become experienced in

local needs.<sup>116</sup> We have adopted a parsimonious and conservative approach and so this potential increase in output, which would further improve the potential returns on investment, has not been captured in our analysis. In our modelling, we have defined a pace of investment, but individual countries might vary in their investment intensity, because the pace of investment would be affected by availability of funding, infrastructure gaps, regulatory procedures, and availability of human resources (panel 3). Other rates of investment that could be explored include gradual or accelerated rates of investment.

With a gradual investment model, 25% of total spending occurs in the first 10 years and the remaining 75% occurs in the last 10 years. In countries such as Malawi, where patients' out-of-pocket expenditures are the primary mechanism of funding for treatment of NCDs,<sup>117</sup> this gradual scale-up might be more appropriate. With an accelerated investment rate, 75% of total planned spending is in the first 10 years, which can be seen in countries with more advanced infrastructure already in place. Brazil, for example, has finalised the purchase of 80 new linear accelerators in the next 5 years to reduce inequality in the northern and northeastern regions of the country, and to satisfy 85% of the country's demand.<sup>118,119</sup> Variation in possible investment rates has been recognised in other investment framework platforms.<sup>23,102</sup>

A further limitation of our analysis is its macro-focus, in that we use gross domestic product per person to classify countries, which does not take into account other regional factors that can affect investment and scalability. For example, we have assumed a 20% gap between use and demand, on the basis of our demand estimations. The results of scale-up efforts of other medical interventions suggest that this gap might be greater in the initial implementation phase. A sound scale-up strategy is essential to ensure optimum uptake of available health-care services by patients and appropriate referrals by health-care providers.<sup>120</sup>

### Part 8: Enabling environment and contextual readiness

To optimise the benefits, radiotherapy has to be deployed for the appropriate patients, in early-stage disease, and when indicated in combination with other treatment modalities. Patients must first be identified and then assessed to determine the best management plan. This process starts with accurate diagnosis (typically with biopsy followed by histopathological assessment, which might include immunohistochemistry and molecular and cytogenetic testing), followed by disease staging, before establishing the overall treatment plan.

Surgery, radiotherapy, chemotherapy, medical imaging, and pathology are the mainstays of cancer diagnosis and treatment, with support from other medical and health-related disciplines. Surgery, radiotherapy, and chemotherapy are not interchangeable, but complementary



	Low-income countries		Lower-middle-income countries		Upper-middle-income countries	
	Nominal	Efficiency	Nominal	Efficiency	Nominal	Efficiency
<b>Net monetary benefit (US\$, billions)</b>						
Human-capital approach	-14.9	-2.4	-18.7	10.7	50.5	95.9
Full-income approach	0.265	12.8	38.5	67.7	239.3	284.7
<b>Return on investment (US\$, billions)</b>						
Human-capital approach	-0.56	-0.17	-0.3	0.32	0.53	1.94
Full-income approach	0.01	0.91	0.62	2.03	2.52	5.77

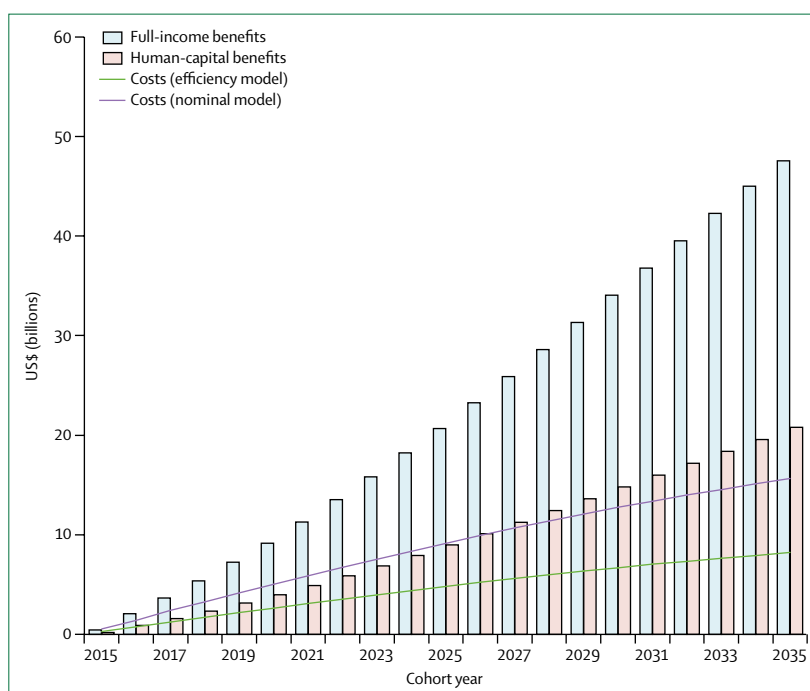
Net monetary benefit=cost of investment–economic return. Return on investment=net monetary benefit / cost of investment. Costing models are described in the text and include both operational and capital costs.

**Table 6: Cost and benefits of investments to scale up radiotherapy services in low-income and middle-income countries, 2015–35**

essential treatment approaches, and an increasing proportion of patients is best treated with at least two and sometimes all three modalities. But in low-income and middle-income countries there are major shortfalls in all these services. For example, 5 billion people worldwide, mostly in low-income and middle-income countries, have limited or no access to surgical and anaesthesia care.<sup>112</sup> Surgery to take a biopsy or remove a suspicious mass that turns out to be malignant is very often the initial point of entry into the cancer treatment system. Unimpeded access to surgery and pathology at this crucial point in the diagnosis and treatment chain is essential to assure equitable access to cancer care. In addition to shortages in surgery, quality diagnostic services are scarce. Difficulties in obtaining timely and correct diagnosis result from substantial shortages of trained health professionals and diagnostic facilities.

This reality plays out daily in low-income and middle-income countries, with devastating results across a range of cancer diagnoses, as shown by the management of cervical cancer, a leading cause of cancer-related suffering and death among women in low-income and middle-income countries (panel 4).

Access to diagnostic and treatment facilities is crucial, but so too is increasing patients' awareness through public education and effective primary care and referral systems. In many regions with adequate treatment facilities, ineffective processes cause unacceptable delays to diagnosis, leading to worse outcomes. Implementation of screening and early detection programmes is helpful to shift presentation to earlier stages and optimise the benefit of treatment approaches. Access to affordable and effective radiotherapy depends not only on infrastructure, facilities, and trained personnel, but also on an organisational and operational framework that supports the delivery of best practice and safe care. Radiotherapy is an effective and safe treatment for cancer when applied in a controlled manner that maximises the benefits to patients and minimises risk to care providers and the general public. This process necessitates both system-level and local planning to ensure appropriate facility design and construction, as well as adherence to manufacturers' recommendations for equipment quality



**Figure 11: Cost and benefits of investments to scale up radiotherapy services in low-income and middle-income countries, 2015–35**

The costing models are described in the text and include both operational and capital costs.

control and maintenance. More fundamentally though, it necessitates an awareness of the importance of radiotherapy quality assurance and safety among health-care leaders and front-line providers alike, nurtured and supported by organisational guidelines tailored to reflect the realities of the local practice environment.

What constitutes best practice in a well-resourced country might not be feasible in low-income and middle-income countries. On the contrary, practices that might be deemed inappropriate in high-income countries—eg, not using image guidance or immobilisation devices—might be acceptable in low-income and middle-income countries when balanced against the alternative of no radiotherapy at all. To maximise the potential of radiotherapy in low-income and middle-income countries, innovative care delivery models adapted to the local social, cultural, and

#### Panel 4: The global challenge of cervical cancer

Cervical cancer is the third most common cancer in women.<sup>1,78</sup> Globally, despite falling age-adjusted incidence, the number of newly diagnosed cases of cervical cancer rose by 0.6% each year from 1980 to 2010; around 75% of new cases were in low-income and middle-income countries.<sup>121</sup> There are important global disparities in diagnosis and treatment of cervical cancer that translate directly to differences in survival. In high-income countries, 50–60% of women are alive 5 years after diagnosis of cervical cancer compared with only 10–20% in some parts of Africa.<sup>122,123</sup> Global access to prevention, early detection, and treatment of both precancerous and invasive cancers, including access to effective, safe, and affordable radiotherapy, is needed to halt this avoidable cause of suffering, premature death, family hardship, and social disruption.

Cervical cancer is caused by human papillomavirus (HPV) infection and typically has a long latency from initial infection to the first manifestation of invasive, life-threatening cancer.<sup>124,125</sup> HPV vaccination programmes, education about safe sexual practices, and screening for precancerous conditions have the potential to reduce the frequency of cervical cancer and have been successful in high-income countries. However, achieving similar results in low-income and middle-income countries with these cost-effective interventions will necessitate novel solutions to assure equitable access and broad-based population uptake of vaccination for HPV.<sup>126</sup> The full benefit of these programmes is unlikely to be realised for many years. For example, even in the unlikely best-case scenario in which every 12-year-old girl in every country is vaccinated every year beginning today, a major reduction in incidence of, and mortality from, cervical cancer will not be realised for 30 years.<sup>127</sup> In the next 20 years, the timeframe of this Commission, we estimate that almost 11 million women in low-income and

middle-income countries will be diagnosed with invasive cervical cancer. Without radiotherapy, most will die.

Cervical cancer most often affects women aged 40–60 years, although spans the full range from very young to elderly women. About 45% of women with cervical cancer are in their reproductive years. In the absence of effective screening, as is the case in most low-income and middle-income countries, about 75% of women are diagnosed with advanced, life-threatening disease that cannot effectively be treated with surgery, but is potentially curable with radiotherapy. When women are unable to access effective and safe radiotherapy, they often receive no treatment or, at the most, palliative chemotherapy to alleviate symptoms. Some will have sufficient cancer regression from chemotherapy to undergo surgery, but most will die quickly from the consequences of progressive disease.

Radiotherapy is a very effective treatment for cervical cancer. About 70% of newly diagnosed patients will benefit from radiotherapy administered either as curative treatment or to control symptoms such as pain or bleeding.<sup>83</sup> Radiotherapy is estimated to improve absolute 5-year survival of women with cervical cancer by 17% over and above the contribution of surgery and chemotherapy, which suggests that closing the radiotherapy gap in the next 20 years will save almost 10 million life-years in low-income and middle-income countries that would otherwise be lost to this disease alone. This is a conservative estimate of the overall effect of radiotherapy, which does not fully account for the social benefits accrued to families and communities<sup>128</sup> or the benefits of alleviated suffering with palliative therapy in the face of incurable, symptomatic disease.

economic environment are needed and should be developed through concerted effort by the global oncology and radiotherapy communities, including equipment manufacturers, working closely with policy makers and front-line care providers.

#### Part 9: Scale-up of radiotherapy

The global gap in access to radiotherapy needs urgent action. This sense of urgency should be balanced against a need for careful resource-planning and responsible investment of scarce resources, especially in low-income countries. Examples of successful investments around the world suggest that to build appropriate and effective radiotherapy services more than financial investment is needed: an enabling policy environment is crucial to scaling up and sustaining radiotherapy services.

A two-pronged approach is required to address the urgent need for radiotherapy services: planning and action. In countries lacking radiotherapy services,

immediate investment in a start-up package (the nominal model) of radiotherapy services should begin in earnest while comprehensive planning takes place. The creation of a radiotherapy facility would not only enable delivery of critically needed care, but also create the setting for training of health professionals and help to establish evidenced-based comprehensive cancer care. Planning needs to begin in parallel to guide continued investment.

As countries transition from low-income to middle-income to high-income status, and as the fiscal environment improves, sustained investment in radiotherapy will ensure progressive expansion of services with modern technology and suitably trained health professionals. Radiation equipment has a long, but nevertheless limited, lifespan. Plans for expansion need to take into account equipment maintenance, upgrades, and replacement with next-generation technology.

An important consideration when investing in radiotherapy is that upfront costs are high, but operational costs per patient are low over the lifetime of

the equipment: with adequate staffing and regular preventative maintenance, the equipment could be used for 8–16 h a day for 15–20 years. For example, a linear accelerator could deliver about 100 000 fractions or doses in 20 years. However, if only 10 000 fractions are delivered because of equipment breakdown or staff shortages, then the cost per fraction increases substantially. Sustained investment is therefore crucial to ensure adequate staffing and preventive maintenance, and web-based instruments have been developed to enable countries to estimate human and other resource needs for cancer control.<sup>129</sup>

The IAEA has introduced radiotherapy to many countries in the past 25 years, which provides valuable lessons that highlight risks of complacency due to failure to: invest in human resources (which results in underuse of radiotherapy equipment and inadequate maintenance); account adequately for so-called brain drain when training health professionals; and scale-up after IAEA technical assistance that enables initial technology transfer and capacity building, which should be continued by the national authorities of beneficiary countries. Increased national wealth does not assure expansion and sustainable development of radiotherapy coverage within countries: the development of evidence-based policies and plans and investment in equipment and human resources are also necessary. Complacency or misalignment of priorities with the changing cancer burden can rapidly lead to shortfall in treatment capacity, with consequent treatment delays and increased mortality.

Inappropriate policies can weaken existing radiotherapy capacity, leading to loss in services and erosion of skills development, and drive cancer services away from best practices. Policy needs to follow the evidence—cancer care involves thoughtful judgment, and betting on new therapies risks undermining proven, evidence-based practice. Such poor policy making can risk undermining years of careful investment. There is evidence of periodic erosion of radiotherapy capacity in developed countries with strong health systems (eg, Australia, Canada, UK) because of injudicious health policies. The case of Ontario, Canada, shows the adverse results of poorly conceived policies and also how the decline can be effectively reversed with a systematic approach (panel 5).

Encouragingly, the expansion of radiotherapy capacity is both feasible and possible in low-income and middle-income countries, with examples in India, Bangladesh, Zimbabwe, and Brazil of different models by which radiotherapy capacity can be increased in such settings. The challenge of providing access to care combined with universal health coverage to prevent catastrophic health expenditure is being addressed in many countries including India, which represents an interesting mosaic of radiotherapy capacity with both a tremendous shortage of basic radiotherapy facilities but also substantial investment in the most advanced and expensive

technologies by the private sector. The country has shown how local capabilities can be developed to increase training and manufacture radiotherapy equipment to rapidly expand radiotherapy services to address the rising cancer burden and meet growing demand for radiotherapy services (panel 6).

The case of Brazil shows how investment in radiotherapy can be achieved with strong commitment from top-level political leaders (panel 7). In Bangladesh, partnerships were harnessed to leverage international expertise and overcome resource shortages (panel 8), whereas Zimbabwe shows that a low-income country with scarce resources can establish radiotherapy services centralised in major hospitals that provide services for cancer treatment and care (panel 9).

### Part 10: Obligation to innovate

Innovations are needed to expand radiotherapy services worldwide by accelerating adoption of existing technologies and creation of new technologies to address diverse needs. Innovations are also needed to develop new service models that remove impediments to efficient and effective care delivery, and improve financing, communication, and advocacy to mobilise support and gain the confidence of decision makers.

The global shortage of radiotherapy professionals is a major barrier to expanding services or effectively operating available capacity. Idle radiotherapy facilities and equipment in many low-income and middle-income countries are a sad reminder of wasted resources. An estimated additional 215 000 health professionals will be needed by 2035 to meet the need for radiotherapy services. Novel competency-based curriculums, new models of training, and credentialing are needed if the human-resource shortfalls are to be met.

The core clinical knowledge of cancer and radiation oncology practice needs to be shared more effectively. Training should leverage advances in communications, including distance learning and e-learning, for undergraduate<sup>162</sup> and postgraduate training of health professionals who could benefit from massive open online courses and variants such as small private online courses. Graduated licensing and stepwise incremental rewards in parallel with on-the-job professional development should accelerate skill development, build a pool of trained professionals, and decrease so-called brain drain from low-income and middle-income countries to high-income countries. Plans for radiotherapy services need to embed staff education and continuous skills development in their mandate and budget. These approaches will position radiotherapy centres to safely integrate innovations that bring advances in care or increases in efficiency.

A critical shortage of radiotherapy resources in low-income and middle-income countries has led to several individual-initiated radiotherapy development and support projects. Such efforts, while much admired, must be massively scaled up to have demonstrable and

### Panel 5: Ontario's crisis in access to radiotherapy

In the 1990s, Ontario, along with several other Canadian jurisdictions, faced a radiation-treatment-capacity access crisis. Years of managerial and political apathy for planning and expansion of radiotherapy facilities meant that demand outstripped supply, leading to long waiting lists for radiotherapy services, which adversely affected service quality, causing a political and public health crisis. The issue of access came about in the face of predictable, rising frequency of cancer brought about by population growth and an ageing population.<sup>130</sup> Rising numbers of patients with cancer, lack of new radiotherapy infrastructure, poor human-resource planning, and lack of financial investment led to inadequate treatment capacity and clinically dangerous waiting lists.<sup>131</sup> This situation led to a well documented loss of local tumour control, and decreasing use of radiotherapy facilities.<sup>132,133</sup> The delays to starting radiotherapy far exceeded times to treatment reported in the USA during the same period. The radiotherapy use rates were 23.7% at 1 year, far lower than international benchmarks and Ontario's expected rate of 45%.<sup>134</sup>

Clinicians were faced with grim choices: treat patients who were waiting too long or arrange treatment in border cities in the USA to reduce unacceptable wait times. The solution was to refer patients to oncology programmes in bordering US cities and begin a rapid cycle plan to expand capacity within the jurisdiction. Sadly, to their detriment, only some patients took the option to travel for timely treatment.<sup>135</sup>

The *Ontario Cancer Plan 2005–2008*, which was crafted by the new leadership of Ontario in 2005, powerfully showed the capacity problems and was rapidly publicised widely to meet population demand.<sup>136</sup> It included a large capital investment for

a multiyear expansion of radiation treatment, including the creation of seven additional local cancer centres with radiation capacity. Demand projections were estimated on the basis of optimum use, informed by evidence, access to radiation services, and appropriate medical and technical professional support. Public and political response to this crisis were funded with hundreds of millions of dollars to build new cancer centres and expand radiation machine capacity, guided by the first of several jurisdictional cancer plans. After a retreat with radiation leaders in Ontario, the new centres bought intensity-modulation radiotherapy machinery to improve the efficiency and precision of radiation treatment and led to optimum use targets rooted in evidence.

The *Ontario Cancer Plan 2005–2008* was followed by the *Ontario Cancer Plan 2008–11*,<sup>137</sup> *Ontario Cancer Plan 2011–15*,<sup>138</sup> and *Ontario Cancer Plan IV 2015–19*.<sup>139</sup> All such plans have been developed through an inclusive multistakeholder process that places patients at the heart of policy development. Ontario now operates a high-quality cancer network with good survival,<sup>140</sup> strong performance management, good access to radiation and other essential cancer services, and transparent public reporting on performance across the continuum of services.<sup>141</sup> Ontario compares well with international peers.<sup>142</sup>

Two lessons arise from this experience: the requirement for public transparency on reporting access to, and performance of, cancer services to show when there is a crisis and the need for change, alongside the need to make a clear, pragmatic, public case for capacity expansion to meet the future burden of patients with cancer.

lasting effect. Innovative leadership and stewardship models are required to promote multinational partnerships with those in need. There are efforts by the medical physics community in close collaboration with the International Organization for Medical Physicists, the American Association of Physicists in Medicine, and the *Physicien Médical Sans Frontières* to expand the Medical Physicists without Borders initiative and harness physics expertise from around the world to support centres in low-income and middle-income countries.

A similar initiative by the International Cancer Expert Corps<sup>163</sup> seeks to empower low-income nations to develop and sustain better cancer care by establishing a network of oncology professionals to mentor and work with local and regional groups. These coordinated approaches are powerful in helping to bring new radiotherapy services online, commission equipment, and train local staff.<sup>164</sup> The GTFRCC started the young leaders' social network movement GlobalRT to initiate the volunteerism necessary to bring radiotherapy resources to parts of the world in need.

Innovation is crucial for the development of radiotherapy technologies that can be deployed rapidly and operated with less complexity, and are robust in social and physical environments that are not well resourced. Processes for establishing radiotherapy services in low-income and middle-income countries are slow and cumbersome, limiting the rate at which the shortfall in cancer treatment capacity can be met. There is a need to accelerate the adoption and deployment of new technologies that meet the contextual needs of low-income and middle-income countries, which can have regular interruptions to energy supply, lack of air temperature control in buildings, and weak health systems. For example, an environmentally friendly radiotherapy accelerator that consumes little power on standby and has reduced heat production, low instantaneous power demand, and local power storage would reduce reliance on the electricity grid (especially if it could be solar powered) and is in development.

The adoption of advanced information technologies and computing power brings additional opportunities. System-wide integration of data allows more accurate

For more on **Medical Physicists without Borders** see <http://mpwb.org>

For more on **GlobalRT** see <http://globalrt.org>

**Panel 6: India—local training and manufacturing to expand high-technology radiotherapy services**

India is a lower-middle-income country, with an area of around 3·3 million km<sup>2</sup> and a population of 1·2 billion, 32% of whom live in urban areas. In 2014, the gross domestic product per person was US\$5800.<sup>143</sup> India's health system is financed from federal, state, and insurance sources and by out-of-pocket expenditures, but does not provide universal health coverage for its population.

In 2015, 363 centres in India were providing radiotherapy services, with 301 linear accelerators, 228 <sup>60</sup>Co units, and 247 brachytherapy systems, of which 233 were high-dose rate brachytherapy units. Most of the linear accelerators have three-dimensional conformal radiotherapy capabilities and 103 machines have intensity-modulated or image-guided radiotherapy capabilities (Shrivastava, Tata Memorial Hospital, personal communication).

More than 2000 trained radiation oncologists practise in India. There is increasing interest among medical graduates to specialise in radiation oncology. Currently, 64 medical colleges provide postgraduate courses and training in radiation oncology to more than 200 students each year. Training for medical physicists and radiotherapy technologists is being expanded to meet the needs of the country. India is projected to have sufficient human resources in 5 years to meet the demand for radiotherapy services.

Although growth in the health workforce has enabled rapid expansion and improvement of radiotherapy services in India, most centres are located in large cities such as Bangalore, Chennai, Delhi, Hyderabad, and Mumbai, with few centres in rural areas. Thus, patients need to travel long distances for treatment. Growth of radiotherapy services in public hospitals has been slow, but several private centres, which have the latest technology and state-of-the-art treatment facilities, have been established.<sup>144–146</sup>

Another limiting factor in meeting the demand for radiotherapy is the cost of equipment, which state-funded health services have not been able to finance. To increase the availability of radiotherapy equipment, the government's Department of Atomic Energy has initiated the development and manufacture of equipment locally. Through this investment, several Indian companies now produce <sup>60</sup>Co systems, linear accelerators, high-dose radiotherapy devices, and radiotherapy simulators at lower cost than devices produced by established international companies. India has installed more than 40 <sup>60</sup>Co machines that have been manufactured in country, with equipment also being donated to Vietnam and Mongolia.<sup>147–149</sup>

**Panel 7: Expansion of radiotherapy services in Brazil**

Brazil is the largest country in South America, with an area of almost 8·6 million km<sup>2</sup> and a population of 203 million, of whom 85·4% live in urban areas. In 2014, the gross domestic product per person was US\$15 200.<sup>143</sup> Brazil has a unified health system with universal health coverage free at the point of delivery supplemented by services provided by the private sector to people who have additional voluntary health insurance or pay out of pocket.<sup>150</sup>

In Brazil, the number of cancer cases was projected to reach 576 000 in 2014,<sup>60</sup> and 830 000 in 2035, with prostate, breast, colorectal, and lung cancers the most common. Brazil has instituted a series of multisectoral policies to address poverty and to expand further health services for underprovided populations to reduce inequities.<sup>151,152</sup> In 2014, Brazil had 337 linear accelerators, 34 <sup>60</sup>Co units and 114 high-dose rate devices distributed across 243 facilities (Braun R, Instituto Nacional de Câncer, personal communication). There are roughly 350 radiation oncologists and 274 medical physicists (Braun R, Instituto Nacional de Câncer, personal communication). However, an estimated 40% of patients requiring radiotherapy do not have access to treatment.

In 2011, the Brazilian Government, under the leadership of President Dilma Rousseff, launched an ambitious plan<sup>153</sup> to

expand radiotherapy services to rectify the shortfall in services and meet existing demand. They committed to investing BRL\$500 million into radiotherapy equipment and infrastructure to develop 41 new facilities with 80 linear accelerators (distributed in 63 municipalities located in 22 of the 27 states and the federal district) to provide an additional 3·5 million fractions per year. The international manufacturer of radiotherapy solutions that has been commissioned to install the radiotherapy facilities and equipment will establish a manufacturing plant in Brazil and will source 40% of the parts, accessories, and software related to the radiotherapy facilities from Brazil.<sup>154</sup>

One of the biggest challenges to rapid expansion of radiotherapy services is to train an appropriate number of health professionals to deliver high-quality radiotherapy treatments safely. To expand human-resource capacity, the secretariats of the Ministry of Health of Brazil and the Instituto Nacional de Câncer have formed a task force to establish training programmes that will develop capacity and train more than 400 new radiation technologists. The capacity development plan is to decentralise the training of these professionals by introducing blended learning that combines distance learning with practical training in local services.<sup>155</sup>



#### Panel 8: Partnerships to expand human-resource capacity in Bangladesh

Bangladesh is a low-income country with an area of 147 570 km<sup>2</sup> and estimated population of 166 million, around 33.5% of whom live in urban areas. In 2014, the gross domestic product per person was US\$3400.<sup>143</sup> Bangladesh has an underfunded health system that does not provide universal health coverage. Government funding levels are low and patients incur high out-of-pocket expenditures. Bangladesh has, however, implemented community-based approaches and partnerships (which include the government, non-governmental organisations, and the private sector) to expand access to health services and achieve substantial improvements in health outcomes.<sup>22</sup> In 2012, there were an estimated 122 700 new cases of cancer in Bangladesh.<sup>156</sup> The most common five cancers were breast, oesophageal, cervical, lung, and lip or oral cavity cancers. Projections to 2035 suggest more than doubling of new cancer cases to 250 000.<sup>157</sup>

In 2015, Bangladesh had 13 linear accelerators, 12 <sup>60</sup>Co machines, and six high-dose radiation units in 15 centres (Kamal Uddin AMF, Bangladesh Atomic Energy Commission, personal communication). Most centres that provide radiotherapy services are public facilities, where radiation treatments are roughly ten times cheaper than those provided in private clinics. An estimated minimum of 135 additional megavoltage

machines is required to meet current radiotherapy needs in Bangladesh.<sup>47</sup> However, there is a very substantial shortfall in human resources to provide radiotherapy services. In 2015, there were only 130 oncologists (mostly clinical oncologists), 14 medical physicists, and 40 radiation technologists.

In addition to the shortfall in human resources, the lack of financial resources poses a major barrier to meeting radiotherapy needs. Investment is needed for additional radiotherapy equipment, new radiotherapy facilities, and health professionals who can deliver radiotherapy services. Bangladesh does not have accredited programmes for radiotherapy training. Several organisations are partnering to address these needs, including the Federation of Oncologists within the South Asian Association for Regional Cooperation, the Bangladesh Atomic Energy Commission, and the International Atomic Energy Agency, and have been actively trying to increase the number of radiotherapy professionals. This process includes providing technical support to radiotherapy centres, the organisation of local week-long training sessions and 3-month training programmes in the USA, Germany, Singapore, and India. The Bangladeshi Government is procuring five more high-dose rate brachytherapy systems and is investing in additional megavoltage machines.

#### Panel 9: Zimbabwe—investing in radiotherapy services

Zimbabwe, which has an area of 390 757 km<sup>2</sup>, had a gross domestic product per person of US\$2000 in 2014, and a population of about 14.5 million, of whom 32.5% live in urban settings.<sup>158</sup> The economic, social, and political crisis experienced by Zimbabwe in the past two decades has severely affected the health system, which remains underfunded with limited access to health services and some of the worse health indicators for mortality in children younger than 5 years, maternal mortality, and HIV in Africa. In 2012, there were 6100 newly diagnosed cancers; the five most common were uterine cervical cancer (19.9%), Kaposi's sarcoma (10%), prostate cancer (8%), breast cancer (7%), and non-Hodgkin lymphoma (7%).<sup>159</sup> Most patients present with late-stage disease, and thus a very high proportion of cases need radiotherapy as part of their cancer management plans.<sup>36,38</sup>

In Zimbabwe, radiotherapy services are centralised in two centres: one in Parirenyatwa General Hospital in the capital, Harare, and the other in the Mpilo Central Hospital in Bulawayo. The Harare centre has three linear accelerators and two high-dose rate brachytherapy units. The Bulawayo centre is currently commissioning two linear accelerators and a high-dose rate brachytherapy unit (Kadzatsa W, University of Zimbabwe, personal communication). Additionally, a private radiotherapy centre in Harare is installing a linear accelerator to be operational in 2015 (Kadzatsa W, University of Zimbabwe, personal communication).

There are currently eight radiation oncologists, five medical physicists, and 30 radiation technologists in Zimbabwe. In 1990, the University of Zimbabwe's medical school began a training programme for radiation oncologists.<sup>160</sup> The programme was established and managed by WHO-sponsored specialists from different countries. The inaugural class had seven students from Zimbabwe, Cameroon, Nigeria, Ethiopia, and Tanzania. The last WHO consultant left in 1992, and the programme continues today with local specialists and ten enrolled students. The University of Zimbabwe also offers training in radiography and oncology nursing, which currently have 15 trainees each. Graduates of these programmes work regionally and internationally.

Zimbabwe faces major challenges to provide enough radiotherapy services, including the retention of highly trained radiotherapy professionals and funding for treatment.<sup>161</sup> More than 70% of the population has no form of health insurance or coverage. The high cost of equipment maintenance, lack of extended warranties, which hinders repair of faulty equipment, and shortage of local engineering expertise are a burden for the local service providers. Despite facing an economic crisis, in 2012, the Zimbabwean Government allocated around \$10 million to replace ageing equipment in the two state-owned radiotherapy facilities. Zimbabwe's aim is to increase the number of linear accelerators to at least 13 to align with the International Atomic Energy Agency's equipment recommendations<sup>47</sup> and to decentralise services to all ten provinces of the country.

and timely reporting of patient-level information to transform medical practice for the benefit of the patients and funders of health services. Use of digital data and cloud-based computing for treatment planning and electronic medical records would reduce power consumption and substantially enhance the reliability of radiotherapy equipment in low-income and middle-income countries. Such next-generation cloud-based radiotherapy platforms could accelerate adoption of automated techniques for treatment planning and quality control, enhance teledosimetry, and, crucially, support peer review, which has several positive benefits, including improved quality, reduced dependence on expertise, and reduced operating costs.<sup>165</sup>

Communications technologies—such as telediagnosis, teleradiology, and telepathology—have made remote diagnosis and planning possible and could benefit low-income and middle-income countries if investments are made in infrastructure and technical capability.<sup>166</sup> Telemedicine has been effectively deployed in high-income countries,<sup>166</sup> where low population density and distance from cancer centres limit convenient access to expert care. These techniques are less well used in low-income and middle-income countries to bring needed expertise to address the radiotherapy service shortfall (with the exception of selected initiatives used by the paediatric oncology community with excellent results<sup>167–169</sup>), offering potential to move beyond proof-of-principle applications to broad deployment.

There are opportunities for increasing financing for radiotherapy services. Despite the global economic crisis beginning in 2008, most low-income and middle-income countries have been able to achieve sustained economic growth and are projected to continue to do so in the next decade.<sup>170</sup> Many African countries have untapped natural resources that could generate more than \$4 billion each year<sup>171</sup> to create additional fiscal space in domestic budgets to increase investment for expansion of radiotherapy services. Furthermore, innovative financing, which was conceived as a measure to meet funding needs for the Millennium Development Goals, offers new opportunities for mobilising, pooling, channelling, and funding radiotherapy services as it has done for AIDS, tuberculosis, malaria, and children's immunisation programmes.<sup>172</sup>

Innovative financing instruments used in global health include the Airline Solidarity Levy (a surcharge on the civil aviation tax on airline tickets introduced by 11 countries including France), which was effectively used by Unitaids; the Global Fund to Fight AIDS, Tuberculosis and Malaria's Debt2Health (whereby a creditor country forgoes a portion of a debt on a debtor country on the condition that the beneficiary invests an agreed counterpart amount in national health programmes), and Product(R)ED (a brand licensed to companies such as Nike to create products with a Red logo—a percentage of the profit generated from the

product sales are donated to the Fund); and GAVI's Advance Market Commitments (long-term purchase commitments by governments that are used to encourage vaccine manufacturers to invest in vaccines for low-income and middle-income countries).<sup>172</sup> Innovative financing that has been used in non-health sectors could also be used to fund radiotherapy programmes that require large upfront infrastructure investments, which the countries could borrow to fund (panel 10).

Diaspora bonds (bonds issued by a country or a private corporation and sold to citizens who have migrated to mobilise financing for their originating country),<sup>175</sup> for example, could help to mobilise remittances from citizens who have migrated to other countries for work. In 2014, remittances to sub-Saharan Africa amounted to \$67·1 billion according to the African Economic Outlook. Social impact bonds allow private investors to invest in social causes and generate suitable financial returns, contingent on quality of outcomes achieved.<sup>176</sup> For the sponsoring government (the bond issuer), the innovative financing instrument offers risk protection and potential cost savings in implementing programmes. Guarantees, which have been provided by the World Bank Group (panel 10), have enabled investments in public–private partnerships and in projects that require upfront capital investments. These experiences could be used to generate new sources of financing for radiotherapy services that need infrastructure investments that can be amortised over 10–15 years.

Low-income countries have several health challenges: cancer is only one of them. Effective implementation of cancer strategy has many elements. Persuading decision makers to invest in radiotherapy remains one of the most difficult challenges to overcome, however. Innovation in advocacy is urgently needed to start immediate investment in new radiotherapy facilities.

## Part 11: Strengthening leadership and accountability

Despite radiotherapy being a critical component of cancer treatment, it is all but absent from global health and development discourse. Several distinct global actions have created a favourable environment for expanding radiotherapy services to improve cancer treatment, care, and control through collective action.

In 2004, the Programme of Action for Cancer Therapy (PACT)—a multipartner initiative led by the IAEA and WHO—highlighted the need for, and sought to stimulate investment in, radiotherapy, recognising that encouraging radiotherapy availability and capacity should also stimulate broader cancer control planning and services efforts in low-income and middle-income countries. Model demonstration sites from the programme have provided a proof of principle of the investment strategy and shown the challenges and commitments required to make this first core investment to address cancer burden and build system capacity.<sup>177–181</sup>

For more on the **African Economic Outlook** see <http://africaneconomicoutlook.org/en>

For the **Global Fund to Fight AIDS, Tuberculosis and Malaria** see <http://www.theglobalfund.org/en/>

### Panel 10: Innovative financing for radiotherapy investments—guarantees by development banks

Guarantees can be used to encourage private financing by mitigating investment risk in low-income and middle-income countries. In 2013, the World Bank Group provided US\$4.5 billion of guarantees across 30 countries.<sup>173</sup> These guarantees were provided by the World Bank's International Development Association, International Bank for Reconstruction and Development, International Finance Corporation, and Multilateral Investment Guarantee Agency. The guarantees were structured as partial risk guarantees, partial credit guarantees, or policy-based guarantees.<sup>174</sup> Partial risk guarantees support private sector investment, including public-private partnerships. Partial credit guarantees enable commercial borrowing in support of public investment projects, and policy-based guarantees support commercial borrowing for budget financing or reform programmes.

Guarantees offer several benefits to borrowers. The reduced risk of default improves the country's ability to borrow for investment. Guarantees can reduce the cost of capital as a result of lower interest rates that the borrowing government has to pay, because these rates are moderated by the guarantor's credit worthiness (the World Bank has AAA rating). Guarantees also allow governments to share the risk of projects with the private sector. The International Finance Corporation and Multilateral Investment Guarantee Agency have provided guarantees of around \$2 billion to the energy sector, with almost \$1.1 billion for African countries. The World Bank's experience will be very useful for the New Development Banks established by BRICS countries (ie, Brazil, Russia, India, China, South Africa), and the new Asian Infrastructure Investment Bank focused on infrastructure development in the Asia-Pacific region.

In 2011, the landmark UN high level meeting on NCDs<sup>177</sup> led to the UN General Assembly Resolution on the prevention and control of NCDs.<sup>178</sup> The *WHO Global Action Plan for the Prevention and Control of NCDs 2013–2020* followed: WHO member states have committed to develop an NCD (and, thus, cancer) plan to attain the 2025 goal of reducing premature mortality from NCDs by 25%.<sup>179</sup> This initiative is the first truly global effort to build capacity to treat cancer. The Plan calls for a health system response to address NCDs with a target to “increase availability of essential medicines and technologies for NCDs to 80% by 2025”. Radiotherapy is one of these cost-effective technologies that can address the growing burden of cancer mortality and associated economic consequences.<sup>180</sup> However, strong leadership at the global and country level is essential if expanded access to radiotherapy is to be achieved.

Global and national organisations need to lead together. Institutions such as WHO, the IAEA, International Agency for Research on Cancer, and the Union for

International Cancer Control; multilateral development agencies; civil society; professional associations; and the private sector have very important leadership roles in expanding worldwide access to radiotherapy services. As the established UN agency, WHO has the opportunity to use its leadership role to mobilise stakeholders to commit to expanding access to radiotherapy services for cancer. WHO's 2014 global status report on NCDs 2014 excludes any discussion of technologies and medicines for cancer,<sup>182</sup> yet the 2014 NCD country profiles show the proportion of deaths due to cancer reaching 10% in low-income countries like Zimbabwe, 13% in lower- middle-income countries like Indonesia, 23% in upper- middle-countries like China, and around 30% in high-income countries.<sup>183</sup>

Thus, focus on prevention has to be combined with treatment to address unnecessary deaths from cancer. It is imperative that WHO engages in a dialogue about cancer treatment and includes radiotherapy, which has not typically been part of the discourse. The WHO consultation to define priority medical devices for cancer management convened in 2015 and provides an opportunity to consider more carefully the important contribution that radiotherapy can make to cancer treatment and care.

The IAEA is a UN agency that works to promote safe, secure, and peaceful use of nuclear technology and has radiotherapy programmes.<sup>184</sup> Through PACT, the IAEA has focused resources on expanding access to radiotherapy and nuclear medicine.<sup>185</sup> The IAEA produces standards and guidelines for radiotherapy implementation, operations, and quality control, and publishes analyses of availability of radiotherapy.<sup>7,49,58</sup> Since 1983, it has invested more than \$270 million in building radiotherapy capacity worldwide. Although the IAEA is committed to securing greater investments in radiotherapy, the amount of resources that is expended to address the shortfall is inadequate. The IAEA is constrained by these inadequate resources and by the fact that they can engage only with member states that request support, which arguably limit its potential to fully address the world's radiotherapy needs.

The IARC has had an important role in measuring the incidence and burden of cancer globally, and in establishing cancer registries in countries. It could extend its role by developing and monitoring accountability frameworks and working closely with the IAEA to establish a global cancer observatory that could monitor country-by-country progress in expanding access to cancer treatment and care, including radiotherapy.

The Union for International Cancer Control has led global advocacy on behalf of a large number of organisations worldwide and has launched the World Cancer Declaration with a call to action to reduce the global cancer burden by delivering on several targets, stressing national cancer control plans and population-based cancer registries as key foundations for effective action.<sup>186</sup> Since 2013, it has included action on

For more on the  
World Bank's International  
Development Association see  
<http://worldbank.org/ida>

For more on the International  
Finance Corporation see  
<http://ifc.org/>

For more on the Multilateral  
Investment Guarantee Agency  
see <http://miga.org>

For more on New Development  
Banks established by BRICS  
countries see  
<http://ndbbrics.org/>

For more on the  
Asian Infrastructure  
Investment Bank see  
<http://aiibank.org/>

radiotherapy in its portfolio of activities by establishing the GTRCC to address the equity gap in access to radiotherapy.

Ultimately, civil society mobilises global and national movements to secure commitment to improve health and other social causes. The independence of civil society from governments enables them to champion patients' rights to achieve equity and hold governments to account. The global response to HIV and AIDS is an excellent example of what can be achieved through concerted efforts by civil society. Advocacy from civil society, driven by patients and affected communities, was instrumental to catalysing a global movement that led to the convening of a special session of the UN General Assembly in 2001 and a declaration<sup>187</sup> that led to creation of global institutions such as the Global Fund to Fight AIDS, Tuberculosis and Malaria.

The role of civil society in engaging in awareness-building, policy development, mobilising support, expanding access, programme implementation, and education is especially important at the national level through action in individual countries. The global civil society can ensure that cancer is framed as an integral part of the global commitments to address NCDs and thereby engage a wider range of supporters for expanding worldwide access to radiotherapy to improve treatment outcomes for cancer. The involvement of patients with cancer is essential in the development of civil society's voice and capability. Patients are well positioned to advocate for access to high-quality services and care.

Professional associations have an important role in expanding worldwide access to radiotherapy through education, training, setting quality standards, disseminating knowledge and evidence, and planning of human and other resource needs. There is an urgent need for global collective action and for the professional societies to work together more effectively to accelerate the progress in expanding worldwide access to radiotherapy. Radiotherapy societies, including the European Society for Radiotherapy and Oncology, the American Society for Radiation Oncology, and the Paediatric Radiation Oncology Society, have mandates to set worldwide standards of excellence with respect to radiation oncology.

Interest and expertise are clearly available to support global development of radiotherapy capacity and these need to be better coordinated for maximum effect. The private sector, especially the industries involved in the design and manufacture of radiotherapy equipment, needs to play a meaningful part in closing the gap in worldwide access to radiotherapy. Radiotherapy cannot be delivered without equipment for diagnosis, planning, and treatment. A few companies dominate the radiotherapy equipment market, which is built on practice in high-income countries. The potential large demand for products in low-income and middle-

income countries creates possibilities for developing innovative products that are less complex and can operate with greater reliability and resilience—ie, new technologies or adaptation of existing solutions to the context is needed, rather than expecting the context to adapt to incorporate existing technologies. Collaborative initiatives that bring together the radiotherapy sector with information and communication technologies, imaging, and laboratory devices would help to create synergies and develop solutions that can be seamlessly deployed.

Despite seemingly extensive efforts, however, there remains an overwhelming lack of access to radiotherapy services in low-income and middle-income countries worldwide. Although the wide-ranging activities of many stakeholders have produced lots of initiatives, they remain mostly at the project level, and have not produced noticeable differences in worldwide access to radiotherapy services and population-level effects. There is, thus, an imperative to build on the global efforts of international agencies, professional associations, civil societies, and the private sector to better coordinate initiatives to act and invest collectively at a scale that will have longlasting effects.

## Part 12: Call to action

Radiotherapy is a crucial and inseparable component of comprehensive cancer treatment and care. For many of the most common cancers in low-income and middle-income countries, including lung, breast, cervical, and head and neck cancer, radiotherapy is essential for effective treatment. In high-income countries, radiotherapy could be used in more than half of cancer cases to cure localised disease, palliate symptoms, or control incurable disease. Without radiotherapy, patients will die and suffer unnecessarily. But when planning and building treatment capacity for cancer, radiotherapy is frequently the last resource to be considered. Consequently, worldwide access to radiotherapy is unacceptably low. Although substantial upfront investment and professionals skilled in operating and maintaining safe practice are needed, radiotherapy is indispensable for the effective treatment of cancer.

We present a new body of evidence that quantifies country-specific and worldwide coverage of radiotherapy services. We show the shortfall in access to radiotherapy by country and globally from 2015 to 2035 on the basis of current and projected need. Our findings show worldwide limitations in access to radiotherapy because of lack of investment. Access to radiotherapy is unequally distributed between high-income countries and low-income and middle-income countries. But even high-income countries do not have sufficient radiotherapy facilities, equipment, and trained staff. Coverage in low-income and middle-income countries, which have underdeveloped infrastructure and weak

**Panel 11: Calls for action**

**Action 1: population-based cancer control plans**

Radiotherapy must be incorporated into population-based comprehensive cancer plans in all countries with explicit targets for scaling up radiotherapy capacity to expand coverage.

Target: by 2020, 80% of the countries should have cancer plans that include radiotherapy.

**Action 2: expansion of access to radiotherapy**

We urge immediate action to establish additional radiotherapy capacity by creating at least one cancer centre in each low-income and middle-income country by 2020. In addition to providing treatments, these new centres should be used to train the radiotherapy workforce to enable further expansion of radiotherapy coverage.

Target: an increase of 25% in the 2015 radiotherapy treatment capacity by 2025.

**Action 3: human resources for radiotherapy**

We call for new approaches to train radiotherapy professionals globally, with the creation of new core curriculums, innovative learning methods, and international credentialing to expand the radiotherapy workforce. Training should become part of the mandate of each national radiotherapy centre to self-propagate the required skills, enabling national expansion of cancer therapies and providing the ability to replace staff as they leave or are recruited out of country.

Target: 7500 radiation oncologists, 20 000 radiation technologists, and 6000 medical physicists to be trained in low-income and middle-income countries by 2025.

**Action 4: sustainable financing to expand access to radiotherapy**

Domestic and international financing will be needed to expand radiotherapy capacity with substantial upfront investment. International development banks and the private sector should work in partnerships with countries to finance investments in infrastructure and radiotherapy services.

Target: \$46 billion of investment by 2025 to establish radiotherapy infrastructure and training in low-income and middle-income countries.

**Action 5: align radiotherapy access with universal health coverage**

We call for inclusion of radiotherapy coverage in each country's universal health coverage plans to prevent catastrophic out-of-pocket expenditures and treatment abandonment.

Target: 80% of low-income and middle-income countries to include radiotherapy services as part of their universal health coverage by 2020.

health systems and where the burden of cancer is rising rapidly, is deplorable. The access problem is most acute in sub-Saharan Africa, where most countries almost completely lack radiotherapy facilities. Such stark inequities in access to radiotherapy result in needless loss of lives.

But there is hope. Scientific advances show that radiotherapy can be highly standardised, effectively applied, and safely delivered. Through case studies we show that successful implementation of radiotherapy is feasible even in low-income settings, and our modelling shows substantial health and economic benefits to investing in radiotherapy.

Our results provide compelling evidence that investment in radiotherapy not only enables treatment of large numbers of cancer cases to save lives, but also brings positive economic benefits. Radiotherapy necessitates a large initial investment, but the timescale for investment is long and the benefits of upfront investments are

realised over 10–15 years. Subsequent operational costs are predictable and very low relative to the initial investment.

Thus, our findings convincingly show the value of radiotherapy as a health-care investment. But the health and economic benefits of radiotherapy will only be fully realised in low-income and middle-income countries when radiotherapy is embedded as a key element of cancer control as part of a national cancer plan or broader national health strategy; there is sustained investment in radiotherapy with appropriate system-level organisation to ensure that patients have equitable access to needed services at each step of their journey from diagnosis to survivorship; patients have unimpeded access to safe radiotherapy in facilities with equipment that is appropriate to the context and clinical need and staffed by trained personnel; the tremendous level of volunteerism, civil society engagement, and philanthropy in global cancer control is extended to radiotherapy; and an inclusive and cohesive action is developed by governments, UN agencies, civil society, professional associations, and the industry involved in radiotherapy.

Our findings provide not only an investment case, but also evidence that implementation and scale-up of radiotherapy services are feasible in low-income and middle-income countries. The time has come, therefore, to put an end to the circular arguments around types of equipment for different settings, the challenges in finding skilled human resources, and the contextual readiness of countries for radiotherapy services, and instead to embark on a decisive set of actions (panel 11).

The development of high-quality radiotherapy services must be underpinned by investment in generation and collection of data for the application of radiotherapy in different contexts to show effective use and benefits, which should at a minimum include collection of radiotherapy treatment records linked to cancer registry data. Investment will also be needed for research and development to produce affordable and reliable radiotherapy infrastructure and new care delivery processes that adapt to the local needs in all countries. The actions proposed are specifically directed to closing the worldwide gap in radiotherapy access.<sup>112,188–190</sup>

There is also an urgent need to integrate these actions to derive the best benefit for patients. Lack of the full set of resources will impede the implementation of effective management pathways and preclude optimum use of existing assets. Unfortunately, in many settings competition for resources results in ineffective cooperation and hinders the development of comprehensive services for cancer.

We have presented a case for investment in radiotherapy showing the economic returns. Investment in radiotherapy can not only save millions of lives and prevent the needless suffering of millions more, but also allow those who would otherwise die to continue to contribute to economic growth. We have shown ways



that perceived barriers to expanding access to radiotherapy have been overcome, and that they should be overcome. Many voiced similar doubts when the global health community faced the challenges of HIV, AIDS, malaria, maternal and child health, and vaccine-preventable diseases in children. The remarkable global progress in these areas provides hope and confidence that the same success can be achieved in cancer control and radiotherapy implementation. Success will come through global solidarity and collective action, and only if we begin by applying what is known and acting on what is clearly possible.

#### Contributors

RA, DAJ, TPH, YL, TYML, DLR, JVD, MYL, EZ, and MG did the literature search. RA, DAJ, MBB, FB, TPH, YL, DLR, JVD, MYL, EZ, and MG worked on the figures. RA, DAJ, FB, MB, TPH, FMK, YL, MM, BOS, DLR, ER, JVD, BV, EZ, MYL, and MG had roles in study design. RA, MBB, FB, MB, TYML, MM, BOS, and BV gathered the data, which were analysed by RA, DAJ, MBB, FB, TPH, YL, TYML, DLR, JVD, EZ, MYL, and MG and interpreted by RA, DAJ, MBB, FB, MB, TPH, FMK, YL, TYML, DLR, ER, JVD, BV, EZ, MYL, and MG. All authors contributed to the writing of this Commission.

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#### References

- 1 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.
- 2 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.
- 3 Murray CJ, Vos T, Lozano R, et al. Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet* 2012; **380**: 2197–223.
- 4 Bloom DE, Cafiero ET, Jané-Llopis E, et al. The global economic burden of non-communicable diseases. Geneva: World Economic Forum, 2011.
- 5 Gunderson LLT, Joel E. Clinical Radiation Oncology, 3rd edn. Philadelphia, PA: Elsevier, 2011.
- 6 Barton MB, Jacob S, Shafiq J, et al. Estimating the demand for radiotherapy from the evidence: a review of changes from 2003 to 2012. *Radiother Oncol* 2014; **112**: 140–44.
- 7 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.
- 8 UN. Political declaration of the high-level meeting of the General Assembly on the prevention and control of non-communicable diseases, A/66/L.1. [http://www.un.org/ga/search/view\\_doc.asp?symbol=A/66/L.1](http://www.un.org/ga/search/view_doc.asp?symbol=A/66/L.1) (accessed April 20, 2014).
- 9 WHO. 65th World Health Assembly. WHA65(8) Prevention and control of noncommunicable diseases: follow-up to the high-level meeting of the United Nations General Assembly on the prevention and control of non-communicable diseases. [http://apps.who.int/gb/ebwha/pdf\\_files/WHA65/A65\\_DIV3-en.pdf](http://apps.who.int/gb/ebwha/pdf_files/WHA65/A65_DIV3-en.pdf) (accessed Jan 15, 2012).

- 10 WHO. Draft comprehensive global monitoring framework and targets for the prevention and control of noncommunicable diseases. Geneva: World Health Organization, 2013.
- 11 WHO. NCD global monitoring framework. [http://www.who.int/nmh/global\\_monitoring\\_framework/en/](http://www.who.int/nmh/global_monitoring_framework/en/) (accessed July 5, 2015).
- 12 Atun R. Decisive action to end apathy and achieve 25x25 NCD targets. *Lancet* 2014; **384**: 384–85.
- 13 Wild CP, Bray F, Forman D, Franceschi S, Sankaranarayanan R, Straif K. Cancer in the 25x25 non-communicable disease targets. *Lancet* 2014; **384**: 1502–03.
- 14 Farmer P, Frenk J, Knaul FM, et al. Expansion of cancer care and control in countries of low and middle income: a call to action. *Lancet* 2010; **376**: 1186–93.
- 15 Zietman A. Bringing radiation therapy to underserved nations: an increasingly global responsibility in an ever-shrinking world. *Int J Radiat Oncol Biol Phys* 2014; **89**: 440–42.
- 16 WHO. WHA67.22-Access to essential medicines. WHA Resolution: Sixty-seventh World Health Assembly. <https://apps.who.int/medicines/en/js21453en/> (accessed July 30, 2015).
- 17 WHO. Surgery: the neglected component of primary care. [http://www.who.int/surgery/esc\\_component/en/](http://www.who.int/surgery/esc_component/en/) (accessed July 30, 2015).
- 18 Burki TK. WHO resolution on access to palliative care. *Lancet Oncol* 2014; **15**: e109.
- 19 Rosenblatt E, Fidarova E. Human Health Series No IAEA 30. Implementation of high dose rate brachytherapy in limited resource settings. Vienna: International Atomic Energy Agency, 2015.
- 20 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**: 462–67.
- 21 Kigula-Mugambe JB, Durosini-Etti FA. Radiotherapy in cancer management at Mulago Hospital, Kampala, Uganda. *East Afr Med J* 1996; **73**: 611–13.
- 22 Chowdhury AM, Bhuiya A, Chowdhury ME, Rasheed S, Hussain Z, Chen LC. The Bangladesh paradox: exceptional health achievement despite economic poverty. *Lancet* 2013; **382**: 1734–45.
- 23 Jamison DT, Summers LH, Alleyne G, et al. Global health 2035: a world converging within a generation. *Lancet* 2013; **382**: 1898–955.
- 24 Meara JG, Leather AJM, Hagander L, et al. Global Surgery 2030: evidence and solutions for achieving health, welfare, and economic development. *Lancet* 2015; **386**: 569–624.
- 25 UN. Sustainable development, the Future We Want, UN General Assembly Resolution, A/66/L.56, para 138–141. <http://www.uncsd2012.org/content/documents/814UNCSD%20REPORT%20final%20revs.pdf> (accessed July 5, 2015).
- 26 Institute of Medicine. Crossing the quality chasm. A new health system for the 21st century. Washington, DC: National Academies Press, 2001.
- 27 Peters LJ, O'Sullivan B, Giralt J, et al. Critical impact of radiotherapy protocol compliance and quality in the treatment of advanced head and neck cancer: results from TROG 02.02. *J Clin Oncol* 2010; **28**: 2996–3001.
- 28 Abrams RA, Winter KA, Regine WF, et al. Failure to adhere to protocol specified radiation therapy guidelines was associated with decreased survival in RTOG 9704—a phase III trial of adjuvant chemotherapy and chemoradiotherapy for patients with resected adenocarcinoma of the pancreas. *Int J Radiat Oncol Biol Phys* 2012; **82**: 809–16.
- 29 USAID ASSIST. Institute of Medicine workshop on quality of health care in low- and middle-income countries. <https://www.usaidassist.org/content/institute-medicine-workshop-quality-health-care-low-and-middle-income-countries> (accessed July 28, 2015).
- 30 UN Development Programme. The rise of the south: human progress in a diverse world. New York: United Nations, 2013.
- 31 Jemal A. The cancer atlas, 2nd edn. Atlanta: American Cancer Society, 2015.
- 32 Gersten OWJ. The cancer transition in Japan since 1951. *Demogr Res* 2002; **7**: 271–306.
- 33 Bray F. Transitions in human development and the global cancer burden. In: Wild CP, Stewart B, eds. World cancer report 2014. Lyon: International Agency for Research on Cancer, 2014: 54–68.
- 34 Wabinga HR, Namboozee S, Amulen PM, Okello C, Mbus L, Parkin DM. Trends in the incidence of cancer in Kampala, Uganda 1991–2010. *Int J Cancer* 2014; **135**: 432–39.
- 35 Forman DBF, Brewster DH, Gombe Mbalawa C, et al. Cancer incidence in continents volume 5. Lyon: International Agency for Research on Cancer, 2014.
- 36 Chokunonga E, Borok MZ, Chirenje ZM, Nyakabau AM, Parkin DM. Trends in the incidence of cancer in the black population of Harare, Zimbabwe 1991–2010. *Int J Cancer* 2013; **133**: 721–29.
- 37 Bray F, Lortet-Tieulent J, Znaor A, Brotons M, Poljak M, Arbyn M. Patterns and trends in human papillomavirus-related diseases in Central and Eastern Europe and Central Asia. *Vaccine* 2013; **31** (suppl 7): H32–45.
- 38 Delaney G, Jacob S, Featherstone C, Barton M. The role of radiotherapy in cancer treatment: estimating optimal utilization from a review of evidence-based clinical guidelines. *Cancer* 2005; **104**: 1129–37.
- 39 Borrás JM, Barton M, Grau C, et al. The impact of cancer incidence and stage on optimal utilization of radiotherapy: methodology of a population based analysis by the ESTRO-HERO project. *Radiother Oncol* 2015; published online May 19. DOI:10.1016/j.radonc.2015.04.021.
- 40 Borrás JM, Lievens Y, Dunscombe P, et al. The optimal utilization proportion of external beam radiotherapy in European countries: an ESTRO-HERO analysis. *Radiother Oncol* 2015; published online May 14. DOI:10.1016/j.radonc.2015.04.018.
- 41 Mackillop WJ, Kong W, Brundage M, et al. A comparison of evidence-based estimates and empirical benchmarks of the appropriate rate of use of radiation therapy in Ontario. *Int J Radiat Oncol Biol Phys* 2015; **91**: 1099–107.
- 42 Kerba M, Miao Q, Zhang-Salomons J, Mackillop W. Defining the need for breast cancer radiotherapy in the general population: a criterion-based benchmarking approach. *Clin Oncol (R Coll Radiol)* 2007; **19**: 481–89.
- 43 Asli LM, Kvaløy SO, Jetne V, et al. Utilization of radiation therapy in Norway after the implementation of the national cancer plan—a national, population-based study. *Int J Radiat Oncol Biol Phys* 2014; **90**: 707–14.
- 44 Wong K. Estimation of the optimal number of radiotherapy fractions for cancer patients: a review of the evidence. Sydney: University of New South Wales, 2012.
- 45 Slotman BJ, Cottier B, Bentzen SM, Heeren G, Lievens Y, van den Bogaert W. Overview of national guidelines for infrastructure and staffing of radiotherapy. ESTRO-QUARTS: work package 1. *Radiother Oncol* 2005; **75**: 349–54.
- 46 International Atomic Energy Agency. Planning national radiotherapy services: a practical tool. IAEA Human Health Series 14. IAEA, 2010. [http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1462\\_web.pdf](http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1462_web.pdf) (accessed June 22, 2015).
- 47 International Atomic Energy Agency. Setting up a radiotherapy programme: clinical, medical physics, radiation protection and safety aspects. Vienna: International Atomic Energy Agency, 2008.
- 48 Datta NR, Samiei M, Bodis S. Radiotherapy infrastructure and human resources in Europe—present status and its implications for 2020. *Eur J Cancer* 2014; **50**: 2735–43.
- 49 Rosenblatt E, Izewska J, Anacac Y, et al. Radiotherapy capacity in European countries: an analysis of the Directory of Radiotherapy Centres (DIRAC) database. *Lancet Oncol* 2013; **14**: e79–86.
- 50 Dunscombe P, Grau C, Defourny N, et al, and the HERO Consortium. Guidelines for equipment and staffing of radiotherapy facilities in the European countries: final results of the ESTRO-HERO survey. *Radiother Oncol* 2014; **112**: 165–77.
- 51 Lievens Y, van den Bogaert W, Kesteloot K. Activity-based costing: a practical model for cost calculation in radiotherapy. *Int J Radiat Oncol Biol Phys* 2003; **57**: 522–35.
- 52 Lievens Y, Defourny N, Coffey M, et al, and the HERO Consortium. Radiotherapy staffing in the European countries: final results from the ESTRO-HERO survey. *Radiother Oncol* 2014; **112**: 178–86.
- 53 International Atomic Energy Agency. DIRAC (Directory of radiotherapy centres), 2011. <http://nucleus.iaea.org/HHW/m/DBStatistics/DIRAC/> (accessed Nov 14, 2014).
- 54 Grover S, Xu MJ, Yeager A, et al. A systematic review of radiotherapy capacity in low- and middle-income countries. *Front Oncol* 2014; **4**: 380.

- 55 Gillan C, Briggs K, Goytisolo Pazos A, et al. Barriers to accessing radiation therapy in Canada: a systematic review. *Radiat Oncol* 2012; 7: 167.
- 56 Radiation Oncology Tripartite Committee. Planning for the best: tripartite national strategic plan for radiation oncology 2012–2022, version 1. Australia: 2012. <http://www.radiationoncology.com.au/supporting-docs/PlanningForTheBest-TripartiteNationalStrategicPlanForRadiationOncology.2012–2022.pdf> (accessed July 13, 2015).
- 57 Cancer Research UK. Achieving a world-class radiotherapy service across the UK. [http://www.cancerresearchuk.org/prod\\_consump/groups/cr\\_common/@nre/@pol/documents/generalcontent/crukmg1000ast-3360.pdf](http://www.cancerresearchuk.org/prod_consump/groups/cr_common/@nre/@pol/documents/generalcontent/crukmg1000ast-3360.pdf) (accessed July 13, 2015).
- 58 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.
- 59 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: 448–57.
- 60 Moraes FY, Marta GN, Hanna SA, et al. Brazil's Challenges and Opportunities. *Int J Radiat Oncol Biol Phys* 2015; 92: 707–12.
- 61 Smigielska M, Milecki P. Investment in radiotherapy infrastructure positively affected the economic status of an oncology hospital. *Rep Pract Oncol Radiother* 2012; 17: 151–56.
- 62 Shulman LN, Mpunga T, Tapela N, Wagner CM, Fadelu T, Binagwaho A. Bringing cancer care to the poor: experiences from Rwanda. *Nat Rev Cancer* 2014; 14: 815–21.
- 63 Samiei M. Challenges of making radiotherapy accessible in developing countries. [http://globalhealthdynamics.co.uk/cc2013/wp-content/uploads/2013/04/83-96-Samiei-varian-tpage-incl-T-page\\_2012.pdf](http://globalhealthdynamics.co.uk/cc2013/wp-content/uploads/2013/04/83-96-Samiei-varian-tpage-incl-T-page_2012.pdf) (accessed July 10, 2015).
- 64 Lee AW, Sze H, Lam KO, Chen X. A tale of two cities in China: Hong Kong and Shenzhen. *Int J Radiat Oncol Biol Phys* 2014; 89: 704–08.
- 65 Peng G, Wang T, Yang KY, et al. A prospective, randomized study comparing outcomes and toxicities of intensity-modulated radiotherapy vs conventional two-dimensional radiotherapy for the treatment of nasopharyngeal carcinoma. *Radiother Oncol* 2012; 104: 286–93.
- 66 International Atomic Energy Agency. Radiotherapy facilities: master planning and concept design considerations 2014. <http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1645web-46536742.pdf> (accessed May 5, 2015).
- 67 Mills EJ, Kanter S, Hagopian A, et al. The financial cost of doctors emigrating from sub-Saharan Africa: human capital analysis. *BMJ* 2011; 343: d7031.
- 68 Nwankwo KC, Dawotola DA, Sharma V. Radiotherapy in Nigeria: current status and future challenges. *West Afr J Radiol* 2013; 20: 84–88.
- 69 Kumar RV, Bhasker S. Is the fast-paced technological advancement in radiation treatment equipment good for Indian scenario? No. *J Cancer Policy* 2015; 4: 26–30.
- 70 Mostert S, Njuguna F, Langat SC, et al. Two overlooked contributors to abandonment of childhood cancer treatment in Kenya: parents' social network and experiences with hospital retention policies. *Psychooncology* 2014; 23: 700–07.
- 71 Kishore J, Ahmad I, Kaur R, Mohanta PK. Beliefs and perceptions about cancers among patients attending radiotherapy OPD in Delhi, India. *Asian Pac J Cancer Prev* 2008; 9: 155–58.
- 72 Halkett GK, Kristjanson LJ, Lobb EA. 'If we get too close to your bones they'll go brittle': women's initial fears about radiotherapy for early breast cancer. *Psychooncology* 2008; 17: 877–84.
- 73 Bernier J, Hall EJ, Giaccia A. Radiation oncology: a century of achievements. *Nat Rev Cancer* 2004; 4: 737–47.
- 74 Thariat J, Hannoun-Levi JM, Sun Myint A, Vuong T, Gérard JP. Past, present, and future of radiotherapy for the benefit of patients. *Nat Rev Clin Oncol* 2013; 10: 52–60.
- 75 Bortfeld T. IMRT: a review and preview. *Phys Med Biol* 2006; 51: R363–79.
- 76 Jaffray D, Kupelian P, Djemil T, Macklis RM. Review of image-guided radiation therapy. *Expert Rev Anticancer Ther* 2007; 7: 89–103.
- 77 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.
- 78 Ferlay JSI, Ervik M, Dikshit R, et al. GLOBOCAN 2012 v1.0, cancer incidence and mortality worldwide. Lyon: International Agency for Research on Cancer, 2013.
- 79 Barton MB, Jacob S, Wong KHW. Review of optimal radiotherapy utilisation rates. Collaboration for Cancer Outcomes Research and Evaluation, 2013. [http://inghaminstitute.org.au/sites/default/files/RTU\\_Review\\_Final\\_v3\\_02042013.pdf](http://inghaminstitute.org.au/sites/default/files/RTU_Review_Final_v3_02042013.pdf) (accessed June 2, 2015).
- 80 Barton MB, Hudson HM, Delaney G, Gruver P, Liu Z. Patterns of retreatment by radiotherapy. *Clin Oncol (R Coll Radiol)* 2011; 23: 10–18.
- 81 Hanna TP, Shafiq J, Delaney GP, Barton MB. The population benefit of radiotherapy for cervical cancer: local control and survival estimates for optimally utilized radiotherapy and chemoradiation. *Radiother Oncol* 2015; 114: 389–94.
- 82 Bese NS, Kiel K, El-Gueddari B-K, Campbell OB, Awuah B, Vikram B, and the International Atomic Energy Agency. Radiotherapy for breast cancer in countries with limited resources: program implementation and evidence-based recommendations. *Breast J* 2006; 12 (suppl 1): S96–102.
- 83 Portenoy RK. Treatment of cancer pain. *Lancet* 2011; 377: 2236–47.
- 84 Cury FL, Shenouda G. Palliative radiotherapy. In: Burnier JVB, Miguel N Jr, eds. Experimental and clinical metastasis: a comprehensive review. New York: Springer, 2013: 351–79.
- 85 MacPherson M, Montgomery L, Fox G, et al. On-line rapid palliation using helical tomotherapy: a prospective feasibility study. *Radiother Oncol* 2008; 87: 116–18.
- 86 Wong RK, Letourneau D, Varma A, et al. A one-step cone-beam CT-enabled planning-to-treatment model for palliative radiotherapy-from development to implementation. *Int J Radiat Oncol Biol Phys* 2012; 84: 834–40.
- 87 Rosenblatt E. International Atomic Energy Agency syllabus for the education and training of radiation oncologists. Vienna: International Atomic Energy Agency, 2009.
- 88 Eriksen JG, Beavis AW, Coffey MA, et al. The updated ESTRO core curricula 2011 for clinicians, medical physicists and RTTs in radiotherapy/radiation oncology. *Radiother Oncol* 2012; 103: 103–08.
- 89 International Atomic Energy Agency. Roles and responsibilities, and education and training requirements for clinically qualified medical physicists. Vienna: International Atomic Energy Agency, 2013.
- 90 International Atomic Energy Agency. a syllabus for the education and training of RTTs (radiation therapists/therapy radiographers). Vienna: International Atomic Energy Agency, 2005.
- 91 International Atomic Energy Agency. Staffing and cost calculation. <http://nucleus.iaea.org/HHW/RadiationOncology/Makingthecaseforradiotherapyinyourcountry/Roleofradiotherapyincancercare/Radiotherapyisacosteffectivesystemwhichneedsabalance/index.html> (accessed March 14, 2014).
- 92 Gardiner & Theobald. International construction cost survey. 2011. <http://www.gardiner.com/assets/files/files/a47a4dcd5d29f0071e00bf2d6c589851ed552cc7/ICCS%202011%20-%20Version.pdf> (accessed March 14, 2014).
- 93 EC Harris Research. International construction costs: a change of pace. 2013. [http://www.echarris.com/pdf/8633\\_international%20cost%20construction%20report%20final2.pdf](http://www.echarris.com/pdf/8633_international%20cost%20construction%20report%20final2.pdf) (accessed March 14, 2014).
- 94 Healy B, Zubizarreta E. Staffing in radiotherapy: an activity based approach. Vienna: International Atomic Energy Agency, 2014.
- 95 World Bank. Country and lending groups. <http://data.worldbank.org/about/country-and-lending-groups> (accessed July 1, 2015).
- 96 Van de Werf E, Verstraete J, Lievens Y. The cost of radiotherapy in a decade of technology evolution. *Radiother Oncol* 2012; 102: 148–53.
- 97 Lievens Y, Grau C. Health economics in radiation oncology: introducing the ESTRO HERO project. *Radiother Oncol* 2012; 103: 109–12.
- 98 Grau C, Defourny N, Malicki J, et al, and the HERO consortium. Radiotherapy equipment and departments in the European countries: final results from the ESTRO-HERO survey. *Radiother Oncol* 2014; 112: 155–64.
- 99 Resch S, Korenromp E, Stover J, et al. Economic returns to investment in AIDS treatment in low and middle income countries. *PLoS One* 2011; 6: e25310.

- 100 Schwartländer B, Stover J, Hallett T, et al, and the Investment Framework Study Group. Towards an improved investment approach for an effective response to HIV/AIDS. *Lancet* 2011; 377: 2031–41.
- 101 Global Fund. The Global Fund Strategy 2012–16. <http://www.theglobalfund.org/en/about/strategy/> (accessed June 30, 2015).
- 102 Stenberg K, Axelson H, Sheehan P, et al, and the Study Group for the Global Investment Framework for Women's Children's Health. Advancing social and economic development by investing in women's and children's health: a new Global Investment Framework. *Lancet* 2014; 383: 1333–54.
- 103 Jaffray DA, Gospodarowicz MK. Radiation therapy for cancer. [http://www.dcp-3.org/sites/default/files/chapters/CANCER\\_ch14\\_Radiation\\_Therapy.pdf](http://www.dcp-3.org/sites/default/files/chapters/CANCER_ch14_Radiation_Therapy.pdf) (accessed May 5, 2015).
- 104 WHO. Making choices in health: WHO guide to cost-effectiveness analysis. [http://www.who.int/choice/publications/p\\_2003\\_generalised\\_cea.pdf](http://www.who.int/choice/publications/p_2003_generalised_cea.pdf) (accessed Aug 23, 2015)
- 105 Najjar H, Easson A. Age at diagnosis of breast cancer in Arab nations. *Int J Surg* 2010; 8: 448–52.
- 106 Harford JB. Breast-cancer early detection in low-income and middle-income countries: do what you can versus one size fits all. *Lancet Oncol* 2011; 12: 306–12.
- 107 Hossain MS, Iqbal MS, Khan MA, et al. Diagnosed hematological malignancies in Bangladesh—a retrospective analysis of over 5000 cases from 10 specialist hospitals. *BMC Cancer* 2014; 14: 438.
- 108 Joshi P, Dutta S, Chaturvedi P, Nair S. Head and neck cancers in developing countries. *Rambam Maimonides Med J* 2014; 5: e0009.
- 109 Shillcutt SD, Walker DG, Goodman CA, Mills AJ. Cost effectiveness in low- and middle-income countries: a review of the debates surrounding decision rules. *Pharmacoeconomics* 2009; 27: 903–17.
- 110 Commission on Macroeconomics and Health. Macroeconomics and health: investing in health for economic development. Report of the Commission on Macroeconomics and Health. Geneva: World Health Organization, 2001.
- 111 Norton WE, McCannon CJ, Schall MW, Mittman BS. A stakeholder-driven agenda for advancing the science and practice of scale-up and spread in health. *Implement Sci* 2012; 7: 118.
- 112 Meara JG, Greenberg SL. The Lancet Commission on Global Surgery global surgery 2030: evidence and solutions for achieving health, welfare and economic development. *Surgery* 2015; 157: 834–35.
- 113 Okungu V, Gilson L. "...still waiting for chloroquine": the challenge of communicating changes in first-line treatment policy for uncomplicated malaria in a remote Kenyan district. *Malar J* 2014; 13: 258.
- 114 Li KM, Rodin D, Wong K-H, Yeung R, Chow E. Palliative radiotherapy. In: Smith HSPJ, ed. The art and science of palliative medicine. Hong Kong: AME Publishing Company, 2014: 556–68.
- 115 Sharma V, Gaye PM, Wahab SA, et al. Patterns of practice of palliative radiotherapy in Africa, part 1: bone and brain metastases. *Int J Radiat Oncol Biol Phys* 2008; 70: 1195–201.
- 116 Bonastre J, Noël E, Chevalier J, et al, and the STIC IMRT 2002 Investigators. Implications of learning effects for hospital costs of new health technologies: the case of intensity modulated radiation therapy. *Int J Technol Assess Health Care* 2007; 23: 248–54.
- 117 Wang Q, Fu AZ, Brenner S, Kalmus O, Banda HT, De Allegri M. Out-of-pocket expenditure on chronic non-communicable diseases in sub-Saharan Africa: the case of rural Malawi. *PLoS One* 2015; 10: e0116897.
- 118 Antonino PHD. Brazilian industrial health complex: availability of access, industrial development, and innovation policy. Geneva: World Health Organization, 2013.
- 119 Da Silva JB Jr, Magalhaes HM Jr. Initiatives in cancer control from Brazil's Ministry of Health. *Lancet Oncol* 2013; 14: 385–86.
- 120 Yamey G. What are the barriers to scaling up health interventions in low and middle income countries? A qualitative study of academic leaders in implementation science. *Global Health* 2012; 8: 11.
- 121 Forouzanfar MH, Foreman KJ, Delossantos AM, et al. Breast and cervical cancer in 187 countries between 1980 and 2010: a systematic analysis. *Lancet* 2011; 378: 1461–84.
- 122 Sankaranarayanan R, Swaminathan R, Brenner H, et al. Cancer survival in Africa, Asia, and Central America: a population-based study. *Lancet Oncol* 2010; 11: 165–73.
- 123 Chemoradiotherapy for Cervical Cancer Meta-Analysis Collaboration. Reducing uncertainties about the effects of chemoradiotherapy for cervical cancer: a systematic review and meta-analysis of individual patient data from 18 randomized trials. *J Clin Oncol* 2008; 26: 5802–12.
- 124 Crosbie EJ, Einstein MH, Franceschi S, Kitchener HC. Human papillomavirus and cervical cancer. *Lancet* 2013; 382: 889–99.
- 125 Goldie SJ, Grima D, Kohli M, Wright TC, Weinstein M, Franco E. A comprehensive natural history model of HPV infection and cervical cancer to estimate the clinical impact of a prophylactic HPV-16/18 vaccine. *Int J Cancer* 2003; 106: 896–904.
- 126 Berkman A, Garcia J, Muñoz-Laboy M, Paiva V, Parker R. A critical analysis of the Brazilian response to HIV/AIDS: lessons learned for controlling and mitigating the epidemic in developing countries. *Am J Public Health* 2005; 95: 1162–72.
- 127 Jit M, Brisson M, Portnoy A, Hutubessy R. Cost-effectiveness of female human papillomavirus vaccination in 179 countries: a PRIME modelling study. *Lancet Glob Health* 2014; 2: e406–14.
- 128 Yamin AE, Boulanger VM, Falb KL, Shuma J, Leaning J. Costs of inaction on maternal mortality: qualitative evidence of the impacts of maternal deaths on living children in Tanzania. *PLoS One* 2013; 8: e71674.
- 129 National Cancer Institute Radiation Research Program. Human resources needed for cancer control in low & middle income countries. [http://rrp.cancer.gov/programsResources/human\\_resources\\_needed.htm](http://rrp.cancer.gov/programsResources/human_resources_needed.htm) (accessed July 5, 2015).
- 130 Sullivan T, Dobrow M, Thompson L, Hudson A. Reconstructing cancer services in Ontario. *Healthc Pap* 2004; 5: 69–80, discussion 96–99.
- 131 Hayter CR, Payne D, Ege GN. Radiation oncology in Canada 1895–1995. *Int J Radiat Oncol Biol Phys* 1996; 36: 487–96.
- 132 Mackillop WJ, Bates JH, O'Sullivan B, Withers HR. The effect of delay in treatment on local control by radiotherapy. *Int J Radiat Oncol Biol Phys* 1996; 34: 243–50.
- 133 Mackillop WJ. Killing time: the consequences of delays in radiotherapy. *Radiother Oncol* 2007; 84: 1–4.
- 134 Mackillop WJ, Groome PA, Zhang-Solomons J, et al. Does a centralized radiotherapy system provide adequate access to care? *J Clin Oncol* 1997; 15: 1261–71.
- 135 Daly RUS. Cities to treat Ontario's cancer victims. The Toronto Star (Toronto), Jan 22, 1991.
- 136 Cancer Care Ontario, Action Cancer Ontario. The Ontario cancer plan 2005–2008. <https://www.cancercare.on.ca/common/pages/UserFile.aspx?fileId=34910> (accessed June 23, 2015).
- 137 Cancer Care Ontario, Action Cancer Ontario. The Ontario cancer plan 2008–2011. <https://www.cancercare.on.ca/common/pages/UserFile.aspx?fileId=13808> (accessed July 6, 2015).
- 138 Cancer Care Ontario. The Ontario cancer plan 2011–15. <https://www.cancercare.on.ca/common/pages/UserFile.aspx?fileId=84204> (accessed July 6, 2015).
- 139 Cancer Care Ontario. The Ontario cancer plan 2015–2019. <https://cancercare.on.ca/common/pages/UserFile.aspx?fileId=333871> (accessed July 6, 2015).
- 140 Coleman MP, Forman D, Bryant H, et al, and the ICBP Module 1 Working Group. Cancer survival in Australia, Canada, Denmark, Norway, Sweden, and the UK, 1995–2007 (the International Cancer Benchmarking Partnership): an analysis of population-based cancer registry data. *Lancet* 2011; 377: 127–38.
- 141 Krzyzanowska MK, Blayney DW, Bosserman LD, Sullivan TJ. Models that work: incorporating quality principles in different clinical settings. *J Oncol Pract* 2013; 9: 135–37.
- 142 Sullivan T. Improving quality and performance in Ontario's cancer services: lessons for constructing a learning healthcare system. *Healthc Q* 2015; 17: 5–9.
- 143 Central Intelligence Agency. The world factbook—2014. <https://www.cia.gov/library/publications/the-world-factbook/> (accessed May 5, 2015).
- 144 Pramesh CS, Badwe RA, Borthakur BB, et al. Delivery of affordable and equitable cancer care in India. *Lancet Oncol* 2014; 15: e223–33.
- 145 Goss PE, Strasser-Weippl K, Lee-Bychkovsky BL, et al. Challenges to effective cancer control in China, India, and Russia. *Lancet Oncol* 2014; 15: 489–538.



- 146 Lyerly HK, Fawzy MR, Aziz Z, et al. Regional variation in identified cancer care needs of early-career oncologists in China, India, and Pakistan. *Oncologist* 2015; **20**: 532–38.
- 147 Planning Commission, Government of India. Eleventh Five Year Plan (2007–2012)—Inclusive growth. [http://planningcommission.nic.in/plans/planrel/fiveyr/11th/v3/11th\\_vol3.pdf](http://planningcommission.nic.in/plans/planrel/fiveyr/11th/v3/11th_vol3.pdf) (accessed Aug 24, 2015).
- 148 Banerjee S, Mahantshetty U, Shrivastava S. Brachytherapy in India—a long road ahead. *J Contemp Brachytherapy* 2014; **6**: 331–35.
- 149 Dinshaw KA. Addressing the cancer agenda: how have we measured up? <http://mohfw.nic.in/WriteReadData/1892s/Addressing%20The%20Cancer%20Agenda-How%20Have%20We%20Measured%20Up.pdf> (accessed June 26, 2015).
- 150 Atun R, de Andrade LO, Almeida G, et al. Health-system reform and universal health coverage in Latin America. *Lancet* 2015; **385**: 1230–47.
- 151 Monteiro de Andrade L, Filho AP, Solar O, et al. Social determinants of health, universal health coverage, and sustainable development: case studies from Latin American countries. *Lancet* 2015; **385**: 1343–51.
- 152 Cotlear D, Gómez-Dantés O, Knaul F, et al. Overcoming social segregation in health care in Latin America. *Lancet* 2015; **385**: 1248–59.
- 153 Ministério da Saúde. Instituto do Plano de Expansão da Radioterapia no Sistema Único de Saúde (SUS). [http://bvsms.saude.gov.br/bvs/saudelegis/gm/2012/prt0931\\_10\\_05\\_2012.html](http://bvsms.saude.gov.br/bvs/saudelegis/gm/2012/prt0931_10_05_2012.html) (accessed July 7, 2015).
- 154 Ministério da Saúde. Implementação de 80 soluções de radioterapia, compreendendo equipamentos, projetos básico e executivo, apoio técnico ao acompanhamento e fiscalização de obras. <http://comprasnet.gov.br/ConsultaLicitações/Download/Download.asp?coduasg=250005&numprp=112013&modprp=5&bird=N> (accessed July 7, 2015).
- 155 Ministério da Saúde. Workshop para Soluções em Formação de Recursos Humanos para Radioterapia. <http://portalsaude.saude.gov.br/index.php/o-ministerio/principal/secretarias/911-sas-raiz/daet-raiz/doencas-chronica/doencas-chronicas-banner/15218-banner-workshop> (accessed July 7, 2015).
- 156 International Agency for Research on Cancer. Globocan 2012, Bangladesh estimated cancer incidence, all ages: both sexes. [http://globocan.iarc.fr/old/summary\\_table\\_pop.html.asp?selection=14050&title=Bangladesh&sex=0&type=0&window=1&sort=0&sbmit=%C2%A0Execute](http://globocan.iarc.fr/old/summary_table_pop.html.asp?selection=14050&title=Bangladesh&sex=0&type=0&window=1&sort=0&sbmit=%C2%A0Execute) (accessed July 4, 2015).
- 157 Hussain SA, Sullivan R. Cancer control in Bangladesh. *Jpn J Clin Oncol* 2013; **43**: 1159–69.
- 158 World Bank. World Bank Development Indicators. Zimbabwe. <http://data.worldbank.org/country/zimbabwe> (accessed July 4, 2015).
- 159 Chokunonga EBM, Nyakabau AM, Makunike-Mutasa. Zimbabwe National Cancer Registry, 2012 annual report. <http://afcrn.org/attachments/article/83/ZNCR%20%202011%20Annual%20Report.pdf> (accessed June 1, 2015).
- 160 Stjernsward J. National training of radiotherapists in Sri Lanka and Zimbabwe: priorities and strategies for cancer control in developing countries. *Int J Radiat Oncol Biol Phys* 1990; **19**: 1275–78.
- 161 McCoy D, Bennett S, Witter S, et al. Salaries and incomes of health workers in sub-Saharan Africa. *Lancet* 2008; **371**: 675–81.
- 162 Al-Shorbaji N, Atun R, Car J, Majeed A, Wheeler E. eLearning for undergraduate health professional education: a systematic review informing a radical transformation of health workforce development. <http://www.who.int/hrh/documents/14126-eLearningReport.pdf> (accessed July 5, 2015).
- 163 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.
- 164 Coleman CN, on behalf of many others. Bringing cancer care to the underserved globally: a challenging problem for which radiation oncology can pioneer novel solutions. *Int J Radiat Oncol Biol Phys* 2014; **89**: 443–45.
- 165 Sharpe MB, Moore KL, Orton CG. Point/Counterpoint: Within the next ten years treatment planning will become fully automated without the need for human intervention. *Med Phys* 2014; **41**: 120601.
- 166 Datta NR, Heuser M, Samiei M, Shah R, Lutters G, Bodis S. Teleradiotherapy network: applications and feasibility for providing cost-effective comprehensive radiotherapy care in low- and middle-income group countries for cancer patients. *Telemed J E Health* 2015; **21**: 523–32.
- 167 Dimaras H, Dimba EA, Gallie BL. Challenging the global retinoblastoma survival disparity through a collaborative research effort. *Br J Ophthalmol* 2010; **94**: 1415–16.
- 168 Gallie BL, Zhao J, Vandezande K, White A, Chan HS. Global issues and opportunities for optimized retinoblastoma care. *Pediatr Blood Cancer* 2007; **49** (suppl): 1083–90.
- 169 Ribeiro RC. Improving survival of children with cancer worldwide: the St Jude International Outreach Program approach. *Stud Health Technol Inform* 2012; **172**: 9–13.
- 170 World Bank. Global economic prospects 2015. <http://www.worldbank.org/en/publication/global-economic-prospects> (accessed July 5, 2015).
- 171 UN Sustainable Development Solutions Network. Harnessing natural resources for sustainable development: challenges and solutions. <http://unsdsn.org/wp-content/uploads/2014/02/TG10-Final-Report.pdf> (accessed May 26, 2015).
- 172 Atun R, Knaul FM, Akachi Y, Frenk J. Innovative financing for health: what is truly innovative? *Lancet* 2012; **380**: 2044–49.
- 173 World Bank. World Bank Guarantee Program—for the consultation of “modernizing the World Bank’s operational policy on guarantees. <http://siteresources.worldbank.org/INTGUARANTEES/Resources/HighlightsWBGProgramforConsulJan252012.pdf> (accessed July 5, 2015).
- 174 World Bank. The World Bank Group guarantee products. [http://treasury.worldbank.org/bdm/pdf/Brochures/WBG\\_Guarantees\\_Matrix.pdf](http://treasury.worldbank.org/bdm/pdf/Brochures/WBG_Guarantees_Matrix.pdf) (accessed July 5, 2015).
- 175 Ketkar SL, Ratha D. Development finance via diaspora bonds track record and potential: policy research working papers. <http://elibrary.worldbank.org/doi/book/10.1596/1813-9450-4311> (accessed May 26, 2015).
- 176 Social Finance UK. Peterborough social impact bond: one year on. <http://www.socialfinance.org.uk/peterborough-social-impact-bond-one-year-on/> (accessed July 4, 2015).
- 177 UN. High-level meeting on non-communicable diseases. <http://www.un.org/en/ga/president/65/issues/ncdiseases.shtml> (accessed July 5, 2015).
- 178 UN. Resolution adopted by the General Assembly on 13 May 2010. 64/265. Prevention and control of non-communicable diseases. [http://www.un.org/en/ga/search/view\\_doc.asp?symbol=A/RES/64/265&Lang=E](http://www.un.org/en/ga/search/view_doc.asp?symbol=A/RES/64/265&Lang=E) (accessed July 5, 2015).
- 179 WHO. Global action plan for the prevention and control of NCDs 2013–2020. [http://www.who.int/nmh/events/ncd\\_action\\_plan/en/](http://www.who.int/nmh/events/ncd_action_plan/en/) (accessed July 5, 2015).
- 180 World Economic Forum. The global economic burden of non-communicable diseases. <http://www.weforum.org/reports/global-economic-burden-non-communicable-diseases> (accessed July 5, 2015).
- 181 UN. Global health and foreign policy. [http://www.un.org/ga/search/view\\_doc.asp?symbol=A/67/L.36&referer=http://www.un.org/en/ga/info/draft/index.shtml&Lang=E](http://www.un.org/ga/search/view_doc.asp?symbol=A/67/L.36&referer=http://www.un.org/en/ga/info/draft/index.shtml&Lang=E) (accessed July 5, 2015).
- 182 WHO. Global status report on noncommunicable diseases 2014. <http://www.who.int/nmh/publications/ncd-status-report-2014/en/> (accessed July 5, 2015).
- 183 WHO. Noncommunicable diseases country profiles 2014. <http://www.who.int/nmh/publications/ncd-profiles-2014/en/> (accessed July 5, 2015).
- 184 Sloan FG, Hellen. Cancer control opportunities in low- and middle-income countries. Institute of Medicine (US) Committee on Cancer Control in Low- and Middle-Income Countries. Washington, DC: National Academies Press, 2007.
- 185 International Atomic Energy Agency. IAEA Human Health Reports. Inequity in cancer care: a global perspective. Vienna: International Atomic Energy Agency, 2011.
- 186 Union for International Cancer Control. World cancer declaration. <http://www.uicc.org/world-cancer-declaration> (accessed July 5, 2015).
- 187 UN. Declaration of commitment on HIV/AIDS. “Global Crisis—Global Action.” <http://www.un.org/ga/aids/coverage/FinalDeclarationHIVAIDS.html> (accessed July 5, 2015).



- 188 Are C, Rajaram S, Are M, et al. A review of global cancer burden: trends, challenges, strategies, and a role for surgeons. *J Surg Oncol* 2013; **107**: 221–26.
- 189 Agenda item 15.5- Strengthening of palliative care as a component of comprehensive care throughout the life course: Hearing before the Sixty-Seventh World Health Assembly(2014). <http://hospicecare.com/uploads/2014/12/WHO%20Palliative%20Care%20Resolution.pdf> (accessed July 5, 2015).
- 190 Knaul FM, Farmer PE, Bhadelia A, Berman P, Horton R. Closing the divide: the Harvard Global Equity Initiative—Lancet Commission on global access to pain control and palliative care. *Lancet* 2015; published online March 8. [http://dx.doi.org/10.1016/S0140-6736\(15\)60289-6](http://dx.doi.org/10.1016/S0140-6736(15)60289-6).

# The intersection of global health with cancer control

Despite major advances in care, global cancer mortality is rising steadily, and disproportionately in low-income and middle-income countries. Through past Commissions and Series, *The Lancet Oncology* has steadily charted this worrying trend and issued multiple calls for action. Our concern is not limited simply to the human cost of cancer: rising cancer incidence carries a very real economic price, both in terms of costs sunk into health care and, given the increasing emergence in patients of working age, in terms of widening inequalities and reducing countries' economic output. We are by no means alone in highlighting what rising incidence of cancer means for the world. Indeed, in 2011, the UN issued a resolution<sup>1</sup> explicitly stating that the rising burden of non-communicable disease "constitutes one of the major challenges for development in the twenty-first century, which undermines social and economic development throughout the world and threatens the achievement of internationally agreed development goals". Unfortunately, the world appears unprepared to meet the challenge. Only this year, for example, did WHO add basic chemotherapy drugs to its list of essential medicines.<sup>2</sup>

Radiotherapy is uniquely placed to deliver highly effective curative and palliative care for patients with cancer, often in a way in which other modalities cannot. Moreover, radiotherapy is more scalable and multifunctional than any other treatment modality. Yet, the world's capacity for radiotherapy is unacceptably low in view of the high burden of disease, and insufficiency exists even in very-high-income countries.<sup>3-5</sup> The investment need, from a health-care perspective, is clear. However, we do not live in a perfect world where all costs and needs are created equally, and competing demands and politics create uneven pressures on finite budgets.

Although it has been previously assumed that radiotherapy is the most cost-effective treatment for cancer treatment, hard evidence has been lacking. The Commission published in this issue now presents convincingly the economic case.<sup>6</sup> In 2013, the Union for International Cancer Control (UICC) created the

Global Task Force on Radiotherapy for Cancer Control (GTRFCC) to address the central role of radiotherapy in cancer treatment. In one of the linked Comments,<sup>7</sup> the leaders of the GTRFCC explain in greater detail the rationale for taskforce's inception. With more than 100 members from 30 countries, more than 2 years of work have now quantified the need, cost, and economic benefit of worldwide investment in radiotherapy.

Given the scale of ambition outlined in the Commission and the associated time horizon, it is imperative that the work begun by the Commissioners continues to reverberate throughout future generations. To that end, the GTRFCC also set up a Young Leaders Programme that includes young radiotherapists, oncologists, and other medical professionals at the beginning of their careers who are dedicated to global health and continuing the work of advocating accessible radiotherapy worldwide.<sup>8</sup>

Too often, calls for the rising tide of cancer incidence to be checked are made with earnest intentions but soft hearts. The evidence presented in this Commission from a global body of experts provides a rational economic case to begin radiotherapy investment worldwide. The time for circular discussion and argument is over; the time for action is now.

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- 1 UN General Assembly. Political declaration of the high-level meeting of the General Assembly on the prevention and control of non-communicable diseases. [http://www.who.int/nmh/events/un\\_ncd\\_summit2011/political\\_declaration\\_en.pdf](http://www.who.int/nmh/events/un_ncd_summit2011/political_declaration_en.pdf) (accessed Aug 26, 2015).
- 2 WHO. 19th WHO model list of essential medicines (April 2015). [http://www.who.int/medicines/publications/essentialmedicines/EML2015\\_8-May-15.pdf](http://www.who.int/medicines/publications/essentialmedicines/EML2015_8-May-15.pdf) (accessed Aug 26, 2015).
- 3 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.
- 4 Abdel-Wahab M, Bourgue JM, Pynda Y et al. Status of radiotherapy resources in Africa: an International Atomic Energy Agency analysis. *Lancet Oncol* 2013; **14**: e168-75.
- 5 Rosenblatt E, Izewska J, Anacak Y et al. Radiotherapy capacity in European countries: an analysis of the Directory of Radiotherapy Centres (DIRAC) database. *Lancet Oncol* 2013; **14**: e79-86.
- 6 Atun R, Jaffray DA, Barton MB, et al. Expanding global access to radiotherapy. *Lancet Oncol* 2015; **16**: 1153-86.
- 7 Jaffray DA, Knaul FM, Atun R, et al. Global Task Force on Radiotherapy for Cancer Control. *Lancet Oncol* 2015; **16**: 1144-46.
- 8 Rodin D, Yap ML, Hanna TP. GlobalRT: building a new radiotherapy community. *Lancet Oncol* 2014; **15**: 926.

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## Global Task Force on Radiotherapy for Cancer Control

See *The Lancet Oncology Commission* page 1153

Cancer is an immense, fast-growing challenge to health and health systems worldwide. Previously thought to be restricted to high-income populations, it is now also recognised as an emerging and critical issue for low-income and middle-income countries. Although the challenge of cancer control in low-income and middle-income countries has been highlighted before,<sup>1</sup> a comprehensive, integrated and global health system response was first forged with the work of the Global Task Force on Expanded Access to Cancer Care and Control, which began in 2009.<sup>2</sup> This effort inspired the creation of the Global Task Force on Radiotherapy for Cancer Control (GTRCC),<sup>3</sup> chaired by David A Jaffray, which consisted of more than 100 members, including radiotherapy professionals, oncology experts, industry representatives, and economists. The Union for International Cancer Control (UICC), a global initiative dating to the 1930s that works to promote greater equity in cancer control, mandated the GTRCC,<sup>4</sup> which was launched under the President's portfolio with essential support from key leaders in the European Society for Radiotherapy and Oncology (ESTRO), the International Atomic Energy Agency (IAEA), and the radiotherapy industry.

Cancer control necessitates comprehensive and coordinated actions that span prevention, access to accurate and timely diagnosis, treatment, and palliation. Radiotherapy is a key curative and palliative treatment modality for cancer. However, the dearth of radiotherapy treatment capacity globally has led to gross inequities in access. The GTRCC took on the task of quantifying the investment needed to close the global radiotherapy access gap.

Through the inspiring leadership of the UICC board members—especially Felicia M Knaul, board member and leader of the GTRCC—the GTRCC recruited the foremost global experts in the field to form the Secretariat to coordinate and direct the task force's efforts. It was recognised that developing the economic case for radiotherapy would be at the core of the GTRCC's efforts, and Rifat Atun, who has extensive experience in global health and innovative financing for health care,<sup>5–8</sup> joined the Secretariat. The GTRCC was fortunate to have the President of Uruguay, Tabaré Vázquez, who is a radiation oncologist, as its Honorary Chair.

The GTRCC assumed as its mandate the documentation of the challenge and quantification of the investment needed to achieve global equity in access to radiotherapy by 2035. The task force was determined to show not only the health benefit of this transformative investment in cancer control, but also the economic benefit of radiotherapy using an investment framework. The GTRCC aims to connect the details of the need for radiotherapy to the global health agenda and machinery to advance comprehensive cancer services worldwide. We engaged *The Lancet Oncology* early in our deliberations<sup>9</sup> and eventually became part of the *Lancet* Cancer Campaign as The Lancet Oncology Commission on Global Radiotherapy.<sup>10</sup>

Over the past 2 years, the GTRCC investigated the role and global need for radiotherapy through the activities of two working groups. The first, under the leadership of Michael B Barton and with input from Freddie Bray of the International Agency for Research on Cancer, estimated the 20-year future burden of cancer requiring radiotherapy and determined the projected benefit in terms of lives saved of making radiotherapy available globally according to evidence-based practice guidelines.<sup>11,12</sup> The second working group was led by Jacob Van Dyk and reviewed the requirements in terms of facilities, equipment, and human resources to generate sufficient capacity to deliver the scale of treatment necessary to deal with the projected burden. It also calculated the capital and operating costs of creating and delivering this capacity. In parallel, Rifat Atun led the development of the investment model to evaluate the economic case for investment in radiotherapy.

The deliberations and progress of the working groups were presented and discussed throughout 2014 at GTRCC-hosted sessions at the annual ESTRO, American Society of Clinical Oncology, American Society for Radiation Oncology, and UICC World Cancer Congress. Additionally, the GTRCC Secretariat held a workshop in Toronto in February, 2015, to reach a consensus on the assumptions required to calculate the economic benefit. The full membership of GTRCC was engaged in the work through participation in meetings, surveys, and a series of webinars held throughout spring of 2015 to canvass opinions and ideas for the final report before publication.

For the full list of members see [www.gtrcc.org](http://www.gtrcc.org)

For more on the *Lancet/Lancet Oncology Cancer Campaign*, please see <http://www.thelancet.com/campaigns/cancer>

The GTRCC concentrated specifically on investment in radiotherapy as a neglected and necessary facet of global cancer control.<sup>13</sup> Our work has attracted considerable interest and great expectations in the global cancer and radiotherapy communities. At the same time, it is clearly evident that to realise the full benefit from radiotherapy a parallel investment has to be made in diagnostic services (pathology and imaging), surgery, chemotherapy, and broader health-care strengthening platforms. The results of the task force complement and contribute to the ongoing efforts of the IAEA, the global cancer community, and WHO to promote greater equity in access to cancer care now and the future.

Closing the gap in equitable access to radiotherapy is a complex undertaking. The effort to provide radiotherapy around the world will continue for decades. In recognition of the magnitude and the need for sustained advocacy and champions, the GTRCC enlisted several young leaders who enthusiastically engaged in the work and created a new effort, GlobalRT, under the leadership of Danielle L Rodin.<sup>14</sup> This social movement aims to connect young people interested in busting the myths and working together to ensure that evidence-based radiotherapy practice is included in the toolbox of cancer therapies available worldwide. Our findings, together with recommendations for concrete steps to close the divide in access to radiotherapy are presented in full in this issue of *The Lancet Oncology*.

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- 1 Sloan FA, Gellband H. Cancer control opportunities in low- and middle-income countries. Washington, DC: National Academy of Sciences, 2007.
- 2 Knaul FM, Frenk J, Shulman Lawrence, for the Global Task Force on Expanded Access to Cancer Care and Control in Developing Countries. Closing the cancer divide: a blueprint to expand access in low and middle income countries. Boston: Harvard Global Equity Initiative, 2011.
- 3 Farmer P, Frenk J, Knaul FM, et al. Expansion of cancer care and control in countries of low and middle income: a call to action. *Lancet* 2010; **376**: 1186–93.
- 4 Global Task Force on Radiotherapy for Cancer Control. A world cancer declaration, target 7 commitment. <http://www.uicc.org/sites/main/files/private/GTRCC%20Introduction.pdf> (accessed Aug 25, 2015).
- 5 Vujcic M, Weber SE, Nikolic IA, Atun R, Kumar R. An analysis of GAVI, the Global Fund and World Bank support for human resources for health in developing countries. *Health Pol Plan* 2012; **27**: 649–57.

For more on GlobalRT see  
<http://www.globalrt.org>

- 6 Resch S, Korenromp E, Stover J, et al. Economic returns to investment in AIDS treatment in low and middle income countries. *PLoS One* 2011; **6**: e25310.
- 7 Cavalli F, Atun R. Towards a global cancer fund. *Lancet Oncol* 2015; **16**: 133–34.
- 8 Schwartlander B, Stover J, Hallett T, et al. Towards an improved investment approach for an effective response to HIV/AIDS. *Lancet* 2011; **377**: 2031–41.
- 9 Rodin DL, Jaffray DA, Atun R, et al. The need to expand global access to radiotherapy. *Lancet Oncol* 2014; **15**: 378–80.
- 10 Atun R, Jaffray DA, Barton MB, et al. Expanding global access to radiotherapy. *Lancet Oncol* 2015; **16**: 1153–86.
- 11 Barton MB, Jacob S, Shafiq J, et al. Estimating the demand for radiotherapy from the evidence: a review of changes from 2003 to 2012. *Radiother Oncol* 2014; **112**: 140–44.
- 12 Shafiq J, Delaney G, Barton MB. An evidence-based estimation of local control and survival benefit of radiotherapy for breast cancer. *Radiother Oncol* 2007; **84**: 11–17.
- 13 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.
- 14 Rodin DL, Yap ML, Hanna TP. GlobalRT: building a new radiotherapy community. *Lancet Oncol* 2014; **15**: 926.

## The verdict is in: the time for effective solutions to the global cancer burden is now

See *The Lancet Oncology Commission* page 1153

That the growing global burden of non-communicable diseases is a human catastrophe requiring action was brought to the world's attention over the past decade by WHO,<sup>1</sup> culminating in a UN declaration in 2011.<sup>2</sup> Non-communicable diseases—respiratory diseases, obesity, cardiovascular disease, and cancer—have common causes, including nutrition, personal habits, environment, and ageing.<sup>3</sup> The importance of non-communicable diseases does not diminish that of communicable diseases, and there are clear links between human papillomavirus and cervical cancer, and the hepatitis viruses and liver cancer.

Effective cancer control necessitates a multi-dimensional, multisectoral, multidisciplinary, and international approach. In debates, the issue of affordability is invariably raised, particularly for radiotherapy, in view of the cost of establishing and maintaining facilities. In this issue of *The Lancet Oncology*, the comprehensive need assessment and economic analysis by Rifat Atun and colleagues<sup>4</sup> rejects the argument that radiotherapy is unaffordable, and shows that investment in radiation oncology both saves lives and is associated with positive economic returns.

Radiotherapy is a key component of curative and palliative treatment. Substantial benefit is achievable from combined treatment with radiation and standard drugs to cure some locally advanced cancers and from short-course radiation (hypofractionation) as part of palliative care. Investment in partnerships is needed to train, educate, mentor, and sustain programmes in settings with limited personnel, resources, and infrastructure. The Global Taskforce on Radiotherapy for Cancer Control set up by the Union for International Cancer Control (UICC) is a remarkable project. Its analyses and robust collection of

contributors provide clear evidence that there could be an effective way forward.<sup>4</sup>

If addressing global cancer care results in both health and economic benefits,<sup>4</sup> why are effective radiotherapy and cancer care programmes so difficult to establish in low-income and middle-income countries? There are several frequently articulated reasons for not addressing this problem, all of which are certainly resolvable.

Some suggest a focus only on prevention. Prevention is crucial, but what happens to patients for whom it is not effective? Furthermore, prevention has not eliminated cancer in resource-rich countries. Others suggest that cancer care is too expensive, or the problems too complicated, but the results of the Commission show that non-treatment is more expensive<sup>4</sup>—and there are examples of high-quality cancer care in low-income and middle-income countries. Successful, affordable treatment regimens exist, and technology can link global experts to centres in low-income and middle-income countries, enabling access to new concepts and mentoring.

Suboptimum health-care and physical infrastructures are other common reasons cited for not addressing the issue. However, systems are in need of repair for everything from maternal and child health, to communicable and non-communicable diseases.<sup>5,6</sup> There is the opportunity for innovative technology to cope with challenging infrastructure. That low-income and middle-income countries do not have the expertise is another common concern, but the world has the expertise to train, mentor, and sustain people in these areas. Effective mentoring models are needed, such as the International Cancer Expert Corps.<sup>7</sup>

Policy makers in resource-rich countries appropriately suggest that they cannot be responsible for provision

For more on the **Global Taskforce on Radiotherapy for Cancer Control** see <http://gtfrc.org/>

For more on the **Union for International Cancer Control** see <http://www.uicc.org>

For more on the **International Cancer Expert Corps** see <http://www.iceccancer.org>



of cancer care worldwide, often pointing to existing global health programmes as addressing the problem. More investment is necessary. Enhancing health care is a means of improving global relationships. There are private sector opportunities that benefit both the donor and recipient countries. Universities and non-governmental organisations have programmes, but these take years to establish and equip with radiotherapy equipment. To accelerate the rate of change, these initiatives can maintain their identity and enhance one another working through broad-based organisations—eg, the UICC, the Consortium of Universities for Global Health, and the Programme of Action for Cancer Therapy from the International Atomic Energy Agency (IAEA).

In high-income countries, key aspects of foreign policy involve fighting terrorism, which might include securing radioactive sources. Although aspects of global unrest and animosity are far beyond health-care issues, medicine is a common language, and tackling cancer, which is feared globally, provides an excellent opportunity for collaboration. As for the security of nuclear material,  $^{60}\text{Co}$  machines can be replaced by linear accelerators. Establishing units where there are none and replacing  $^{60}\text{Co}$  machines creates a substantial commercial opportunity for radiation equipment, estimated to be at least 5000 units.<sup>8</sup> To meet this need extensive building and sustaining of a capable workforce and infrastructure are required.<sup>4</sup>

Another question commonly raised in resource-rich countries that have medically underserved populations, including geographically remote indigenous populations, is why should they take care of people in other countries when they have their own problems? We should aim to take care of both our citizens and those of other countries, and learn from one another, especially in view of the similarities in issues between low-income and middle-income countries and geographically remote indigenous populations in resource-rich countries. The UICC has an indigenous populations group and a National Cancer Institute programme showed that investment in indigenous populations is effective.<sup>9</sup>

Numerous people with an interest in global health report that their hospital directors or senior managers will not afford them the time to take an active role in the global fight against cancer. This matter is one of priorities and valuing activities that might not have

immediate financial benefits. We propose that altruistic service can be as important to career fulfilment as caring for patients, research, and teaching.<sup>10</sup>

The final misconception is that only academia can tackle this issue. However, a wealth of unused talent can be tapped, including health-care workers in private practice and senior mentors or retirees.<sup>7</sup>

According to gap projections by the IAEA,<sup>8</sup> if only one effective radiation treatment unit is commissioned every week it will take a century to solve this problem. A rapid exponential solution can come from engaging people who can design a path forward using that suggested from the work by this Commission<sup>4</sup> and supporting those making it happen. It is time for health-care careers to include global service as an integral component rather than a personal diversion during people's spare time.<sup>10</sup> Atun and colleagues conclude the Commission<sup>4</sup> by providing examples of how the world makes progress when it invests in difficult problems. Global solidarity, collective action, transformative thinking, and action are needed now.

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- 1 Alwan A. Global status report on noncommunicable diseases. Geneva: World Health Organization, 2011.
- 2 UN. Draft political declaration of the high level meeting on the prevention and control of non-communicable diseases. [http://www.un.org/en/ga/ncdmeeting2011/pdf/NCD\\_draft\\_political\\_declaration.pdf](http://www.un.org/en/ga/ncdmeeting2011/pdf/NCD_draft_political_declaration.pdf) (accessed Aug 28, 2013).
- 3 Hunter DJ, Reddy KS. Noncommunicable diseases. *N Engl J Med* 2013; **369**: 1336–43.
- 4 Atun R, Jaffray DA, Barton MB, et al. Expanding global access to radiotherapy. *Lancet Oncol* 2015; **16**: 1153–86.
- 5 Kim JY, Farmer P, Porter ME. Redefining global health-care delivery. *Lancet* 2013; **382**: 1060–69.
- 6 Love RR, Ginsburg OM, Coleman CN. Public health oncology: a framework for progress in low- and middle-income countries. *Ann Oncol* 2012; **23**: 3040–45.
- 7 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.
- 8 International Atomic Energy Agency. Availability of radiation therapy. <http://www.iaea.org/newscenter/focus/cancercare/dirac2012.pdf> (accessed Aug 28, 2013).
- 9 Wong RS, Vikram B, Govern FS, et al. National Cancer Institute's Cancer Disparities Research Partnership Program: experience and lessons learned. *Front Oncol* 2014; **4**: 303.
- 10 Coleman CN, Love RR. Transforming science, service, and society. *Sci Transl Med* 2014; **6**: 259fs42.

For more on the Consortium of Universities for Global Health see <http://www.cugh.org>

For more on the Programme of Action for Cancer Therapy see <http://cancer.iaea.org>

## Expanding global access to radiotherapy: the European Society for Radiotherapy and Oncology perspective

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"Every cancer patient in Europe will have access to state of the art radiation therapy, as part of a multidisciplinary approach where treatment is individualised for the specific patient's cancer, taking account of the patient's personal circumstances." This statement is taken from the European Society for Radiotherapy and Oncology's 2012 vision for radiation oncology,<sup>1</sup> which recognised that access to high-quality radiotherapy is one of the cornerstones of optimum oncological care.

The Union for International Cancer Control has embraced that same objective in its Global Task Force on Radiotherapy for Cancer Control (GTRCC), and has applied a broad worldwide perspective to it in this issue of *The Lancet Oncology*,<sup>2</sup> with a special emphasis on low-income and middle-income countries. From an initially more limited focus questioning which investments are required to close the gap in global access to radiotherapy by 2035, this project evolved towards an all-encompassing investment framework.

On the basis of the burden of cancer—both that now and in the decades to come—the current and future shortfalls in radiotherapy services have been calculated. Huge variation among countries was noted in cancer incidence and profile, and in current radiotherapy coverage, which is insufficient or even non-existent in many low-income and middle-income countries.

Estimated future requirements were also presented.<sup>2</sup>

Investment in radiotherapy is often thought to be too complex and expensive. The GTRCC for the first time presents worldwide cost estimates. The one-time upfront cost to establish new capacity, covering start-up investment and professional training, hovers around US\$350 per fraction in low-income and middle-income countries and \$800 per fraction in high-income countries. Thereafter, operating costs, including capital depreciation, range from a mere \$60 to \$86 per three-dimensional conformal radiotherapy fraction in low-income and middle-income countries, compared with \$235 in high-income countries, for which costs were calculated for a mix of conformal and intensity-modulated fractions.

Although these costs compare favourably with the high costs of cytotoxic drugs (especially new drugs), formal cost-effectiveness data and elaborate business models are typically required to support health-care policy making and investment planning for new radiotherapy resources. Economic evaluations comparing radiotherapy with systemic treatments alone are often unrealistic because of the different disease entities in which both treatment modalities are used. We should not, however, forego the fact that cancer care is best served by an integrated multidisciplinary approach. Thus the innovative approach used by the GTRCC—ie, an investment framework that scales up the radiotherapy costs to the required capacity in 2035 and balances them against the expected life-years gained—is particularly noteworthy. Their work shows that a positive return on investment can be anticipated over the analysed period, especially if scientific advances enable more efficient radiotherapy.

Because of the better radiotherapy coverage in high-income countries—with even a perceived overcapacity in some countries—the GTRCC project did not further elaborate on the investment framework in these nations. But sufficient resources do not by themselves safeguard access to state-of-the-art radiotherapy. In a heterogeneous region such as Europe, for example, the diversity in cancer incidence and survival, and the



Laurence Ollagnier/BSIP/BSIP/Corbis

organisation and economic determinants of health care, are deemed to increase inter-country variations in access to radiotherapy. The European Society for Radiotherapy and Oncology's Health Economics in Radiation Oncology (HERO) project<sup>3</sup> was launched in 2011 with the overall aim of developing a knowledge base and a model for health economic evaluation of radiation treatments at the European level. The data collection and analyses accomplished so far have not only made explicit the huge variations in radiotherapy availability and related key parameters,<sup>4,5</sup> but also shown that, even in Europe, the actual use of radiotherapy is substantially lower than the optimum use predicted from evidence-based estimates. Less than a fifth of included countries treat at least 80% of the optimum radiotherapy indications and about half remain substantially less than 70%.<sup>6</sup>

Part of this variation can surely be traced back to the differences in wealth among the countries—a higher gross national income typically translates into better resource coverage. But geographical impediments to access; the health-care financing structure of the country; patients' characteristics including age, comorbidity, socioeconomic status and personal opinion; and the physician's preferences, awareness, and knowledge all have roles in referral to, and acceptance of, radiotherapy.

Although education and clinical science dissemination are the foundations needed to empower the radiotherapy community to take up its full potential in the multidisciplinary oncology arena,

there is much more to be done. To achieve the goal of providing the right treatment to every patient, an even greater emphasis is needed on health services research. The European Society for Radiotherapy and Oncology is responding through its HERO project, which mainly helps European national radiotherapy societies to strengthen the profession in their respective countries. On a global level, we are happy to support the work of the GTRCC, which enables countries worldwide to estimate the radiotherapy investments that are imperative to provide effective and efficient multidisciplinary cancer care.

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- 1 Valentini V, Bourhis J, Hollywood D. ESTRO 2012 strategy meeting: vision for radiation oncology. *Radiother Oncol* 2012; **103**: 99–102.
- 2 Atun R, Jaffray DA, Barton MB, et al. Expanding global access to radiotherapy. *Lancet Oncol* 2015; **16**: 1153–86.
- 3 Lievens Y, Grau C. Health economics in radiation oncology: introducing the ESTRO-HERO project. *Radiother Oncol* 2012; **103**: 109–12.
- 4 Grau C, Defourny N, Malicki J, et al. Radiotherapy equipment and departments in the European countries: final results from the ESTRO-HERO survey. *Radiother Oncol* 2014; **112**: 155–64.
- 5 Lievens Y, Defourny N, Coffey M, et al. Radiotherapy staffing in the European countries: final results from the ESTRO-HERO survey. *Radiother Oncol* 2014; **112**: 178–86.
- 6 Borras JM, Lievens Y, Dunscombe P, et al. The optimal utilization proportion of external beam radiotherapy in European countries: an ESTRO-HERO analysis. *Radiother Oncol* 2015; **116**: 38–44.

## Radiotherapy in southeast Asia: room to grow

The Lancet Oncology Commission on global access to radiotherapy<sup>1</sup> is prescient work that should become required reading for all who have influence in national health-care systems. Despite nearly 120 years of effective use in cancer treatment and demonstrable cost-effectiveness,<sup>2</sup> the Commission's findings show that substantial numbers of patients with cancer are unable to access correct treatment because of inadequate radiotherapy resources. This deficit is clearly in evidence in many regions of the world, including southeast Asia, which covers roughly 4·3 million km<sup>2</sup>, is home to 625 million people, and has a gross domestic product

of US\$2·5 trillion. Of the nations, two (Brunei and Singapore) are high-income countries, two (Malaysia and Thailand) are upper-middle-income countries, five (Burma, Indonesia, Laos, Philippines, and Vietnam) are lower-middle-income countries, and Cambodia is a low-income country.

Southeast Asia's gross domestic product has grown by 5–5·5% per year over the past 15 years.<sup>3</sup> Central to sustained economic improvement is a stable political sphere with good governance. To bring about improvements in health care, including cancer care, strong governmental actions are needed to channel

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some of the fruits of economic growth towards the development, resourcing, and operationalisation of health-care plans. Furthermore, health-care plans must be supported by good plans and policies in general education and professional training, reliable infrastructure in transport and utilities, and a rational health-funding policy to ensure equitable access and sustainability. Each of these presents unique challenges to the region.

The needs and challenges for each country in southeast Asia are varied. Difficulties in access to radiotherapy centres are typical in a region where large rural populations exist. This issue is particularly obvious in Indonesia, which is an archipelago of roughly 17 500 islands, more than 900 of which are permanently inhabited. The country stretches more than 5000 km east to west, but the vast majority of its 24 radiotherapy centres are located in Sumatra and Java in the west.<sup>4</sup> Expansion of capacity tends to occur in large cities, compounding this inequality. In parts of southeast Asia, frequent power-grid failures can lead to treatment interruptions and machine downtimes (particularly with linear accelerators, which need a stable supply of electricity), further complicating the issue of inadequate capacity and highlighting the need for improved infrastructure.<sup>5</sup>

In terms of increasing machine capacity, to achieve the widely accepted—albeit crudely estimated—figure of four megavoltage machines per 1 000 000 population, the region has a deficiency of about 2230 machines. Governments need to spend their health budgets in such

a way that this deficit is reduced by investing in the most suitable equipment that gives the best outcomes at a population level. The priority must be to treat patients who would otherwise die because of inaccessibility to treatments that are too expensive either because of physical distance to a centre or because the high costs of buying unnecessarily advanced machines are transferred to the patient. In this regard, world bodies such as the International Atomic Energy Agency could issue guidance for a set of optimum specifications for equipment with the aim of helping governments in the region to set up cost-effective centres that address the particular issues of those countries.

Equipment availability and access are only parts of the equation. An adequate and trained workforce is also a challenge to recruit in this region. It would take years to train the additional 700 radiation oncologists, 500 radiation physicists, and 1800 radiation technologists required to run centres in southeast Asia safely and effectively. The difficulties of attracting and retaining capable staff are accentuated by a global demand for such personnel, and the poor salaries in the region. In small nations, such as Brunei, the small size of yearly cohorts of students makes the development of local education programmes not cost effective. Recruitment from out of country thus becomes the main solution. Although these issues seem intractable, there is hope that increasing wealth at the personal and national levels will generate improved awareness among the public and health-care leaders, leading ultimately to the development of more robust cancer services, including radiotherapy.

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- 1 Atun R, Jaffray DA, Barton MB, et al. Expanding global access to radiotherapy. *Lancet Oncol* 2015; **16**: 1153–86.
- 2 Lederman M. The early history of radiotherapy: 1895–1939. *Int J Radiat Oncol Biol Phys* 1981; **7**: 639–48.
- 3 Organisation for Economic Co-operation and Development. Pocket edition of economic outlook for southeast Asia, China and India 2014 by the OECD Development Centre. <http://www.oecd.org/site/seao/Pocket%20Edition%20SAE02014.pdf> (accessed Aug 26, 2015).
- 4 Gondhowiardjo SA, Prajogi GB, Sekarutami SM. History and growth of radiation oncology in Indonesia. *Biomed Imaging Interv J* 2008; **4**: e42.
- 5 Stoker SD, Wilderman MA, Fles R, et al. A prospective study: current problems in radiotherapy for nasopharyngeal carcinoma in Yogyakarta, Indonesia. *PLOS One* 2014; **9**: e85959.



# Expanding global access to radiotherapy: the IAEA perspective

2015 is a momentous year for global health and a time of immense opportunity. World leaders will meet at the UN Headquarters in New York (NY, USA) during the UN Sustainable Development Summit (Sept 25–27) to adopt a new set of universal and transformative Sustainable Development Goals (SDGs). For the first time, a target calling for a reduction by a third in premature mortality from non-communicable diseases—including cancer—by 2030 will be included.

So far, global efforts to address the growing demands for comprehensive cancer control in low-income and middle-income countries have been insufficient, and cancer has become a leading cause of premature death worldwide.<sup>1</sup> Radiotherapy plays an indispensable part in the management of cancer. It not only generates substantial benefits for patients in terms of survival and improved quality of life, but also is of immense palliative value, reducing pain and suffering, particularly in settings with limited access to appropriate pain medication. The Lancet Oncology Commission<sup>2</sup> presents robust and compelling evidence of the notable health gains associated with the clinical applications of radiotherapy, and also quantifies for the first time the noteworthy economic benefits of increased investment in radiotherapy. It also substantiates the experience of the International Atomic Energy Agency (IAEA) that radiotherapy is affordable, feasible, and can be safely and consistently deployed in low-income and middle-income countries.

The economic models proposed by the authors quantify the gradual yet substantial investments needed to ensure greater equity in the global access to this essential health technology. Although their analysis was based on several assumptions and approximations with inherent limitations, the authors provide a general assessment of the economic effects of the cancer epidemic and the level of investment needed to close the gap and align resources with the actual burden of cancer, enabling estimation of the level of research, innovation, and global commitment required to achieve the maximum public health impact in cancer management.

As the authors of the Commission recognise, the IAEA has more than 30 years' experience of supporting countries in setting up and upgrading radiation medicine infrastructure and training the necessary professionals for

the effective diagnosis and radiotherapeutic treatment of cancer. As an organisation that has been actively working to strengthen radiotherapy capacity worldwide, the financial investment made by the IAEA in the past decades has been substantial.<sup>3</sup> Additionally, the IAEA ensures that the delivery of teletherapy, brachytherapy, quality-assurance, and dosimetry equipment is supported by appropriately trained professionals and service maintenance contracts.<sup>4</sup> This approach contributes to the safe and effective use of equipment and to its sustainability.<sup>5</sup>

Through its various programmes, such as the Technical Cooperation programmes, the Human Health programme and, more recently, the Programme of Action for Cancer Therapy, which was established in 2005, the IAEA is committed to continuing to capitalise on previous experience and introduce, expand, and improve radiotherapy services, working with partners such as WHO to improve cancer treatment, care, and control through collective action in low-income and middle-income countries. The need is large: 36 low-income countries still do not have any radiotherapy capacity.<sup>1,6</sup> Thus, installation and operation of radiotherapy centres around the world has to be approached on a country-by-country basis, assessing needs and providing solutions to the individual country's particular situation.<sup>7,8</sup>

As noted in the Commission, other major factors, such as political commitment, public awareness, education about the benefits of radiotherapy, reduction of stigma associated with cancer and radiotherapy, transportation options for patients, and affordability need to also be adequately addressed to ensure accessibility to radiotherapy services. The Commission's findings provide an important contribution to catalyse global discussion on how to overcome these challenges. The IAEA is committed to expand and fast-track its active dialogue with policy makers, international stakeholders, and the private sector to promote the introduction and expansion of suitable, effective, and high-quality radiotherapy technology solutions worldwide.

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For more on Sustainable Development Goals see <https://sustainabledevelopment.un.org>



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- 1 Stewart BW, Wild CP. World cancer report 2014. Lyon: International Agency for Research on Cancer, 2014 (accessed Aug 28, 2015).
- 2 Atun R, Jaffray DA, Barton MB, et al. Expanding global access to radiotherapy. *Lancet Oncol* 2015; **16**: 1153–86.
- 3 Rosenblatt E, Acuña O, Abdel-Wahab M. The challenge of global radiation therapy: an IAEA perspective. *Int J Radiat Oncol Biol Phys* 2015; **91**: 687–89.
- 4 International Atomic Energy Agency. Setting up a radiotherapy programme: clinical, medical physics, radiation protection and safety aspects. Vienna, International Atomic Energy Agency, 2008.
- 5 Abdel-Wahab M, Rosenblatt E, Homberg O, Meghizifene A. Safety in radiation oncology—the role of international initiatives by IAEA. *J Am Coll Radiol* 2011; **8**: 789–94.
- 6 Abdel-Wahab M, Bourque J-M, Pynda Y, et al. Status of radiotherapy resources in Africa: an International Atomic Energy Agency analysis. *Lancet Oncol* 2013; **14**: e168–75.
- 7 Page B, Hudson A, Brown DW, et al. Cobalt, linac, or other: what is the best solution for radiotherapy in developing countries? *Int J Radiat Oncol Biol Phys* 2014; **89**: 476–480.
- 8 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**: 448–57.