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Overview

Analysis of Global Radiotherapy Needs and Costs by Geographic Region and Income Level

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Abstract

Recent years have seen various reviews on the lack of access to radiotherapy often based on geographic regions of the world such as Africa, Asia Pacific, Europe, Latin America and North America. Countries are often defined by their national income per capita levels based on World Bank definitions of high income, upper middle income, lower middle income and low income. Within the world regions, there are significant variations in gross national income (GNI) per capita among the different countries, and even within similar income levels, large variations exist. This report presents the actual status of radiotherapy and analyses the current needs and costs to provide full access in the different regions of the world. Actual coverage of the needs ranges from 34% in Africa to over 92% in Europe to about double the needs in North America. In line with this, proportional additional investments and operational costs are as high as more than 200% in Africa to almost none in North America. Two world regions face substantial challenges: Africa, based on the important demands to build new capacity and subsequently to maintain operational capability; and Asia Pacific, due to its high population density, translating into large absolute needs in radiotherapy treatments and resources, and hence in associated costs. With the data highlighting a large variability of GNI/capita even within similar income levels in the various world regions, it is expected that additional investment in resources and costs may be more dependent on income level of the country than on the GNI group or the geographic region of the world.

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Key words: Access; low- and middle-income countries; radiotherapy availability; radiotherapy costs; radiotherapy needs; world regions

Statement of Search Strategies Used and Sources of Information

The list and income classification of countries was taken from the World Bank, Country and Lending Groups, 2017 fiscal year (<http://data.worldbank.org/about/country-and-lending-groups>). Data on population, number of cancer cases per country and per region, and number of cancer cases for each cancer site were obtained from GLOBOCAN 2012 (<http://globocan.iarc.fr>; http://globocan.iarc.fr/Pages/fact_sheets_population.aspx). Data on availability of radiotherapy equipment were obtained from the IAEA Directory

of Radiotherapy Centres (DIRAC), publicly available online at <http://dirac.iaea.org>. We used an internally produced Excel sheet with data from December 2015.

Introduction

In recent years, a large body of evidence has emerged on the availability and needs of radiotherapy. In contrast to common expectations, considerable gaps in access to radiotherapy have not only been observed in low- and middle-income countries (LMICs) [1–6], but also in most European countries. Although the latter region is typically considered a high-income region where resources and access consequently should be optimal, important variations have been observed in available human and capital resources, translating into variable gaps in radiotherapy provision [7–12]. The most comprehensive, worldwide,

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analysis on the topic has been published by the Union for International Cancer Control's Global Task Force on Radiotherapy for Cancer Control (GTRCC) [2].

These reports have used different sources for input data collection and computed the gap in access to radiotherapy using different methodological approaches. The Health Economics in Radiation Oncology (HERO) project from the European Society for Radiotherapy and Oncology used data from their own survey, obtained and validated in close collaboration with the national societies for radiotherapy in Europe [7–9] and reported the gap between the evidence-based optimal and the actually delivered radiotherapy treatments across Europe [11]. It was concluded that access to radiotherapy remains limited in many European countries, even some of the more affluent. Most other studies relied on data input from the Directory of Radiotherapy Centres (DIRAC), the International Atomic Energy Agency's (IAEA) voluntary global registry on radiotherapy resources [2,10,12,13]. In most instances, the actual needs were estimated as the additional number of capital (mostly linear accelerators; linacs) and/or human resources required to allow full coverage of radiotherapy in a subset of countries or certain regions, based on generally accepted definitions on resource throughput and using various assumptions on other parameters such as operating hours [10,12,14,15]. The GTRCC report used a more refined time-driven activity-based costing (TD-ABC) approach that did not only allow computing investment and operational costs, but also provided insight into resource utilisation and shortfalls in coverage [2]. Although the number of additional machines needed varies between these reports, the overall conclusion is that around 50% of cases requiring radiotherapy in LMICs do not have access to treatment, and the figure of unavailable need rises to 90% in low-income countries (LICs).

Accurate data on the cost of radiotherapy remain scarce in today's literature. A recent systematic review of the available radiotherapy costing literature observed that only a minority of costing studies used conventional costing methodologies, which, together with the large heterogeneity in scope of the analyses and in inputs used and outputs reported, did not allow the presentation of a consistent picture of radiotherapy costs [16]. Moreover, only one of the studies in the review provided cost data for a range of different countries [17]. To date, the GTRCC is the only report that has estimated the investment and operational costs for radiotherapy across the globe. To provide input to an investment model that would allow closing the gap in radiotherapy provision by 2035, the report focused on incremental costs to cover additional resources needed over the next 20 years [2].

Here we present the current radiotherapy needs in LMICs, together with the investment and operational costs for optimal coverage to date. Moreover, being aware that LMICs are spread around different regions in the world, we analyse the needs and costs on the proportion of low-, lower middle- (L-MIC), upper middle- (U-MIC) and high-income (HIC) countries in the different world regions.

Countries and Regions

Countries were classified according to the definitions of the World Bank for 2017 [18]. For the current 2017 fiscal year, low-income economies are defined as those with a gross national income (GNI) per capita, calculated using the World Bank Atlas method, of US\$1025 or less in 2015; lower middle-income economies are those with a GNI per capita between US\$1026 and US\$4035; upper middle-income economies are those with a GNI per capita between US\$4036 and US\$12 475; high-income economies are those with a GNI per capita of US\$12 476 or more. The World Bank includes 217 economies, of which 79 are categorised as HIC, 55 as U-MIC, 52 as L-MIC and 31 as LIC. Forty-three small countries in this list are not reported by GLOBOCAN or DIRAC, hence they were not included in the analysis. The final number of economies included was 174, divided into 53 HIC, 46 U-MIC, 45 L-MIC and 30 LIC.

The actual analysis was carried out by geographic regions, based on the definition of regions used by the IAEA Technical Cooperation Department. Europe includes the post-Soviet countries in Central Asia and contains 29 HICs, 14 U-MICs and six L-MICs. North America refers to Canada and the USA, and Asia Pacific includes the rest of Asia and Oceania, with 15 HICs, eight U-MICs, 18 L-MICs and three LICs. Latin America is formed by seven HICs, 15 U-MICs, five L-MICs and one LIC and Africa by nine U-MICs, 16 L-MICs and 26 LICs. Interestingly, the population of Asia Pacific is 41% bigger than all four other regions combined.

Courses, Resources and Costs

The actual situation, based on today's available resources, was evaluated and compared with the optimal situation, where resources would match the needs to treat all patients with an indication for radiotherapy. Resources in the latter situation are further referred to as 'total resources' and the associated costs as 'total costs'.

Two previously published models were used. The total number of radiotherapy courses needed to treat all patients with an indication for radiotherapy to date was calculated using the evidence-based estimation method (EBEST) from the Collaboration for Cancer Outcomes Research and Evaluation (CCORE) [19–21]. The TD-ABC model developed for the GTRCC [2], based on former IAEA activity-based costing and staffing models [22,23] was used to compute the total resources needed to deliver these courses as well as to calculate the costs, actual and total investment and operational costs, and costs per course.

The main assumptions and input variables, which are largely in line with those used for the GTRCC report [2], are described below.

Courses

Based on data from GLOBOCAN 2012 [24], the number of current radiotherapy indications, for external beam

radiotherapy and for cervical cancers requiring brachytherapy, was calculated for each country with the latest version of the CCORE-EBEST model [19,20,21].

The average number of external beam radiotherapy fractions per radiotherapy case was 19.4 for all scenarios. All patients were assumed to be treated with three-dimensional conformal radiation therapy (3DCRT) in LMICs. In HICs, 50% of the patients were assigned to 3DCRT, 50% to intensity-modulated radiotherapy and half of the total number were assumed to have daily image-guided radiotherapy. Retreatment was not considered, primarily because it has been described to have a very small (1–4%) impact on the results [2,25].

Brachytherapy was not assumed to be essential for other tumour sites. The proportion of radiotherapy cases requiring brachytherapy was 1.5% for HICs, 4% for U-MICs, 10% for L-MICs and 14% for LICs, generally ranging between one and five fractions [26].

Resources

The number of radiotherapy departments and megavoltage (MV) machines, i.e. linacs and cobalt machines, was taken from IAEA-DIRAC, as of December 2015 [13]. An average of two MV machines per department was used for the calculations in line with available data showing that the actual average number of MV machines per department is less than two [10]. Radiotherapy departments were assumed to operate 12 h per day, 5 days per week and 50 weeks per year. As in the report of the GTFRC, all equipment-related quality assurance and preventive maintenance activities were assumed to be undertaken outside clinical hours [2].

In all scenarios, half of the linacs were assumed to have a single photon energy. For current capacity, 75% were estimated to be equipped with multileaf collimators and electronic portal imaging devices in HICs, 10% in U-MICs and none in L-MICs and LICs. On-board imaging cone beam computed tomography was assumed to be present on 25% of the linacs in HICs only. For total capacity, all linacs in all scenarios were upgraded to have multileaf collimators and electronic portal imaging devices, and 50% of linacs in HICs were upgraded with on-board imaging cone beam computed tomography. No cobalt machines were added to generate full capacity, but existing ones were maintained.

Data on ancillary radiotherapy equipment are non-existent at the global level. Hence, in addition to the assumptions on the linac-related image-guidance equipment, each department was assumed to have one computed tomography simulator, a 3DCRT-capable radiation treatment planning system, an oncology information management system and appropriate dosimetry, quality assurance and radiation protection equipment. This, as well as facility layout and size being based on IAEA guidance documents, conformed to the approach used in the GTFRC [2].

Similarly, as there are no reliable world-wide data on the availability of radiotherapy professionals, staffing levels were assumed to be adequate for handling the equipment in both the actual and optimal situations, i.e. actual and total

staffing levels align with calculated actual and total equipment and treatments. The same approach was used by the GTFRC [2].

Costs

Salaries were based on surveys and global databases, and as with the training, equipment and construction costs, they were the same as those used by the GTFRC [2].

Different Regions Across the Globe: a Highly Variable Picture

Figure 1 gives an overview of the GNI/capita in the five world regions with each dot representing a country. For each region, the blue dots represent the weighted average – based on the size of the countries' populations in that region and income level. Although, according to the World Bank, GNI regions are defined by upper and/or lower GNI/capita thresholds, it is clear that within the different geographic regions, the actual income of the countries within a specific income level varies a lot. Also, across regions, the weighted average GNI/capita is not consistent. For instance, although the average for HICs is similar in Europe and Asia Pacific, these are lower than the average in North America and much higher than that for Latin America. Similarly, in L-MICs, the Asia Pacific average is clearly lower than that for Europe, the latter being more in line with Latin America and Africa.

Table 1 provides a detailed overview of the main findings of the calculations carried out in this study, organised by the different world regions. It shows the currently available resources and the related costs – annual operational costs and average cost per course – calculated for the status of equipment to date. In addition, it presents an estimate of the total number of courses needed to generate full access, with the related projection of total resources needed. Finally, it gives the total investment costs, based on capital investment and training, needed to optimise access, as well as the operational costs and cost per course projected for this optimal situation. As can be observed, the coverage in Africa is only about one third of the optimal, whereas coverage nearly reaches two-thirds in Asia Pacific and in Europe and Latin America it hovers around 90%. Conversely, based on our computations, North America seems to be significantly over-resourced. It can only be hypothesised that this finding is due to a combined effect of a real excess in available equipment together with different operational models (less working hours per day, longer treatment time slots – all or not related to more complex treatment strategies) used in today's US radiotherapy practice.

Figure 2 provides further insight into the investments needed to close the gap in the different world regions, compared with the investments by income group. It is clear that at the regional level, overall challenges are biggest for Asia Pacific, predominantly in the U-MICs and L-MICs. Africa has important needs in L-MICs and LICs. Both Europe and North America still have additional needs in the HIC group,

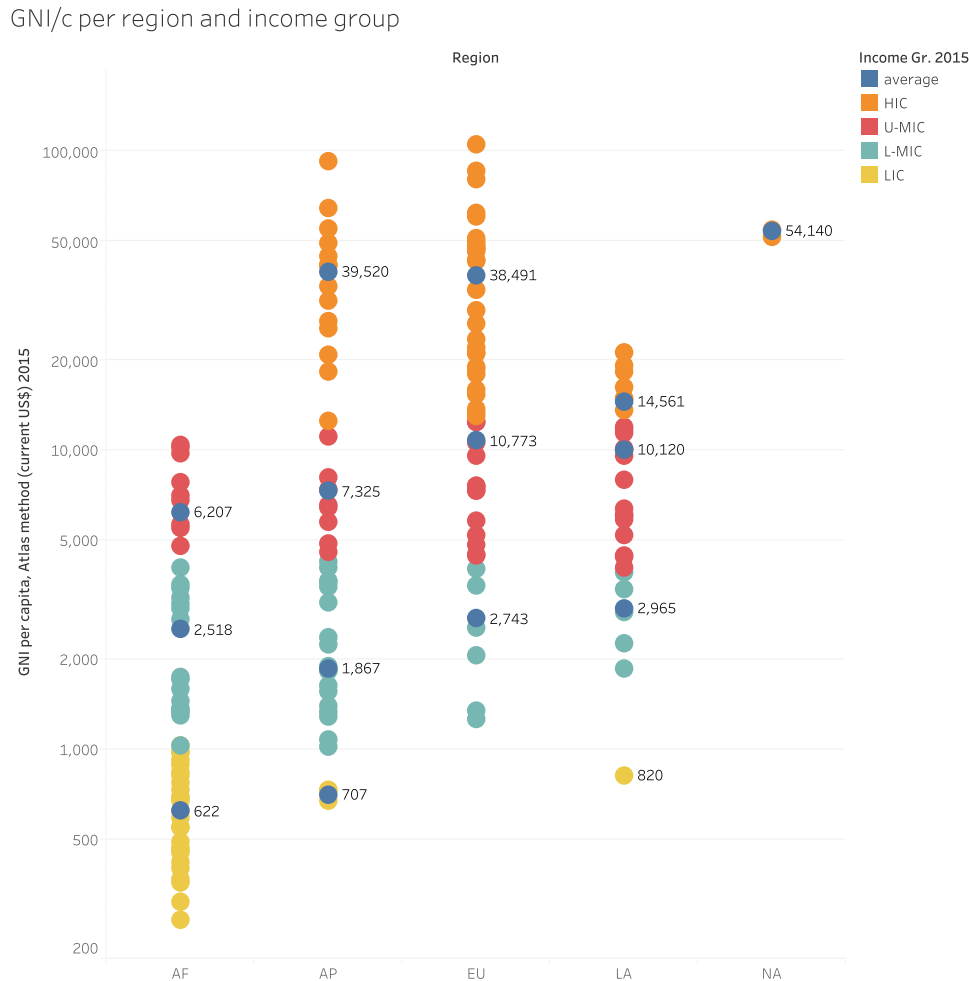


Fig 1. Gross national income (GNI)/capita in different regions of the world together with country income groups. Each dot represents a country with the colours illustrating the income group of that country. The averages of a particular income group in a particular region are illustrated by the dark blue dots. AF, Africa; AP, Asia Pacific; EU, Europe; LA, Latin America; NA, North America; HIC, high-income country; U-MIC, upper middle-income country; L-MIC, lower middle-income country; LIC, low-income country.

which is due to a combination of capital investment and training in Europe, and is mainly based on investment in human resources, especially physicists, in North America. Looking at the companion part of the figure with distribution by income groups, it is again the total investment needs of Asia Pacific that dominate the picture, in U-MICS and L-MICs.

Although in absolute numbers the needs of Asia Pacific are clearly the most impressive, in relative numbers (Figure 3), it is clear that Africa is also facing a major, be it completely different, challenge: it has to build up a large amount of capacity almost from scratch, yielding additional needs and costs in the order of 200%. In relative terms, additional needs of Asia Pacific only hover between 40 and 70%. Based on the parallel expansion of courses and resources in the model, the incremental cost per course is limited in all regions of the world, with even a slightly lower cost observed in Asia Pacific, due to the increased proportion of lower cost per course from Asia Pacific U-MICs and L-MICs in the final cost per course.

Lessons From These Data

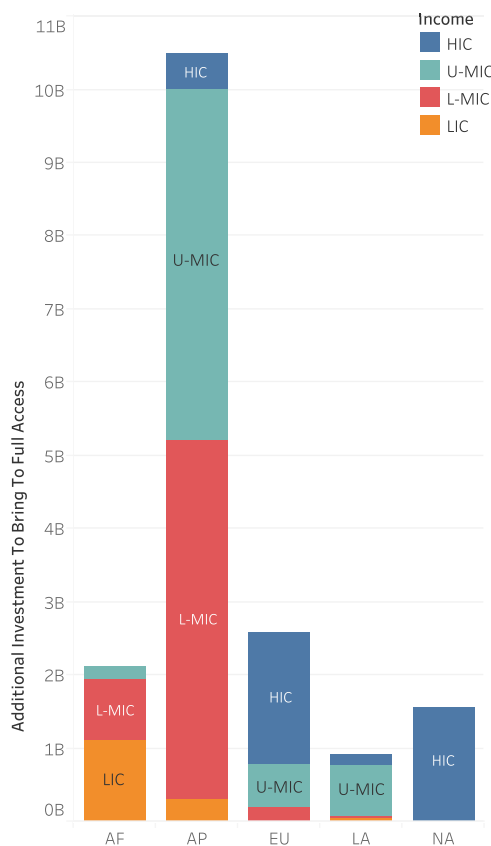
Variability of Available Resources Within Geographic Regions

It is clear that there is a huge worldwide variation in the availability of radiation therapy [2]. Although, broadly speaking, this variation tracks with regional income levels, the data in this paper show plainly that there are large variations in GNI/capita for different countries within each of the 'geographic' regions, indicating that these regions are by no means homogeneous in that respect. The exception to this is North America but even here this is not truly correct as, for the regional definition, North America is defined to be Canada and the USA and does not include Mexico, which is in the Latin American region. It should be noted that even within Canada and the USA there are also large variations in income levels – the variation within the USA being a factor of two or five depending on whether the District of Columbia is included or not [27] and in Canada the ratio is

Table 1
Summary of actual status and total needs to provide full access to radiotherapy in the different regions of the world

	Africa	Asia Pacific	Europe	Latin America	North America
Population and courses					
Population (million)	1070	4108	893	601	350
Actual radiotherapy courses	148 600	1 914 454	1 712 000	503 000	934 746
Total radiotherapy courses	437 624	3 277 387	1 884 893	573 385	934 746
Resources					
Actual radiotherapy centres	140	2585	1431	620	2787
Total radiotherapy centres needed for full access (working 12 h/day)	407	3503	1449	624	1200
Actual megavoltage machines	277	3894	3751	968	4243
Percentage cobalt machines	30.0%	19.8%	16.0%	30.1%	3.6%
Total megavoltage machines needed for full access (working 12 h/day)	813	6406	4098	1106	2175
Actual coverage of the needs	34%	61%	92%	88%	195%
Costs					
Capital + training costs needed to bring to full access (million US\$)	2118	10 497	2573	918	1558
Actual operational costs/year (million US\$)	182	4638	5868	975	6151
Total operational costs/year (million US\$), assuming full access	571	6968	6573	1192	6588
Actual cost per radiotherapy course (US\$)	1226	2423	3428	1939	6581
Total cost per radiotherapy course (US\$), assuming full access	1306	2126	3487	2079	7048

Additional investment per geographical region



Additional investment per income group

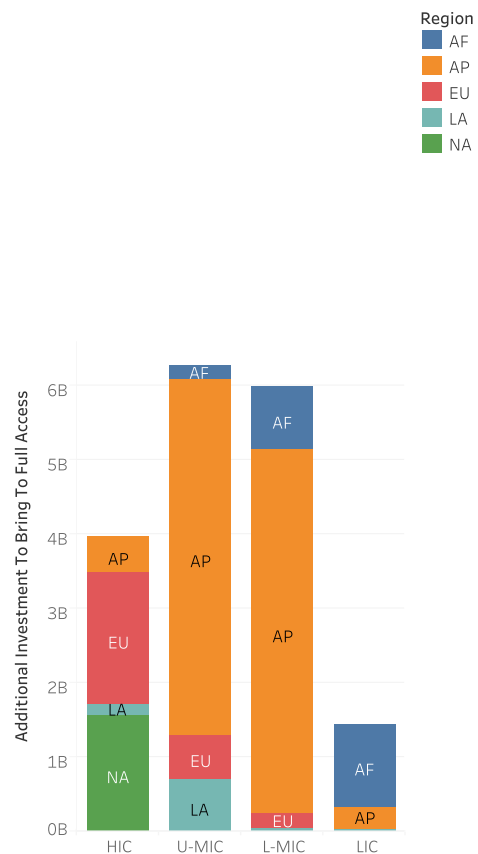


Fig 2. Additional investment needed to provide full access to radiotherapy by geographic region and by income group. AF, Africa; AP, Asia Pacific; EU, Europe; LA, Latin America; NA, North America; HIC, high-income country; U-MIC, upper middle-income country; L-MIC, lower middle-income country; LIC, low-income country.

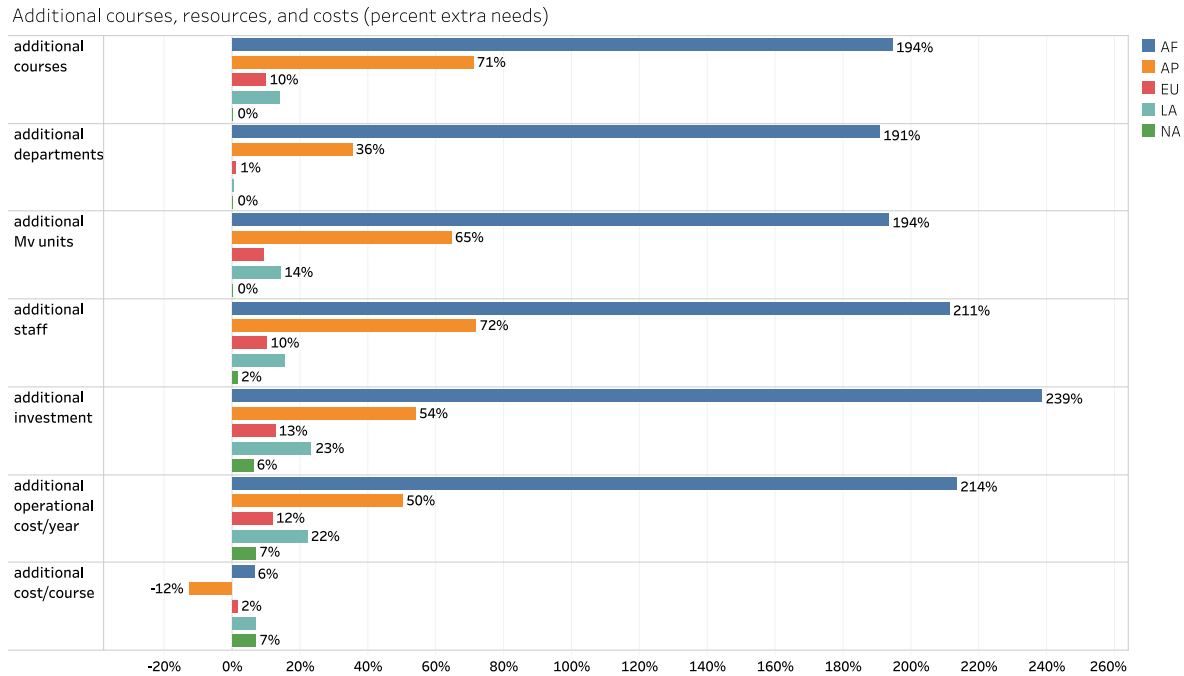


Fig 3. Additional courses, resources and costs (percentage extra needs). AF, Africa; AP, Asia Pacific; EU, Europe; LA, Latin America; NA, North America.

2.6 between the highest and lowest province or territory [28]. Even larger spreads can be seen in the Asia Pacific region, where variations for some of the large countries range between US\$60 070 for Australia and US\$1590 for India [29].

Whereas in Asia Pacific and Latin America the four different income levels are represented, this is not the case for Africa, where there are no HICs, or for Europe, where LICs are non-existent. The exceptional situation of North America only constituting HICs has already been discussed. Overall, the weighted average GNI/capita in Africa is three times lower than in Asia Pacific, five times lower than in Latin America and represents only 8.1% and 3.8%, respectively, of the GNI/capita in Europe and North America. On top of this, even if the GNI/capita has been clearly defined by income level, it should be noted that the distribution of wealth among the different countries of a geographic region may be quite inhomogeneous, with variable average GNI/capita as a result. As an example, the weighted average GNI/capita in HICs of Latin America is less than 40% of that in Asia Pacific and Europe and 27% of that in North America.

This large worldwide variability in wealth translates into variations in available resources for radiotherapy, as has been highlighted in the report of the GTFRC [2]. This kind of variability has also been observed before in various regions of the world. In Europe, for example, the HERO project described the large variation in available staff [7] and equipment [8] per million inhabitants. Moreover, activity levels, such as annual courses per machine or personnel type, were found to be inversely related to the country's wealth and a corresponding clustering of resources according to GNI/capita was found [9]. Recent reports from

the IAEA have indicated the actual status of radiotherapy resources in Africa and more globally in LMICs. Here too, large inter-country variations were observed [4,12].

Where do we Need Additional Resources and What are the Foreseeable Investments?

The additional resources projected in the calculations – in the order of magnitude of 200% – show that relatively Africa has the greatest needs, with a present capacity of 34% of their optimal needs (Table 1, Figure 3). Europe and Latin America are relatively close (within 12%) in their needs, whereas North America has almost twice the capability compared with what they actually need based on the calculation methodology of this report. Overall, there is a reasonably good alignment between the additional courses needed per region and the capital resources, especially the number of linacs. However, in spite of the assumption made in our model, where personnel requirements were aligned to the capital resources, our data show that the relative staffing needs do not exactly track with the machine capacity. For example, although Africa is in need of more than double their present staff, in line with the departmental and equipment needs, North America shows a need of an additional 2% in its staff, regardless of the fact that it has double the capacity in terms of available machines. This can be explained by the projected technological upgrades, differing between LMICs and HICs. As a consequence, North America is still assumed to require an adjustment in staffing levels, especially for medical physicists.

This fine-tuning of the needs to the assumed complexity of the treatments, hence technological capability of the

equipment and related specialised personnel required, is unique for the activity-based approach used in this model. This methodology was first adopted in the report of the GTFRC [2], yet all other previous publications estimating the needs of radiotherapy capital and/or personnel resources used more simple computations relying on an average throughput of treatment courses per year, per linac or per radiotherapy professional [5,6,10,12,30]. Seeing the quickly evolving radiotherapy landscape, in terms of treatment techniques as well as fractionation schedules, approaches such as the one presented, taking into account these variables, may provide more accurate estimates.

The results of Table 1 and Figure 2 show regional averages. However, additional investment may be more dependent on the income level of the specific country than on the GNI group or the geographic region. This is clear in Asia Pacific: overall, this is the region with the highest absolute investments needed, in line with its high population density and the ensuing cancer incidence and additional radiotherapy treatments indicated. Yet, in this geographic region there are huge disparities in radiotherapy coverage, varying from countries with no radiotherapy availability to countries with optimal access, as shown in the GTFRC report [2]. As an example, one can look at the differences between countries like Australia, India and Afghanistan, with the former having adequate radiotherapy coverage and the second between 40% and 60%, both assuming 12 h of operation daily, whereas the latter had no radiotherapy at the time of the report [2].

Ongoing Operating and Treatment Costs

Once the additional resources to generate new capacity have been defined, the ongoing operating costs need to be maintained, both to treat patients and to maintain the infrastructure. Although the *Lancet Oncology* report [2] indicated that the percentile importance of capital and human resources does vary by income regions – for HICs, total operating costs were divided between equipment (30%), facilities (6%) and salaries (64%), whereas in LICs these were 81%, 9% and 10%, respectively – this has less of an impact on the total additional operating costs, as calculated at present. Indeed, the additional operational costs in all world regions align closely with the additional investment (Figure 3). As shown in Figure 3, in regions where personnel costs on average are very low, especially in Africa and to a lesser extent in Asia Pacific, this translates into a slightly lower incremental operational cost in comparison with the investment. Thus, the challenges are not only to generate the funding for capital and training costs, but also to maintain operational capability. These challenges have a somewhat different emphasis in different income settings.

The intra-regional disparities are further exemplified when comparing these results with the results of the GTFRC report [2]. From GTFRC, the HIC operating cost per fraction is US\$235, whereas the similar result for North America from this study is US\$363 (Table 1, with cost per course divided by 19.4 fractions). The reason for the large difference is due to North America having a utilisation rate

of 53% for linacs in a scenario of 12 working hours per day, which increases the impact of maintenance and amortisation costs in the annual operational costs. Africa being largely an L-MIC region has a cost/fraction of US\$67 in this study compared with the US\$60 and US\$65 for LIC and L-MIC in the GTFRC report.

Turning to the actual cost per treatment course, there are limited data to compare these results with previous reports. Data for lower income settings are sparse, only cover the treatment delivery component and are now out-dated [17]. There are some data available for Belgium, an HIC in Europe, where the costs have been computed with a similar TD-ABC approach at the departmental level. In a report of the Belgian Health Care Knowledge Centre, where the treatment costs of 10 operational departments were analysed in 2012, the average treatment cost amounted at €4209 (US\$5472) [30]. In a single institution exercise, analysing treatment costs after the introduction of intensity-modulated radiotherapy, a similar cost of €3656 (US\$4753) was calculated in 2009 [31]. Based on these limited comparative data, using a similar calculation method, the costs calculated in this report for the Europe region seem to be valid.

Our data provide a picture of investment, operational and radiotherapy costs per treatment in the various regions of the world, using TD-ABC. Resource cost data calculated with conventional cost-accounting models such TD-ABC are to date scarce and are mostly focusing on costs at the departmental level [16]. In view of the observed variation in the average GNI/capita in the different countries constituting the income levels per world region, further cost analyses at the country level would be welcomed to provide more refined insight and allow benchmarking among countries.

The Bigger Picture

In HIC environments, the healthcare costs can be as much as 8.4% (UK in 2007) to 18% (USA in 2009) of a country's gross domestic product [32]. Cancer consumes about 5–10% of the global healthcare budget, of which radiotherapy only consumes about 5% [32–34]; thus, radiotherapy consumes about 0.5–1% of the total healthcare budget. In the 28 member states of the European Union, the average healthcare expenses of cancer were equivalent to US\$114 per citizen, but varied substantially from US\$18 per person in Bulgaria to US\$205 per person in Luxembourg [34]. Based on data obtained in our model, the cost per capita related to radiotherapy in the 49 European countries considered in this report, amounted to US\$7.36 on average, and more specifically to US\$11.86 in HICs, US\$2.02 in U-MICs and US\$1.25 in L-MICs. Although this type of data has not been reported for the other geographic regions in the world, the consistency found for our European data with the data from Luengo-Fernandez *et al.* [34] allow us at least to make some assumption regarding the other regions: the average cost for radiotherapy spent per capita based on our calculations was US\$0.53 for Africa, US\$1.70 for Asia Pacific, US\$1.98 for Latin America and US\$18.80 for North America.

Certainly for HICs, the cost of radiotherapy is a very small fraction of the total healthcare budget. Recognition of this low cost is significant considering that about 20–25% of the population is expected to go through radiation treatment at some point in their lives.

Summary

Reviews of the cost of healthcare are often carried out based on geographic regions of the world, such as Africa, Asia Pacific, Europe, Latin America and North America. Furthermore, countries are often defined by their income levels based on World Bank definitions of HIC, U-MIC, L-MIC, LIC.

This analysis has described the actual status and the present needs and costs to provide full access to radiotherapy globally, with a focus on the geographic regions. Our data have shown that the costs – including investment as well as operational costs and cost per treatment – vary substantially by geographic region. These cost data are in line with the treatment courses and associated resources required to close the gap in radiotherapy coverage that exists to date. Actual coverage of the needs ranges from 34% in Africa to over 92% in Europe to about double the needs in North America. In line with this, proportional additional investments and operational costs are as high as more than 200% in Africa to almost none in North America.

Two world regions face a substantial challenge: Africa, as in a vast proportion of the continent radiotherapy has almost to be built up from scratch, with the related investments in human and capital resources and the subsequent challenge to maintain operational capability; and Asia Pacific, mainly due to the high population density, translating into large absolute figures in terms of radiotherapy indications, resources needed and associated costs.

As our data have highlighted it is clear that additional investment in resources and costs may be more dependent on the income level of the country than on GNI group or geographic region of the world. This should be taken into account for decision-making regarding expansion of radiotherapy services in specific countries. Further analysis on investment models and operational sustainability at the country level is needed, which should go beyond the availability of radiotherapy resources as such, yet should also encompass analysis of service distribution models, of enabling services supporting a global oncology programme and of the contextual readiness in terms of general infrastructure, finances and awareness at country level.

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