Global Access to Radiotherapy Services: Have We Made Progress During the Past Decade?

abstract

Purpose The global incidence of cancer is rising, particularly in low- and middle-income countries. Radiotherapy is an important cancer treatment in the curative and palliative setting. We aimed to estimate the global demand for and supply of radiotherapy megavoltage machines (MVMs) and assess the changes in supply and demand during the past decade.

Materials and Methods Cancer incidences for 27 cancer types in 184 countries were extracted from the International Agency for Research on Cancer GLOBOCAN database. The Collaboration for Cancer Outcomes Research and Evaluation radiotherapy utilization rate (RTU) model was used to estimate the number of patients in each country with an indication for radiotherapy for each cancer type and estimate the demand for MVMs. The radiotherapy supply data were accessed from Directory of Radiotherapy Centres database maintained by the International Atomic Energy Agency.

Results RTU varied by country, from 32% in Mongolia to 59% in Comoros. The average optimal world RTU was 50%, equating to 7 million people in 2012 who would benefit from radiotherapy. There remains a deficit of more than 7,000 machines worldwide. During the past decade, the gap between radiotherapy demand and supply has widened in low-income countries.

Conclusion RTU varies significantly between countries. Approximately half of all patients with cancer worldwide should receive radiotherapy; however, more than 2 million people are unable to access it because of a lack of MVMs. Low- and middle-income countries are particularly disadvantaged by this deficit.

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Presented at the Royal College of Radiologists Combined Scientific Meeting, Melbourne, Australia, September 6, 2014.

Authors' disclosures of potential conflicts of interest and contributions are found at the end of this article.

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INTRODUCTION

The major demographic changes worldwide are leading to considerable changes in the structure of the global population and thus to the scale of the cancer problem. The 14.1 million new cases of cancer in 2014[1] will increase to 21.6 million in 2030,[2] a projected 53% increase based solely on demographic changes. If the trends observed for the major cancers continue, however, incidence may increase by a further 1.2 million new cases per year by 2030, pushing the annual incidence to more than 23 million.[3] The increases will be proportionally greater in low- and middle-income countries (LMICs; gross national income [GNI] per person per year of ≤ $12,475 in 2012).

Radiotherapy is a vital component of a cancer care service. Radiotherapy can be used to cure cancers, either alone or in combination with systemic therapies and/or surgery. It can also be used to palliate distressing symptoms in patients with incurable disease. In terms of radiotherapy, LMICs are poorly resourced,[4] with the majority of countries in Africa having no access.[5]

In 2006, we reported on the demand for and supply of radiotherapy in LMICs.[6] Since the time of reporting, a number of changes have occurred that may affect our previous findings. GLOBOCAN, comprising up-to-date national estimates of cancer incidence, mortality, and prevalence worldwide, has been updated by the International Agency for Research on Cancer and is currently available for 2012.[1] In addition, our radiotherapy utilization rate (RTU) model has been updated to include contemporaneous evidence.[7] During the past decade, the number of radiotherapy machines available worldwide has also changed.

A recent study[8] reported on radiotherapy resource provision in LMICs and used a single RTU rate of 62.5% to estimate demand for radiotherapy for all LMICs regardless of case mix. This is higher than

other published reports. There is considerable variation in RTU between countries[7] in both the proportion of new cases with indications for radiotherapy and in the retreatment rate that will significantly affect the estimates of demand globally.

To date, there has not been a report on radiotherapy provision on all countries in the world. Nor has there been a study estimating country by country RTU according to individual case mix. It is also unclear whether there has been any improvement in access to radiotherapy services by country in the past decade after taking into account the increasing cancer incidence during that time. For these reasons, we have expanded our previous work to include high-income countries (HICs; GNI per person in 2012 > $12,475) as well as LMICs. We aimed to estimate the change in the global need for radiotherapy from 2002 to 2012. We also aimed to compare the deficit in radiotherapy service provision in 2012 to that of 2002.

MATERIALS AND METHODS

Global Cancer Distributions

The estimated number of new cases of 27 cancer sites and for the aggregated category of all cancers excluding nonmelanomatous skin cancers was extracted for 184 countries from the GLOBOCAN 2012 and 2002 online databases.[9,10] The sources of data and the methods of estimation used in GLOBOCAN have been previously described.[11] There was a difference between the incidence of cancers in the world and in the cancer incidence of the 184 countries combined. This difference in totals was included in other countries, countries for which an estimate was not available through GLOBOCAN. There was also a difference between the summed incidences of the 27 cancer subsites and all cancers excluding nonmelanomatous skin cancers. This difference was labeled as other cancers and includes other and unspecified cancers, as described elsewhere.[11]

RTU

The RTU was calculated based on methods previously reported.[12] An indication for radiotherapy was defined as a clinical situation for which radiotherapy is recommended as the treatment of choice, on the basis of evidence that it has a superior outcome compared with alternative treatment modalities and where the patient is suitable to undergo radiotherapy. Because the previous RTU had been calculated based on evidence up to 2003 only, an update of the RTU was performed to include evidence-based treatment guidelines and epidemiologic data issued by major national and international organizations during the past decade.[7] The 2003 RTU model was applied to the 2002 GLOBOCAN data and the 2013 RTU model to the 2012 GLOBOCAN data. The 2013 RTUs ranged from 0% in liver cancer to 100% in nasopharyngeal cancer. We also created a low-income stage distribution model for the sensitivity analysis to explore the effect of more advanced stages at presentation on the RTU. This model removes stage I and II presentations from the model and adjusts the proportions of other stages accordingly (Data Supplement).

Global Demand for Radiotherapy Megavoltage Machines

The number of radiotherapy megavoltage machines (MVMs) required to meet the global cancer demand was calculated by estimating that 500 courses would be performed on each MVM per year in LMIC.[13] This is the maximum recommended by the International Atomic Energy Agency. A megavoltage machine was defined as either a linear accelerator or Cobalt-60 machine. Given the likely higher complexity of treatments in HIC,[14] 400 courses per MVM per year were estimated for these countries. Of these courses, 10% were assumed to be for non-notifiable cancers (including nonmelanomatous skin cancers), leaving 450 and 360 courses per year, respectively, for the treatment of notifiable cancers. We attributed 25% of these courses in HICs to retreatments, on the basis of previous published data.[15] We assumed a lower retreatment rate of 10% in LMICs. Therefore, each MVM was assumed to treat 409 new patients per year in LMICs and 288 new patients per year in HICs. A sensitivity analysis was performed to test the assumptions of workload using a range of 350 to 450 new patients per year in LMICs and 250 to 350 new patients per year in HICs.

Global Application of RTU and Cases

The RTUs for each of the individual 28 cancer types, including others, was applied to the corresponding number of cases in each country. The sum of these formed estimates of the number of cancer cases in each country that would require radiotherapy sometime during their cancer treatment. The RTU per individual country was calculated by dividing the total number of patients requiring radiotherapy in each country by the total number of new cancer cases in that country. The 2003 RTU was applied to the 2002 GLOBOCAN incidence data, and the 2013 RTU applied to the 2012 GLOBOCAN data.

Global MVM Supply

Data on machine numbers were accessed from the Directory of Radiotherapy Centres[16] (DIRAC) registry of worldwide radiotherapy facilities, maintained by International Atomic Energy Agency. The methods on DIRAC data collection have been previously published.[17] We used 2004 and 2013 data. In 2013, data were reported from 193 countries. There were 33 countries that reported data in 2013 but did not report data in 2004.

Income Classification

Countries were divided into income groups using the World Bank 2012 fiscal year classifications.[18] This classifies countries into low-income countries (LICs), which had GNI per capita of ≤ $1,025 in 2012; lower-middle-income countries (LO-MIC) > $1,025 but ≤ $4,035; upper-middle-income countries (UP-MICs) > $4,035; and HICs > $12,475.

RESULTS

Cancer Incidence and Existing MVM Numbers

The number of new cases of cancer in 2012 globally was 14.1 million, compared with 10.9 million in 2002, an increase of 29% in 10 years. Table 1 lists the cancer incidences, RTUs, and number of patients requiring radiotherapy in each income group. The proportions of cancer cases attributed to each of the income groups was stable from 2002 and 2012.

Eleven countries/territories included in the 2012 GLOBOCAN database were not present in the 2002 GLOBOCAN database. These countries included Montenegro, South Sudan, and State of Palestine, included as individual countries in our study. Data from eight smaller countries/territories without 2002 GLOBOCAN data were included in others: French Guadeloupe, La Reunion, Martinique, New Caledonia, Maldives, French Guyana, Timor-Leste,

and Western Sahara. The last five countries were reported to DIRAC as having no radiotherapy machines.

Thirteen countries were included in the DIRAC database but did not have available GLOBOCAN data. Countries/territories not included in the analysis are Antigua, Falklands, Greenland, Grenada, Holy See, Lichtenstein, Marshall Islands, and Seychelles, all of which do not have any MVMs. Kosovo, Taiwan, Monaco, and Curacao had DIRAC data for 2013 and were included in the other countries category. There were machine data for 2004 for Hong Kong but not 2013, so the 2004 machine total was added to China.

Three countries had GLOBOCAN incidence data but were not found in the DIRAC database: Vanuatu, French Polynesia, and Comoros; these were also moved to the others category. This left 173 countries whose individual demand and supply were calculated.

Demand for Radiotherapy

On the basis of the 2004 Collaboration for Cancer Outcomes Research and Evaluation (CCORE) RTU model, the global RTU was 56% and ranged from 55% in LICs to 58% in LO-MICs. Using the updated CCORE model for 2013, the global RTU was 50% and ranged from 47% in UP-MICs to 53% in LO-MICs. RTU for individual countries ranged from 32% in Mongolia to 59% in Comoros (Data Supplement). The sensitivity analysis performed with a low-income RTU model is shown in the Data Supplement. The RTU would increase in each LIC with a low-income model by a median of 4% (range, 0% to 9%). Given the small increase, we elected not to use the low-income model for our final calculations.

The estimated number of new patients with cancer with an indication for radiotherapy in 2002 was 6.1 million and 7.0 million in 2012. The proportions

Table 1 – Estimated Cancer Cases Requiring Radiotherapy in 2012 *v* 2002

Income Group	New Cases of Cancer		RTU (%)		RT Cases		Increase in RT Cases
	2002	2012	2002	2012	2002	2012	
LIC	575,555	666,616	55	52	319,044	344,750	25,706
LO-MIC	1,867,015	2,365,146	58	53	1,080,094	1,262,807	182,713
UP-MIC	3,517,143	4,923,563	56	48	1,953,226	2,373,918	420,692
HIC	4,866,254	6,021,308	56	50	2,709,310	2,989,253	279,943
Other	36,529	113,516	60	47	22,016	53,665	31,649
World	10,862,496	14,090,149	56	50	6,083,690	7,024,393	940,703

Abbreviations: HIC, high-income country; LIC, low-income country; LO-MIC, lower-middle-income country; RT cases, new cancer cases diagnosed that year that have an indication for radiotherapy; RTU, radiotherapy utilization rate; UP-MIC, upper-middle-income country.

of these patients attributed to each of the income groups were also stable from 2002 to 2012.

The global demand and supply of MVM is listed in Table 2. The estimated demand was 17,656 MVMs in 2002 and 20,243 MVMs in 2012, an increase of 2,587 (15%). The greatest increase in MVM demand was in UMICs, with an increase of 1,028 MVMs required. The demand and supply of MVMs in each individual country is shown in the Data Supplement. Nine countries did not have a demand for MVMs in 2002. Five of these were because of missing 2002 GLOBOCAN data, and four others (Guam, Samoa, Belize, and Cape Verde) had low cancer numbers. In 2013, four countries did not individually have a demand for an MVM because of the low incidence of cancer: Samoa, Belize, Cape Verde, and The Gambia.

The total number of MVMs reported to DIRAC was 7,039 machines in 2004 and 13,136 in 2013. There were an additional 6,097 machines reported in 2013, mostly in HICs. The United States had the highest absolute increase of 1,660 machines (72%).

In 2004 there were 49 countries reported as having no MVMs. In 2013, 35 of these countries were still reported as having no services. Fourteen countries were reported to have acquired machines by 2013. There were 20 countries that had a decrease in the number of reported machines from 2004 to 2013. This included four countries reported as having MVMs in 2003 but having none in 2013: Republic of Congo, Madagascar, Mozambique, and Liberia. South Sudan had no machines in 2013 and was not recognized as a country in 2004. Therefore, a total of 36 (21%) of the 169 countries with a demand for radiotherapy reported having no MVMs available in 2013 (Table 3). Twenty-two of these were LICs, corresponding to 65% of all LICs with no radiotherapy services in 2013.

In 2002, 11 countries with a demand for radiotherapy had this demand met, five in UP-MICs and six in HICs. The global deficit of radiotherapy provision in 2012 is seen in Figure 1. In 2012 there were 16 countries with a demand for radiotherapy that had their demand met. Two were LO-MICs (Honduras and Guyana); seven were UP-MICs (Suriname, Mauritius, Gabon, Jordan, Lebanon, Venezuela, and Turkey). Seven were HICs (Oman, Barbados, Kuwait, Qatar, Saudi Arabia, United Arab Emirates, and the United States). In the United States, supply exceeded demand by an estimated 1,060 MVMs. There were no LICs that met demand in either 2002 or 2012 (except The Gambia, where demand was less than one MVM).

There were modest improvements in the number of patients per MVM in all income groups from 2002 to 2012. However, none of the income groups meet the optimal new patients/MVM load in 2012, with 431 patients/MVM in HICs and 3,769/MVM in LICs. The inverse relationship between GNI per person of each country and the number of patients per MVM is demonstrated in Figure 2.

When comparing the gap in radiotherapy services between optimal and actual supply from 2002 to 2012, there was a small global decrease by 3,509 MVMs. However, 77% of this decrease occurred in HICs. The magnitude of the gap in individual countries is shown in Figure 3. The gap increased in LICs and LO-MICs, and there was a modest decrease in the gap in UP-MICs.

There remains a deficit of approximately 7,100 MVMs globally. The sensitivity analysis for the world demand and supply of MVM, by adjusting the number of new patients per MVM per year, is shown in the Data Supplement. Even at a best-case scenario, there is a deficit of 4,300 MVMs globally.

Table 2 – Radiotherapy Megavoltage Machine Supply and Demand

Income Group	Demand for MVMs			Supply of MVMs			Gap Between Demand and Supply			RT Patients per MVM per Year	
	2002	2012	Difference Between 2002 and 2012	2004	2013	Difference	2002	2012	Difference Between 2002 and 2012	2002	2012
Low	780	843	63	41	62	21	−739	−781	42	5,844	3,769
Low middle	2,640	3,087	447	576	1,021	445	−2,064	−2,066	2	1,757	1,085
Upper middle	4,775	5,803	1,028	1,260	3,146	1,886	−3,515	−2,657	−858	789	616
High	9,407	10,379	972	5,158	8,842	3,684	−4,249	−1,537	−2,712	492	431
Others	54	131	77	4	65	61	−50	−66	16	5,504	826
World	17,656	20,243	2,587	7,039	13,136	6,097	−10,617	−7,108	−3,509	864	535

Abbreviations: MVM, radiotherapy megavoltage machine; RT patients, new patients with cancer with an indication for radiotherapy.

Table 3 – Countries with a Demand for Radiotherapy but No Radiotherapy Services Available

Country	Region	Income Group	RT Patients
Afghanistan	Asia	L	10,796
Bahrain	Asia	H	472
Benin	Africa	L	2,578
Bhutan	Asia	LM	214
Brunei	Asia	H	272
Burkina Faso	Africa	L	3,700
Burundi	Africa	L	3,806
Central African Republic	Africa	L	1,482
Chad	Africa	L	3,288
Congo, Democratic Republic of	Africa	L	18,600
Congo, Republic of	Africa	LM	1,107
Cote d'Ivoire	Africa	LM	5,569
Djibouti	Africa	LM	307
Equatorial Guinea	Africa	H	274
Eritrea	Africa	L	1,601
Fiji	Oceania	UM	591
Guam	Oceania	H	185
Guinea	Africa	L	2,442
Guinea-Bissau	Africa	L	402
Haiti	Caribbean	L	4,091
Lao PDR	Asia	LM	2,080
Lesotho	Africa	LM	662
Liberia	Africa	L	958
Madagascar	Africa	L	10,042
Malawi	Africa	L	7,589
Mali	Africa	L	4,859
Mozambique	Africa	L	10,308
Niger	Africa	L	2,838
Rwanda	Africa	L	3,886
Sierra Leone	Africa	L	1,322
Solomon Islands	Oceania	LM	211
Somalia	Africa	L	4,105
South Sudan	Africa	LM	4,279
Swaziland	Africa	LM	382
Togo	Africa	L	1,776
Turkmenistan	Asia	UM	3,283
Total (N = 36)			120,357

NOTE. We did not include 16 other countries that also had no radiotherapy services available in 2013 because they either had missing data or were included in the others category (n = 12), or because individually, they did not have enough RT patients to translate into a demand for radiotherapy (n = 4); however, collectively, they would result in a demand.

Abbreviations: H, high; L, low; LM, lower middle; RT patients, patients diagnosed with cancer in 2012 with an indication for radiotherapy; UM upper middle.

DISCUSSION

RTU varies significantly between countries. We estimate that there is nearly a two-fold difference in the demand for radiotherapy in countries around the world. It is therefore necessary to estimate demand for radiotherapy on a country-by-country basis, taking into account the difference in case mix. It is likely that retreatment rates also vary significantly because of these differences in case mix. Our findings demonstrate a substantial shortage of radiotherapy services globally. There has been only a modest increase in MVMs over the last decade, and the majority of countries across all income groups remain underserviced. LMICs are markedly disadvantaged in terms of radiotherapy services. The largest gap in radiotherapy services is found in UP-MICs, because this is where the greatest number of cancer cases occurs. In LICs and LO-MICs, the small increase in MVMs in the last decade has lagged behind the greater increase in cancer numbers, leading to an increase in the gap in services. The majority of LICs have no radiotherapy services available at all.

Our RTU estimates are conservative because they were not adjusted for the different distributions of stages at cancer presentation in each country. Patients from LMICs are likely to present with more advanced disease,[19] and this is likely to result in higher demand for radiotherapy compared with HICs. For example, a large population-based study[20] found that 70% of patients with cervical cancer in four middle-income countries presented with regional or distant disease, compared with 50% in our CCORE model. If we adjusted the CCORE-RTU model for differences in stage at presentation, the RTU for cervical cancer would be 85% in middle-income countries, compared with 71% in Australia. There are similar effects in other tumor groups, which we have demonstrated when performing sensitivity analysis with the low-income model. The RTU would increase in all LICs by a small amount if we assumed no patients presented with early-stage disease. Given that data on stage at presentation in LMICs are not available in the literature for the 27 cancer subtypes used in our model, we did not alter the model for this study. Another factor that could increase the RTU in LMICs is a lack of access to specialized surgery for cancers where surgery is normally indicated instead of radiotherapy, such as early-stage cervix cancer or lung cancer.

The limitations of our study relate to the quality of the available data. Details of the data sources used in GLOBOCAN to compile the national estimates are provided online.[21] Data from LMICs tend to be
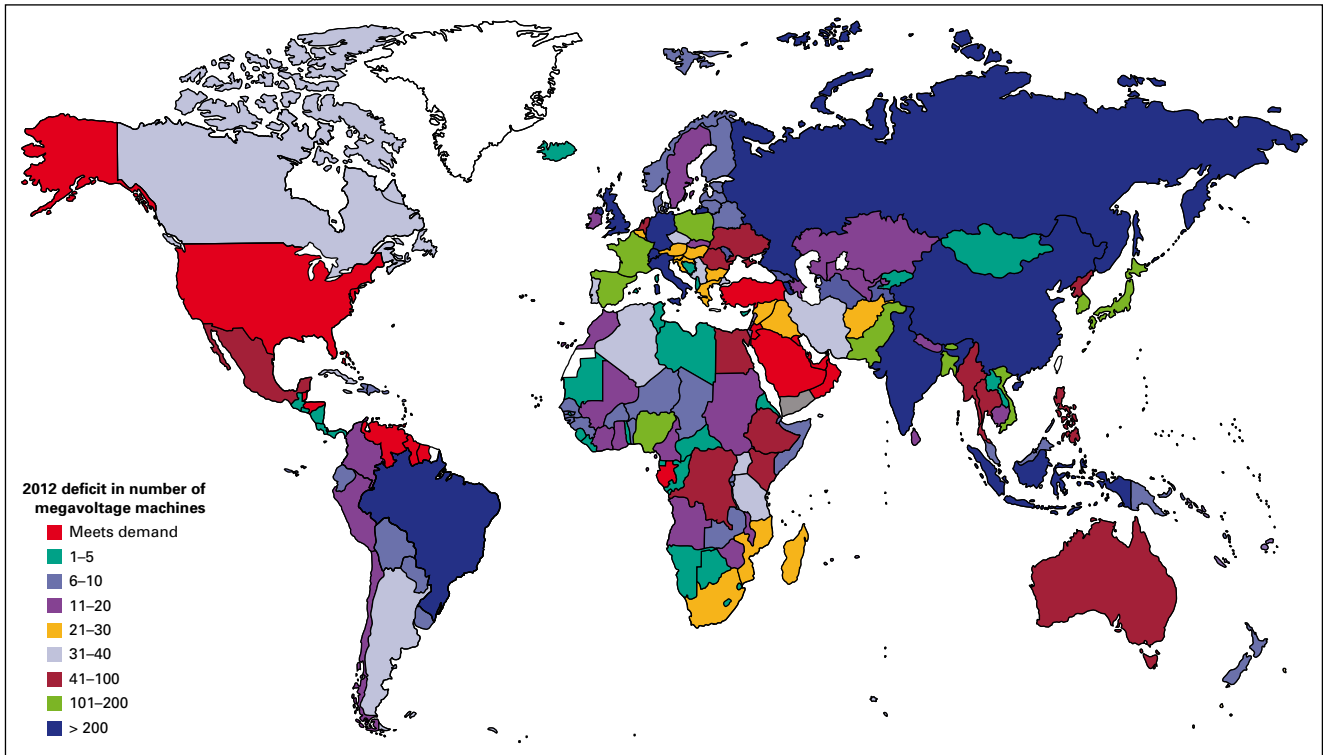
Fig 1 –

Difference between demand and supply of megavoltage radiotherapy machines in the countries of the world.

of limited availability and lesser quality than their HIC counterparts. Some degree of caution is needed in interpreting the changing incidence from 2002 to 2012, given the estimates derived are linked to expanding data availability over time. The availability of machine data to DIRAC also varies between countries, with most self-reported from direct online update, national databases, and professional societies. Given the possibility of under-reporting, detailed country and regional plans for radiotherapy

service should include an accurate census of radiotherapy resources rather than rely on the DIRAC.[22] Other radiotherapy technologies such as brachytherapy machines have a role in LMICs but have not been included in this analysis and will be the subject of future work using our brachytherapy model.[23]

Datta et al[8] recently estimated the radiotherapy resources available in 84 LMICs and found that 80 of these countries did not meet the estimated

Fig 2 –

Megavoltage machines per 1,000 radiotherapy patients versus gross national income (GNI) per person in 2012. MVM, radiotherapy megavoltage machines; USD, US dollars.
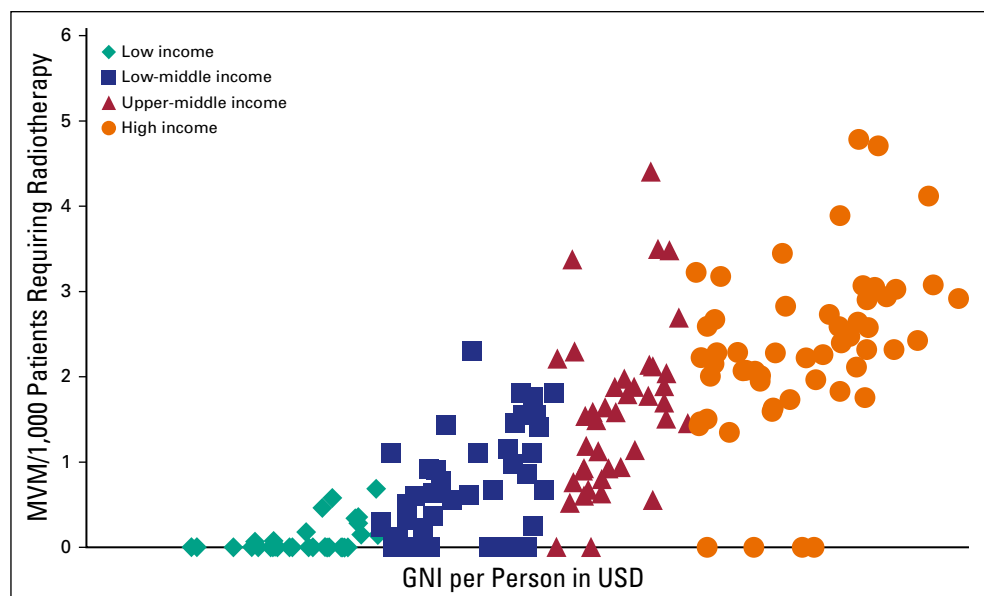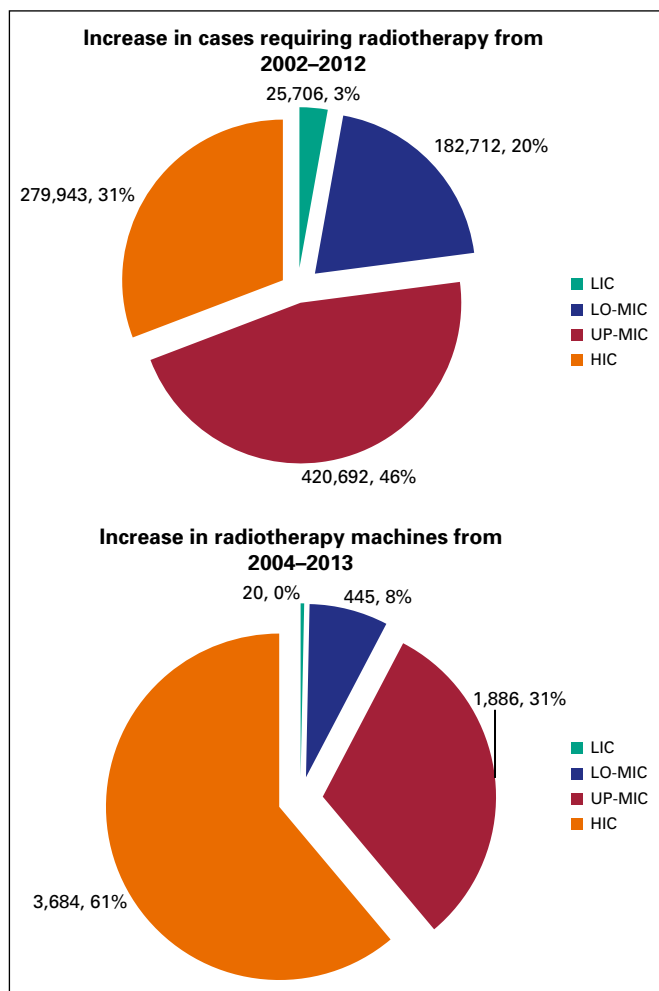
Fig 3 –
These figures demonstrate that although the majority of the increase in cancer cases requiring radiotherapy (RT) has occurred in low- and middle-income countries, the increase in RT megavoltage machines has been predominantly in high-income countries (HICs). LIC, low-income country; LO-MIC, lower-middle-income country; UP-MIC, upper-middle-income country.

demand. As part of the methodology, the authors applied a single 62.5% RTU rate for all LMIC countries: 50% for new patients and adding a further 12.5% for retreatment. Although the conclusions of our studies in regard to LMIC radiotherapy provision are similar, our absolute MVM deficit estimates are more accurate because we calculated the RTU per country on the basis of each country's unique cancer case mix.

There are a number of barriers to meeting the radiotherapy demand globally. Competing issues

in many countries, such as poverty, political instability and/or corruption, have led to cancer services sitting low on governments' priorities. In the past, radiotherapy has often been viewed as costly, despite evidence to the contrary.[24,25] There are countries that have recently undergone rapid economic and political change and many more that are currently, or soon to be, in the midst of such change. For these countries, the need for radiotherapy services is pressing. The recent Global Taskforce in Radiotherapy for Cancer Control Lancet Commission paper presented a compelling investment case for radiotherapy provision globally, outlining potential economic benefits to countries in addition to lives saved.[26] Industry provision of low-cost MVMs, access to universal health care, and a diagonal approach[27] to cancer planning will be vital in achieving equitable access.

Education is a vital component of addressing the issue of radiotherapy shortage. Radiotherapy machines form just one component of the radiotherapy service; trained, specialized staff is required to ensure safe and accurate delivery of radiotherapy. Initiatives that may assist include global partnerships[28,29] and education programs.[30] Education of the general community also remains paramount. In some cultures, there is a fear of cancer diagnosis and treatment and the fallacy that cancer is incurable.[31] Recent advocacy platforms globalrt.org[32] and targetingcancer.com.au[33] are important in promoting awareness of the need for equitable access to radiotherapy globally.

The significant shortage of global radiotherapy services is just one part of the global cancer crisis we currently face. Cancer diagnosis and prevention, palliative care programs, and access to other treatment modalities such as specialized surgery and chemotherapy must also be addressed. Global cancer research should be made a priority. We, with others,[25,27,34] call on our colleagues in oncology, global health, and policy to rise to this challenge.

AUTHOR CONTRIBUTIONS
Conception and design: Mei Ling Yap, Michael Barton
Collection and assembly of data: All authors
Data analysis and interpretation: All authors
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No relationship to disclose

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