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GLOBAL HEALTH

Radiation Therapy Infrastructure and Human Resources in Low- and Middle-Income Countries: Present Status and Projections for 2020

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Summary

Availability of radiation therapy infrastructure and staffing for cancer treatment in low- and middle-income countries (LMICs) is one of the crucial global health care issues. Presently, one-third of the global teletherapy units exist in LMICs to treat nearly 60% of the world's cancer patients. A systematic assessment of the present gaps in radiation therapy capacity and those needed by 2020 in these LMICs has been conducted. Twelve pragmatic steps to address this crisis are proposed.

Purpose: Radiation therapy, a key component of cancer management, is required in more than half of new cancer patients, particularly in low- and middle-income countries (LMICs). The projected rise in cancer incidence over the next decades in LMICs will result in an increasing demand for radiation therapy services. Considering the present cancer incidence and that projected for 2020 (as listed in GLOBOCAN), we evaluated the current and anticipated needs for radiation therapy infrastructure and staffing by 2020 for each of the LMICs.

Methods and Materials: Based on World Bank classification, 139 countries fall in the category of LMICs. Details of teletherapy, radiation oncologists, medical physicists, and radiation therapy technologists were available for 84 LMICs from the International Atomic Energy Agency—Directory of Radiotherapy Centres (IAEA-DIRAC) database. Present requirements and those for 2020 were estimated according to recommendations from the IAEA and European Society for Radiotherapy & Oncology (ESTRO-QUARTS).

Results: Only 4 of the 139 LMICs have the requisite number of teletherapy units, and 55 (39.5%) have no radiation therapy facilities at present. Patient access to radiation therapy in the remaining 80 LMICs ranges from 2.3% to 98.8% (median: 36.7%). By 2020, these 84 LMICs would additionally need 9169 teletherapy units, 12,149 radiation oncologists, 9915 medical physicists, and 29,140 radiation therapy technologists. Moreover, de novo radiation therapy facilities would have to be considered for those with no services.

Conclusions: Twelve pragmatic steps are proposed for consideration at national and international levels to narrow the gap in radiation therapy access. Multipronged and

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coordinated action from all national and international stakeholders is required to develop realistic strategies to curb this impending global crisis.

Introduction

Cancer has been designated the second most important cause of death among noncommunicable diseases, and its incidence is expected to rise in the coming decades (1). According to the World Health Organization (WHO), the cancer incidence between 2008 and 2030 is projected to rise by 82%, 70%, and 58% in low, low-middle, and upper-middle income countries, respectively, compared with 40% in high-income countries. Moreover, two-thirds of the cases are expected in low- and middle-income countries (LMICs) (2).

Radiation therapy is estimated to be required in 45% to 55% of newly diagnosed cases (3). Of those cured, 40% are by radiation therapy alone or by combination with other modalities (4). The 66th United Nations (UN) General Assembly has listed cancer as a part of "a rising epidemic" of the noncommunicable diseases and has noted the inadequate radiation therapy services in developing countries (5). A number of authors have examined radiation therapy services in different continents, and the severe gap has been a major concern (6-10). At various international levels, efforts are underway to confront the impending "silent crisis" faced primarily by LMICs (11, 12).

A comprehensive analysis of present radiation therapy infrastructure and staffing in each LMIC and their projected needs for 2020 was undertaken. All estimates are based on data retrieved from public domain websites of the concerned UN agencies. Furthermore, 12 pragmatic steps that could be considered at various levels to address this global crisis are proposed.

Methods and Materials

Data sources

LMICs were classified according to the criteria adopted by the World Bank (gross national income [GNI] per capita $\leq$US $12,615) (13). Cancer incidence rates for "all cancers excluding non-melanoma cancers" for each LMIC were obtained from the GLOBOCAN, International Agency for Research on Cancer (IARC) (14). The present cancer incidence refers to 2012, whereas predicted incidence rates for 2020 were considered to compute the projected requirements for that year. Regarding radiation therapy infrastructure and human resources, the present availability of teletherapy and personnel (ie, radiation oncologists, medical physicists, and radiation therapy technologists) were taken from the Directory of Radiotherapy Centres (DIRAC) of the International Atomic Energy Agency (IAEA) (Supplementary Table S1) (15). All calculations presented below are based on information posted at GLOBOCAN and IAEA-DIRAC as of Jan 18, 2014. The geographical distributions of the LMICs and their populations in 2012 were derived from the UN Population Division (16).

Guidelines used for computation of radiation therapy capacity requirements

Computation of the requirements of radiation therapy units and staffing was based on recommendations from the European Society for Radiotherapy & Oncology (ESTRO) in its ESTRO-QUARTS [Quantification of Radiation Therapy Infrastructure and Staffing Needs] project and the IAEA (Table 1) (3, 17). In accordance with ESTRO-QUARTS and IAEA guidelines, it was assumed that 62.5% of all cancer patients in LMICs would require radiation therapy (50% of new cancer patients plus 25% of this number for reirradiation) (9, 18, 19). Estimation for brachytherapy has not been undertaken as specific guidelines were not available in ESTRO-QUARTS or in IAEA publications.

Results

Data availability for computation of radiation therapy facilities in LMICs

A total of 139 countries, whose GNI/capita data were available, were grouped as LMICs (13). Of these, 110 are member states of the IAEA (20). Radiation therapy status and cancer incidence were obtained from DIRAC and GLOBOCAN for 84 countries, 3 of which are not IAEA member states (DPR Korea, Guyana, and Suriname). In the remaining 55 countries, 29 IAEA member states had no radiation therapy facilities listed in DIRAC. No information on radiation therapy status was accessible for another 26 countries (Fig. 1). Thus, a total of 55 LMICs representing a population of 358 million presently lack any access to radiation therapy.

The cancer incidence for 2012 was available in 125 of these 139 countries in GLOBOCAN (14). Thus, 56.4% of the world's total cancer patients had access to only 31.7% of the global teletherapy units (Supplementary Fig. S1). It was evident that LMICs have 0.71 teletherapy units/million population, in contrast to 7.62 teletherapy units/million population for high-income countries. This assumes further significance because by 2020 the cancer incidence relative to 2012 is expected to increase by approximately 23.9% in LMICs.

Present radiation therapy capacity in LMICs with existing teletherapy facilities

Present and future radiation therapy needs were computed for the 84 countries whose details of radiation therapy

Table 1 Present status of radiation therapy infrastructure and staffing in LMICs, with projected needs for 2020 according to Directory of Radiotherapy Centres (15)

Infrastructure and personnel	No. of units or personnel/no. of patients (or range)*	No. of units or personnel/no. of patients used in this analysis	Present status (n = 84 countries)		Required by 2020 (n = 84 countries)	
			Existing/required	% of present deficit†	Total needed	% of additional required‡
Teletherapy units	1/450 patients	1/450 patients	4138/10,735	61.4%	13,307	+221.6%
Radiation oncologists	1/250-300 patients	1/250 patients	11,803/19,323	38.9%	23,952	+102.9%
Medical physicists	1/450-500 patients (3) 1/300-400 patients (17)	1/450 patients	3392/10,735	68.4%	13,307	+292.3%
Radiotherapy technologists	1/100-150 patients	1/150 patients	10,780/32,204	66.5%	39,920	+270.3%

Abbreviation: LMICs = low- and middle-income countries.

Values shown for teletherapy and staffing have been rounded to the nearest integer.

* Standards are based on guidelines from European Society for Radiotherapy & Oncology Quantification of Radiation Therapy Infrastructure and Staffing Needs (3) and International Atomic Energy Agency (17).

† Percentage of present deficit (according to guidelines) = [(number presently required − number presently available)/(number presently required)] × 100.

‡ Percentage of additional required (according to guidelines) = [(number required in 2020 − number presently available)/number presently available] × 100.

infrastructure and staffing were available in DIRAC. Presently, a deficit of 61.4%, 38.9%, 68.4%, and 66.5% was observed in teletherapy, radiation oncologists, medical physicists, and radiation therapy technologists, respectively (Table 1). Only 4 countries (Jordan, Lebanon, Suriname, and Venezuela) fulfill their teletherapy requirements. In the remaining 80 LMICs, 2.3% to 98.8% (median: 36.7%) of cancer patients have access to radiation therapy (Table 2). This was inversely related to the GNI/capita of the countries (r^2 = 0.42) (Supplementary Fig. S2). Two LMICs (China and India) have the highest teletherapy units, at 1535 and 511, respectively, among the 139 LMICs. However, they also face the burden of dealing with the highest cancer cases of 3 million and 1 million, respectively, resulting in radiation therapy access to 36.1% and 36.3%, respectively.

For the 125 countries whose cancer incidence rates were available from GLOBOCAN, a wide range in median radiation therapy accessibility was observed: 0% in Africa (range: 0%-88.6%, 52 LMICs), 31% in Asia (range: 0%-135.1%, 35 LMICs), 55.7% in Latin America and Caribbean (range: 0%-170.8%, 22 LMICs), 42% in Europe (range: 25.6%-87.2%, 10 LMICs), and 0% in Oceania (range: 0%-19.5%, 6 LMICs) (Table 2).

Projected requirements for 2020 in LMICs with teletherapy facilities

The projected number of teletherapy, radiation oncologists, medical physicists and radiation therapy technologists required by 2020 are detailed for each of the 84 countries in Table 2, and the additional demand, above the present availability, would be 9169, 12,149, 9915, and 29,140 respectively (Fig. 1 and Supplementary Fig. S3). The geographical distribution of additional teletherapy in the 84 LMICs is shown in Figure 2. Only Suriname currently has adequate teletherapy units for 2020.

Requirements in countries presently without radiation therapy facilities

Fifty-two of the 55 countries with no radiation therapy facilities are members of the UN, of which 30 are in Africa, 7 are in Asia, 6 are in Latin America and Caribbean, 1 is in Europe, and 11 are in Oceania. In 41 of these 55 countries, the cancer incidence is expected to increase by 24.5% from 2012 to 2020. Presently, approximately 0.14 million patients/year need radiation therapy, and this figure will rise to 0.17 million patients/year by 2020. To cater to this patient population, 390 teletherapy machines would be required by 2020 (Table 3). In the remaining 14 countries, no estimate could be performed because there is a lack of cancer incidence data in GLOBOCAN.

Limitations of the calculations in this study

Both GLOBOCAN and DIRAC databases are dynamic and expected to be updated periodically. GLOBOCAN estimates are for 2012 whereas recent figures could be available in each country (14). The DIRAC database is voluntary and compiles data from questionnaires circulated by the IAEA (15). To the best of our knowledge, it is the only global database accessible in public domain providing details of current radiation therapy capacity. Periodic updates to DIRAC could be made mandatory, at least for all IAEA member states, as lack of updated figures could result in inadvertent inaccuracies. Individual countries should compute their radiation therapy capacity requirements based on their updated data.

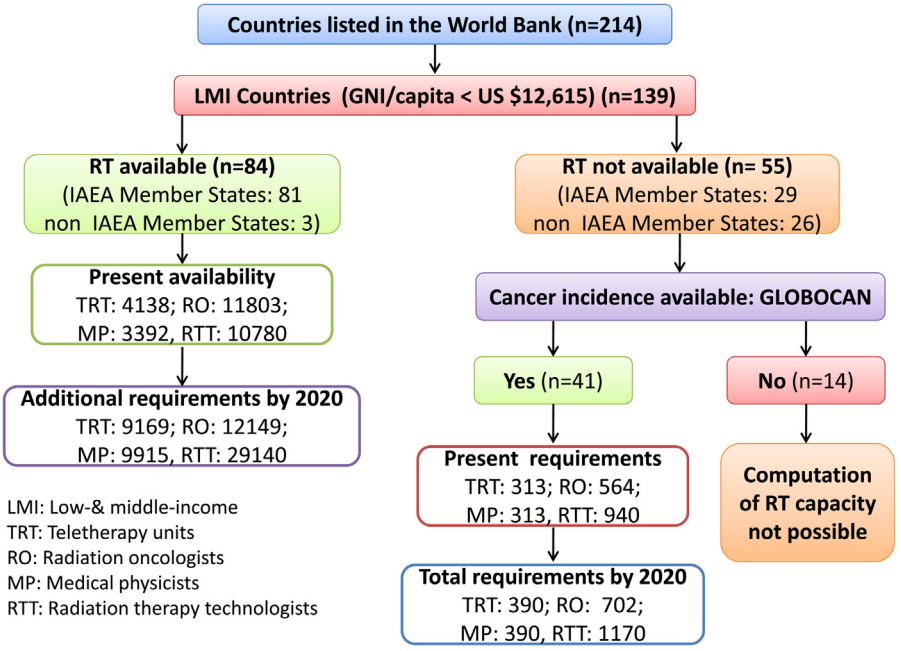

Fig. 1. Flow chart shows the inclusion of various groups of countries based on the information available from the World Bank (13), GLOBOCAN (14), and IAEA-DIRAC (15). Present availability and requirements for 2020 for each of the radiation therapy capacity components have been summarized. GLOBOCAN = Global Cancer Incidence, Mortality and Prevalence; DIRAC = Directory of Radiotherapy Centres; IAEA = International Atomic Energy Agency.

As most guidelines provide a range and a deviation of ±20% is allowed by the IAEA, especially with regard to staffing, all estimates derived in this study could be considered a working template (17).

Discussion

The inadequacy of radiation therapy facilities in LMICs has been a subject of considerable concern (5-11). Apart from a shortage of radiation therapy capacity, other major obstacles in the delivery of radiation therapy service in LMICs include lack of accessibility and affordability of treatment, shortage of nurses and support staff, inadequate training, and problems related to equipment maintenance (11).

Although it has been assumed that radiation therapy would be indicated in half of the new cancer cases, the optimal utilization rate of radiation therapy for different cancer types could vary from 0% to 100% as reported from Australia (21). Thus, it is important for each country to work out their own radiation therapy utilization rates based on types of cancers, stages, and prevalent clinical practices before estimating their present and future needs. The same would also hold true for brachytherapy.

Screening usually forms part of any cancer control program as early stage cancer has the best chance of cure. However, in LMICs with no or inadequate treatment facilities, early detection of cancers for which radiation therapy is indicated may force patients to bear the psychological trauma of living and suffering with untreated cancer. Thus, to make screening programs meaningful, they must be supported with adequate treatment facilities.

Palliative therapy is an important part of cancer care, with the objective to improve the terminal patient's quality of life. The WHO has contributed immensely to easing the suffering of cancer patients by promoting access to morphine. However, radiation therapy is one of the most cost-effective and quickest modes of sustainable pain relief in a number of situations resulting in a better quality of life. This too calls for adequate radiation therapy services, not only for curative but also for palliative therapy.

The WHO, the IARC, the IAEA through its Programme of Action for Cancer Therapy (PACT), the Union of International Cancer Control (UICC), and the International Network for Cancer Treatment and Research (INCTR) and a host of nongovernmental organizations and national bodies have been engaged in addressing this crisis. Nevertheless, the present situation requires reexamination of the strategies to evolve a coordinated effort at all levels to, at least, reduce the rising trend of this "epidemic," if not reverse it. This could in the long term reduce the need for supplementing treatment facilities, including radiation therapy.

Possible pragmatic steps

A multicompartmental but interdependent and integrated approach for countries, manufacturers, and international

Table 2 Radiation therapy infrastructure and staffing in 84 low- and middle-income countries

No.	Country	% of patients with access to RT*	Present deficit of no. of RT infrastructure and staffing†				Additional number of RT infrastructure and staffing required by 2020‡			
			TRT unit	RO	MP	RTT	TRT unit	RO	MP	RTT
1.	Albania	50.4	−5	−5	−3	−16	7	9	5	22
2.	Algeria	32.3	−36	−75	−42	−117	53	105	59	168
3.	Angola	21.0	−11	−24	−10	−35	16	32	15	48
4.	Argentina	71.3	−46	−112	−62	−130	69	154	85	200
5.	Armenia	33.1	−10	−13	−8	−38	11	14	9	40
6.	Azerbaijan	31.0	−13	−21	−14	−44	17	27	18	54
7.	Bangladesh	11.2	−151	−282	−165	−487	203	375	217	642
8.	Belarus	60.0	−18	39	9	−26	19	−38	−8	28
9.	Bolivia	38.3	−10	−17	−11	−31	14	25	15	44
10.	Bosnia-Herzegovina	87.2	−2	2	3	5	3	1	−2	0
11.	Botswana	44.0	−1	−2	−1	−1	1	2	1	1
12.	Brazil	57.6	−258	−703	−352	−970	418	992	512	1451
13.	Bulgaria	33.7	−30	−26	−23	−56	30	26	23	56
14.	Cambodia	4.7	−20	−35	−18	−52	29	51	27	80
15.	Cameroon	5.2	−18	−30	−17	−54	23	39	22	68
16.	China	36.1	−2723	−562	−3017	−7979	3808	2515	4102	11,235
17.	Colombia	69.5	−30	−92	−50	−170	63	151	83	268
18.	Costa Rica	72.4	−3	−4	1	−6	8	12	4	19
19.	Cuba	23.8	−42	−61	−26	−102	54	82	38	138
20.	Dominican Republic	54.0	−9	−25	−14	−36	14	33	19	50
21.	Ecuador	52.4	−15	−30	−16	−49	27	51	28	83
22.	Egypt	37.8	−94	−35	−55	−176	122	85	83	259
23.	El Salvador	39.9	−8	−16	−6	−18	10	19	8	24
24.	Ethiopia	2.4	−83	−149	−83	−250	108	194	108	325
25.	Georgia	35.0	−11	−5	−7	−33	12	6	8	34
26.	Ghana	13.7	−19	−35	−15	−50	23	41	19	61
27.	Guatemala	54.3	−8	−23	−13	−28	14	33	19	44
28.	Guyana	70.8	−1	−3	−1	−4	1	3	2	5
29.	Honduras	77.5	−2	−15	−7	−9	5	20	10	18
30.	Hungary	57.1	−30	−19	−21	−83	33	25	24	93
31.	India	36.3	−899	−2186	−1217	−3787	1215	2756	1533	4737
32.	Indonesia	8.7	−380	−712	−375	−1111	474	880	469	1391
33.	Iran	56.0	−52	−65	−4	−21	85	124	37	120
34.	Iraq	28.1	−26	−43	−18	−68	38	66	30	105
35.	Jamaica	37.2	−5	−11	−3	−18	7	13	5	23
36.	Jordan	124.1	2	5	26	18	2	2	−22	−6
37.	Kazakhstan	71.3	−16	89	−35	−163	23	−76	42	185
38.	Kenya	10.5	−51	−91	−48	−145	71	128	68	205
39.	Korea, DR	5.2	−73	−137	−76	−230	84	157	87	263
40.	Kyrgyzstan	37.2	−5	0	−6	−19	7	3	8	25
41.	Lebanon	135.1	4	−10	−3	3	1	20	8	14
42.	Libya	59.2	−3	−8	4	−9	6	12	−1	16
43.	Macedonia, FYR	29.5	−7	4	−4	−12	9	−1	6	16
44.	Madagascar	4.0	−24	−42	−23	−67	31	55	30	89
45.	Malaysia	78.9	−11	−88	−42	−143	27	115	57	189
46.	Mauritania	39.1	−2	−3	0	−2	3	4	1	5
47.	Mauritius	82.4	−1	−1	−1	1	2	2	2	2
48.	Mexico	61.3	−80	−158	−163	−444	141	268	224	627
49.	Moldova	29.1	−10	2	−10	−26	10	−1	10	28
50.	Mongolia	35.5	−4	−2	−2	−9	5	5	3	14
51.	Montenegro	68.1	−1	−3	−1	−5	1	4	1	5
52.	Morocco	61.7	−19	18	−15	−48	28	−1	24	77

(*continued on next page*)

Table 2 (*continued*)

No.	Country	% of patients with access to RT*	Present deficit of no. of RT infrastructure and staffing†				Additional number of RT infrastructure and staffing required by 2020‡			
			TRT unit	RO	MP	RTT	TRT unit	RO	MP	RTT
53.	Myanmar	7.9	−81	−136	−84	−252	108	184	111	332
54.	Namibia	53.7	−1	−1	−1	−1	1	2	1	1
55.	Nepal	23.0	−20	−31	−17	−57	26	41	23	74
56.	Nicaragua	28.1	−5	−10	−6	2	7	14	8	5
57.	Nigeria	9.2	−129	−225	−123	−398	156	275	150	481
58.	Pakistan	21.4	−162	−339	−187	−564	210	425	235	708
59.	Panama	66.5	−3	−3	−1	−6	5	8	3	14
60.	Papua New Guinea	19.6	−8	−18	−10	−31	11	24	13	40
61.	Paraguay	44.2	−6	−13	−7	−18	9	19	10	27
62.	Peru	57.1	−26	−60	−31	−103	42	90	47	152
63.	Philippines	26.4	−100	−70	−93	−262	140	141	133	382
64.	Romania	28.3	−78	−113	−63	−218	86	127	71	241
65.	Senegal	10.6	−8	−15	−9	−27	13	22	14	40
66.	Serbia	25.6	−44	−51	−36	−81	45	53	37	85
67.	South Africa	69.7	−33	−51	−59	−12	56	93	82	82
68.	Sri Lanka	39.6	−20	−41	−19	−39	26	52	25	56
69.	Sudan	35.4	−18	−32	−14	−37	26	47	22	61
70.	Suriname	170.8	1	1	1	−3	−1	0	−1	3
71.	Syria	23.1	−23	−45	−25	−67	34	64	36	98
72.	Tajikistan	39.0	−5	−14	−8	−23	8	20	11	34
73.	Tanzania	6.4	−44	−79	−43	−128	58	104	57	170
74.	Thailand	39.6	−104	−238	−126	−391	140	302	162	499
75.	Tunisia	88.6	−2	−4	−3	−4	7	13	8	19
76.	Turkey	98.8	−3	130	−3	−44	63	−20	63	226
77.	Uganda	2.5	−40	−68	−38	−113	54	94	52	156
78.	Ukraine	54.6	−89	97	−78	−535	89	−97	78	535
79.	Uzbekistan	57.3	−13	−57	−31	−94	22	72	40	120
80.	Venezuela, RB	127.3	16	66	−11	−13	1	−36	28	64
81.	Vietnam	21.3	−137	−201	−116	−423	185	288	164	569
82.	Yemen	12.7	−14	−28	−16	−47	18	36	20	59
83.	Zambia	13.6	−13	−21	−13	−39	17	29	17	52
84.	Zimbabwe	13.9	−19	−33	−16	−48	24	43	21	65
	Total		−6597	−7519	−7343	−21,424	9169	12,149	9915	29,140

Values shown for various teletherapy and staffing have been rounded to the nearest integer. Table shows radiation therapy (RT) infrastructure and staffing in 84 low- and middle-income countries, listing patients with present access to radiation therapy (RT), present deficit, and additional number of teletherapy (TRT) units, radiation oncologists (RO), medical physicists (MP), and radiation therapy technologists (RTTs) required by 2020. Calculations are based on databases from GLOBOCAN (14) and IAEA-DIRAC (8, 15). See text for details.

* % of patients with access to radiation therapy = [no. of patient with radiation therapy access/no. of patients estimated to need radiation therapy] × 100.

† Negative values indicate deficits, whereas positive values indicate an excess with respect to teletherapy units and RT staffing.

‡ Positive values indicate additional requirements, whereas negative values indicate no additional requirement.

agencies is proposed to narrow the existing gap in radiation therapy (Fig. 3). These approaches include:

1. **At country level, coordinated by the national cancer control program**

   - *Periodic update of databases*. As evident from this analysis, cancer incidence of 14 countries was unavailable. In some LMICs, the estimates in GLOBOCAN could be based on the assumptions and extrapolations from neighboring countries or regions due to lack of reliable cancer registries. Thus, to assist the health policy makers, it is essential to have reliable, accurate, and periodically updated databases from population-based cancer registries from each country. In this context, IARC's "Global Initiative for Cancer Registry Development in LMICs" is an important project which could improve data availability and facilitate development of realistic cancer plans (22).

For a true assessment of the present radiation therapy capacity, each country should ensure periodic updates to the IAEA-DIRAC database. This could be coordinated

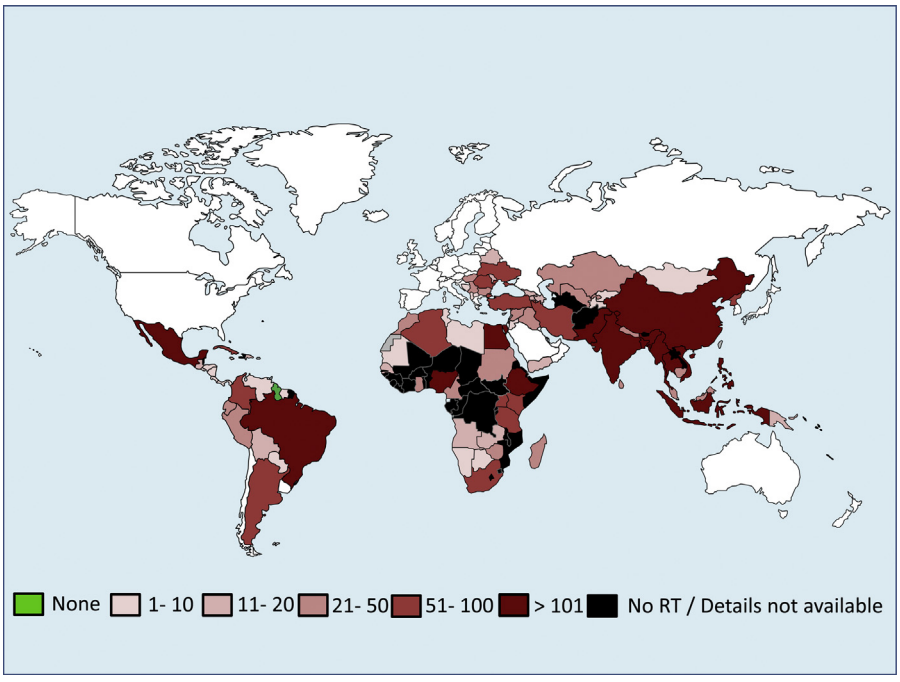

Fig. 2. Additional teletherapy units needed by 2020 in low-and middle-income group countries. No teletherapy facility presently exists in 55 of these 139 countries.

by respective national regulatory authority for radiation and waste safety.

- *Estimated future radiation therapy needs*. To estimate the future needs in radiation therapy, each country needs to look critically at their projected trends in their cancer incidence demography and current clinical practices. A radiation therapy utilization rate based on these could then be computed from the case mixture, as has been conducted in some developed countries (21, 23, 24). ESTRO has also launched its ESTRO-HERO project to evaluate the needs, accessibility, and cost effectiveness of radiation therapy in Europe (25). A similar endeavor has been initiated by UICC for LMICs (26). Reports from these task forces are awaited.
- *Radiation therapy capacity building*. Capacity building for radiation therapy is vital for adequate use of available infrastructure. This is even more difficult because training takes many years. Most countries could strengthen their existing training programs. The IAEA could be the fulcrum for devising a structured time-bound professional qualification program. The PACT division of the IAEA has the Virtual University for Cancer Control Network (VUCCnet) for Africa, with participation of 6 countries. This could be further expanded to countries lacking professional training programs (11, 27).
- *Tele-radiation therapy/tele-oncology network*. The global explosion of telecommunication technology and its widespread availability could be used to integrate the limited radiation therapy services by sharing resources in a given region (5). This network could be used to create a 3-tier radiation therapy service consisting of primary, secondary, and tertiary radiation therapy centers that have graded levels of expertise and equipment (28). All these could be networked, permitting transfer of DICOM-RT

Table 3 Cumulative radiation therapy infrastructure and staffing requirements for low- and middle-income countries that presently do not have any radiation therapy service or whose status is unknown

Parameter	Status in 2012 (n=41 countries)	Expected status by 2020 (n=41 countries)
Cancer incidence	225,564	280,874
Patients needing radiation therapy	140,977	175,546
*Teletherapy units needed	313	390
*Radiation oncologists needed	564	702
*Medical physicists needed	313	390
*Radiation therapy technologists needed	940	1170

Abbreviations: QUARTS = Quantification Of Radiation Therapy Infrastructure And Staffing Needs; GLOBOCAN = Global Cancer Incidence, Mortality and Prevalence; 225,564 indicates the Total Cancer incidence. It does NOT indicate 225,564/X population.

Calculations are based on guidelines from European Society for Therapeutic Radiology and Oncology-Quantification of Radiation Therapy Infrastructure and Staffing Needs (3) and International Atomic Energy Agency (17).

* Values shown have been rounded to the nearest integer.

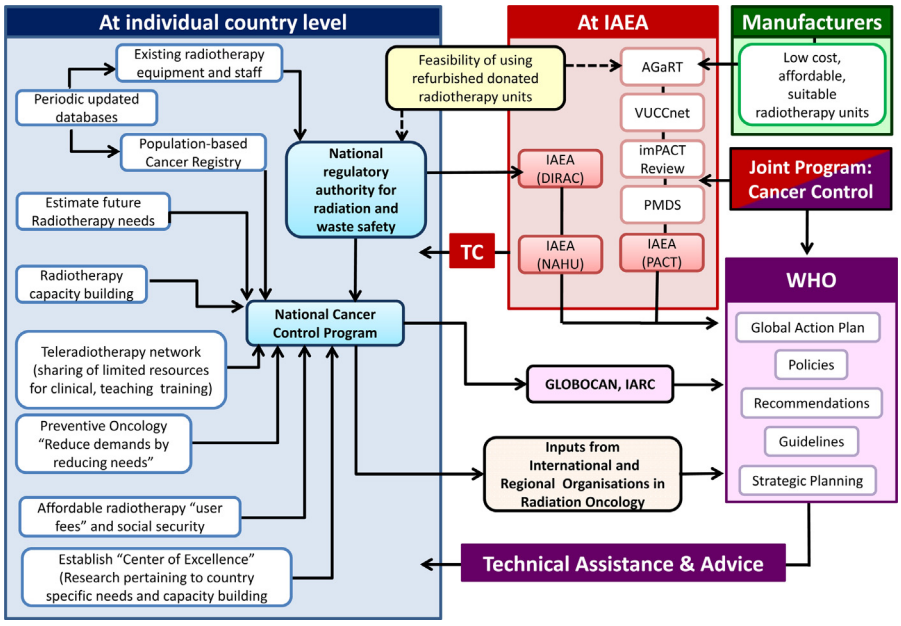

Fig. 3. Flow chart shows the role and interplay of various national and international agencies in a joint collaborative effort to reduce the gap in radiation therapy services in low- and middle-income countries (see text for details). AGaRT = Advisory Group on increasing access to Radiotherapy Technology; DIRAC = Directory of Radiotherapy Centres; IAEA = International Atomic Energy Agency; IARC = International Agency for Research on Cancer; NAHU = Division of Human Health, IAEA; PACT = Programme of Action for Cancer Therapy; PMDS = PACT model demonstration sites; TC = Department of Technical Cooperation, IAEA; VUCCnet = Virtual University for Cancer Control Network; WHO = World Health Organization.

images, treatment plans, video conferencing, teleconsultations, teaching, and training with the help of other centers of excellence. This 3-tier system would enable patients to have access to the best possible care within the constraints of limited resources. Efforts in this direction have already been taken up by a number of centers with encouraging outcomes (29, 30).

- *Preventive oncology through cancer control programs to reduce the demand by reducing the need*. It will be a nearly impossible task to fulfill the demand for more than 9000 teletherapy units by 2020 for the LMICs. In addition to the need for huge investments, it is unrealistic to expect the units to be made available by the manufacturing firms in such a limited time. Moreover, enormous human resources are required to run these units. It is estimated that more than 50% of the cancers could be prevented (31). Thus, preventive oncology and health education from the grass root level backed by health-friendly legislations and taxation could assist in reversing the trend of the rise in cancer incidence. Moreover, it could also concurrently reduce the incidence of other noncommunicable diseases since a number of etiological factors are common to both (2, 5, 32).
- *Affordable user fees for radiation therapy and social security*. In LMICs with no or limited insurance coverage, patients usually must bear the treatment costs themselves. Furthermore, user fees could create barriers to seeking treatment (5, 11, 33). Both of these issues could defeat the very purpose of providing adequate health care. Individual countries could frame financially sustainable health care systems for their patients from the low socioeconomic strata. Moreover, a government supported social security system could cover the treatment costs and rehabilitation and compensate for the salary loss from absence from work due to treatment.
- *Setting up cancer centers of excellence*. A government-funded center of excellence could provide quality services and guide their national cancer control program. In addition, they could be entrusted with responsibility of research directed to address specific problems in the country and train manpower. A South-South collaboration would ensure appropriate training with a holistic approach (11, 34).
- *Use of refurbished teletherapy units with adequate service support*. Because radiation therapy is undergoing rapid technological developments, a number of centers in high-income countries could be keen to replace their existing functional radiation therapy units with state-of-the-art technology. Some of these units that still have useful life could be donated to needy LMICs, with support from the manufacturers for periodic maintenance at the recipients' sites. This could be further explored by the

respective national regulatory bodies in consultation with the IAEA.

2. **Manufacturers of radiation therapy equipment**

   Manufacturers of radiation therapy equipment should create low-cost, affordable, and suitable low-maintenance costs units. Through its PACT program, the IAEA has initiated the creation of the Advisory Group on increasing access to Radiotherapy Technology (AGaRT) in LMICs in this regard (11, 27).

3. **Coordination with international agencies**

   - *IAEA*. The IAEA through its PACT Division has undertaken several steps to assist the LMICs in developing and implementing national cancer control programs and has enabled many countries to initiate comprehensive radiation therapy services (19, 27). The Department of Technical Cooperation, IAEA, in consultation with the PACT and Division of Human Health (NAHU) has also initiated a number of projects in various African countries to establish their first radiation therapy center and supported capacity building (35).
   - *Regional, international organizations and professional societies in radiation oncology*. They could provide consensus guidelines on radiation therapy practices, infrastructure requirements and staffing and even assist in training for individual countries or regions (18, 25, 26).
   - *WHO*. With the GLOBOCAN data from IARC, WHO has been the key resource center for global epidemiological and demographical cancer data. The WHO global action plans and recommendations have formed the basis of policies and strategic partnerships at the highest political levels. Moreover, the technical assistance and guidance from WHO have been of assistance to individual countries for framing their cancer control programs. Existing gaps in radiation therapy in LMICs, too, have been acknowledged as one of the key challenges to be addressed, as it is a cause of a major impediment in providing adequate care to these patients (34).

Conclusions

Based on the assessment of gap in radiation therapy in LMICs, it is evident that there is no one blueprint nor any magic bullets to resolve the crisis in radiation therapy accessibility in LMICs. Urgent, coordinated, and multipronged approaches at individual country levels are desirable that could be supplemented with assistance from international organizations and health policy makers.

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