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Original Article

The Practice of Paediatric Radiation Oncology in Low- and Middle-income Countries: Outcomes of an International Atomic Energy Agency Study

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Abstract

Aims: Childhood cancer survival is suboptimal in most low- and middle-income countries (LMICs). Radiotherapy plays a significant role in the standard care of many patients. To assess the current status of paediatric radiotherapy, the International Atomic Energy Agency (IAEA) undertook a global survey and a review of practice in eight leading treatment centres in middle-income countries (MICs) under Coordinated Research Project E3.30.31; 'Paediatric radiation oncology practice in low and middle income countries: a patterns-of-care study by the International Atomic Energy Agency.'
Materials and methods: A survey of paediatric radiotherapy practices was distributed to 189 centres worldwide. Eight leading radiotherapy centres in MICs treating a significant number of children were selected and developed a database of individual patients treated in their centres comprising 46 variables related to radiotherapy technique.
Results: Data were received from 134 radiotherapy centres in 42 countries. The percentage of children treated with curative intent fell sequentially from high-income countries (HICs; 82%) to low-income countries (53%). Increasing deficiencies were identified in diagnostic imaging, radiation staff numbers, radiotherapy technology and supportive care. More than 92.3% of centres in HICs practice multidisciplinary tumour board decision making, whereas only 65.5% of centres in LMICs use this process. Clinical guidelines were used in most centres. Practice in the eight specialist centres in MICs approximated more closely to that in HICs, but only 52% of patients were treated according to national/international protocols whereas institution-based protocols were used in 41%.
Conclusions: Quality levels in paediatric radiotherapy differ among countries but also between centres within countries. In many LMICs, resources are scarce, coordination with paediatric oncology is poor or non-existent and access to supportive care is limited. Multidisciplinary treatment planning enhances care and development may represent an area where external partners can help. Commitment to the use of protocols is evident, but current international guidelines may lack relevance; the development of resources that reflect the capacity and needs of LMICs is required. In some LMICs, there are already leading centres experienced in paediatric radiotherapy where patient care approximates to that in HICs. These centres have the potential to drive improvements in service, training, mentorship and research in their regions and ultimately to improve the care and outcomes for paediatric cancer patients.

Keywords: Developing countries; paediatric cancer; radiation oncology; radiotherapy

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Introduction

Childhood cancer is rare, but when measured in terms of the potential life-years that may be lost, it represents the fourth most important malignancy after lung, breast and colorectal cancers. Fortunately, the types of cancer that are seen in children, and their biology, differ significantly from adult cancers; many paediatric cancers respond well to treatment and more than 80% of children in high-income countries (HICs) are now cured [1–5]. However, 90% of children in the world live in low- and middle-income countries (LMICs), where cure rates are significantly lower [6] (Figure 1). Although children represent only 2% of cancer patients in Europe and North America, the proportion is as high as 5% in some countries [6]. Sadly, most children with cancer living in LMICs have limited access to modern cancer diagnosis and management and few can benefit from modern and complex therapies, such as radiation therapy. As a result, more than 90% of all childhood cancer deaths occur in LMICs [7]. Although there are several international initiatives and projects targeting epidemiology, diagnosis and treatment of childhood cancers in LMICs [4,5,8,9], those targeting paediatric radiotherapy specifically are extremely scarce. Gaps in the practice and quality of radiotherapy services in LMICs are significant and mandate urgent improvements at local, national and regional levels [10].

The Division of Human Health in the International Atomic Energy Agency (IAEA) supports member states developing and expanding nuclear technology in medical services [11]. This includes applications in the diagnosis and treatment of cancer and encompasses training, service and research protocols. In 2007, the IAEA coordinated a preliminary survey that was sent to IAEA member states around the world to identify which radiotherapy centres treated paediatric cases. Following this, a meeting of experts in global oncology and radiology was convened in 2008 at the IAEA headquarters in Vienna, Austria, to discuss what activities should be undertaken to understand current practices and challenges to care delivery. Twelve radiation oncologists who were identified in the initial survey as practicing paediatric radiotherapy in large regional or national referral centres for paediatric cancer patients in LMICs were then invited to draft a protocol for a clinical research project to review the status of paediatric radiotherapy in LMICs. Eight of these clinicians formed the Paediatric Radiation Oncology Network (PRON; Table 1) and implemented this project. The objective of the study was to evaluate current practices and challenges in the optimisation of treatment protocols and procedures in radiotherapy for paediatric cancer patients in LMICs. It was perceived that the data would be useful to understand patterns of radiotherapy practice in developing countries, with the ultimate goal being to recommend implementation strategies that would improve the overall survival, management of symptoms and quality of life of paediatric patients. This article presents the results of the project and makes recommendations for future directions to enhance paediatric radiation oncology in LMICs.

Materials and Methods

The IAEA project was designed in two parts:

(i) Understanding the patterns and problems of radiotherapy practices in LMICs: To achieve this, a questionnaire was developed by the Applied Radiation Biology and Radiotherapy section of the IAEA and distributed online to 189 radiotherapy centres worldwide, selected from more than 7800 radiotherapy centres listed in the IAEA Directory of Radiotherapy Centres [12] to include facilities in HICs and LMICs where IAEA staff were aware that paediatric radiotherapy was undertaken. Those centres were also requested to forward the questionnaire to appropriate regional colleagues to reach as many centres in LMICs practicing paediatric radiotherapy as possible. The questionnaire consisted of 24 items addressing the infrastructure of the hospital and the radiotherapy department, radiotherapy human resources, radiotherapy techniques and paediatric radiotherapy procedures (see Appendix 1) Online responses were collected between 2012 and 2013 from 134 centres in 42 countries (see Appendix 2), which was considered satisfactory to illustrate the general status of paediatric radiotherapy worldwide.

(ii) Understanding patient outcomes: Under IAEA coordination, the PRON group developed a database of patient data comprising 46 variables related to daily radiation oncology practices, such as treatment decisions, treatment planning procedures, radiotherapy techniques, patient immobilisation equipment and use of anaesthesia (see Appendix 3). Eight centres contributed data from the treatment of 1329 individual patients, which was stored within the Paediatric Oncology Networked Database (POND) [13], developed and provided by the International Outreach Program of St. Jude Children's Research Hospital in Memphis (TN, USA).

Results

Phase 1: Global Survey of Paediatric Radiotherapy Practices

Data from 134 radiotherapy centres revealed that there were considerable differences between centres in HICs and LMICs in daily paediatric radiotherapy practices. To illustrate where resource limitations impacted most obviously on services, the data are presented in five domains and tabulated according to gross domestic product per capita of the host country; high income, upper middle income, lower middle income and low income. (It should be noted that radiotherapy facilities are rare in low-income countries and consequently only three centres participated.)

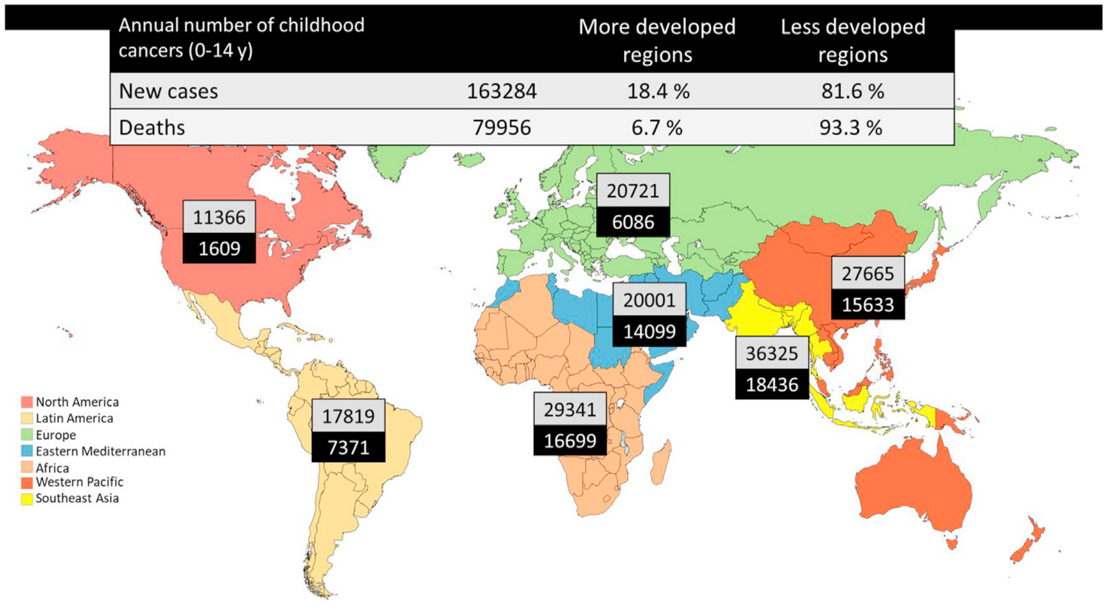

Fig 1. Annual numbers of childhood cancers: new cases and deaths in the world and its regions [6]. More than 80% of all childhood cancers and more than 90% of all deaths from childhood cancers occur in less developed regions. The ratio of annual deaths to new cases of childhood cancer is 17.83% in more developed regions, compared with 55.96% in less developed regions.

Clinical care environment (Table 2)

Numbers of radiation oncologists were fewer in resource-limited countries and a dedicated role in paediatric radiotherapy was less common. However, only a minority of paediatric radiation oncologists took responsibility for paediatric chemotherapy in any setting and paediatric oncology and surgery departments were usual. Diagnostic facilities were available in most centres surveyed, including pathology and radiology departments, although imaging technology above computed tomography scanning level notably declined with income bracket. Overall, a striking difference was the sequential decrease in multidisciplinary tumour board management, a methodology of care that has a proven impact on treatment decision making [14]. The availability of supportive services, such as hostel beds and free transport facilities, also declined. Anaesthesia for young children during radiotherapy was available in more than 90% of the centres surveyed, both in HICs and LMICs. Long-term follow-up of survivors into adulthood was more common in higher income environments, with some evidence that this is more commonly undertaken by the radiation oncologist in lower income environments and through paediatric services in HICs.

Radiotherapy department staff and technology (Table 2)

Numbers of medical physicists and radiotherapy technicians in radiotherapy facilities decreased with income bracket, which may affect both the quality and the flexibility to increase efficiency with an extended day working. All centres in HICs had linear accelerators and use of cobalt teletherapy in paediatric patients was uncommon; in low-income environments, this was the only equipment available in two of three centres. Increasing use of fluoroscopic simulation and a decrease in the availability of a dedicated computed tomography scanner for radiotherapy planning was also seen, although in general computed tomography was available within the hospital. Access to advanced technology features, such as electronic portal imaging,

Table 1
The paediatric radiation oncology network (PRON)

Centre	City	Country	Abbreviation	No. patients (%)	Male:female
Tata Memorial Hospital	Mumbai	India	TATA	156 (11.7)	3.73
Ege University Hospital	Izmir	Turkey	EGE	243 (18.3)	1.60
Children's Cancer Hospital	Cairo	Egypt	CCHE	427 (32.1)	1.56
Centro Infantil Boldrini	Sao Paulo	Brazil	BOLDRINI	147 (11.1)	1.17
Cipto Mangunkusumo Hospital	Jakarta	Indonesia	RSCM	109 (8.2)	1.42
National Institute of Oncology and Radiobiology	Havana	Cuba	INOR	191 (14.4)	1.38
Instituto de Medicina Integral Prof. Fernando Figueira	Recife	Brazil	IMIP	41 (3.1)	1.93
The National Cancer Centre of Mongolia	Ulaanbaatar	Mongolia	NCCM	15 (1.1)	1.50

record and verify, *in vivo* dosimetry, brachytherapy and multileaf collimation, clearly declined with income bracket.

Workflow and service (Table 2)

Although the range was greater, the average numbers of paediatric patients receiving radiotherapy was variable within income brackets as well as between them, with no clear trend. Overall, fewer paediatric cases occur in HICs, but planned centralisation of specialist services may contribute to this. The clearer conclusion was that the percentage of children treated with curative intent falls with income bracket (average 82% in HICs falling sequentially to 53% in low-income countries).

There was no clear lengthening of the working day or increase in daily shifts in lower income environments, and this may be precluded by staff numbers, but a sequential increase in numbers of operational days per week was observed. The complexity of radiotherapy technique was generally seen to decline, with less access to intensity-modulated radiotherapy, stereotactic radiotherapy and more sophisticated methods of whole central nervous system radiotherapy planning.

Clinical governance (Table 3)

A decrease in the use of paediatric radiotherapy protocols was observed in more resource-constrained environments, where published 'guidelines' may be of minimal relevance, and national cancer registries were uncommon. However, the evidence of chart reviews, clinical reviews, recording of acute toxicity and radiotherapy quality assurance programmes showed commitment to the principles of governance in all environments.

Academia, trials and research (Table 3)

Paediatric oncology services in HICs exist mainly in high-level academic environments, with 73% being based in university hospitals, and activities in training, clinical trials and research were the norm. The improvements in outcomes seen in the past 50 years may reflect this. Although training and access to study resources were common across the table, almost inevitably opportunities for participation in trials and research fell from HICs to LMICs, and published output decreased.

Database Related to Individual Patient Data

Between 2009 and 2012, data were collected from 1329 paediatric radiotherapy patients from eight centres in the PRON group (Table 1). These were high-profile centres in middle-income countries (MICs), with 622 datasets collected from four centres in upper MICs (Turkey, Brazil and Cuba) and 707 from centres in lower MICs (India, Egypt, Indonesia and Mongolia). Most were regional or national reference centres for paediatric radiotherapy, with staff experienced in treating children, modern radiotherapy infrastructure and an academic affiliation. Overall, more than half of the patients treated were diagnosed with solid tumours (53.8%) followed by lymphomas (17.2%), leukaemias (15.0%) and central nervous system tumours (13.6%.) The distribution of diagnoses varied between centres depending on the local case mix, referral patterns, experience of the centre and treatment protocols used (Figure 2) but the standards of radiotherapy management and care were comparable and approximated to the situation seen in HICs (see Tables 2 and 3). More than 90% of children were treated with curative intent and 94% of the patients were discussed at multidisciplinary tumour boards. Overall, 93% of patients were treated according to clinical guidelines; 52% by national or international protocols and 41% in accordance with local guidelines. The radiotherapy delivery parameters are displayed in Table 4. Computed tomography planning was standard and three-dimensional techniques were used in 85% of patients, although the manual calculation rate of around 5% was unexpectedly high. Linear accelerators were used for almost 90% of treatments with cobalt-60 machines used in less than 10%. The use of immobilisation devices was 92% and individual beam shaping and isocentric treatment was almost always available. Use of advanced radiotherapy remained less common than in HICs but 71.6% of patients were treated with conformal three-dimensional techniques and 13.4% with intensity-modulated radiotherapy. Anaesthesia was available in all sites; 23% of patients required it and most received it for all fractions. Radiotherapy was completed in 93.3% of patients but no data were collected on treatment interruptions.

Discussion

Radiotherapy, used in combination with chemotherapy and surgery, continues to be an essential part of paediatric cancer management. In common with other medical disciplines, paediatric radiotherapy in LMICs faces many obstacles due to social and economic problems [15,16], which could be overcome by close collaboration of health authorities, academic institutions and international organisations. However, paediatric cancers are not common; many radiotherapy centres treat only a few patients annually and do not invest in dedicated resources. The infrastructure, equipment and staff necessary for optimal radiotherapy of paediatric patients, such as immobilisation equipment in child sizes, anaesthesia equipment, post-anaesthesia recovery rooms, play areas and support staff experienced in childcare (nurses, social workers), are either inadequate or not available in many centres globally. Deficiencies are also apparent in training syllabi; paediatric radiotherapy is not part of the training curriculum in many countries, and most radiation oncology graduates will have treated few paediatric patients.

However, paediatric cancer treatment is not necessarily expensive when resources are used properly and treatment of children with cancer is cost-effective in LMICs [17,18]. Survival of paediatric cancer patients in HICs increased significantly starting from the 1970s, with optimum use of early chemotherapy drugs (e.g. cyclophosphamide, vincristine, doxorubicin, 5-fluorouracil and cisplatin) and two-dimensional radiotherapy using cobalt-60 machines, proving that it is possible to reduce childhood cancer

Table 2
Clinical care environment, radiotherapy department staff and technology, and workflow and service survey results stratified by economic group

	High-income countries ($n = 67$)	Upper middle-income countries ($n = 28$)	Lower middle-income countries ($n = 35$)	Low-income countries ($n = 3$)
Clinical care environment				
Number of radiation oncologists (average)	15.5	7.1	4.7	6
Dedicated radiation oncologists for paediatric radiotherapy	85%	81%	53%	33%
Radiation oncologists responsible for paediatric chemotherapy	8%	15%	13%	67%
Paediatric oncology department	85%	93%	59%	100%
Paediatric surgery department	84%	85%	60%	100%
Tumour board	89%	69%	52%	67%
Anaesthetics department	99%	100%	100%	100%
Radiology department	99%	100%	100%	100%
Computed tomography	99%	100%	100%	100%
Magnetic resonance imaging	96%	85%	66%	33%
Positron emission tomography	69%	56%	21%	0%
Nuclear medicine department	88%	100%	69%	100%
Pathology department	97%	96%	100%	100%
Patient hostel	73%	37%	44%	67%
Transport service	48%	19%	18%	0%
Palliative medicine department	96%	59%	74%	100%
Hospice beds	64%	50%	65%	33%
Dietician services	99%	93%	89%	67%
Psychology Services	99%	96%	74%	67%
Follow-up into adulthood	86%	75%	53%	100%
Follow-up by radiation oncologist	70%	74%	97%	67%
Follow-up by paediatric oncologist	98%	96%	68%	67%
Radiotherapy department staff and technology				
Number of medical physicists (average)	7.1	4.8	2.7	3.5
Number of radiotherapy technicians (average)	34.1	15.7	9	12.7
Linear accelerators	100%	96%	71%	33%
Linear accelerators 15–18 MV	67%	80%	37%	33%
Electrons	99%	92%	72%	33%
Cobalt-60 teletherapy	16%	56%	51%	67%
Percentage of centres treating any children with cobalt-60 teletherapy	12%	29%	40%	67%
Maximum percentage of paediatric radiotherapy delivered with cobalt-60 teletherapy	30%	100%	100%	100%
Orthovoltage	41%	23%	9%	33%
Fluoroscopic simulator	49%	78%	64%	100%
Computed tomography simulator	94%	62%	66%	33%
Access to computed tomography for radiotherapy planning	100%	96%	86%	100%
Dicom	100%	89%	74%	100%
Three-dimensional treatment planning system	99%	93%	91%	33%
Electronic portal imaging	91%	81%	51%	33%
Record and verify	99%	77%	85%	33%
In vivo dosimetry	83%	58%	49%	67%
Maintenance contract	99%	85%	86%	67%
High dose rate brachytherapy	78%	68%	60%	67%
Low dose rate brachytherapy	39%	18%	14%	33%
Eye plaque therapy	21%	14%	9%	33%
Immobilisation	100%	96%	89%	100%
Customised blocks	90%	89%	91%	100%
Multileaf collimator	97%	81%	63%	33%
Workflow and service				

(*continued on next page*)

Table 2 (*continued*)

	High-income countries ($n = 67$)	Upper middle-income countries ($n = 28$)	Lower middle-income countries ($n = 35$)	Low-income countries ($n = 3$)
Number of paediatric patients per year (range)	0–250 Average 38.4	0–400 Average 82.5	0–500 Average 42.3	40–90 Average 65
% curative	82%	81%	59%	53%
% palliative	16%	19%	26%	47%
Waiting time 0–2 weeks	75%	68%	61%	67%
Operating hours (range)	2–15 Average 9.7	4–15 Average 10.6	6–18 Average 9.1	8–24 Average 10.7
Number of shifts per day	1: 51% 2: 44% 3: 5%	1: 26% 2: 48% 3: 26%	1: 55% 2: 32% 3: 13%	1: 50% 3: 50% (1 non-responder)
Number of operational days per week	5: 95% >5: 5%	5: 93% >5: 7%	2–5: 81% >5: 19%	5: 67% >5: 33%
Isocentric technique used for paediatric radiotherapy	100%	96%	82%	67%
Immobilisation for paediatric patients	89%	85%	79%	100%
All fields treated daily	100%	96%	91%	100%
Intensity modulated radiotherapy	73%	41%	71%	0%
Stereotactic radiotherapy	64%	41%	15%	0%
Total body irradiation	82%	30%	12%	0%
Whole central nervous system radiotherapy supine	91%	65%	80%	33%
Whole central nervous system radiotherapy prone	59%	76%	75%	100%
Whole central nervous system radiotherapy with moving junctions	90%	73%	50%	67%

Table 3
Clinical governance, academia, trials and research survey results stratified by economic group

	High-income countries ($n = 67$)	Upper middle-income countries ($n = 28$)	Lower middle-income countries ($n = 35$)	Low-income countries ($n = 3$)
Clinical governance				
Cancer registry (any type)	98%	96%	81%	100%
Cancer registry (national)	54%	27%	21%	67%
All cases recorded	94%	92%	72%	67%
Paediatric protocols	91%	93%	88%	33%
Chart reviews	91%	96%	88%	100%
On treatment reviews	98%	84%	100%	100%
Acute toxicity recording	98%	93%	85%	100%
Late toxicity recording	83%	67%	76%	33%
Radiotherapy quality assurance	99%	96%	100%	100%
Academia, trials and research				
University hospital	73%	68%	60%	100%
Radiation oncology trainees	85%	89%	41%	67%
Library	91%	81%	74%	100%
Access to journals	96%	100%	76%	100%
Internet access	97%	96%	89%	100%
Trials activity	89%	81%	55%	100%
Paediatric research	83%	44%	32%	67%
Publications	82%	78%	46%	100%
Paediatric oncology publications	75%	46%	28%	67%
Ethics board	100%	100%	97%	100%

mortality significantly with cheap drugs and simple radiotherapy techniques. The use of newer, more expensive drugs and high-end linear accelerators with sophisticated treatment techniques may exceed the budget, infrastructure and manpower in some countries, but can be added after optimising the use of simpler, more accessible treatments.

Although several reports have detailed the distribution and availability of radiotherapy services in various regions of the world, no studies were available specifically targeting the quality of radiotherapy practice in paediatric cancer patients. This IAEA project, which is a collaborative effort in the field of paediatric radiation oncology, was developed in this context. The objectives were to survey global paediatric radiotherapy practices, to collect data to evaluate current practices and challenges in radiotherapy for paediatric cancer patients in LMICs and to form a group of specialised paediatric radiotherapy centres from LMICs for further collaboration.

The global survey served to show what was considered routine practice in HICs for the parameters surveyed. Increasing challenges were identified in lower resource settings in diagnostic imaging equipment, multidisciplinary tumour board working, radiotherapy department staff numbers, equipment for planning and treatment and radiotherapy delivery technique. The percentage of children treated with curative intent was seen to decrease; stage distribution was not recorded, but higher stage disease in lower income environments would explain the higher percentage of palliative treatments and use of simple technology (even where more advanced options were available.) Access to anaesthesia was surprisingly high in all environments, but the quality merits further study, e.g. was it anaesthesia or deep sedation and was it delivered by a qualified anaesthetist and available consistently throughout planning and treatment. Other services, such as radiotherapy patient 'hostels' and free transport services, were also less usual in lower income sites. These 'soft' services may be crucial for young parents challenged financially by a long-term illness and provision may reduce treatment abandonment.

Among these challenges, the lack of multidisciplinary working was striking, with multidisciplinary team decision making being absent in a third of LMIC centres overall. The impressive advances in childhood cancer survival have resulted from the seamless delivery of multimodal therapy and lack of this approach impacts negatively on outcomes. This appears to be a good target where buddy partnerships may be able to support development. Discussion of cases increases confidence and a major goal of the PRON group is to provide online options for such discussion (e.g. [19]).

The PRON survey showed that the development of referral centres specialised in the management of paediatric radiotherapy patients is possible in LMICs and offers a good option to move towards delivery of optimum care. The data from the eight PRON centres, which included almost equal numbers of cases from upper and lower middle-income environments, are striking and showed that good paediatric radiotherapy is possible in MICs when children are treated in referral centres where clinicians have the time and resources to adopt modern approaches and radiation oncologists specialising in paediatric radiotherapy work in direct collaboration with multidisciplinary paediatric oncology teams. Specialised referral centres are clearly highly desirable and can function as hubs for training and mentorship for the development of the further centres required in the region. As such, they are a critical first step towards the goal of universal access to high-quality radiotherapy in all corners of the world, which is one component of universal healthcare coverage, a central mandate of the World Health Organization. It was notable, however, that even these centres often developed local guidelines, suggesting that many international published protocols may lack relevance. The development of treatment protocols and

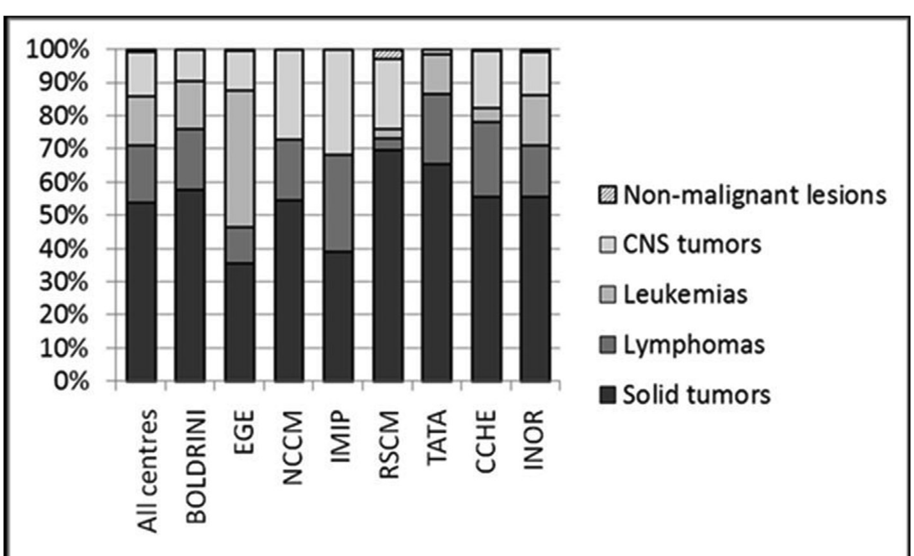

Fig 2. Distribution of case mix at each of the Paediatric Radiation Oncology Network (PRON) centres.

Table 4
Survey 2: combined data from 1329 individual paediatric cancer patients treated with radiotherapy in eight large radiotherapy centres in lower middle-income countries. Data were collected in the Paediatric Oncology Networked Database (POND)

	Percentage
Multidisciplinary decision	94.6
Curative treatment intent	91.4
Use of guidelines	93
National/international	52
Local	41
Immobilisation	
Thermoplastic	76.9
Vacuum cushion	8.0
Straps	4.1
Knee cushion	1.6
Bite block	0.7
Stereotactic frame	0.3
Plaster of Paris	0.2
Belly board	0.1
None	7.9
Isocentric set-up	97.5
Individual beam shaping	92.2
Simulation	
Computed tomography simulation	59.3
Computed tomography and fluoroscopic	19.7
Fluoroscopic	18.2
None	2.8
Planning	
Two-dimensional manual plan	5.2
Two-dimensional computer plan	9.8
Three-dimensional conformal plan	71.6
Intensity-modulated radiotherapy plan	13.4
Radiation source	
Linear accelerator (photons)	89.3
Cobalt-60	9.2
Electrons	1.4
Brachytherapy	0.1
Anaesthesia	23.0
Radiotherapy schedule completed as planned	93.3

guidelines for paediatric radiotherapy that consider the capacity and the needs of LMICs seems essential. In this regard, the Paediatric Oncology in Developing Countries Working Group of the International Paediatric Oncology Society (SIOP-PODC) has already published guidelines for radiation therapy-containing treatment regimens for several paediatric tumours developed specifically for use in LMICs [20–26] and currently, as part of the comprehensive 'Global Initiative in Childhood Cancer,' collaborators from the World Health Organization, St. Jude Children's Research Hospital, Paediatric Radiation Oncology Society and the IAEA are drafting advisory documents for paediatric radiotherapy service delivery and disease-specific guidelines.

The key to successful change is effective collaboration among stakeholders, which should include health authorities, academic institutions, patient support groups, non-governmental organisations, professional organisations and international institutions related to childhood cancer [27–32]. National cancer plans should include the development of national/regional reference centres where paediatric cancer patients will be treated. Training programmes coordinated by bodies such as IAEA, Paediatric Radiation Oncology Society and the European Society for Radiology and Oncology should continue and be supported [32].

Conclusions

The number of children diagnosed with cancer in LMICs is rising for reasons including success in the millennium goal of decreasing under five mortality, vaccination programmes, control of major infectious diseases and increased diagnostic capacity. This increase can be predicted to continue and the development of services that can offer children in LMICs the chance of survival seen in HICs is critical. Radiotherapy is an essential component in the treatment of many common paediatric cancers, yet its practice in LMICs has not previously been researched.

This study evaluated the practice and patterns of care of paediatric radiotherapy in LMICs. The global survey illustrated the key areas where quality declined with income resource, whereas the PRON survey showed that high-quality paediatric radiotherapy, approximating to that considered standard in HICs, can be delivered in specialised regional centres in both upper and lower middle-income environments. The authors conclude that every effort should be made to allow children with cancer to receive radiotherapy in such centres and to support the role of existing specialists there to lead the development of further high-quality facilities in their regions. In addition to practical resources, specific areas where it appeared that advisory support may be beneficial was in the strengthening of multidisciplinary team tumour board processes and the development of robust and relevant guidelines.

Although we could not address every aspect of the services, we hope that these data will alert health policy makers, authorities and national and international cancer organisations to the challenges in paediatric radiotherapy and provide a benchmark for further innovation, service development and research.

Conflicts of interest

The authors declare no conflicts of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.clon.2020.11.004.

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