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Scientific Article

Radiation Therapy Physics Quality Assurance and Management Practices in Low- and Middle-Income Countries: An Initial Pilot Survey in Six Countries and Validation Through a Site Visit

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Purpose: Our purpose was to assess physics quality assurance (QA) practices in less resourced radiation therapy (RT) centers to improve quality of care.

Methods and Materials: A preliminary study was conducted in 2020 of 13 select RT centers in 6 countries, and in 2021, our team conducted onsite visits to all the RT centers in Ghana, one of the countries from the initial survey. The RT centers included 1 private and 2 public institutions (denoted as Public-1 and Public-2). Follow-up surveys were sent to 17 medical physicists from the site visit. Questions centered on the topics of equipment, institutional practice, physics quality assurance, management, and safety practices. Qualitative and descriptive methods were used for data analysis. Questions regarding operational challenges (machine downtime, patient-related issues, power outages, and staffing) were asked on a 5-point Likert scale.

Results: The preliminary survey from 2020 had a 92% response rate. One key result showed that for RT centers in lower gross national income per capita countries there was a direct correlation between QA needs and the gross national income per capita of the country. The needs identified included film/array detectors, independent dose calculation software, calibration of ion chambers, diodes, thermoluminiscence diodes (TLDs), phantoms for verification, Treatment Planning System (TPS) test phantoms, imaging test phantoms and film dosimeters, education, and training. For the post survey after the site visit in 2021, we received a 100% response rate. The private and the Public-1 institutions each have computed tomography simulators located in their RT center. The average daily patient external beam workload for each clinic on a linear accelerator was: private = 25, Public-1 = 55, Public-2 = 40. The Co-60 workload was: Public-1 = 45, Public-2 = 25 (there was no Co-60 at the private hospital). Public-1 and -2 lacked the equipment necessary to conform to best practices in

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Task Group reports (TG) 142 and 198. Public-2 reported significant operational challenges. Notably, Public-1 and -2 have peer review chart rounds, which are attended by clinical oncologists, medical physicists, physicians, and physics trainees. All 17 physicists who responded to the post site visit survey indicated they had a system of documenting, tracking, and trending patient-related safety incidents, but only 1 physicist reported using International Atomic Energy Agency Safety in Radiation Oncology.

Conclusions: The preliminary study showed a direct correlation between QA needs and the development index of a country, and the follow-up survey examines operational and physics QA practices in the RT clinics in Ghana, one of the initial countries surveyed. This will form the basis of a planned continent-wide survey in Africa intended to spotlight QA practices in low- and middle-income countries, the challenges faced, and lessons learned to help understand the gaps and needs to support local physics QA and management programs. Audits during the site visit show education and training remain the most important needs in operating successful QA programs.

Introduction

Cancer is responsible for more deaths globally than human immunodeficiency virus, malaria, and tuberculosis combined.[1] Although communicable diseases still carry a significant burden, studies show the morbidity and mortality rate has been reduced in the last decade.[2] However, significant disparities in the diagnosis and treatment of cancer persist globally.[3] In 2018, more than 50% of the 18.1 million new cancer cases were in low-income countries, which also accounted for 65% of the estimated 9.5 million deaths.[4] It is further projected that this burden will increase to 75% by 2030 globally,[5] with low- and middle-income countries (LMICs) experiencing about a 90% surge in cases. This burden will be highly experienced by countries in Africa, because the continent has the highest number of LMICs.[5]

Africa has a population of over 1.2 billion comprising 54 countries, and cancer care services are limited in many of those countries. There are 222 reported radiation therapy (RT) centers in 29 countries. The continent has the highest number of lower middle-income countries and lower income (42.6% [23/54]) for any continent, 11.1% (6/54) upper-middle income (UMIC), and 3.7% (2/54) high-income countries.[6] In some countries in Africa, medical physics is not recognized as part of the health care professional team under the ministry of health, and physicists have relatively limited resources. RT centers in Africa are not the only ones that suffer from the issue of being under-resourced. A recent survey of Caribbean Community member states (14 countries) showed that only 50% had RT machines and only 1 country met International Atomic Energy Agency (IAEA) standards for adequate radiation oncologists and only 3 for adequate physicists based on population data.[7]

In the effort to expand and improve cancer care to RT centers in limited resource areas, some researchers have worked on developing cost-effective technologies for RT in LMICs,[8-10] and others have focused on the need to improve infrastructure and fill the gaps in equipment through donation.[11-13] In addition to the need to expand RT services in LMICs, there is the need to establish and maintain the quality of those services, and numerous reports have focused on safety and quality in RT,[14,15] and a key component is the quality assurance (QA) practices largely overseen by medical physicists.

Medical physics QA in radiation oncology includes a set of procedures that are put in place to ensure a consistent and safe environment. A comprehensive QA program is needed because of the high radiation dose delivered and the importance of accuracy needed in delivering such doses. An inadequate QA program can result in errors, which can be detrimental to the patient and increase radiation exposure to personnel. Sources of errors include but are not limited to incorrect tumor localization, lack of patient immobilization, errors in daily patient set-up, and equipment-related issues. The American Association of Physicists in Medicine (AAPM) Task Group 142 report emphasizes the importance of RT facilities establishing a comprehensive QA program and recommends that the nature of the program be dependent on the objectives and resources of the clinical services and facilities.[16-18] However, very few reports have focused on medical physics QA practices in the context of RT centers that are under-resourced around the world.

It has been reported that RT centers in lower-income regions or in regions classified as higher income countries (HICs) by the World Bank economic ranking, but which fall in the lower half of that income scale, have insufficient personnel and infrastructure to carry out procedures in RT. As a result, this staffing deficit can have a direct and adverse effect on the ability to conduct appropriate QA practices, with a potential negative effect on patient safety.[7,19]

This is contrary to what studies like the AAPM Task Group 100 report indicate, highlighting that the lack of resources, inadequate training, and lack of standardized procedures can lead to significant failure in RT clinical practice.[20] The objective of this study was to assess medical physics QA and quality management practices in less resourced facilities to determine the effect on their practice. We also aimed to spotlight the correlation between the gross national income per capita (GNIpc) of the RT center and the medical physics QA and quality management practices. We designed a preliminary study to assess the feasibility of this study in sample clinics in 6 different countries in the Caribbean and Africa. The results of the preliminary study indicated that to get a better understanding of the medical physics QA and practices we needed to conduct an onsite visit to 1 of the countries; hence, we followed up with a visit to the 3 RT centers in a single country.

Methods and Materials

This study was approved by the institutional review board. Both studies employed descriptive survey design while employing a mixed method approach. The scope of this study includes a preliminary study in 2020 of 13 RT centers in 6 countries, a site visit to 3 centers in a single country, and a post site visit survey sent to 17 clinical physicists in the 3 centers in 2021.

All survey questionnaires centered on the topics of equipment availability, institutional practice, physics QA, management, and safety practices. The dual nature of the second study presented the perfect opportunity to validate the survey results. Qualitative and descriptive methods were used for data analysis. We assessed operational challenges during the site visit using a 5-point Likert system (never = 1, rarely = 2, sometimes = 3, often = 4, always = 5) for the following issues: machine downtime, patient-related issues, power outages, and staffing. Using the responses from each center, a box plot was plotted for each center to show how often these issues affected their clinical practice.

Preliminary survey

The preliminary survey was conducted among 13 RT centers from 6 different countries. These countries were selected based on the feasibility of our research group being able to contact all the RT centers in each country. This resulted in surveys of all the RT centers in 5 countries, namely the Bahamas, Barbados, Ghana, Jamaica, and Trinidad and Tobago. In addition, the survey was distributed to 2 representative practices in South Africa as a baseline comparison for a center that is regional but where RT practices are potentially more advanced compared with other centers in LMICs. The countries span from HICs and lower income countries according to the World Bank.[21] Although some of these countries (eg, Trinidad and Tobago, Barbados, and the Bahamas) are classified as HIC by the World Bank economic ranking, they fall in the lower half of the income scale. For this preliminary study only the head of medical physics in each center was invited to fill out the survey. Using the GNIpc data from the World Bank we showed the relationship between the numbers of patients irradiated annually per teletherapy unit by dividing the GNIpc by the total number of patients/linear accelerator (LINAC)/year, and the results are shown in Fig. E1.

The survey questions were developed through a consensus process with medical physics experts in radiation oncology with experience ranging from 2 years to over a decade, and have contributed to the development of other surveys that have led to published task group reports.

The process began with an initial draft of survey questions, followed by multiple edits and revisions by medical physicists on our research team until a consensus was reached to distribute the survey questionnaires to begin the data collection process. This resulted in a survey that contained questions probing the following areas: education and training, recognition of medical physics as a profession in the country, nature and type of external beam equipment, patient workload on LINACs and/or Co-60 teletherapy units, high dose rate (HDR) and low dose rate (LDR) brachytherapy for centers with brachytherapy services, physics QA practices, and the availability of equipment and medical QA devices to carry out QA. Data regarding the number of RT machines and the availability of brachytherapy services were also collected in the survey. Some centers did not respond to the questions about RT machines, and in these cases, data were extracted from the directory of RT centers database.[22] We extracted the amount of RT equipment in a country for centers in South Africa, Jamaica, Barbados, and Trinidad and Tobago to calculate the number of patients who are likely to be treated per machine in the country. Survey data were collected and managed using invitations sent via a Research Electronic Data Capture.[23]

Twenty-five survey questions were sent to heads of physics in the centers described previously. Supplementary data were collected via phone interviews and responses recorded in the database. The data were analyzed using descriptive statistics. To further validate the results of this preliminary survey to plan for a more extensive future survey, a site visit was conducted to 3 of the clinics surveyed, which represent all the RT centers in a single country, which was partly due to the limited funds available.

Site visit to the 3 RT centers in a single country

A site visit was conducted to each of the 3 RT centers currently serving the population of 31 million in Ghana. Two of these centers (Public-1 and Public-2) are publicly owned by the government and serve as academic training centers for the country's health care professionals, and the other is privately owned. Public-1 is in the capital city and Public-2 is in a large regional capital. The site visit spanned a period of 28 days in 2021 with the time divided roughly equally between the 3 RT facilities. The purpose of the site visit was to understand the environment in which the physicists worked and to validate the responses from the survey with observations from the site visit by cross-referencing responses with what was observed.

To gather further information on these practices, a questionnaire with 46 questions developed by medical physics experts was sent to practicing medical physicists in the 3 different institutions. Seventeen clinical physicists were invited to complete the questionnaire and all 17 responded. The survey questions were in 4 categories: (1) institution; (2) RT equipment (external beam, treatment planning software availability of computed tomography [CT] simulator, and access to diagnostic equipment); (3) QA in terms of dosimetry, imaging, and mechanical and safety performance on the external beam equipment; and (4) quality management and patient safety. Questions on brachytherapy were not asked in the follow-up onsite survey because the focus was mostly on external beam RT. In the post visit questionnaire, respondents were asked to assess the following operational challenges on a 5-point scale: machine downtime, natural disasters, patient-related issues, power outages, and staffing as it affects patient treatments and clinic workflow. A score of 1 is the least challenging; a score of 5 is the most challenging.

Audit of survey responses and site visit

The purpose of our site visit to these clinics was to give our team an opportunity to directly observe the infrastructure available in the RT facilities and the routine daily workflows. This gave us the opportunity to audit or cross-reference the survey responses that we received from the physicists from what was observed. Through the audit, we found some areas of discrepancy. One example was responses about in-house clinic CT simulators and access to other diagnostic tools such as magnetic resonance imaging (MRI) and SPECT (single-photon emission CT)/CT for staging diseases. Public-2 has no inhouse CT simulator and uses the services of a private diagnostic center at an outside facility, but survey responses showed 3/8 physicists responded to having an in-house CT simulator. In addition, survey results suggested that Public-2 had a SPECT/CT scanner installed. However, the site visit showed that this device was not yet commissioned and in service. Also, although the survey responses indicated that the private clinic had an MRI, at the time of visit this scanner was nonfunctional. All 3 institutions responded that they performed daily, monthly, and annual kV and cone beam CT (CBCT) imaging QA. However, none of the institutions has kV imaging capabilities.

Some of these discrepancies in the survey results versus on-site visits could be because of a gap in the understanding of the technologies and techniques in use in the field. We provide a summary background on the path to becoming a medical physicist in Ghana, which entails graduates completing a minimum of 2 years postgraduate education at the University of Ghana's School of Nuclear and Allied Sciences. Local graduates are required by the medical physics professional association and the Allied Health Professional Council to complete a 1-year clinical internship after completing a 2-year academic program. This approach ensures that medical physicists with clinical qualifications receive at least 2 years of clinical training. The trainees are eligible to take a license examination at the end of their first year, which is regulated by the Allied Health Professional Council. In addition, a 4-year PhD program with both academic and clinical training components is available to students who want a further advanced degree in medical physics.

The graduate school has been the educational center for training medical physicists locally and from other African countries; however, the lack of technological resources in the country has caused some roadblocks, given the limited exposure to modern technology for a comprehensive clinical training during the intern years. Most of the interns demonstrate theoretical knowledge of concepts and techniques but lack the practical aspects, an issue that the stakeholders are aware of, and work is being done to bridge this knowledge gap.

The site visits also revealed added information that differed from the questions asked in the survey. One such observation was the absence of in vivo dosimetry performed for patients undergoing external beam radiation. Although Public-2 had newly purchased diodes for patient dose monitoring, these devices were in storage because of lack of vendor support to commission the diodes. In addition, Public-1 had previously received donated diodes for in vivo dosimetry, but at the time of the site visit these were not functioning. Another observation from the site visit was that physicists did not perform initial, weekly, or end-of-treatment chart reviews at any of the clinics. However, physicians and physicists performed an ad hoc review of the plans once they were completed.

In creating cancer care awareness, Public-2 has worked to increase the public awareness and shape the perception of the importance of seeking early treatment and reporting unusual findings to clinicians. The institution has collaborated with the local traditional medicine group and has appointed representatives to attend meetings, using these opportunities to educate the public.

Results

Survey results from the 13 RT centers in 6 countries

Responses were received from 12 of the 13 centers (92%). Four out of 12 (33.3%) were from an HIC, 5 out of

12 (41.7%) were from centers in UMICs, and 3 out of 12 (25%) of the centers were in a country categorized as LMIC by World Bank standards. All figures and tables relating to the preliminary study are included in the Supplementary Materials of this manuscript.

Respondents from UMICs (41.7%) and HICs (33.3%) reported that medical physics is a recognized profession in their countries, whereas all the respondents (25%) from the center in the LMIC reported that medical physics is a recognized health care profession under the ministry of health. Of the 12 physicists who participated in the study, 58% have a master's degree and 42% a doctoral degree.

Figure E1A shows the number of patients per year treated on external beam therapy with LINACs or Co-60 machines plotted against the GNIpc of the country in which the clinic is located. The clinics in the lower-income country have higher workload with values (greater than 1 per 500,000) that are comparable to other surveys in Eastern Europe and other regions.[12,24] One RT center did not provide any response on patients treated using external beam therapy equipment, and another center had only a Co-60 teletherapy device. Similarly, Fig. E1B shows the workload on the teletherapy machines in terms of the total number of fractions treated on each external beam machine per year. The RT centers in the lower GNIpc country had a higher treatment fraction workload compared with the recommended limit of 7500 fractions/year.[25]

The results also showed that all the centers surveyed had 3-dimensional conformal RT and 9/12 intensity modulated RT, with 1 center with total body irradiations and stereotactic radiosurgery, and this was a center in South Africa. The oldest external beam therapy device used at an institution was reported to be older than 15 years, with the median age of a LINAC being between 6 and 10 years. Seven out of 12 (7/12) centers use HDR brachytherapy for treatment of gynecologic cancers. Five out of 12 (5/12) centers reported not having HDR services. Centers with HDR reported they treated an average of 10 patients per week. Four of the 12 (4/12) centers have LDR brachytherapy, treating an average of 2 patients per week with this modality. Two centers have a combination of both LDR and HDR, and 2 centers reported neither.

To develop an overall sense for access to RT services in the countries surveyed, we plotted the number of RT machines per million populations for responding clinics in Fig. E1C.

We evaluated staffing for the workload at the centers by comparing the ratio of the number of patients treated per year to the number of physicians, physicists, and radiation therapists in each center, shown in Fig. E2.

Notably, all respondents indicated that the physicist at their centers provided both diagnostic and therapeutic services. This contrasts with other parts of the world where qualified medical physicists often provide only diagnostic or therapeutic services but not usually both.

Post site visit questionnaire responses from the 3 RT centers

Clinical practice

We received a 100% response rate to the post site visit questionnaire distributed to 17 different physicists. Two were from the private institution, 7 from Public-1, and 8 from Public-2. Three of the participants identified as chief physicists, and 2 identified as trainees who had taken on the role of physicist in the private institution because of a lack of physics staffing in their clinic. These were all the physicists who were currently practicing at the time of the visit to these clinics.

Although all 17 physicists identified as RT physicists, 9 identified as also working as diagnostic imaging physicists, 4 as nuclear medicine physicists, and 3 as health physicists.

An overview of the practices at these centers is shown in Tables E1 and E2, and Fig. 1 provides an overview of the practices at these centers. Figure E3 shows a breakdown of the staff workload detailing which staff are responsible for specific QA duties per TG-142 and 198 recommendations at each clinic, as well as a comparison between the physics staff workload per patient per year at each clinic.

From Table E2, the most treated disease sites in the 2 public institutions are breast, gynecologic, genitourinary, and head and neck cancers, consistent with patterns reported in literature.[26] For the commonly treated diseases, almost all the physicists responded to treating such diseases at their center, and about 2 physicists in both public hospitals responded to treating the diseases categorized as uncommon in Table E2. The results in Fig. 1 show that 3-dimensional conformal RT is the common treatment modality in all 3 RT centers visited, and Public-1 has the highest average daily patient workload of patients both on their LINAC and on their Co-60 machine (LINAC: private = 25, Public-1 = 55, Public-2 = 40; Co- 60: Public-1 = 45, Public-2 = 25). Observation from the visit revealed that the LINAC at Public-1 is not commissioned to produce electron energies. Table E3 lists the availability of CT simulations at the individual institutions, the treatment planning systems used, and the availability of other diagnostic tools to aid in cancer staging and image visualization by clinicians.

QA practices

Personnel who perform the daily, monthly, or annual QA in each institution are shown in Table E4 except for the private institution, where the physicists and trainees perform the daily QA. As mentioned earlier, one of the focal points of this study was to compare survey responses with what our team observed at the 3 clinic centers.

Table 1 lists the tests performed during daily, monthly, and annual QA. We assessed the frequency of intensity modulated RT patient-specific QA for Public-1 using a 5-point Likert system, and results show that on average 4/5

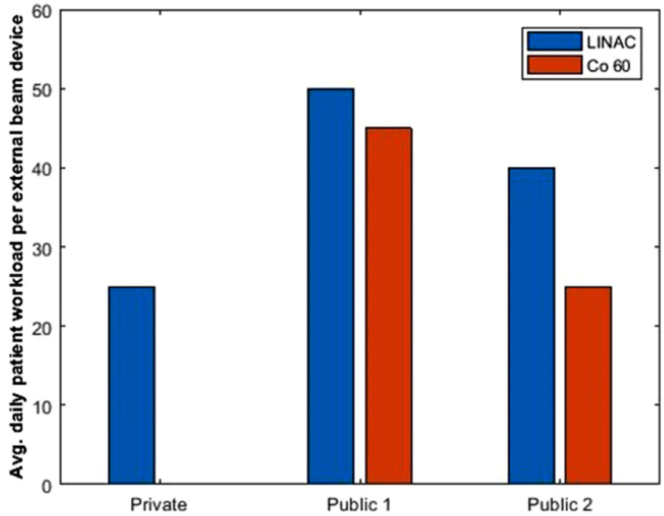

Figure 1 Treatment machine workload at the site-visit centers.

Table 1 Annual QA test performed at each radiation therapy center

Procedure	Test performed/device used	Private	Public-1	Public-2
Daily QA				
Output measurements	Photon/electron output measurement	✓	✓	✓
Mechanical checks	Laser localization	✓	✓	✓
	Distance indicator	✓	✓	✓
	Collimator size indicator	✓	✓	✓
Imaging***	Planar MV (EPID) imaging	✓	✓	✓
	Planar kV and MV (EPID)	✓	✓	✓
	Cone beam CT (kV and MV)	✓	✘	✘
Safety interlocks	Door interlocks, stereotactic interlocks, door closing safety, radiation monitor beam-on indicator, audiovisual monitors	✓	✓	✓
Monthly QA				
Output measurements	Photon/electron output measurement	✓	✓	✓
Mechanical checks	Light/radiation field coincidence	✓	✓	✓
	laser	✓	✓	✓
	ODI calibration	✓	✓	✓
	Gantry/collimator angle indicators	✓	✓	✓
	Graticule	✓	✓	✓
	Multileaf collimator positions	✓	✓	✓
	Jaw positions	✓	✓	✓
	Crosshair centering	✓	✓	✓
	Couch rotation iso-center	✓	✓	✓
	Treatment couch position	✓	✓	✓
	Accuracy of wedge placement	✓	✓	✓

(*continued on next page*)

Table 1 (*Continued*)

Procedure	Test performed/device used	Private	Public-1	Public-2
Safety interlocks	Door interlocks, stereotactic interlocks, door closing safety, radiation monitors beam-on indicator, audiovisual monitors	✓	✓	✓
Annual QA				
Dosimetry	Output factors, flatness, symmetry check	✓	✓	✓
	Beam quality			
Mechanical checks	Collimator rotation iso-center	✓	✓	✓
	Gantry rotation iso-center	✓	✓	✓
	Couch rotation iso-center	✓	✓	✓
	Electron applicator interlocks	✓	N/A	✓
	Coincidence of radiation and mechanical iso-center	✓	✓	✓
	Couch top sag	✘	✓	✓
	Gantry/collimator angle indicators	✓	✓	✓
	Couch travel maximum range movement in all directions	✓	✓	✓
Safety interlocks	Door interlocks, stereotactic interlocks, door closing safety, radiation monitors beam-on indicator, audiovisual monitors	✓	✘	✓

Abbreviations: CT = computed tomography; EPID = electronic portal device; MV = mega-voltage; ODI = optical distance indicator; QA = quality assurance.

physicists performed patient-specific QA using a 2-dimensional array phantom. Observation during onsite visit showed that secondary monitor unit (MU) calculations were performed prior to 3-dimensional treatments, and the physicist in the private institution performed clinical sets for electron treatment recorded in paper files. Our team helped in creating electronic documentation to help improve the current workflow.

Quality management and patient safety

The results for the operation challenges are shown in Fig. 2. Seventy-five percent of the respondents reported

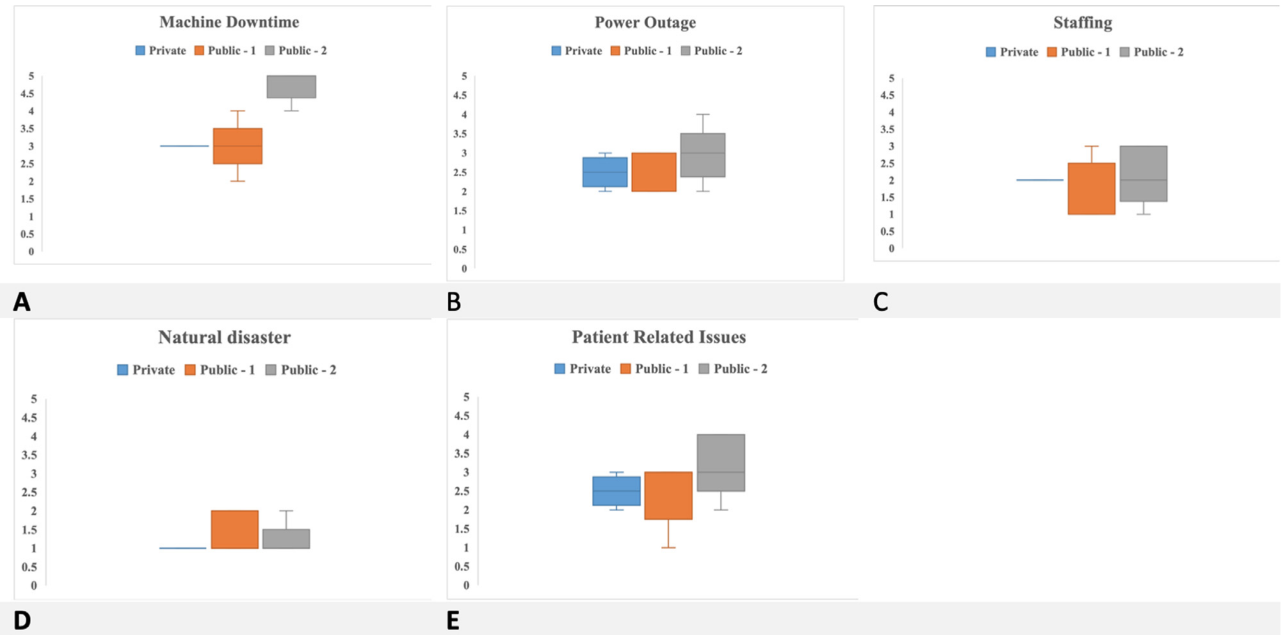

Figure 2 Clinic operational challenges: (A) machine downtime, (B) power outage, (C) staffing, (D) natural disasters, and (E) patient-related issues.

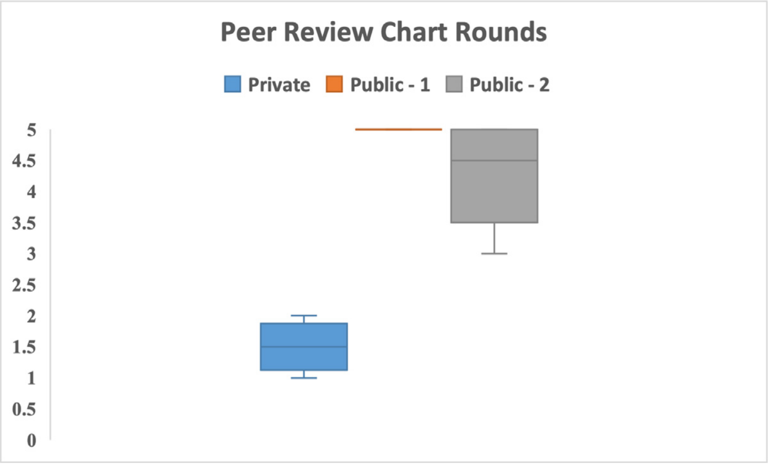

Figure 3 Peer review chart rounds.

that their institution has peer review chart rounds and the radiation/clinical oncologists, medical physicists, and physician and physicist trainees or interns mostly attend these. Sometimes radiation oncology nurses attend peer review chart rounds. Figure 3 shows that most peer reviewed chart rounds are completed before the first fraction of treatment.

All participants responded to having a system of documenting, tracking, analyzing, and trending patient safety–related incidents in their institutions. Further probe revealed that only the private institution had a hospital-wide system for charting patient safety–related incidents, and only 1 physicist from Public-1 uses the voluntary reporting and incident learning system from the IAEA Safety in Radiation Oncology.

Availability of equipment for QA

In this section, we combine the responses from the preliminary survey and the post visit questionnaire to assess the availability of QA devices in the centers we surveyed. Responses are shown in Tables 2 and 3.

Table 2 shows that there is a direct relationship between QA needs and the GNIpc of the RT center; centers in the LMIC (those indicated with *) reported more QA needs than those in UMIC and HIC countries. Table 3 shows that the equipment needs from the 2 public institutions were greater in comparison to the private institution.

In the preliminary survey, most of the centers (75%) responded to modeling their QA program after recommendations from the AAPM, 66.7% after the IAEA, and 16.7% according to local practices. Respondents expressed a wide range of needs for QA devices or equipment for both patient-specific QA and for their teletherapy machines that may improve their clinical practice.

Discussion

In HICs, there have been remarkable advancements in RT technology and medical physics QA, which has helped to achieve high-quality treatments. However, the availability of quality health care in RT varies widely in various parts of the world. The study reported here was conducted in 2 parts: (1) a preliminary survey of 13 RT centers in 6 countries, including all the RT centers in 5 of these countries (as one goal of this study was to probe the connection between medical physics QA and the availability of QA devices in less resourced clinics), and (2) a follow-up study including a site visit by our team in 3 of these centers in a single country to assess the validity of the survey results and to provide a foundation for a broader survey of medical physics practices across countries in Africa. There are very few studies in the literature reporting medical physics quality–related practices in the global context, and none, to our knowledge, which directly compare these practices and needs in countries across the development spectrum.

Countries included in this study are HIC (eg, Trinidad and Tobago, Barbados, and the Bahamas) but fall in the lower half of that income scale. We surveyed all radiation oncology practices in these countries and some similarities with operations in LMICs were observed. For example, Fig. E1A and B show the presence of Co-60 equipment with high patient and machine workload and Table 2 shows the need for medical physics QA devices.

A critical look at Fig. 1A and B shows that there are only 2 income groups as opposed to the 3 income groups reported earlier. This is because the UMIC and HIC are found in 1 group (in the 16,000-18,000 GNIpc range)

Table 2 RT centers in lower-income countries, UMIC, and HIC

Patient- or machine-specific QA needs					
UMIC and HIC	**In vivo**	**Secondary MU verification software**	**Machine QA needs**	**Calibration of dosimetry equipment**	**Other**
Center 1[*]	✘	✘	Array detector	✘	Film dosimetry
Center 2[*]	✘	Independent MU software	✘	Calibration of ion chambers	✘
Center 3[*]	Diodes, MOSFETS, TLDs	✘	Phantom for machine output checks	QA equipment	TPS test phantoms, imaging test phantoms, film dosimetry
Center 4[†]	✘	✘	✘	Calibration of dosimetry equipment	✘
Center 5	✘	✘	✘	✘	EPID dosimetry for VMAT/IMRT
Center 6	✘	✘	✘	✘	QA software
Center 7	✘	✘	✘	Calibration of dosimetry equipment	QA equipment
Center 8	✘	✘	Backup ionization chambers, electrometer	✘	Anthropomorphic phantom for TPS commissioning, education, and QA techniques
Center 9[†]	EPID-based in vivo dosimetry	✘	✘	✘	✘
Center 10	EPID-based in vivo dosimetry (required by law)	✘	✘	✘	IT infrastructure needs
Center 11[†]	✘	✘	✘	✘	QA software and equipment for transitioning to LINAC treatments
Center 12[†]	✘	✘	✘	✘	QA needs unspecified

Abbreviations: EPID = electronic portal device; GNIpc = gross national income per capita; HIC = higher income countries; IMRT = intensity modulated radiation therapy; IT = information technoloy; LINAC = linear accelerator; LMIC = low- and middle-income countries; MOSFETS = metal oxide semi-conductor field effect transistor; MU = monitor unit; QA = quality assurance; RT = radiation therapy; TLD = thermoluminiscence diodes; TPS = treatment planning system; UMIC = upper-middle income; USD = United States dollars; VMAT = volumetric modulated arc therapy.

* RT centers in LMIC.

† RT centers in HIC with limited resources.

Lower-income countries = countries with GNIpc <10,000 USD.

HIC = countries with GNIpc >10,000 USD.

Table 3 Equipment needs assessed in the 3 centers selected for site visit

Institution	Daily checks	Patient specific	In vivo	Machine QA needs	Calibration of dosimetry equipment
Private	✘	✘	Film	Solid water phantom	✘
				Graph paper	
Public-1	Array detectors	2D/3D diode array	Film	Front pointer, film, ruler	ADCL calibrated electrometer and ionization chamber
				Graph paper	
Public-2	Array detectors	2D/3D diode array	Film	Film, front pointer set	ADCL calibrated electrometer and ionization chamber

Abbreviations: 2D = 2-dimensional; 3D = 3-dimensional; ADCL = acredited dosimetry calibration lab; QA = quality assurance.

because the HICs that we surveyed fall at the lower end of the HIC range[21] of GNIpc. The GNIpc ranges from as much as 110,000 USD to as little as 12,000 USD. Countries like Trinidad and Tobago, Barbados, and the Bahamas are listed as HICs but fall in the lower half of that income scale. This creates a false perception that there is no correlation between GNIpc and the machine workload and the need for QA equipment for physics QA. Also, having some QA items is not sufficient for the QA measurements needed to be performed by medical physicists per TG-142 and 198 recommendations, which is worth drawing attention to. Also, it is interesting that Co-60 units form a larger fraction of the higher income machines, and this is a practicality and underscores the need for this work, as some countries that are categorized as UMIC or HIC still have RT centers that operate with Co-60 and other limited resources.

From Fig. E1C and Table 2, the LMICs had a higher workload per teletherapy machine, greater than 500 patients per teletherapy machine. These clinics expressed a greater need for physics QA equipment such as TPS test phantoms, imaging test phantoms, secondary dose calculation software, array detectors, and diodes for in vivo dosimetry. This was in contrast to the UMICs, which had workloads of about 450 patients or less per teletherapy machine, in keeping with recommendations by the IAEA,[27] and which reported more advanced technologies for QA such as electronic portal device dosimetry and IT infrastructure to support QA measurements and data collection.

Another important finding of this study relates to the guidelines that govern QA practices. The data presented here suggest that RT centers in LMIC follow AAPM, IAEA, and other local guidelines in their countries. However, these documents are written for clinics in HICs and may be challenging to implement in other environments with fewer resources given the available infrastructure.

In this study, we assessed the staff workload in each of the 13 centers (Fig. E2). These data show that on average there were 360 patients/year/physicist and 210 patients/year/radiation oncologist (or therapist). In the site visit, none of the 3 clinics reported a lack of staffing in their centers, consistent with the survey results. These staffing levels are comparable to benchmark data from the Health Economics in Radiation Oncology audit initiative[28] and contrast with publications that indicate the lack of staffing in RT centers in LMICs.[29] However, there are several limitations to these results. First, this work is exploratory and does not give complete information in a broader context given the number of centers. Second, medical physicists in these areas often perform dual and multifunction roles in radiation therapeutics, radiation diagnostics, or nuclear medicine, and a recent newsletter from the Federation of African Medical physics organizations revealed there are about 1041 medical physicists in RT centers serving an African population of over a billion.[30] Hence, as we continue to expand this study, we hope to gain further insight into the question of staffing. More broadly, this study highlights a need for increased access to quality RT services and puts the focus on the staffing QA measures and equipment needed to support it. All centers surveyed in the preliminary survey had fewer than the current recommendation of 1 teletherapy machine per 250,000 population.[31] Also, from the data presented in the preliminary survey, there may appear to be an underutilization of teletherapy equipment regarding number of patients treated, although literature suggests countries with fewer resources have an equipment shortfall. There are several factors that account for the data looking like RT equipment is underused. We asked the centers to report the number of patients treated on the average, but from verbal conversations, a significant percentage of the patients do not complete their treatment because of cost and access to the RT centers. Also, 3 of the centers recently had transition from Co-60 to conventional LINAC and this may account for the underutilization of the teletherapy equipment, although literature may suggest otherwise.

Onsite visit and validation of the survey

Although the survey results reported provide interesting information in themselves, we sought further validation of the results. In the second part of this study, therefore, we undertook to validate the survey results by performing a visit and auditing the survey responses from all the RT clinics in 1 LMIC country. The overall goal of this is to better inform future surveys, and our long-term goal is to develop a comprehensive understanding of medical physics QA practice in LMIC countries.

Data reported in the preliminary survey echoed the data gathered during the site visit. In both studies, medical physicists provided services in more than 1 physics discipline. For external beam treatment delivery, 3-dimensional conformal treatment remains the most common type of treatment delivery, and breast, genitourinary, gynecologic, and head and neck remain the most widely treated cancers in the 3 centers.

Through the site visit audit, we found the answers to the survey were valid, for example, the QA procedures performed, the personnel responsible, and the equipment available for performing the procedures or the lack thereof. The site visit gave our team an understanding of the type of clinical practice through detailed observations of the physicians and physicists onsite. For the most part, the specific QA tasks were performed by individuals recommended to perform such tasks per AAPM written recommendations. In terms of patient workload per physicist, the private institution had the highest workload per physicist in comparison to the public institution, given the public institution employs over half of the medical physicists trained in the country and per the data provided in Fig. E3. With fewer physicists employed in the private facility there is an increased burden on the physicists, which leaves room for a lot of preventable errors.

There were some responses provided in the survey that did not match the reality of operations. Examples were the survey questions about in-house CT simulators and other diagnostic tools such as MRI and SPECT-CT. Public-2 has no in-house CT simulator and uses the services of a private diagnostic center as well as the services of the radiology department, but survey responses showed 3/8 physicists responded to having an in-house CT simulator. Similarly, although the survey response indicated the private clinic had an MRI at the time of visit, the equipment was not in service. Additionally, at the time of the visit, Public-2 had a SPECT/CT scanner installed but it was not commissioned, so although the survey response shows the availability of the SPECT/CT, the patient population did not yet have access to the equipment.

To address these discrepancies, we recommend that future surveys rephrase such questions and ask if participating centers have functioning equipment and follow it up with questions that probe on how to better support based on the responses. This is because although some equipment may be available in the clinics, it may be non-functioning or may have been purchased and installed but not available for patient treatment or diagnosis.

Another example of a discrepancy is the response about daily, monthly, and annual kV and CBCT imaging QA. All 3 clinics responded to performing this QA; however, none of the institutions have kV imaging capabilities. This discrepancy could be because of the lack of exposure to these technologies, resulting in the inability to accurately respond to questions about planer kV and CBCT image guidance systems, as none of the institutions have either. In future surveys we recommend asking specifically if the clinics have a functioning in-room kV imaging system (eg, rail-track mounted, ceiling/floor mounted, gantry mounted, etc).

Although physicists reported the lack of total body irradiations/total skin electron treatment test phantom and Winston Lutz phantoms as devices they need, none of the centers deliver any treatment services that require the need of such phantoms for QA. Additionally, physicists did not report needing secondary MU verification software, as shown in Table 3. Follow-up questions during the site visit revealed that this is because physicists in the 2 public institutions reported using a custom MU calculation software built in-house. Therefore, this did not show up in the request for devices or equipment for QA support.

It should be noted that the site visit revealed added information not gathered from the questions asked in the survey. One such observation was the absence of in vivo dosimetry and routine physics chart checks performed for patients undergoing external beam radiation. The report of the AAPM task group 62[32] explains that in vivo dosimetry is the most direct method for maintaining the dose delivered to patients receiving RT. The report further explains that in vivo dosimetry provides an additional safeguard against transcription errors that were missed during pretreatment chart check for clinics that do not perform in vivo dosimetry. This presents an opportunity to improve the safety and quality of care.

In addition, the absence of routine patient plan and chart review presents another issue in the management and quality of care delivered. As noted in the results, none of the clinics performed a physics weekly or end-of-treatment chart review, although physicians and physicists always reviewed the plans once they were completed. Apart from 1 clinic, the other clinics performed peer-review chart rounds. It should be noted that one of the key challenges noted in the AAPM task group report 275[33] is present here, namely the manual recording of patient information in 2 of the clinics. This results in a lack of standardization of data transfer, which makes it difficult to implement the recommendations of the task group. Implementing a physics plan and chart review program in clinics with less IT infrastructure presents a challenge and potential for future study including comparative risk profiling. A future goal is to work with the physicists in the 3 institutions about the importance of in vivo dosimetry and routine patient chart checks. Some of this work is underway. For example, as part of our initiative to work with the physicists to improve best practices in the private and Public-2 institutions, our team helped put together documentation for monitoring monthly QA outputs and an electron calculation sheet for patients receiving electron treatments.

The site visits also provided additional data beyond the preliminary survey. One aspect was an assessment of the most important challenges for operations and patient treatments. As shown in Figs. 2 and 3 aspects present the most significant challenges, namely machine down time, infrastructure, and patient-related issues. In 1 clinic, machine downtime was a significant challenge. Machine downtime and interruptions in the clinic workflow due to the instability in power outages caused interruption in patient schedules, which led to some patients not completing their scheduled treatments. All 3 clinics reported having a system within their clinics for incident reporting, and only 1 physicist reported using the IAEA Safety in Radiation Oncology.

Observations made from the visit showed that education, training, and exposure to newer technologies are important to improve the skills and expertise of physicists in LMICs and translate into the quality of care that patients receive. Finally, an interesting observation from the visit was learning the innovative ways the institution has worked to increase the public perception of the importance of seeking early treatment and reporting unusual findings to clinicians. Public-2 institution has registered and collaborated with traditional medicine groups and has appointed a representative to attend meetings, using that as an opportunity to educate the public.

Conclusion

We conducted a preliminary survey and a follow-up assessment of physics QA and management practices in RT centers with fewer resources to better understand clinical practice, develop support plans, and establish collaborations. Our preliminary study showed a direct correlation between QA needs and the development index of a country. Although not quantifiable, observations and interaction during onsite visits also showed that education and training remains the most important need in these areas in operating successful local physics QA and safety programs. These results provide an important baseline for future studies and will inform our future work of a first continent-wide survey intended to explore physics QA practices in LMICs.

Disclosures

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

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