Surveying the challenges of providing LINAC-based RT in Africa: A unique collaborative platform of all 28 African countries to improve access to treatment

Authors: Taofeeq Abdallah Ige [1,2], Alexander Jenkins[3], Graeme Burt[4], Deepa Angal-Kalinin[5], Peter McIntosh[5], C. Norman Coleman[6], David A. Pistenmaa[6], Donna O'Brien[6], Manjit Dosanjh[3,6,7*]

Affiliations:

[1] National Hospital Abuja, Abuja, Nigeria
[2]University of Abuja, Abuja, Nigeria
[3] University of Oxford, Oxford, UK
[4]University of Lancaster, Lancaster, UK
[5]STFC Daresbury Laboratory, Warrington, UK
[6]International Cancer Expert Corps, Washington, DC.
[7]CERN, Geneva, Switzerland

*Correspondence to: Manjit Dosanjh, PhD, International Cancer Expert Corps, 1608 Rhode Island Ave NW Suite 243. Washington DC 20036 manjit.dosanjh@cern.ch + 41 75 411 47 25

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Abstract

Radiation therapy (RT) for the curative treatment or palliation of symptoms due to advanced cancers is critical for over half of all patients with cancer, yet there is a global shortage in access to this treatment, especially in Sub-Saharan Africa where there is a shortage of technical staff as well as equipment. Linear accelerators (LINACs) offer state-of-the-art treatment but this technology is high cost to acquire, operate and service, especially for low- and middle-income countries (LMICs), and often their harsh environment negatively affects performance of LINACs causing downtime. A global initiative was launched in 2016 to address the technology and system barriers to providing RT in LMICs through the development of a novel LINAC-based RT system designed for their challenging environments.

As the LINAC prototype design phase has progressed, it has been recognized that additional information was needed from LMICs on the performance of LINAC components, on variables that may influence machine performance and their association, if any, with equipment downtime. Thus a survey was developed to collect these data from all countries in Africa that have LINAC-based RT facilities. In order to understand the extent to which these performance factors are the same or different in high-income countries (HICs), facilities in Canada, Switzerland, U.K. and the U.S. were invited to participate in the survey as was Jordan, a middle-income country (MIC). Throughout this process LMIC representatives have provided input on technology challenges in their respective countries. This report presents the method used to conduct this multi-level study of the macro- and micro-environments, the organization of departments, the technology, the training and the service models that will provide input into the design of a LINAC prototype for a LINAC-based RT system that will improve access to RT and

thus improve cancer treatment outcomes. A detailed analysis of data is underway and will be presented in a follow-up report. Selected preliminary results of the study are the observation that LINAC-based facilities in LMICs experience downtime associated with failures in multi-leaf collimators and vacuum pumps as well as power instability. Also that there is strong association of gross national product (GNP) per capita with the number of LINACs per population.

Introduction

Radiation therapy is a critical component for curative and palliative treatment of cancer and is considered a necessary component of treatment for over half of all cancer patients.[1] There is, however, a global shortage and disparity in the access to RT leaving a tremendous void in the multidisciplinary care of cancer patients, especially for patients with advanced cancers for whom treatment with both chemotherapy and radiotherapy is indicated. In recent reports, only 10-40% of the approximately 4.0 million cancer patients annually in LMICs who required RT were able to access such treatment. [2,3,4,5] With many LMICs having inadequate or, in many cases, no RT centres, it is projected that approximately 12,600 RT machines will be needed globally over the next 2-3 decades to meet the demand in LMICs.[6,7]

Many LMICs provide RT using cobalt-60 technology because these treatment units are generally less expensive than LINACs , are less dependent upon local infrastructure and are easier to operate and maintain. Current cobalt-60 machines incorporate multi-leaf collimators that improve the efficacy of treatment with fewer adverse effects. However, the greater depth-dose penetration of x-ray beams from LINACs can decrease the adverse effects of treatment relative to cobalt-60 machines even with comparable treatment techniques. LINACs are preferred by radiation oncologists for their technical capabilities to deliver complex curative and palliative treatments but a dilemma for LMICs is that currently available LINACs are significantly more expensive, complex and labour-intensive to operate and maintain than are cobalt-60 machines. Now being better appreciated in the overall cost of operation of cobalt-60 machines is the expense of radioactive source replacement and disposal, in addition to the reduced treatment capacity due to increased treatment time per patient as the source decays. As pointed out by Healy, et al[8], these technical factors that pose particular challenges in LMICs must be considered in terms of the complex economic, physical infrastructure, societal priorities and workforce shortages that can influence the ability of these countries to provide cancer treatment using LINAC-based RT technology in lieu of or in addition to treatment with cobalt-60 machines.[7] An unrelated concern about cobalt-60 machines is the potential terrorist risks posed by the radioactive material in cobalt-60 machines.[9] This is of special concern in selected regions of Africa where there is significant terrorist activity.

Recognizing that addressing the barriers to providing LINAC-based RT in LMICs would require multilevel global collaborative strategies, including public-private partnerships, multi-disciplinary collaboration, industry partnerships, innovative strategies and support from healthcare systems and governments, the International Cancer Expert Corps (ICEC) sponsored an international workshop hosted by CERN in Geneva in 2016. Participants included experts from the fields of oncology, accelerator physics and healthcare as well as representatives from industry and government-funded science institutes from around the world.[10,11,12] In addition to confirming the shortage of LINACs (and associated software packages that constitute a RT system) in LMICs, the workshop identified a significant shortage of adequately trained personnel at all levels of responsibility as noted by Barton, et al [12] and Eriksen.[13] The need for postgraduate education in radiation oncology and considerations in providing it in LMICs are also presented by Eriksen.[13] Other specific challenges to overcome in LMICs are a lack of resources for investment in healthcare, environmental conditions that affect the performance of sophisticated RT technology (power, electricity, clean water), insufficient space to house new equipment, the cost of the technology and the shielded facility and the high cost of servicing and maintaining LINACs.

The ongoing collaboration established at this workshop includes personnel from ICEC, CERN, the U.K. Science and Technology Facilities Council, Lancaster University and University of Oxford. They have been joined in this effort by experts representing several LMICs. All participants have a common goal of developing an affordable and high-quality LINAC-based RT systems solution for challenging environments based on recognition that there are substantial opportunities for scientific and technical advancement in the design of the LINAC and the associated elements of a RT system. These considerations have been discussed and debated in several subsequent design workshops that included LMIC stakeholders. [14,15,16] The results of the subject survey will benefit the funded ITAR (Innovative Technologies towards building Affordable and equitable global Radiotherapy capacity) initiative by providing critical information on persistent shortfalls in basic facility infrastructure, RT equipment and the specialist workforce.[17,18] Some of the opportunities to improve LINAC design that are being explored include: extending the life of LINAC sub-system components, making components easier to replace, reducing the dependency on highly trained internal staff or external service personnel to avoid associated delays in the repair of equipment and minimizing the impact of highly variable electricity supply. Another survey that is nearing completion is designed to assess current general staffing levels in 28 African countries that provide LINAC-based RT. It will be reported separately.

The absence of detailed statistical data regarding the exact effects that challenging LMIC environmental factors have on LINAC downtime and failure modes presents a critical barrier in determining design features to improve the performance of current LINAC technology. A limited LINAC-based study looking at barriers to providing RT services by facilities in Gaborone, Botswana and Abuja, Nigeria compared to Oxford, UK was conducted in 2018 by Wroe et al.[19] They reviewed the equipment maintenance logs of LINACs in single locations in each of the three countries.[19] Later, at a technical design workshop held in Washington DC in 2019, it was determined that the ongoing design and prototyping process required more detailed and comprehensive information on equipment failures, maintenance and service shortcomings, personnel, training, country-specific healthcare challenges, etc. from a much larger representation of LMICs. That decision led to the survey that is the subject of this paper, namely a study to collect data to make better informed decisions on the re-engineering needed to produce a novel, robust, modular and more effective LINAC for use in LMIC environments.

Methods

Data collection in HICs and MICs is relatively straightforward, however, in LMICs it is a substantial effort to build the trusted partnerships, collect initial data and further refine data collection and analysis within newly formed collaborations. The few existing data sets regarding the average number and types of radiation therapy units in African countries provide mainly high-level data.[1-5,20-23] What is needed are more data from the radiation oncologists and medical physicists in LMICs who use LINAC technology and who can provide the detailed information required to improve RT technology. Unfortunately, there is commonly a lack of these resources to gather data in African countries and in other LMICs because such surveys are limited by the extent of participation. That the painstaking work required to secure the commitment of a network of experts in LMICs – already facing overwhelming challenges to provide treatment to cancer patients – is based on trust and a sense of common purpose is well known to those working in global health.[24-27] The inclusion of LMIC representatives was central to this project from its inception. Strong relationships were established around a common goal.

In a few months we succeeded in securing the commitment of radiation oncologists and medical physicists from RT facilities in all 28 countries in Africa that have LINAC-based RT (Figure 1) to participate in the survey and have obtained preliminary data. We believe that the level of cooperation of the oncologists and medical physicists in the future has been enhanced by recognizing them as co-authors on a book chapter in " Approaching Global Oncology: The win-win model"related to this survey and in the acknowledgment to this article. Through their interest and commitment, the oncologists and medical physicists from the 28 African countries have created a platform suitable for subsequent collaborative efforts through which further details on possible LINAC design changes to overcome environmental and other challenges to RT delivery in LMICs can be determined and, equally important, can address issues of staffing and staff training as well as problem solving by way of ancillary technological improvements through artificial intelligence (AI) and machine learning (ML). Another area for future investigation - and ultimately implementation of improved treatment capacity and capability -

is to obtain data on the type, stage and incidence of the various cancers in the participating countries. These data will contribute to a much better RT system that will improve access to RT equitably for patients with cancer in all countries in Africa as well as to patients globally.

Figure 1. Map showing the location of all 28 African countries with LINAC-based RT that responded to the survey. Countries which are not shaded do not have LINAC-based RT.

Scores of cancer providers and medical physicists interested in improving access to and the quality of cancer care globally have been involved from the outset of this project in 2016 to develop a better LINAC and the rest of the RT system. With input from stakeholders, a survey questionnaire was constructed to obtain maximum information for defining design parameters to improve access to LINAC-based RT in LMICs (Appendix A). The survey questionnaire was sent by TI to the designated facilities in the 28 African countries by personal communication. As shown in Table 1 that summarizes the questionnaire, the survey includes questions related to macro-environmental metrics among the 28 African countries with LINACs (see Figure 1) related to structure of and investment in healthcare systems, investment in infrastructure and economic capacity that influence access to RT.[1-5,28-30] Because of these variations in settings across the LMICs, the detailed analysis will examine factors for each country in the macro-environment section of Table 1. In addition to differences described above that influence access to RT,[1,2] there are also differences among countries in cancer incidence including the top three cancer types for which treatment with RT is needed .[2,5,21,22,23]

Micro-environmental metrics being surveyed and analyzed (see Table 1) include for each facility: a) LINAC manufacturer, model and age; b) facility environment (e.g. humidity and room temperature); c) reliability of electrical power; d) availability of equipment service and maintenance; e) critical LINAC sub-system information such as radiation production, electromechanical collimation of the x-ray beam, power consumption and heat dissipation; and f) safety as well as information on diagnostic imaging, treatment capability, training and technical support. Understanding how these conditions affect access to LINAC technology, especially downtime, in LMICs compared to HICs has not been studied extensively. [19] Therefore, a comparison with HIC facilities in the U.S., Switzerland, U.K. and Canada as well as a facility in Jordan, a MIC, was added to the current survey. As expected, data is more readily available from facilities in HICs by way of providers and professional societies.

Table 1. Selected metrics by country and the data sources that are used in the survey.

Level	Metric by country	Data source
Macro-Environment	World bank classification	World Bank
	GNP per capita	World Bank[24]
	Population	UN[25]
	# LINACs	IAEA DIRAC[15]
	Average temperature and precipitation	World Bank[26]
	Power outages by country	World Bank[26]
	Cancer incidence	WHO
	Top three cancer disease sites	WHO
Micro-Environment Healthcare Organization	Space dimensions and shielding	Survey
	Room temperature and humidity	Survey
	Internet reliability	Survey
	Power stability	Survey
	Water quality	Survey
	Utilization – patient volume	Survey
Technology Performance Support	Staff expertise	Survey
	Local maintenance capability	Survey
	Service contract	Survey
	Availability of spare parts	
Technology	Manufacturer	Survey
	Model	Survey
	Age	Survey
	Ancillary features (imaging, couch)	Survey

Results

Comparative data on LINAC access

Preliminary data developed by ICEC showing the marked variation in LINAC-based RT capacity (the number of people served by each LINAC) across the continent of Africa is presented in Table 2 and also is shown graphically in Figure 2. There are varying benchmarks for the recommended number of RT units per population. For this paper, the number of RT units needed and RT capacity in Table 2 are based on the IAEA recommendation of 1 RT unit per 200,000 population.[20] Although 28 African countries have LINAC-based RT facilities, 27 other African countries, unfortunately, have no LINAC-based RT facilities whatsoever. The majority of LINACs in Africa are found in the Mediterranean countries (227) and in South Africa (97).[20] The lack of RT capacity is especially pronounced in the Sub-Saharan region where most of the 27 countries that do not have LINAC-based RT are located. Unfortunately, almost all of the countries in the Sub-Saharan region that do have LINACs have very few such machines in proportion to their populations. The ratio of the number of machines to people in the 28 countries with LINAC-based RT facilities ranges from one machine to 423,000 people in Mauritius, one machine to almost five million people in Kenya[20] and one machine to over 100 million people in Ethiopia. In comparison, in HICs such as the U.S., Switzerland, Canada and the U.K., the ratio is one RT machine to 87,000, 119,000, 134,000 and 195,000 people, respectively. Jordan has a ratio of one RT machine to 762,000 people.[20] To draw a stark comparison, Africa has approximately one LINAC per 3 million people whereas the U.S. has 1 LINAC per 87,000 people, a factor of 35.[20]

Table 2: Access to radiation therapy in 28 African countries with LINACs compared to access in 1 middle-income country (Jordan) and 4 high-income countries shown in order of best access to RT (most LINACs per population) to poorest access to RT (fewest LINACs per population).

COUNTRY	POP. IN MILLIONS	POP./ MACHINE	RT UNITS IN USE	RT UNIT NEEDED	RT CAPACITY (%)
USA	331	87,000	3827	1655	231.2
Switzerland	8.6	119,000	72	43	167.4
Canada	37.6	132,400	284	197	144.2

UK	67.9	195,000	348	340	102.4
Jordan	9.9	762,000	12	50	26
28 AFRICAN COUNTRIES WITH LINACs					
Mauritius	1.27	423,000	3	6	50.0
Tunisia	11.7	509,000	23	58	39.7
S. Africa	59	608,000	97	295	32.9
Egypt	102	857,000	119	510	23.3
Morocco	36.9	880,000	42	184	22.8
Gabon	2.2	1.1M	2	11	18.2
Libya	6.9	1.15M	6	34	17.6
Algeria	43.8	1.18M	37	219	16.9
Namibia	2.5	1.25M	2	12	16.7
Zimbabwe	14.8	2.1M	7	74	9.5
Botswana	2.3	2.3M	1	11	9.1
Mauritania	4.6	2.3M	2	23	8.7
Kenya	53.8	4.89M	11	269	4.1
Rwanda	10.5	5.25M	2	52	3.8
Senegal	16.3	5.43M	3	81	3.7
Sudan	43.9	5.49M	8	219	3.7
Zambia	17.9	6M	3	89	3.4
Ghana	31.0	7.75M	4	155	2.6
Angola	32.9	11M	3	164	1.8
Tanzania	59.7	11.9M	5	298	1.7
Cote d'Ivoire	26.4	13.2M	2	132	1.5
Madagascar	27.7	13.85	2	138	1.4
Mali	20.2	20.2M	1	101	1.0
Nigeria	206	29.4M	7	1027	0.7
Cameroon	26.5	26.5M	1	132	0.8
Mozambique	31.2	31.2M	1	156	0.6
Uganda	45.7	45.7M	1	228	0.4

Ethiopia	115	115M	1	575	0.2

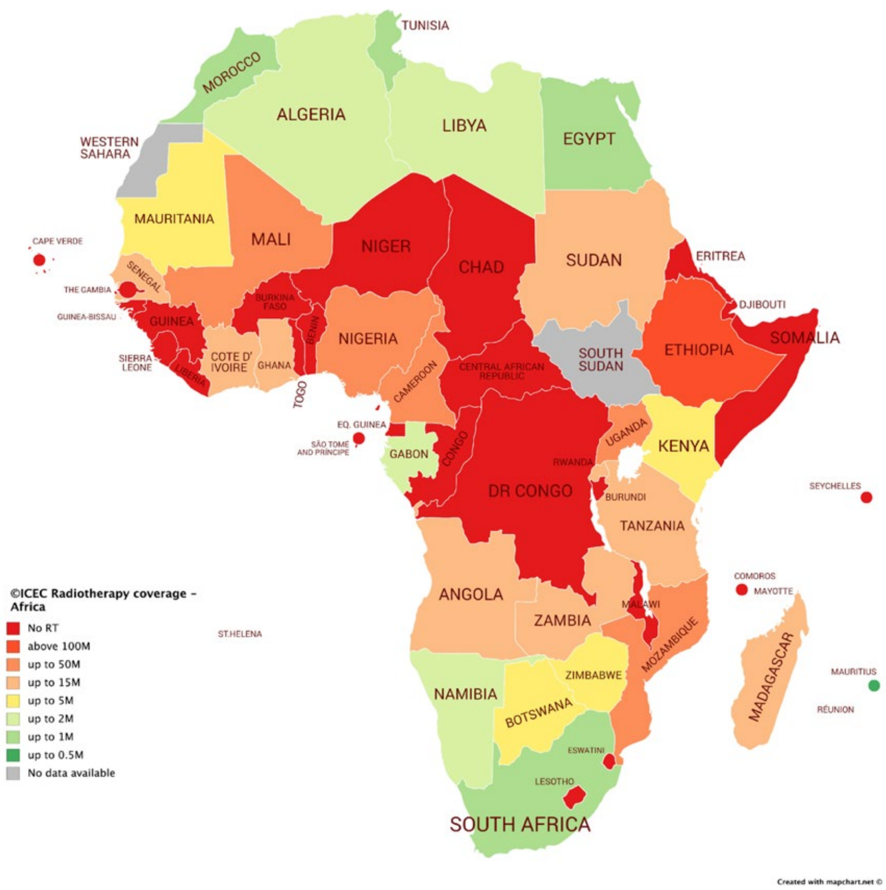

Figure 2. Graphic representation of preliminary data developed by ICEC that shows the marked variation across Africa in LINAC-based RT capacity (the number of people served by each LINAC).

Ongoing analysis

At this point in the data collection and analysis, there are 100 LINACs in the two arms of the study representing a number of manufacturers. It is not the intent of this effort to compare the equipment by manufacturer but rather to address the commonality of problems in infrastructure and in the RT systems that will provide information to produce effective design solutions. The data will allow for the determination of those characteristics of LINACs and radiation treatment procedures that can be improved by technology (hardware and software) in order to enhance the capability and capacity of LMIC facilities to treat cancer patients. The ongoing detailed multi-level and multi-variate analyses of the data obtained in the survey will be used to assess the relationship between each data variable and LINAC downtime. In addition to information related to survey variables that affect the performance of LINACs, our analysis includes data related to the level of resources of each country in terms of GNP (Gross National Product) per capita and the number of LINACs per country population. GNP per capita is generally associated with the extent of healthcare infrastructure and investment.[28-30] Because of these variations in settings across the LMICs, this study also analyzes factors for each country in the macro-environment section of Table 1.

Of interest, our initial analysis shows a strong association of GNP per capita with the number of inhabitants per RT machine, consistent with this relationship shown in other studies.[1-5,28-30] The countries in Africa with LINAC-based RT facilities fall into two clusters as shown in Figure 3. The countries in Sub-Saharan Africa principally constitute the cluster with the poorest access to RT(upper left). The cluster of HICs shown in the lower right of Figure 3 have high GNPs per capita and the greatest access to RT. The cluster in between shows a strong representation of northern African countries that generally have higher GNPs per capita. Jordan falls in the favourable (right) side of the middle group.

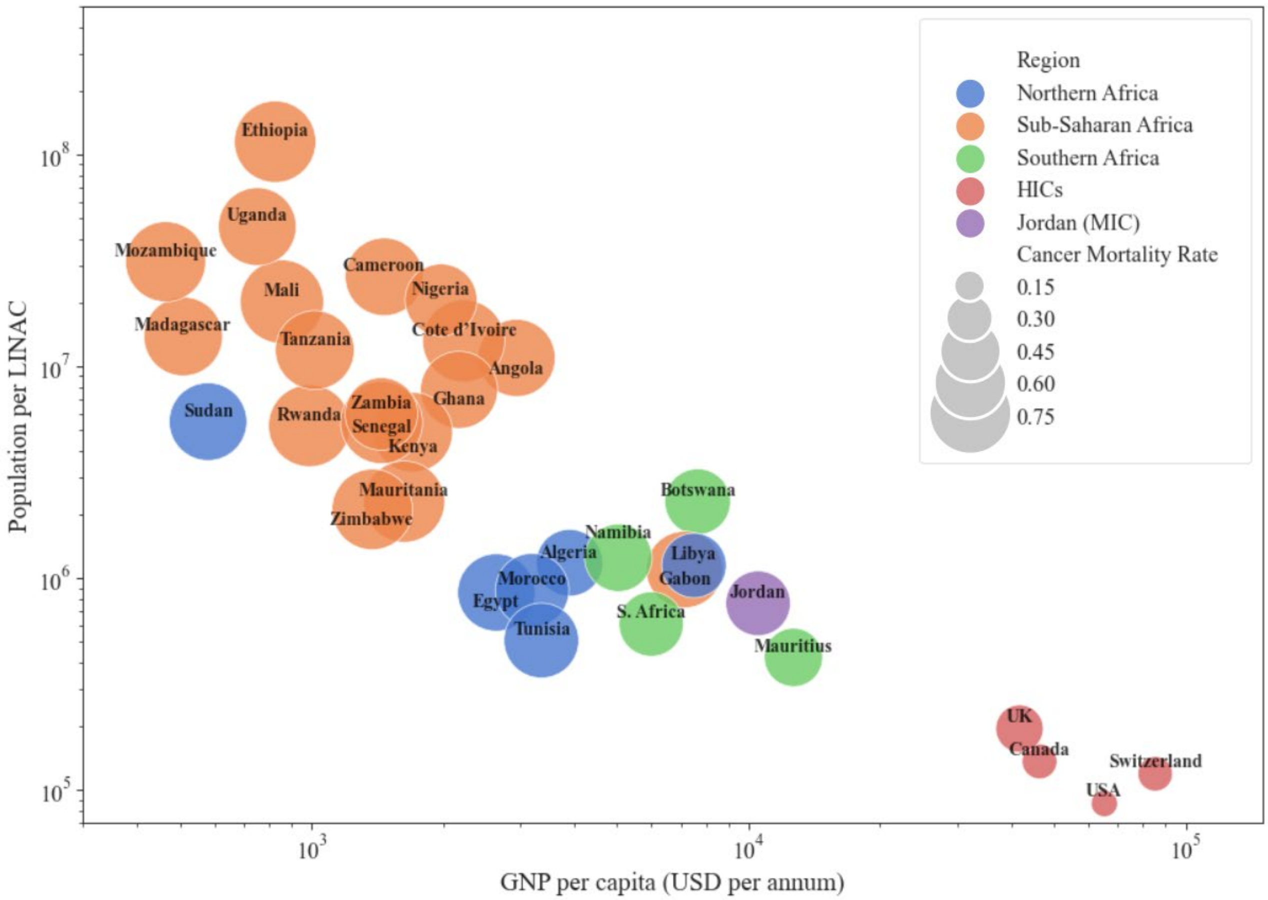

Figure 3: Countries in the Study Plotted Graphically by GNP per Capita and the Ratio of Inhabitants to RT Machines

Among the micro-environmental findings regarding technology reported by the RT facilities in the 28 African countries that have LINACs are that downtime appears to be associated with vacuum pump and multi-leaf collimator failures as well as power instability. This is consistent with the previous findings of Wroe et al.[19] Thus, minimizing the frequency of vacuum pump failures is a major factor for consideration in the design of LINACs specifically for LMIC settings in conjunction with recommending improvements in preventive maintenance programs. Further analysis will provide information on how these and other equipment failures are managed such as by maintaining spares for selected components, having staff expertise or contracts for servicing LINACS and the extent to which these measures influence downtime. Overall, the operational reliability of LINACs as solicited by the survey of facilities with LINAC-based RT across the 28 African countries, shows unscheduled downtime levels from several weeks to 10's of weeks per year (see Figure 4). This most certainly identifies a direct and critical need to significantly improve the operational robustness of these and other LINAC-based RT clinical treatment facilities.

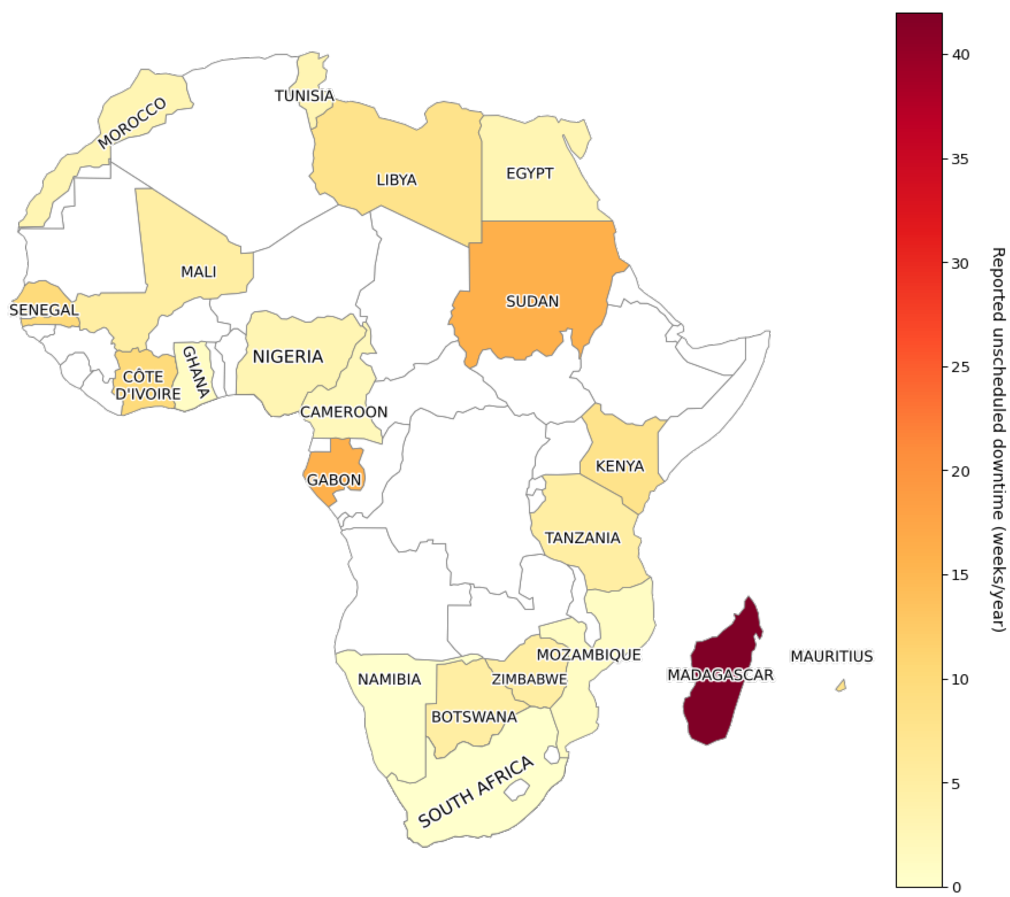

Figure 4: Reported unscheduled downtime for operational LINAC-based RT facilities in weeks/year.

These results will be compared to the experience with LINACs in MICs and HICs. One limitation of the study is the fact that complete information on service contracts was not provided by all respondents because medical physicists did not always have access to all of the administrative information that was requested.

Further data acquisition to “fill in gaps” in the desired data is ongoing and will be analyzed in a subsequent report. The participating MIC and HIC RT facilities represent a variety of settings in terms of economic resource levels, healthcare infrastructure, public and private hospitals and different manufacturers and ages of the RT machines which will provide insights on the differential influence of these variables on technology performance. Data from facilities in HICs can help discern whether resources or environmental factors, or both, affect LINAC performance in LMICs. Interestingly, this study can address whether new technologies designed to improve the reliability of RT machine performance in LMICs can have potential benefit in HICs.

Conclusion

This study has provided an important snapshot of a dynamic healthcare situation in Africa as exemplified by Togo’s acquiring a dual energy linear accelerator since we initiated our survey and that Ethiopia has acquired several linear accelerators, yet to be installed, to complement their one operational LINAC. Hopefully, this is the beginning of a wave of LINAC acquisitions in Africa. As additional data are obtained, we will be able to provide a detailed analysis of the factors most commonly associated with LINAC performance, especially downtime, in LMICs. This may provide information of interest to management and health policy officials in HICs and

MICs as well as to those in LMICs regarding the potential to mitigate some of the factors that affect LINAC downtime in the current environment in LMICs. The ongoing data analysis, an understanding of what aspects of the improvements are most critical and the implementation of solutions can contribute to improving the timely and effective treatment of patients with cancer thereby reducing mortality as well as improving the palliation of symptoms caused by advanced cancers, a common problem in LMICs.

Clearly, a one-size-fits-all approach will not work in such diverse settings. However, aggregating the detailed responses, opinions and suggestions from the teams of medical physicists and radiation oncologists that participated in this report forms the basis for the development, both from “bottom-up” data and “top-down” experience, of a set of critical solutions appropriate for each setting.

Critical for the success of this study was the establishment of a productive global collaboration among the scientific and medical communities, as previously demonstrated by the ENLIGHT network,[27,28] that includes healthcare representatives from MICs, HICs and LMICs, that latter uniquely represented by facilities in all 28 African countries with LINAC-based RT. All participants are joined in the common purpose of improving access to LINAC-based RT in LMICs. The high level of engagement by individuals and participation of individuals in African facilities in this study was achieved primarily due to the trust developed among participants that was established during this multi-year collaboration. This collaboration with and among oncologists and medical physicists in Africa forms an invaluable asset not only for the attainment of the goals of the study but as a platform for subsequent informative surveys to evaluate the effects of improvements in care that are implemented and other innovations in cancer care.

In summary, the ultimate aim of this study is to target RT technology developments to produce a robust linear accelerator that is capable of performing well in challenging environments such as those encountered in many LMICs and that will require fewer qualified experts for routine operation and maintenance, especially those personnel who currently are lacking in LMICs. The detailed analysis of the information from this study that will be reported later will complement general LINAC design considerations that include well- recognized factors such as ease of operation, reliability, robustness, easy repairability, self- diagnosis of subsystem faults, insensitivity to power interruptions, lower power requirement, reduced heat production and easy upgradability.

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APPENDIX A

Survey Participants

COUNTRY	RT FACILITY – LOCATION	PARTICIPANT
AFRICA		
Algeria	CAC (Anti Cancer Centre) – Setif, Algeria	Saad Khoudri
	CAC Oran – Clinique Oncopole L'espoir, Oran	Ismail Zergoug
Angola	Instituto Angolano de Controlo de Câncer, Luanda.	Higidio Miezi Eduardo
Botswana	Life Gaborone Private Hospital, Gaborone	Surbhi Grover, Remigio Makufa
Cameroon	Hopital General, Douala NRPA, Yaounde Cameroon Oncology Center, Douala	Anne Marthe Maison Mayeh, Samba Richard Ndi, Apolinaire Ngnah
Cote D'Ivoire	Centre for Medical Oncology and Radiotherapy – Cocody	Tofangui Alain Ouattara
Egypt	Radiation Oncology and Nuclear Medicine Department, El-Hussein Hospital, Al-Azhar University – Cairo NCI, Cairo	Khaled El-Shahat, Ehab Attalla, Nashaat Deiab
Ethiopia	Black Lion Specialized Hospital – Addis Ababa,	Eskadmas Yinesu Belay
Gabon	Institut de Cancerologie de Libreville (ICL) – Libreville, Gabon	Rolland Kayende
Ghana	Komfo Anokye Teaching Hospital –Kumasi,	E. K. T. Addison
	Korle Bu Teaching Hospital – Accra, Ghana	S.N. Tagoe

COUNTRY	RT FACILITY – LOCATION	PARTICIPANT
	Sweden Ghana Medical Centre – Accra AFRICSIS, Accra SNAS, University of Ghana, Atomic, Accra.	George F. Acquah, Emmanuel Amankwa-Frempong Hubert Foy Francis Hasford
Kenya	Kenyatta National Hospital – Nairobi	Ejidio Ngigi
Libya	Tripoli Central Hospital (TCH) – Tripoli Benghazi Radiology and Radiotherapy Centre, Benghazi	Fadwa Badi, Fairoze El Tashani, Ihab Elburi
Madagascar	Oncology-Radiotherapy Department, CHU HJRA, Antananarivo	Tovo Harivony, Jean Norbert Randriamarolahy
Mali	Mali Radiation Oncology Centre – Bamako	Aphousalle Kone, Siaka Maiga, Drissa Samake
Mauritania	Centre National d'Oncologie-Nouakchott-Mauritanie	Moussa Cheibetta, Ahmedou Tolba
Mauritius	Victoria Hospital, Quatre Bornes, Candos	Seeven Mootoosamy
Morocco	INO (National Oncology Institute) – Rabat	Salwa El-Boutayeb
Mozambique	Central Hospital of Maputo – Maputo,	Ainadine Momade
Namibia	The Namibian Oncology Centre, Windhoek	Melanie Grobler
Namibia	Dr A. B. May Cancer Centre, Windhoek Central Hospital	Wilfred Midzi
Nigeria	National Hospital – Abuja	Simeon Chinedu Aruah
	UDUTH – Sokoto	Hassan Ibrahim
	UNTH – Enugu	Kenneth Nwankwo
Rwanda	Radiotherapy Center, Military Hospital, Kigali	Joel Kra, Pacifique Mugenzi
Senegal	Hopital Universitaire le Dantec - Institut Curie – Dakar, Senegal	Magatte Diagne
S. Africa	Eastern Cape Health – Port Elizabeth	Ayron Rule
	Tygerberg Hospital – Cape Town	Chris Trauernicht
	Inkosi Albert Luthuli Central Hospital – Durban	Graeme Lazarus
Sudan	National Cancer Institute, Univ. of Gezira, Wad Medani RICKS, Khartoum	Fawzia Elbashir, Nadir Abd Ellatif Ali
Tanzania	Ocean Road Cancer Institute (ORCI) – Dar es Salaam	Hellen Makwani, Shaid Yusuph
Tunisia	Institut de Salah Azaiez – Tunis Sfax Oncology Centre, CHU Habib Bourguiba, Sfax	Mounir Besbes, Leila Farhat

COUNTRY	RT FACILITY – LOCATION	PARTICIPANT
Uganda	Mulago Teaching Hospital – Kampala	Kavuma Awusi
Zambia	Zambia Teaching Hospital – Lusaka	Barbara Mule
	Cancer Diseases Hospital – Lusaka	Mutule M. Kanduza
Zimbabwe	National University of Science and Technology – Bulawayo	Godfrey Azangwe
	Parirenyatwa Radiotherapy Centre – Harare	Edwin Mhukayesango
	Oncocare Cancer Treatment Centre – Harare	Lawrence Mhatiwa
HIGH AND MIDDLE INCOME COUNTRIES		
Canada	Princess Margaret Cancer Center, Toronto	Rebecca Wong
	Princess Margaret Cancer Center, Toronto	Daniel Letourneau
	Odette Cancer Center, Toronto	Stephen Breen
	Southlake Cancer Center, Newmarket	Ivan Yeung
	Juravinski Cancer Center, Hamilton	Gordon Chan
Jordan	King Hussein Cancer Center	Jamal Kadar
CH	Genolier Clinic, Geneva	Jacques Bernier, Shelley Bulling, Oscar Matzinger
UK	Royal Devon and Exeter Hospital	Jose Eduardo Villarreal-Barajas, Joseph Bateman
	Guy's and Thomas' NHS Foundation, London	Ajay Aggarwal, Michael Pearson, Winston Swaby
	Oxford University Hospitals NHS Foundation Trust	Frank van den Heuvel
	Royal Preston Hospital, Preston	Natalie Thorp
	South-West Wales Cancer Service, Singleton Hospital, Swansea	Richard Hugtenburg
USA	Northeast Radiation Oncology Centers, Scranton, PA,	Christopher Peters
	Maine Medical Center, Portland, ME USA	Scot Remick, Steven Ryan
	Monument Health/Avera Health System – Rapid City, SD,	Marvin Glass, Daniel Petereit
	Lifespan Health System/Warren Alpert Medical School of Brown University	David Wazer, Eric Klein
ITAR TEAM MEMBERS		
	STFC Daresbury Laboratory, Warrington	Boris Militsyn
	University of Lancaster, Lancaster	David Cheneler
	STFC Daresbury Laboratory, Warrington	Trevor Hartnett
	University of Oxford, Oxford	Suzanne Sheehy

COUNTRY	RT FACILITY – LOCATION	PARTICIPANT
	OTHERS	
ICEC, USA	International Cancer Expert Corps Inc., Washington DC	Harmar Brereton, Lee Chin, Ceferino Obcemea, Nina Wendling

APPENDIX B

PROJECT STELLA SURVEY

DESCRIPTION
Models
Manufacturer and model and year of the LINACs in your facility
Number of treatments performed per year on each LINAC
Environmental factors
What is the temperature in the area where the LINAC is housed and what is the variability of temperature?
What is the humidity in the area? High/Medium/Low
What is the speed and availability of the internet connection? High/Medium/Low
What is the fluctuation of the mains at the machine (voltage variation, frequency variation, blackout durations and frequency)
What is the floor area and ceiling height of the shielded area?
What photon energy/dose is your shielded area able to safely operate at?
Services
Service Contract: do you have one? If so which type, manufacturer, government, local companies, own maintenance
Service Contract: If yes which type, manufacturer, government, local companies, own maintenance
Service Contract: if yes, what is the annual cost? What is the average additional repair cost you have paid in the past 3 years?
Service Contract: If no, what is the average repair cost you have paid in the last 3 years
How often does the machine have maintenance/tuning/calibration?
What kind of water supply and chiller type are used for cooling water? What is its stability & variation of the temperature?

What type of failures can you repair locally?
Do you do your own in between small services and repairs, if so what type?
Number of staff available for each service if carried out in house - electronics, electrical, mechanical engineers and/or technicians
Do you do any special checks or procedures for restarting a LINAC after being shut down for a period of time (e.g. for maintenance, repairs)
How are technical staff trained to maintain the LINAC? Please name the training provider and length of training.

Subsystems
When there is a fault in your machine, how easy it is to find out which subsystem has failed?
Do you experience any issues with the vacuum system? If so, how often?
How often do vacuum pumps fail and how long does it take to replace them? Do you keep spares? Can you repair locally?
Do you keep spare RF sources? Can you repair locally?
How often does the MLC fail and how long does it take to replace them? Do you keep spares? Can you repair locally?
How often does the electron gun fail and how long does it take to replace it? Do you keep spares? Can you repair locally?
What percentage of time is your LINAC down due to system failures?
Do you have any software problems?
Treatment and imaging
Does your hospital have diagnostic CT near the radiotherapy area?
Do you use a tilting Couch? How important is this feature?
How important is it for a LINAC to offer electron treatment mode?