STATUS OF MEDICAL PHYSICS IN CENTRAL AMERICA

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***Abstract*— "Status of medical physics in Central America" is a study from data collection and additional resources from each country available until the year 2018. The study is based in the incidence of patients with cancer diagnosis, the number of diagnostic and treatment centers, the number of equipment according to use and modality, the professional personnel in medical physics working in the areas of Radiotherapy, Diagnostic Radiology, Nuclear Medicine and Radiation Protection, and the demand projection of professionals for the upcoming years. The information used was obtained from recent national and international studies available in each country; data provided from personnel working in national entities such as hospitals, health ministries and statistical ministries who have relation in the application of radiation to diagnose and treat. The objective of the study is to attain an update of the status of the medical physics specialty in Central America with the most recent available resources. Hence, introducing an estimate of the demand of such profession for the following years. The results shown are complete in most countries. However, in case of lack of information, this data was included in the study as: No Data Available (NDA), thus requiring a more in to depth study.**

***Keywords*— Medical Physics, Central America, status, update, cancer, diagnosis, treatment.**

I. HISTORY OF MEDICAL PHYSICS IN CENTRAL AMERICA

On November 8, 1895, Wilhelm Conrad Röntgen (1845 to 1923) discovered a mysterious new ray that he later called the "x-ray" [1]. After the discovery, the development in the application of the x-rays for medical science began to be implemented around the world, and with this flourished the need of a medical physics profession that now a days is increasing gradually.

Central America is a region between North America (from Mexico) and South America (until Colombia) and is comprised of seven countries: Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama.

Medical physics in Central America started with the implementation of x-rays machines for medical diagnose by reproducing the experiment that took place to the discovery. The first equipment used in the Central America´s region and second one in Latin America was in Guatemala in November 1896, just one year after the discovery of W. Röntgen [2]; this was achieved thanks to the reconstruction of an x-ray tube, with the help of Ph.D. Darío Gonzalez. Ph.D. Darío Gonzalez, of Salvadoran origin, and an associate professor in the Faculty of Medicine at the university (Universidad de San Carlos de Guatemala), initiated the radiological practice in the region [3] with the use of the reconstructed x-ray tube at such institution. In the next years the use of X-ray machines was later developed throughout countries of Central America.

By 1897 with the help of M.D. Miguel Ángel Ugarte, the first equipment for x-rays was acquired from Germany; this marked the beginning of the radiology in Honduras [2].

In Nicaragua the first x ray machine was acquired in 1902 by Ph.D. Rosendo Rubí Altamirano [2], who also was the first radiologist in the national hospital in Nicaragua.

With the studies of M.D. Carlos de Cespedes about the evolution of the radiology as a medical specialty during the XX century, documented in the year 1904. This date marked the beginning of the radiology in Costa Rica followed by the purchase of the first X-ray machine by Professor José Brunetti Félix, of Italian origin [2].

In 1907, the first equipment was installed in El Salvador with the help of M.D. Alfonso Quiñonez Molina. Molina was responsible for acquiring the first bone and thorax radiography in that country [2].

The first x-ray equipment that worked in Panama was brought by M.D. Pedro Obarrio, installed in the ancient hospital Santo Tomás in 1912 [4]. In Belize the information is not public available.

Since the first time of the implementation of an x-ray generator machine, medical physics has been growing at different levels in each country. Some other historical dates in the development of medical physics are shown in a timeline summary of Central America in Table 1. A description of the status of medical physics in Central America is available in the next sections. This has been done according to the demographical and territorial indices, the number of new cases in cancer diagnose during the 2018, the professional source, the technology available for

diagnosis and treatment and a projection of professional demand to cover in the next years.

Table 1. Timeline of medical physics in Central America.

Year – Event
1896 - First X-rays in Central America (Guatemala) [2]
1897 - 1912 First X-ray in the rest of Central America [2], [4]
1921 - First Brachytherapy in Guatemala [3]
1956 - First Brachytherapy in Nicaragua [5]
1957 - First Radio Oncologist in Guatemala [3]
1960 - First Brachytherapy in Honduras [2]
1960 - 1969 First Cobalt-60 Unit in Guatemala, Honduras, Nicaragua, Panama, Costa Rica and El Salvador [2],[6],[7]
1975 - First Brachytherapy in El Salvador [8]
1975 - First Medical Physicists in Costa Rica [7]
1980 - First Radio Oncologist and Medical Physics in Honduras [9]
1985 - First CT in El Salvador [2]
1986 - First Radiotherapist Oncologist in Costa Rica [7]
1993 - First MR in El Salvador [2]
1994 - First MR in Honduras [2]
1996 - Accident with Cobalt-60 Unit in Costa Rica [10]
1998 - First LINAC in Guatemala [3]
1999 - First LINAC in Costa Rica [7]
2000 - 2001 Accident with TPS in Panamá [11]
2008 - First CT in Honduras [2]
2009- First Rapid Arc in Latin America (Guatemala) [3],[12]
2011 - First Nuclear Medicine Center in Nicaragua [5]
2011 - First Nuclear Diagnosis in Nicaragua [5]
2013 - First Cyclotron in Central America (Panama) [13]
2014 - First IGRT in Costa Rica [7]
2015 - First Advance Technique in RT in El Salvador [8]
2015 - First Advance Technique in RT in Nicaragua [5]
2016 - First Nuclear Diagnosis in Honduras [9]
2018 - First Brachytherapy in Honduras [9]
2018 - First LINAC in Nicaragua [5]
2019 - Robotic Radiosurgery with CyberKnife in Costa Rica) [14]

II. Demography and geography features

The official language spoken throughout Central American countries is Spanish with the exception of Belize, where the official language is English. The central American region has a territory of 522 thousand square kilometers with an estimated population of 48 million.

All the countries are members of the Atomic International Energy Agency (IAEA). The description of population, geographical area, growing population, Gross Domestic Product (GDP) and type of income group is shown in Table 3 according to each country [15].

III. Incidence of cancer in central america

In order to understand the demand of equipment and professionals in medical physics is described a reference of the number of new cases diagnosed per year. The number of new cancer cases per year in a given population is obtained from the national population statistics, which is based on the cancer registry according to the oncology centers. In most cases in Central America this information is not publicly available for national centers; in private centers there is less possibility to have access to such information. This data is used as a statistic per working year progress because there is no journal/registry in the national health ministry that provides detailed description of the analysis or information for new cancer cases. Thus, the best estimation of the new cases is taken from the International Agency for Research on Cancer (IARC).

The incidence of cancer in Central America during the year 2018 is taken from the data base of IARC with Global Cancer Observatory Globocan-2018 [16]. Table 2 shows the percentage of cases according to the gender for all ages, and the total number of cases during this year.

The percentage of most frequent cancer case types diagnosed in the 2018 in Central America are shown by gender in Figure 1, for males containing: prostate, stomach, liver and lung cases. In Figure 2, for females containing: breast, cervix, stomach, liver and lung cases.

Table 2. Incidence of cancer in Central America during the year 2018.

Country	Percentage Distribution		Total
	Male	Female	
Belize	48.6%	51.4%	358
Costa Rica	50.0%	50.0%	12957
El Salvador	40.0%	60.0%	10326
Guatemala	43.5%	56.5%	16332
Honduras	44.3%	55.7%	9942
Nicaragua	45.7%	54.3%	7956
Panama	50.7%	49.3%	8244

Table 3. Demography and Geography features of Central America.

Country	Belize	Costa Rica	El Salvador	Guatemala	Honduras	Nicaragua	Panama
Population (thousands)	374.68	4,905.77	6,377.85	16,913.50	9,265.07	6,217.58	4,098.59
Geographical Area (km^2)	22,970.00	51,100.00	21,040.00	108,890.00	112,490.00	130,370.00	75,420.00
Population Growing Rate (%)	2.04%	1.19%	2.50%	1.93%	3.90%	1.06%	1.53%
Gross Domestic Product, GDP (Billion US$)	1.863	57.286	24.805	75.62	22.979	13.814	62.384
Income group	Upper middle income	Upper middle income	Lower middle income	Upper middle income	Lower middle income	Lower middle income	High income

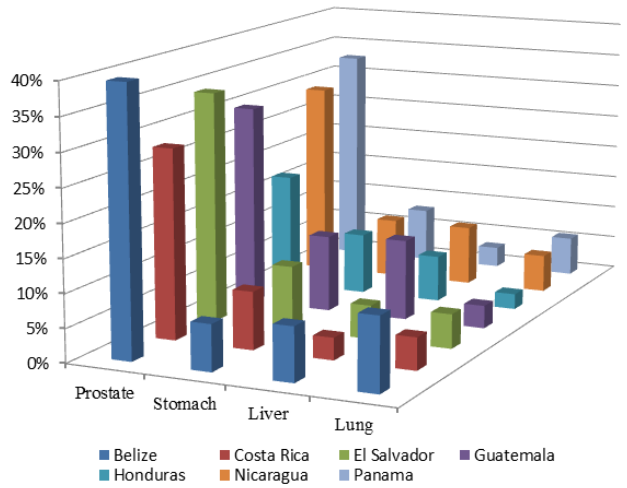

Fig. 1 Percentage of incidence of the most frequent types of cancer in Males in Central America, 2018.

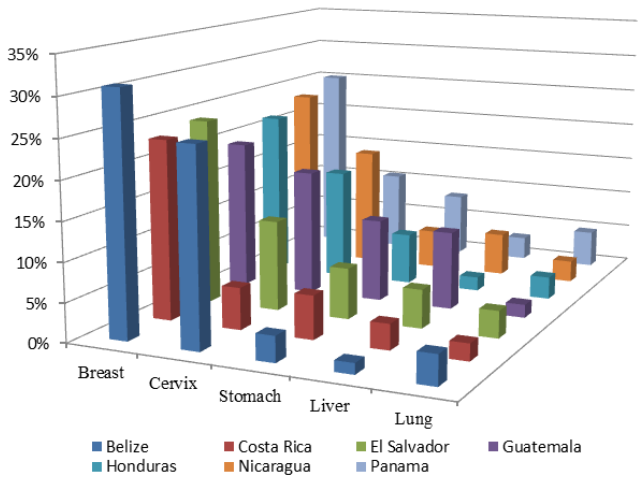

Fig. 2 Percentage of incidence of the most frequent types of cancer in Females in Central America, 2018.

IV. Professional Status and Medical Physicist Recognized in Central America

The Central American countries, although they share cultural and historical aspects, they presently have broad differences in human and scientific development at different stages. These differences are found in the requirements that each country requests for the professional practice of medical physics, and in some cases, it is adjusted to the academic resources. For this reason, there is no Central American norm that integrates, homogenizes and regulates the exercise of the profession for medical physicists in the region. The following paragraphs describe the necessary requirements for the practice of medical physics in each country of the Central American region.

Belize doesn't have Medical Physicist.

Costa Rica for professional practice the following is a requirement: master´s degree in medical physics, a certification proving they have planned and accomplished 50 treatments in radiotherapy (2D, 3D-CRT or IMRT). A license is given with validity for Radiotherapy and Superficial X-ray therapy. To work on radiation protection, it is necessary to have courses in shielding calculation. The license for brachytherapy is obtained by demonstrating that 50 patients have been planned [7].

El Salvador for professional practice the following is a requirement: Degree in Physics (must include courses of ionizing radiation) [8].

Guatemala for professional practice the following is a requirement: master´s degree or PhD degree in medical physics, this should be accredited by the national university; the recognition is evaluated by a board in medical physics, the medical physicist is registered in the College of Engineers of Guatemala. A minimum of two years training in of the specialty with the approval of a recognized medical physicist.

Honduras for professional practice the following is a requirement: Degree in Physics (must include courses of ionizing radiation) or grade in Biomedical Engineer [9].

Nicaragua to be able to practice the profession the following is a requirement: Master's degree in medical physics. The master's degree must be accredited by a national university and must comply with the sanitary code from the Ministry of Health, clinical practice license, medical and psychological fitness, inscription in the official newspaper and a two-year experience [5].

Panama the information is not available.

Table 4. Academic Offer to produce medical physicist per country of Central America.

Country	Bachelor degree	Master's degree	PhD
Belize [18]	-----	-----	-----
Costa Rica [7]	*Bachelor in physics*	• Professional Master's degree in Medical Physics • Academic Masters' degree in Medical Physics	-----
El Salvador [8]	*Bachelor in physics*	-----	-----
Guatemala [17]	*Bachelor in physics*	-----	-----
Honduras [9]	• *Bachelor in physics* • *Biomedical engineer*	-----	-----
Nicaragua [5]	*Bachelor in physics* with mention in medical physics	-----	-----
Panama [19]	*Bachelor in physics*	-----	-----

Table 5. Professionals working in medial physics according to specialties in Central America.

	Belize [18]	Costa Rica [7]	El Salvador* [8]	Guatemala [17]	Honduras [9]	Nicaragua [5]	Panama [19]
Radiotherapy	0	18	11	7	3	3	9
Nuclear Medicine	0	5	2	2	1	0	NDA
Diagnostic Radiology	0	2	0	4	1	1	1
Radiation Protection	0	4	3	3	1	2	NDA
Medical Physicist Recognized	0	NDA	1	7	3	5	15
Physicist Working in the Area	0	23**	13	7	3	5	15

*Physicist not recognized.
**Radiotherapy plus nuclear medicine physicist, real data is not available.

In order to ensure the academic training of medical physicists, each country offers different academic programs according to the requirements necessary to practice the profession. Guatemala and Nicaragua, however, are an exception to that rule since a degree in medical physics is required even though such career does not exist in the country. Table 4 shows the academic offer in each country in Central America.

Even with the mentioned difficulties there is an existing number of medical physicists specialized in the region, such number of professionals is increasing on a yearly basis. In most cases the formation of such professionals is carried out in foreign countries such as Argentina, Mexico, Italy amongst others, thanks to international programs' acceptance of the Latin American community and worldwide. The actual status of physicist working in the area of medical physics is shown in Table 5. Note, the total representation of the medical physicist may no match in some cases with the total staff working due to differences in internal normative for recognition.

V. DIAGNOSTIC AND TREATMENT CENTERS

There are not enough diagnostic and treatment centers in Central America, hence the need for more centers to treat all cancer diagnosed patients on a yearly basis. In most cases the diagnostic centers are distributed in the region according to the population concentration distribution. Many at times without meeting the normative for safety issued from the government that provides the regulatory requirements recommended by the IAEA. Within the recommended IAEA's requirements failure to abide is in terms of staff

training, adequate documentation for standard operating procedures (SOP's), quality control or preventive maintenance of the equipment. The latter, related to fulfilling the growing demand of the services by the population and resulting in little or no time for preventative or regular maintenance of equipment; the end consequence then, is no dosimetry audits or any growing control over the operational services.

Therapy centers in most of the cases are centralized in the capital city of each country despite the difficult access this represents for rural areas due to distance, accommodation and or travelling expenses. These centers are however, more organized in regards to the regulations stipulated by the government. In the Central American region every country with the exception of Belize, has at least one governmental or non-governmental organization for radiotherapy center. In most countries, however, the private centers provide services to more than half of the population. The previous being a major setback for patients with low incomes. The quantity of centers that give the services for diagnosis and therapy are shown in the Table 6.

Table 6. Diagnosis and Treatment Centers in Central America.

Service Type	Belize [18]	Costa Rica [7]	El Salvador [8]	Guatemala [21]	Honduras [9]	Nicaragua [5]	Panama**
Brachytherapy	0	1	3	4	2	1	2
Nuclear Medicine	NDA	6	3	2	2	2	5
Radiotherapy	0	3	5	4	5	1	4
Based in x-ray modalities	NDA	NDA	200	12*	200	50	NDA

*Public Institutions in 2012 [19].
** Information obtained from [19] and [20].

Table7. Equipment according to modality in Central America.

Equipment type	Belize [18]	Costa Rica [22]	El Salvador [8]	Guatemala [21]	Honduras [9]	Nicaragua [5]	Panama [20]
LINAC	0	5	4	5	3	1	6
CO60	0	1	2	1	4	2	0
Magnetic Resonance	NDA	12	10	NDA	4	NDA	NDA
Mammography	NDA	NDA	40	97	50	--	NDA
Computed Tomography	NDA	NDA	30	95	8	--	NDA
Conventional X ray	NDA	NDA	100	327	50	--	NDA
Fluoroscopy	NDA	NDA	20	77	15	116**	NDA
PET	NDA	2	0	0*	1	0	NDA
SPECT/Gamma camera	NDA	9	3	2*	1	2	NDA

*Data from the year 2012 [19].
**Number that corresponds to equipment for radiology diagnosis and intervention.

VI. Equipment

The number of centers described in the previous sections indicate the possibilities of a patient to be diagnosed or treated. Each center contains different number of equipment in terms of the demand and recurrence of the diagnostics of their population. A radiotherapy center in each country contains at least one LINAC or Co60 and in some cases a low or high dose rate brachytherapy for therapy.

The diagnostic equipment in each country is distributed amongst centers; in some countries in Central America there is no data control making it difficult to have accurate information. The found data for existing equipment by country is summarized in Table 7.

VII. Estimating demand

There exists different ways to estimate the demand of medical physicist as described in [23]: i) range of applications of physics in medicine, ii) scale of organizational and management responsibilities (number of hospitals, population served), iii) the amount and complexity of equipment and procedures used in related clinical specialties, iv) number of patients examined and treated in the relevant modalities and the complexities of these examinations or treatments, v) the load for formal teaching and training, vi) the level of participation in research, development and clinical trials vii) the number of supporting staff (e.g. technical and radiographic).

According to the information in this article, the quantity of whole time equivalent (wte) medical physicists along with the necessary equipment for Radiotherapy, Diagnostic Radiology and Nuclear Medicine are estimated as follows:

1. Medical Physics in Radiotherapy:

- 1 high energy LINAC: 0.8 wte physicist.
- 1 major item equipment (Co60, TPS for LINAC, Brachytherapy service): 0.4 wte physicist.
- 1000 patients in radiotherapy: 1.2 wte physicist.

2. Medical Physics in Nuclear Medicine:

- 1 SPECT/CT or Gamma Camera: 0.75wte physicist.
- 1 PET/CT: 0.25 WTE physicist.
- Up to 5000 examinations per year and 50 treatments for year in a Nuclear Medicine Center: 0.75 wte physicist.

3. Medical Physics in Diagnostic Radiology:

- Population of 500,000: 1 wte physicist.

Table 8. Medical Physicist demand according to specialty in Central America.

	Belize**	Costa Rica	El Salvador	Guatemala	Honduras	Nicaragua	Panama
Radiotherapy*	0	15	13	18	12	7	13
Nuclear Medicine	0	11	4	3	2	2	4
Diagnostic Radiology	1	10	13	34	18	12	8
Total Medical Physicist	1	36	30	55	32	21	25
According to Italian system	5	67	87	232	127	85	56

*Patients in radiotherapy estimated as a 50% of the total [25].
**No radiotherapy and Nuclear Medicine services.

The estimation of the total number of medical physicists is summarized in Table 8. Such information is taken as a reference for minimum staffing for the few parameters used. These values acquired can be compared with a developed medical physics system, similar to that of the Italian, where in the year 2017 it was calculated a mean number of medical physicists being: 13.7 medical physicist per million of habitants [24], including all the specialties of the entire country.

The estimation of staff in radiation protection is not calculated due to the fact that this figure is not restricted to a physicist, in some Central American countries can also be a physician or a professional in another area with knowledge in radiation.

VIII. Discussion

Historically the Central American region has used ionizing radiation applied to medicine shortly after its discovery by Röntgen in 1895. Since the first decade of XX century, x-rays were used in diagnosis as shown in Table 1. With the implementation of new technologies involving radiation sources such as Co-60 and subsequently the LINAC, the region has failed to adapt. One of the reasons is largely due to development and socio-economic issues as shown in the Table 3. Central American countries have the lower GDP values of the American continent similar to the Caribbean ones.

These unfortunate realities result in limited or no access to healthcare, even with the high incidence of cancer in the region. In 2018, 66,115 new cases of cancer were reported in the region, with the predominance of prostate cancer among men and breast cancer among women as seen in the Figures 1 and 2. There is an equivalent rate of incidence among men and women as shown in the Table 2. To deal with this situation, the region needs to incorporate medical physicists in the public and private hospitals. The requirements for the qualification of a medical physicist depend on the academic resources that each country can offer. Costa Rica is currently the only country that can satisfy their own requirements, as they benefit from their own masters programme in medical physics. In the other countries, only bachelor's degrees in physics exist, with additional courses orientated to ionizing radiation as shown in the Table 4. In order to solve this issue, professionals migrate to satisfy academic necessities. An example of this high demand, is the master programme in medical physics of the ICTP in conjunction with the Università degli studi di Trieste, in Italy. This programme has contributed to the development of the medical physics practice in Central America [26].

As shown in Table 5, radiotherapy is the most developed specialty in Central America, even though there exists a large number of diagnostic equipment (Table 7). This disparity between available equipment and clinically trained physicists creates a great need for specialists in the area of diagnosis and nuclear medicine (Table 6). An estimation of the number of medical physicists needed for Central America was made in Section VI. Utilizing the criteria set

forth by EFOMP, it was determined that 200 physicists are needed to satisfy the minimum requirements of the region. A further calculation was done using the Italian system, to provide a more ideal number, for which the region should aim in the future.

The training of such professionals should be organized together with the heads of government of each country. Collaborations of this nature will produce better environments to implement correct practices in each center of diagnose and treatment, better application of radiation to medicine, and improved attention to the patients that need healthcare. The challenge that the Central American countries must face in the coming years, involve education, health and scientific plans.

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Annex

The following is the translation of the form used for data acquisition.

Status of medical physics in:_____

Fill in the below table with the information requested as accurate as possible:

I) Educational programs for medical physics

Bachelors level			
University			
Degree			
Duration time			

In case of clinical training acquired, indicate the quantity of hours necessary.

Master level			
University			
Degree			
Duration time			

In case of clinical training acquired, indicate the quantity of hours necessary.

II) Qualifies to be recognized as a medical physicist in the country

Academic level	
Quantity clinical experience years	
Others	

III) Quantity of medical physicist in the different areas of work in the country

Radiotherapy	
Nuclear Medicine	
Diagnostic Radiology	
Radiation Protection	
Total number of medical physicists in the country	

In the absence of medical physicist professionals indicate the profile of the person that works in the roll of medical physicist:

IV) Services and Equipment for diagnose and treatment

Quantity of centers where radiotherapy is practiced	
Quantity of centers that deliver studies of diagnosis based on x-ray modalities (Tomography, mammography, CT, fluoroscopy, etc.)	
Quantity of centers where nuclear medicine is practiced	

Equipment type	**Quantity**
LINAC and Co60	
Magnetic Resonance	
Mammography	
Computed Tomography	
Conventional X ray	
Fluoroscopy	
Brachytherapy services	
Nuclear Medicine treatment	
PET	
SPECT	
Gamma Camera	

V) In the following table some historical information about the evolution of medical physics in the country is required. Provide dates and a brief description.

Event	**Year and Description**
First equipment for Radiotherapy installed	
First radiotherapy treatment delivered	
First Radio-oncologist	
First medical physicist	
First brachytherapy delivered	
First diagnose in nuclear medicine	
First radiotherapy treatment with an advanced technique delivered	
Another important event	