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IOMP

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MPI

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THE JOURNAL OF

THE INTERNATIONAL ORGANIZATION FOR MEDICAL PHYSICS

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The Journal of the International Organization for Medical Physics

Aims and Coverage:
Medical Physics International (MPI) is the official IOMP journal. The journal provides a new platform for medical physicists to share their experience, ideas and new information generated from their work of scientific, educational and professional nature. The e- journal is available free of charge to IOMP members.

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EDITORIALS

Perry Sprawls, MPI Co-Editor-in-Chief, Atlanta, USA

Physicists and engineers have made many contributions to the advancement of medicine with the development of technology and procedures for both diagnostic and treatment purposes. The origin of modern medical physics was the discovery and extensive research by the physicist Wilhelm Röentgen in 1885 introducing "a new kind of radiation" (to become known as x-rays or Röentgen rays) and demonstrating the ability to produce images of the anatomical structures within the human body. This was soon followed by experiments investigating the use of the radiation for therapeutic purposes, especially to treat cancer. The developments that occurred over the next 130+ years are the foundation of our medical physics history and heritage. This has been through expanding the scope of physics into previously unknown areas, for example radioactivity, and the extensive development of equipment and technology to apply the newly discovered physics principles to improving human health around the world.

The research, developments, and many clinical applications of "the new physics" have been published in many scientific and medical journals along with textbooks of the period. Of great value to our modern medical physics profession is looking at and developing an appreciation for the "big picture" of the ongoing process of innovations in both diagnostic medical imaging and therapeutic procedures. There are many contributing factors to this, ranging from the creativity of individual physicists to the extensive developments in technology for other applications, such as communications and photography.

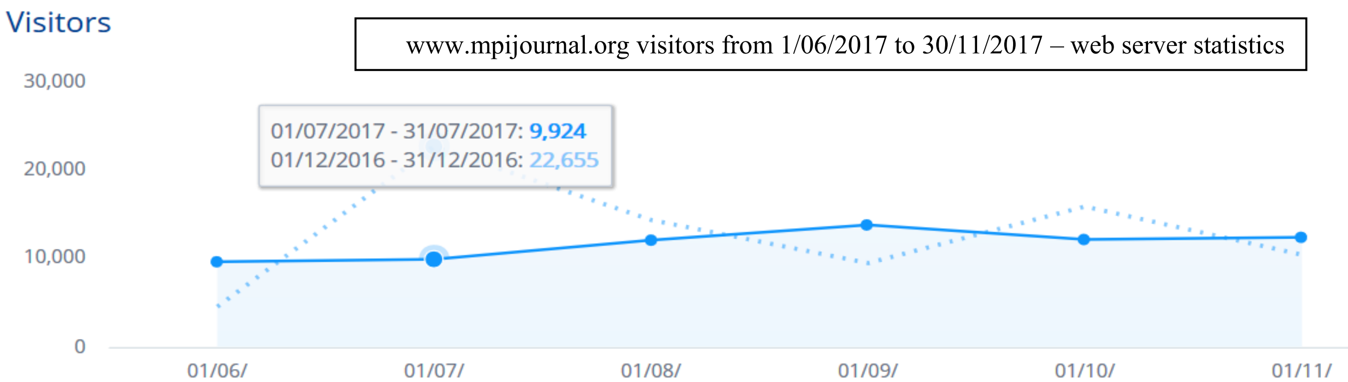
Beginning in 2018 Medical Physics International will begin publishing an additional series devoted to the history and heritage of medical physics. The first edition to be published in January will contain articles relating to the historical development of two major technologies, x-ray tubes and film-based radiographic receptors. As described in the previous issue of our Journal these articles will form the volumes of the IOMP project "History of Medical Physics"

Slavik Tabakov, MPI Co-Editor-in-Chief, King's College London, UK

After the first publications of the Medical Physics International (MPI) Journal, it steadily increased its popularity. The first Editorial period was completed this year and we all can be happy with the achievements of the IOMP Journal – the number of readers per month increased more than twice, having at present around 10,000-12,000. The diagram from the web server shows 70,000 visits over the past 6 months (Jun-Nov 2017). Taking only one month as a sample (Sep 2017) we have 13,800 visits, 58% of which are from Asia, Latin America and Africa (where about 1/3 of all medical physicists are situated). This clearly shows the need of the MPI Journal for the education, training and professional development in many Low-and-Middle Income (LMI) countries. Another important statistics is that about 3/4 of all visits are direct hits, showing the popularity of the Journal.

We would like to thank all contributors to the Journal, and all members of the Editorial team, specifically mentioning the Technical Editor Prof. M Stoeva, the Editorial Assistant Dr V Tabakova and the IOMP Secretary General Dr V Tsapaki.

It was agreed at the latest meeting of the IOMP ExCom that the MPI Editors in Chief (S Tabakov and P Sprawls) will continue for another period of 4 years and additional members will be included in the MPI Editorial Board. One of the important tasks in the period ahead will be the publications of the Special Issues related to the IOMP project "History of Medical Physics", what we highlight here below. We are looking forward to the further success of the MPI – the IOMP Journal dedicated to education, training and professional issues.



COLLABORATING ORGANIZATIONS

THE ROLE OF THE INTERNATIONAL RADIATION PROTECTION ASSOCIATION (IRPA)

Roger Coates, IRPA President [1]

[1] c/o EDF – PRESIDENCE Inspection Générale pour la Surete Nucléaire et Radioprotection, Paris, France

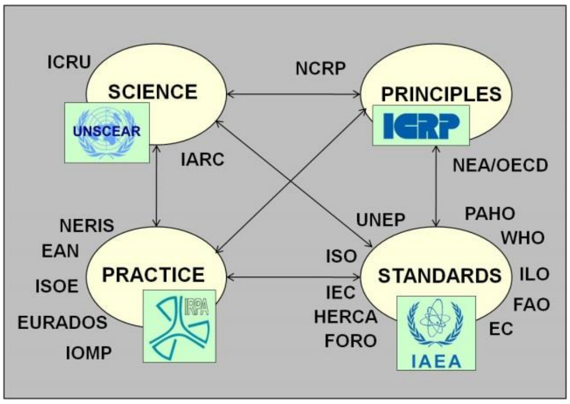
Abstract— **This article presents briefly the roles of the International Radiation Protection Association**

I. INTRODUCTION TO IRPA

The International Radiation Protection Association (IRPA) is an independent non-profit association of radiation protection professionals joining through national and regional radiation protection societies (the Associate Societies - AS). The defined **Mission Statement** of IRPA is as follows:

IRPA is the international professional association for radiation protection. Through national and regional Associate Societies and radiation protection professionals, IRPA promotes excellence in radiation protection by providing benchmarks of good practice and enhancing professional competence and networking. IRPA encourages the application of the highest standards of professional conduct, skills and knowledge for the benefit of individuals and society.

The figure below shows schematically the relationship of the international organizations and professional bodies in the system of radiation protection. It identifies the primary functions of organizations in the four pillars of science, principles, standards and practice, and underlines the organizations having a leading role and a responsibility in these functions.



The Four pillars of Radiation Protection

It is noted that the diagram is not an exhaustive identification of all the organizations involved in radiation protection worldwide. The diagram also illustrates the evolution of the international organization of radiation protection with the increasing role of professional networks.

IRPA has the pre-eminent role in the generic field of radiation protection 'practice'. Our strength is the involvement of professionals/practitioners across all fields of radiation protection, covering scientific research, teaching, regulation, medical practice, nuclear and non-nuclear industry, national/international policy and all other fields. Through our 18,000 members in 52 Associate Societies (AS) covering 67 countries, we encompass the full spectrum of national experiences, from large developed countries through to practitioners working in small developing nations.

IRPA has defined the following **Vision statement**:

IRPA is the international voice of the radiation protection profession.

II. IRPA AND IOMP

As is evident from the above introduction, IOMP and IRPA are essentially sister organisations. We are both in effect 'international federations' of national/regional societies, representing the views and interests of our respective professions. IRPA's sole focus is radiation safety, with no interests in wider technological issues or in other technologies. Whilst the majority of our members work outside of the medical sector, healthcare is nonetheless our largest single sector, with around 25% of our members working alongside medical physicists and doctors in the medical environment. Indeed many individuals are members of both our organisations.

III. THE IRPA STRATEGIC PROGRAMME 2016-2020

IRPA is managed in a four year cycle, beginning and ending at successive International Congresses. The current period commenced at the IRPA14 Cape Town International Congress in May 2016 and runs through to the IRPA15 International Congress in May 2020, which will be held in Seoul, South Korea. An Executive Council (EC) is appointed for each term, and the composition of the current EC is given in the Appendix.

Our strategic priorities for 2016-2020 are grouped under four headings, each of which has several specific work programmes:

- To promote our role as the international voice of the RP profession through engagement with other international organisations and professional bodies on the development of the system of protection, giving emphasis to impacts on practical implementation.

Liaison with our partner international organisations: Consultation on the system of protection: Horizon scanning: Enhancing the interface with key international organisations in the medical sector

- To support the needs of the Associate Societies by developing, enhancing and sharing good practice and high standards of professionalism.

Radiation Protection Culture: Ethics in Radiation Protection: Public Understanding: Implementation of the Eye Dose Limit: Security of Radioactive Sources: Young Professionals Network

Sharing Good Practice: Underpinning the future of our profession: Supporting the AS in developing effective national interfaces between the AS and the medical sector: Implementation of systems for the recognition of competence: Supporting the development of AS through the exchange of general good practice and experience.

- To support the education and training of RP professionals

Education & Training practices: IRPA's Regional and International Congresses: Coordination and promotion of AS training activities and associated events: Database of training events: Scientific developments update.

- To enhance IRPA Governance and the interface with the Associate Societies.

Enhanced regional engagement: Interface and Communications with the Associate Societies: The 'View of the Profession': Guidance for the Organisation of IRPA Congresses.

This will form the core of IRPA's activities for the current term up to 2020, and we look forward to cooperation with the Associate Societies, individual members and the international organisations including IOMP in delivering this programme. Full details of this programme are available through the IRPA website [www.irpa.net].

Selected Highlights from the Programme

We are actively pursuing all of the activities defined in our strategy as outlined above, but it is appropriate to expand on some selected key topics as below.

International Voice of the Profession

IRPA has direct engagement with many international organisations, including ICRP, IAEA, WHO and many others. Our key role is to help ensure that the development of philosophies, systems and standards in radiation protection takes account of the practical experience and needs of the practitioners. Through our congresses and information systems we also provide opportunities for our partner international organisations to keep the practitioner community informed of their activities.

The Future of the Profession

Many radiation protection societies around the world are facing a challenge to ensure that there is a continuing flow of young persons into the profession to meet the needs of the future. In many societies there is a trend of declining membership numbers. IRPA has a strong emphasis on supporting and developing the young scientists and professionals already within our ranks, and we are also looking to share the many good ideas for attracting students and other new recruits into the profession.

Public Understanding of Radiation and Risk

We all have experiences which clearly demonstrate the lack of understanding of radiation and risk amongst many parties within 'the public', and indeed within some professional sectors such as medicine where the level of general knowledge about radiation effects is often very low. This lack of understanding can lead to outcomes which sometimes seem to be based on a fear of radiation which we would consider as irrational, but which nonetheless is the real perception of many.

During the previous IRPA term we established a Public Understanding Task Group to encourage and support the AS in the development of effective means of enhancing public understanding of radiation risk through the sharing of good practice, ideas and resource material. We believe that there is a growing need and interest for the AS to enhance their programmes in this important area. This is a key but challenging activity which needs further support. Our work is therefore continuing, with the objective of broadening from sharing materials to assisting the AS and individual professionals to better understand the challenges of communication, and to be better equipped to meet them. We welcome IOMP's engagement in this programme.

Radiation Protection Culture

In 2014 IRPA published our Guiding Principles for Establishing a Radiation Protection Culture. All AS are encouraged to develop plans and additional material to support local implementation within all our workplaces. It also became apparent that it would be helpful to develop high level guidance specifically for the medical sector. This ongoing joint programme with IOMP and WHO is very active and well supported, and will be the subject of a further paper. We are also considering the development of higher level guidance for other sectors, such as Higher Education, Research and Teaching (HERT).

IV. CONCLUSIONS

Many of you will always think of IRPA as the organisation that holds congresses – both international and regional. Such congresses have been a long-standing part of our programme since our inception over 50 years ago. Of course these remain central to our identity, but I hope that the above outline of our activities clearly demonstrates that IRPA has a much wider role in support of the profession.

IRPA is well placed and respected by the wider international organisations to feed back the practical experience of day to day professional RP activities into developing top tier philosophy and standards. We actively promote the sharing of good practice and good ideas around our community of radiation protection societies around the world, leading to greater professionalism in the way we all act. And we support and provide for the training and education of our individual members.

Given the closeness of our work in the healthcare sector, it is imperative that IRPA and IOMP work together to deliver radiation safety within this sector. By using all our resources and experience for the benefit of the common good we can jointly achieve huge strides in embedding radiation safety in healthcare. We look forward to working with you at this exciting and challenging time for radiation protection.

Appendix: **The IRPA Executive Council 2016 – 2020**

President: Roger Coates (UK)
Vice-President: Eduardo Gallego (Spain)
Vice President for Congress Affairs:
Jong Kyung Kim (South Korea)
Executive Officer: Bernard Le Guen (France)
Treasurer: Richard Toohey (US)
Publications Director: Christopher Clement (Canada)
Elected Council Members:
Ana Maria Bomben (Argentina)
Alfred Hefner (Austria)
Sigurður Magnùsson (Iceland)
Marie-Claire Cantone (Italy)
Klaus Henrichs (Germany)
Hiroko Yoshida (Japan)

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PROFESSIONAL ISSUES

STATUS OF MEDICAL PHYSICS EDUCATION, TRAINING, AND RESEARCH PROGRAMS IN MIDDLE EAST

Azam Niroomand-Rad[1], Slavik Tabakov[2], Ibrahim Duhaini[3], Rabi Mahdavi[4], Behrouz Rasuli[5], Nabaa Naji[6], Muthana Al-Ghazi[7], Areen Albashir[8], Ali H. Al-Akhras[9], Meshar Al-Nuaimi[10], Zakiya Salem Al-Rahbi[11], Ismail Abuawwad[12], Tarek Al-Kaissi[13], Huda AlNaemi [14]Abdollah Al-Haj[15], Belal Moftah[16], Osama Anjak[17], Hatice Bilge[18], Jamila Al Suwaidi[19], Alfan Al Ameri[20], Entesar Dalah[21], Abdo Al-Oubati[22]

1 IOMP Past President, Prof. Emeritus, Georgetown Univ. Washington DC, USA
2 IOMP President, Hon. Prof., King's College London, UK,
3 MEFOMP Past President, Med Physicist (RHUH) & Instructor, Lebanese Univ., Lebanon
4 IAMP President, Prof. Iran Univ. of Medical Sciences, Tehran, Iran
5 Faculty Member, Behbahan Faculty of Medical Sciences, Behbahan, Iran
6 Nabaa Naji, Med. Physicist, IMPS President, Mustansiriyah Med College, Baghdad, Iraq
7 Muthana Al-Ghazi, Prof., Univ. of California, Irvine, CA, USA, Iraq
8 Areen Al-Bashir, Prof., Jordan Univ. of Sciences & Technology, Irbid, Jordan
9 M-Ali Al-Omari, Prof., Jordan Univ. of Science & Technology, Ramtha, Jordan
10 Meshari Al Nuaimi, Head, Kuwait Cancer Control Center, Sulibekhat, Kuwait
11 Zakiya Salem Al-Rahbi, Med. Physicist, Nat'l Oncology Center, Muscat, Oman
12 Ismail Abuawwad, Med. Physicist, Cancer Care Center, Jerusalem, Palestine
13 Tarek El-Kaissi, Sr. Med. Physicist, Nat'l Center for Cancer & Research, Doha, Qatar
14 Huda Al Naomi – QMPS President, Hamad Medical Corporation, Doha, Qatar
15 Abdalla N. Al-Haj, MEFOMP President, Saudi Arabia,
16 Belal Moftah, Chair, Biomedical Physics, KFSH&RC Riyadh, Saudi Arabia
17 Ossama Anjak, Medical Physicist, Damascus, Syria
18 Hatice Bilge, TSMP President, Prof. Istanbul University, Istanbul, Turkey
19 Jamila Al Suwaidi, Consultant Med. Physicist, Dept. of Med. Education, UAE,
20 Alfan Al Ameri, ESMP Vice President, Med. Physicist, Mafrat Hospital, Abu Dhabi, UAE
21 Entesar Dalah, Prof**.,** Muweilah Medical Center, Sharjah, UAE
22 Abdo Al-Qubati, Medical Physicist, Yemen Cancer Care Center, Yemen

Abstract— **Middle East Federation of Organizations of Medical Physics (MEFOMP) was established in 2009 initially with 12 participating countries: Bahrain, Iran, Iraq, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates and Yemen. Since then considerable efforts have been directed to establish medical physics society /association for Palestine. A Questionnaire was designed to compile the current status of medical physics in MEFOMP countries, focusing on the education, training, and research programs, as well as the year the society/association was established, approximate number of the members (male/female with PhD/MSc), graduate medical physics degrees granted (PhD/MSc), and equipment available for the programs. While there is a wide disparity among medical physics programs in Middle East, some programs have flourished since the inception whereas some programs have weakened due to the conditions beyond control of medical physicists and a few struggles to survive.**

Keywords— **Medical Physics, Education, Training, Research, Middle East, MEFOMP**

V. INTRODUCTION

The idea of setting up an organization for medical physics societies and associations in the Middle East was first introduced after completion of the IOMP [1] (International Organization for Medical Physics) and AAPM [2] (American Association of Physicists in Medicine) International Scientific Exchange programs (ISEP) in Manama, Bahrain in 2007 under the leadership of Azam Niroomand-Rad, founder of the IOMP/AAPM ISEP programs. The establishment of the Middle East Federation of Organizations of Medical Physics [3] (MEFOMP) was part of the IOMP effort to organize regional medical physics societies under its umbrella to further enhance and improve the status of medical physics across the Globe. The formation of MEFOMP was endorsed by several medical societies in the Middle East as well as IOMP and AAPM. The MEFOMP organization, which is a regional organization of IOMP, was officially formed in 2009 at the IUPESM [5] (International Union for Physical and Engineering Sciences in Medicine) XXII World Congress on Medical Physics and Biomedical Engineering in Munich, Germany under the leadership of Ibrahim Duhaini, who served as MEFOMP first President. The Organization consisted of 12 countries in Middle East: Bahrain, Iran, Iraq, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, and Yemen.

The main mission of MEFOMP [4] organization are to educate, train, and to promote research within local society members, to promote advancement in medical physics, and to encourage exchange of expertise and information among societies by organizing regional conferences and symposiums. The goals and objectives of MEFOMP are executed and moved forward by the Executive Officers (President, Vice-President, Past President, Secretary-General, and Treasurer) with input from Chairs of Committees (Education & Training, Science, Publications, Professional Relations, Awards & Honors, and Newsletter & Website).

VI. METHOD FOR UPDATING MEDICAL PHYSICS EDUCATION, TRAINING, AND RESEARCH PROGRAMS IN THE MIDDLE EAST

A Questionnaire was designed by Azam Niroomand-Rad with input from Slavik Tabakov and Ibrahim Duhaini to collect information on the current status of medical physics in MEFOMP countries, focusing on the education, training, and research programs, as well as the *year* the society/association was established, approximate number of the members (male/female) with (PhD/MSc), graduate medical physics degrees granted (PhD/MSc) institutions, and equipment available for treatment, diagnosis of patients for their programs. This project is part of a larger IOMP project "History of Medical Physics – A Brief Project Description" that was launched by Slavik Tabakov [6] during the past year. The 14 countries considered for this project are shown in **Appendix I**: Bahrain, Iran, Iraq, Jordan, Kuwait, Lebanon, Oman, Palestine, Qatar, Saudi Arabia, Syria, Turkey, United Arab Emirates and Yemen. However, we received very limited information from Bahrain at the time of preparation of this report.

The Questionnaire had several sections as shown in **Appendix II**: (A) Profile of association /society including number of medical physicists (male, female) with PhD, MSc and BSc degrees working in therapy, diagnostic / nuclear medicine, radiation safety / regulatory duties and other areas that could be specified by the respondents; (B) Summary of usual and customary meetings / conferences / seminars / workshops; (C) List of awards, honors, and special recognitions given to the medical physicists (male, female); (D) List of the university / institution where graduate medical degrees (PhD / MSc) are offered including length of the program and number of students (male / female) admitted to the program; (E) List of the university / institution where *clinical training* are provided to the medical physicists (male, female) including length of training program; (F) List of the university / institution where *research* in medical physics and related topics are performed; (G) Number of equipment available in therapy (G.1) such as (Cobalt 60, Linear Accelerator, High Dose Rate (HDR) Remote After Loading, Low Dose Rate (LDR) Remote After Loading), in Radiology (G.2) such as (CT, MRI, Ultrasound, Fluoroscopy), and in nuclear medicine (G.3) such as (PET, SPECT, PET-CT, SPECT-CT, Gamma Camera). Some respondents specified other equipment such as Simulator, Orthovoltage, CybereKnife, GammaKnife, Tomotherapy and Proton.

VII. RESULTS OBTAINED FOR MEDICAL PHYSICS EDUCATION, TRAINING, AND RESEARCH PROGRAMS IN THE MIDDLE EAST

Responses to Sections (A – G) of the Questionnaire are compiled and discussed in Tables [A – G (G.1, G.2, G.3)] respectively.

Table A shows the profile of Medical Physics Societies and Associations in the Middle East Countries including Date Founded, Founding President, Website, Approximate Numbers of Medical Physicists (male and female) with PhD, MSc, and BSc degrees as outlined here:

<u>The gender (Male, Female)</u> of **1584** Medical Physicists who work in the Middle East region are as follows:

- 852 (~ 54%) are Male
- 705 (~ 44%) are Female
- 27 (~ 2%) genders are not specified

<u>The college degrees (PhD, MSc., and BSc.)</u> of **1511** (~ 95%) of 1584 Medical Physicists whose degrees were specified are as follows:

- 347 (~ 23%) of 1511 Medical Physicists have PhD degree. The gender of Medical Physicists with PhD degree are as follows:
  - 187 (~ 54%) are Male
  - 122 (~ 35%) are Female
  - 38 (~ 11%) genders are not specified

- 912 (~ 60%) of 1511 Medical Physicists have MSc degree. The gender of Medical Physicists with MSc degree are as follows:
  - 396 (~ 44%) are Male

- 403 (~ 44%) are Female
- 113 (~ 12%) genders are not specified

• 252 (~ 17%) of 1511 Medical Physicists have BSc degree. The gender of Medical Physicists with BSc degree are as follows:

- 104 (~ 41%) are Male
- 78 (~ 31%) are Female
- 70 (~ 28%) gender are not specified

As shown, the overall number of female Medical Physicists in the Middle East region is about 10% lower than male. Similarly the numbers of female Medical Physicists with PhD and BSc are about 10% lower than male. However, the numbers of female with MSc degree are comparable.

The major specialties of **1572** (~ 99%) of 1584 Medical Physicists in this region are reported; of which:

• 722 (~ 46 %) of 1572 Medical Physicists work in Radiation Therapy. The genders of the Medical Physicists who work in Radiation Therapy are as follows:

- 354 (~ 49%) are Male
- 332 (~ 46%) are Female
- 36 (~ 5%) gender are not specified

• 342 (~ 22%) of 1572 Medical Physicists work in Diagnostic and Nuclear Medicine. The gender of the Medical Physicists who work in Diagnostic and Nuclear Medicine are as follows:

- 172 (~ 50%) are Male
- 135 (~ 40%) are Female
- 35 (~ 10%) gender are not specified

• 182 (~ 12%) of 1572 Medical Physicists work in Radiation Safety and Regulatory positions. The gender of the Medical Physicists who work in Radiation Safety and Regulatory positions are as follows:

- 110 (~ 60%) are Male
- 72 (~ 40%) are Female

• 326 (~ 20%) of 1572 Medical Physicists work in Biophysics, Biomedical Engineering, Optics/Laser, and Academia. The gender of the Medical Physicists who work in these areas are as follows:

- 51 (~ 16%) are Male
- 54 (~ 16%) are Female
- 221 (~ 68%) gender are not specified

As shown, majority (~ 46%) of the Medical Physicists work in Radiation Therapy with number of male (~ 49%) almost comparable with female (46%). About (~ 22%) of Medical Physicists work in Diagnostic and Nuclear Medicine in which number of females are (~10%) lesser than males. About (~20%) of Medical Physicists work in academia and are mostly engaged in research in Medical Physics related areas such as biology, biomedical engineering, optics and lasers and the number of males and females are almost the same (~ 16%). In addition, about (~ 12%) of the Medical Physicists work in Radiation Safety and Regulatory positions; in which number of females are (~20%) lesser than males.

Table B describes the frequencies and approximate number of the meetings, conferences, seminars and workshops organized within each country and/or in collaboration with other organizations and international agencies. In most countries there are some forms of routine meetings at least on annual basis. In some countries Medical Physicists often participate in training courses, conferences and workshops organized by (IAEA) [7] (International Atomic Energy Agency), AAPM, MEFOMP and Arab Health [8].

Table C shows awards, honors, and special recognitions established by the medical physics societies and associations in the Middle East region. Our intent for Section C of the Questionnaire was to learn how Medical Physicists, especially junior Medical Physicists and students studying Medical Physics, have been or are being recognized by their peers. However, only 3 countries have established such award and recognition for Medical Physicists: Iran (Parsai Award for Medical Physics Students on triennial basis), Qatar (Medical Physicist of the Year Award on annual basis) and Turkey (Best Paper Award on annual basis). Other countries stated awards that were mostly received by senior medical physicists in the region. Even then we believe this is a partial list of the awards received by Medical Physicists in the Middle East.

Table D is a list of the universities and institutions with graduate Medical Physics Programs; length and year (PhD / MSc) programs were established and annual (approximate) number of the students (male, female) admitted to the programs. Excluding the programs that are currently "on hold" in Iraq, the total number of graduate Medical Physics Programs in the Middle East that offer PhD and MSc degrees is 33, of these, 16 institutions offer PhD degrees. The length of the PhD programs in Iran are 4 years and in Saudi Arabia and Turkey are 3 years. The length of all MSc programs is 2 years in all institutions in the Middle East. Excluding the programs that did not specify gender of the students, approximate numbers of PhD students that are admitted on annual basis to the PhD programs are about 19 males and 14 females. Similarly, the approximate numbers of students admitted to MSc programs are about 94 males and 87 females. It should be noted that several countries do not offer graduate programs in Medical Physics and students often have to go abroad to study Medical Physics. Moreover, there is one institution in Yemen that offers an undergraduate BSc program in Medical Physics.

Table E is a list of the clinics, universities and institutions that offer *clinical trainings* to Medical Physicists (male, female) admitted to the graduate programs during PhD and MSc studies. The length of the program is also included. Except for Oman (2 years), Saudi Arabia (3 years) and Syria (4 years), most of the clinical training programs are few months in duration and are offered during MSc programs. The approximate number of students admitted to clinical training has not been specified by most of the respondents.

Table F is a list of the universities and institutions with medical physics *research* programs and description of research performed in collaboration with other centers and hospitals. It is shown that many different types of medical physics related research are performed in over 50 research centers in the Middle East; some of which are in collaborations with other centers and hospitals.

Table G.1 shows the approximate numbers of therapy equipment used for treatment, diagnosis, teaching, training, and research in this region. Excluding the countries for which we did not receive estimate for teletherapy equipment, it is shown that linear accelerators (~ > 382) units are far more common than Cobalt 60 (~ > 92) units. For brachyteherapy equipment, high dose rate remote loading (~ > 67) units are also more common than low dose rate remote loading (~ 5) units. Moreover, there are about 15 GammaKnife, 15 CyberKnife and 15 Tomotherapy, 2 High-Intensity Focused Ultrasound (HIFU), 2 Orthovoltage unit and 1 Proton unit (operational in 2018) for external irradiation.

Table G.2 shows approximate numbers of diagnostic equipment used for diagnosis, teaching, training, and research in this region. As expected, there are more computed tomography (CT) units (~ > 3296) than magnetic resonance imaging (MRI) units (~ > 2005). The other commonly used equipment is Ultrasound (~ > 8378), Fluoroscopy (~ > 2407), Dental Units (~ > 1044), and Mammography Units (~ > 60).

Table G.3 shows the approximate numbers of equipment used in the nuclear medicine procedures and imaging for diagnosis, training and research in this region. As shown, there are more Gamma Camera units (~ > 6600) than Positron Emission Tomography (PET) that are reported to be 5 units. The approximate numbers of Single Photon Emission Computed Tomography (SPECT) are about 221 units, Positron Emission Tomography–Computed Tomography (PET-CT) are about 151 units and Single Photon Emission Computed Tomography (SPECT) are about 164 units. There are also 11 Cyclotron units reported; of which 1 (one) unit is in Qatar and ten (10) units are in Saudi Arabia. However, we think that there are more Cyclotron units in the Middle East than reported here.

VIII. Conclusion and recommendations

The formation of the Middle East Federation of Organizations of Medical Physics [4] (MEFOMP) as a regional organization of IOMP [1] in 2009, has been a major step in helping to establish Medical Physics Associations / Societies in the Middle East countries where there was none before. The process of establishing such organizations and recognition by the respective governments, varied greatly among the 14 countries that participated in this project. Overall, however, they have proven to be an effective channel to facilitate education, training, and research in all countries in this region. As per data of the IOMP that was reported by Slavik Tabakov [10], survey shows that the number of the Medical Physicists in the Middle East was almost doubled during the past 2 decades. This achievement requires special congratulations to all colleagues who supported and worked for the development of the Medical Physics Profession in the Middle East. However, it is very important to continue and accelerate the growth of Medical Physics profession in this region. In particular special attention needs to be paid by MEFOMP to the advancement and development of Medical Physics Profession in few countries, such as Bahrain, Palestine, and Yemen. The MEFOMP [4] as well as IOMP [1] and IAEA [7] need to actively work with medical physicists in these countries to teach, train, and advance Medical Physics Professionals in these countries. In addition to social / political challenges in these countries, lack of financial resources and equipment are serious problems especially in Palestine and Yemen.

Graduate Medical Physics educational and training programs offering PhD and/or MSc degrees are currently available in 7 (seven) countries: Iran, Iraq, Jordan, Lebanon, Saudi Arabia, Syria, and Turkey. One undergraduate medical physics program, offering BSc degree, is also available in the Ibb University in Yemen. To a large extent, of the 33 graduate Medical Physics Programs offering PhD and MSc degrees in the Middle East, most of them are in Iran (14) with (6) PhD programs and in Turkey (11) with (8) PhD programs. Noteworthy is that the approximate numbers of females admitted annually to PhD Medical Physics Programs (~ 14) are almost comparable to the numbers of males (~ 19). Similarly, the numbers of females admitted to the MSc programs (~ 85) are also comparable to male (~ 92). While the lengths of the PhD programs are 3 to 4 years, the length of all MSc programs are 2 years.

In addition to teaching and training, Medical Physicists are often involved in research and technical development in most academic settings. While the type of research conducted in most universities and institutions varies, research in radiation dosimetry is the most common one in the 3 (three) main subspecialties of the Medical

Physics: therapy, radiology, and nuclear medicine. In some institutions Medical Physicists are also engaged in radiation biology and biomedical research in collaborations with other hospitals and centers. Though research is required from all the PhD students, students in MSc programs are also encouraged to have optional research projects.

In most countries continuing education and training are offered in annual conferences, seminars, and workshops. In some countries Medical Physicists often participate in training courses and workshops organized by MEFOMP [4], IAEA [7], AAPM [2] and Arab Health [8] conferences in the region. Since 2013, a one-day symposium is organized in most countries on the occasion of the International Day of Medical Physics (IDMP) on November 7th of each year. Medical Physicists are sometimes recognized with honors and awards during national and international symposium and conferences.

The equipment used by medical physicists in this region differs greatly in various countries. Depending on financial resources available to the Medical Physicists, some advanced equipment has been acquired for treatment and diagnosis of diseases of cancer patients. However, from the data available at the World Health Organization [9] (WHO), we do not know with certainty if conventional equipment is adequate for cancer patients in this area. According to WHO, however, the number of lung cancer has increased in this region and will continue to increase in the next 10 years. Therefore the number of Qualified Medical Physicists, as defined by the IOMP [1], and number of educational and training programs must increase to meet the needs in this region. According to a report [11] by Nelly Enwerem-Bromson and May Abdel-Wahab, “Expanding global access to radiotherapy: the IAEA perspective” and a Task Group report by Rifat Atum et. Al [12] “Expending global access to radiotherapy” it is projected that the number of Medical Physicists per million of the population will have to triple by 2035. Otherwise in future this may cause significant problems to healthcare providers in the Middle East - especially in the fields of Radiotherapy, Medical Imaging and Radiation Safety.

IX. AUTHORS CONTRIBUTIONS AND ACKNOWLEDGMENT

The first author carried out most of the data collection and writing. She reviewed the Questionnaire, resolved discrepancies, and performed the full analysis and reviewed main literature for this project. The second and third authors helped to edit the manuscript and check data consistency as related to the Tables. However, it was not possible to ask all the authors to read and/or approve the final manuscript. This was done on one-on-one basis with contributors from each country.

We would like to thank the contributors from all countries for providing updated educational, training, and research opportunities for Medical Physicists in their countries. Attempts were made to acknowledge all authors in this report. However, we realize that more colleagues may have contributed to this project than we could possibly acknowledge them. We, therefore, hereby apologize to them

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Appendix 1

14 Countries in Middle East Participated in this Project

Appendix II

Questionnaire Designed for Educational, Training, and Research Programs in Middle East

Status of Medical Physics Education, Training, and Research Programs in
Country of : --------------------------------

A. Official name of the medical physics Society / Association in English:

Date (Year) it was established: --
Name of the Founding President: --
Official Website Address (if any): --
Approximate number of members at establishment (if known): -----------------
Approximate number of members at present (Male / Female): M ------- F -------
Approximate number of the members (Male / Female) with PhD working in:

(a) Therapy: M --------- F ------------
(b) Diagnostic / Nuclear Medicine: M ----- F -------
(c) Radiation Safety / Regulatory Officer: M ------- F --------
(d) Others (Specify): -------------------------------------

Approximate number of the members (Male / Female) with MSc. working in:

(a) Therapy: M ------ F -------
(b) Diagnostic / Nuclear Medicine: M ----- F -------
(c) Radiation Safety / Regulatory Officer: M ----- F ------
(d) Others (Specify): -------------------------------------

Approximate number of the members (Male / Female) with BSc. working in:

(a) Therapy: M ------ F -------
(b) Diagnostic / Nuclear Medicine: M ----- F -------
(c) Radiation Safety / Regulatory Officer: M ----- F ------
(d) Others (Specify): -------------------------------------

B. Specify approximate number of the meetings / conferences / seminars / workshops organized in your country and/or combined with other countries: including their frequencies:

C. Specify the **Awards, Honors and Special Recognitions** Granted to the medical physicists (Male / Female); including their frequencies:

D. Name and address of the university / institution where graduate medical physics degrees are granted; including annual number of the students (Male / Female) admitted to the program, length of the educational programs, and date they were established:

(Note: Please revise and/or add row(s) to table below as needed)

Name of University / Institution, City, Province	Length of Graduate Program (PhD / MSc.)	Date Graduate Program was Established (PhD / MSc	Annual Number of PhD Students Admitted M / F	Annual Number of MSc. Students Admitted M / F
	/	/	/	/
	/	/	/	/
	/	/	/	/
	/	/	/	/
	/	/	/	/

E. Name and Address of clinic / university / institution where clinical trainings are provided to medical physicists with PhD and MSc degree (Male / Female); including length of the clinical training program:

(Note: Please revise and/or add row(s) to table below as needed)

Name of Clinic / University / Institution, City, Province	Length of Clinical Training Program	Annual Number of PhD Medical Physicists Admitted M / F	Annual Number of MSc Medical Physicists Admitted M / F

		/	/
		/	/
		/	/
		/	/
		/	/

F. **Name and address of university / institution / clinics where medical physics researches are performed; including type of research:**

(Note: Please revise and/or add row(s) to table below as needed)

Name of University / Institution City, Province	Briefly Specify Type of Research

G. **Equipment available to medical physicists for Teaching, Training, Research, and Cancer Diagnosis and Treatment:**

(Note: Please revise and/or add row(s) to table below as needed)

Equipment in Therapy	Approximate Number of Equipment
Cobalt 60 Unit	
Linear Accelerator	
High Dose Rate Remote After Loading	
Low Dose Rate Remote After Loading	
Other Equipment (specify)	

Equipment in Radiology	Approximate Number of Equipment

CT	
MRI	
Ultrasound	
Fluoroscopy Units	
Other Equipment (specify)	

Equipment in Nuclear Medicine	**Approximate Number of Equipment**
PET	
SPECT	
PET-CT	
SPECT-CT	
Gamma Camera	
Other Equipment (Specify)	

H. **Additional Comments on any specific feature(s) of medical physics teaching, training and research programs in your country which were not covered above (Optional):**

I. **Name and e-mail address of individual(s) filling out this Questionnaire including the date it was completed:**

Please Return this Questionnaire to:

Prof. Azam Niroomand-Rad, PhD, DSc., IOMP Past President

azam@georgetown.edu

Thank you

Table A

Table A. The Profile of Medical Physics Societies and Associations in Middle East Countries including Date Founded, Founding President, Website, Approximate Numbers of Medical Physicists (Male and Female) with PhD, MSc, and BSc Degrees

Country	Association / Society (Website / Twitter)	Founded Year	Founding President	Approximate Male / Female	PhD Degree Male / Female	MSc Degree Male / Female	BSc Degree Male / Female
Bahrain	Bahrain Society of Med Phys Bio-Eng. (BSMPBE)	2008		7 / 6 Not Specified 27	/	/	/
Iran	Iranian Asso. of Med Physicists - (iamp.ir)	1994	Azim Arbabi	233 / 172	100 / 50	120 / 110	13 / 12
Iraq	Iraqi Med Physics Society (IMPS)	2011	Nabaa Naji	14 / 30	0 / 3	2 / 7	5 / 6
Jordan	Jordanian Assoc of Physicists in Medicine - (japm-jo.org)	2006	Abdul Majeed Al-Yaseen	30 / 50	0 / 1 Not Specified 4	3 / 2 Not Specified 12	12 / 6 Not Specified 37
Kuwait	Kuwait Asso of Med Physics (@kuwaitmp)	2016	Meshari Alnuaimi	16 / 8	1 / 2	5 / 2	10 / 4
Lebanon	Lebanese Asso of Med Physics (LAMP)	2005	Ibrahim Duhaini	12 / 8	10 / 3	2 / 5	0 / 0
Oman	Oman Med Phys. Society (OMPS)	2011	Afkar AL-Farsi	24 / 27	2 / 1	2 / 9	1 / 17
Palestine	Palestine Med Physics Society (PMPS)	2006		2 / 2	0 / 0	1 / 1	1 / 1
Qatar	Qatar Med. Phys. Society (QaMPS)	2009	Huda AlNaomi	17 / 8	7 / 2	9 / 5	1 / 1
Saudi Arabia	Saudi Med Phys Society (SMPS): smps.org.sa	2006	Ahmed Outif	282 / 94	33 / 10 Not Specified 34	97 /31 Not Specified 101	35 / 12 Not Specified 33
Syria	Syrian Med Physics Asso (SyMPA)	2009	Hassan Kharita	29 / 11	16 / 3	4 / 7	9 / 1
Turkey	Turkish Med Physics Asso (TMPA) – medikalfizik.org	1988	Seyfettin Kuter	172 / 237	16 / 10	140 / 215	16 / 12
UAE	Emirates Med Physics Society (EMPS)	2005	Jamila Salem Al-Suwaidi	7 / 51	2 / 37	5 / 9	0 / 5
Yemen	Yemen Med Physics Asso (YMPA)	2013	Mogib Al-Makdad	7 / 1	0 / 0	6 / 0	1 / 1

Table B

Table B: Approximate Number of the Meetings, Conferences, Seminars and Workshops Organized in the Country with Frequency of the Program and/or in Collaboration with Others (Specify)

Country	Meetings, Conferences, Seminars, Workshops	Frequency	Others (Specify)
Iran	IAMP Board of Directors Meeting	Monthly	
	IAMP Conference	Triennial	
	Workshops per Program at Various Sites, twice per month	Bimonthly	
	1st Int'l Conference on Radiation and its Role in Diagnosis and Treatment, Tehran	2000	AAPM / IOMP
	1st MEFOMP International Conference in Medical Physics, Shiraz	2011	MEFOMP
Iraq	8 Meetings: 2009, 2010, 2011, 2013, 2014, 2015, 2016, 2017	8	
	9 Seminars: 2013 - 2017	9	
	3 Workshops: 2015, 2016, 2017	3	
Jordan	JAPM Board of Directors Meeting (Administrative)	Monthly	
	JAPM Board of Directors Meeting (Public Board)	Annual	
	1 Conference, 1 Conference (in preparation)	1	
Kuwait	1 Medical Physics Conference in March	Annual	
	1 International Day of Medical Physics in November	Annual	
	1 Radiation Safety Refresher Course in May	Annual	
	Radiation Physics Seminars in Nuclear Medicine in September	Annual	
Lebanon	LAMP Meeting every 3 to 6 months	3 to 6 month	
	LAMP Workshops and Seminars once per year	Annual	
Oman	8 International Oncology Conference	8	
	1 Radiation Protection Workshop	Annual	
Palestine	Onsite Training Workshops with Varian when new machine is purchased	As needed	Vendors
Qatar	IAEA Training Course on Calibration of External Beam Radiotherapy Equipment	2012	IAEA
	IAEA Training Course on Brachytherapy	2013	IAEA
	1 Symposium, PET/CT, Doha	2015	MEFOMP
	1 Workshop, Radiation Safety in cardiology 2016, 2016, 2017, Doha	Annual	MEFOMP
	1 Workshop (Spect CT) 2015, (CT) 2016, 2017, Doha	Annual	MEFOMP

	1 Nuclear Medicine Conference, Doha	2015	MEFOMP
	2 Regional Meetings of MEFOMP (Spring and Fall), Doha	2015	MEFOMP
	1 International Day of Medical Physics (IDMP), Doha	Annual	
	1 Summit on Radiation in Life, Radiation Protection, Doha	2015	MEFOMP
	1 Workshop on Laser Safety Training Course	2017	MEFOMP
Saudi Arabia	2 SMPS Conference	Annual	
	20 Seminars and Workshops	Annual	
	1 International Conference on Radiation Medicine (ICRM)	Annual	
	6 Workshops at International Conference on Radiation Medicine	Annual	
	10 Radiation Safety Courses/Workshops (KFSH&RC, KFMC, SMPS, Others)	Annual	
Syria	Training on Radiation Protection	4	
	Training on Radiation Dosimetry		
Turkey	TMPA National Medical Physics Congress, every 2 years (16th on Oct. 2017)	Biennial	
	Meetings /Workshops organized by various centers, 5 to 6 times per year	5 to 6 per year	
	Refresher Courses with International Organizations	1995	AAPM
	Refresher Courses with International Organizations	2011	AAPM
UAE	6 IAEA Meetings, workshops, training courses, every 2 months	Every 2 years	IAEA
	1 Conference in conjunction with Radiology, Arab Health Conference	Annual	Arab Health
	3 Radiation Protection Continuing Professional Development (CPD) Programs	Annual	
	3 Basics of Radiation Protection in Hospital – Radiology Practices (Dubai Health Authority)	Annual	
	2 Radiation Protection for Dental Radiology Practice (Dubai Health Authority)	Annual	
	3 Implementing Radiation Protection in Radiology Practice: What to do?, When? (Dubai Health Authority)	Annual	
	1 Workshop, Radiation Safety & Protection: Application of Ionizing Radiation and Detection Method, Univ. of Sharjal	2017	
	1 Workshop, Patient Radiology Services Referral Quidlines, Sheikh Khalifa General Hospital-Umm Al Quwain , Radiation Dose Monitoring	2017	IAEA
	1 Forum, 2nd Sciences & Engineering Research Group, Univ. of Sharjal	2017	
	1 Symposium, International Day of Radiology, University Hospital Sharjah	2016	
	1 Symposium, International Education Exhibition, EXPO Sharjah	2016	
	1 Seminar, 7th Medical Diagnostic Imaging, University of Sharjah	2015	

Table C

Table C: Awards, Honors and Special Recognitions Established by the Medical Physics Societies and Associations in Middle East including Frequency / Year Awarded

Country	Awards, Honors, Special Recognition	Frequency	Others (Specify)
Iran	1 Parsai Award to Medical Physics Students, every 3 years	Triennial	
	IOMP Young Investigator Award at World Congress-2006	2006	Dr. Ali A. Mowlavi
Lebanon	IDMP- IOMP Award 2015 For MEFOMP	2015	Mr. Ibrahim Duhaini
	IOMP Presidential Award	2016	Mr. Ibrahim Duhaini
	IOMP Fellowship (FIOMP) in 2017	2017	Mr. Ibrahim Duhaini
Oman	1st Prize in Middle East Abstract (?) to Female (?)		
Qatar	1 Medical Physicist of the Year Award	Annual	
	IDMP- IOMP Award 2017 For MEFOMP	2017	Dr. Huda AL Naemi
Saudi Arabia	6 KA CARE Awards - Radiation Protection Experts, 2017	2017	
	1 Award by IDMP-IOMP For MEFOMP	2016	Dr. Abdallah AL Haj
	2 Canadian College of Physicists in Medicine (CCPM) Fellowship		
	2 Canadian College of Physicists in Medicine (CCPM) Membership		
	10 Diplomat of the American Board of Radiology (DABR)		
	8 Institute of Physics and Engineering in Medicine Membership (MIFEM)		
	5 Institute of Physics and Engineering in Medicine Fellowship (FIFEM)		
	5 International Atomic Energy Agency (IAEA) Experts		
Turkey	TMPA Best Paper Award at National Medical Physics Congress	Annual	
UAE	Presidential Award for Scientific Research in 2012	2012	Dr Jamila Salem AlSuwaidi
	Pioneers Award to the First Medical Physicist in 2015	2015	Dr Jamila Salem AlSuwaidi
	Sheikh Hamdan Award for Medical Sciences in 2014	2014	Dr Jamila Salem AlSuwaidi

Table D

Table D: Universities and Institutions with Graduate Medical Physics Programs, Length and Year (PhD / MSc) were Established and Annual Numbers of the Students (Male / Female) Admitted to the Programs

Country	University / Institution, City	Length of Program (PhD / MSc.)	Year Established (PhD / MSc.)	Annual No. PhD Admitted Male/Female	Annual No. MSc. Admitted Male / Female
Iran	Tehran Uni. of Med Sci., Tehran	4 / 2	1999/1995	2 / 2	4 / 4

	Iran Uni. of Med Sci., Tehran,	4 / 2	?/?	2 / 2	3 / 3
	Mashhad Uni of Med Sci., Mashad,	4 / 2	1997/1991	1 / 1	3 / 3
	Tarbiat Modares Uni of Med Sci., Tehran	4 / 2	1989/1985	1 / 1	3 / 3
	Ahwaz Uni of Med Sci., Ahwaz	4 / 2	2007/1976	4 / 4	2 / 2
	Tabriz Uni of Med Sci., Tabriz	2 years (MSc)	?	-	4 / 4
	Isfahan Uni of Med Sci., Ishahan	4 / 2	2007/1997	1 / 1	4 / 4
	Shahid Beheshti Uni of Med Sciiences	2 years (MSc)	2012	-	2 / 2
	Shiraz Uni of Med Sci., Shiraz	2 years (MSc)	2012	-	3 / 3
	Yazd Uni of Med Sci., Yazd	2 years (MSc)	2013	-	3 / 3
	Kermanshah Uni of Med Sci., Kermanshah	2 years (MSc)	2009	-	3 / 3
	Urmia Uni of Med Sci., Urmia	2 years (MSc)	2012	-	3 / 3
	Semnan Uni of Med Sci., Semnan	2 years (MSc)	2011	-	3 / 3
	Kashan Uni of Med Sci., Kashan	2 years (MSc)	2013	-	2 / 2
Iraq	Univ. of Mustansirita Medical college, Baghdad	3 / 2	2000 /1989	On Hold	2 / 3
	Univ. of Baghdad Medical college, Baghdad	2 years (MSc)	2006-2014,	On Hold	
	Univ. of Nahrain Medical college, Baghdad	2 years (MSc)	2016		2 / 2
	Univ. of Sulaimania Med. College, Sulaimaniya	2 years Diploma	2015		2 / 0
Jordan	University of Jordan, Amman	2 years (MSc)	2007		
Lebanon	Lebanese University, Beirut	2 years (MSc)	2014		~ 6 / 6
	Beirut Arab University, Beirut	2 years (MSc)	2017		2 / 2
Saudi Arabia	King Faisal Specialist Hosp., Research Centre, Riyadh	3			2 / 1
	King Fahad Specialist Hosp., Dammam	3			1 / 0
Syria	Damascus Univ., Damascus	2 years (MSc)	2014-2015		5 / 8
Turkey	Istanbul Univ., Oncology Institute, Istanbul	3 / 2	1986/1986	~ 1 / 1	~ 3 / 3
	Hacettepe Univ., Univ. of Ankara, Ankara	3 / 2	2013/1993	~ 2 / 0	~ 1 / 1
	Ege Univ., Ismir	3 / 2	2015/2004	~ 2 / 0	~ 3 / 3
	Dokuz Eylul Univ., Ismir	3 / 2	2014/2006	~ 2 / 0	~ 5 / 5
	Trakya Univ., Edirne	3 / 2	2013/2008	~ 0 / 1	~ 1 / 1
	Uludag Univ., Bursa	3 / 2	2014/2008	~ 1 / 1	~ 2 / 1
	Erciyes Univ., Kayseri	2 years (MSc)	2007		~ 1 / 1
	Cukurova Univ., Adana	2 years (MSc)	2011		~ 5 / 5
	Akdeniz Univ., Antalya	2 years (MSc)	2013		~ 3 / 1
	Acıbadem Univ., Istanbul	3 / 2	2010		~ 5 / 1
	Medipol Univ., Istanbul	3 / 2	2014		~ 1 / 1
Yemen	Ibb University, Ibb	BSc in Med Physic			2 Graduated

Table E

Table E: Clinics, Universities and Institutions with Length of Clinical Trainings and Approximate Numbers of Medical Physicists (Male / Female) Admitted to the Programs During (PhD / MSc) Studies

Country	Clinic, University, Institution, City	Length of Clinical Training Program	Annual No. PhD Admitted M / F	Annual No. MSc Admitted M / F
Iran	Imam Khomeini Hosp. Radiotherapy Physics Section, Tehran	3 months	/	/
Jordan	King Hussain Cancer Foundation, Amman	3-6 months	/	0 / 2
Lebanon	Rafik Hariri University Hospital	4- 6 months	/	1 / 1
	American University Hospital	4- 6 months	/	1 / 1
	Bsalim Hospital	4- 6 months	/	1
	Reyak Hospital	4- 6 months	/	1
Oman	Local Training for Junior Medical Physicists	2 years	/	/
Saudi Arabia	King Faisal Specialist Hospital & Research Centre, Riyadh.	3 years	/	2 /1
Saudi Arabia	King Fahad Specialist Hospital, Dammam	3 years	/	1 /
Syria	AlBaironee Hospital, Damascus	4 years	/	2 / 3
Turkey	Istanbul Univ., Oncology Institute, Istanbul	During MSc	/	/
Turkey	Hacettepe Univ., Univ. of Ankara, Ankara	During MSc	/	/
Turkey	Ege Univ., Ismir	During MSc	/	/
Turkey	Dokuz Eylul Univ., Ismir	During MSc	/	/
Turkey	Trakya Univ., Edirne	During MSc	/	/
Turkey	Uludag Univ., Bursa	During MSc	/	/
Turkey	Erciyes Univ., Kayseri	During MSc	/	/
Turkey	Cukurova Univ., Adana	During MSc	/	/
Turkey	Akdeniz Univ., Antalya	During MSc	/	/
Turkey	Acıbadem Univ., Istanbul	During MSc	/	/
Turkey	Medipol Univ., Istanbul	During MSc	/	/
UAE	On Job Training within Hospitals		/	/

Table F

Table F: Universities and Institutions with Medical Physics Research Programs and Description of Research Performed in Collaboration with other Centers and Hospitals.

Country	University, Institution, City	Description of Research and Collaboration with Other (Centers / Hospitals)
Iran	Tehran Univ. of Med Sci., Tehran	Radiotherapy, Diagnostic Radiology, Nuclear Medicine, Ultrasound, Bioelectricity, Radiobiology, Optical Imaging, Nanotechnology
	Iran Univ. of Med Sci., Tehran	Radiotherapy, Diagnostic Radiology, Nuclear Medicine, Ultrasound, Bioelectricity, Radiobiology, Optical Imaging, Nanotechnology
	Mashhad Univ. of Med Sci., Mashhad	Radiotherapy, Diagnostic Radiology, Nuclear Medicine, Ultrasound, Bioelectricity, Radiobiology, Optical Imaging, Nanotechnology
	Tarbiat Modares Univ. of Med Sci., Tehran	Radiotherapy, Diagnostic Radiology, Nuclear Medicine, Ultrasound, Bioelectricity
	Ahwaz Univ. of Med Sci., Ahwaz	Radiotherapy, Bioelectricity
	Tabriz Univ. of Med Sci., Tabriz	Radiotherapy, Diagnostic Radiology, Bioelectricity, Radiobiology, Nanotechnology
	Isfahan Univ. of Med Sci., Isfahan	Radiotherapy, Diagnostic Radiology, Nuclear Medicine, Bioelectricity, Radiobiology
	Shahid Beheshti Univ. of Med Sci., Tehran	Radiotherapy, Diagnostic Radiology, Nuclear Medicine, Radiobiology
	Shiraz Univ. of Med Sci., Shiraz	Radiotherapy, Ultrasound, Bioelectricity
	Yazd Univ. of Med Sci., Yazd	Radiotherapy, Diagnostic Radiology
	Kermanshah Univ. of Med Sci., Kermanshah	Radiotherapy, Radiobiology
	Urmia Univ. of Med Sci., Urmia	Radiotherapy, Diagnostic Radiology, Radiobiology
	Semnan Univ. of Med Sci., Semnan	Radiotherapy, Ultrasound, Bioelectricity
	Kashan Univ. of Med Sci., Kashan	Radiotherapy, Diagnostic Radiology, Ultrasound, Radiobiology
Iraq	Mustansiriya Med. College, Baghdad	MSc. Radiotherapy planning (A- Amel Radiotherapy Center)
	Mustansiriya Med. College, Baghdad	MSc. Radiotherapy Planning & Dosimetry (Baghdad Radiotherapy Hosp. & Med. City)
	Mustansiriya Med. College, Baghdad	MSc. Radiotherapy (Neurosurgery Sciences Hospital)

	Mustansiriya Med. College, Baghdad	MSc. Radiation Protection (College of Science in Baghdad Univ.)
	Mustansiriya Med. College, Baghdad	MSc. Radiation Protection (Iraqi National Center for Radiation Protection)
	Mustansiriya Med. College, Baghdad	MSc. Radiotherapy (Iraqi National Center of Cancer Research)
	Mustansiriya Med. College, Baghdad	MSc. Radiotherapy & Dosimetry (Iraqi National Center of Hematology)
	Sulaimaniya Med. Univ., Sulaimaniya	Diploma: Radiotherapy Training (Zhianawa Cancer Center)
Jordan	Univ. of Jordan, Amman	Nuclear Medicine
	Yarmouk Univ., Irbid	Radiation Protection, Dosimetry, Medical Imaging
	Hashemite Univ., Alzarqa	Radiotherapy, Jell Dosimetry
	Univ. of Science and Technology, Irbid	Monte Carlo Simulation, Radiation Protection
	King Hussain Cancer Foundation, Amman	Support Different Types of Research
Kuwait	Cancer Control Center, Shuwaikh	Dosimetry, PET and Radionuclide Therapies
	Sheikh Jabir Molecular Imaging Center	PET
Oman	National Oncology Center, Royal Hospital, Muscat	Radiotherapy and Diagnostic (NM) Dosimetry, Radiation Protection
Qatar	Hamed Medical Corporation, Doha	Dosimetry, Quality Control, Radiation Protection
Saudi Arabia	King Faisal Specialist Hosp. & Research Centre, Riyadh	Radiation Dosimetry, Secondary Standards Dosimetry, Radiotherapy, Radiation Protection, Diagnostic and Nuclear Medicine, Electronics
	King Fahd Univ. of Petroleum, Minerals, Dhahran	Radiation Physics, Dosimetry, Radiotherapy,
	King Fahd Medical City, Riyadh	Dosimetry, Radiotherapy, Radiation Protection, Diagnostic, Nuclear Medicine
	Prince Salman Military Hosp., Medical City, Riyadh	Radation Dosimetry, Radiotherapy, Radiation protection, Diagnostic, Nuclear Medicine
	King Abdulaziz Medical City, Riyadh	Radation Dosimetry, Radiotherapy, Radiation Protection, Diagnostic Radiology, Nuclear Medicine
	King Saud Univ. Hosp., Riyadh	Radiotherapy, Dosimetry and Diagnostic Radiology
	King Faisal Specialist Hosp. & Research Centre, Jeddah	Radiotherapy, Dosimetry and Diagnostic Radiology
	King Abddulaziz Univ., Jeddah	Radiotherapy, Dosimetry and Diagnostic Radiology
Syria	AlBaironee Hospital / Damascus Univ., Damascus	Radiation Dosimetry and Radiation Protection
Turkey	Istanbul Univ., Oncology Institute, Istanbul	Dosimetry, Research & Technical Development (R&D)
	Hacettepe Univ., Univ. of Ankara, Ankara	Dosimetry, Research & Technical Development (R&D)
	Ege Univ., Ismir	Dosimetry, Research & Technical Development (R&D)
	Dokuz Eylul Univ., Ismir	Dosimetry, Research & Technical Development (R&D)
	Trakya Univ., Edirne	Dosimetry, Research & Technical Development (R&D)
	Uludag Univ., Bursa	Dosimetry, Research & Technical Development (R&D)
	Erciyes Univ., Kayseri	Dosimetry, Research & Technical Development (R&D)
	Cukurova Univ., Adana	Dosimetry, Research & Technical Development (R&D)
	Akdeniz Univ., Antalya	Dosimetry, Research & Technical Development (R&D)

	Acıbadem Univ., Istanbul	Dosimetry, Research & Technical Development (R&D)
	Medipol Univ., Istanbul	Dosimetry, Research & Technical Development (R&D)
UAE	Dubai Health Authority (DHA), Dubai	Patient Radiation Safety

Table G.1

Table G.1: Approximate Numbers of Therapy Equipment Used for Treatment, Diagnosis, Teaching, Training and Research in Middle East

Country	Cobalt 60 Unit	Linear Accelerator	High Dose Rate Remote Loading	Low Dose Rate Remote Loading	Others (Specify)
Iran	70	100	15		
Iraq	3	15	2		10 CT-Simulator
Jordan	1	10	2	1	1 Gamma Knife, 1 Treatment Planning System, 1 Brachytherapy (Seeds)
Kuwait	2	3	1	1	
Lebanon	2	17	3	1	
Oman		2	1		Simulator
Palestine		2	1		
Qatar		2	1		1 CyberKnife, 1 MRI Simulator, 1 CT Simulator, 1 High-Intensity Focused Ultrasound (HIFU)
Saudi Arabia	1	21	7	1	I Co-60 GammaKnife, 6 Intraoperative, 2 Orthovoltage, 3 CyberKnife, 10 CT Simulator, 4 Conventional Simulator, 3 MRI Simulator, 1 PET/CT Simulator, 1 Proton, 1 HIFU
Syria	5	3	1	1	
Turkey	8	207	33		13 GammaKnife, 11 CyberKnife, 15 Tomotherapy,

Table G.2

Table G.2: Approximate Numbers of Diagnostic Equipment Used for Diagnosis, Teaching, Training and Research

Country	CT	MRI	Ultrasound	Fluoroscopy	Others (Specify)
Iran	1000	500	5000	1000	
Iraq	> 70	70	250 - 300	2	

Jordan	100	55	600	60	5 CT Simulator, >50 Mammography Units, 40 Cath Lab
Kuwait	36	14	23	26	
Lebanon	265	~ 100	> 1000	250	125 Cath Lab
Oman	3	2	2 - 3	3	
Palestine	1		1	1	
Qatar	13	9		54	9 Mammography, 80 X-Ray Units, 40 Dental Units
Saudi Arabia	150	50	> 500	> 500	Dental Units > 1000
Syria	150	50	> 1000	> 500	
Turkey	1500	1150	Unknown	Unknown	
UAE	7	5		11	4 Dental Units, 11 Intraoral Units
Yemen	1		2		Mammography, X-Ray Units

Table G.3

Table G.3: Approximate Numbers of Equipment Used in Nuclear Medicine Procedures and Imaging for Diagnosis, Teaching, Training and Research

Country	PET	SPECT	PET-CT	SPECT-CT	Gamma Camera	Others (Specify)
Iran	1	100				
Iraq		1			2	
Jordan	1	1 (Dual Head)	8		15	25 Bone Densitometer (DEXA)
Kuwait			8	12	6	4 Thyroid Uptake, 1 Urea Breath Test Device
Lebanon		20	15	1	5	
Oman		1	1		4	
Palestine						
Qatar	1			1		1 Cyclotron
Saudi Arabia	2	8	7	4	20	10 Cyclotron
Syria		8	2			
Turkey		80	110	145	600	3 PET-MR
UAE		2		1	4	
Yemen					2	

MEDICAL PHYSICS PROFESSIONAL DEVELOPMENT AND TRAINING IN ZAMBIA

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Abstract— **This paper highlights the roles of Medical Physicists in Zambia, as well as the opportunities for professional development and training in Medical Physics. Currently, the highest of priority for Medical Physicists in Zambia, is to fight Cancer. For this reason, all Medical Physicists are currently trained or will be trained in Radiotherapy Physics. However, there is room for growth and diversification of roles. Zambia's many medical imaging centres need the attention of Diagnostic Radiology Physicists and Nuclear Medicine Physicists. Plans are already in place to train and employ more Medical Physicists to meet the need to provide safe and optimal radiotherapy and medical imaging services countrywide.**

Keywords— **Zambia, medical physics, training, education, radiotherapy, medical imaging, diagnostic radiology, nuclear medicine**

I. INTRODUCTION

Zambia is a land-locked country found in the south-central region of Africa. The capital city is Lusaka. It has a population of approximately sixteen (16) million people. The official language is English and there are seventy-two (72) ethnic groups in the country. Zambia has a nominal Gross Domestic Product (GDP) of approximately twenty-point-six-billion United States Dollars (US$ 20.6 billion) or twenty-point-six-trillion Zambian Kwacha (ZMK 20.6 trillion) (Zambia 2016).

Currently, there are only five (5) Medical Physicists working in Zambia and they are all stationed at the Cancer Diseases Hospital (CDH) in Lusaka, Zambia. Three (3) of these are clinically qualified while two (2) are in clinical training. Their main area of work is in Radiotherapy (RT) but they also play the roles in Diagnostic Radiology (DR) and Nuclear Medicine (NM) both at CDH and at other medical imaging centres in the country (see Fig 1). There is no National Medical Physics Society that represents these physicists but they do have representation under the Radiological Society of Zambia.

Recently, the Government of Zambia approved the Cancer Diseases Hospital Phase III Project for the expansion of Radiotherapy services to all the remaining nine (9) provinces in Zambia, which will introduce more jobs in healthcare, including Medical Physics jobs (Government of Zambia 2014). According to the Cancer Diseases Hospital Strategic Plan 2014-2016, Zambia has the highest cancer incidence and mortality rates, at thirty-eight-point-six percent (38.6%), in the African region. For this reason, the Government of Zambia has chosen to prioritize the Sustainable Development Goal No. 3 (SDG 3), to reduce the number of deaths due to non-communicable diseases (NCDs), such as cancer, by one third (1/3) by 2030 (Government of Zambia 2006) (Government of Zambia 2016) (United Nations 2015). Once SDG No. 3 has been achieved, the priorities of Zambia concerning Medical Physicists may be much more welcoming toward more diverse roles other than Radiotherapy Physics.

There is room for Medical Physicists in Zambia to diversify into DR and NM Physics. Plans are already in place to introduce more clinical imaging equipment and to upgrade the current existing imaging centres. These advances in healthcare will create more opportunities for the roles of DR and NM Physicists to be realized in the years to come, especially post-2030. There are currently about ninety (90) public medical imaging centres in Zambia (see Fig. 1 below) equipped with one hundred and forty-six (146) x-ray machines, eighty-four (84) ultrasound, nine (9) Computed Tomography (CT), one (1) Magnetic Resonance Imaging (MRI) machine and one (1) Single Photon Emission Computed Tomography (SPECT) machine. One of these centres functions as both a radiotherapy centre and a medical imaging centre. This is the Cancer Diseases Hospital (CDH). Other than imaging equipment this hospital has one (1) Linear Accelerator (Linac), two (2) Cobalt Teletherapy machines and one (1) Simulator for to provide radiotherapy services. (Sindaza 2016) (Government of Zambia 2011)

II. EDUCATIONAL OPPORTUNITIES AND PROFESSIONAL DEVELOPMENT

Note that Zambia's Professional Development and Education Programme for Medical Physicists is still under development. There is no established and approved documentation or programme currently in place. Despite this, efforts are being made to fill this gap. The Physics Department of the University of Zambia offers a new optional *Introduction to Medical Physics* module under its Bachelor of Science in Natural Sciences programme – for Physics major students only. This module was piloted in 2016 with students in their fourth (4^{th}) year (The University of Zambia 2013). To obtain a qualification in Medical Physics at either Bachelor's or Master's level, one would have to be enrolled at a University outside Zambia, that offers these programmes.

Clinical training in Medical Physics is provided at the CDH under the supervision of clinically certified Medical Physicists. This kind of training opportunity can be made available to those who hold a Master of Science in Medical Physics or a similar field, through either a clinical attachment or as a member of staff. On a clinical attachment, the trainee is not remunerated nor do they have to pay for the training. They will have the opportunity to shadow the clinically certified

Fig. 1 Map of Zambia displaying the distribution of medical imaging centres and radiotherapy centres in Zambia. Derived from an inventory database from the Ministry of Health (Sindaza 2016).

Physicists for as long as agreed upon by the hospital's management and supervising Physicist. As a member of staff, one is to be assessed and registered under the Health Professions Council of Zambia (HPCZ) and thereafter, training will occur on the job (HPCZ 2016). This clinical training includes activities in Radiotherapy, DR, and NM. It may also include Biomedical Engineering, with assistance from the University Teaching Hospital (UTH), upon request.

Further professional development or Continuous Professional Development (CPD) opportunities in Medical Physics are hosted both locally and internationally. Recently, the Radiation Protection Authority (RPA) and the Radiological Society of Zambia hosted an event to facilitate the training of Radiation Protection Officers (RPOs) from around the country, in Lusaka, Zambia (Radiation Protection Authority 2016). Internationally, professional development events and resources are provided by the Federation of African Medical Physics Organisations (FAMPO), the Abdus Salam International Centre for Theoretical Physics (ICTP), the International Atomic Energy Agency (IAEA), etc. (FAMPO 2010) (IAEA 2016) (ICTP 2016). One example is the annual "College on Medical Physics: Enhancing the Role of Physicists in Clinical Medical Imaging…" held at the ICTP (ICTP 2016). So far, three (3) Medical Physicist from Zambia have attended this event.

III. CONCLUSION

Plans for Medical Physicists in Zambia are still under development. Discussions are being held to secure educational, employment and professional development opportunities in Medical Physics. On the educational front, strides are being made to introduce and maintain Medical Physics programmes at tertiary level. For example, at the University of Zambia; if the pilot year for the Introduction to Medical Physics module at Bachelor's level proves to be successful, this may mean that the module continues. More students will be made aware of the opportunities in Medical Physics and an increased awareness about this career option among youth will increase Zambia's potential for human resource building in this field. Also under discussion are plans for the introduction of a Medical Physics programme at Master's level. The outcomes of these discussions are yet to be shared with the public.

Other than this, Zambia is a part of an inter-governmental agreement that assists African member states to establish cooperation in nuclear science and technology called the Africa Regional Cooperative Agreement for Research (AFRA). Among the themes covered by this agreement include Radiation Safety, Education, and Human Health. This agreement supports, among other activities, the expansion of Zambia's Radiotherapy and Nuclear Medicine services through training of healthcare staff. (AFRA 2016)

The newly approved CDH Project (Phase III) Proposal outlines a plan to extend the reach of Radiotherapy services to all the other nine (9) provinces in Zambia. This will be done by establishing Radiotherapy centres in the designated locations and hiring of staff members, including Medical Physicists, to provide cancer care services (Government of Zambia 2014). As such, the focus of Medical Physicists in Zambia will be on cancer treatment using Radiotherapy and soon using Nuclear Medicine. This implores for the need for NM Physicists to help provide these services.

In Fig. 1 above is a map displaying the locations of ninety (90) public medical imaging centres. As mentioned earlier, there are only five (5) Medical Physicists working in Zambia, that means there is approximately one (1) Medical Physicist for every eighteen (18) public imaging centres. There are approximately two hundred and forty-five (245) imaging and radiotherapy devices in these centres. This implores for more Medical Physicists and specifically DR Physicists to ensure the safe and optimal provision of clinical imaging services. It has been estimated that a minimum of two (2) clinically qualified Medical Physicists are required per Radiotherapy department; one (1) per Diagnostic Radiology department and one (1) per Nuclear Medicine department (Vassileva 2017). This means that, ideally, ninety-three (93) Medical Physicists are required right now (for the ninety (90) diagnostic radiology departments, one (1) radiotherapy department and one (1) nuclear medicine department) and at least eighteen (18) more will be required for the nine (9) new radiotherapy facilities to be built.

In conclusion, although Medical Physicists in Zambia are focussed on providing cancer treatment and ultimately contributing to achieving SDG No. 3, there is room for growth. This growth is in terms of human resource capacity and the diversification of the role of Medical Physicists to meet the needs in the provision of safe and optimal clinical imaging and radiotherapy services, countrywide.

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CAPACITY BUILDING OF MEDICAL PHYSICS IN GHANA AND AFRICA

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Abstract- **Medical physics activities in Ghana has seen tremendous growth in diverse fields. These include training of personnel, delivery of clinical services, research work, as well as international affiliations. The medical physics training program is well-structured and coordinated, adopting the International Atomic Energy Agency's (IAEA) harmonised Regional Syllabus for academic and clinical training. The program has since its inception trained 40 medical physicists who offer services in divergent fields. Upon its recognition by the IAEA and the African Regional Co-operative for Research, Development and Training related to Nuclear Science and Technology (AFRA) as Regional Designated Centre (RDC) for Academic Training of Medical Physicists in Africa, it has subsequently developed capacity to train IAEA fellows as well as students from other African countries. The Ghana Society for Medical Physics (GSMP), has in collaboration with the Allied Health Professions Council successfully worked towards the passage of a law backing the practice of the profession and continues to actively engage in activities that gives the profession the needed publicity necessary for growth and expansion. While these feats present formidable grounds for the furtherance of the nation's radiological health agenda, a number of challenges such as professional remuneration package, non-existence of medical physics department in major hospitals and most diagnostic centres is currently receiving redress by the appropriate authorities.**

Keywords: **capacity-building, infrastructure, imaging modality, challenges, regulatory-bodies**.

I. INTRODUCTION

The practice of medical physics in Ghana began in the 1970s when physicists were trained in developed countries (mostly in Europe) jointly through the support of the Government of Ghana (GoG) and International Atomic Energy Agency (IAEA) [1]. Upon the return of the trained medical physicists, majority of them worked with the Ghana Atomic Energy Commission (GAEC) where they contributed to the growth of the profession through education, training, clinical and research work [1, 2]. Their pioneering activities drew attention and interest to the medical physics profession, and subsequently influenced the establishment of two state owned radiation oncology centres and one nuclear medicine centre, with support from the IAEA. These centres were sited in Kumasi and Accra to respectively serve patients from the northern and southern sectors of the country. Subsequently, a third radiation oncology centre which is privately owned has been built in Accra [1].

Presently, there are forty (40) trained medical physicists practicing in various fields in Ghana. The distribution of medical physics practitioners in the various sectors of practice is presented in Figure 1 [3].

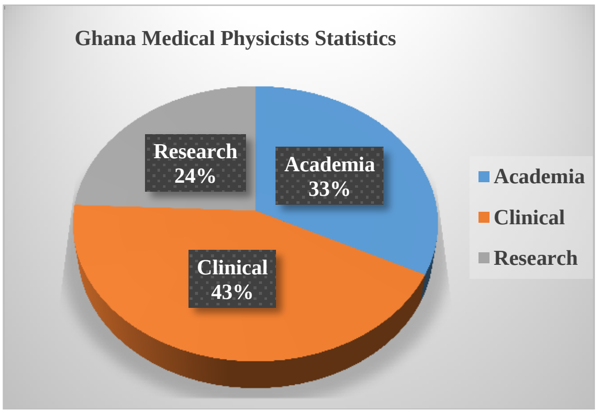

Fig. 1. Distribution of medical physicists in various sectors of practice [3]

Diagnostic radiological services has seen tremendous growth in Ghana, with the introduction of more imaging modality systems such as computed tomography, magnetic resonance imaging, mammography, conventional X-ray, dental X-ray, dual energy X-ray absorptiometry and fluoroscopy. Many diagnostic imaging centres have also migrated from film-screen radiography to computed and full digital radiology.

With Ghana's fast growing economy (presently, lower middle income status) and improvement in diverse sectors especially healthcare, it is projected that by 2019 each major (teaching, regional, district, etc.) hospital offering diagnostic radiological services would have at least 2 resident medical physicists.

The aim of this paper is to outline the various capacity building initiatives of medical physics in Ghana and Africa. The challenges of medical physics practice are discussed.

II. EDUCATION AND TRAINING OF MEDICAL PHYSICISTS IN GHANA AND AFRICA

The increase in awareness of the medical physics profession in Ghana and the urgent need for qualified personnel to support the nation's expanding radiological health program necessitated the development of capacity locally to train professionals. In 2004, a two year postgraduate course in medical physics education and training started in Ghana with 6 students. The program was hosted by the School of Allied Health Science (SAHS), College of Health Sciences, University of Ghana (UG) [1, 2]. The intensions of promoting post graduate education and training for preservation and enhancement of nuclear knowledge in Ghana and the rest of Africa saw the establishment of the Graduate School of Nuclear and Allied Sciences (SNAS) in 2006, jointly by GAEC and UG with support from the IAEA. Subsequently, the medical physics program was migrated from the SAHS and placed under the department of medical physics, SNAS, UG which is the only educational facility for the training of medical physicists in Ghana. In 2009, doctor of philosophy (PhD) programme in medical physics was also introduced and currently has duration of four (4) years.

In 2014, the department of medical physics, SNAS, was recognised as Regional Designated Centre (RDC) for Academic Education in Medical Physics by the IAEA and the African Regional Co-operative for Research, Development and Training related to Nuclear Science and Technology (AFRA).

Until 2009, the medical physics program was run as a biennial model. A total number of 74 students have successfully graduated at the master's level since the inception of the program. Eleven (11) IAEA fellows as well as 4 other foreign students have benefitted from the program. At the PhD level, the program has produced 4 PhD holders [1].

The Medical Physics Department is well resourced with professors, associate professors, and lecturers. The academic programme is interspersed with structured clinical training regimes at the three radiotherapy centres and other medical imaging facilities. Some of the lecturers double as clinical training supervisors, making the medical physics programme well harmonized and coordinated. Adjunct professors, lecturers and consultants have also been recruited from partner institutions from other IAEA member states to co-supervise research studies of PhD candidates who are on sandwich programs [1].

Local students undergo one year clinical internship after the master's programme, after which they are eligible to sit for a certification exam conducted by the Allied Health Professions Council (AHPC) of Ghana. Successful candidates are then certified and could undergo state registration and practice.

In Ghana, the pathway to training clinical medical physicists is presented in Fig 2.

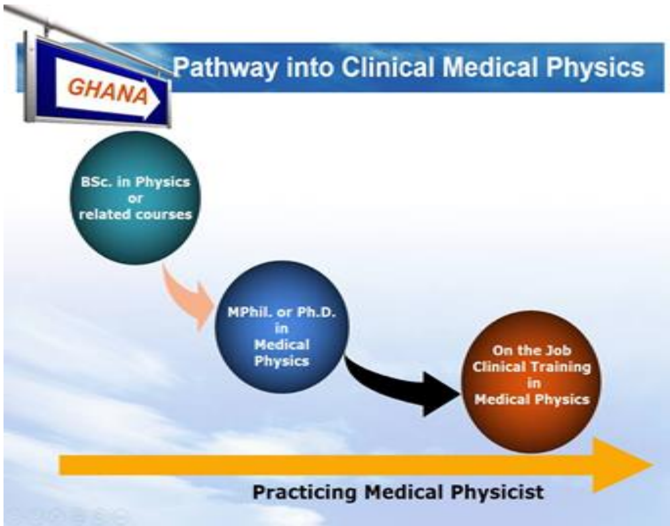

Fig. 2. Pathway to training a clinical medical physicist in Ghana [3]

Infrastructure available for education and training in the medical physics programme include:

- National Centre for Radiotherapy and Nuclear Medicine, Korle Bu Teaching Hospital, Accra.
- Oncology Directorate, Komfo Anokye Teaching Hospital, Kumasi.
- Sweden Ghana Medical Centre, Accra.
- 37 Military Hospital, Accra.

In addition, there are several other diagnostic radiology centres in both public and private hospitals which are contributing to the nation's medical imaging programme [4].

Accreditation of the training programme is done by the National Accreditation Board of Ghana through a standardised accreditation format [5]. The IAEA also undertakes frequent audits of the programme. Both institutions use the services of international experts and consultants to ensure neutrality and maintenance of high academic standards

III. GHANA SOCIETY FOR MEDICAL PHYSICS (GSMP)

The Ghana Society for Medical Physics (GSMP) was established in 2011 with an ultimate aim of promoting the application of physics to medicine [6]. The Society serves as checks and balances on the activities of professional medical physicists and contributes to the training of medical physics students in Ghana. With the passage of the Health Professions Regulatory Bodies Act 2013 (Act 857) [7], GSMP is mandated to regulate activities of medical physicists. Internationally, GSMP is affiliated to the Federation of African Medical Physics Organizations (FAMPO) and the International Organization for Medical Physics (IOMP). GSMP operates with a Constitution, Code of Ethics and Practice Standards, and achieves its objective by:

- Encouraging advancing and disseminating technical information, theory and practice of medical physics and related fields.
- Promoting a high level of ethical practice among medical physicists.
- Ensuring that medical physicists are engaged in technical procedures, which form part of patient care and treatment and
- Ensuring that medical physicists undergo certification examination and award of license to practice.

IV. ROLE OF REGULATORY AGENCIES

A. *ALLIED HEALTH PROFESSIONS COUNCIL (AHPC)*

The AHPC is the body established by an Act of Parliament (Act 857, 2013) to regulate the training and practice of allied health professions in Ghana [7]. This Act gives legal and professional recognition to the practice of medical physics in Ghana. This is in conformity with the classification of medical physics as a profession by the International Labour Organization (ILO) [8]. As part of its mandate, the Council is responsible for granting professional accreditation for all allied health programmes including medial physics. The Council is responsible for ensuring the highest standard in the practice of allied health profession in Ghana. The functions of the AHPC include the following;

1. Regulating the standard of services for the practice of allied health professions;
2. Ensuring that standards of study and training in recognised institutions are improved;
3. Setting practice standards of proficiency and conduct for allied health professionals;
4. Registering practitioners;
5. Monitoring and inspecting allied health facilities in collaboration with the health facilities regulatory agency;
6. Facilitating continuing professional development of practitioners;
7. Determining, in consultation with the appropriate educational institutions, courses of instruction and practical training for allied health professionals;
8. Determining and implementing post registration continuing education and continuing professionals development programmes for practitioners;
9. Ensuring that education and training of allied health practitioners and other allied health care providers are carried out at approved educational institutions;
10. Advising the Minister of Health on matters relating to allied health practice;
11. Conducting licensure examination for the registration of allied health professionals; and
12. Performing any other functions that are ancillary to the object of the Council

The AHPC has formulated a technical draft Legislative Instrument (LI) for allied health professions' regulatory bodies in accordance with the Health Professions Regulatory Bodies Act, 2013 (Act 857) [7]. All recognized allied health professions captured in the Health Professions Regulatory Bodies Act 857 (2013), including medical physics, have been given the opportunity to make an input into the LI.

B. *NUCLEAR REGULATORY AUTHORITY (NRA)*

There has been an enactment of a new independent "Nuclear Regulatory Authority (NRA) Act", Act 895 of 2015 to regulate the peaceful uses of ionizing radiation in Ghana [9]. Before the NRA came into being, the Radiation Protection Board of GAEC was the national competent authority for authorization and inspection of practices and activities involving radiation sources [10, 11]. The NRA took the regulatory functions of GAEC to enable GAEC focus on its core functions of research and training. It is anticipated that the NRA will seek to establish high standards of safety, security and safeguards in accordance with international best practices and in line with the IAEA Basic Safety Standards (BSS). The BSS used by Member States of the IAEA range in scope from engineering safety, operational safety and radiation, radioactive and nuclear material transport, and waste safety. The new Act addresses nuclear liability in accordance with IAEA conventions on liability.

V. CAPACITY BUILDING PROGRAMMES PROJECTS

A. *NORWEGIAN PARTNERSHIP PROGRAMME FOR GLOBAL ACADEMIC COOPERATION (NORPART-2016/10470): GHANA-NORWAY COLLABORATION IN MEDICAL PHYSICS AND RADIOGRAPHY EDUCATION*:

The main goal of the Norwegian Partnership Programme for Global Academic Cooperation (NORPART) project is to establish a partnership for education and research between institutions in Ghana and Norway within the fields of Medical Physics, Radiation Protection and Radiography. The main partners in the NORPART project are the Norwegian University of Science and Technology (through its Department of Physics) and the School of Nuclear and Allied Sciences, University of Ghana (through its Medical Physics Department). In addition, there are other network institutions both from Norway and Ghana of which GSMP is one. The objectives of NORPART are as follows;

1. Partnership for education and research in Medical Physics, Radiation Protection and Radiography.
2. Increased mobility of Medical Physics and Radiography students between the partner institutions.
3. Increased contact between and mobility of academic staff at the partner institutions

4. Increased quality and internationalization at the level of master and PhD study programs in Medical Physics and Radiography at the partner institutions

B. UNIVERSITY COLLEGE LONDON (UCL) PARTNER PROJECT

GSMP and SNAS have also been involved in a partnership on radiotherapy with the University College London under a project code named *paRTner*. This project involves medical physicists, and the objectives include; training of personnel, development of techniques and protocols, and increasing capacity of equipment.

In order to achieve the said objectives, the scope of the *paRTner* project encompasses the following;

a. Provision of resource in terms of training, teaching, personnel and equipment
b. Location of funding for training support, and assistance to help Ghanaian radiotherapy departments secure funding internally
c. Practical training course tailored to local needs
d. University collaborations, both in the UK and Ghana, and between Ghanaian universities and hospital departments.
e. Development of medical physics profession in West Africa through setting up an African radiotherapy consortium, a local training scheme and formalizing a career structure.

There has been some donation of radiotherapy equipment from the paRTner project to Ghana for clinical use and training.

C. IAEA RESEARCH PROJECTS

Under the auspices of the IAEA, a number of national Technical Cooperation (TC) projects on medical physics, radiation protection, radiation oncology, diagnostic radiology and nuclear medicine are currently ongoing. Ghana is involved in the following IAEA TC projects;

a. RAF6048: Strengthening Medical Physicists' Capacities to Ensure Safety in Medical Imaging, with an Emphasis on Paediatric Imaging Safety
b. RAF9033: Strengthening Radiological Protection of the Patient and Medical Exposure Control
c. RAF6044: Strengthening Medical Physics in Support of Cancer Management II.
d. GHA6017: Establishing a Nuclear Medicine, Medical Imaging and Radiotherapy Centre for Cancer Prevention, Treatment, Research and Development.
e. RAF9048: IAEA Regional Post-Graduate Education Course on Radiation Protection and Safety of Radiation Sources
f. RAF-057-9002-1: Strengthening National Capabilities on Occupational Radiation Protection in Compliance with Requirements of the New International Basic Safety Standards
g. RAF9053: Strengthening Member States' Technical Capabilities in Medical Radiation Protection in compliance with requirements of the new International Basic Safety Standards (BSS).

D. INTERNATIONAL DAY OF MEDICAL PHYSICS (IDMP) CELEBRATION- GSMP

Celebration of International Day of Medical Physics (IDMP) throughout the world has involved organizing seminars, symposia and public lectures among a host of other activities to draw gatherings and for practitioners and the general public to receive in-depth information about the medical physics profession. GSMP has actively celebrated the IDMP in Ghana on 7th November each year since its institution by the IOMP in 2013. This has given the medical physics profession a huge publicity in Ghana. Based on the theme for each year, the Society selects appropriate speakers for its celebrations. A list of speakers and their topics reflecting IOMP's theme for the year is presented in Table 1 below.

Table 1: Symposia for International Day of Medical Physics (IDMP) Celebration in Ghana for 2013-2016

Year	IOMP Theme	Speakers / Topic
2013	Radiation Exposure from Medical Procedures: Ask the Medical Physicist	Prof. C. Schandorf: Radiation Exposure from Medical Procedures - Ask the Medical Physicist
2014	Looking into the body – Advancement in imaging through Medical Physics	Mr. Eric Kotei Addison: Role of Medical Physics in Ultrasound Imaging Dr. Mumuni Abdul Nashirudeen: Role of Medical Physics in MRI Applications Dr. Alfred Ankrah: Nuclear Applications in Medicine (Nuclear Medicine) Dr. Samuel Asiamah: Computed Tomography Applications in Medicine
2015	Better Medical Physics = Better Cancer Care in Radiation Oncology	Dr. Joel Yarney: Better Cancer Care: Radiation Oncologist Perspective Ms. Clothida Muronda: General Cancer Care in Radiation Oncology Dr. Joseph Kwabena Amoako: The Role of the Regulator in the Advancement of Cancer Management Mr Eric Kotei Addison: Role of Medical Physicist in Better Cancer Care Management
2016	Education in Medical Physics: The Key to Success	Dr. Stephen Inkoom: Norwegian Partnership Programme for Global Academic Cooperation (NORPART) on Ghana-Norway Collaboration in Medical Physics and Radiography Education Dr. Mercy Afadzie: Sharing of Experiences as a Student in Norway Prof. Catharina de Lange Davies: Education and Training in Medical Physics: The Norwegian Experience

a. IMPORTANT MILESTONES AND FUTURE PROJECTIONS

Over the years, some key milestones have been achieved in the field of Medical Physics by key actors and stakeholders in the country, based on which some future projections are made:

b. The SNAS has since its establishment become a centre of excellence in Africa, and has consequently been accredited by the IAEA as a RDC by AFRA for Academic Education in Medical Physics in Africa [1, 2]. Through this, the IAEA as well as Governments of other African countries send students to be trained in this program. Every year, a number of well-trained medical physicists are churned out who feed into the growing national and African radiological health program
c. In 2011, the GSMP was formed as a professional association to promote the application of physics to medicine and to regulate the activities of clinical medical physicists [1, 7]. Led by the AHPC of Ghana, GSMP together with other professional associations making up the Ghana Federation of Allied Health Professions, have successfully worked towards the passage of the Health Professions Regulatory Bodies Act (Act 857 of 2013) [7]. The passage of the Act backs the practice of the profession and gives it the professional recognition it deserves. This is in conformity with the classification of medical physics as a profession by the ILO [8]. The GSMP draws inspiration from the IOMP and ensures that the roles and responsibilities of medical physicists are clearly adhered to [12].
d. The GSMP in collaboration with the Radiological and Medical Science Research Institute (RAMSRI) of the GAEC successfully implemented the National Project on Quality Assurance Audit of Radiotherapy Facilities in November 2016. The exercise which was based on the recommendations of the IAEA served purposes of giving credence to the quality of radiotherapy services being offered to patients who patronize these facilities. Owing to the success of this activity, there are plans to undertake similar missions for Quality Assurance Audit of Diagnostic Radiology and Nuclear Medicine Facilities in 2017 [1].
e. In December 2016, RAMSRI through the GAEC, IAEA, the World Health Organization's Regional Office for Africa and the International Agency for Research on Cancer, hosted a 5-day Workshop on the establishment of Cancer Registries to intensify Cancer Control. The workshop brought together participants, health authorities and cancer control experts from 20 different Anglophone countries. Cancer registries compile and provide information on the number of new cancer cases, in addition to the total number of cancer cases, as well as death and survival rates. With this data, policymakers can more effectively plan services, from prevention campaigns to treatment for cancer patients. The GSMP was well represented through this workshop as it presented credible roadmaps in the management of cancer in Ghana [13].

VI. CHALLENGES OF MEDICAL PHYSICS PRACTICE IN GHANA

A. *PLACEMENT OF MEDICAL PHYSICISTS IN THE HEALTH SERVICE SALARY STRUCTURE*

Currently, medical physicists are not captured on the salary structure of Ghana's Health Ministry. The GSMP has therefore petitioned the Ministry of Health to consider the medical physics profession as a Medical Occupation (Health Professional) in the Health Structure. The petition is humbly seeking to address non-existence of the medical physics profession in the health structure as a clinical specialty although the Health Professions Regulatory Bodies Act 857 of 2013 legally recognizes the Medical Physics profession as an Allied Health Profession [7].

Other challenges are the non-existence of medical physics departments in the major hospitals and the non-availability of resident medical physicists at most diagnostic imaging centres. However, these challenges are being addressed by the regulatory agencies. There are also challenges with unavailability of some selected advanced phantoms and dosimetry equipment for students' clinical training and research studies.

VII. THE WAY FORWARD

The future of medical physics in Ghana is bright. The implementation of Act 857 and the passage of the NRA Act 895 will see more employment opportunities for medical physicists. It is equally anticipated that the full recognition of the profession will come with well deserving conditions of employment. The acquisition of more equipment (two linear accelerators presently under installation), especially in the two public oncology centres proffer greater advantages to boost student experiences during clinical rotations. With admission into the 2-year master's program becoming keener and keener largely due to increasing number of applications from both locals and foreign students, it is suggestive, that the number of qualified medical physicists in Ghana will increase in the very near future which casts a bright shadow on the sustenance of our radiological health program.

There are also proposals to establish Ghana College of Allied Health in the near future. A technical committee has been put in place and is working on establishing the framework for the College. Once established, the College will offer training to allied health professionals in specialized areas and to become consultants who would handle complex medical conditions with great success.

This will reduce the over reliance of training consultant medical professionals outside the country.

VIII. CONCLUSION

Medical physics training and practice in Ghana has been fairly successful since it begun. Clinical medical physicists have over the years played central roles in imaging, therapy and nuclear medicine procedures. As the GSMP continues to grow in numbers (qualified medical physicists), there is an anticipated sustainability in both training and practice of radiological procedures in the country. The profession can therefore look confidently into the future and hope to offer significant contributions in healthcare.

IX. ACKNOWLEDGEMENT

The authors do express sincere gratitude to the Government of Ghana, IAEA, IOMP, GSMP, GAEC and SNAS/UG for the investments they have made into the program. Heartfelt appreciations goes to all the radiological health centres who allow their facilities to be used during clinical training of students

X. CONFLICT OFINTEREST

The authors hereby declare that there is no conflict of interest in the publication of this article.

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EDUCATIONAL ISSUES AND RESOURCES

IOMP PUBLICATION: IOMP ACCREDITATION MANUAL

Abstract— **The Manual addresses the accreditation of Educational Courses (specifically MSc courses). The IOMP Accreditation Manual presents the work of the IOMP Education and Training Committee (ETC, Chair Prof. J Damilkais, 2015-2018) and in particular the current IOMP ETC Accreditation Board, including J. Prisciandaro, R. Ritenour, H. Round, M. Ghezaiel, M. Kortesniemi, K. Ng, E. Samara, J. Vassileva. Input to the preparation of the Manual have also the IOMP President and the Executive Committee.**

I. Scope

The IOMP Accreditation Board accredits medical physics degree programs, medical physics education and training institutions/centres and education and training events. Initially its work will be limited to accreditation of postgraduate degree courses and Continuing Professional Development (CPD) courses. The IOMP Accreditation Board will develop guidelines and policies in the future to accredit residencies, conferences and other education and training events.

II. Iomp accreditation board compostion

IOMP Accreditation Board operates under the guidance of the IOMP Education and Training Committee, which in turn reports to the IOMP Executive Committee. The Chair of the Education and Training Committee chairs the IOMP Accreditation Board. The IOMP Accreditation Board consists of its Chair, the Vice-Chair and 7 members. The Vice-Chair and the members are appointed by the Chair for a 3-year period after consulting with the IOMP President. The Vice-Chair and the 7 members of the IOMP Accreditation Board must be approved by the Executive Committee prior to appointment by the Chair. The Vice-Chair will be the Secretary to the IOMP Accreditation Board. The IOMP Treasurer will be the non-voting Treasurer to the IOMP Accreditation Board. The Chair shall take into consideration the desirability of a regional balance amongst the membership. All members of the IOMP Accreditation Board should be prominent Medical Physicists with expertise in the education and training of medical physicists as well as in medical physics professional matters. All members of the IOMP Accreditation Board act for IOMP on a volunteer basis. The members, including the Chair and the Vice-Chair serve for a term of 3 years. No one can serve for more than 2 terms. For the first Board, Chair of the Accreditation Board will be the Chair of the Education and Training Committee J. Damilakis. The Chair will appoint the Vice Chair after consulting with the IOMP President from the members of the IOMP accreditation subcommittee 2015-2018 (J. Prisciandaro, R. Ritenour, H. Round, M. Ghezaiel, M. Kortesniemi, K. Ng, E. Samara, J. Vassileva). The other 7 members of the accreditation subcommittee will become the members of the first Accreditation Board. The first term of the Chair, Vice Chair and members of the first Board will expire at the end of the term of the current IOMP Education and Training committee in 2018.

III. Meetings

The IOMP Accreditation Board normally works by email and on-line meetings. Online meetings will be convened on a periodic basis depending on the needs of the IOMP Accreditation Board. There will be a face-to-face meeting at each World or International Congress.

IV. Operating procedures

The IOMP Accreditation Board is responsible for:
1. Carrying out accreditation processes
2. Maintaining a database of all applications and supporting documents
3. Financial control including the setting of fees
4. Appointing a committee to investigate appeals and deciding the outcome of these appeals
5. Maintaining a register of all accredited centres and associated records
6. Submitting an annual report to the IOMP Executive Committee

V. Accreditation standards and procedures

5.1 Accreditation of postgraduate degree courses

5.1.1 Accreditation standards

Applicants must meet standards to be accredited. For IOMP Accreditation Board Standards please see:
1. IAEA Publication, Training Course Series No. 56 (Endorsed by the IOMP) which also incorporates the IOMP Model Curriculum: http://www-pub.iaea.org/books/IAEABooks/10591/Postgraduate-Medical-Physics-Academic-Programmes
2. IOMP Policy Statement No. 2 'Basic requirements for education and training of medical physicists'

5.1.2 Accreditation process

Step 1

The accreditation process requires a substantial investment of time and effort. Potential applicants are encouraged to contact IOMP Accreditation Board to discuss in advance details of their program and decide if IOMP accreditation is suitable for their program. IOMP does not charge for this discussion and there is no obligation to continue any further in the process.

Step 2

Organizer of the event submits the completed application form to the Vice-Chair of the IOMP Accreditation Board via email. All information required must be in English. Additional information may be requested by the Vice-Chair. A fee is charged for each application to cover the costs of the accreditation process. Self-assessment is an important quality improvement tool. IOMP strongly encourages applicants to undertake a self-assessment preferably prior to application. The application form may be used as a guide for the self-assessment procedure.

Step 3

Upon receipt of the completed application form, the Chair of the IOMP Accreditation Board nominates an Assessment Team (AT) to assess the application and conduct the site visits. AT is composed of 3 Accreditation Board members one of whom is appointed by the Chair of the Accreditation Board as Lead Assessor (LA). LA coordinates the AT, communicates with the Chair and the Vice-Chair of the Accreditation Board, communicates with applicants and maintains a record of all communications. The submitted application form will be reviewed to assess whether all information has been adequately provided. Applicants will receive a request from the Vice-Chair for any missing information.

Step 4

As soon as the submitted application has been reviewed and approved by the AT, applicants will be notified of the date of site visit and the member(s) of the AT conducting the site visit. It will be at the discretion of the AT to select external experts to visit the site of the applicant. The main purpose of the site visit is to verify the information provided in the application form and assess parameters that cannot be described adequately in written form (for example, assess labs and other key facilities, meet faculty members, students and administrative officials, review dissertations etc). Following the accreditation site visit, the AT will send a formal report to the applicant with comments and recommendations. The applicant will have 3 weeks within which to submit comments on the accuracy of the report. If no comments are received it will be assumed that the report is accurate. The AT will produce the final report taking into consideration any comments received from the applicant.

Step 5

The AT will submit the final report to the chair and members of the IOMP Accreditation Board with recommendations for accreditation. The members of the Board will vote on the accreditation status of the applicant. The possible actions taken by the IOMP Accreditation Board are:

a) Initial accreditation – this action is levied to new programs which have made progress towards meeting IOMP Standards but have not graduated at least one class of students. Initial accreditation is valid for a period of 3 years. To maintain accreditation these programs are required to submit annual reports during the 3 years of initial accreditation to provide evidence of progress toward meeting all Standards. These reports will be evaluated by the AT that assessed the application and performed the site visit of the program. The 3 years of initial accreditation may be extended to 5 years if adequate evidence of progress has been provided by annual reports. Programs that fail to submit an acceptable annual report will lose their status as a program enrolled in IOMP Accreditation.

b) Accreditation – this action is levied to programs that are fully operational. Accreditation is valid for a period of 5 years. Accredited programs are required to submit an annual report to update the IOMP Accreditation Board on any changes affecting the program, for example change in mission or goals of the program, considerable change in faculty size and/or composition, major curricular changes etc.

c) Probation - this action is levied to accredited programs that are subsequently determined not to be in compliance with the IOMP Standards. Reconsideration of a recommendation for probation is possible only when the applicant provides evidence documenting compliance with Standards. The program may only be on probation for up to 1 year. An additional fee of the cost of a round trip airline ticket and accommodation for 2 nights for 1 person is assessed anytime a site visit is required for probation.

d) Withholding accreditation – this action is levied to programs that are found to be non-compliant with IOMP Standards. The IOMP decision to withhold accreditation may be appealed. The applicant may apply again for accreditation when the program is considered to be in compliance with the IOMP accreditation standards.

Step 6

The Vice-Chair of the Accreditation Board a) submits the final report to the IOMP Executive Board as an information item and b) notifies applicants of the outcome of the assessment for accreditation. Assuming the recommendation is approved, the Board will issue a certificate of accreditation.

5.1.3 Renewal of accreditation

To maintain accreditation through IOMP, applicants must undergo a comprehensive re-evaluation. The re-evaluation process will be similar in every respect to initial evaluation. A fee is charged for each application to cover the costs of the reaccreditation process. The renewal process is initiated at least 6 months prior to the expiration date of current accreditation. Re-accreditation is valid for a period of 5 years

5.2 Accreditation of Continuing Professional Development events

IOMP accredits CPD events provided by educational institutions, professional and scientific associations, hospital departments, units or divisions, research organizations and other scientific organizations. IOMP does not accredit CPD events organized by the industry.

5.2.1 Accreditation standards

1. Target Audience

There should be a clearly defined target audience.

2. Learning objectives of the program

There should be clearly defined learning objectives and a clear statement of what a participant is expected to learn. The learning objectives must be specifically defined to indicate what knowledge, skills and competences the participants are expected to obtain

3. Programme content and structure

There should be a detailed statement outlining the content and structure of the program and the expected outcome.

4. Teaching methodology

There should be a clear statement about what teaching methodology will be used (lectures, presentations, discussions, technical demonstration, hands-on training etc)

5. Supporting information

Supporting information should be sufficient to support the learning outcomes and material should be accessible and up-to-date at the time of event.

6. Teaching staff

Organisers of the activity should demonstrate that the teaching staff is qualified to deliver the educational programme and meet the learning objectives.

7. Evaluation and quality assurance.

There should be a clear statement outlining how the organiser will conduct an evaluation of the activity.

8. Commercial interest

Education providers have to guarantee that non-biased education is given.

9. Administrative arrangements and verification of attendance

Organizers of the activity should describe the mechanism in place to record and verify participation (attendance list, badges, etc).

5.2.2. Accreditation Process

Step 1

Organizer of the event should submit the completed application form to the Vice-Chair of the IOMP Accreditation Board via email at least four months prior to the activity. All information required must be in English. Additional information may be requested by the Vice-Chair. A fee is charged for each application to cover the costs of the accreditation process.

Step 2

Upon receipt of the completed application form with fee, the Chair of the IOMP Accreditation Board nominates an Assessment Team (AT). The AT assesses the application normally without a site visit. AT is composed of 3 Accreditation Board members one of whom is appointed by the Chair of the Accreditation Board as Lead Assessor (LA). LA coordinates the AT, communicates with the Chair and the Vice-Chair of the Accreditation Board, communicates with applicants and maintains a record of all communications. The submitted application form will be reviewed to assess whether all information has been adequately provided. Applicants will receive a request from the Vice-Chair for any missing information.

Step 3

The AT will evaluate the application according to standards (paragraph 5.2.1). The LA will draft the final report taking into consideration all assessment reports.

Step 4

The LA will submit the final report to the chair and members of the IOMP Accreditation Board with recommendations for accreditation within 4 weeks of the complete documentation having being received. The members of the Board will vote on the accreditation status of the applicant. Applicants should be informed within 6 weeks of the complete documentation having being received.

Step 5

The Vice-Chair of the Accreditation Board a) submits the final report to the IOMP Executive Committee as an information item and comments, if any within 3 days b) notifies applicants of the outcome of the assessment for accreditation. Assuming the recommendation is approved, the Board will issue a certificate of accreditation.

5.2.3. Credit points

For face-to-face meetings (lectures, seminars, tutorials, technical demonstrations etc) as well as for on-line lectures, credits are earned at 1 credit per hour for events without a final examination and 2 credits per hour for events with a final examination. The text: “This course has been accredited by IOMP Accreditation Board as CPD event and awarded ….. CPD credit points” is mandatory in the publicity of the event and in the diplomas/certificates awarded to participants.

If a course or event is scheduled with an optional examination, two different CPD credit points will be assigned (with and without assessment). For those participants who do not pass the examination, the CPD credit points without assessment will be assigned.

5.2.4 Post activity report

Following the activity, organizers must send a report to IOMP Accreditation Board summarizing the main points of the activity, strengths and limitations. The names of participants to receive credits and the number of credits for each participant must be included in the report.

5.2.5 Certification

The IOMP Accreditation Board provides guidance and scientific support to organizers of CPD activities for conducting examinations of individuals participating in these activities. Organizers should indicate in the application form that they need this support by the IOMP Accreditation Board. On receipt of the information the chair of the IOMP Accreditation Board will select two experts who will provide the required support. A fee is charged for each application to cover the costs of the certification process.

VI. APEAL OF AN ACCREDITATION DECISION

An applicant that is the object of an adverse decision might wish to appeal that decision to the Board. Appeals must be submitted to the Vice-Chair in writing and within 15 days of receiving the decision about the accreditation. The Chair of the Accreditation Board appoints an Appeals Committee (AC) consisting of a chairman, an Accreditation Board member and an IOMP Executive Committee member. AC does not include members of the AT that took the initial action being appealed. AC prepares a written report within 30 days after the date of the submission of the appellant's appeal that describes its findings and action taken on the appeal. AC submits that report to the Accreditation Board and informs the appellant. The decision of the AC is final. The Vice-Chair will inform the appellant of the outcome of the appeal giving reasons for the decision. Applicants that choose to appeal a decision will pay a fee to cover the cost of convening the AC.

VII. RECORDS

The Accreditation Board shall keep a database of all applications. Application forms, supporting documents, assessors' reports, evaluation reports, number of points awarded to CPD events, any reports of appeal panel and minutes of Board meetings should be kept secure in hard copy and/or electronic formats with electronic records being backed up regularly.

VIII. PUBLIC AND CONFIDENTIAL INFORMATION ABOUT APPLICANTS

Names, contact information and accreditation status of accredited providers is considered public information and may be released by the IOMP Accreditation Board. The Board will maintain as confidential information the minutes of the Board meetings, information submitted to the Accreditation Board by the applicant and correspondence between AT and the applicant relating to the accreditation process.

IX. ANNEX: FEES

Accreditation of postgraduate degree courses

First application and reaccreditation:
US $ 3000 maximum fee + the cost of 2 return airline tickets + the cost of accommodation for 2 nights for 2 persons

The fee will be on a sliding scale based on UN determinations of per capita income, the exact formula being specified by the Finance Committee and approved by Council.

Accreditation of Continuing Professional Development events

First application of an event (first time to be accredited):
US $ 350

Second time and every subsequent time:
US $ 150

CPD courses, certification support:

US $ 300 + the cost of a return airline ticket + the cost of accommodation for 2 nights for 1 person

Appeal

Application for appeal:
US $ 100

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EDUCATION MODELS FOR THE EXPANDING ROLE OF CLINICAL MEDICAL PHYSICS

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Abstract— **All modern medical imaging methods are significantly complex with many adjustable factors, especially relating to the digital imaging format, that determine image quality. Medical physics activities to achieve appropriate image quality must involve the actual clinical imaging procedures in addition to traditional quality control functions relating to equipment. This expanding role requires knowledge of the anatomical, physiological, and pathological characteristics of the human body and how they are visualized through imaging methods. Several methods, or models, for providing this education are compared with respect to their effectiveness and efficiencies.**

Keywords— **Image Quality, Procedure Optimization, Medical Sciences, and Expanding roles.**

I. INTRODUCTION

Effective medical physics educational activities are those that provide knowledge that the learner can use to perform specific professional functions. As the practice of clinical medical physics evolves and expands in scope so do the educational requirements. The purpose here is to compare some traditional and expanding medical physics activities in clinical medical imaging (diagnostic radiology) and describe several methods, or models, for providing the required education. There is no one educational approach or method that is appropriate for all medical physics educational programs. Each specific educational activity (classroom discussion, self-study, hands-on, etc.) is characterized by two conflicting factors, *effectiveness* and *efficiency*. Each program can select and develop methods or models that fulfill their needs and capabilities.

In the field of medical imaging the development of many new modalities and methods has greatly increased diagnostic capability by providing visibility of a more extensive range of clinical conditions within the human body. A significant factor is the potential for detection and diagnosis of pathologic conditions, including cancer, when they can be more effectively treated. The modern imaging methods with their increased diagnostic capability also are much more complex from a physics perspective.

Regardless of the imaging method, medical physicists are the professionals with the knowledge and experience for ensuring image quality and managing related risks. Factors that affect image quality are in two major categories: those relating to the equipment and associated technology, and those related to the actual imaging procedure for patients. For the purpose of educational needs the medical physics activities relating to the evaluation of equipment in the context of quality control and assurance programs is designated as *traditional*. These are the functions that we medical physicists have been performing for many years. The medical physics activities to ensure appropriate image quality relating to the actual imaging procedures are designated as *expanding* roles. These include a variety of professional functions and interactions that continue to increase in scope and "expanding" educational needs and learning activities.

II. TRADITIONAL MEDICAL PHYSICS ACTIVITIES

As a point of reference consider typical traditional medical physics activities illustrated in Figure 1.

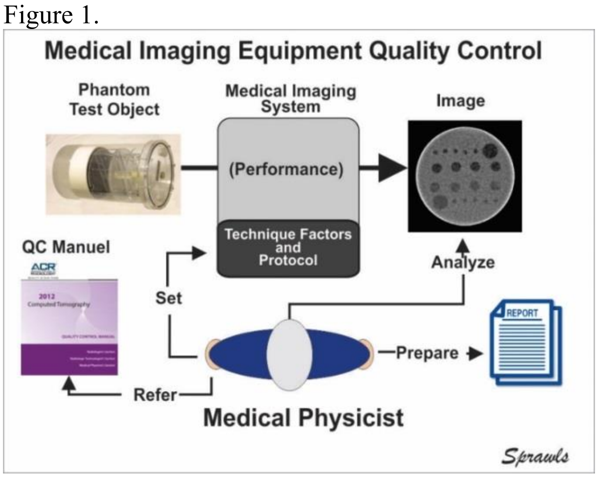

Figure 1. A traditional medical physics activity of performing quality control evaluation of imaging equipment.

These medical physics functions are not only valuable contributions to patient care; they are required by accrediting organizations, including the American College of Radiology (ACR) and government agencies, including the Federal Drug Administration(FDA).

A common function in most medical physics QA or QC procedures is to produce and evaluate images of specific test objects or phantoms. The imaging protocols or technique factors used are often prescribed in recommended testing procedures established by the agencies requiring the procedures.

This removes variations in the operating factors so that the testing provides an evaluation of equipment performance, not the imaging procedure itself. This is a major factor distinguishing between the more traditional role and the expanding role of medical physicists in clinical medical imaging.

III. MODERN MEDICAL IMAGING METHODS AND IMAGE QUALITY

The availability of a variety of imaging modalities and methods--CT, MRI, PET, ultrasound, in addition to radiography and nuclear medicine applications--provides the opportunity for visualizing a large range of body functions and pathologic conditions. With this increasing clinical capability comes an increased complexity of the imaging process and factors that can have an effect on image quality. A common characteristic of modern imaging methods is the production or formation of images in a digital format. While this provides many advantages it adds some complexity to the process. Digitizing is a sampling process in which the patient's body is divided into many small samples—voxels--and certain tissue characteristics within each voxel are displayed in corresponding pixels within an image. With virtually all imaging methods the size of voxels and pixels is an adjustable factor that has major impact on image quality. The significance is that voxel/pixel size affects two different image quality characteristics, blur (detail and resolution) and noise, and has an indirect effect on radiation dose to patients in many procedures. This is illustrated in Figure 2.

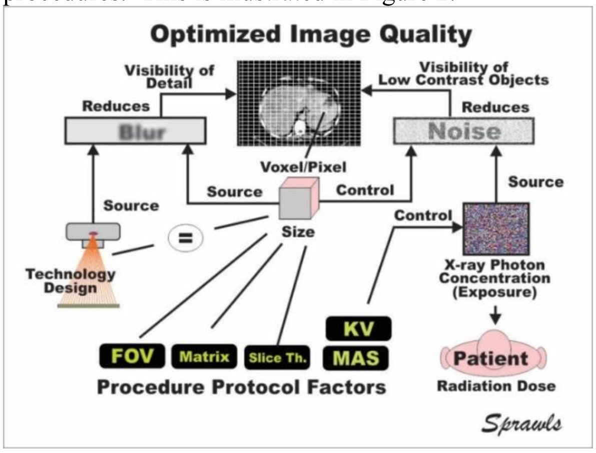

Figure 2. The general relationship of voxel size to image quality.

IV. IMAGE QUALITY OPTIMIZATION

With imaging methods using images in a digital format, quality control and quality assurance take a completely different and expanded approach. Most traditional QC activities involving equipment performance testing generally focus on each individual image characteristic--contrast, blurring (resolution), artifacts, etc. With the methods using digital images the requirement is for *image quality optimization.* This occurs when selecting and adjusting the technique or protocol factors for each imaging procedure, not with the testing of the equipment.

Image quality optimization is very different from traditional image quality control and is a complex process. It is an activity in which medical physicists can make significant contributions to the quality of medical imaging procedures.

V. THE EXPANDING ROLE OF MEDICAL PHYSICS IN CLINICAL MEDICAL IMAGING

An overview of medical physics activities to contribute to high-quality medical imaging procedures is illustrated in Figure 3.

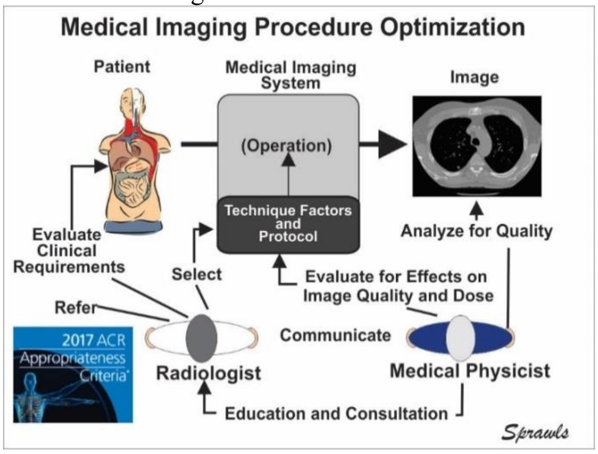

Figure 3. An overview of the collaborative process for optimizing image quality in clinical procedures. (Compare to Figure 1.)

This requires knowledge and experience beyond that needed to perform the traditional QC and QA procedures. A significant factor is that it involves interactions with other medical professionals, especially radiologists, in both educational activities and ongoing consultations.

Because of the extensive capability and complexity of modern medical imaging methods the radiologist or other physician is challenged with selecting the most appropriate protocol for each specific clinical case. This is usually done based on personal experience or consultation with colleagues but also based on recommendations published in *Appropriateness Criteria* by professional organizations, including the ACR. This provides guidance for selecting imaging methods but not some of the details with respect to image quality and radiation dose, if that is a factor.

It is the medical physicist who can evaluate images with respect to quality characteristics and relate these to the selection of technique factors and the protocol used for a specific procedure. To be most effective in this and provide the greatest value to clinical medical imaging, medical physicists must have a comprehensive knowledge in three related areas as illustrated in Figure 4.

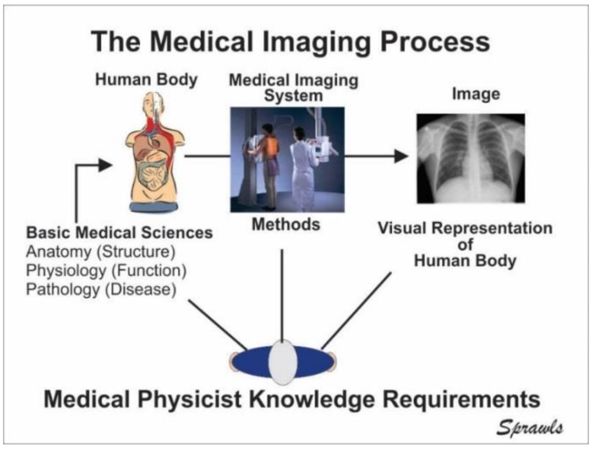

Figure 4. Areas of knowledge required for effective medical physics contributions to high-quality medical imaging procedures.

A major objective of this article is to identify the educational needs for expanding medical physics activities and consider models for effective educational activities to meet those needs. This requirement for medical physics education with more clinical medical science content is now recognized by various organizations including the American Board of Radiology (ABR) in the certification of medical physicists.

VL. IMAGE FOCUSED MEDICAL PHYSICS EDUCATION

The medical image is a unifying factor in effective medical physics education. It is the physical object physicists evaluate with respect to image quality characteristics and then make recommendations on producing images appropriate for specific clinical applications. Beyond knowledge of the physical characteristics of images (contrast, blur, noise, etc.) there is the need for knowledge of both the conditions within the human body and the imaging process that "connects" the image to the body. Figure 4 illustrates medical images that provide visualization of the three basic clinical sciences that are significant for medical imaging: anatomy (structure), physiology (function), and pathology (disease).

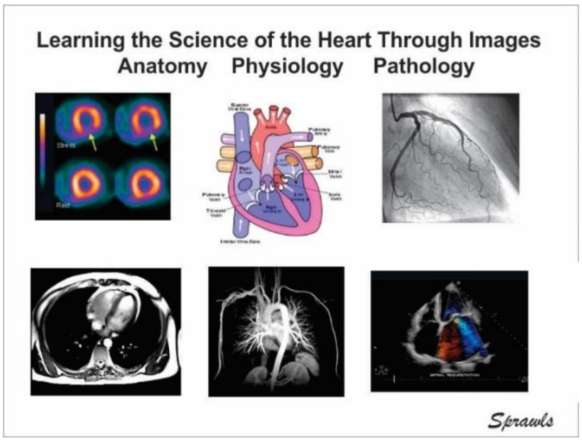

Figure 4. Medical images that provide visualization of the clinical conditions associated with the heart.

Using clinical images within the context of medical physics education activities adds significant value. It provides a basis for learning the three medical sciences in a form that directly applies to the physics of medical imaging. This can be provided with a combination of at least three different learning resources and activities or models. Here each will be considered in terms of its effectiveness and its efficiency.

VII. MODELS FOR LEARNING ACTIVITIES

Effectiveness

The *effectiveness* of a learning activity is its ability to produce knowledge that supports specific functions. Of special interest here are the functions illustrated in Figure 3. The effectiveness is the major goal of a learning activity. If it is not effective it has limited value.

Efficiency

The *efficiency* of a learning activity is determined by the effort, resources, and other costs needed to provide it. Efficiency is often a limiting factor that makes some potential learning activities unavailable or not practical.

Textbooks

Text and reference books primarily for other medical imaging professionals, especially technologists, are useful for medical physics education. Kowalczyk (1) is an example that correlates the three medical sciences and related imaging methods. It is a valuable resource for medical physicists and students for self-study and reference in combination with other activities. The use of appropriate textbooks is both effective and efficient providing extensive information at a relatively low cost.

Radiology Clinical Involvement and Conferences

When medical physicists, students, or residents are directly involved in clinical radiology or academic departments attending discussions and conferences, there is an opportunity to learn the various imaging procedures and the pathological conditions where they are applied. While this provides valuable exposure to clinical activities it is somewhat limited with respect to both effectiveness and efficiency. The focus on most presentations and discussions is for physicians and not medical physicists.

Clinical Science and Imaging Methods Education within Medical Physics Programs

The most effective learning activities covering the medical sciences and imaging applications are those developed and provided within medical physics academic programs as illustrated in Figure 5.

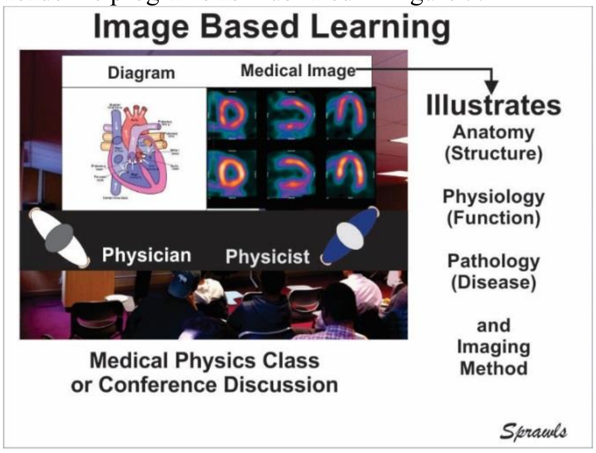

Figure 5. A highly effective learning activity for medical physics students.

A very effective learning activity to prepare medical physicists to contribute to improved and optimized image quality in clinical procedures includes several features as illustrated. A major factor is correlating medical images with the characteristics of the human body and using the images to learn the basic medical sciences.

This can be most effective when the discussions are conducted by a physicist and physician working together. It provides both physics and clinical perspectives of the imaging process. There is also value in experiencing the communication process between physicists and physicians.

While this type of class or conference is highly effective it has some limitations and challenges with efficiency. Considerable effort is required to produce the curriculum and visuals. There is the opportunity for this to be done as a collaborative and shared effort among educators, organizations, and even institutions. One purpose of this publication is to illustrate the characteristics and need for these educational resources and encourage their development.

Most radiologists or other physicians within an institution have limited time to devote to teaching within physics programs. In institutions with radiology residency programs there is the opportunity for some residents to participate as discussion leaders on a rotating basis. They benefit from enhancing their teaching skills and perhaps learning some physics in the process. Another possibility is to engage retired physicians giving them the opportunity to share their extensive knowledge and experience and contribute to the education of young scientists.

VIII. SUMMARY AND CONCLUSION

Physics is the foundation science of all medical imaging methods and physicists are the scientists who make major contributions to effective and safe imaging procedures through a variety of professional activities. With most modern imaging methods the variations and possible deficiencies in image quality now depend more on the procedure factors and protocols than on the performance characteristics of the equipment. To contribute to high-quality and optimized image quality medical physicists need education that includes the three basic medical sciences, anatomy, pathology, and pathology, along with an understanding of the imaging methods that provide visualization of these body and tissue characteristics.

There are several different approaches, or models, for including this in medical physics education. No one model fits all. It is a continuing process in which educators will develop learning activities that are appropriate for their needs and capabilities. There is the opportunity for collaborative efforts in developing and sharing resources to support the expanding roles of medical physicists in the field of clinical imaging.

The ultimate goal is medical physicists with the education and experience to contribute to the production of medical images with the quality characteristics required for highly-effective clinical procedures using the advanced technology and methods that are the foundation of modern medicine.

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IMPROVING QUALITY AND SAFETY IN RADIOTHERAPY USING WEB-BASED LEARNING

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Abstract– **To meet the need for training in techniques of quality and safety improvement in radiotherapy an e-learning program has been developed. Topics such as Incident Learning, Failure Modes and Effects Analysis and Safety Culture are introduced and discussed. The program consists of approximately 1200 slides with voice-overs, divided into 12 modules, and can be completed typically in 5-7 hours of self-study. A survey of early registrants strongly suggests that the program has been very well received and has been found to be useful and easy to access.**

Key Words– **quality, safety, radiotherapy, e-learning.**

I. INTRODUCTION

Concurrently with rapidly developing technology there has been an increasing emphasis on safety and quality in radiotherapy in recent years. While radiotherapy professionals have always placed the patient at the centre of their practice, reports in the popular press and scientific literature have highlighted those rare but devastating events which have seriously compromised clinical outcomes and even led to the deaths of patients.

Reflections of the high-level interest in and commitment to improving the quality and safety of radiotherapy are the publication of a number of reports, by professional and scientific bodies, discussing the current situation and making recommendations for improvement. Altogether these reports run to many hundreds of pages, contain a large number of recommendations, and inevitably have some overlap. However, one consistent theme runs through many of these influential documents. An analysis of 7 such publications has identified education and training as a recommendation for safer radiotherapy in all 7[1]. Although the focus of such education and training is rarely specified and is presumably aimed at developing competence in routine clinical activities, given the current emphasis on quality and safety it seems reasonable to add these topics to any program for radiotherapy professionals already in the field or in training.

There are, however, major challenges in developing effective programs. The provision of radiotherapy care is very much a multidisciplinary team effort with radiation oncologists, medical physicists and radiation therapists as the primary, but by no means the only, players. An ideal educational program would be relevant and useful for these different disciplines. However, an even bigger challenge is making such a program practically accessible to all in the radiotherapy field irrespective of the funding context of their situation. The enormity of this particular challenge can be gauged by looking at the number of medical physicists worldwide. One estimate has put this number at 24,000[2]. If European ratios[3] between the different professional groups are applicable worldwide then, based on the estimate for the number of medical physicists[2], there are over 100,000 radiotherapy professionals who could potentially benefit from education in quality and safety. Traditional approaches to learning cannot even start to address a challenge of this enormity and other options have to be explored.

The internet is establishing itself as probably the premier vehicle for the dissemination of educational material to very large audiences. Certainly, in medical physics there are many programs available bringing significant benefits to the community through the ease of accessibility[4].

The International Atomic Energy Agency (IAEA) has chosen the web as the basis for its program on Safety and Quality in Radiotherapy. The project, described in this brief article, was funded through the IAEA's Technical Cooperation Program in the Asia Pacific Region.

II. MATERIALS AND METHODS

A. The Educational Program

The overall aim of the program was described thus: *This e-Learning Program is designed to equip radiotherapy professionals with the knowledge to enhance the safety and quality of their practice and hence to provide patients with optimum outcomes.*

Good pedagogical practice was used to drive the design of the program. The content was divided into 12 modules with each module further divided into 3 – 5 sections. As far as possible these sections were self-contained and were largely understandable without reference to other sections. This structure allowed busy professionals to fit their learning activities in between clinical obligations without the necessity to refresh memories on previously studied sections. Each module and section starts with a list of objectives so the learner knew exactly where they were going. Likewise each section concludes with a brief summary reminding the learner of where they have been.

Common strands running through a program such as this can be helpful to the learner in providing continuity as well as reinforcing messages. The themes running through much of this program were three well-known radiotherapy accidents. These will be identified later.

At the end of each module is a 6 question quiz which can be repeated as often as desired. Such quizzes have value both for the learner and the learner's institution. The learners confirm for themselves that they have an adequate grasp of the material presented. Successful completion of all 12 quizzes results in the award of Certificate of Completion. From the institution's perspective the Certificate of Completion verifies that an individual has satisfactorily completed the course. This feature could be particularly valuable for undergraduate, graduate and residency education and training programs which incorporate Quality and Safety in their curriculum.

Articulate web-based learning software (https://articulate.com) was used for course development. Volunteers from within the IAEA provided voice-overs, from a script, for each element of the program.

The program was implemented on the Cyber Learning Platform for Network Education and Training (http://clp4net.iaea.org). This platform allows users to easily find education resources and supports the dissemination of e-learning self-study resources to a wide audience.

B. Users' Evaluation

To ensure the program was achieving its objective and that there were no unforeseen problems with any of the content, format or navigation tools an on-line survey of users who signed up within the first four months after release was conducted. The first 4 questions elicited demographic data about the responder. The next 16 questions, with responses on a 5 point Likert scale, enquired into issues such as the utility of the program and ease of access. The final 5 questions were free text and allowed the responder to make comments and suggestions in an unstructured way.

III. RESULTS

A. The Educational Program

The educational program was released on the IAEA website on 1st December 2016 (http://elearning.iaea.org/m2/course/view.php?id=392). To access the program the user has to first register with NUCLEUS which is straightforward and free. As mentioned previously the program itself consists of approximately 1200 slides with voice-overs, divided into 12 modules, which in turn are divided into 3-5 sections, Figure 1.

On entering the program the first slides encountered present an outline of the content and describe the convenient navigation tools which are built in.

A very brief synopsis of the content of each of the 12 modules is provided below.

Module 1 sets the scene by looking at the scope of the cancer problem worldwide; suggests the connection between quality and safety in radiotherapy; looks at the limited statistics on incidents in radiotherapy and concludes with an overview of some of the recent literature and recommendations in the field.

Fig 1. An example of an entry screen into a module.

Module 2 introduces the three threads that run though much of the program. The well-known radiotherapy incidents in New York State, U.S., Epinal, France and Toulouse, France are described with the descriptions based on the excellent summaries developed by the IAEA(https://rpop.iaea.org/RPOP/RPoP/Content/AdditionalResources/Training/1_TrainingMaterial/AccidentPreventionRadiotherapy.htm).

Module 3 introduces the learner to Incident Learning Systems with a discussion of the structural and design features of such systems, an overview of some of the currently available systems and concludes with a detailed discussion of the IAEA's Safety in Radiation Oncology (SAFRON) system (https://rpop.iaea.org/RPOP/RPoP/Modules/login/safron-register.htm).

Module 4 delves deeper into the key components of an Incident Learning System. The 4 sections in this module address Process Maps, Severity Metrics, Basic (or Root) Causes and Safety Barriers.

Module 5 sees a return to the SAFRON approach (from Module 3) to incident learning in which the 3 incidents described in some detail in Module 2 are entered into SAFRON. It will be apparent from this module that even reporting incidents, which is an essential feature of an effective safety culture, is far from straightforward as we rarely know precisely what happened.

Module 6 commences the examination of the engine of an Incident Learning System, viz. Root Cause Analysis (RCA). Following an overview of the principles of RCA there are brief discussions of Rasmussen's human factors model and Basic Causes. The module demonstrates the challenges of identifying Basic Causes through examination of the 3 theme incidents: New York State, Epinal and Toulouse.

Module 7 delves deeper into an effective Incident Learning System through discussions of Safety Barriers and Preventive Actions. Again the discussion is facilitated through the use of the 3 theme incidents in the context of the SAFRON Incident Learning System.

Module 8 moves from retrospective safety and quality management accomplished through the use of Incident Learning Systems to the complementary approach of prospective techniques and, in particular, Failure Modes and Effects Analysis (FMEA). Following an everyday example of the application of FMEA, subsequent sections of the module present suggestions as to how an FMEA might be applied to the clinical situations in which the 3 theme incidents occurred.

Module 9 introduces the prospective quality management tool of Fault Tree Analysis and again the 3 theme clinical situations are used to illustrate the application of the technique.

Module 10 moves to the overarching issue of Safety Culture. The discussion is based on the 10 safety traits identified by the IAEA[5]. Each of these 10 safety traits is disaggregated into their component parts and suggestions are made as to the measures that might be implemented in practice to enhance concordance with the traits, Fig. 2.

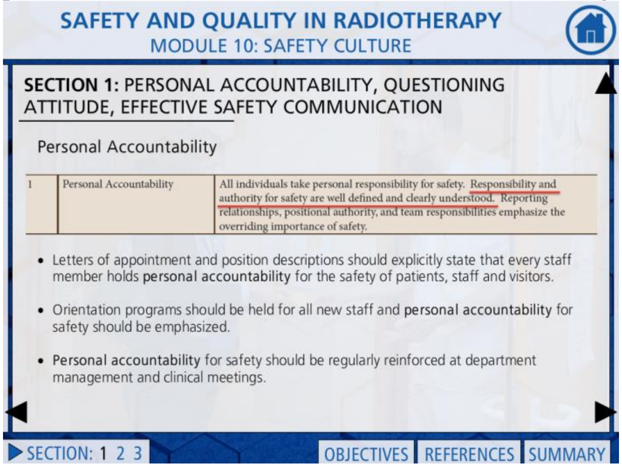

Fig. 2. An example of the advice provided to enhance concordance with one statement in the first safety trait.

Module 11 identifies additional resources to help the individual practitioner and clinic maintain and enhance the safety and quality of care delivered to radiotherapy patients. The resources discussed include the IAEA sponsored Quality Assurance Team for Radiation Oncology[6] and the AAPM's Safety Profile Assessment[7].

Module 12 addresses some very practical issues surrounding the application of the knowledge and tools presented in this e-learning program. The establishment of an effective and efficient Quality Assurance Committee is one such issue. A possible budget, in terms or personnel time, is also presented so that individuals and clinics are fully cognisant of the resources they need to commit if they are serious about moving their quality/safety agenda forward.

Each of these modules is followed by a quiz consisting of 6 multiple choice questions. The pass mark is 5/6 correct answers. However, the quizzes may be taken multiple times. Success at all 12 quizzes leads to the award of a Certificate of Completion.

This program was released on 1st December 2016. At the time of writing, October 2017, 1281 individuals have registered and 337 have been awarded a Certificate of Completion.

B. Users' Evaluation

At the time of the survey 120 registrants had been awarded Certificates of Completion and were invited to participate in the users' evaluation. Of these, 48 from 32 different countries responded.

By far the majority of those who responded were medical physicists, Fig 3.

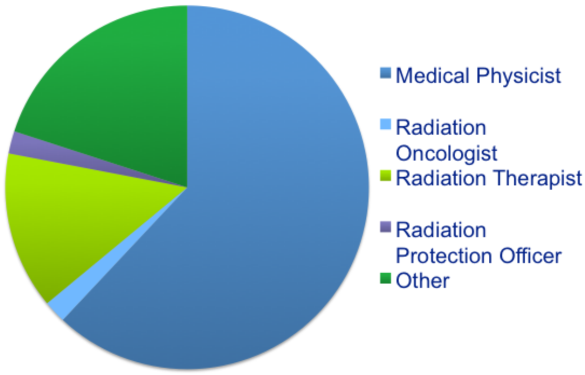

Fig 3. The distribution of professions amongst responders.

There was very strong agreement amongst the responders that the program was easy to access, Fig 4.

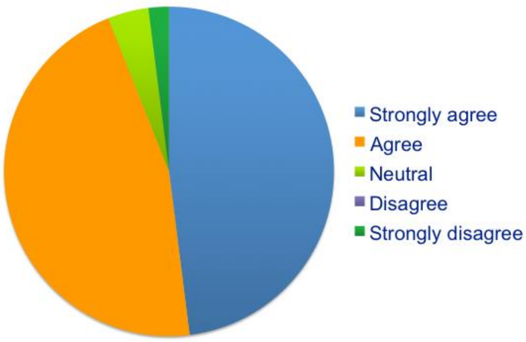

Fig 4. The survey statement was: It was easy to access the e-learning.

Responders were asked about their views on the overall presentation of the on-line course, Fig 5.

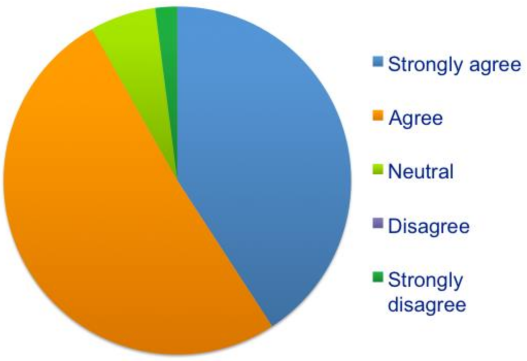

Fig 5. The survey statement was: The design of the course was appealing and easy to follow.

The course content was considered to be relevant to the needs of the majority of responders, Fig 6.

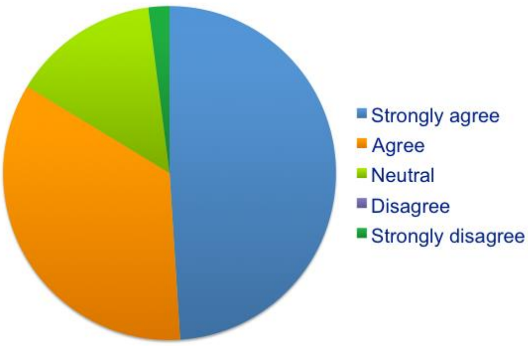

Fig 6. The survey statement was: The content of the course provided was relevant to my needs.

Clearly it is important that any course should meet its goals and, from the responses received, this course did, Fig 7.

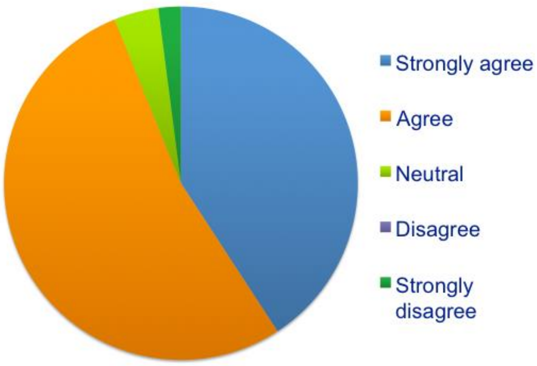

Fig 7. The survey statement was: The course met the goals and objectives.

Amongst other information gleaned from the survey was that more than 70% of responders were between the ages of 25 and 35; 40% had between 1 and 5 years clinical experience while 25% had more than 15 years.

In the majority of cases (40%) the course took 5 – 7 hours to complete.

Minor, but rare, constructive criticisms received were that some of the graphs were overly complex and, on occasion, the narration was too fast.

IV. DISCUSSION

Overall, this e-learning project has reached its aim as defined earlier in this paper. The responses from the survey, although limited, have been very positive. At the outset of the project its uptake was unknown. With very limited promotion current registration is running at ???? which is certainly satisfactory after less than one year since release. However, the data in Figure 3 do serve to highlight a not unexpected challenge. Uptake by professions other than medical physics is quite low. Educational programs of all types on Quality and Safety in radiotherapy, and the experts to deliver them, are in relatively short supply. This particular e-learning program has the potential to fill a much needed, but perhaps unrecognized demand, particularly at the trainee level.

V. CONCLUSION

A 12 module e-learning program on Quality and Safety in radiotherapy has been developed. The program of approximately 1200 slides with voice-overs takes typically 5 – 7 hours to complete and, with success at 12 quizzes, leads to the award of a Certificate of Completion. The program has been well received by the initial cohort of registrants.

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A Website for Teaching Digital Radiography Principles

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Abstract—**The physics properties of digital x-ray receptors are very different from that of film. In order to teach these principles for digital systems a web-based simulation was developed using images of a body phantom. The simulation shows example images while explaining these principles.**

Keywords— **Radiography, Digital, Image Quality**

I. INTRODUCTION

Film served the radiology community for over one hundred years in the triple role of acquisition, viewing, and archiving. The physics principles of image quality and the sensitometric response of film to radiation was straightforward and required knowledge for radiology residents and radiographers.

Over the last several decades radiography has migrated from film to various digital technologies, most notably computed radiology and digital radiology. Computed radiology (CR)[1] employs analog photostimulable cassettes which replaced film and which could be used with existing radiographic equipment. Digital radiology (DR) [1] uses an electronic receptor which can take the form of either a fixed structure or a cassette which can be placed in a conventional bucky.

Fig 1. Digital Radiograph Simulator Home Page.

The sensitometric response of digital systems to radiation is very different from that of film. Image quality is a function not only of the digital system hardware but also software that renders the digital latent image into a readable radiograph. One of the challenges in transitioning from film to digital was that technique changes made when using film to address image quality or sensitometry cannot be applied to digital. Film has a well-defined response to radiation [2]. If an image is lighter than desired, an increase in radiation will make it darker. And if an image is too dark, the problem can be resolved by reducing radiation. Thus for a given film type and processing there was a "Goldilocks" dose that would result in a radiograph of optimal density, not too light and not too dark.

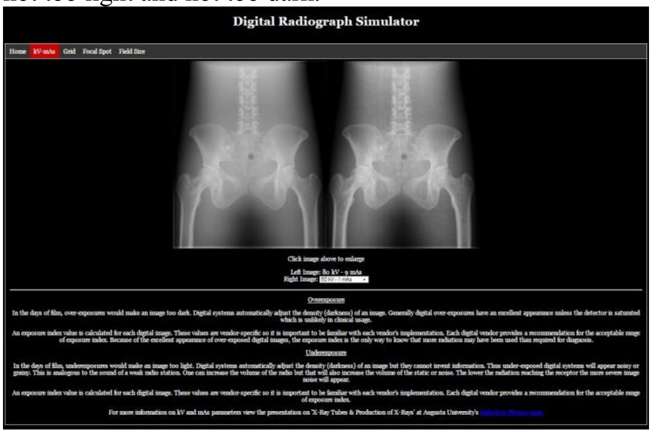

Fig 2. Comparison of Images Taken at Different Values of mAs.

The response of digital systems to radiation is completely different. Software is designed to optimize image density much as a radio's volume control can achieve any desired volume for both strong and weak stations. Thus image density is no longer a reliable indicator that the proper amount of radiation was used [3].

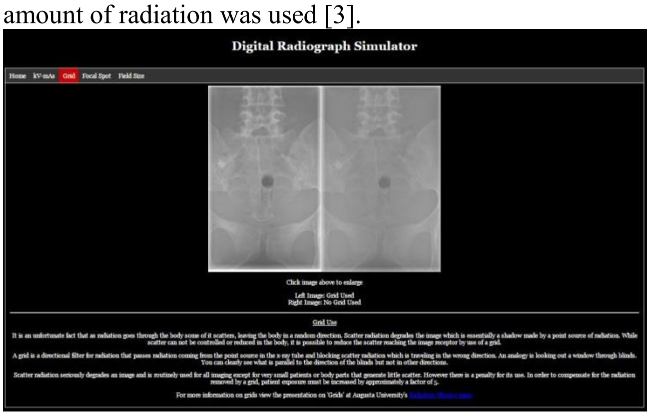

Fig 3. Comparison of Images Taken With and Without a Grid.

In both CR and DR digital systems, differing amounts of radiation will affect image noise. If too little radiation is used, image noise can mask subtle low contrast differences and may render images unreadable even though density appears correct. Too much radiation will reduce noise and improve the appearance of an image without darkening the image. Only if the detector is saturated will image quality degrade. However, detector saturation requires so much radiation it is unlikely to occur clinically. Since image density is controlled by software and since the amount of noise that can be tolerated for a particular study is subjective, there is no longer a correct or "Goldilocks" amount of radiation based on density.

Vendors provide feedback in the form of a quantitative dose index for each CR or DR image [4]. The calculation of dose index is vendor-specific, although there is an industry-wide effort to standardize it [2,3]. Software attempts to isolate anatomy from collimated areas and areas of raw radiation. Receptor dose is then averaged only for these anatomic areas. While serving as a useful metric, dose index can be influenced by the software's identification of anatomy which can be affected by positioning or the choice of study or views.

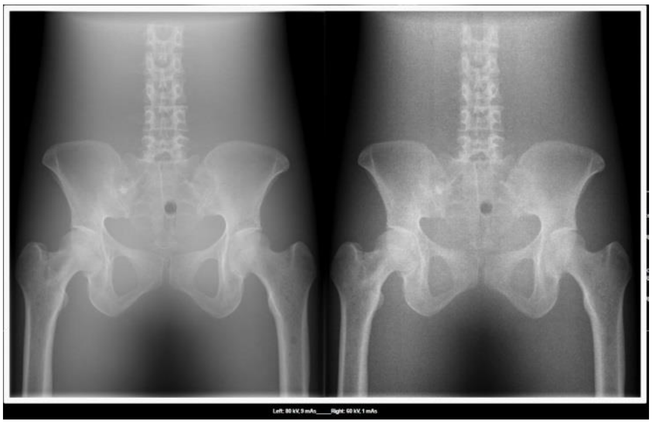

Fig 4. Enlarged Comparison Images.

Radiology residents and radiographers are tested on the differences in response between film and digital receptors. We felt we could enhance the teaching of these principles by making example radiographs using a body phantom changing one technical parameter at a time, something that would be impossible using clinical images. A web page was developed to providing example images along with descriptions of the underlying physics.

II. DISCUSSION

A web site was written to enhance the teaching of digital imaging physics. The web site allows users to view the result of various changes by putting images side by side. All images were made on a Philips Digital Diagnost 4 radiographic unit using a SkyPlate digital radiography system[5].

First a phototimed reference image of a Lucite abdomen/pelvis phantom was acquired using the machine's clinical protocol. A series of images using identical positioning was made at several combinations of kVp and mAs. Images were also made using both focal spots, three field sizes, and with and without a grid.

A web page was then written (Figure 1) allowing the user to select an image to compare with the reference image. An explanation of the difference is displayed just below the image pair. For example, the user can view images taken at various kVp / mAs combinations along side the reference image (Figure 2) or an image made without a grid along side the reference image which was taken with a grid (Figure 3). Both figures show the text description of the principle demonstrated by the pair of images. One can also enlarge the image pair to better discern the differences in image quality (Figure 4).

The goal of the web site development was to create a simulation where a user can make single changes to technique and observe the effect of that change while reading an accompanying text of the underlying principles.

The website described here can be accessed at the following link:

http://medicalphysics.augusta.edu/DRSim/

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CELEBRATING NEW MEDICAL PHYSICISTS AT ICTP: 20 GRADUATES FROM 20 COUNTRIES

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Abstract— **This article overviews the new cohort of young medical physicists from the MSc course at ICTP, Trieste, Italy – a unique a cooperative MSc program between ICTP and the University of Trieste, supported strongly by the AIFM, EFOMP and IOMP (who accredited the MSc) and also supported financially by the IAEA. The MSc is coordinated by R Padovani and R Longo and is specially designed to educate colleagues from Low-and-Middle Income countries.**

The abstracts of all MSs projects are included in an Annex.

Keywords— **MSc programmes**

Thanks to its innovative master's degree programme in medical physics, ICTP is steadily supporting the improvement of the quality of health services in the developing world. Recently, the Centre celebrated the graduation of twenty students—the third class of medical physicists to complete the degree requirements—who will soon return home to spread new knowledge and expand professional networks.

ICTP's Masters of Advanced Studies in Medical Physics (MMP) programme is designed to provide young, promising graduates of physics or related fields with postgraduate academic and clinical training so that they can independently function as clinical medical physicists in their home countries. These new medical physicists will help expand care and therapy options in areas where medical physics knowledge can be scarce. With this third class, a total of 46 medical physicists from 30 countries have trained in the internationally rigorous MMP programme.

Medical physics expertise is a key part of health care, applied in all aspects of radiation medicine, from diagnostic imaging to radiation oncology. Cases of non-communicable diseases such as cardiac and neurological disorders and cancer are rising, but the resources needed to diagnose them are often scarce, including human resources. Using radiation effectively and safely in medicine requires skilled medical physicists in the clinical staff, however their training is difficult to get or non-existent in some countries. "I got to use technologies and equipment that I had only heard about before," says Fama Gning, an MMP graduate from Senegal. "It was amazing to be able to use them. It was like I was being included in science."

The dearth of training and equipment in developing countries is why ICTP and the University of Trieste partnered to prepare the MMP programme, with help from the International Atomic Energy Agency (IAEA), one of ICTP's UN sponsors. After completing a year of academic training in Trieste, the students spend a year in professional clinical training at various Medical Physics Departments in Italy. Each Master's candidate completes and defends a dissertation in the last months of their clinical time. The clinical work, made possible with the help of medical physicists at many hospitals, is a key part of the programme. Ala 'Ahmad Amin Allouzi, a graduate from Jordan who did her clinical training in Ferrara, said of her experience, "Everyone there was incredibly supportive and welcoming. I would call my supervisor in Jordan to tell them about new techniques, and explain methods that we used at home to my supervisor in Ferrara. This constant exchange was one of the most important parts of the programme for me."

At the ceremony, ICTP Director Fernando Quevedo congratulated the graduates on their hard work. "Today is one of the days I really appreciate being the director of ICTP. It's great to see the success stories of each one of you." The Rector of the University of Trieste, Maurizio Fermeglia, was also there to commend the students: "The world is full of problems, and none of these will be solved by a single discipline; cross-disciplinary work is a must. Mixing medicine with physics—you are on the right track."

The graduation ceremony gave the opportunity for Director Quevedo to thank the organizations that support the Masters in Medical Physics programme, including the IAEA, the University of Trieste, the International Organization of Medical Physics (IOMP), the European Federation of Organisations for Medical Physics (EFOMP), and the Italian Association of Medical Physics (AIFM). Addressing the graduates, Harry Delis of IAEA's Human Health Division said, "The IAEA is working on developing capacity in human health. These medical physics graduates will ensure safe and effective treatment in their home countries, and spread their knowledge to future generations." The IAEA gives scientific and financial support to the MMP programme in the form of student fellowships and educational materials used in courses.

Most of the MMP students are supported by their government and employers as they do advanced training at ICTP. After graduating with both theoretical and clinical training, students typically return to their jobs, with new knowledge and skills to use and pass on to colleagues.

"The most valuable part of this whole programme is the network we build here, of experts and colleagues. We can ask questions with a lot of confidence, knowing that they're not only colleagues but often friends too," said Alejandro

Arnulfo Coloma Espin, an MMP graduate from Ecuador. This international network is essential to collaboration and continued technical development, that the students can further extend to the network of medical physicists in their countries. "There are not many medical physicists in my country with this training," says Antony Kevin Reyes Ramos, a graduate from Honduras. "I'm one of the first ones, so I'll be helping to build a network there similar to what I've found here."

Christoph Henrich of the IAEA’s Technical Cooperation programme at the IAEA, agreed: "The international nature of the programme is a great thing¬—it broadens the horizons and opens the perspective. For the future, it enables the graduates to have a network, not only among themselves but with well-known medical physicists." The programme, he added, is a great way to reach larger goals: "Technical cooperation is largely about human resource capacity building, knowledge sharing, partnership building, and networking, and this programme, over the last three years, has shown that it's a very good example how to have a real impact."

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INVITED PAPER

How to Optimize Radiation Dose in Computed Tomography Examinations: Available Methods and Techniques

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Abstract— **In this review, available methods and techniques for optimizing the radiation dose in computed tomography (CT) examinations are described. Automatic exposure control can adapt tube current according to the patient attenuation needed for achieving a specified image quality by performing tube current modulation (TCM), which allows the tube current to be automatically modulated during the acquisition. TCM is generally divided into the following five types: longitudinal (z-axis), angular (xy-axis), longitudinal and angular (xyz-axis), organ based, and electrocardiogram gated. Optimizing tube voltage is effective for reducing patient dose while maintaining a desired contrast-to-noise ratio. Furthermore, optimization of the reconstruction kernel (including consideration for using an iterative reconstruction), slice thickness of images, bowtie filter, and number of acquisition phases are needed to further optimize the radiation dose. In addition, applications of selective organ shielding (e.g., bismuth shield), dual-energy CT, and newly developed X-ray detection systems may further reduce patient dose.**

Keywords— **computed tomography, radiation dose, optimization, tube current modulation, iterative reconstruction**

I. INTRODUCTION

Computed tomography (CT) is widely used as an essential diagnostic imaging tool in clinics. The introduction of multi-detector CT (MDCT) has increased the number of CT examinations worldwide. However, concern about CT radiation doses has been expressed in the literature [1-3]. Because children are more radiosensitive than adults, potential cancer risks associated with ionizing radiation requires attention, particularly in pediatric CT examinations. Pearce et al. [4] reported that in children, the use of CT with cumulative doses of approximately 50 mGy might almost triple the risk for leukemia and doses of approximately 60 mGy might triple the risk for brain cancer. Mathews et al. [5] also reported that among people aged 0–19 years, the overall cancer incidence was 24% greater for those exposed to radiation than for those unexposed to radiation. Therefore, justifying each CT examination by weighing the benefits against the risks is important.

In addition to justifying each CT examination, radiation doses used should be as low as reasonably achievable (ALARA). To implement ALARA principles in CT image acquisitions, radiologists, physicists, and technologists should make efforts to produce optimal images with the lowest dose to patients; this process is called optimization. Fortunately, CT manufacturers provide various methods and techniques for optimizing radiation doses in CT examinations. Therefore, radiologists, physicists, and technologists need to be familiar with these methods and techniques.

In this review, we introduce methods and techniques for optimizing the radiation dose in CT examinations. To satisfy the ALARA principle, the dose optimization methods and techniques described in this review should be well understood and appropriately used.

II. TUBE CURRENT MODULATION

Dose, tube current, and exposure time are proportionally related. The noise level is inversely proportional to the square root of tube current (milliampere, mA) or tube current–time product (milliampere-second, mAs). An excessive increase in tube current or tube current–time product causes an increase in the patient dose, but excessive tube current reduction can adversely increase image noise levels.

For CT, Brooks and Di Chiro [6] showed the following association between image noise (standard deviation of CT numbers, σ) and patient dose (D):

$$D \propto \frac{e^{-\mu d}}{\sigma^2 \cdot a^2 \cdot b \cdot h} \qquad (1)$$

where, μ represents the mean linear attenuation coefficient of the object, d represents the diameter of the object, a represents the sample increment, b represents the sample width, and h represents the slice thickness. Formula (1) is known as Brooks' formula and shows that patient dose and image noise are inversely related to each other.

Although a CT operator must consider patient size when selecting the tube current, adjusting the tube current immediately and appropriately according to the patient size is difficult. In addition, the tube current should be optimized for the thickest or highly attenuated part of the patient when using a fixed tube current, leading to excessive exposure in other parts of the patient.

Automatic exposure control (AEC) is implemented on CT to adapt the tube current according to the patient attenuation needed to achieve a specified image quality using the tube current modulation (TCM) technique. TCM allows the tube current to be automatically modulated during acquisition, and there is no doubt that TCM is effective in optimizing patient dose in CT. Although dose modulation techniques vary among vendors, they are generally divided into the following five modulation types: longitudinal (z-axis), angular (xy-axis), longitudinal and angular (xyz-axis), organ based, and electrocardiogram (ECG) gated.

A. Longitudinal (z-axis) modulation

In longitudinal modulation, the tube current is adjusted according to the size and anatomical regions of patients. This modulation is performed to produce relatively uniform noise levels through the entire acquisition range. The tube current is modulated to provide the desired image quality at the chosen attenuation on the basis of prior calculations from a localizer radiograph.

Examples of longitudinal dose modulation for thoracic CT for a female RANDO phantom (RAN110; The Phantom Laboratory, Salem, NY, USA) among manufacturers are shown in Fig. 1. Although the tube current is modulated across various anatomical regions, the characteristics of dose modulation vary among manufacturers. Operators should understand that longitudinal modulation that uses data obtained from localizer radiographs cannot appropriately adjust the tube current if the patient is not positioned at the isocenter of the CT gantry [7].

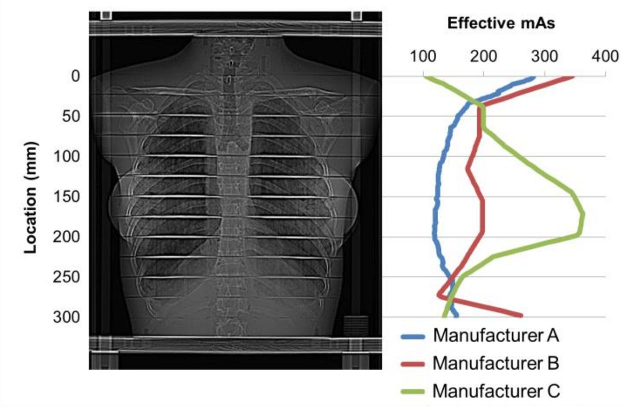

Fig. 1 Comparison of the tube current when applying longitudinal modulation among manufacturers

B. Angular (xy-axis) modulation

X-ray is attenuated more in the lateral direction than in the anteroposterior direction; thus, it is effective that the tube current is modulated within one gantry rotation. The tube current is adjusted according to the attenuation data from the localizer radiograph or in near-real time according to the measured attenuation from the previous 180° projection.

Examples of angular modulations are shown in Fig. 2. These profiles were acquired using the AEC system CARE Dose 4D (Siemens Healthineer, Erlangen, Germany), semiconductor detector CT Dose Profiler (RTI Electronics, Mölndal, Sweden), and custom-made elliptical polymethyl methacrylate phantoms, measuring 180 × 260 mm (small) and 260 × 380 mm (large) in diameter (Fig. 3), when helical CT acquisitions were performed with and without angular modulation. The semiconductor detector was inserted in the center of the phantom, and time series data of the absorbed dose rate were acquired. With both phantom sizes, the absorbed dose rates were relatively similar between the fixed tube current (FTC) and TCM in the first two cycles. After the first two cycles, the absorbed dose rates stabilized, with only slight fluctuations when TCM was used. These fluctuations were smaller than those with FTC, irrespective of the phantom size.

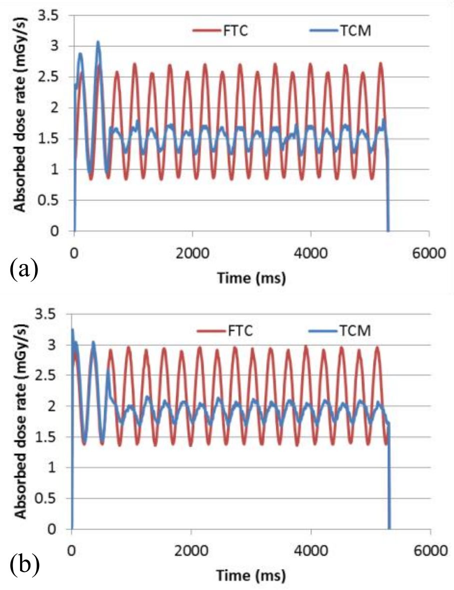

Fig. 2 Examples of absorbed dose rate profiles at the centers of elliptical phantoms with and without angular modulation: (a) absorbed dose rate profiles for a large phantom, (b) absorbed dose rate profiles for a small phantom

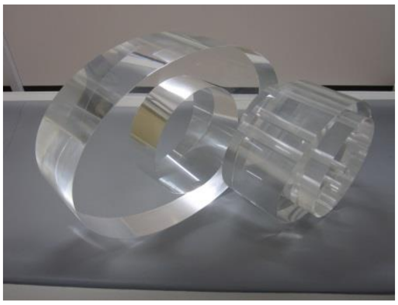

Fig. 3 Custom-made small (right) and large (left) elliptical polymethyl methacrylate phantoms. They can be used by inserting a commercially available 16-cm CT dose phantom into these phantoms

C. Longitudinal and angular (xyz-axis) modulation

The simultaneous combination of longitudinal and angular modulations involves the variation of tube current along both the longitudinal (z-axis) and in-plane (xy-axis) directions of a patient. This modulation is the most comprehensive approach for reducing CT dose because the dose is adjusted according to patient-specific attenuations in all three planes.

D. Organ-based modulation

Organ-based modulation is used for reducing the dose in radiosensitive organs such as the breast, thyroid, and eye lens. In this technique, the tube current is decreased over radiosensitive organs.

One study demonstrated that for thoracic CT, organ-based modulation reduced the absorbed dose in the breast by apprixmately 22%, without changing CT values and noise levels, relative to those of the reference [8]. The noise levels do not change because the tube current is increased during the remaining acquisition range. Exposure to multiple diagnostic radiographic examinations during childhood and adolescence increases the risk for breast cancer among women with scoliosis [9]. Therefore, organ-based modulation is also preferable for specific patient groups such as children and young women for whom the risk for breast cancer might be increased by thoracic CT.

The International Commission on Radiological Protection revised the occupational equivalent dose limit for eye lens from 150 mSv/y to 100 mSv/5y (no single year exceeding 50 mSv). Patient dose, in addition to occupational dose, for eye lens should be reduced, and organ-based modulation is preferable for reducing the equivalent dose for eye lens during head CT [10]. An example of surface absorbed doses within a single section of the head RANDO phantom (RAN110; The Phantom Laboratory) with and without organ-based modulation (X-CARE; Siemens Healthineer) using standard parameters for head CT is shown in Fig. 4. The results showed that anterior surface doses were lower with organ-based modulation than without it.

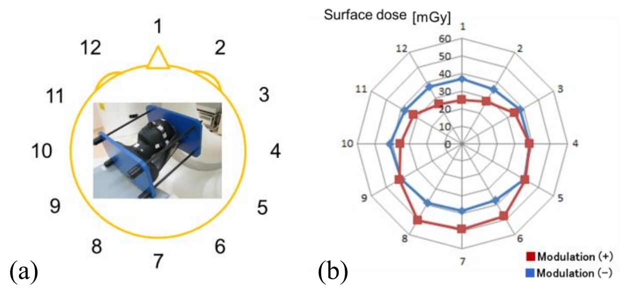

Fig. 4 An example of surface absorbed doses within a single section of the head phantom with and without organ-based modulation: (a) phantom and locations for measuring surface absorbed doses and (b) surface absorbed doses with and without organ-based modulation

E. ECG-gated modulation

In this modulation, a standard tube current is applied over a limited range of heart phases to ensure low noise levels during the phase while minimizing the tube current during the remaining heart phases to reduce the patient dose.

Another type of ECG-gated modulation is to employ prospective gating axial acquisitions in which X-rays are turned on only during a limited heart phase and are completely turned off during other heart phases. However, this method can only be used for patients with low and stable heart rates. Different types of ECG-gated modulation are shown in Fig. 5.

One study demonstrated that in retrospectively ECG-gated helical acquisitions, ECG-gated modulation reduces 3.4–9.2% of the doses absorbed by thoracic organs compared with the reference dose and that in prospectively ECG-gated axial acquisitions, the modulation reduces 66.1–71.0% of the doses absorbed by thoracic organs [11].

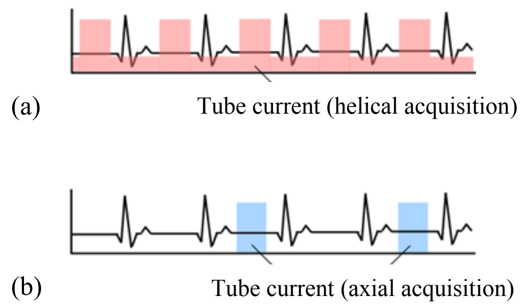

Fig. 5 Different types of ECG-gated modulation: (a) retrospective gating and (b) prospective gating

III. TUBE VOLTAGE ADJUSTMENT

Dose is approximately proportional to the square of the tube voltage (kilovoltage, kV). Therefore, the tube current and tube voltage should be adjusted according to the patient size to optimize the patient dose. Reducing the tube voltage is effective for reducing the patient dose while maintaining a desired contrast-to-noise ratio (CNR) [12].

An example of a semi-automatic tube voltage adjustment tool is CARE kV (Siemens Healthineer), which automatically adjusts the optimal kV setting for each individual patient for a CT examination. Data from localizer radiographs are used for optimizing the tube voltage and tube current so that a user-chosen CNR is maintained with the lowest dose (Fig. 6). The tube voltage cannot be modulated during acquisition. A previous study demonstrated that the radiation dose and amount of contrast material could be reduced in abdominal dynamic CT without deteriorating the image quality [13].

However, changes in kV result in a change in X-ray photon energy, and changes in X-ray photon energy result in a change in tissue CT values. Therefore, variations in kV cause substantial changes in image contrast.

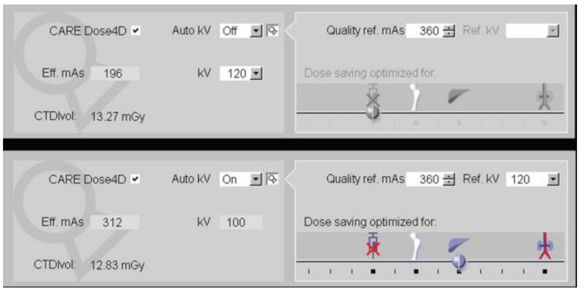

Fig. 6 Screen shot of the CARE kV (Siemens Healthineer) operation display. The tube voltage is adjusted according to the examination purpose selected by sliding the blue circle at the right lower part, “Dose saving optimized for”

IV. Optimizing reconstruction kernel

Reconstruction kernels themselves are not directly related to the patient dose, but the patient dose may be reduced by selecting an optimal reconstruction kernel. If high resolution kernels are used, image noise levels increase. If low resolution (smooth) kernels are used, image noise levels decrease without increasing the patient dose.

Iterative reconstruction (IR) is an algorithm for generating cross-sectional images from measured projections of an object. The algorithm has been applied to single-photon emission CT or positron emission tomography. In CT, this method was not used because of its significantly slower calculation speed than that of filtered back projection (FBP), which is the standard CT image reconstruction algorithm. However, various new image reconstruction systems that use IR algorithms have been recently developed. Using these systems, patient doses can be reduced while maintaining the image noise levels.

Although specific algorithms differ among manufacturers, the clinical basis for the benefits of IR implementation primarily involves reducing image noise levels, leading to improved objective and subjective image quality compared with those using FBP reconstructions [14]. However, IR techniques can result in the degradation of image quality by imparting an unfamiliar “plastic” texture to images that can interfere with the accuracy of diagnosis to an extent [15]. Another limitation is that computational power and time are required for IR. Delay between data acquisition and availability of images depends on the type of IR algorithm and the number of images.

Some third-party vendors have recently provided systems that are based on the IR approach. One example of these systems is SafeCT (Medic Vision, Tirat Carmel, Israel) (Fig. 7). It is a centralized network-based add-on system that can connect to any CT systems in an imaging department via digital imaging and communications in medicine network. Even if CT systems do not have image reconstruction systems that use IR algorithms, it can receive images from the CT console, automatically process them using IR algorithms, and transfer the processed images to the picture archiving and communication system for interpretation.

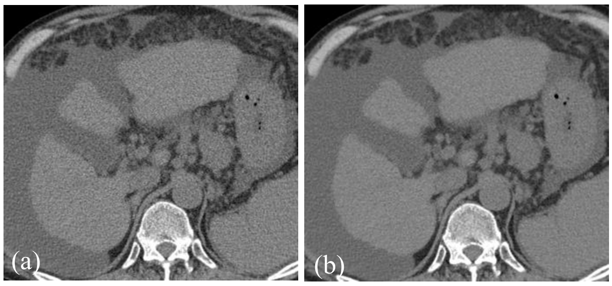

Fig. 7 An example of abdominal CT images before (a) and after (b) process using SafeCT (Medic Vision): The image noise levels decreased after process without deteriorating the spatial resolution

V. Optimizing image slice thickness

Images that have thin slice thicknesses can be easily obtained if MDCT systems are used. A thinner image thickness decreases the partial volume effect but increases image noise levels. To obtain thinner image thicknesses with lower image noise levels, higher radiation doses are required. However, CNR and visibility of small lesions can improve, despite increased noise levels when thinner slice thicknesses are used [16].

VI. Optimizing bowtie filter

CT systems use bowtie filters to shape the X-ray beam and remove lower energy photons before the beam reaches the patient. The filter equalizes the radiation amount reaching the detector (Fig. 8).

In general, an optimal bowtie filter is selected when an optimal scan field of view is chosen. Therefore, operators should choose an optimal scan field of view according to the anatomical size and acquisition region of the patient.

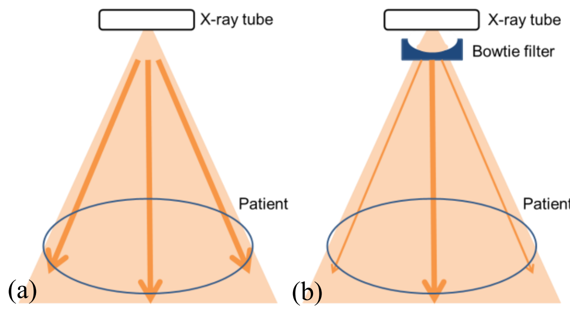

Fig. 8 Effectiveness of bowtie filter: (a) without a bowtie filter and (b) with a bowtie filter. The bowtie filter hardly absorbs X-rays at the center but absorbs off-axis X-rays to maintain a more uniform X-ray field at the detector

VII. Optimizing number of acquisition phases

There is no doubt that the patient dose increases when the number of acquisition phases increases. However, optimizing the number of acquisition phases is not easy. For example, one study reported that the detectability of hepatocellular carcinoma improved using four-phase CT image acquisitions [17], but another study reported that four-phase CT image acquisitions compared with three-phase CT image acquisitions did not improve the detection of hepatocellular carcinoma [18]. It is necessary for radiologists to keep in mind that the number of repetitions should be minimized.

VIII. APPLICATION OF SELECTIVE ORGAN SHIELDING

Selective organ shielding may be one of the choices for reducing the radiation dose in radiosensitive organs such as the breast, thyroid, and eye lens. A latex sheet that contains bismuth is generally used for this purpose. Fig. 9 shows an image of breast shielding that was achieved by applying a commercially available latex sheet over the breasts. The shield can attenuate many X-ray photons that would be absorbed by the breasts so that the absorbed dose in the breasts can be decreased.

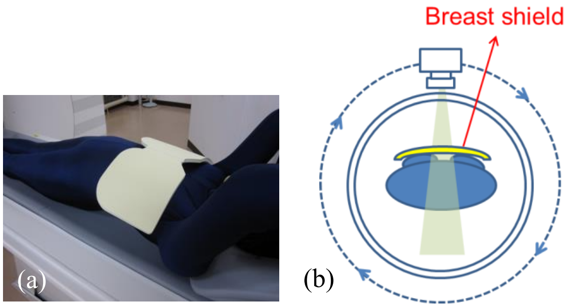

Fig. 9 Breast shielding: (a) placing a bismuth breast shield (AttenuRad ARB42; F&L Medical Products, Vandergrift, PA, USA) over the breasts and (b) illustration of breast shielding in CT

The use of selective organ shielding for pediatric and coronary calcium scoring CT has been recommended because the diagnostic image quality is not seriously affected by the shielding [19,20]; in contrast, shielding in thoracic CT has not been recommended because of its effect on CT numbers, artifacts, and image noise levels [21,22]. Therefore, judging whether selective organ shielding should be applied or not on the basis of the examination purpose is important.

If selective organ shielding is applied, some AEC systems that use at least one localizer radiograph to calculate the attenuation profile of the patient cannot correctly calculate the attenuation profile of the patient. Although the issue can be avoided by placing a shield after obtaining the localizer radiograph, the shield may prevent obtaining images with the quality required for the diagnosis. Other AEC systems that modulate the tube current according to the near-real-time attenuation data obtained from the previous 180° projection during the scan cannot correctly calculate attenuation data, even if the shield is placed over a radiosensitive organ after obtaining the localizer radiograph.

IX. APPLICATION OF DUAL-ENERGY CT

Radiation doses in dual-energy CT are similar to those in single-energy CT [23]. However, dual-energy CT allows the differentiation among multiple materials and the quantification of the mass density of two or three materials in a mixture with known elemental composition [24]. One of the examples that uses a three-material decomposition algorithm is a virtual non-contrast (VNC) image. This algorithm can remove iodine from contrast-enhanced CT images. If VNC images can be used instead of true non-contrast (TNC) images, TNC acquisition can be omitted to reduce the total patient dose. Previous studies showed that VNC images can replace TNC images for detecting or diagnosing a subarachnoid and intracranial hemorrhage, acute ischemia, liver lesion, hypoattenuating pancreatic lesion, hyperdense renal lesion, and urinary stones [25-30].

An example of abdominal dual-energy CT images before and after iodine subtraction is shown in Fig. 10. It is confirmed that iodine is removed from contrast-enhanced CT images to obtain VNC images. A previous phantom study revealed that VNC images provide reliable attenuation measurements for low, moderate, and high iodine-induced attenuations; however, for tissues with an extremely high iodine contrast agent load (e.g., excretory phase of CT urography), VNC values become less accurate and VNC attenuation increases over TNC attenuation because of beam hardening of X-rays [31].

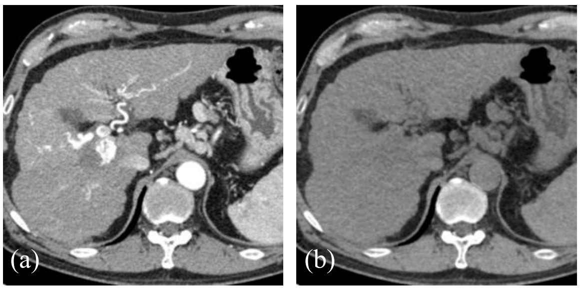

Fig. 10 Abdominal dual-energy CT images: (a) before iodine subtraction (contrast-enhanced image) and (b) after iodine subtraction (VNC image)

X. APPLICATION OF NEWLY DEVELOPED X-RAY DETECTION SYSTEM

CT basically uses scintillators such as cadmium tungstate to turn X-rays into light. The light is then converted into electrical signals using a photo diode. If the efficient of X-ray detection can be increased or electronic noise levels can be reduced in an X-ray detection system, further patient dose reduction is possible.

One manufacturer uses a new garnet gemstone material (Gemstone Detector; GE Healthcare, Milwaukee, WI, USA) as a scintillator. The advantage of the material includes high X-ray detection efficiency, and the gemstone-based scintillator can significantly reduce radiation doses [32].

Another manufacturer uses praseodymium-activated scintillator in their detector ($^{\text{PURE}}$ViSION Detector; Toshiba

Medical Systems, Tochigi, Japan). Similar to the Gemstone Detector, its advantage is high X-ray detection efficiency.

A third manufacturer uses integrated CT detectors (Stellar and Stellar^{INFINITY} Detectors; Siemens Healthineer) that directly couples the photodiode with the analog-to-digital convertor to reduce the amount of electronic noise levels and artifacts [33], thereby reducing radiation doses.

XI. Conclusions

CT examinations are associated with substantially higher radiation exposure than conventional X-ray examinations, making radiation exposure from CT examinations a potential concern. In recent years, the news media, in addition to professionals, have focused on the potential risks of radiation exposure from CT examinations. In such situations, it is important for radiologists, physicists, and technologists to recognize the benefits and risks of CT examinations and follow ALARA principles by becoming familiar with available methods and techniques, described in this review, for optimizing patient dose in CT examinations. We hope that readers can optimize CT dose while maintaining diagnostic examination quality.

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HOW TO

COMPARISON OF MODULATION TRANSFER FUNCTION MEASUREMENTS FOR ASSESSING THE PERFORMANCE OF IMAGING SYSTEMS.

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Abstract - **Modulation Transfer Function (MTF) is the basic tool widely used in assessing the performance of imaging systems. The most common imaging systems employed in MTF measurement include image capture devices and medical imaging systems. The various methods of MTF used in assessing the performance of these imaging systems have shown different outcomes. It is still not clear the exact method that should be adopted as a standard procedure in the measurement of MTF. In this review, we summarize, compare and identify research gaps on some works that have been done toward measurement of MTF. Cataloging these varieties of methods and outcomes may help simplify future investigations of MTF measurement as well as identify a standard procedure which should be followed in the measurement of MTF for imaging systems.**

Key words - Modulation Transfer Function, Nyquist frequency, Spatial frequency, Fourier transform.

I. INTRODUCTION

The Modulation Transfer Function (MTF) is a method commonly used to quantify the performance of most imaging systems. Images from capture devices such as camera-based systems, flat-bed scanners, drum scanner and medical imaging systems such as Computed Tomography (CT) scanners are commonly employed in MTF measurement. The performance of an imaging system is characterized by spatial resolution. Spatial resolution is how well an imaging system can differentiate small objects that are adjacent to one another. MTF is a common metric used in defining the spatial resolution characteristics of imaging systems [1].

The MTF of an imaging system can be measured directly or indirectly. Indirect measurement of MTF is obtained from either the spread function or the edge response function. Measurements taken from images of photographic emulsions are often degraded by noise and the data obtained from physical experiments contains errors. As a result, current measurement of MTFs either directly or indirectly requires some degree of smoothing to minimize these errors.

In the spatial domain, the spatial resolution of an imaging system is characterized by its point spread function (PSF). Theoretically, the PSF is the image of an infinitesimal point object that can be defined as a function in two-dimension. The MTF is then obtained from the PSF as the magnitude of its two-dimensional Fourier transform. In practice, one major limitation in determining the PSF is the difficulty to produce exactly the image of the infinitesimal point object. In order to reduce the difficulty associated with measuring the PSF, a slit was introduced to measure the Line Spread Function (LSF). The LSF is a one-dimensional representation of the two-dimensional PSF. The width of the slit must be sufficiently narrow so that the spread in the image slit does not entirely contribute to the blurring. The Fourier transform of the LSF is the MTF. Alternatively, measuring the MTF using the edge approach requires an object that transmits radiation on one side of an edge, but is perfectly attenuating on the other. The density profile from the image of the edge gives the Edge Spread Function (ESF). The derivative of the ESF is the LSF, the Fourier transform of which yields the MTF in one dimension [2].

Several methods have been proposed from previous works for measuring the MTF of optical systems based on detector arrays of charge-coupled devices. These methods differ mainly in the type of target or pattern used as object pattern [3]. These techniques have been classified into five categories; the sine-wave method, the bar-target method, the edge-gradient method, the series-expansion method and the random pattern method [4].

In this review, we have summarized, compared and identified some limitations of some previous works that have been done toward the measurement of MTF.

II. THE MEASUREMENT OF MODULATION TRANSFER FUNCTION WITH DIFFERENT TARGETS

Measurement of MTF from PSF in computed tomography is often performed by scanning a point source phantom such as a thin wire or a microbead. These methods are most widely utilized in current CT systems [5-12] as they are conceptual simplicity and relatively easy to implement. The method used in determining the PSF using the bead and the thin wire are described in the Catphan 600 phantom laboratory manual [13] and Kayugawa et al.[14] respectively. As indicated by Kayugawa et al., it is difficult to exactly determine PSF and MTF with high precision and accuracy because the image of the point source is blurred and degraded noise by the imaging system. There is a dependence of PSF on the region of interest (ROI) in the image of the point source. As a result, the MTF is largely affected by changing the ROI. Increasing the ROI in general tend to increase the MTF. However, this trend is not consistent as the MTF values produced can show random variation with some kennels as the ROI increases.

Measurements of PSF can be limited by the Nyquist frequency of the discretization in the acquisition system. In order to overcome this, the image of a knife or step edge is required. However, the image produced is usually a blurred step image and several ESFs have to be estimated along the length of the edge in order to reduce the blurredness. Each of the ESFs are then registered to a reference point (Fig. 1) and accumulated to form a super-resolution ESF that contain frequency information above the Nyquist limit of the sampling grid.

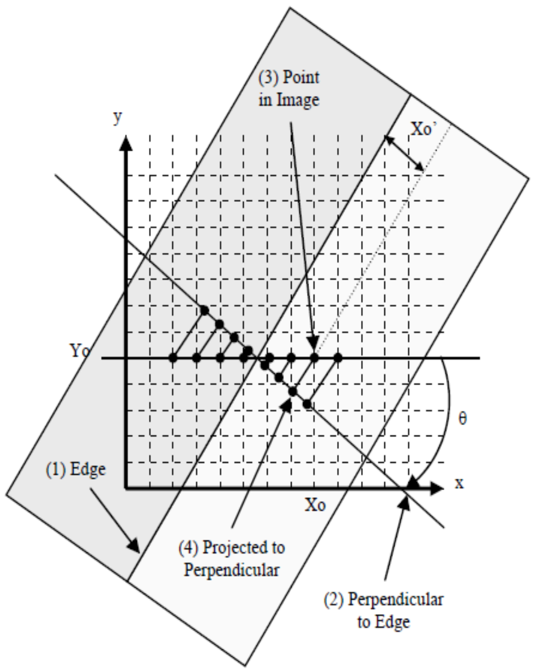

Figure 1: ESF registration onto a reference point

The PSF is more useful than the ESF for DFD measurement and image simulation as it can be directly convolved with an input image to estimate the output image [15,16,17]. In practice PSF information beyond the Nyquist limit of the array is often required, Reichenbach *et al* [18]. The PSF is obtained by differentiating the ESF. One difficulty in using a step edge image to estimate the PSF is that, any level of low noise in the ESF can result in high levels of noise in the PSF and render it unusable. The Fourier transform of the PSF is the Modulation Transfer Function (MTF), and both measures have been widely used to characterize the performance of imaging systems.

The most frequent way in determining the MTF using the edge method is by obtaining the ESF from the image of an opaque surface and differentiating the ESF to obtain the LSF. The differentiation has been done in different ways, each with its outcome[19-21]. For example, the differentiation has produced a non symmetric LSF curve with negative values. As result, the MTF values are significantly affected such that only values of MTF below 0.15 are shown to illustrate detail at high spatial frequencies [19-21]. Alternatively, some researchers have differentiated the ESF numerically without forcing their data to an assume model using the finite element technique. This technique has shown that, the resulting MTF (taking the Fourier Transform of the LSF) contains an error due to the spacing of the sampled data if the system is not sufficiently oversampled [22]. As a result, detail of MTF values would be under estimated or over estimated for sampling rates less than four times (x4) or greater than four times (x4) the Nyquist frequency.

Also, an alternative method under the edge method for measuring the MTF is the slanted edge method. This method which is well established in ISO 12233 [23] still presents some disadvantages, the most principal one being the long measurement time. The slanted edge method requires imaging an edge onto a detector, slightly tilted to the detector rows (or columns). Orienting the edge vertically produce a horizontal spatial frequency detector responds which gives different ESF due to different phases. This causes the ESF to be under sampled and therefore affects the MTF. Although it possible to increase the sampling frequency mathematically by projecting the data along the edge [24], ideally the orientation of the edge to the detector should produce an ESF above the Nyquist frequency.

The MTF of an imaging system has also been measured with a bar target. This approach is achieved by taking the image of a fabricated three-bar or four-bar binary pattern with equal width of lines and spaces. Each bar target is specified in terms of its fundamental frequency. The modulation depth of the image waveform is then measured as a function the fundamental frequency. This measurement has proven to introduce extra frequency components at both higher and lower frequencies than the fundamental frequency [25]. These frequency components can be removed by computation using the Fourier decomposition of the square waves [26]. However, the Fourier decomposition of the square waves are not strictly valid because the Fourier transform of the three-bar and four-bar target is a continuous function of frequency rather than discrete harmonic Fourier series.

Another approach which is used in the measurement of MTF is the sine-wave method. This method requires an exposed photographic emulsion with varying sinusoidal intensity distribution of known spatial frequency and modulation. The image of the sinusoidal emulsion is then scanned with a microdensitometer to give the effective exposure modulation. The MTF is then calculated as the ratio of the output effective exposure modulation, to the input exposure modulation at a given spatial frequency (Fig. 2).

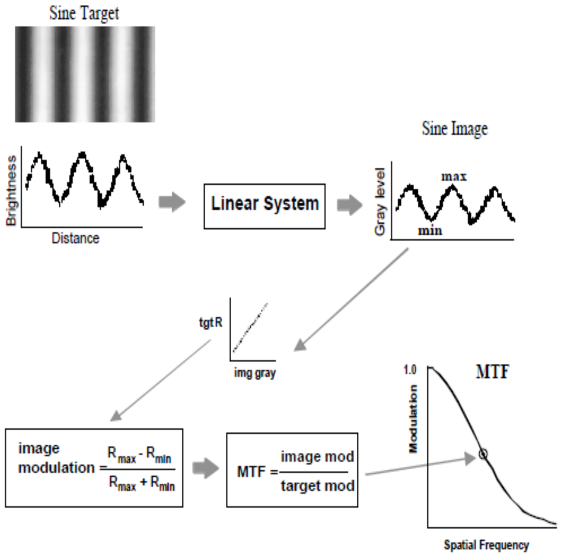

Figure 2: Generating the MTF curve from a sine wave target.

One major difficulty with this method is the production of targets with accuracy that are truly sinusoidal with known modulations [27]. This results in relatively low signal strength at high spatial frequency and poor overall optical efficiency.

III. Conclusion

MTF is the most widely acceptable way of verifying the performance of most imaging systems in terms of their spatial resolution and contrast. However, previous studies on MTF have shown that MTF can be ambiguous when used to characterize errors that can cause the MTF to deviate from its expected value. This variation in errors is due to the type of target or pattern used as object pattern. Hence for coherence MTF results on future research works, we proposed from this review a unique type of target or wave pattern specific to every imaging system as test objects. This would help produce consistent MTF results devoid of the method used as well as reduce the ambiguity towards the measurement of MTF. In addition, working equations should be developed for specific targets for future image evaluation methods to serve as correction factors for MTF measurement. The various techniques analyzed in this paper can help provide useful guidelines and expected outcomes for future research works in MTF measurement.

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BOOK REVIEW

FUNDMENTAL MATHEMATICS AND PHYSICS OF MEDICAL IMAGING A BRIEF OVERVIEW

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Abstract— **This article reviews Fundamental Mathematics and Physics of Medical Imaging by Jack Lancaster and Bruce Hasegawa.**

Series Editors: John G. Webster, E. Russell Ritenour, Slavik Tabakov, and Kwan-Hoong Ng

Fundamental Mathematics and Physics of Medical Imaging (Series in Medical Physics and Biomedical Engineering). CRC Press; Taylor & Francis Group, Boca Raton, FL, 2017. 346 pp. Price: $79.96. ISBN: 978-1-4987-5161-2 (hardcover).

Keywords— **Diagnostic Imaging, educational textbooks.**

I. INTRODUCTION

Fundamental Mathematics and Physics of Medical Imaging is a comprehensive outline of the underlying mathematics and physics concepts of radiologic imaging. The textbook provides a structured overview of the mechanisms of image formation and image quality and characterization, in 5 sections and 16 chapters. The book is a thorough re-write based off of the second and last edition of *The Physics of Medical X-Ray Imaging* which was penned by the late Bruce Hasegawa and printed in 1991 by Medical Physics Publishing. It provides engineers and medical physicists in-training with a review of some of the more detailed concepts in medical imaging to help deepen the reader's knowledge and understanding of topics such as contrast, spatial and temporal resolution, and noise. The book serves as a timely addition to the CRC Press *Series in Medical Physics and Biomedical Engineering*, all of whose editors and contributors are accomplished physicists and experts in their respective fields.

II. AUDIENCE

The This book is based on an advanced diagnostic imaging course that has been taught by the author at The Research Imaging Institute at The University of Texas Health Science Center in San Antonio for over 20 years. The course *'Physics of Diagnostic Imaging II'* is aimed at second year graduate students of diagnostic imaging and focuses on the theory and applications of various forms of electronic imaging systems and their analysis, image processing, and display.

While written with medical physics students and residents specifically in mind, this volume can also prove equally beneficial to researchers and clinicians in the imaging sciences who wish to integrate their work or research program into the field as is currently practiced. A basic understanding of physical concepts in imaging such as Bremsstrahlung or photoelectric and Compton interactions is assumed, as are the units, measurement, and principles of radiation protection and nuclear medicine imaging. Although the minimal coverage of background concepts limits the utility of the book to advanced undergraduate or beginning graduate students of medical physics at first glance, the stratifying of the topics into beginner, intermediate, and advanced level sections will enable many readers without the prerequisite training in basic imaging physics to be able to engage and comprehend its material well.

III. CONTENT AND FEATURES

The book begins by painting a broad view of basic imaging principles revolving around three central notions namely noise, contrast, and resolution. These are the pillars which the author then spends the subsequent chapters elucidating in detail how each is tied to performance measures such as Wiener Spectra, Signal-to-Noise ratio, Modulation Transfer Functions, and receiver operating characteristic (ROC) analysis. Topics pivotal to the digital era such as sampling requirements and detector technology are interspersed throughout the book.

The text then iterates these three concepts at a more detailed level using Fourier, Bessel, and Hankel transforms, convolution, and various spread functions and probability distributions. Homework problems and more specialized appendices appear at the end of each chapter with online answers. The Rose Model and derivation of Contrast-Detail curves are covered sufficiently well. Many of the problems in the book make use of a java based software package called *Mango*, free for download, which was developed by the author himself, and which provides analysis tools and a user interface to navigate image volumes. The software program comes with several plugins primarily applied to neuroimaging. [1]

The text then covers digital subtraction angiography (DSA) and temporal filtering in separate treatments using the three main concepts discussed in previous chapters, before delving into the final section of the book which examines CT, SPECT, and MRI independently.

IV. Assessment and comparison

This is a welcome text that many students and researchers should find useful as a follow-up to an upper level introductory physics or engineering course in medical imaging. It is detailed yet concise in its format, and has a lucid but efficient style to its writing. While the utility and clarity imparted therein is never in question, some of the figure diagrams, particularly those from the previous edition can use an upgrade in their presentation.

In short, this book is an indispensable reference for anyone who wishes to specialize in medical imaging physics beyond introductory levels or who intends to enter the field to gain a better understanding of the inner workings of contemporary imaging systems. No doubt, there is considerable need for a resource that is designed to provide additional perspective given the excelling and ongoing advancement of imaging physics in clinical settings.

Table 1 Contents

Section I	**Basic Concepts**
Chapter 1	Overview
Chapter 2	Medical Imaging technology and Terminology
Chapter 3	Digital Imaging in Diagnostic Radiology
Section II	**Intermediate Concepts**
Chapter 4	Physical Determinants of Contrast
Chapter 5	Mathematics for Linear Systems
Chapter 6	Spatial Resolution
Chapter 7	Random Processes
Chapter 8	Noise and Detective Quantum Efficiency
Section III	**Advanced Concepts**
Chapter 9	Noise-Resolution Model
Chapter 10	The Rose Model
Chapter 11	Receiver Operating Characteristic (ROC) Analysis
Section IV	**Dynamic Imaging**
Chapter 12	Digital Subtraction Angiography
Chapter 13	Temporal Filtering
Section V	**Tomographic Imaging**
Chapter 14	Computed Tomography
Chapter 15	**Single-Photon Emission Computed Tomography**
Chapter 16	**Magnetic Resonance Imaging**

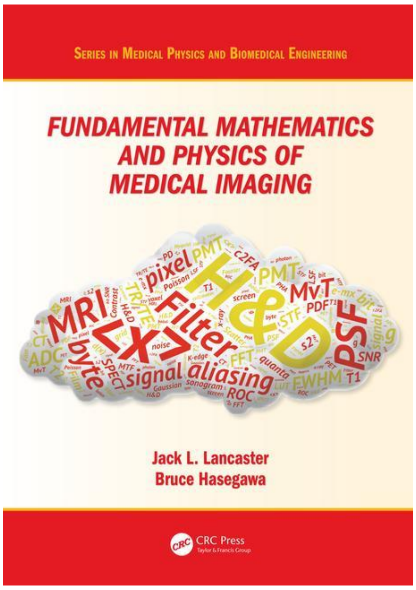

Fig. 1 Fundamental Mathematics and Physics of Medical Imaging

V. Conclusions

The purpose of this book principally is to provide the readers with a more thorough exposition of the mathematical foundations required for the formation of diagnostic images. The textbook will serve as a solid reference for biomedical engineering and medical physics trainees by going beyond the mere description of all ionizing radiation modalities, including MRI and nuclear medicine. The book aims to cover a range of material that is either not available in more introductory books on general medical imaging or is not emphasized well enough in scope or sufficient level of detail.

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"THE PHYSICS OF DIAGNOSTIC IMAGING" - A BRIEF OVERVIEW

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Abstract— **This article is a brief review of the textbook The Physics of Diagnostic Imaging, (2017 Revised Reprint of the 2006 Second Edition), David J. Dowsett, Patrick A. Kenny and R. Eugene Johnston, CRC Press, ISBN-13 978 0 340 80891 7**

The book by Dowsett, Kenny and Johnston is a well-known teaching aid for many young medical physicists. It is one of the best illustrated books on the subject, written very well, and thus allowing a smooth knowledge transfer.

The whole book is written with the aim to allow the reader to understand the basic concepts of Diagnostic Imaging – physical principles, equipment, image quality and radiation safety. The book has 22 chapters which lead the reader from basic mathematics and physics, to X-ray imaging principles and equipment, Nuclear Medicine principles and equipment, Ultrasound principles and equipment, MRI principles and equipment, Radiation protection principles. The book has 725 pages, which include an extended index with 32 pages.

Based on the fact that X-ray imaging continues to comprise more than 2/3 of all imaging procedures in healthcare, the main part of the book is dedicated to X-ray imaging principles and equipment (about half of it). This is one of the specific advantages of the book. The description of the other imaging modalities are relatively equally distributed in the remaining half of the book.

The book includes many illustrations – about 580 figures, some of which with two or more images. The figures are perfectly executed with many additional explanations, related to the subject. The quality of the printout of the diagrams and diagnostic images is excellent. The book also includes many tables with coefficients and useful data – about 230 tables in total.

A unique feature of the book are the Boxes with examples (e.g. calculating the total efficiency of a detector). There are about 115 Boxes with examples and they are excellent teaching aids.

Each chapter includes also a list of keywords with explanations, which are in fact a brief dictionary. Many chapters include also recommended further reading.

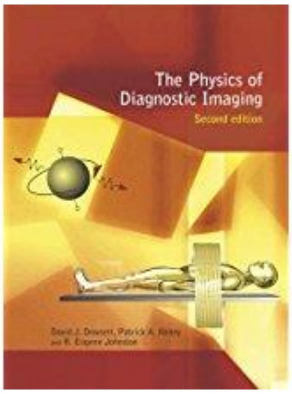
The chapters have many sub-chapters, thus transforming the book into an easy to navigate reference material. Sometimes sub-chapters finish with a Summary. All text in the book is very easy to read. One feels that each sentence has been carefully crafted. This will be useful to a very wide spectrum of readers – from radiology or radiography students to medical physics post-graduates.

The introductory chapters related to Basis of mathematics and physics will be very useful to readers in the medical profession. At the same time the physics of various imaging modalities (supported with relevant diagrams and equations) is suitable for young medical physicists. Again, the examples are making clear the explanations using real quantities – e.g. Box 16.5 "Relationship between matrix size and noise for three sizes of matrix" and Figure 16.7 (d) "Loss of visible contrast through the imaging chain from uses of different gamma values".

This is a typical teaching textbook, not for the advanced researcher, but for students and colleagues from different fields of the profession, who would like to quickly refresh part of their knowledge.

Medical physics is a very dynamic profession and obviously each author of a textbook is aware that the book will be soon be in need of upgrade. The current upgrade of The Physics of Diagnostic Imaging has been completed to a high standard – keeping all essential materials from the previous editions, as well as inserting new elements.

This book can easily be seen as essential textbook on the subject, which can be used by students in various countries. It is without doubt one of the best textbooks on Physics of Diagnostic Imaging.



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Abstract— **Paper abstract should not exceed 300 words. Detailed instructions for preparing the papers are available to guide the authors during the submission process. The official language is English.**

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I. INTRODUCTION

These are the instructions for preparing papers for the Medical Physics International Journal. English is the official language of the Journal. Read the instructions in this template paper carefully before proceeding with your paper.

II. DETAILED INSTRUCTIONS

Paper Size: A4

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Margins: The page margins to be set to: "mirror margins", top margin 4 cm, bottom margin 2,5 cm, inside margin 1.9 cm and outside margin 1.4 cm.

Page Layout: 2 columns layout.

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Fonts: Times New Roman with single line spacing throughout the paper.

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Indentation: 8 point after the title, 10 point after the authors' names and affiliations, 20 point between author's info and the beginning of the paper.

Abstract: Font - 9 point bold. Maximum length - 300 words.

Style: Use separate sections for introduction, materials and methods, results, discussion, conclusions, acknowledgments and references.

Headings: Enumerate Chapter Headings by Roman numbers (I., II., etc.). For Chapter Headings use ALL CAPS. First letter of Chapter Heading is font size 12, regular and other letters are font 8 regular style. Indents - 20 point before and 10 point after each Chapter Heading. *Subchapter Headings* are font 10, italic. Enumerate Subchapter Headings by capital letters (*A.*, *B.*, etc.). Indents - 15 point before and 7,5 point after each Subchapter Heading.

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Tables: Insert tables as close as possible to where they are mentioned in the text. If necessary, span them over both columns. Enumerate them consecutively using Arabic numbers and provide a caption for each table (e.g. Table 1, Table 2, ...). Use font 10 regular for Table caption, 1st letter, and font 8 regular for the rest of table caption and table legend. Place table captions and table legend above the table. Indents - 15 point before and 5 point after the captions.

Table 1 Font sizes and styles

Item	Font Size, pt	Font Style	Indent, points
Title	14	Bold	After: 8
Author	12	Regular	After: 10
Authors' info	9	Regular	After: 20
Abstract	9	Bold	
Keywords	9	Bold	
Chapters			
Heading - 1st letter	12	Regular	Before: 20
Heading - other letters	8	Regular	After: 10
Subchapter heading	10	Italic	Before: 15, After:7,5
Body text	10	Regular	First line left: 4mm
Acknowledgment	8	Regular	First line left: 4mm
References	8	Regular	First line left: 4mm
Author's address	8	Regular	
Tables			
Caption, 1st letter	10	Regular	Before: 15
Caption – other letters	8	Regular	After: 5
Legend	8	Regular	
Column titles	8	Regular	
Data	8	Regular	
Figures			
Caption - 1st letter	10	Regular	Before: 15
Caption – other letters	8	Regular	After: 5
Legend	8	Regular	

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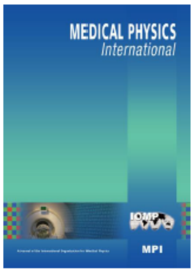

Fig. 1 Medical Physics International Journal

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$$A + B = C \qquad (1)$$

$$X = A \times e^{st} + 2lkt \qquad (2)$$

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- First item
- Second item

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ANNEX

Issue #

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The Abdus Salam International Centre for Theoretical Physics

Abstracts Booklet of the MMP Thesis

(3rd cycle)

Master of Advanced Studies in Medical Physics

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Third cycle
2016-2017

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Title:

Commissioning of a mHDR Brachytherapy System and Implementation of Transit Dose calculation.

Prospective/Objective: To commissioning a new Flexitron treatment delivery Brachytherapy system, implement the Transit dose calculations and validate the Advanced Collapsed cone Engine (ACE) dose calculation engine of Oncentra Brachy (OcB) treatment planning system using an 192I r source.

The Acceptance test are mandatory as part of the commissioning of a new ma-chine as recommended by the AAPM TG-43 and TG-186. The next challenge was to introduce transit dose calculation for to be confident if transit dose is significant in plans performed in female patients that are subjected to intracavitary technique. Accurate dose calculation is a crucial part of the treatment planning in Brachytherapy. Several reviews have put the attention on TPS with model-based algorithms that better take into account the effects of the patient individual distribution of tissues and applicator shielding attenuation, aspects that are not taken in account by TG-43 formalism which simply maps homogeneous water dose distributions onto the patient.

Materials and methods. Following the guidelines (AAPM TG-43, TG-56, TG-59, TG-41, TG-186 and ESTRO booklet 8) commissioning was performed for Flexitron Brachytherapy system and Oncentra brachy TPS V4.5. Wall ionization chamber, portables dosimeters, virtual water phantom, set of applicators (for calibration and treatment) were used during commissioning. The new test was implemented for the measures of tip applicator distance. Transit dose was calculated, thanks to the software developed in MatLab that permits to calculate dynamic doses in a faster way, and measured with calibrated Gafchromic films. Transit dose was evaluated also for another brachytherapy machine, Nucletron Microselectron. As for the commissioning of the ACE algorithm, we adapted the process recommended by TG-186.

Results. The periodic tests of radioprotection and emergency procedure were performed success-fully and in good agreement with the manufacturer; measurements of ambient dosimetry are in agreement with Italian radioprotection law. Source positioning is within §0.5mm from the expected position. The maximum efficiency collecting point of wall ionization chamber was found at 1135 mm and the measure of air kerma strength within 0.4% respect to the value of source certificate. The linearity of the timer is reproducible and error is less than §0.01%. Tip applicator distance was evaluated respect to declared values for vaginal and fletcher applicators with

Gafchromic films (agreement better than 4.2%) and with Oncentra TPS (perfect agreement for fletcher applicator and with a difference of 7.1% for vaginal one). For transit dose, Gafchromic films were calibrated between 20cGy and 180cGy. Considering a source of 10Ci activity (that is a typical value of new sources), the transit dose in contact with the applicator for single fraction calculated with MatLab for Flexitron is 7.2cGy, with an agreement of 4% with the measured one. Applying the same conditions, for MicroSelectron the calculated transit dose is 7.9cGy with an agreement of 8%. Transit dose depends linearly with activity source and number of fractions, and increase with the number of catheters. As for ACE validation, the comparison with a TG-43 formalism for gynecological treatments doesn't show a significant difference in terms of doses received by 90% of PTV and by 2cc of OAR (bladder, bowel, rectum). For vaginal cases, the maximum difference is for bowel (3.2%) and for Fletcher case is for bladder (2.3%). In particular, the median of relative percentage difference for the vaginal case is smaller than 1%, and for Fletcher cases smaller than 2%. DVH analysis confirms the same trend.

Conclusion. The acceptance test shows that the status of the machine and its components are functioning well and the machine is ready for to be used in clinical practice. In order to enhance safety and reliability of high dose rate brachytherapy, above all for specific anatomical sites, dynamic dose calculations should be integrated into all high dose rate TPS and not be assumed negligible. For gynecological treatments, ACE doesn't seem to add a significant improvement respect to TG-43 formalism. Some limitations were found in ACE since the user cannot modify the CT to density table; the user can only choose the method used by TPS to define electron mass density: uniformity density, that uses tabulated value in TG-186, or HU-based, that uses HU values according to the paper of KNÖÖS [19].

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Title:

Validation of the ArcCheck diode array for the patient specific Quality Assurance in Stereotactic Body Radiotherapy Treatment (SBRT) delivered with VMAT

Prospective/Objective:
Employment of cylindrical diode array for patient specific Quality Assurance (QA) in small fields used for Stereotactic Body Radiotherapy Treatment (SBRT) is still not clearly well stated and remain debatable. This is due to the dose map collected represents the projections of the 3D dose distribution on the target away from the isocentre. The cylindrical array detectors also have sparse low spatial resolution. The aim of this study was to evaluate the accuracy of the measured dose distribution by ArcCheck diode array (Sun Nuclear) in SBRT that demands extraordinary attention to Quality Assurance (QA) issues related to the high geometric and dosimetric accuracy.

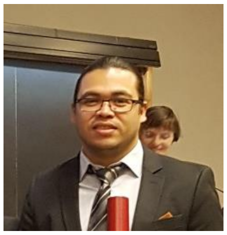
Materials and methods. SBRT on 12 virtual spherical tumors of different radii ranging from 4mm to 15mm with an increment of 1mm on ArcCheck phantom were generated with volumetric modulated arc therapy (VMAT) and flattening filter free (FFF) with RayStation 5v5.01 (Raysearch) Treatment Planning System. All plans were delivered through Varian Trilogy TX Linac (6MV) on ArcCheck phantom consisting of a cylindrical array of diode detectors with MultiPlugTM homogeneous RW3 cylinder with a Gafchromic EBT3 film inserted in a coronal plane at the isocenter. The measurements were done for both standard (Sm) and high density (HDm) ArcCheck mode that creates a high-density measurement through double measurements using the shift markers on the ArcCheck phantom. Films were scanned using an EPSON 10000 XL flatbed scanner using a tool of MapCheck (Sun Nuclear) to convert the gray-level of the film to planar dose. Analysis of ArcCheck and films measurement was performed through local gamma index analysis, (%PASS) percentage of evaluated measurements points passing criteria of dose difference (D%) and the distance to agreement in mm (DTA).

We studied the passing rates in ArcCheck Sm, in HDm, in film and the dependence of the passing rates (%PASS) with the relevant parameters such as DTA and D% criteria used for QA and on the target volumes.

Results. The agreement between the calculated dose with the one measured by the EBT3 film with the ICRU point for each target at isocenter was optimal with a dosimetric uncertainty below the 3%, considering that the uncertainty budget of dose determination for EBT3 film is close to3%. The major influencing factor affecting the passing rate of the Gafchromic film is observed to be the DTA. A %PASS > 75% on whole film appeared as a predictor of a 90% passing rate in the target and peripheral region generally for the DTA:1mm and D% >3 criteria. The mean value of %PASS in HDm was slightly lower than in Sm. The difference between Sm and HDm tested was significant, but not clinically relevant. In Sm ArcCheck, DTA was the main prognostic factor for passing rate as expected for the high gradient SBRT dose distribution delivered at the isocenter. Although statistically significant, the correlation with the sphere volumes was weak. In the ArcCheck in Sm, similar passing rate (same sensitivity) could be obtained with different gamma criteria combinations. The standard criteria of gamma (DTA: 2mm, D%: 2) had passing rates similar to the gamma (DTA: 1mm, D%: 4). ArcCheck Sm passing rates were well correlated with the radiochromic film passing rates. The optimal level of agreement was found between the ArcCheck gamma (DTA: 1mm, D%:4) criteria and film gamma (DTA:1mm, D%:3) criteria. ArcCheck passing rates were biased by a small overestimation (about 3%, clinically negligible) and a level of agreement contained in 5%

Conclusion. These results showed optimal agreement and high accuracy level for the whole end to end test performed with the ArcCheck phantom and that ArcCheck Sun Nuclear phantom with measurements in standard mode can be an adequate verification system for small fields in SBRT.

In SBRT where the geometric uncertainty is the major concern the criteria DTA 1 mm and D% 4 with a passing rates superior to 75% (threshold 20%) in ArcCheck can be more favorable to assess patient specific QA. Above this limit (action level), 90% of points in the target and in the dose falloff region met the DTA=1mm requirement on the Gafchromic EBT3.



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Title:
Angular dependency correction of a 3D dosimetry system for verification of Cyberknife® treatments

Prospective/Objective: Modern technologies applied in clinical practice such as volumetric modulated Arc Therapy (VMAT), Intensity-Modulated Radiation Therapy (IMRT), Stereotactic Radiosurgery (SRS) and Stereotactic Body Radiation Therapy (SBRT) have the necessity to present an accurate delivery of dose, for this multiple ways for planning verification are applied nowadays result of which depends of the delivery complexity and machine used.

Different commercial 3D dosimetry systems are available for conventional flattened and flattened filter free (FFF) linacs, such as ArcCHECK®, Octavius 4D, Delta^4, however the appropriateness of these systems is to be assessed for unconventional linacs e.g. Cyberknife® systems.
In Cyberknife® plan delivery, the treatment verification becomes more complex due to the inclusion of multiple entrances of non-coplanar beams and the steep gradients. Thus the performance of patient specific quality assurance (QA) systems developed for IMRT/VMAT treatments needs to be fully understood using.

The 3D dosimetry system Delta^4 (ScandiDos) is factory calibrated using a conventional Linac and provided with an internal data base of correction coefficients depending on the irradiation geometry. For plan verification the Delta^4 software learns the plan irradiation geometry from a DICOM file (RTplan) provided by the Treatment Planning System (TPS). In Cyberknife treatments the beam geometry is potentially very different from conventional linac treatments and at the moment the dedicated TPS (Multiplan®) does not output an RTplan DICOM file readable by the Delta^4 system. The aim of this work is to provide means to fill this communication gap and to evaluate and characterize the Delta^4 dosimetry system for verification of Cyberknife® treatment delivery with particular care in the study of the angular response using multiple tests (irradiation setups) and a homemade MatLab code.

Materials and methods. Plans corresponding to reference beam directions made on Multiplan® using the largest fixed collimator and delivered on a Cyberknife® M6™ Series system, were selected to be verified on a the 3D system Delta^4 (ScandiDos) which consists of diode matrices in two orthogonal planes inserted in a cylindrical PMMA or Plastic Water phantom material that is 22 cm in diameter and 40 cm longitude, has 1069 p-Si detectors with distance in the central area (6x6 cm^2) each 5 mm and in the outer area each 10 mm. Comparisons were performed between measured and calculated (given by the TPS) sagittal and coronal planar doses for each of the available beam directions of a SBRT treatment and maximal collimator size. A MatLab homemade code was used to extract the planar dose data from the planned distribution (taken as gold standard).

Results. A set of matrices of correction coefficients to be applied in the verification of a clinical plan was obtained. In the comparison between the calculated and measured dose of the clinical plan, performed in the sagittal and coronal detector planes, 71.8% of the irradiated diodes in the sagittal and coronal detector planes were within the 2% of Dose Difference (DD) when no correction is applied. Using the correction matrix this percentage raises to 83.1%.

Conclusion.
The results obtained confirm the need to improve the performance of the Delta^4 system in the verification/evaluation of treatments performed with a Cyberknife® through the use of special correction matrices. With this correction in a treatment plan of low complexity (less than 30 nodes and only one collimator size) we have an almost 12% increase in the percentage of measurement where the agreement between calculated and measured dose is better than 2%.
In addition, the performance of the measurements shows an evident necessity of the inclusion of internal and/or external fiducial markers on the Delta^4 phantom to avoid misalignment and unnecessary automatic positioning "corrections" performed by the Cyberknife® robot.

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Title:

Verification of the physics model of the treatment planning system Pinnacle3 through Monte Carlo simulations.

Prospective/Objective: The main purpose of the present work was to verify the physical model in Pinnacle3 (TPS) in general and when a new treatment planning technique is implemented, by means of Monte Carlo (MC) simulations of a 6 MV photon beam, with the DOSXYZnrc and EGS_chamber codes. For example, we wanted to verify the use of one isocenter in the 3DCRT for the treatment planning of breast and Supraclavicular (SC).

Materials and methods. Monte Carlo simulations of a 6 MV photon beam were performed by using EGSnrc MC codes. BEAMnrc code (1) was used to model an Elekta Synergy linear accelerator: the input file consisted of 8 component modules (CM), from the source to the lower diaphragms. The benchmark of the accelerator was done previously. The DOSXYZnrc code (2) was used to simulate percentage depth doses (PDD) and profiles (Off Axis Ratio) in a cubic water phantom. The MC data are then normalized and compared to the ones calculated with Pinnacle3 TPS. The egs_chamber code (3) was used to simulate profiles obtained with a semiflex ion chamber, to compare with measurements. In particular, in the first stage, PDD and profiles of symmetric fields were simulated with DOSXYZnrc for several field sizes: 5cm x 5cm, 10cm x 10cm, 20cm x 20cm and 40cm x 40cm. In the second stage, asymmetric fields were also simulated: hemi fields from 0 to 2.5cm in X direction, for the 5cm x 5cm, and from 0 to 5cm for the 10cm x 10cm field etc. The largest fields were considered of interest because they are used clinically in the case of 3DCRT planning for breast with supraclavicular involvement

Results. Profiles of symmetric fields were analyzed and compared with the ones obtained from Pinnacle3 TPS. The uncertainties of MC simulations were less than 1% in the central field area and less than 2% in the penumbra region, the profiles of the two sets coincide within that uncertainty. In the second stage of this work, asymmetric profiles for the same set of field sizes were simulated. As shown in fig. 2, the profiles of simulated hemi-fields are in agreement with the ones obtained from TPS within the mentioned range of uncertainty for MC simulation.

Conclusion. When new planning technique is being used it is of importance and responsibility of the medical physicist to analyze how that technique is appropriate to the physics model provided by the TPS, since the model is always a compromise between measured data for different beam setups and beam sizes.

In this work, beam data for the simulated linac, were compared to the ones from the TPS. Profiles related to clinical treatment planning technique 3DCRT breast+SC with one isocenter was simulated and analyzed. The shape of the profile of hemifields reflects the observed worsening at the border of the field in the longitudinal direction (Y), with a loss of dose coverage in treatment planning when a one isocenter technique is used compared to the two isocenters planning technique.

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Title:

Characterization of density model of the CT part of GE Discovery 710 PET/CT scanner using Gammex 467 phantom for MultiPlan Treatment Planning used in Cyberknife system

Prospective/Objective: It is estimated that there is about 30% error is prescription dose due to not correcting for tissue inhomogeneity. The use of prostheses and other life saving devices in the body is beneficial to patients but inability to correct for inhomogeneity in densities of these material could account for in treatment planning process, big errors could result in a mistreatment or even death.

The purpose of the work is to characterize the density model of of the CT part of the PET/CT using Gammex 467 phantom to be used in MultiPlan Treatment system used in CyberKnife System.

Materials and methods. Gammex 467 phantom with 16 different material inserts was scanned using GE Discovery 710 PET/CZ scanner using body protocol at 120 kVp. A second scanner was performed after replacing one insert with Titanium insert. The images were downloaded and analyzed with ImageJ software. Regions of Interest (ROIs) were drawn on the central position of the different material inserts of the axial images and mean CT numbers and their standard deviation were estimated/determined. The mean CT numbers were plotted against the relative electron density and mass density of the insert materials are provided by the Gammex manufacturer. Linear interpolation was done between the highest CT numbers from the scan without Titanium insert and the CT number of Titanium. The maximum permissible relative electron density and mass density and their corresponding CT numbers were fitted into the curve. The resulting CT numbers and the relative electron densities and mass density were then entered into the Treatment Planning System.

Result.
The mean CT numbers determined ranged from 330±46 HU to 2180±28 HU for the lung 300 to the Cortical bone inserts and a value of 4050±120 HU for the Titanium insert. A linear interpolation links
Two curves are plotted for CT number /mass density and CT number/ relative density model.
The mass density model represents materials of mass densities from 0.31 to 1.823 and their corresponding CT numbers from 330 to 2180. The linear interpolation shows the link between the cortical bone with density of 1.823 and mass density of Titanium which is 4.59 and corresponding CT number of 4050.
The TPS allows maximum mass density of 2.65 g/cm^3 which corresponds to CT number of 2737.
If density model characterization is not performed with Titanium insert and a patient with metallic prostheses is scanned for planning, the TPS assign cortical bone density as the limit even if the

prostheses is of higher mass density.

If a tissue characterization is however performed of Gammex 467 with Titanium insert and modelled in to the TPS, the system forced to assigned a higher mass density limit of 2.65 to any prosthetic material of CT number equal or higher than 2737.Meaning that with Titanium prosthesis the TPS will assign a limit mass density of 2.65.

The electron density model represents materials of relative electron densities from 0.304 to 1.695 and their corresponding CT numbers from 330 to 2180. The linear interpolation between the cortical bone with density of 1.695 and electron density of Titanium, which is 3.79 and corresponding, Titanium CT number of 4050.

Conclusion

For accurate dose calculations, it is necessary to provide a correct relationship between the CT numbers and mass and electron densities in radiotherapy treatment planning systems (TPSs). The PET/CT is now used in Radiotherapy treatment planning in many centres hence there is a need to characterize their density models to deliver accurate doses with maximum curative effects to the target minimizing harm to normal surrounding tissues.

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Title:

Quantification of Transit Time of High Dose Rate Brachytherapy 192Ir Stepping Source-Transit Dosimetry

Prospective/Objective: To quantify the interdwell transit time of HDR brachytherapy treatment unit and to gain insights into the accuracy of brachytherapy treatment and the quality controls

Materials and methods. Transit time was determined from a linear regression analysis of measured charge as a function of dwell time. In this investigation a Dosimetry Systems comprising of a PTW Well-type ionization chamber model 077094 and electrometer PTW UNIDOS Webline model T10021was used to measure charge generated during source dwelling to pre-programmed position and during transit. The brachytherapy machine used was a Nucletron microselectron-HDR v3.

Results. The average transit time was found to be 0.90 and 0.94, seconds respectively by linear regression analysis and multiple exposure method. The average standard deviations were 0.01 seconds and 0.03 seconds respectively. The average speed of the source was found to be 41cm/second, while the average time for source to travel 1cm was found to be 0.02 second.

Conclusion. This was investigative study to quantify the transit time of HDR Brachytherapy unit. It showed good agreement of calculated interdwell transit time between the two methods. It highlights the importance of quality control as a tool to check against transit dose to patients. This procedure has the potential to be utilized for routine quality assurance and
Quality control check of the interdwell position transit time of any remote after-loading HDR brachytherapy source and during commissioning.

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Title:

Radiochromic Film Dosimetry for Output Factors in Intraoperative Radiotherapy

Prospective/Objective: The present work aims at investigating the output factors of Mobetron 2000, a dedicated mobile LINAC for IORT used in CRO hospital, with radiochromic films, because of their weak energy dependence and high spatial resolution. Then the history and properties of the dosimeter chosen to characterize the electron energy of this machine, radiochromic films, are described. The output factors measured with gafchromic EBT3 are compared with values obtained with stereotactic field diode at the time of commissioning of the machine. The second aim of the work was to determine if the presence of tissue heterogeneities such as bone can influence measured doses in vivo. For this purpose, measurements in water with radiochromic films in presence of an insert of density equivalent to that of cortical bone were performed.

Materials and methods. For calibration of Gafchromic EBT3 films, these were irradiated with electron beam of 6, 9, and 12 MeV, the same beam qualities of the Mobetron 2000, delivered by a 2100C/D Varian conventional LINAC. The films were scanned using a flatbed document scanner in RGB mode. The calibration curves for each energy were obtained by fitting a polynomial equation as described by Devic et al dosimetry protocol. The output factors were measured with EBT3 at depth of maximum dose on the clinical axis, for applicators of different sizes, with 0°, 15° and 30° angles and normalized to 10 cm diameter 0° beveled applicator. The results were compared with those obtained with stereotactic field diode and Advanced Markus ion chamber that were performed at the time of commissioning of Mobetron 2000 unit.
Additionally, a dose measurement was also performed in water with EBT3 attached to a small cylindrical phantom of density equivalent to the density of cortical bone in order to assess if the presence of bony structure (in case of soft tissue sarcoma of extremities) influences the measured in vivo dose.

Results and Conclusion. The output factors measured with Advanced Markus plane parallel chamber were equivalent to Gafchromic EBT3 films for 0° beveled applicators. Significant difference resulted in the output factors in some cases (up to 6%) as measured by EBT3 films when compared to stereotactic diode results. Thus, for output factor measurements for Mobetron 2000, radiochromic films can be considered as the reference detector because of the negligible thickness, high spatial resolution, and low energy dependence of response. Moreover, the study showed that the presence of bones in the irradiated region in IORT can increase dose readings in vivo, e.g. for treatments of extremities, up to

3.7% increase in output factor was resulted when measurement was performed with a phantom material having density equivalent to that of cortical bone.

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Title:

Verification of the Implementation of Enhanced Dynamic Wedge in the Treatment Planning System Eclipse before use in clinic.

Prospective/Objective: The objective of the study is to verify the implementation of the Enhanced Dynamic Wedge (EDW) before the use in clinical operation in the Treatment Planning System Eclipse model 13.6 of the Varian Company.

Materials and methods. This was done by comparing the dose calculated by the TPS and the measurement according to the TRS-430. Dose was calculated with the AAA (Anisotropic Analytical Algorithm). The Linac used was the model 2100 CD of the Varian. PDD, absolute dose and Dose distribution along the field was measured. All the measurement was simulated with the TPS and same setup was established for both. Absolute dose was measured using the FC65G and the A14SL Ionization Chamber (IC) with a collective volume of 0.6 〖cm〗^3 (more than 4×4 cm2) and 0.009 cm3 (less than 3×3 cm2) for all possible setup that can be met during a radiotherapy treatment: square, rectangular, off-axis field with Y1-in and Y2-out with different wedge angle. Absolute Dose difference was calculated by [|(measured-calculated/measured)×100|] , and was evaluated with a dose difference (DD) of 2%. For small field an attempt with Gafchromic film was done to measure the absolute dose, film was scanned with the Epson flatbed scanner, conversion optical density to dose was done with Mathlab. Dose distribution along the field was checked using the Delta4 phantom manufactured by Scandidos and was evaluated using 2% DD, DTA of 2 mm (Distance To Agreement), and also gamma analysis was used to analyze the whole distribution: 2% DD and DTA of 2 mm. PDD was measured with the IC model CC13 with a collective volume of 0.13 cm3 with a step of 2 mm from the surface to 2 cm depth and beyond dmax with a step of 5 cm till 30 cm depth and was also evaluated with a DTA of 2 mm in the buildup region to have better resolution and with DTA of 2 mm and 2% DD beyond the buildup region.

Results. Absolute dosimetry with Gafchromic associates a discrepancy of 5%. Absolute dosimetry with IC was all less than 2%. For the PDD measurement the criteria was all met (2mm DTA in the buildup region, 2% DD and 2mm DTA beyond the buildup region). All dose distribution along the field satisfies the criteria (2 mm DTA in gradient region, 2% DD in the flat region of the field). For PDD and dose distribution, a disagreement for DD in the gradient region was found.

Conclusion.
Good agreement with the measured and calculated dose was obtained. TPS models the EDW with good accuracy. 3D conformal radiotherapy with EDW is very fast

to plan and could be a good solution for a busy radiotherapy clinic. The EDW in this linac satisfy the dosimetry criteria and can be used in the clinical routine.

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Title:

IMRT and VMAT patient's pre-treatment quality assurance using Electronic Portal Imaging Device (EPID) dosimetry

Prospective/Objective: Pre-treatment verification can discover the possible difference between the planned dose and the actual delivered dose. To evaluate the influence of the differences between planned and delivered photon beams, a 3D dose verification method has been developed that reconstructs the dose inside a phantom. The pre-treatment procedure is based on portal dose images measured with an EPID. The converted EPID dose distribution can be compared to dose calculation from the Treatment Planning System (TPS). A Quality Assurance (QA) program for IMRT and VMAT verification with an electronic portal imaging device, has been doing for 5 years (2013-2017).The goal of the present work is to discover a potential relationship between pre-treatment verification results and different irradiation parameters in order to understand whether the plan complexity can influence the QA outcome. As an additional investigation, QA tests ability to find out possible delivery error was studied, by introducing voluntary modification in the total monitor unit number.

Materials and methods. A total of 1147 VMAT and 520 IMRT cases (including prostate, head and neck, breast, brain, lung, pelvis, mediastinum) were enrolled on a pre-treatment verification using EPID. For VMAT plans 711 patients were treated with energy 6MV and 436 patients with 10MV. For IMRT plans 310 patients were treated with 6MV and 210 patients with 10MV. All plans were optimized and calculated with Monaco version (5.11.0.1) and Oncentra version (4.3) treatment planning systems respectively for the two techniques.
Patient's QA plans were calculated too and the Elekta EPID iViewGT were used to verify the dose and the measurements were performed with two Elekta linear accelerators Synergy and Synergy S equipped with multileaf collimators. In order to compare the measured dose and the computed dose, the EPIDose software with gamma evaluation analysis (3%-3mm) was used.

Results. Over 1147 VMAT analyzed patients' plans the average passing rates were 97.23% ± 3.61% and 95.25% ± 3.75% for 6MV and 10MV respectively and over 520 IMRT analyzed patients' plans average passing rates were 99.04% ± 2.05% and 97,07% ± 2.81% for 6MV and 10MV respectively.

The results showed that the average passing rates of the points pass the gamma criteria for both VMAT and IMRT.
The relationship between passing rate and the other variables was investigated but no correlations were found
A simulated error was also done to see how EPID is a useful tool for detection of errors during pre-treatment verification. And the

results of this simulating showed a difference between the passing rate (95.3%) of the original plan to the passing rate (63.1%) of the plan where an under dosage was observed with gamma criterion of 3%-3mm.

Conclusion. The use of EPID is adequate for pre-treatment verification technique. The benefit of using the EPID is to its potential for high accuracy, large active area, and high resolution to intercept clinically relevant dosimetric errors prior to the beginning of treatments.

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Title:

Radiation Therapy Techniques and Treatment Planning for Breast Cancer.

Prospective/Objective: The treatment of breast cancer involves a multi-disciplinary approach with radiation therapy playing a key role. Along the years different techniques were used beginning with conventional 2D radiation therapy techniques to 3D radiation therapy (3DCRT) and more precise yet expensive, Intensity modulated radiation therapy (IMRT) and the newest technique VMAT (volumetric radiation therapy). The aim of this study is to determine and compare the dosimetric parameters of PTV and organs at risk for the breast irradiation among the three planning techniques 3DCRT, IMRT and VMAT.

Materials and methods. Two right and two left-sided breast cancer patients were selected; we divided all patients into two categories: Group-I (patient-1, -2) breast only and Group- II (patient-3, -4) breast and supraclavicular area. Dose prescription was 50 Gy to the PTV, 25 fractions of 2Gy in each fraction. The virtual simulation images of these patients were used to generate 3DCRT, IMRT and VMAT plans by Varian Eclipse (V. 10.0.34). Dose volume histograms were generated for 3DCRT, IMRT, and VMAT plans and various dosimetric parameters such as Dmax, Dmean, Dmin, D2%, D98%, V95%, V107%, Conformity Index (CI), Homogeneity Index (HI) and Uniformity Index (UI) for the PTV and dose to ipsilateral lung, contralateral lung, heart, contralateral breast and also body were calculated. The patient quality assurance for IMRT and VMAT plans performed by gamma analysis. The 3mm DTA & 3% and 2mm DTA & 2% dose difference of the global Gamma Index ($\gamma \leq 1$) were used for the analysis.

Results. The CI, HI and UI were significantly better for IMRT and VMAT compared to 3DCRT and also there was minor difference between IMRT and VMAT for both groups. The Dmin was higher for VMAT than IMRT and 3DCRT for both groups. The V95% and V107% as well as for D2%, D98% were better of IMRT techniques than 3DCRT and VMAT plans for both groups. The maximum and mean lungs and heart dose were higher with VMAT and IMRT compared to 3DCRT for both groups. The volume of ipsilateral lung and heart receiving 5 Gy and 10 Gy were higher for VMAT for both groups. The mean dose to contra lateral breast, lungs and body were similar for IMRT and 3DCRT, but higher with VMAT. For global gamma analysis, the gamma passing rate (%GP) in the criteria of 3%/3 mm exhibited above 95% but the 2%/2 mm exhibited above 91% for IMRT and VMAT plans of both groups.

Conclusion. Newer modalities of breast irradiation such as IMRT and VMAT appear to provide better dose coverage, conformity, homogeneity and uniformity to complex PTV. 3DCRT showed dosimetric benefit in standard breast cancer, IMRT & VMAT combined the advantages of good target coverage and homogeneity, reduction of high-dose volumes in organ at risk and a modestly higher dose to adjacent healthy tissues. In future, the breath hold technique should also be considered because of the significant reduction in radiation dose to the heart compared with free breathing technique for left breast radiotherapy.

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Title:

Evaluation of EPIDose^{TM} and Dosimetry Check^{TM} for EPID based dosimetry

Prospective/Objective: To optimize the EPIDose™ parameters to improve the accuracy of dose reconstruction with this software as a RapidArc pre-treatment quality assurance tool. To evaluate the versatility of Dosimetry Check™ as a pre-treatment quality assurance tool, and as an in-vivo tool for RapidArc^{TM} plans. And to verify the EPID response stability as well as its mechanical alignment to ensure the robustness of these quality assurance methodologies.

Materials and methods. The PortalVision aS500 EPID, attached to a Varian Clinac DHX linear accelerator, was used for EPIDose^{TM} optimization and Dosimetry Check^{TM} evaluation. The effect of image calibration and change in dose rate in the EPID response was analyzed. The EPIDose^{TM} physics model was optimized by searching the best fit between the treatment planning system calculations to EPIDose^{TM} calculations while varying the redistribution kernel and the Dose/EPID Ratio MLC Transmission parameter.

Dosimetry Check^{TM} was evaluated in-air and in-transit mode. Open and modulated arc fields were tested in a homogeneous phantom and in the patient's CT scans. In the homogeneous phantom, additional tests with the gantry reset to 0° were performed to compare the results to those obtained with EPIDose^{TM}.

Results. EPID image calibration changed the CAX response; increasing 0.6\% after DF and FF calibration, and decreasing 0.5\% for a change in the dose rate. The EPID shifts in the lateral and longitudinal directions were smaller than 3~mm. The optimized EPIDose^{TM} physics model planar doses are in well agreement to TPS calculations, with an average two dimensional gamma passing rate of 97.0% +/- 1.8% for twelve plans analyzed. Dosimetry Check^{TM} in-air and in-transit with the homogeneous phantom overestimates the dose around 2%, compared to treatment planning system calculations. Dosimetry Check^{TM} in-transit mode produced dose differences in head and neck cases up to 15%, while in rectum and metastasis cases up to 10%, which is reflected in the decreasing and spreading of the gamma passing rates as compared to the pre-treatment case.

Conclusion. EPID image calibration changed the CAX response; increasing 0.6\% after DF and FF calibration, and decreasing 0.5% for a change in the dose rate. The EPID shifts in the lateral and longitudinal directions were smaller than 3~mm. The optimized EPIDose^{TM} physics model planar doses are in well agreement to TPS calculations, with an average two dimensional gamma passing rate of 97.0% +/- 1.8% for twelve plans analyzed.

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Title:

Two dimensional ionization chamber array: characterization and clinical applications

Prospective/Objective: Ionization chamber array is nowadays the standard tool for pre-treatment verification of radiation therapy complex planning (VMAT). It is therefore imperative to characterize such systems. The aim of this work is to evaluate the response of the PTW 2D Array seven29 detector in terms of reproducibility, linearity, percentage depth dose, output factor and directional dependence for photon beams.

Materials and methods. The PTW 2D Array seven29 consists of a matrix of 729 cubic vented ionization chambers with 0.5 cm × 0.5 cm cross section, spaced 1 cm center-to-center, giving a total area of 27 cm× 27 cm. Pinpoint ionization chamber (model 31016) was used, and also the RW3 slab designed for high energy radiation therapy dosimetry. For direction (angular) dependence, Elekta Monaco (version 5.11) treatment planning system was used, which is a Monte Carlo-based treatment planning system. The statistical analysis throughout this thesis was done with PTW Verisoft software (version 6.1) and Excel 2007 in order to evaluate all the results. The measurements were done with Elekta Synergy linear accelerator. All the readings for PTW 2D array were taken according to the central axis (CAX) ionization chamber. The fields size used are between (2x2 cm^2 until 25x25 cm^2) with different monitor units (2 to 500 MU), and different energy photon beams (4 MV and 6 MV) depends on what every measurement needs.

Results. The reproducibility of the measurements in 10x10 cm^2 within each batch is good with a value of the standard deviation of the mean not exceeding 0.2%. The PTW 2D Array shows a perfect linear dependency to the monitor units delivered in the range 2 - 500 MU, with $R^2=1$. We determined the effective point of measurement (EPM) by comparison between percentage depth dose curves on the CAX of PTW 2D Array with PinPoint ionization chamber, we found that PTW 2D array adjusts at 8 mm comparing with EPM of PinPoint (5 mm) as a reference, which give us a difference of 3 mm. The output factor results to a good agreement between our two devices with maximum deviation of 1%. For directional response evaluation the difference between the measured and calculated dose within the 2D Array was calculated, and the difference between the total dose given to the central detector and expected was 1.2% when the 2D Array was scanned in the OCTAVIUS phantom (Air), and was 0.9% when the ionization chambers are considered as filled by water, by forcing the electron density to 1 (Dens).

Conclusion. PTW 2D Array seven29 is a very reliable, accurate, fast and precise tool for pre-treatment verification of radiation therapy complex planning (VMAT).

It’s a useful device for QA and patient specific pre-treatment radiotherapy plan verification in clinical settings.

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Title:

Out of field dose in radiation therapy planning: evaluation and measurements in clinical cases

Prospective/Objective: New radiation therapy techniques greatly improved our ability to deliver higher tumor doses while minimizing the dose to the adjacent organs at risk. This improved conformality has not mitigated the problem of doses to normal tissues outside the treated volume. Out-of-field doses are mostly due to photons, electrons from linac head (jaws, multi-leaf collimator, shielding), patient and table. That scattered radiation can cause detrimental health effect, such as cataract for eye lens and dysfunction of cardiac implantable electronic devices (CIED). In this study we evaluate out-of-field dose with two different dosimeters, thermoluminescence dosimeter (TLD) and film, considering two applications: the estimation of eye lens dose and the estimation of dose to the pacemaker at different distances from beam edge.

Materials and methods. Firstly, TLD and film were evaluated for out-of-field dose measurements and compared with ion chamber ones, in a fixed 20x20 cm2 field. Secondly, VMAT and SRS/SBRT plans were generated on Elekta MONACO Treatment Planning System (TPS) and recalculated on the Alderson RANDO phantom, as a part of the QA program. We considered 6MV VMAT plans: for the "eye lens case": treatment on the brain and rhinopharynx, and for the "pacemaker case": treatment on breast, lung and neck. The out-of-field doses were calculated at different distances from field edge in the cranio-caudal direction. For the "pacemaker case" we measured the dose with the dosimeters placed on phantom surface. For the "eye lens case" we compared dosimeters measurements with the TPS calculations. The clinical impact of out-of-field doses for both cases were investigated according to AAPM TG-158 protocol.

Results. TLD and film are in good agreement with the ion chamber, within ± 1% dose difference with respect to the central axis dose. Pacemaker dose decreases with distance from field edge and depends on the Planning Target Volume (PTV). In the "eye lens case" TPS overestimates the dose at field edge (3% - 7% of the prescription dose) and underestimates it after 1 cm (-1.5% - -0.5% of the prescription dose). We estimate a safe distance of 3cm for low risk pacemaker dose and eye lenses cataract disease for the evaluated plans.

Conclusion. TLD and film dosimeters are suitable for out-of-field measurements. Dose to the pacemaker depends both on PTV volume and beam edge distance, so in vivo dosimetry is preferred for accurate evaluation, especially for the high clinical risk patients. TPS overestimates the out-of-field doses below 1.5cm from field edge comparing with the measurements, while it

underestimates the out-of-field doses after that. By normalising calculated and measured doses by prescription dose, the underestimation will be less than 2%.

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Title:

Analysis of Set-up Uncertainties and Organ Motion in Prostate Radiotherapy Based on Day to Day CBCT Verification

Prospective/Objective: The basic goal of this thesis is to propose an optimal definition of PTV evaluating setup and organ motion uncertainties for prostate tumor.

Materials and methods. For the development of this work we have considered selection of the patients made from the database from January to April 2017. Thirty-three patients with adenocarcinoma of the prostate staged T1 to T4, treated using volumetric modulated arc therapy (VMAT), were evaluated.

The evaluation of systematic and random errors was performed using image registration between daily Cone Beam Computed Tomography (CBCT) and CT used for planning. Bone anatomy was used as fiducial marker for setup and gold seeds implanted within the prostate as fiducial markers for organ motion. To perform the analysis, the displacement between registered bone position and laser position was listed for setup and between registered gold seed and registered bone position for organ motion.

Results. Matching of two scans with about 60 slices of 256 x 256 pixels takes about 2 min on a workstation and achieves subpixel registration accuracy. Matching of the organ contours takes about 30 s. The accuracy in determining the relative setup movement and organ motion was 0.9 to 1.5 mm and 0.3 to 0.9 mm, respectively. From the analysis of setup errors and organ motion, an optimized margin was obtained to define the PTV from CTV: 4.4 mm in the anterior-posterior direction, 3.3 mm in the cranio-caudal direction, 3.7 mm in the lateral-lateral direction.

Conclusion. Cone Beam CT is an accurate and precise tool for image guidance that provides many useful information: in this study CBCT was used only to evaluate bone and gold seeds position but the 3D images make it possible to evaluate in the same time all other modifications within the patient and help the physician to take a decision in case of doubt.

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Title:

Feasibility of the commissioning of a Radiotherapy treatment planning system focusing on multileaf collimator dosimetric properties using GAFchromic films.

Prospective/Objective: To characterize a treatment planning system (RayStation 6) supplied with data measured with a radiochromic film dosimetry system, for the improved modeling of the dosimetric parameters of multileaf collimators. Ionization chambers are usually used to measure data from the radiation machine to supply the TPS. However, these dosimeters are no longer appropriate for the measurements of small fields as they do not describe accurately the penumbra region. This work uses dosimetric information for open fields measured with Gafchromic film, which allowed a better definition of the penumbra region in the TPS.

Materials and methods. The data was acquired using a UNIQUE 6MV single energy photon accelerator with Millenium MLC-120 leaf model. GAFchromic film and DoseLab software were used for film characterization and processing, as well as for the profile acquisition. Measurements at different depths were done for open fields, one set of data for fields collimated with jaws and the other set for fields shaped with MLCs. Due to the size of the radiochromic films, information from fields larger than 15cm × 15cm were obtained from existing measurements performed with a water tank and semiflex chamber for previous commissioning of the machine. The required profiles were extracted from the measured dose distributions in order to supply the radiation treatment planning system. Three beam models were characterized, one with information acquired for jaws collimated fields and two for MLC shaped fields. The MLC shaped models vary among them only in the values of the leaf tip width. Calculations and comparisons for validation of the models inside the Beam 3D module of RayStation 6 were made. Beam calculation and clinical verifications were made using field tests, patient QA tests and gamma analysis.
These test were carried out using two methods, the first using GAFchromic film and DoseLab, and the second one using ArcCheck and SNC, which are used for routine QA tests. Acquisition and validation tests were followed according to literature.

Results. The difference between delivered and computed field sizes is less than 2mm for the three models. The penumbra was modeled more accurately within less of 1 mm due to the high spatial resolution of GAFchromic film. Gamma analysis results for the models line within the criteria of acceptability.

Conclusion. The modeling of the penumbra region in the three models was improved when using

GAFCHROMIC™EBT3 sheets than with a semiflex chamber. Moreover, the third proposed model shows the best agreement among them in the penumbra region. The results of this work suggest that the use of Gafchromic films for the commissioning of MLC dosimetric properties is feasible, even though it is time consuming. With more time invested, further work on the optimization of MLC parameters, as well as more verifications tests could be carried out.

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Title:

Comparison between Analytical Anisotropic Algorithm and Collapsed Cone Convolution in 3DCRT and VMAT modalities for Lung Region

Prospective/Objective: This work has the purpose to study the dosimetric differences between Analytical Anisotropic Algorithm implemented into EclipseTM TPS (Varian Medical Systems, Palo Alto, CA, USA) and Collapsed Cone Convolution from RayStationTM (RaySearch Laboratories), in 3DCRT and VMAT modalities. They are applied to lung region, using gamma index 3D evaluation between dose map distribution calculated for both TPS, and gamma index 2D evaluation for dose map distribution, calculated for both TPS and compared to gafchromic films.

Materials and methods. In this study nineteen lung cancer patients were selected, 9 with 3DCRT and 10 with VMAT plans, all of them previously treated using Eclipse TPS. The plans were exported to RayStation TPS and new plans were calculated for a 6-MV photon beam on a Clinac® DHX linear accelerator (Varian Medical Systems, Palo Alto, CA, USA). Also, verification plans were created in an anthropomorphic phantom, in both EclipseTM and RayStationTM TPS. Gamma index 3D evaluation was performed in PTW MEPHYSTO® VeriSoft Patient Plan Verification at 2%/3mm and 3%/3mm, after that, a subgroup of five patients, two for 3D and three for VMAT were selected for measurements using GAFCHROMIC® EBT2 Dosimetry Film.

Results and Conclusion. From 2D gamma evaluation it was obtained that AAA has a better agreement with irradiated gafchromic films in comparison with the results obtained when dose distribution computed by CCC was evaluated. The best outcomes for gamma evaluation were found for VMAT plans, compared with 3D technique. Applying 3%/3mm criteria, the following results were obtained: 95.6% (patient 2) and 94.6% (patient 5) agreement for 3D modality – AAA; 95.2% and 89.0%, respectively, with CCC. For VMAT plans, the gamma evaluation for AAA with 3%/3mm criteria, for patients g, h and i, was 99.1%, 94.8% and 98.8%, respectively; for CCC the gamma passing rates were 98%, 90.5% and 90.6%, respectively. The failed points during gamma evaluation were observed in the lung region. Through this study a good estimation of the algorithms behavior in inhomogeneous regions was achieved, but it is recommended to perform more verifications using gafchromic films.

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Title:

Evaluation of a commercial orthopedic metal artefact reduction tool in radiation therapy

Prospective/Objective: Computed Tomography images in radiation therapy are used for localize the planning target volume (PTV), the organs at risk (OARs) and calculate the dose distribution by treatment planning system (TPS). Image artifacts could lead either a wrong definition of structure contours by the clinician either an erroneous computation of dose due to inaccuracies in the Hounsfield Unit (HU) values. Radiotherapy patients often have metal implants and this causes several image artifacts. This study focused on the advantages using a commercial metal artifacts reduction algorithm, O-MAR (Philips Healthcare System, Cleveland, OH) and its effect on dose calculation.

Materials and methods. The study five head and neck cases were considered with metal dental implants. Patients were scanned on a large bore CT Brilliance Philips. The scanned images were reconstructed with standard and O-MAR algorithm for each patient. The structures drawing by the clinicians on the O-MAR series were copied on the originally CT images to evaluate the dose distribution on the same volume. Plans were performed on Pinnacle TPS with intensity modulated radiation therapy technique (IMRT). The treatment provided two or three PTVs, respectively with 54/66 Gy and 54/60/66 Gy and dose were evaluated on different OARs, close to the artifacts region, such as bone marrow, parotids, mandible. Hounsfield Units (HU) variation were analyzed also in additional region of interest (ROI) near the dental implant.

Results. In OMAR images, noise value is reduced, standard deviation of HU is lower than in standard reconstructed images. Statistical analysis on HU values was performed, but no significant difference between the two data sets was founded. Evaluating the dose distribution and the dose volume histogram (DVH) with the physicians, no significant differences were detected by a clinical point of view.

Conclusion. In head and neck case, when patients have dental implants, the use of O-MAR improve the entire radiation treatment planning process, especially for contouring because increase the accuracy of CT HU and reduce the noise. No significant changes in dose calculation were founded.

Title:

Adaptive Radiotherapy in Lung Cancer: Dosimetric and Clinical Aspects

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Prospective/Objective: The aim of this study is to evaluate if the standard ITV (Internal Target Volume) which was adopted by a physician for patients have lung cancer, has a sufficient margin to maintain an optimal coverage of GTV (Gross Target Volume) during all treatment course.

Materials and methods. 7 patients have adenocarcinoma lung cancer were selected for this study, they were treated at the Department of Radiation Oncology between 2013 and 2014. GTV and CTV were contoured by the specialist and a non-personalized ITV was defined (with an expansion of 1cm in cranial-caudal direction and 0.5 cm in other direction from CTV). For each patient 3D planning was available and several CBCT (from 7 to 9, that means about a CBCT every 3 fractions).

By using MIM- MAESTRO software (MIM Soft-ware, Inc., Cleveland, OH, USA) the physician propagated GTV and PTV contours from pCT (CT of planning) to each CBCT, then he corrected them manually. We superimposed new contours on pCT and on planned dose for each CBCT. The we evaluated the mean deviation of the volume and GTV coverage. Also to obtain accumulated DVH we used MIM software; first we generated deformed dose and contours of pCT on CBCT, then we propagated contours and dose from the planned CT to the last CBCT. In this case we verify and accepted deformable registration of CBCT and structures and automatic propagation of doses and structures.

Results. For what concerns GTV volume which defined by the physician, we observed that in 3 of 7 cases had a percentage significant difference between pCT and mean values obtained from CBCT, so only in these cases it could be useful to replan. To decide if replan might be necessary we evaluated mean coverage of GTV related to pCT (we considered the 95% of prescription dose). All percentage difference is less than 3%. This data was also confirmed by accumulated DVH, 6 of 7 cases had the difference in coverage less than 2%; only in for one patient it was around 3%, but for PTV these differences in the coverage were less than 5%.

Conclusion. The mean difference within pCT of GTV's coverage obtained by superimposition of deformed contours by physician is in line with results obtained automatically in accumulated DVH by MIM. This means that we could be confident in deformable registration and propagation of MIM automatic workflow. We could say that CBCT set up verification and correction for these kinds of patients is enough to control GTV coverage. This is due to the fact that the security margin adopted for standard ITV is corrected. In adenocarcinoma lung cancer adaptive radiotherapy couldn't be necessary.

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Title:

Experimental Measurements for the Implementation of Total Body Irradiation with Modulated Arc Beam

Prospective/Objective: The aim of these experimental measurements was to implement a modulated arc technique for treatment with Total Body Irradiation (TBI), to be performed in a standard treatment room, with a 6MV Elekta Versa Linac, without any additional equipment.

Materials and methods. The measurements were performed with a PMMA solid phantom of 30x90x20cm3, and a Farmer type ionization chamber. The characterization of the profile parallel to the direction gantry rotation, generated by an arc between 290º and 70º using a field size of 40x40cm2, was the first beam data measurement; in order to provide a modulated arc beam, the individual contribution and weighting factors of each sub-arc were determined. Profiles acquisition in 'Entrance' and 'Exit' and transverse profile

were acquired to estimate the dose at patient`s skin and transversal homogeneity. The relation between the doses for different thicknesses of the phantom in 'Entrance', 'Mid-Plane' (prescription) and 'Exit were evaluated.

The acquisition of the PDD curve for TBI setup was performed. The dose valuation of the attenuation of lead shielding blocks in homogeneous and nonhomogeneous medium; and how their presence affects the profile was studied.

In-Vivo dosimetry was performed with diodes, which were calibrated, validated and implemented through dedicated software PTW - VivoSoft. After the determination of all technical and dosimetrical parameters, measurements and analysis, a procedure of the process was created and a complete validation of the arc technique was performed.

Results. The theoretical curves proved to be accurate in the prediction of the weighing factors for the determination of modulated arcs, with arc dose homogeneity of 2,3% in the L-R profile. The homogeneity derived from the measurements in the phantom surfaces (representative of the patient`s skin) was of +7,06% with respect to the CAX and +7,11% with respect to the prescription mid-plane; the maximum variation in homogeneity of the transversal profile was of 3,48%. According to the study of the variation of dose for different phantom thicknesses, in 'Entrance', 'Mid-Plane' and 'Exit' positions, the expected linear and exponential decreasing behaviors respectively were obtained. The PDD curve in TBI conditions obtained was fitted to a second grade polynomial equation from where the values of PDD needed to calculate the calibration factors (CF) for the theoretical estimation of the mid-plane dose were obtained. The presence of lead shielding blocks attenuates the dose with a quadratic behaviour respect to its thickness; the blurring effect is present in the profile, the penumbra in the L-R direction causes over and under-dosage, that must be taken into account for the shielding design. During the validation process, the measurements performed for different phantom thicknesses/homogeneities and in the anthropomorphic phantom for different procedure implementations were satisfactory.

Conclusion. Arc therapy is not only a convenient and robust method for the implementation of TBI technique but also easily applicable in a standard treatment room; guaranteeing an optimal dose homogeneity throughout the body, comfort and reproducibility of the patient´s position and fast irradiation. In-Vivo dosimetry was successfully implemented, the use of PTW-VivoSoft provide a quick and visual tool of the dose measurements during the irradiation, allowing the detection of errors or changes, which may lead to dose correction or adjustment to the prescribed dose of the patient.

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Title:

Evaluation of performance parameters of the new Philips Ingenuity TF PET/CT scanner.

Prospective/Objective: To evaluate the performance characteristic of Philips Ingenuity TF PET/CT system (Philips Healthcare, Cleveland, OH, USA) of both PET and CT parts. A comparison of different image reconstruction protocols for EARL FDG-PET/CT accreditation programme (European Association for Nuclear Medicine Research, Ltd) was also performed.

Materials and methods. Philips Ingenuity TF is a hybrid PET/CT scanner equipped with LYSO type detector which generates images using list-mode reconstruction algorithm, and 64 slices CT with dose reduction tools such as DoseRight and IDose.
Performance measurements on PET scanner were performed according to the NEMA NU2-2012 standard. Image quality was extended by accounting for different reconstruction parameters (frame timing range from 10 to 1 minute, PSF iteration number 1 to 25, PSF regularization from 2 to 8 mm). A NEMA IEC-61675-1 NU2-2001 body phantom with lesion-to-background ratios 10:1 was used for suitable image reconstruction protocol evaluation, according to EARL guideline procedures.
Performance measurements on CT scanner were performed according to IAEA No.19 (Human Health Series) publication. For different CT exposure parameters check, CTDI measurements in Air, Head and Body phantoms with 16 cm and 32 cm diameter respectively, using the CT detector of Raysafe Xi were performed. Geometrical efficiency was evaluated by exposure of various beam collimations on Gafchromic XRQA2 radiochromic films. Image quality parameters (MTF, Noise) using all clinical reconstruction filters, resolution modes and noise reduction tool (IDose Index) were obtained by image analysis in commercial available software Radia (Radiological Imaging Technology, Inc) of Catphan® 600 (The Phantom Laboratory, Inc) acquisitions. Influence of DoseRight index parameter change from 30 to 10 on patient dose was studied using anthropomorphic phantom acquisitions.

Results. Spatial resolutions ranged from 4.6 mm at 1 cm to 6.0 mm at 20 cm. Sensitivity measured in the centre and at 10 cm were 7.58 and 7.43 cps/kBq, respectively. The measured noise equivalent count rate (NECR) peak was 122.7 kcps at 20.3 kBq/cm3. The scatter fraction was 36.6%. Manufacturer's EARL dedicated reconstruction protocol does not perfectly meet accreditation requirements as all others reconstructions with PSF correction. CT acceptance parameters, in most cases, meet manufacturers and international guidelines tolerance specifications. All CTDIair and CTDIvol obtained values were inside manufacturer's specification range. Measured difference for geometrical efficiency of 5 mm, 2.5 mm and 1 mm beam collimations was -15.4%, -36.9%, 13.7%, respectively. Decreasing DoseRight index from standard 26 to 24 and 16 dose reductions of 19.8% and 67.3% are observed.

Conclusion. Philips Ingenuity TF PET/CT system has overall good performance characteristics, comparable with similar scanners from other manufacturers. The CT part performance meets manufacturer's specifications with some discrepancies, which do not have a significant impact on clinical use. For EARL accreditation programme a better adjustment of reconstruction protocol without PSF algorithm is needed.