MEDICAL PHYSICS
International

The Journal of the International Organization for Medical Physics

Volume 3, Number 2, November 2015

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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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Welcome Massage from Thai Medical Physicist Society

ICMP
9-12 DECEMBER 2016
Bangkok, Thailand

On the behalf of Thai Medical Physicist Society and the local organizing committee, I am pleased to extend our warm welcome to the 22nd International Conference on Medical Physics 2016 held on December 9-12, 2016 at the Shangri-La Hotel, Bangkok, Thailand.

The Theme of the Conference is

"Medical physics propelling global health"

The Conference is hosted by the cooperation of:

- International Organization of Medical Physics (IOMP)
- Asia- Oceania Federation of Organizations for Medical Physics (AFOMP)
- European Federation of Organizations for Medical Physics (EFOMP)
- Middle East Federation of Organizations for Medical Physics (MEFOMP)
- South-East Asian Federation of Organizations for Medical Physics (SEAFOMP)
- Japanese Society of Radiological Technology (JSRT)
- Thai Medical Physicist Society of Medical Physics (TMPS)
- Thailand Convention & Exhibition Bureau (TCEB)

It is the first time that Thailand hosts the International Conference on Medical Physics(ICMP) in Bangkok, the 'City of Angels' and the 'Venice of the East' which you can enjoy the Asian culture of the gorgeous temples and Grand Palace along the Chao Phya River with the fantastic world famous Thai food.

The Scientific and Commercial Exhibition Committee are preparing for the highest scientific and educational quality through lectures, symposium, workshop, proffered papers, e-posters together with the radiological products of advanced technology from every corners of the world.

I wish you participate the coming conference arranged with the Welcome Reception, Lunch Symposium, Scientific and Exhibition sessions with several social programs in December 9-12, 2016 Bangkok, Thailand.

Thank you,

Anchali Krisanachinda, Ph.D.
President, TMPS
November 12, 2015

www.icmp2016.org

EDITORIALS

Discussion About the Future Medical Physics Education – Moving into the BSc Level?

Slavik Tabakov, Co-Editor

Medical Physics education is at the heart of the profession and a main topic of our Journal. It is excellent to see many articles in the MPI Journal about the education in various countries - new educational technologies, initiatives and courses worldwide. At the same time we all know that the volume of our profession is growing rapidly and those who are dealing with education can no longer include even half of the new content in the limited hours of one masters course.

What options do we have? One option, used in some places, is to include more information in the practical training linked to the educational university courses. This way, however, limits the academic coverage of the material transferred into training, which could affect the future research. Another option, used in other places, is early narrow specialization. This could provide the necessary classical and modern academic information in one sub-field of the profession (e.g. Radiotherapy), but would decrease the horizon of the graduates. Whatever we do, if we follow the existing post-graduate (masters) educational model, it will not be enough for our very dynamic profession.

At the same time there are fast growing new strands in the interface between medicine and exact sciences - the very interface where medical physicists and engineers are the pioneers.

We have to be ready to collaborate (and perhaps to lead) the new research in this direction. This means that, in addition to the enlarged volume of the classical medical physics fields, we have to increase the coverage of our profession. This can only happen with an increased volume of education – i.e. BSc + MSc in Medical Physics.

We obviously have to consider moving into the under-graduate (bachelors) educational field. If we should develop this new type of medical physics education, it would need to include a combination of undergraduate physics modules (those essential for our profession) plus an introduction to all branches of medical physics. The following masters course would then concentrate in depth in some of the professional sub-fields.

If we consider this model, we should also think about including, at both BSc and MSc levels, subjects related to modeling, as well as math and programming linked to better use of the vast medical imaging information. We have to consider such expansion of the scope of the profession, keeping in mind its future application in new areas - for example, personalized medicine.

BSc courses in medical physics already have been initiated in some countries. MPI would be very interested to hear about their experience, and we would support any discussion on the subject.

Children Are Not Just Small Adults

Perry Sprawls, Co-Editor

The fact that children, especially infants, are not just small adults presents a major challenge for x-ray imaging including computed tomography (CT). It also provides an opportunity for medical physicists to use their knowledge, experience, and leadership to contribute to more effective diagnostic imaging balanced with appropriate risk management.

The challenge with imaging children is a combination of three factors. Within the body differences among the tissues that form physical contrast is less developed. Also, many anatomical structures and features are small requiring more high detail imaging procedures. A second factor is the potential higher sensitivity to the biological effects of radiation. A third factor, especially a challenge for radiographers and technologists conducting the procedures, is minimizing motion during acquisition of images.

When children are imaged in dedicated pediatric hospitals and clinics there are an increased possibility that the procedures are more optimized because the staff is trained and experienced in the special requirements for appropriate x-ray imaging.

However, often children are imaged along with adults when there are no dedicated pediatric facilities and staff available.

A normal procedure in radiography is to reduce exposure (a combination of KV and MAS) in relation to body size. While this might produce what appears to be a good image it is not necessarily an optimized procedure with respect to all image quality characters and radiation dose to the patient.

Optimizing x-ray imaging procedures, including CT, for pediatric patients is a somewhat complex process. It requires the collaborative actions of medical physicists, radiologists and other physicians, radiographers and technologists, and especially radiological and medical imaging educators.

To address the complexity of the challenge and provide guidance and resources to be used for more appropriate and optimized pediatric x-ray procedures the Image Gently program was developed. We are pleased that the invited article for this edition, Image Gently Campaign: Making a World of Difference, provides medical physicists in all countries with an opportunity to provide leadership in their institutions and make a major contribution to improved imaging of children.

COLLABORATING JOURNALS

BRIEF HISTORY OF RADIOLOGICAL PHYSICS AND TECHNOLOGY JOURNAL (RPT)

Kunio Doi[1], Fujio Araki[2,3], Masahiro Endo[2,4], Tomoyuki Hasegawa[2,5], Shigehiko Katsuragawa[2,6], Yoshie Kotera[2,7], Shigeru Sanada[2,8]

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Abstract **A concise article on brief history, unique features, and current status of the journal Radiological Physics and Technology (RPT) by Editor-in-Chief and Deputy Editors**

Keywords **Radiological Physics, Medical Physics, Radiological Technology**

I. AIMS AND SCOPE

Radiological Physics and Technology (RPT) is the official English-language journal of the Japanese Society of Radiological Technology (JSRT) and the Japan Society of Medical Physics (JSMP), which have a combined membership of more than 18,000. Although a large fraction of the articles in this relatively new journal may be written by members of these societies, we welcome contributions from authors in many countries around the world. The first issue was published in 2008, and the journal has been published biannually since then. The purpose of the journal Radiological Physics and Technology is to provide a forum for sharing new knowledge related to research and development in radiological science and technology, including medical physics and radiological technology in diagnostic radiology, nuclear medicine, and radiation therapy among many other radiological disciplines, as well as to contribute to progress and improvement in medical practice and patient health care.

Five types of contributions are published in the RPT, including review articles, research articles, technical notes, clinical procedures and techniques, and letters to the editor. Manuscripts submitted are initially reviewed by the Editor-in-Chief, who will then select a Deputy Editor for additional review. The Deputy Editor chooses an Associate Editor, who is responsible for further evaluation and peer review. The manuscripts are reviewed by the Associate Editor and by at least one referee, who is chosen by the Associate Editor. The final decision on acceptance is made by the Editor-in-Chief in consultation with the Deputy Editor.

Authors should submit their manuscript online at the site: https://www.editorialmaneger.com/rpte and upload all of the manuscript files following the instructions given on the screen. The article will be published online first after the receipt of the corrected proofs. This is the official first publication citable with DOI. After release of the printed version, the paper can be cited by the issue and page numbers. The electronic version of the RPT is available freely for one year at htpp://link.springer.com/journal/12194. For orders and inquiries about subscription, please contact a bookseller or Springer Customer Service at subscription@springer.com.

II. TECHNOLOGY

We believe that new ideas and new findings are the most important ingredients in scientific and technical publications. It is worthwhile to report new ideas and new findings as soon as possible, even if the supporting data might not be completely available at an early phase of research and development. Therefore, we welcome short articles clearly describing new ideas and new findings that are likely to have a significant impact on radiological physics and technology in the future. We are willing to take a small risk against a potentially large benefit to the societies. Authors can then publish long articles later, with comprehensive analysis and extensive data, which will provide strong evidence and support for their early findings. Another advantage of short articles is that they can be prepared by authors quickly, reviewed by referees

quickly, and read by many readers quickly. Note also that the value of an article is not dependent on the length of the article. For example, Paul C. Lauterbur wrote a short article of two pages about his early findings on MRI, for which he later received a Nobel Prize.

We believe that one of the roles of the journal is to assist young researchers in nurturing their growth as a scientist, and thus our editorial policy includes trying to salvage a manuscript as much as possible by providing constructive reviews to authors, if the manuscript has at least a potentially publishable content, although the manuscript appears to be written poorly. Because the native language of many authors is not English, the RPT provides a special editing service by our Editorial Assistant, which is free to authors, for initial polishing of all manuscripts submitted, and also a final polishing only for technically accepted manuscripts. However, authors whose native language is not English are strongly advised to have their manuscripts checked by an English-speaking person who understands the material, before submission to the journal.

III. CURRENT STATUS OF RADIOLOGICAL PHYSICS AND TECHNOLOGY

The RPT has published eight volumes of journals from January 2008 to July 2015. The number of articles and the number of pages in each issue are illustrated in Fig. 1, which indicates a gradual increase in the number of articles.

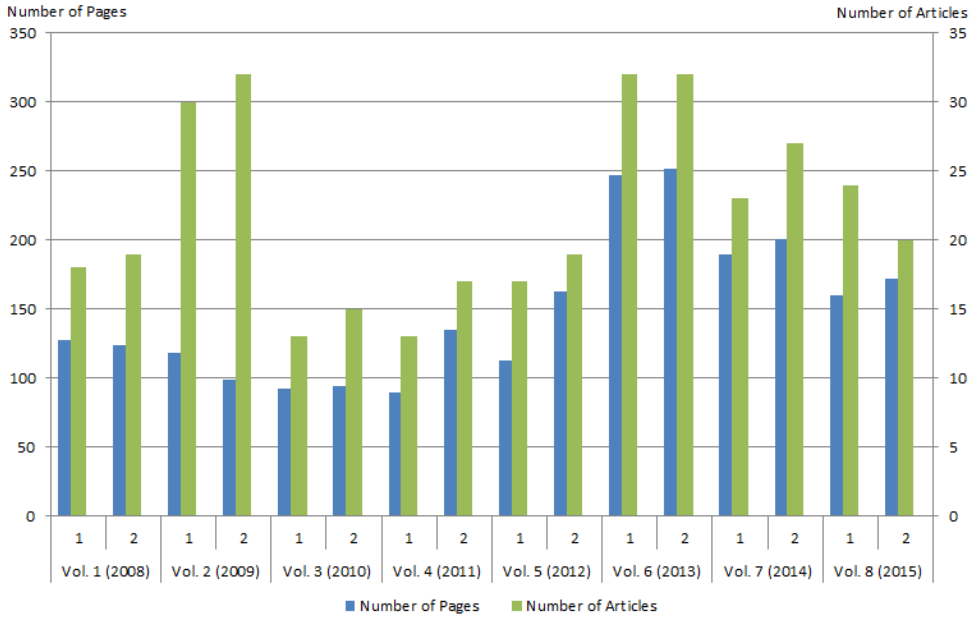

Fig.1 Number of articles and number of pages of the RPT from 2008 to 2015

The total number of manuscripts submitted from 2007 to July 2015 is 459, and the total number of accepted manuscripts is 308, thus providing an average acceptance rate of 67.1% (the annual acceptance rate ranges from 46.9% to 94.4%). Approximately 25-30% of the total submissions originated outside Japan, including Asia, North America, Europe, the Middle East, South America, and Africa. The number of downloads has increased substantially from below 11,000 in 2011 and 2012 to above 16,000 in 2013 and 2014. Downloads by geography indicate 54% from the Asia-Pacific region, 23% from Europe, 16% from North America, and 7% from the remaining regions. Some of the most downloaded articles in 2014 are shown in Table 1.

Table 1 Articles in the RPT with top 15 downloads from September 2014 to August 2015

Article	Author	Publication Year	Downloads
ROC analysis in medical imaging: a tutorial review of the literature	Charles E. Metz	2008	434
Evaluation of the effectiveness of X-ray protective aprons in experimental and practical fields	Hiroshige Mori	2014	365
Effects of diffusional kurtosis imaging parameters on diffusion quantification	Issei Fukunaga	2013	333
Calculation of air-kerma rate of diagnostic X-ray generators	Yoh Katoh	2011	305
Comparison of magnetic resonance imaging sequences for depicting the subthalamic nucleus for deep brain stimulation	Hiroshi Nagahama	2015	279
Validation of a quick three-dimensional dose verification system for pre-treatment IMRT QA	Yuji Nakaguchi	2015	261
Optimization of acquisition parameters and accuracy of target motion trajectory for four-dimensional cone-beam computed tomography with a dynamic thorax phantom	Yoshinobu Shimohigashi	2015	254
Radiologic assessment of a self-shield with boron-containing water for a compact medical cyclotron	Genki Horitsugi	2012	252
Modulation transfer function measurement of CT images by use of a circular edge method with a logistic curve-fitting technique	Tomomi Takenaga	2015	252
Antoine Henri Becquerel (1852–1908): a scientist who endeavored to discover natural radioactivity	Masaru Sekiya	2015	241
Development of GATE Monte Carlo simulation for a dual-head gamma camera	Mehdi Momennezhad	2012	239
Comparison of neutron fluxes in an 18-MeV unshielded cyclotron room and a 16.5-MeV self-shielded cyclotron room	Toshioh Fujibuchi	2012	209
Spatial resolution measurement for iterative reconstruction by use of image-averaging techniques in computed tomography	Atsushi Urikura	2014	200
Factors affecting the chemical exchange saturation transfer of Creatine as assessed by 11.7 T MRI	Shigeyoshi Saito	2015	185
Copper filtration in pediatric digital X-ray imaging: its impact on image quality and dose	Philippe Brosi	2011	176

The15 most cited articles up to the present are listed in Table 2. The journals frequently citing articles published in the RPT are Medical Physics, Physics in Medicine and Biology, Journal of Applied Clinical Medical Physics, and Proceedings of SPIE. The origins of authors citing the RPT are the USA, Japan, Germany, China, Switzerland, and others.

Table 2 Most cited articles in the RPT from 2008 to 2015

Article	Author	Publication Year	Number of Cites
ROC analysis in medical imaging: a tutorial review of the literature	Charles E Metz	2008	47
Demonstration of iodine K-edge imaging by use of an energy-discrimination X-ray computed tomography system with a cadmium telluride detector	Abulajiang Abudurexiti	2010	26
X-ray fluorescence camera for imaging of iodine media in vivo	Hiroshi Matsukiyo	2009	21
Experimental verification of proton beam monitoring in a human body by use of activity image of positron-emitting nuclei generated by nuclear fragmentation reaction	Teiji Nishio	2008	19
Simulation and experimental studies on magnetic hyperthermia with use of superparamagnetic iron oxide nanoparticles	Kenya Murase	2011	12
A review of image-guided radiotherapy	George T Y Chen	2009	10
Evaluating the performance of a MOSFET dosimeter at diagnostic X-ray energies for interventional radiology	Koichi Chida	2009	10
System design of a small OpenPET prototype with 4-layer DOI detectors	Eiji Yoshida	2012	9
Application of an artificial neural network to the computer-aided differentiation of focal liver disease in MR imaging	Xuejun Zhang	2009	9
Development of a GPU-based multithreaded software application to calculate digitally reconstructed radiographs for radiotherapy	Shinichiro Mori	2009	8
Analysis method of noise power spectrum for medical monochrome liquid crystal displays	Katsuhiro Ichikawa	2008	7
Dosimetric evaluation of nuclear interaction models in the Geant4 Monte Carlo simulation toolkit for carbon-ion radiotherapy	Satoru Kameoka	2008	7
Three-dimensional motion study of femur, tibia, and patella at the knee joint from bi-plane fluoroscopy and CT images	Takashi Ohnishi	2010	7
Polarity effect in commercial ionization chambers used in photon beams with small fields	Tetsunori Shimono	2009	7
Use of a clinical MRI scanner for preclinical research on rats	Akihide Yamamoto	2009	7
Imaging simulations of an “OpenPET” geometry with shifting detector rings	Taiga Yamaya	2009	7

IV. RECOGNITION OF GREAT PIONEERS IN RADIOLOGICAL SCIENCE

For the cover of the journal RPT, we decided to honor the great pioneers in radiological science by displaying their portraits, laboratories and unique equipment that they used or developed, and relevant images. As illustrated in Fig. 2, the first pioneer is Wilhelm. C. Roentgen (vol. 1, 2008); then follow Marie Curie (vol. 2, 2009), Godfrey Hounsfield (vol. 3, 2010), Peter Mansfield and Paul C. Lauterbur (vol. 4, 2011), Shinji Takahashi (vol. 5, 2012), Kurt Rossmann (vol. 6, 2013), Hal O. Anger (vol. 7, 2014), and Antoine Becquerel (vol. 8, 2015). The next issue in 2016 will have Rolf M. Sievert (vol.9). Articles about the lives and achievements are provided for Shinji Takahashi [1], Kurt Rossmann [2], Hal Anger [3], and Antoine Becquerel [4].

V. REVIEW ARTICLES BY LEADING SCIENTISTS

Review articles are intended to be authoritative reviews of subjects of significance to the field of radiological science and technology. Seven invited review articles* and three proffered review articles published in the RPT are listed in Table 3, which are commonly cited and also downloaded frequently.

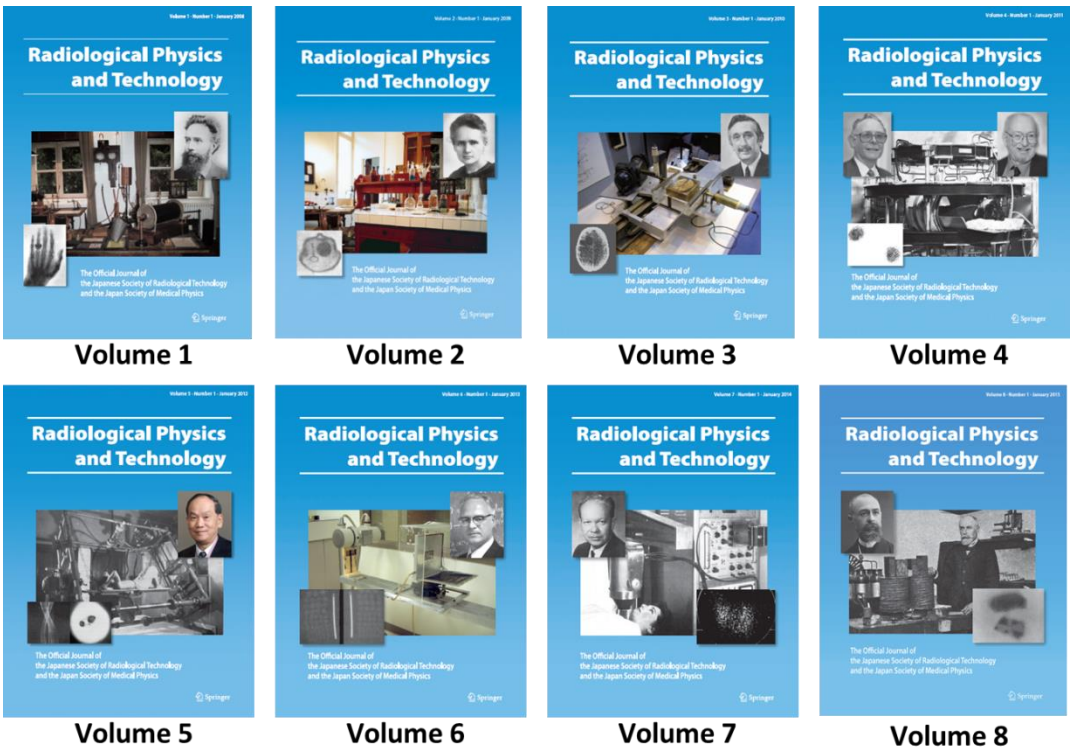

Fig.2 Top cover pages of the RPT from 2008 to 2015

Table 3 Invited* and proffered review articles by leading scientists

Article	Author	Publication Year
ROC analysis in medical imaging: a tutorial review of the literature*	Charles E. Metz	2008
A review of image-guided radiotherapy*	George T. Y. Chen; Gregory C. Sharp; Shinichiro Mori	2009
Water-equivalent pathlength reproducibility due to respiratory pattern variation in charged-particle pancreatic radiotherapy	Motoki Kumagai; Shinichiro Mori; Ryusuke Hara; Hiroshi Asakura; Riwa Kishimoto; Hirotoshi Kato; Shigeru Yamada; Susumu Kandatsu	2009
Calculation of air-kerma rate of diagnostic X-ray generators	Yoh Katoh; Sogo Mita; Masahiro Fukushi; Yoshiyuki Nyui; Shinji Abe; Junichi Kimura	2011
From PACS to Web-based ePR system with image distribution for enterprise-level filmless healthcare delivery*	H. K. Huang	2011
Current status and future prospects of multi-dimensional image-guided particle therapy*	Shinichiro Mori; Silvan Zenklusen; Antje-Christin Knopf	2013
Patient investigation of average glandular dose and incident air kerma for digital mammography	Ai Kawaguchi; Yuta Matsunaga; Tomoko Otsuka; Shoichi Suzuki	2014
Medical imaging, PACS, and imaging informatics: retrospective*	H. K. Huang	2014
Research in digital mammography and tomosynthesis at the University of Toronto*	Martin J. Yaffe	2014
Potential clinical impact of advanced imaging and computer-aided diagnosis in chest radiology: importance of radiologist's role and successful observer study*	Feng Li	2015

VI. RECOGNITION OF OUTSTANDING ARTICLES PUBLISHED IN RADIOLOGICAL PHYSICS AND TECHNOLOGY

The JSRT and the JSMP established the Doi Award in 2008, to be given for outstanding articles in each of the three primary fields related to diagnostic imaging, nuclear medicine, and radiation therapy physics published in the RPT each year. The Doi Award has been named in view of Professor Kunio Doi's notable contributions to medical imaging and computer-aided diagnosis while he has been Professor of Radiology at the University of Chicago during the last 40 years, and also the first Editor-in-Chief of the journal RPT. Outstanding articles which received the Doi award are listed in Table 4. The recipients of the Doi Award receive cash awards, and they give an invited lecture at the annual meeting of the Japan Radiology Congress (JRC) in Yokohama, Japan. Authors from oversees are encouraged and qualified to be candidates for the Doi Award, as long as an individual is not a previous recipient.

Table 4 Articles with Doi Awards from 2009 to 2014

Year	Fields	Article	Author
2009	Diagnostic Imaging	Study of intra-abdominal fat distribution in sigmoid colon cancer in Japanese patients by use of MDCT data	Toshihiro Ogura
	Nuclear Medicine and MRI	Imaging simulations of an "OpenPET" geometry with shifting detector rings	Taiga Yamaya
	Radiation Therapy Physics and Health Physics	Measurement of thermal neutron fluence distribution with use of 23Na radioactivation around a medical compact cyclotron	Toshioh Fujibuchi
2010	Diagnostic Imaging	Three-dimensional motion study of femur, tibia, and patella at the knee joint from bi-plane fluoroscopy and CT images	Takashi Ohnishi
	Nuclear Medicine, MRI, Informatics, and General	Creation and application of three-dimensional computer-graphic animations for introduction to radiological physics and technology	Tomoyuki Hasegawa
	Radiation Therapy Physics	Practical approaches to four-dimensional heavy-charged-particle lung therapyShinichiro	Shinichiro Mori
2011	Diagnostic Imaging	Effectiveness of temporal and dynamic subtraction images of the liver for detection of small HCC on abdominal CT images: comparison of 3D nonlinear image-warping and 3D global-matching techniques	Eiichiro Okumura
	Nuclear Medicine, MRI, Informatics, and General	Automated segmentation method of white matter and gray matter regions with multiple sclerosis lesions in MR images	Taiki Magome
	Radiation Therapy Physics	Simulation and experimental studies on magnetic hyperthermia with use of superparamagnetic iron oxide nanoparticles	Kenya Murase
2012	Diagnostic Imaging	Automated segmentation of psoas major muscle in X-ray CT images by use of a shape model: preliminary study	Naoki Kamiya
	Nuclear Medicine and MRI	Optimization of injection dose based on noise-equivalent count rate with use of an anthropomorphic pelvis phantom in three-dimensional 18F-FDG PET/CT	Kazumasa Inoue
	Radiation Therapy Physics	In-treatment 4D cone-beam CT with image-based respiratory phase recognition	Satoshi Kida
2013	Diagnostic Imaging	Computerized image-searching method for finding correct patients for misfiled chest radiographs in a PACS server by use of biological finger prints	Risa Toge
	MRI, Nuclear Medicine and Informatics	Feasibility of MR perfusion-weighted imaging by use of a time-spatial labeling inversion pulse	Yoshiyuki Ishimori
	Radiation Therapy Physics	Technical approach to individualized respiratory-gated carbon-ion therapy for mobile organs	Mutsumi Tashiro
2014	Diagnostic Imaging	Development and evaluation of statistical shape modeling for principal inner organs on torso CT images	Xiangrong Zhou
	MRI, Nuclear Medicine and Informatics	A method for assessing metabolic information on liver and bone marrow by use of double gradient-echo with spectral fat suppression	Harumasa Kasai
	Radiation Therapy Physics	A formulation of cell surviving fraction after radiation exposure	Hiroyuki Date

VII. FINAL THOUGHTS

The RPT is a relatively new journal in the field of radiological science and technology, which has made good progress over the last eight years. So far, however, we were not able to acquire the impact factor, which is considered an indicator of the usefulness of a scientific and technical journal worldwide. The lack of the impact factor can be a considerable handicap for a new journal to be able to grow quickly. Some academic institutions do not allow trainees such as Ph.D. students to publish their dissertations in journals without the impact factor. Therefore, we have been struggling to improve the RPT significantly and quickly to attain this goal. We do hope that many researchers in many countries around the world will seriously consider publishing their articles in Radiological Physics and Technology.

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4. Sekiya M, Yamasaki M. (2015) Antoine Becquerel (1852-1908): a scientist who endeavored to discover natural radioactivity Rad Phys Technol 8: 1-3

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PROFESSIONAL ISSUES

EUTEMPE-RX MODULE MPE01: 'DEVELOPMENTS IN THE PROFESSION AND CHALLENGES FOR THE MEDICAL PHYSICS EXPERT (D&IR) IN EUROPE' – A FIRST IN INTERNATIONAL MEDICAL PHYSICS E&T

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Abstract—**The EUTEMPE-RX project is an EC funded project which is developing modules principally targeted to clinical medical physicists aspiring to Medical Physics Expert status in Diagnostic and Interventional Radiology. Module MPE01 is the first module and provides foundation for all the other modules. It is effectively a mini-MBA for future leaders of the profession. In today's rapidly changing and highly competitive world, being a good scientist is not sufficient for a professional to prosper; good leadership, managerial and strategic planning skills have become essential. It is suggested that such a module be made available to young medical physicists worldwide.**

Keywords— **Medical Physics Experts, Education and Training, Leadership, Professional Issues, Challenges.**

I. INTRODUCTION

The EUTEMPE-RX (European Union Training and Education for Medical Physics Experts in Diagnostic and Interventional Radiology) project [1] is an EC funded project for the education and training of young medical physicists aspiring to Medical Physics Expert (MPE) status as defined by EU directive 2013/59/EURATOM [2] and elaborated in the 'European Guidance on the Medical Physics Expert' document [3] and EFOMP Policy Statement 12.1 [4]. The project consists of a set of 12 modules at level 8 (highest level) of the European Qualifications Framework [5]. This article describes module MPE01, the first module, which lays the foundations and defines the narrative for all the other modules (http://www.eutempe-rx.eu/index.php/ct-menu-item-3/14-sample-data-articles/82-course-1). The module has perhaps been most appropriately described by one of the first group of participants as a 'Mini-MBA (Master of Business Administration) for Medical Physicists'.

II. MATERIALS AND METHODS

The content of module MPE01 was developed by the authors following an extensive literature search on curriculum development for leadership, management and strategic planning and an in-depth study of the relevant learning outcomes for MPEs in Diagnostic and Interventional Radiology from the 'European Guidelines on the MPE' document [3]. Early on in the project it was decided that each module should consist of a preparatory asynchronous online phase followed by an intensive face-to-face phase. This blended learning mode of curricular delivery would ensure that the participants can take part without undue disruption to their clinical duties. All modules end with an examination and are accredited by the European Federation of Organizations for Medical Physics.

III. RESULTS

The resulting module is best described by its abstract and objectives which describe its intent, content and aspects of curricular delivery [1]:

"This module aims to help the future MPE in Diagnostic and Interventional Radiology (including imaging outside the D&IR department proper) acquire the knowledge, skills and competences necessary to exercise a leadership role within the profession in his own country and in Europe. The content of the module will provide a framework for discussions for all the other modules. In

the face-to-face phase participants will have the opportunity to discuss the major issues facing the profession directly with the present European leaders of the profession. The participants would also be updated with the latest EU directives, guidelines and activities impacting the role to ensure they are at the forefront of these developments. The module will achieve its learning objectives using a combination of online and face-to-face readings, fora, presentations and discussions. The online component will consist of a series of sets of compulsory readings. Each set will be accompanied by an online forum for difficulties and to promote reflection and discussion in preparation for the assessment. The online phase will be asynchronous so that participants would not need to take time off their clinical duties and there will not be a problem with time zones. Each presentation during the face-to-face will be presented by a leader in the area and will be followed by a discussion involving a panel made up of the present European leaders of the profession. Module participants would put forward the issues they are facing in their own country so that we may create a harmonized approach. As preparation for the assessment, case studies

Table 1 Learning Objectives for EUTEPME-RX Module MPE01

MPE01.01 Take responsibility for researching, evaluating, leading, and offering vision for the development of the role of the MPE (D&IR,) in the ambit of European and national legislation and a holistic vision of healthcare.
MPE01.02 Implement and evaluate strategic solutions to the challenges faced by the MPE (D&IR) in own country and Europe.
MPE01.03 Evaluate the various models of management in terms of suitability for a Medical Physics Service and the issue of staffing levels.
MPE01.04 Take responsibility for the development of the role of the MPE (D&IR) in healthcare governance and management in D&IR.
MPE01.05 Take responsibility for ethical issues in medical physics particularly in the areas of research and radiation protection in D&IR and apply them in practice.
MPE01.06 Discuss the role of the MPE (D&IR) in service development, health technology assessment (HTA), innovation and expert consultancy.
MPE01.07 Research, develop and lead the development of the role of the MPE (D&IR) in the education and training of medical physics trainees and other healthcare professionals.
MPE01.08 Manage the relationship of the MP/MPE with other healthcare professions in D&IR, with patients and the general public.
MPE01.09 Manage priorities regarding radiation protection research and medical physics input to clinical research projects needing the support of MPEs.
MPE01.10 Implement safety culture in their practice.
MPE01.11 Participate in networks for research and development at the European and international level.
MPE01.12 Take responsibility for the role of the MPE (D&IR) in and unintended medical exposures in D&IR and radiation accidents.
MPE01.13 Interpret the significance of liaising with the Radiation Protection Expert.

will be discussed with the panel. All presentations will be sent to the participants 2 weeks before the start of the face-to-face phase".

The learning objectives are listed in Table 1. The examination was open book and consisted of case studies involving challenges facing the profession. Sample questions are shown in table 2. The quality survey completed anonymously by the participants produced high satisfaction scores and comments were very positive: "Online content was excellent, great overview. The use of case studies throughout the online phase was very useful to focus on specific learning outcomes. The face-to-face phase reinforced knowledge from the online phase, complemented it with additional information and gave a great insight into what is required of one in order to be a successful MPE"

IV. CONCLUSIONS

In today's rapidly changing and highly competitive world, being a good scientist is simply not sufficient for a professional to develop; good leadership, managerial and strategic planning skills have become essential. It is therefore suggested that such a module be considered for adoption by medical physics educators worldwide. Meanwhile the next run of the module is scheduled to start October 2016 (updates via the EUTEMPE-RX website).

Table 2 Sample examination questions

Case Study 1: Up to now there have only been Medical Physics Experts in Radiation Oncology and Nuclear Medicine in your country. However, EU Directive 2013/59/EURATOM has recognized the importance of the MPE also in Diagnostic and Interventional Radiology. You are having discussions about this issue with your healthcare authorities. One representative from the Ministry of Health tells you: "I can't understand why Medical Physicists are required in Diagnostic and Interventional Radiology. In addition, you don't have the high doses you have in Radiation Oncology" How would you tackle it?
Case study 2: There are 5 chest radiography rooms in your hospital each run by a different team of radiographers. You have noticed that one of the rooms is repeatedly exceeding the local DRLs which you have established. How would you tackle it? You know that the teamof radiographers desnt like people investigating their techniques.
Case study 3: You are the head of the Medical Physics department at a large hospital which is expanding its Diagnostic and Interventional facilities owing to a large population increase in the region. You want to employ additional medical physics staff but the human resources manager tells you that you have enough staff. How would you tackle it?

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MEDICAL PHYSICS EDUCATION IN MALAYSIA –WITH THE EXAMPLE OF THE MASTER OF MEDICAL PHYSICS PROGRAMME AT THE UNIVERSITY OF MALAYA

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Abstract— **This paper presents an overview of the education and training of the medical physics at the postgraduate level in Malaysia. The history of formation, the curriculum and the execution of the Master of Medical Physics programme at the University of Malaya were described in details. This programme was launched in 1997 to meet the critical need of medical physics expertise in the country. The programme was accredited by the Institute of Physics and Engineering in Medicine (IPEM), United Kingdom in 2002. This was the first instance where recognition was awarded outside the British Isles. In 2008, it was successful in securing a reaccreditation by the IPEM and subsequently an extension of the accreditation to August 2015. Over the last two decades, the programme has undergone various cycles of curriculum review and improvement. The programme has been leading in the post-graduate education of medical physicists by adapting to the rapid development in healthcare.**

Keywords— **Malaysia, medical physics, postgraduate education, professional training**

I. INTRODUCTION

Technological advances and developments in medicine, particularly in radiology, radiation oncology (radiotherapy) and nuclear medicine, have created a demand for qualified medical physicists to manage and monitor the medical usage of radiation in all its forms. Worldwide, numerous master level programmes were created to educate and train scientists in this growing field.

The medical physics education and training as Master of Science programme in Medical Physics in Southeast Asia started in Thailand (1972), followed by Philippines (1981), Malaysia (1994), and Indonesia (1998). Vietnam established M.Sc. in Bio-Medical Engineering in 2003. As of 2010, 13 universities in South-East Asia provide medical physics education and training at different levels.(1)

In Malaysia, currently, there are three universities that offer a total of 10 postgraduate level medical physics programmes: namely, University of Malaya (UM), University of Science Malaysia (USM) by coursework; and University of Technology MARA (UiTM) by research. Further details of these programmes are listed in section VII.

In 1998 the University of Malaya launched the Master of Medical Physics programme to meet this growing national need. Since then, over 80 students have graduated from this programme. This is a one year programme, carried out within two semesters (one calendar year). The medium of instruction and assessment is in English.

The programme is accredited by the Institute of Physics and Engineering in Medicine (IPEM), United Kingdom since 2002.(2) At present, the University of Malaya programme is the only one outside the British Isles (United Kingdom and Ireland) to receive such prestigious recognition.

This programme provides postgraduate training in the clinical applications of physics in medicine and biology, particularly with regard to ionizing radiation. The main areas of focus are the planning, quality control and safety considerations for medical imaging (general x-ray machines, computed tomography (CT) scanners, magnetic resonance imaging (MRI) scanners, ultrasound scanners, etc.), nuclear medicine imaging (gamma cameras, single photon emission computed tomography (SPECT) scanners, positron emission tomography (PET) scanners, etc.) and radiotherapy (linear accelerator, brachytherapy equipment, etc.)

This programme trains and equips students to take up professional positions in education, research and service orientated positions in hospitals, universities, government agencies, research laboratories, regulatory agencies, medical industries and nuclear technology industries.

II. ENTRY REQUIREMENT

Primary requirement: a Bachelor's degree with honours in a programme of study consisting of significant courses in physical sciences from recognized universities, or equivalent qualifications.

Secondary requirements: candidates with good computing knowledge (e.g. programming, image processing), or having previous research experience (including basic statistical analysis), or are familiar with basic medical concepts (e.g. anatomy, physiology) will be at an advantage.

International candidates are required to have at least IELTS Band 6 or TOEFL 550 if their first degree is from a university where English is not the medium of instruction; or pass an English proficiency test approved by the University.

III. CLINICAL POSTING

This programme, being administered under the Faculty of Medicine, University of Malaya, allows the students access and exposure to the clinical environment of the University of Malaya Medical Centre (UMMC). The objective of the clinical postings is to give an overview of the role of medical physicists in Radiology, Nuclear Medicine and Radiation Oncology (radiotherapy). The students are required to carry out clinical postings in Radiology, Nuclear Medicine and Radiation Oncology departments for the whole duration of the programme.

IV. FACULTY MEMBERS

Teaching faculties comprise of the academic members from the Department of Biomedical Imaging, Clinical Oncology Unit, Department of Physiology, the Medical Physics Unit of the University Malaya Medical Centre (UMMC), Faculty of Science, Ministry of Health, Malaysian Nuclear Agency, and Atomic Energy Licensing Board (AELB). Teaching collaboration was also established with other local universities such as National University of Malaysia (UKM).

We have had visiting lecturers and professors, namely Dr. Adrian Perry, Professor Tomas Kron, Mr. Chris Fox, and Professor Anatoly Rozenfeld.

We had embarked on tele-teaching for our students. Our online teaching faculty were Dr. Perry Sprawls and Dr. Milton Woo.(3)

A list of the external examiners:

Period	External examiner
1998 Nov-2000 May	Prof. Larry A. DeWerd, PhD
2000 Nov-2002 May	Prof. Gary D. Fullerton, PhD,
2002 Nov, 2003 Nov	Prof. William R. Hendee, PhD
2003 May	Dr. Timothy Van Doorn, PhD
2004	Dr. David J. Dowsett, PhD
2004 – 2006	Dr. Roger M. Harrison, PhD
2006 Nov - 2008 May	Dr. David Sutton, PhD
2008 Nov -2010 May	Prof. Alan C. Perkins, PhD
2010-2011	Dr. Roger M. Harrison, PhD
2011-2014	Prof. David Lurie, PhD
2014-2015	Prof. Peter Metcalfe, PhD

V. PROGRAMME STRUCTURE

The programme is offered in the form of coursework programme. Since the programme first started, it has undergone four cycles of curriculum reviews.

VI. CURRICULUM REVIEWS

The initial framework of the coursework programme is shown in Table 2. The programme started out as a coursework and dissertation programme. The structure of examination is shown in Table 3. There were three papers and a dissertation. The passing mark for each component is 50% of the aggregate marks. Candidates who have obtained ≥75% of the aggregate marks will be awarded a Pass with Distinction.

Table 2: Course structure (Coursework and dissertation), first presented in 1997.

Part I	Courses	Credit hour
	Anatomy and Physiology	2
	Biostatistics	1
	Computing and Medical Informatics	1
	Applied Radiation Physics and Dosimetry	1
	Radiobiology and Radiation Protection	2
	Non-ionizing Radiation in Medicine	1
Part II		
	Medical Imaging	2
	Radiotherapy Physics	2
	Nuclear Medicine	2
	Medical Physics Research Project	

Minimum period: 1 year
Maximum period: 5 years

Table 3: Examination format (1997 – 2005).

Part I	Component	Maximum marks
A. Written Papers		
Paper I		100
	Anatomy and Physiology Biostatistics Computing and Medical Informatics	
Paper II		100
	Applied Radiation Physics and Dosimetry Radiobiology and Radiation Protection Non-ionizing Radiation in Medicine	
B. Continuous Assessment		100
Total marks		**300**

Part II		
A. Written Paper		
Paper III		200
	Medical Imaging	
	Radiotherapy Physics	
	Nuclear Medicine	
	Medical Physics Research Project	
Continuous Assessment		100
B. Dissertation		
	Dissertation	300
	Viva Voce	100
Total marks		**700**

In the first curriculum review held in 2002, there were no changes in the course structure. The same structure was used for the Malaysian Department of Public Service accreditation.

In 2005, there was a major revamping of the course structure following the introduction of semester system (instead of the term system) in the University of Malaya. Together with this system, the cumulative grade points average (CGPA) system was also introduced. The credit hours were changed to credits (Table 4). The total duration of the study was still kept to two semesters (equivalent to 1 year).

Table 4: Course structure after the 2nd curriculum review(2005)

Semester I	**Courses**	**Credits**
	Anatomy and Physiology	4
	Biostatistics	3
	Computing and Medical Informatics	3
	Applied Radiation Physics and Dosimetry	3
	Radiobiology and Radiation Protection	3
	Non-ionizing Radiation in Medicine	3
Semester II		
	Medical Imaging and Nuclear Medicine	3
	Radiotherapy Physics	3
	Nuclear Medicine	3
	Medical Physics Research Project	12
	Total credits	**40**

Minimum terms: 2 semesters
Maximum terms: 8 semesters
Total credits : 40

Table 5: Course structureafter the 2010 curriculum review

Semester I	**Courses**	**Credits**
	Anatomy and Physiology	4
	Biostatistics	2
	Computing and Medical Informatics	4
	Applied Radiation Physics and Dosimetry	4
	Radiobiology and Radiation Protection	4
Semester II		
	Medical Imaging and Nuclear Medicine	5
	Radiotherapy Physics	5
	Medical Physics Research Project	12
	Total credits	**40**

Minimum terms: 2 semesters
Maximum terms: 8 semesters
Total credits : 40

In 2010, following the requirements by the Malaysian Quality Assurance (MQA), the programme underwent a 3rd cycle of curriculum review. During this review, the topics which were originally covered under non-ionizing radiation in medicine were merged into applied radiation physics and dosimetry (for the physics part) and radiobiology and radiation protection (for the radiobiological effects parts) courses. in the 2nd semester, the nuclear medicine topics were merged with the medical imaging topics (Table 5).

In June 2015, we have completed 4th cycle of curriculum review.

VII. OTHER PROGRAMMES

There are a total of 10 postgraduate level medical physics programmes offered by various universities in Malaysia (Table 6).

Table 6: Postgraduate level medical physics programmes available in Malaysia.

University	**Name of the programme**
University of Malaya (UM)	Master of Medical Physics by coursework M. Medical Science (Medical Physics) by research PhD – Doctor of Philosophy (Medical Physics) by research
University of Science Malaysia (USM)	M.Sc. - Master of Science (Medical Physics) by research M.Sc – Master of Science (Physics) in Medical Physics and Radiation Science by research Master of Science (Medical Physics) by coursework

	PhD – Doctor of Philosophy (Medical Physics) by research PhD – Doctor of Philosophy (Physics) in Medical Physics and Radiation Science by research
University of Technology MARA (UiTM)	Master of Science Specializing in Medical Physics by research PhD – Doctor of Philosophy Specializing in Medical Physics by research

Amongst these, the coursework programme offered by the University of Science Malaysia (USM) has a similar programme structure to the University of Malaya. They are the only other programme that provides the alternative coursework master programme for medical physics in Malaysia. Their programme structure is shown in Table 7.

Table 7: Course structure of the M. Sc. (Medical Physics) programme (as of 2015)

Semester I	**Courses**	**Credits**
Core	Human Anatomy and Physiology	4
	Radiation Physics	4
	Dosimetry and Radiation Protection	4
	Physics of Diagnostic Radiology	4
	Medical Physics Practical	4
Semester II		
Core	Nuclear Medicine and Radiotherapy Physics	4
	Medical Physics Practical II	4
Elective	Ultrasound and Magnetic Resonance Imaging	2
	Radiobiology and Radiation Chemistry	2
Compulsory	Research Project	8
	Total credits	**40**

VIII. IPEM ACCREDITATION

The University of Malaya, in her quest to achieve excellence and international benchmarking, applied to the Institute of Physics and Engineering (IPEM), U.K. for the accreditation of the Master of Medical Physics programme.

On September 30 and October 1, 2004 two IPEM assessors, namely Professor Tony Evans and Professor Alun Beddoe, visited the University to carry out the accreditation process. This included: inspection of examination questions, outline answers, answer scripts; interviewing of teaching staff, current and ex-students; inspection of training facilities, laboratories, libraries, etc.

At the end of the visit, the assessors were satisfied with the high standard of the programme and they conveyed to us that we were successful. However they raised a few concerns that we have to address within a set time-frame, the major of which is the shortage of experienced teaching staff especially in the area of radiation oncology. The others are minor but relate to the method of assessment i.e. the style of the questions set.

The official notification and details were sent to the University after the IPEM council meeting on November 11, 2004. The recognition was for a 5-year period (October 2002 – October 2007) during which time we must progress towards overcoming the shortcomings that they have listed by submitting an annual report.

This is the first instance where recognition was awarded outside the British Isles. IPEM accreditation is very difficult to achieve since not only must the MSc Medical Physics degree undergo independent scrutiny by the Council of the IPEM but the external examiners and students involved, must also show high academic achievement.

Implications for the University of Malaya include:

1. The Master of Medical Physics of the UM programme has been awarded an international recognition never previously given to any other university programmes outside the United Kingdom and Ireland.
2. However we need to recruit more senior staff at the level of professor and associate professor to support the programme.
3. We have enquired with numerous eminent international medical physicists if they would like to take up our offer of a senior post but thus far we have not been successful. We will continue trying.
4. The programme has been operating with no additional funding or staffing to the Department of Biomedical Imaging, the budget for the purchase of books and teaching tools, etc. all additional programmes are operating with existing staffing.

In 2008, the programme was successful in securing a second reaccreditation from IPEM. This accreditation extended the accreditation till 31 August 2012. Dr. DA Bradley and Dr. H Porter visited the university in September 2007 for the accreditation purpose. In 2013, this programme was granted an extension of the accreditation until August 2015.

Any course accredited by IPEM will be eligible for the IPEM Student Prize Award Scheme. The student will receive a prize certificate and a cheque for £250(4). Table 8 shows the list of IPEM award recipients from 2011 to 2014.

Table 8: Recipients of IPEM student prize awards

Year	Recipients
2011	GS Sim
2012	N Abdullah
2013	JS Yong
2014	YL Woon

IX. DEMOGRAPHICS AND STATISTICS

Since the starting of the Master of Medical Physics programme in 1997, 86 students had graduated from this programme (Figure 1). Amongst them, 52 were female and 34 were male. More than 89% of the students were from Malaysia. The programme has also garnered much response from the international community (Figure 2). The programme is also recognised by the IAEA as a training programme for medical physicists, particularly for the training and development of medical physicists in the developing countries such as Cambodia. For the past three years, the IAEA has sent two students, funded under the IAEA fellowship to this programme.

The programme is structured to be a one-year programme. Most students (84.9%) completed the course within the stipulated one year programme (Figure 3). 7.0% of the students completed the course within two years. 7.0% of the students dropped out of the programme due to various personal reasons.

The graduates from this programme have been highly appraised by the industry with the employment rate of more than 88% (Figure 4). Amongst those employed, it was not surprising that a vast majority of the graduates worked as physicists, particularly in radiotherapy (Figure 5 and Figure 6). A large number of the graduates have also went on to further study (PhD) and joined the academia (8.1%).

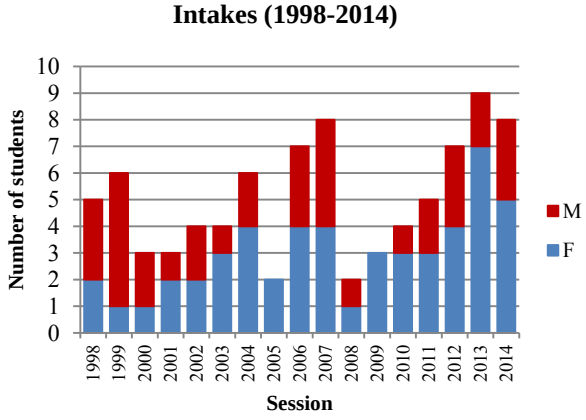

Figure 1: Number of student intakes from 1998 to 2014

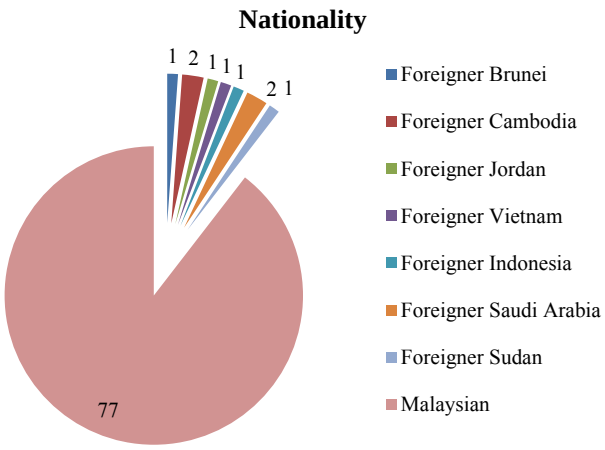

Figure 2: Nationality of the alumni

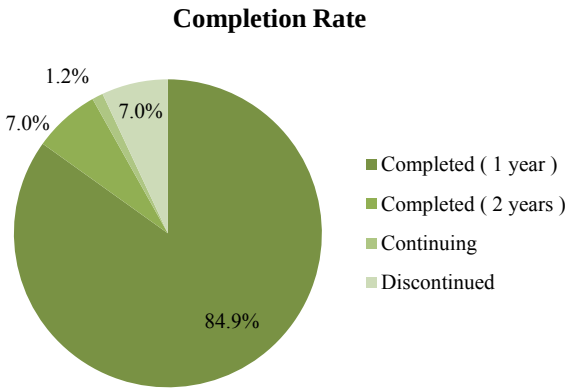

Figure 3: Completion rate of the alumni

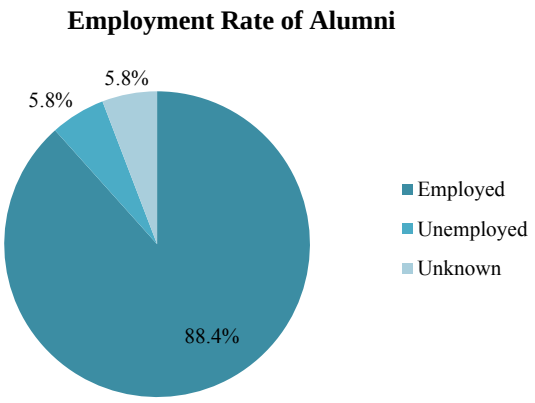

Figure 4: Employment rate of alumni

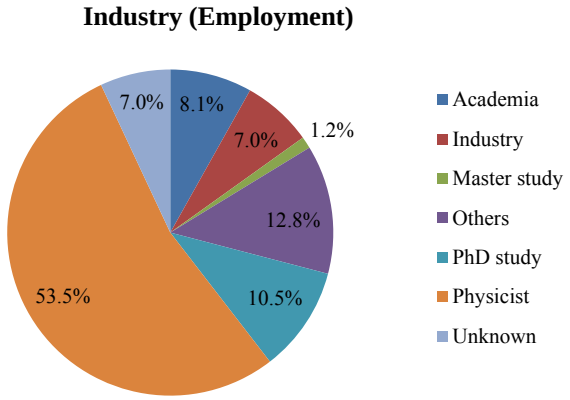

Figure 5: Distribution of alumni working in various sectors

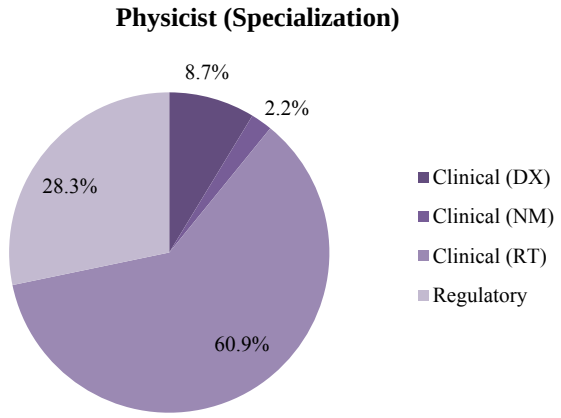

Figure 6: Clinical specialization distribution of alumni working as physicists.

X. STUDENT ACTIVITIES

The Master of Medical Physics programme of University of Malaya pride itself as a programme that aims to provide a holistic approach to the education of medical physics. The students were encouraged to participate in various activities, within and outside of the programme framework. These includes carrying out practicals (Figure 7) and research projects (Figure 8) at various departments. The students were encouraged to present their research projects by participating and presenting in various local, regional and international conferences (Figure 9). These exposures are important to develop various soft skills, training them to be all rounded individuals. In addition to attending conferences, the students, under the leadership of the medical physics professor and lecturers had participated in organising conferences (Figure 10).

In terms of teaching, we have engaged prominent researchers and medical physicists in complementary teaching, either via tele-teaching method (Figure 11) or by inviting them over to the university (Figure 12). The students were also kept updated with the trends and development of the field when the then IOMP president, Dr. KY Cheung visited our university in 14 May 2014 and gave a lecture on the "Global Development of Medical Physics – IOMP Perspective" (Figure 13).

At the International Congress of Medical Physics (ICMP) Brighton, 2013, Professor KH Ng, was recognized as one of the top 50 medical physicists in the world (Figure 14).

Figure 7: Practical session conducted in the radiotherapy department.

Figure 8: Students carrying out various research projects.

Figure 9: A strong presence of the Medical Physics team from the University of Malaya attending and presenting at the 13th AOCMP and 11th SEACOMP Congresses in Singapore (2013).

Figure 10: Student organizers for the EMF conference 2007 posing with some of the invited speakers.

Figure 11: Teleteaching session with Professor P Sprawls.

Figure 12: Students posing with Visiting Professor, Prof. Dr. Anatoly Rozenfeld after his lecture (2014).

Figure 13: The then IOMP president, Dr. KY Cheung visited our university and gave a lecture on the "Global Development of Medical Physics – IOMP Perspective".

Figure 14: Professor KH Ng recognized as one of the top 50 medical physicists in the world by the IOMP.

XI. CHRONOLOGY OF IMPORTANT MILESTONES

Table 9 shows the important milestones of the Master of Medical Physics programme, University of Malaya, Malaysia. Over a period of two decades, the programme has certainly come of age. From the humble beginning of one medical physics lecturer, with 5 students in 1997 to a full fledge team of medical physics academics (1 professor, 4 senior lecturers (with PhD qualifications), 2 lecturers (with master qualifications), and 1 trainee lecturer (on PhD study). The student intake has also increased to 16 in 2015.

Table 9: Important milestones of the Master of Medical Physics programme, University of Malaya, Malaysia.

Year	Milestones
1997	Set up of the Master of Medical Physics programme, University of Malaya
1998	1st intake of students (5 students)
2002	1st curriculum review
2004	Obtained IPEM accreditation (valid from 2002 – 2007)
2005	2nd curriculum review
2007	IPEM reaccreditation (valid from 2007 – Aug 2013)
2010	3rd curriculum review (MQF compliant)
2013	Extension of IPEM accreditation (valid from 2013 – Aug 2015)
2015	4th curriculum review

The Master of Medical Physics programme at the University of Malaya has largely maintained the same structure and content of the medical physics education since its inception in 1997.

However, the landscape of medical physics is experiencing drastic changes, with molecular revolution and with the advent of newer technologies such as nanotechnology, drug discovery, pre-clinical imaging, optical imaging and bioinformatics.(5)

The traditional distinction of the three major medical physics field (radiology, radiotherapy and nuclear medicine) is gradually blurring with knowledge and technology being more and more multi-disciplinary and cross-disciplinary in nature. Conventional method of training, confined within the traditional areas of medical physics may not be adequate in the near future. Perhaps, it is high time for medical physics education to embrace contemporary sciences e.g. molecular biology, systems biology, synthetic biology, nanotechnology, advanced materials, bioinformatics, spectroscopy, etc. Thinking beyond the narrow confines of our own discipline – e.g. chemistry, molecular biology and other subjects may become relevant depending on which area of innovation we decide to immerse ourselves in. Cross-fertilization between various disciplines often yields innovative ideas and techniques. (5)

With a positive outlook and the right approach, the next generation of medical physicists will remain relevant and could confidently look forward to making more significant contributions to achieve higher standards in healthcare.

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EDUCATIONAL RESOURCES

IAEA EDUCATION AND TRAINING ACTIVITIES IN MEDICAL PHYSICS

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Abstract— **The IAEA's core mission is to promote and verify the safe, secure and peaceful use of nuclear sciences and technologies with the aim of reaching peace, health and prosperity throughout the world. The IAEA specifically address the important topic of health through its Human Health programme, which aims at supporting Member States in building their capacity to prevent, diagnose and treat health problems by applying nuclear and radiation-based techniques in the most effective way. Consequently, medical physics, as the discipline that tackles optimization and quality assurance in medical applications of radiation, is an important area of expertise that must be supported and nurtured. The lack of adequate academic education and clinical training, as well as continuous professional development, is an important issue for the medical physics profession that affects many countries and that can lead to ineffective and sometimes harmful uses of radiation in diagnosis and therapy of patients. The IAEA is committed to support education, training and continuous professional development (CPD) of medical physicists worldwide to ensure the achievement of the highest level of quality and effectiveness of diagnostic and therapeutic procedures involving ionizing radiation. To achieve this goal, the IAEA offers to Member States a variety of education and training tools and activities with the drive of addressing specific situations through tailored intervention while harmonizing the overall level of medical physics applications worldwide. The ultimate achievement resides in guarantying to patients the same highest standard of diagnostic and treatment procedures employing ionizing radiation wherever in the world.**

Keywords— ***Medical physics, education and training, competency building, guidelines***

I. INTRODUCTION

Education and training are important components of the work of the International Atomic Energy Agency (IAEA) [1], since they represent a way to ensure the achievement of the highest level of effectiveness and safety in every application of nuclear technologies, including the protection of human health and the environment against ionizing radiation. Support to education directly originates from the IAEA's mandate linking to the strengthening and spreading of the safety culture in Member States. The IAEA's core role is to promote and verify the safe, secure and peaceful use of nuclear sciences and technologies with the aim of reaching peace, health and prosperity throughout the world. The IAEA's Member States (164 as of July 2015) can benefit from technical and specialized assistance and be supported in different ways, including education and training, in reaching their developmental goals through a peaceful, safe and effective use of nuclear technologies. The IAEA role includes support to Member States for the application of nuclear sciences and technologies in the most effective way, providing scientific guidance and fostering harmonization of procedures among countries. The IAEA is formally authorized by its Statute to "establish standards of safety for protection of health and to provide for the application of these standards". For this purpose, international safety standards are developed, published and disseminated, in an effort to achieve standardization and encourage best practices. As an example, the International Basic Safety Standards (BSS) for Protection against Ionizing Radiation and for the Safety of Radiation Sources aims at establishing basic requirements for protection against the risks associated with exposure to ionizing radiation and for the safety of radiation sources that may deliver such exposure [2]. These Standards have been developed from widely accepted radiation protection and safety principles, endorsed by the main partner organizations: the European Commission (EC), the Food and Agriculture Organization of the United Nations (FAO), the IAEA, the International Labour Organization (ILO), the OECD Nuclear Energy Agency (OECD/NEA), the Pan American Health Organization (PAHO), the United Nations Environment Programme (UNEP) and the World Health Organization (WHO). The BSS also provide an agreed on definition of the role and duties of medical physicists, an important point in the process of supporting the recognition of the medical physics profession worldwide. Health is a specific area of interest of the IAEA and through its Human Health programme [3], the IAEA responds to the needs of Member States, supporting the enhancement of their capacity to prevent, diagnose and treat health problems by applying nuclear and radiation-based techniques. Consequently, medical physics, as the discipline that tackles

optimization and quality assurance in medical applications of radiation, is one of the core topics included in this area of interest. Through the work of the Dosimetry and Medical Radiation Physics Section [4], the IAEA supports activities specifically related to medical radiation physics, focussing on clinical and highly specialized technical topics in radiotherapy and diagnostic imaging (nuclear medicine and diagnostic and interventional radiology). The spreading of the culture of quality and the technical support to medical physics are carried on in different forms including support to education, production of specific publications and training activities.

II. HARMONIZATION OF MEDICAL PHYSICISTS' EDUCATION AND TRAINING

The roles, responsibilities and, consequently, clinical training requirements of medical physicists are still today very diverse among countries. The medical physics profession plays a key role in the safe and effective application of medical diagnostic imaging and therapy. Therefore, the IAEA is dedicated to work toward the definition of internationally endorsed roles and responsibilities of medical physicists, establishing harmonized requirements for education and supporting and promoting clinical training worldwide.

The lack of adequate academic education and clinical training, as well as continuous professional development, is an important issue for the medical physics profession that affects many countries. Medical physicists are health professionals with specialist education and training in the concepts and techniques of applying physics in medicine [2]. They are competent to practise independently in one or more of the specialties of medical physics and their responsibilities include as well being in charge of the maintenance of a correct quality management program of high technology medical equipment. Therefore, providing adequate education and training of medical physicists is an important point in the process of ensuring quality and effectiveness in the use of radiation in human health. Currently, a wide spectrum of different levels of education can be found in different countries, sometimes even inside the same country, as a result of lack of recognized and well-structured educational programmes. The IAEA directly addressed in a specific publication the recommendations for the academic education and training programmes of clinically qualified medical physicists, including guidelines for their accreditation, certification and registration, along with continuous professional development. This publication, "Roles and Responsibilities, and Education and Training Requirements for Clinically Qualified medical physicists" [5], has been jointly endorsed by the International Organization for Medical physics (IOMP) and the American Association of Physicists in Medicine (AAPM). The publication introduces the denomination of Clinical Qualified Medical Physicist (CQMP) which corresponds to the same level of training and education of "qualified expert in medical physics" defined in the BSS [2] and the "medical physics expert" defined by the European Council Directive 2013/59/Euratom [6]. In support to the previously described publication and in response to an increasing number of Member States seeking support to establish specific education paths in medical physics, the IAEA worked to provide guidelines for a postgraduate academic education programme for medical physicist, issuing "Postgraduate Medical Physics Academic Programmes", also endorsed by the International Organization for Medical Physics (IOMP) [7]. In addition to academic education, medical physics' students should be required to undertake specialized clinical training which needs to be monitored, properly structured and supervised. It is also recommended to put in place a formal mechanism for registration and/or accreditation or certification; this would help to maintain a verified level of professionalism, fostering the organization of continuous professional development (CPD) programs. A proper harmonization and certification is also a first step towards the adequate recognition of the profession of medical physicist, a common problem in many countries. To support the establishment of structured practical clinical training programmes for medical physicists, the IAEA has issued three Training Course Series publications (Figure 1), which provide references and guidelines to clinical training material for medical physicists specializing in radiation oncology (TCS-37 [8]), diagnostic radiology (TCS-47 [9]) and nuclear medicine (TCS-50 [10]).

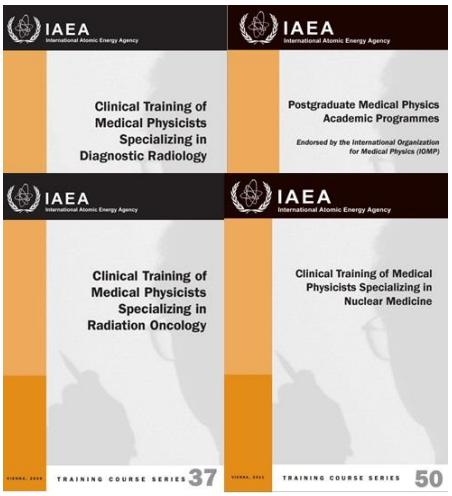

Fig. 15 IAEA Training Courses Series on education and training of medical physicists

III. DEVELOPMENT OF EDUCATIONAL AND TRAINING MATERIAL

Publications of guidelines represent an important tool for the dissemination and support of best practices in quality assessment and management. Furthermore, in the medical

physics area, special attention has been dedicated to the production of three comprehensive handbooks (Figure 2) in Radiotherapy Physics [11], Diagnostic Radiology Physics [12] and Nuclear Medicine Physics [13].

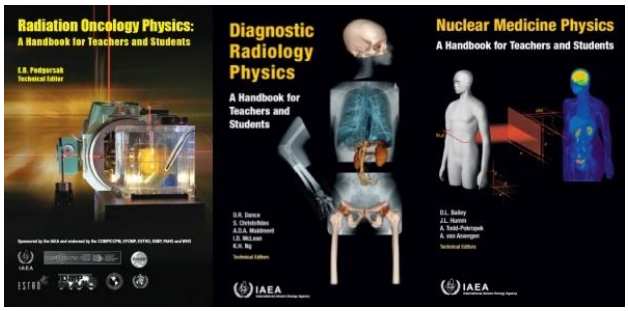

Fig. 2 IAEA freely downloadable handbooks

These handbooks, produced by international leading scientists, aspire to serve as primary text for medical physics students and reference support for lecturers and professionals. For the Radiotherapy Physics and the Diagnostic Radiology handbook, freely downloadable PowerPoint slides are also offered (currently in preparation for Nuclear Medicine Handbook) to ease the use of these Handbooks by teachers. To promote the diffusion of the highest level of education in an affordable way, all of the handbooks and related material are made available for free download from the IAEA website [14].The IAEA also aims at supporting the everyday work of medical physicists in hospitals, providing help in standardizing it according to international and widely accepted best practice. For this reason, the IAEA issues publications that can be used as guides for applications in a clinical environment and that are available on the website [15]. These publications address major broad topics or more specialized ones, which are relevant for the medical physics community. These needs are identified by the IAEA through consultancies with professional societies and international experts, with the aim of addressing the most relevant topics in a comprehensive way. Special attention is dedicated to commissioning and quality assurance, since these activities are important for the application and maintenance of quality management procedures in the use of nuclear science and radiation technologies for human health. Furthermore, standardizing these procedures will help to harmonize quality and efficiency in the use of radiation for diagnosis and treatment worldwide. Guidelines and technical reports on acceptance testing, commissioning and quality assurance (QA) procedures are available for both equipment and patient-related procedures in radiotherapy [16, 17, 18, 19], radiology physics [20, 21, 22, 23] and nuclear medicine physics [24, 25, 26, 27]. Specific codes of practice are also published for radiotherapy dosimetry [28, 29, 30], as well as publications on clinical dosimetry [31], publications on dosimetry in X-ray diagnostic radiology [32, 33, 34] and radioactivity measurements in nuclear medicine [35]. Specific publications are also available to provide support in the application of best practices during the process of planning and setting up clinical radiation facilities [36, 37, 38, 39].In the case of centres planning a change or transitioning to new technologies, publications are issued to offer guidance and expert advice for the process [40, 41]. All publications can be freely downloaded from the IAEA's website [15].

IV. Guidance, Training, Competency Building and Research Activities in Medical Physics

In addition to publications and guidelines, the IAEA is committed to practically support their clinical application, fostering the maintenance and implementation of quality procedures worldwide. The IAEA also offers support through its dosimetry audit services to Member States, for example by providing postal dose verification of radiotherapy beam outputs. Through the IAEA Dosimetry Laboratory, located in Seibersdorf, in the framework of the IAEA/WHO Network of SSDLs [42], support in the correct application of guidelines and dosimetric measurements is provided to Secondary Standards Laboratories (SSDLs) and radiation therapy centres in Member States on regular basis, for applications in radiotherapy, diagnostic radiology and radiation protection. Thermoluminescent dosimeters (TLD) are sent to participating radiotherapy centres and SSDLs who request the services, irradiate under specific conditions by the participants, then return them to the IAEA for readout and analysis. The dose received by the TLD is compared with the intended dose stated by the staff of a participating institution. When discrepancies are detected, the IAEA establishes a follow-up programme for quality improvement, including on-site visits by local or international experts, as required. In response to requests by Member States, the Agency provides this way dose quality audits to over 1500 end-user institutions in regions that have no other means to participate in a dose verification process. Member States can receive different types of direct support and training by the IAEA through the specific Technical Cooperation (TC) programme [43]. The TC programme supports transfer of know-how and technology through the procurement of equipment, training and expert missions, and operates in four geographic regions: Africa, Asia and the Pacific, Europe and Latin America. Through TC, the IAEA directly supports medical physicists worldwide, responding to Member States' requests in different and customized ways: providing guidance from international experts for specific tasks, helping organize on-the-job training, granting fellowships to professionals working in medical physics for well-defined training. Support is also provided for building competencies on a large scale, for example, setting-up national medical physics education and clinical training programs in Member States. Through TC, the IAEA offers for example the possibility of a comprehensive audit to assess the whole radiotherapy

process [44, 45] or imaging modalities [46, 47]. These comprehensive peer-review missions aim at evaluating the effectiveness and quality of all components of the practice at the institution, including safety, as well as professional competences and training activities. IAEA activities also include the organization of workshops, conferences and meetings at a national, regional and international level to address specific subjects and topics of interest for the worldwide medical physics community. Furthermore in the Laboratories in Seibersdorf, the IAEA has also set up a gamma camera laboratory, which is used to develop and implement practical courses on topics considered essential for practical training of medical physicists specializing in Nuclear Medicine. The request of support by the IAEA through the TC programme is based on formal requests that have to be completed on-line [48] and submitted to the IAEA through the relevant national authorities. Requests for fellowships and scientific visits, and for participation in meetings, workshops and trainings, should be related to an on-going IAEA TC project, and must be channelled through the National Liaison Officer of the applicant's country. The IAEA also encourages research in medical physics through dedicated Coordinated Research Activities (CRAs). These projects aim at transferring knowledge and know-how among the participants while achieving specific research and development objectives consistent with the IAEA programme of work. Most of the CRAs are carried out under Coordinated Research Projects (CRPs), which bring together experts from high income to lower and middle income countries to work and collaborate on topics of common interest. Examples of ongoing CRP in medical physics are Doctoral CRP in "Advances in Medical Imaging Techniques" [49] and "Development of Quality Audits for Advanced Technology (IMRT) in Radiotherapy Dose Delivery" [50]. The CRP participants prepare the project work plan, regularly meet and review the ongoing work, thus creating a network that often favours new collaboration and leads to new developments. The IAEA ensures that the end results of the research and collaboration activities are freely available to all its Member States. This is usually achieved through the publication of the results in the form of a technical document, an IAEA report or in the open literature. To participate in the CRAs, proposals should be prepared by institutes in IAEA Member States and submitted to the Research Contracts Administration Section [51].

V. Human health campus website

The IAEA, besides its general website, also offers an entire web platform dedicated to learning, the Human Health Campus [52]. On this platform (Figure 3), different areas of science applied to human health are covered, including medical radiation physics.

Fig. 3 IAEA Human Health Campus website

This web space has been created by the IAEA with the aim of becoming a free reference virtual resource centre for professionals and students who work in health, providing coverage for the main topics related to every relevant scientific area and selected link to useful documents. Under the medical physics section, educational material and references can be found for the three main subspecialties (Diagnostic Radiology, Radiotherapy and Nuclear Medicine). For each subspecialty, a wide offer of selected references is available, including links to IAEA publications but also international references and journal articles. A special chapter is dedicated to the medical physics career, professional roles and responsibilities, continuing professional development (CPD) and the educational and training requirements.

VI. Conclusions

Medical physics plays an important role in the effectiveness and quality of clinical applications of radiation therapy, nuclear medicine and diagnostic radiology; this is more and more evident considering the fast and major improvements of technology. Treatment and diagnosis are intertwined with technology and computer tools, and are becoming increasingly complex. The medical physicist is called to verify and ensure the correct functioning of these high tech systems and, at the same time, to favour the link between technology and medicine. The work of a medical physicist is then constantly evolving. Multiple diverse skills are requested and must be acquired, maintained and developed. The IAEA, as an international hub, collect inputs from all over the world and identifies the gaps and needs for assistance, especially in training and continuous education. At the same time, the world situation is very diverse and it is then necessary to customize the support. The IAEA is working to support and harmonize the medical physicist work worldwide, providing tools, responding to immediate needs and, at the same time, planning on long term actions to achieve improvements in efficacy and safety of medical application of radiation for the benefit of patients worldwide.

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TEACHING RADIOTHERAPY PHYSICS CONCEPTS USING SIMULATION: EXPERIENCE WITH STUDENT RADIOGRAPHERS IN LIVERPOOL, UK

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Abstract— **Therapeutic radiography students (student radiation therapists) are challenged with acquiring a wide range of clinical, empathetic and technical skills for the benefit of cancer patients. Certain aspects of the technical skills (radiotherapy physics) can be difficult since they are not practical experiences encountered by the students' first-hand in their clinical placements. As part of a wide ranging, blended learning approach, real-world technology is used in our directorate together with hybrid virtual radiotherapy systems (VERT^{TM}) to enhance student learning and provide an engaging, safe and effective environment for it. This paper discusses our experiences with the physics module of VERT^{TM} with year groups disseminated into small groups to undertake practical experiments using the VERT^{TM} system in the same way one would use a real clinical linear accelerator for teaching with dosimetric equipment. Key concepts such as inverse square law and dosimetric consequences of incorrect set-up (SSD), measurements of quality control parameters and derivation of key data charts were the three main experiments examined here. Undergraduate and postgraduate radiotherapy students were divided into workgroups with specially designed training and workbooks for performing calculations and verifying predictions with simulated dosimetric measurements. Our results, from evaluations performed by all students, coded and analysed into common themes of response, showed that students engaged extremely well with the process, finding these methods valuable, practical and engaging particularly in terms of linking theory and practice and enhancing their skills. Minimal less positive responses were received and the majority appreciated the individualized tutoring which was the natural result of small groups engaged with the virtual software and this highly kinesthetic environment. We found that VERT^{TM} Physics and this practical method of simulated dosimetric measurements is a highly productive learning environment; helping students apply theory to clinical situations and learn in a more illustrative and dynamic way.**

Keywords— **Simulation, radiotherapy physics, radiographers, virtual environment, VR.**

I. INTRODUCTION

The teaching of modern, 21st century radiotherapy to therapeutic radiography students (student radiation therapists) is challenging, requiring the development of in-depth clinical and empathetic skills with appropriate patient care and compassion, with sufficient understanding of complex radiation physics and technology. The latter is understandably difficult, since elements of (for example) beam data generation, quality control measures and radiation dosimetry are not experiences encountered first-hand in clinical placements.

It is found that for the allied health workforce, a blended learning approach is often viewed as best practice for developing these complex qualitative and quantitative skills – by carefully integrating online and web-based learning methods with more traditional face-to-face experiences [1]. The approach also ensures that the teaching is both research-led and research-informed - two of the key research typologies proposed by Griffiths (p11 of [2]), producing an environment which is research based and highly valued by students in their learning experience [3].

Within the University of Liverpool, our aims and objectives have always been to do this and take the blended approach a step further; expanding the range of experiences and learning strategies, and developing skills (complementary with clinical competencies) using real-world radiotherapy technology. This is naturally achieved in the clinical placement setting, but can also be complemented by a range of real-world radiotherapy technologies and software in the academic setting – lending itself to a safe but clinically effective environment [4, 5].

The use of the Virtual Environment for Radiotherapy Training (VERT^{TM}) (www.vertual.co.uk) has been a key component in this approach in our university and across the UK for many years [6-8], providing a hybrid virtual environment skills facility, initially simulating radiotherapy equipment and treatment rooms, and then developing to visualize anatomy and planned dose distributions for both simple and more complex radiotherapy techniques (from, for example, simple single fields to complex IMRT and VMAT). Following a potential crisis in England for training staff and students for radiotherapy treatment of cancer, in 2007/8 the UK government provided VERT^{TM} to all clinical radiotherapy departments and those universities involved with radiotherapy education. Since that time, the use of VERT^{TM} has developed internationally for the highly successful training of student and qualified radiographers (radiation therapists) [9-12] through its various hardware and software platforms (www.vertual.co.uk) – from full 3D immersive laboratory facilities (a 'hands on' mode with real radiotherapy equipment hand pendants) to desktop/laptop/tablet versions for demonstrating radiotherapy planning, anatomy and delivery to staff and patients alike using workbooks and other methods. The software is not open source or freely available; it is a commercial product, but its various software versions enable it to be used in more modest economies (e.g. with a

laptop and extended desktop to a large monitor) very effectively

Recent developments in the software have introduced components which help students with some of the fundamental concepts and practicalities of radiotherapy physics [13-15], with the advantages again of helping students learn these challenging topics (which are more remote from their clinical day-to-day experiences) in a safe and accessible environment. Our experience with using the software for teaching student radiographers at both undergraduate and postgraduate level in this highly kinesthetic manner is the focus of this paper; where the VERT^{TM} Physics package is used to demonstrate not only commonly used dosimetric equipment and it use, but also to simulate a medical linear accelerator (linac) for performing virtual dosimetric experiments. The work reported here has been run with second year undergraduates and both first and second year postgraduate radiotherapy students for the last two academic years – approximately 40 in total for each year.

II. Materials and Methods

A. Methods

A.1 Groups and revision lecture: Each year group was divided into smaller groups, with a maximum of 7 students in each. This was done to ensure that the 'hands-on', kinesthetic nature of the practical work could be undertaken by all students. For the first year of working with the software, a formal lecture was held immediately prior to the practical work to help students revise and recall the foundational scientific concepts for the 'virtual' experiments which would be performed (Fig 1). This recap focused on;

(i) the concept of inverse square law and the dosimetric effects to the patient of setting incorrect SSDs

(ii) the collection of central axis percentage depth dose data (using a water tank) and the measurement of quality indices in routine quality control checks and

(iii) the collection of data and the derivation of field size factors for manual monitor unit calculations.

This lecture was not undertaken in the second year, in order to allow more time for practical experiments – in direct response to the student evaluations.

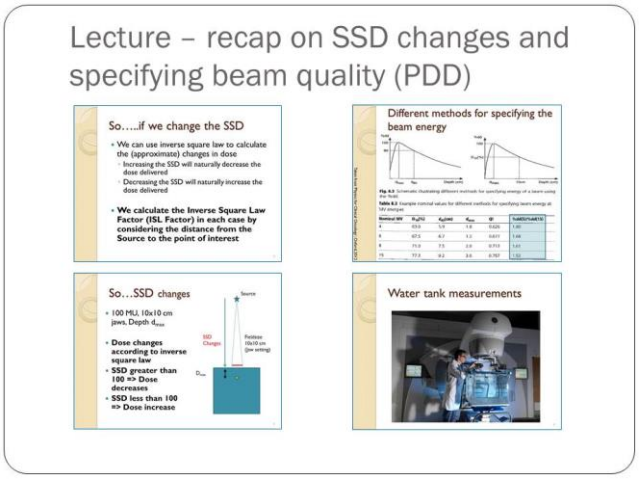


Fig. 1 Example of the presentation slides given during the revision lecture before the practical experiments using VERT^{TM}

A.2 VERT^{TM} Physics overview: At the start of the practical experiments, a demonstration overview of the VERT^{TM} Physics software was given by the tutor, followed by detailed instructions on how the students would use the software in conjunction with the virtual linac. Aspects of the demonstration are shown in Figure 2.

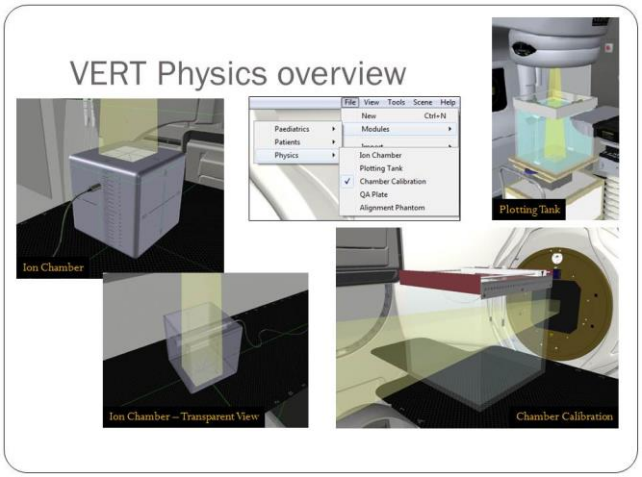


Fig. 2 The demonstration overview given to students of the VERT^{TM} Physics software, prior to practical experiments

The demonstration included dosimetric methods using a Farmer type ionization chamber within a tissue equivalent solid water phantom; typical data collection using a water tank (central axis depth dose curves and beam profiles); and the principles of cross-comparison for ionization chamber calibration. Being a virtual system, the concepts of isocentricity and alignment were also demonstrated using modes whereby the solid water phantom could be rendered translucent.

A.3 Practical work – simulated 'virtual' linac experiments: The main focus of the sessions, however, was practical 'virtual' experiments undertaken with the VERT^{TM} Physics software. The software allowed for virtual irradiations (of equal monitor units) for two different x-ray beam energies (6 and 15 MV) for a range of field sizes and a variety of depths within the ionization chamber solid water phantom. The student groups of approximately 7 were split into two further groups so that one group could practically 'set-up' the experiment using the linac hand pendant (the 'measurement group') whilst the other attempted the required calculations for each experiment (the 'calculation group'). Ion chamber depths in the phantom were set-up using the software controls to required depths, but all other parameters (couch height, collimator and gantry rotation, collimator settings) were set-up manually using the hand pendant. This simulated a completely independent set-up of phantom and ionization chamber; all parameters being changed before the groups swapped over for further experiments. Each student had an individual workbook and set of instructions indicating the objectives of the experiments and the methods required for performing the virtual dosimetric measurements. Each student completed their own workbook, but only after working as a team for the calculations and with the measured data on whiteboards to enhance the practical, kinesthetic aspects of learning together. All students had the opportunity to tutor each other regarding the calculations with the help of individual and group guidance from the tutor. Students in the 'measurement group' were encouraged to help each other with the use of the linac hand pendant, especially if the linac was one which they were unfamiliar with in clinical practice. Once an individual experiment was completed, the 'measurement' and 'calculation' groups would swap over – so one half concentrated on the practical set-up of the linac, the other on the calculations for the next virtual experiment.

Figure 3 illustrates the fully immersive 3D VERT^{TM} suite at the University of Liverpool with its life-size simulation of a radiotherapy treatment room and displaying the virtual linac with its solid water phantom (left), the dosimetry interface for measuring each radiation 'exposure' (top-right), and the linac control panel displaying parameters such as collimator settings, gantry angle etc. (bottom-right). The 3D back projection display is approximately 4 m wide by 2 m high.

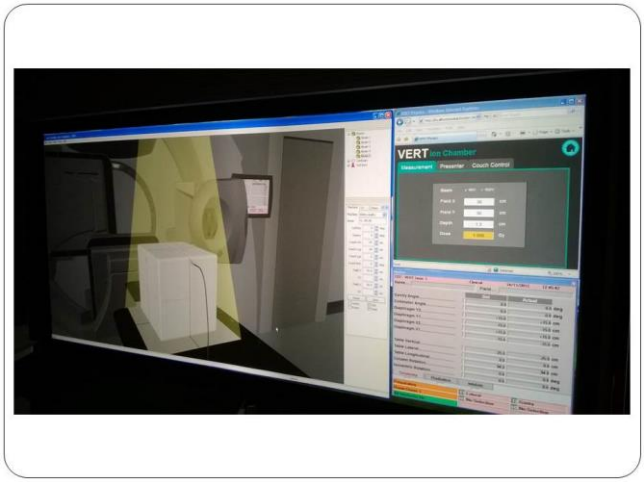
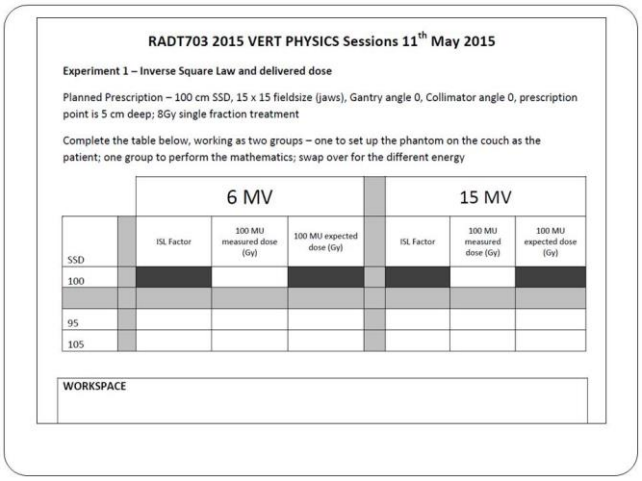


Fig. 3 The fully immersive 3D VERT^{TM} suite at the University of Liverpool, arranged for demonstrating the ionization phantom, the dosimetry measurement panel and the linac set-up parameters

The three virtual experiments used were the following:

A.3.1 Inverse square law and delivered dose: Here the intention was to simulate the dosimetric effect of incorrect SSD set-up for a single field. The ionization chamber in the virtual solid water phantom was used. The 'measurement group' used the hand pendant to set-up the parameters shown in figure 4; with the intended (planned) SSD of 100 cm.



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Experiment 1 – Inverse Square Law and delivered dose

Planned Prescription – 100 cm SSD, 15 x 15 fieldsize (jaws), Gantry angle 0, Collimator angle 0, prescription point is 5 cm deep; 8Gy single fraction treatment

Complete the table below, working as two groups – one to set up the phantom on the couch as the patient; one group to perform the mathematics; swap over for the different energy

	6 MV			15 MV		
SSD	ISL Factor	100 MU measured dose (Gy)	100 MU expected dose (Gy)	ISL Factor	100 MU measured dose (Gy)	100 MU expected dose (Gy)
100						
95						
105						

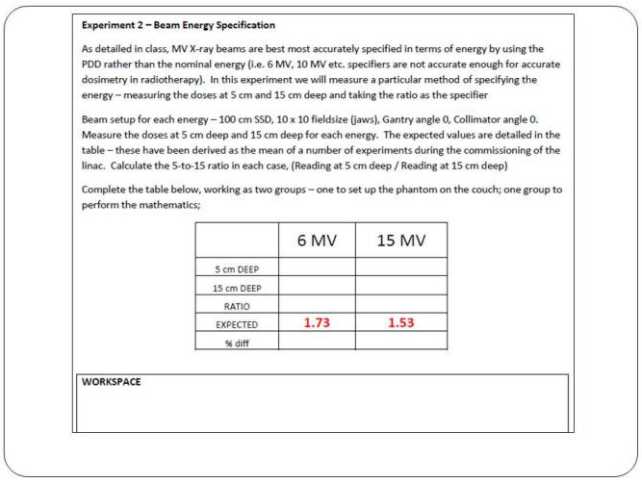
WORKSPACE

Fig. 4 The workbook page for the first virtual experiment (A.3.1) – inverse square law and delivered dose

Whilst this was undertaken, the 'calculation' group calculated the relevant inverse square law factor (ISL Factor) to predict the delivered dose for the two scenarios of an incorrect set-up of 95 SSD and 105 SSD. Once the virtual dosimetric measurements were made at 100 cm SSD, the calculation group applied their predictive inverse square

law factors to predict the resultant readings for 95 and 105 cm SSD, whilst the measurement group members adjusted the couch height to perform the virtual measurements. The predicted and measured readings were then compared and discussed with regard to whether the error in SSD would be dosimetrically significant for the patient.

A.3.2 Beam energy specification (quality index): Here the intention was to simulate typical quality control measures which could be undertaken for checking the x-ray beam energy (quality index) on a routine basis (Figure 5). The 'measurement group' and the 'calculation group' swapped roles, so that the required set-up was achieved using the hand pendant of the virtual linac (as detailed in Figure 5), whilst the new 'calculation group' discussed the way the quality index would be calculated, together with the percentage difference from the nominal, expected value for each energy for comparing with the parameter tolerance of 1%. Virtual measurements were made at the required depths for both x-ray beam energies and the results analysed by all students.



Experiment 2 – Beam Energy Specification

As detailed in class, MV X-ray beams are best most accurately specified in terms of energy by using the PDD rather than the nominal energy (i.e. 6 MV, 10 MV etc. specifiers are not accurate enough for accurate dosimetry in radiotherapy). In this experiment we will measure a particular method of specifying the energy – measuring the doses at 5 cm and 15 cm deep and taking the ratio as the specifier

Beam setup for each energy – 100 cm SSD, 10 x 10 fieldsize (jaws), Gantry angle 0, Collimator angle 0. Measure the doses at 5 cm deep and 15 cm deep for each energy. The expected values are detailed in the table – these have been derived as the mean of a number of experiments during the commissioning of the linac. Calculate the 5-to-15 ratio in each case, (Reading at 5 cm deep / Reading at 15 cm deep)

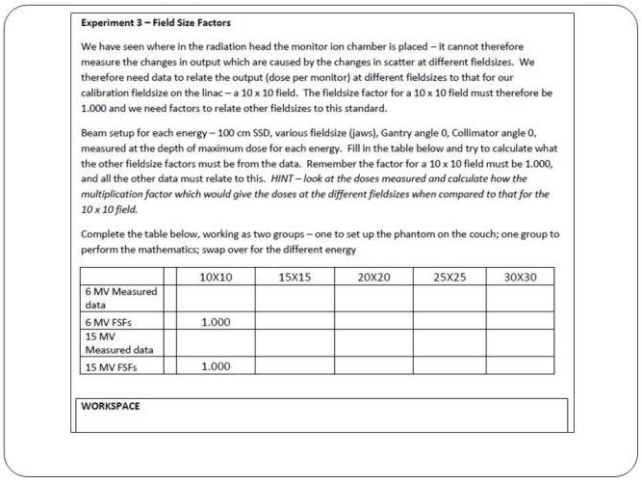
Complete the table below, working as two groups – one to set up the phantom on the couch; one group to perform the mathematics;

	6 MV	15 MV
5 cm DEEP		
15 cm DEEP		
RATIO		
EXPECTED	1.73	1.53
% diff		

WORKSPACE

Fig. 5 The workbook page for the second virtual experiment (A.3.2) – beam energy specification (quality index)

A.3.3 Field size factors: Here the intention was to simulate typical measurements used to acquire and create a field size factor table for use with manual monitor unit calculations (for, for example, typical isocentric parallel opposed pair treatment fields). The 'measurement' and 'calculation' groups swapped roles again, with the 'measurement group' undertaking practical set-up and virtual measurements for a series of fieldsizes, as detailed in figure 6. The 'calculation group' would discuss how to create the field size factor tables, knowing that the field size factor for a 10 x 10 field would need to be unity, and all other factors relate to this. The typical whiteboard workspace is shown in figure 7.



Experiment 3 – Field Size Factors

We have seen where in the radiation head the monitor ion chamber is placed – it cannot therefore measure the changes in output which are caused by the changes in scatter at different fieldsizes. We therefore need data to relate the output (dose per monitor) at different fieldsizes to that for our calibration fieldsize on the linac – a 10 x 10 field. The fieldsize factor for a 10 x 10 field must therefore be 1.000 and we need factors to relate other fieldsizes to this standard.

Beam setup for each energy – 100 cm SSD, various fieldsize (jaws), Gantry angle 0, Collimator angle 0, measured at the depth of maximum dose for each energy. Fill in the table below and try to calculate what the other fieldsize factors must be from the data. Remember the factor for a 10 x 10 field must be 1.000, and all the other data must relate to this. *HINT – look at the doses measured and calculate how the multiplication factor which would give the doses at the different fieldsizes when compared to that for the 10 x 10 field.*

Complete the table below, working as two groups – one to set up the phantom on the couch; one group to perform the mathematics; swap over for the different energy

	10X10	15X15	20X20	25X25	30X30
6 MV Measured data					
6 MV FSFs	1.000				
15 MV Measured data					
15 MV FSFs	1.000				

WORKSPACE

Fig. 6 The workbook page for the third virtual experiment (A.3.3) – field size factors

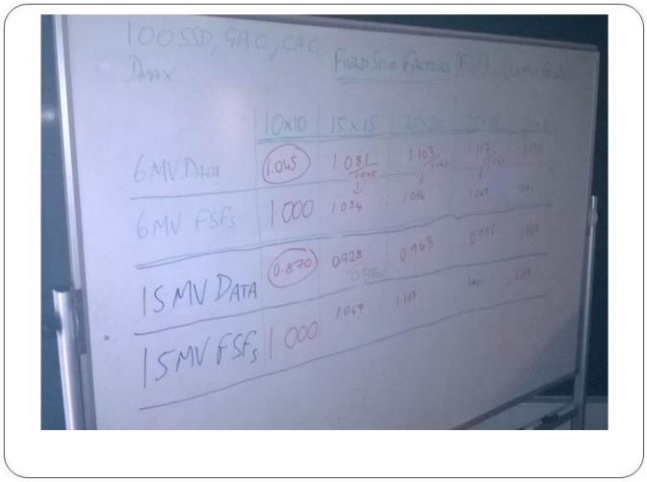


Fig. 7 The whiteboard workspace used by the 'calculation group' for each experiment. Here the experiment is to virtually measure field size factors (A.3.3)

B. Evaluation

B.1 Evaluations post session: Once each workgroup of 7 students had completed all three virtual experiments, they were invited to complete a short evaluation sheet designed to give immediate feedback on the session, for analysis and the benefit of future students. Students were asked for the most positive aspects of the VERT™ Physics session; the least positive aspects and any suggested changes for future sessions. All responses were qualitatively coded and organized into descriptive, common themes and responses. The frequency of common responses were represented as bar and pie charts and also as a 'word cloud' graphic, for easy analysis.

III. Results

The themed responses are shown in figures 8-11.

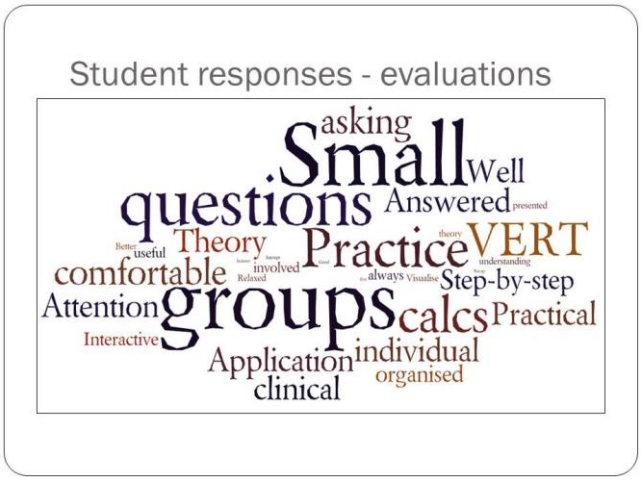


Fig. 8 A 'word cloud' graphic, constructed from the frequency of themed responses from the students 'most positive aspects' of the sessions.

The overall responses were heavily weighted towards the more positive side; nearly ten times as many positive comments than less positive comments – and even a couple of the latter featured students stating that there were no less positive comments to make about the session. The overwhelmingly positive response was with regard to the small group work – students found this the most positive aspect, which possibly enabled the environment to be more conducive and comfortable for asking questions, without risking negative comments from peers. Within this smaller environment, answering individual questions and indeed ensuring that each student had a certain amount of individual attention was a factor felt by the students and also by the tutor. The students felt more involved and could understand the calculations easier in the step-by-step manner in which they were taken – a necessary requirement of the combination of practical measurement and calculation work. Some commented also on the more relaxed atmosphere and the opportunity to discuss and attempt solutions for themselves before seeing and analyzing the results obtained by measurement.

Significant numbers of positive comments were also received on having more time to practice with the virtual linac, as an enhancement of their clinical skills and experience with the linac hand pendants; something marked as always useful by some students. Some also noted positively the clear connection between the theory and practical work, and how it could be applied to clinical practice, helping to visualize the theory through the interactive nature of the sessions. Over twenty percent of the comments focused on the organization of the sessions, feeling that they were good and well presented.

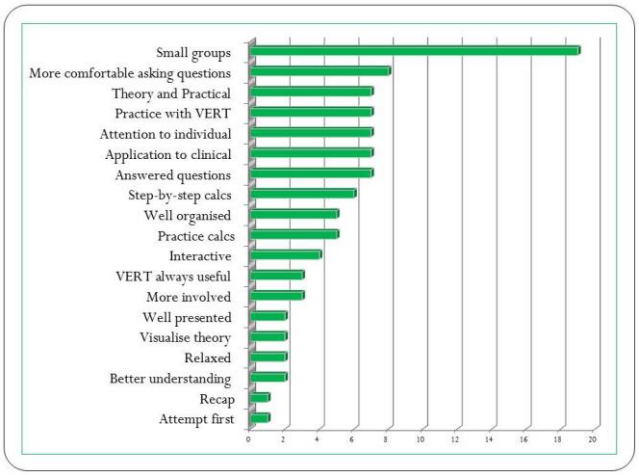


Fig. 9 A bar chart summarizing the frequency of themed responses from the students' most positive aspects of the sessions.

By contrast, very few less positive comments were received. They are summarized in the bar chart of figure 10, showing that most felt the presentation (the revision lecture) at the beginning made the session too long and difficult to focus, and appreciate, the practical aspects with VERT™ Physics. This was possibly reflected too in those responses which looked for more time for the calculations and for the session as a whole. One comment received mentioned the unfamiliarity with the hand pendant – something which was originally intended as a positive feature – for those students working in a department with one particular manufacturer to gain practical experience through VERT™ with the equipment of another; with hindsight, this perhaps clouded the main objective of the session. Two comments received noted that they could not find any less positive comments to make about the sessions.

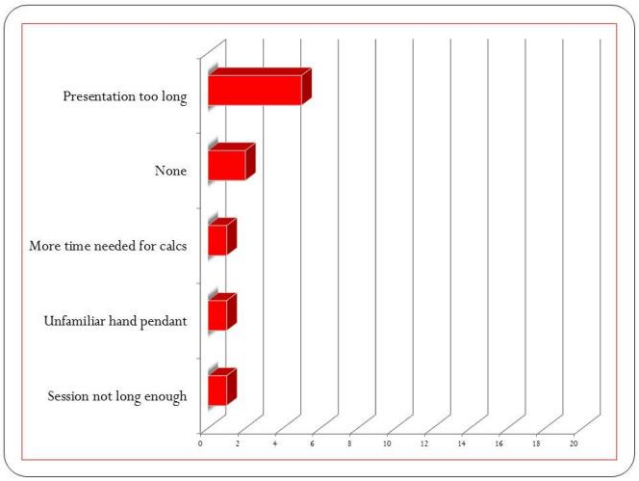


Fig. 10 A bar chart summarizing the frequency of themed responses from the students' least positive aspects of the sessions.

In terms of suggestions for changes for future sessions, again very few comments were received, possibly highlighting that by far the majority of students were satisfied with the outcomes of the sessions. Some would have preferred the groups to be smaller still and certainly to break up the presentation (the initial revision lecture) with the practical aspects; or indeed not have the revision lecture at all. Notably a positive comment was received regarding the recap lecture at the beginning of the session. Most comments highlighted having more – more sessions like this, more calculations covered in this way, more questions and tests in this manner, more time for the sessions as a whole. The summary of responses are shown in the pie chart in figure 11.

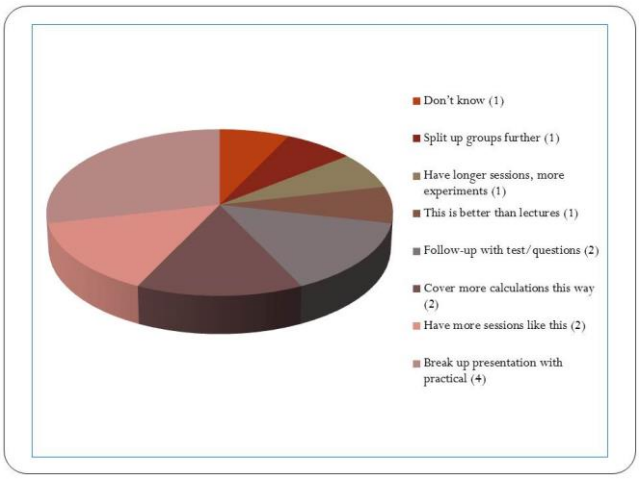


Fig. 11 A pie chart summarizing the frequency of themed responses from the students' suggested changes for future sessions. The number of responses received from each theme are shown in the key in brackets.

IV. Discussion

It is interesting to see that the overwhelmingly positive comments were received concerned with the small group environment and the individualized attention received by students, making a very conducive aspect for open and safe discussion and comment. This is an aspect which is necessitated by the design of the session – being impractical for either the measurement or the calculation group to be too large, and with the objective of all students gaining real, practical experience in all aspects of the session – experience with VERT^{TM}, practical control of the virtual linac using the hand pendant, individual set-up of the physics experiments, opportunities to discuss and attempt calculations within individual and peer-to-peer mentoring with a piecewise, step-by-step, logical approach and answering of all questions posed. The revision lecture at the beginning clearly had an adverse effect on some students, who placed greater value on the practical time for the sessions, alluding to preferring the more kinesthetic environment generated by these sessions. As a result, the lecture was removed for further delivery of these sessions in the second year, and incorporated into the normal face-to-face lectures within the module, but scheduled in the week leading up to the VERT^{TM} Physics sessions, so the material would be fresh in students' minds.

From a tutor's perspective, the software was extremely easy to use (as evidenced by the complete absence of student comments to the contrary), enabling excellent interactive sessions, making the subject material 'come alive'. Distinct advantages of the virtual software is the ability to do things which cannot be done in the real world – for example, make 'instant' changes in ion chamber positioning within the solid water phantom, without entering the room; being able to see through the solid water phantom to illustrate ion chamber positioning and the concepts of isocentricity. Disadvantages are that the dosimetric measurements for a particular set-up are always identical, there is no variability and no need to make multiple readings, as in the real world; the field sizes available can be limited and the calibration point for the linac is isocentric as opposed to a fixed SSD point, as is traditionally used in many centres in the UK.

However in all other respects, the VERT^{TM} system worked perfectly as a virtual linac, simulating what could be performed in the clinic with a real linac for teaching these aspects of radiotherapy physics. It enabled important clinical concepts (such as illustrating the dosimetric significance to the patient of incorrect setup) to be investigated; predicted by calculation and verified by experiment by the students themselves. It also enabled simple, practical demonstration of some quality control measures and the generation of data used for calculations – something the students had undertaken themselves within the same teaching module, in manual monitor unit calculations for isocentric parallel opposed pairs.

V. Conclusions

In conclusion, these practical sessions worked extremely well, evidenced by the overwhelmingly positive comments received through the student evaluations; working well as a teaching tool, simulating the measurements that can be and are often conducted in the clinical environment on real linacs. Here the virtual system worked well as a replacement linac; one which the students could easily access and experiment with in a very practical way, in a safe, supportive and highly positive environment. Learning outcomes were satisfied in ensuring a combination of simulated measurements with real calculations, allowing theory to be applied and verified by measurement. It is seen as merely part of the overall learning experience for our

students, but one which enables good, focused small group work, with a logical, individual step-by-step approach taken for the theory and calculations. Individual attention was appreciated many students and different ways of learning was achieved to complement the more traditional (but equally valid) methods used in other parts of the radiotherapy programmes.

Some extensions to the software for future use are being discussed with the manufacturer – for example, to introduce elements of variability to the measured results (simulating the reality of dosimetric measurements on a real linac) and perhaps too the potential for different monitor unit calibration points – reflecting different protocols used. Overall, the objectives of these educational sessions were achieved, illustrating how certain concepts of radiotherapy physics can be more dynamically taught through simulation using the VERT^{TM} Physics system and software.

ACKNOWLEDGMENT

The author would like to thank the undergraduate and postgraduate students in radiotherapy at the University of Liverpool for their engagement and enthusiasm within the sessions, and willingness to feedback through the evaluation questionnaires. The support of colleagues in driving forward teaching and learning methods using real and virtual radiotherapy technology within all our programmes is noted with great appreciation.

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INVITED PAPER

IMAGE GENTLY CAMPAIGN: MAKING A WORLD OF DIFFERENCE

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Abstract—**Focused care that addresses the needs of the pediatric patient during imaging should improve diagnosis and reduce radiation doses. This requires trained staff correctly operating appropriately configured imaging equipment. This is one of the objectives of the Image Gently Campaign (IGC) by the Alliance for Radiation Safety in Pediatric Imaging (IGA). This article features a description of IGA's campaigns, an explanation of the methods used to develop and disseminate its message, and a description of the IGA's current and future goals. The concept and model of IGA, along with the provision of the citations of the majority of its published resources, is provided to the international medical physics community so that they might be used for local pediatric applications worldwide. A brief summary of the fundamentals of medical physics that should be applied during pediatric imaging concludes this discussion. The ultimate goal is imaging with the appropriate amount of radiation required to provide adequate image quality and imaging guidance. The reduction in the x-ray flux during pediatric imaging provides the opportunity for the medical physicist to recommend different x-ray tube voltages/added filtration, reduced pulse widths, or focal spot sizes that either improve image quality, reduce patient dose, or both. The medical physicist needs to ensure that the desired acquisition parameter changes for pediatric imaging are incorporated into the configuration of the installed imaging device.**

Keywords—**Image Gently, pediatrics, radiation dose, image quality**

I. Introduction

While most state-of-the-art imaging equipment provides reasonable image quality on teenagers using the manufacturer's recommended configurations for adults, excessive radiation dose levels and less than optimum image quality may result when imaging smaller children. [1,2] This deficiency during imaging may be more acute when using imaging equipment manufactured prior to 2010. Focused care, which addresses the needs of the patient during pediatric imaging may improve diagnosis and reduce pediatric radiation doses. This is achieved when appropriately trained staff members operate properly configured imaging equipment. [3]

This paper has two main goals. First, the formation of the Image Gently Campaign (IGC) by the Alliance for Radiation Safety in Pediatric Imaging [Image Gently Alliance (IGA)] is described. [4,5] This is followed by a review of its campaigns, an explanation of the methods used to develop and disseminate its message, and a description of the IGA's current and future goals. The concept and model of the IGC, along with the provision of the citations of the majority of its published resources, are shared with the international medical physics community so that they might be used for local applications worldwide. One of the objectives of the IGC is to assist radiologists and radiologic technologists in improving imaging performance in children.

The second goal is a brief summary of the fundamentals of medical physics that should be applied to imaging devices that will be used to image children. The ultimate goal is to perform necessary imaging "with the least amount of radiation required to provide adequate image quality and imaging guidance."[6] Section IV of this paper stresses the importance of teamwork and the important role of the medical physicist. The fundamental differences between small children and adults are briefly discussed. The fundamental reduction in the x-ray flux emitted by the x-ray tube during pediatric imaging pro-vides the opportunity for the medical physicist to recom-mend different x-ray tube voltages/added filtration, reduced pulse widths, or focal spot sizes that either improve image quality, reduce patient dose, or both. The medical physicist needs to ensure that the desired acqui-sition parameter changes for pediatric imaging are incor-porated into the configuration of the installed imaging device.

II. The image gently allianz

A. *Rationale*

The Alliance for Radiation Safety in Pediatric Imaging (imagegently.org) was officially announced in 2007, after nearly a year of developing the concept. The organization was formed by members of the Society for Pediatric Radiology (SPR) from a shared sense that what was a long-standing commitment to safe and effective imaging in children needed to find a broader audience including patients, parents and other caregivers, our colleagues who cared for children including pediatricians and family practitioners, and the public. This need was partly a result of a growing visibility in both the healthcare and public sector of the issue of potential cancer induction due to radiation from diagnostic imaging, especially due to the relatively higher doses from computed tomography (CT). While the cautious use of radiation is particularly relevant in the pediatric population and was familiar to the pediatric radiology community, other unique considerations in the care of children may have received less attention. These included the need for dedicated time for informed conversations with parents and caregivers, the need for technical adjustments across the wide range of sizes when imaging children, and strategies that can be different between adult and pediatric populations (i.e. ultrasonography is much more frequently employed in children with possible appendicitis versus the overwhelming use of CT in the adult population in the United States). These differences resonate in the introduction to the CT campaign on the IG website: "One size does not fit all…when CT is the right thing to do, child-size the mA and kVp, one scan (single phase) is often enough, [and] scan only the indicated area".

The four founding, and still the masthead organizations for the Alliance were the Society for Pediatric Radiology, American Association of Physicists in Medicine (AAPM), American College of Radiology (ACR), and American Society of Radiologic Technologist (ASRT). One fundamental consideration for organizational success of the Alliance was inclusion of major stakeholders in pediatric imaging: medical physicists, radiologists, and radiologic technologists, through the parent U.S. organizations. These groups contributed, then, to the development of the mission statement, organizational structure and strategic priorities. The leadership also felt it was important to design an Alliance structure that would partner with other relevant professional societies and organizations, in part to share resource and expertise. These groups included imaging organizations such as the Radiological Society of North America (RSNA) as well as signature pediatric health care societies, such as the American Academy of Pediatrics (AAP). The initial efforts were anticipated to be directed at a North American, and mostly U.S. market, however, interest in and affiliation with international organizations began almost immediately. In the first few years, the number of affiliated organizations grew from 13, and now comprises nearly 100, representing over 1,000,000 professional members, which include scientists (e.g. medical and health physicists), radiologists, dentists and dental surgeons, radiologic and dental technologists, pediatric surgeons, and pediatricians. The number of international alliance members based outside North America currently totals 35.

Leadership of the Alliance began with a steering committee of approximately 15 individuals, headed by Marilyn Goske, M.D. The initial committee represented (predominantly academic) pediatric radiologists, radiologic technologists, medical physicists, and individuals with media, marketing, or administrative/executive experience. More recently the steering committee has added individuals with adult radiology expertise, dental expertise, community radiology practice, and patient advocacy representation. The initial and expanded constituencies were considered critical in assuring a representative voice in Image Gently efforts. Marilyn Goske served as a chair from 2007-14, and co-chair 2014-15 together with Donald Frush, M.D., an original steering committee member who then assumed the chair position in July 2015. Keith Strauss, MS, a diagnostic medical physicist, also an original steering committee member, now serves as vice chair.

The initial organizational structure consisted of arenas that included research, finance, international affiliations, and modality-based campaign elements. This structure was recently re-engineered in the spring of 2015 to resonate with a strategic plan with formalized major goals: (1) advocacy and awareness, [7] (2) education [8,9], (3) research, and (4) assurance of long term Alliance stability. This organizational structure now consists of committees under these goals consisting of at least one steering committee member with additional membership for direct activities such as international and other organizational partnerships (goals 1 and 2), campaigns (goal 2), and document review (e.g., from The Joint Commission, proposed regulations to states by Conference of Radiation Control Program Directors (CRCPD), Food and Drug Administration, Nuclear Regulatory Commission, etc.—goal 1). The mission statement that was also recently distilled to capture a simple and evocative sense of purpose is "… through advocacy, to improve safe and effective imaging care of children worldwide". This modification was in part due to rapidly growing international presence and recognition. In addition, there was a carefully considered and crafted operational approach, with the fundamental principles which will be described below, fortified through substantive content, a consistent investment by

the Image Gently Alliance. Part of this content is through the campaigns, which will be subsequently discussed.

B. *Scope of Campaigns to Cover Modalities Using Ionizing Radiation*

Each of the six campaigns below address a different imaging modality. Educational material for each campaign provides helpful information for parent/guardians, radiologists, radiologic technologists, and medical physicists. In some instances information is provided for referring physicians. Published resources written by Alliance members that cover the modality in general are listed immediately after the 'slogan'' associated with each modality. If a more focused paper was also published, the reference to that paper is listed in the description for the modality. An image of the poster used to illustrate each campaign is provided.

1. CT: "One Size Does Not Fit All" [10-15]

Fig. 1 "One Size Does Not Fit All"

This first campaign of the Alliance in 2008, increased awareness that $CTDI_{vol}$ is not a patient dose and underestimates CT radiation doses to the smallest pediatric patients up to three-fold.[16] As this campaign was initiated, basic recommendations were posted on the IG website to assist end-users in reducing their CT techniques (mAs) to ensure that any size patient's CT radiation dose was similar to that of the facility's standard sized adult. In 2014, these recommendations were modified, improved, and expanded. Now the end-user has three choices of reduction of patient dose, i.e. smallest patients receive 100%, 75%, or 50% of the adult radiation dose at a given facility. Two additional publications were created to help end-users and medical physicists use these recommended protocols. [17,18]

2. Interventional radiology: "Step Lightly" [19-22]

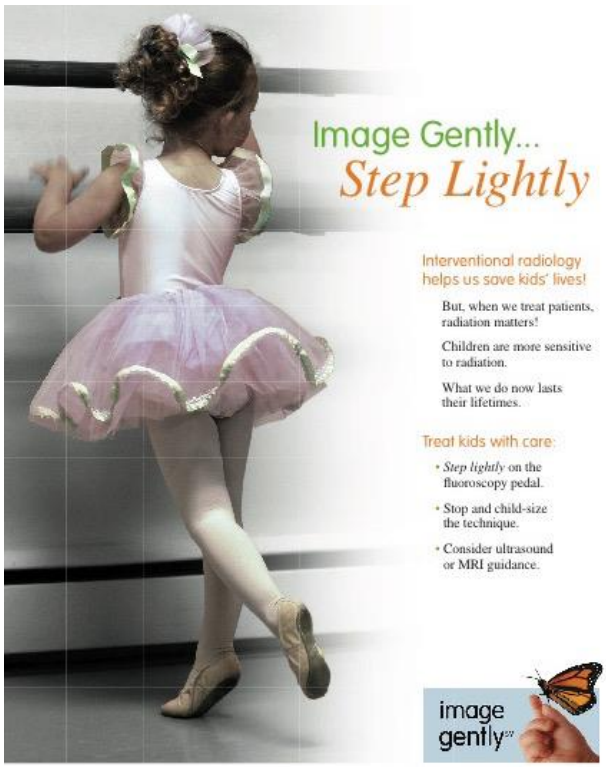

Fig. 2 "Step Lightly"

This campaign encourages the operator of an interventional fluoroscope to make sure that appropriate acquisition parameters designed for the specific size of the patient are appropriately selected. The operator is encouraged to limit the amount of fluoroscopic exposure time during the procedure. Three links are provided on the IG website to provide access to three educational modules for radiologists and radiologic technologists. The three modules are entitled 'Enhancing radiation protection in pediatric fluoroscopy: prior to, during, and after the fluoroscopic procedure.' These modules apply to either interventional or general fluoroscopy.

3. General fluoroscopy: "Pause and Pulse" [23,24]

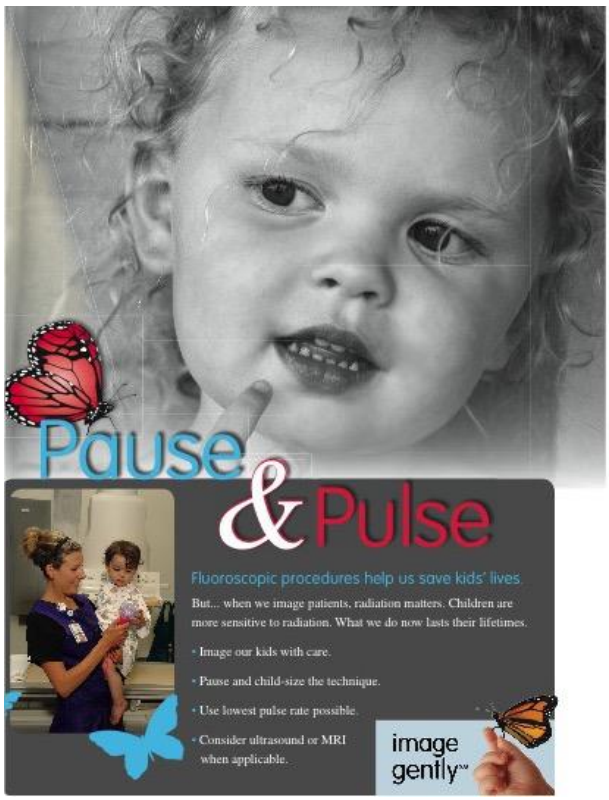

Fig. 3 "Pause and Pulse"

Fig. 4 "Back to the Basics"

The operator is reminded of steps that can be taken to reduce patient dose during general fluoroscopic studies: tightly collimate, minimize the use of electronic magnification, minimize fluoroscopic time, substitute fluoroscopic images for fluorography images where appropriate, select pulsed fluoroscopy as opposed to continuous fluoroscopy if both modes are available.

4. Digital Radiography: "Back to the Basics" [25-29]

The IG website contains links to multiple power point presentations on various aspects of digital radiography. This campaign helped lead to the adoption of the EI dose index on digital radiographic images developed by Task Group 116 of the AAPM as the standard for dose indices for digital radiography. [30]

5. Nuclear Medicine: "Go with the Guidelines" [31,32]

Fig. 5 "Go with the Guidelines"

The cornerstone of this campaign is the 'North American Guidelines for Pediatric Nuclear Medicine' for High Quality Images at low Radiation Dose that have been converted more recently to an international scope. This document

is used as a guide to standardize the radiation dose received by pediatric patients from the radionuclides injected for nuclear medicine studies. [31]

6. Dental: "Image Gently Campaign in Dentistry" [33,34]

Fig. 6 "Image Gently . . . in Dentistry"

The most recent campaign of IG stresses that cone beam CT should be used only when necessary and standard dental x-rays should be acquired based on an individual patient's need as opposed to routine. Two helpful presentations are linked to the IG website, one for parents and one for medical physicists.*C. METHODS*

As previously discussed, the formation of the IGA was based on careful consideration of what was originally an implied set of principles (in essence a constitution) which has been consistently adhered to; the success of the organization can easily be defended as due in large part to this constitution. In developing this constitution, the values of the IGA were *safety, effectiveness, consensus, advocacy, and accessibility.* The goals of these values are to have IG be strong, stable and strategic. To accomplish these values, the blueprint was based on the following fundamental elements: the message, the messengers, and the messaging.

The *message* is fundamental. Each IG campaign message was embedded by the short, simple, memorable phrase, one that resonated effectively – be gentle with our children. This was easily understood and difficult to not support (at least publicly). Critical in this age of alarmist messages both from within and outside of the Radiology profession, [35,36] is IG's positive message, about improvement (rather than current or past failure). This position of advocacy has been consistent and clear throughout the educational products, website content, campaign materials, and publications and presentations. While other voices espousing the negative perspective that we are doing harm to children have often captured the public attention, [35] the enduring stance of the steering committee, the founding organizations, and the nearly 100 affiliates (through pledging to the IG position) has been that a balanced approach of radiation safety through improved delivery while creating quality imaging, (a perspective of assurance) should and will prevail. The phrase "image gently" was crafted by Jennifer Boylan, the executive director of the SPR, in 2007, and was immediately recognized as the embodiment of the mission of the Alliance. In addition to this taproot of the Alliance, other messages are found in the publications, presentations, educational modules, and other website material.

The *messengers* are also critical in IG's success. In keeping with the values of consensus efforts, the Alliance needed to have *engaged* representation from the major stakeholders, but with equal voice *despite what might be unequal contribution of resources such as personnel, time, or financial support*. Alienation of any group would potentially undermine the value of that group and the ability to conscript these professionals in Alliance efforts, as all Alliance member groups are messengers. These groups, in their partnership in the Alliance would agree to help with appropriate educational and other informational content (e.g., meeting assistance including speakers, manuscript preparation, email blasts from their membership lists during campaign roll outs). No financial contribution was requested or accepted from the Alliance members that joined following the formation of the organization. Industry or individual practices or university programs were not considered for Alliance membership to facilitate independence and to maintain partnership along professional denominations. The message and messengers then could not be construed as serving purposes other than advocacy for children. The strength of the messenger, a responsibility of the Alliance partners, was through a bidirectional flow to have amplification in messaging to members through the affiliate organizations as well as to provide expertise and guidance to the Alliance when relevant. Other messengers consisted of content experts. Image Gently content experts were carefully selected (see below). An additional important messenger was the website. A

recent presentation at RSNA [37] notes that there were substantial increases in website activity following the CR/DR and dental campaigns, as well as the publication relating childhood CT to the development of cancer. [38] In addition, a website revision in January, 2014, resulted in notable and sustained increased activity.

Messaging was also a critical element in the Alliance success. The model of the IG Alliance is social marketing. In social marketing, behavior/perspective is influenced by information primarily through educational campaigns to benefit those targeted by this information, not to the benefit of the organizations responsible for the educational campaigns. [8] As introduced previously, there was a core group of speakers identified who were provided IG materials with consistent messages. Relevant materials often from a pool created and reviewed by members of the steering committee were made available. Messaging has included 39 peer review publications (most including IG steering committee authorship) specifically titled as addressing IG efforts up through the end of 2014. [15] In addition, conferences including manufacturer summits for CT in 2008, CR/DR in 2010, as well as multispecialty conferences organized by the IG steering committee and based on the IG ALARA theme 2014. Messaging includes cooperation with groups in document review such as the Food and Drug Agency (FDA), the Environmental Protection Agency (EPA), and The Joint Commission (TJC) providing content expertise and guidance related to medical imaging in children.

Part of messaging is control of branding. The hallmark IG butterfly logo, Fig. 7, was not provided to groups and there was no cobranding with groups such as insurance companies, radiology benefit managers, or radiology practices wishing to promote that they supported and/or practiced safe imaging for children. Not that this proclamation was inconsistent with the Alliance, but it would be impossible to assure that representation of the IG brand was always harmonious with IG principles. While such cobranding would probably have had an initial expanded visibility, this would likely not be enduring and could be detrimental depending on unforeseen motives. This would be impossible to predict given resources and virtually impossible to police. It was strongly believed that this brand control would best assure that Image Gently would be recognized, and the message not diluted or misrepresented.

Early in Alliance conception, it was universally recognized that appropriate messaging was important for multiple stakeholders with different levels of under-standing, and different magnitudes of interest (discussed in more detail in III.B.). These include radiologic technologists, radiologists, medical physicists, pediatric clinical care providers, patients, parents and other caregivers, as well as the public, administrators, and guidance, regulatory, or governmental organizations as well. For example, there is information for parents and caregivers for many of the campaigns. All efforts, including messaging, are volunteer except for a portion of administrative support. Success is maintained with volunteers' heads (content), hands (i.e., crafting information through presentation, for example), and hearts (Image Gently serves a need and it is the right way to serve this need).

Fig. 7 Image Gently Logo

There has been some grant support obtained by steering committee members. There are no private donations accepted and no industry support with the exception of an initial unrestricted educational grant by General Electric at the concept and development stages, before the Alliance was official. The adult imaging community embraced the mission of the Image Gently Alliance with the creation of Image Wisely for adults. The Alliance organization and use of social marketing methods for advocacy and education were pioneering and some elements were used as a template for subsequent important global initiatives such as EuroSafe and AfroSafe.

D. *Additional Publications*

In addition to its website, publications in peer reviewed journals provide additional information for the end-user conducting pediatric imaging. A few additional published manuscripts published by individuals associated with the Alliance are cited here. [39-43] These articles respectively discuss:

1. Importance of Alliance partnerships
2. Lessons from the past applied to the present
3. Child-sizing radiation doses to children
4. ACR Dose Index Registry and Diagnostic reference ranges
5. ACR sponsored CT training website

III. GOALS OF THE ALLIANZ

The Alliance currently has a number of goals in progress.

A. CREATE A TEMPLATE FOR SUCCESS FOR OTHER ALLIANCES WITH A DIFFERENT FOCUS

The IGC has achieved success by using a social marketing model and associated organizational structure as previously discussed in Section II.B. For example, a similar Alliance, Image Wisely, was created in the United States a couple of years after the formation of the IGC to address adult imaging concerns. While the regulatory environment in countries outside the United States may be considerably different, social marketing should also be successful in other countries.

B. PROVIDE INFORMATION RELEVANT TO RADIATION DOSE MANAGEMENT (ALONG WITH IMAGE QUALITY MANAGEMENT) FOR PEDIATRIC IMAGING PROCEDURES

1. Provide parents/caregivers with information before performing imaging procedures of their children

   Parents/caregivers need information about their children's imaging procedures. The Alliance has developed multiple, informative pamphlets for caregivers which have been translated into multiple languages. These pamphlets, posted on the IG website, assist caregivers in asking questions and making more informed decisions about their child's medical care. [5,44-47]

2. Healthcare providers

   Referring physicians and other healthcare professionals in the United States provide the primary medical care for patients in the United States. These individuals select or request their patients' diagnostic studies, or in the case of dental care both determine the need for and perform imaging examinations. These individuals need to know the strengths and weaknesses (including the relative radiation dose) of each type of diagnostic imaging exam available with respect to answering the clinical question at hand. IGC's website contains information to help the referring physician sort through these differences.

4. Imaging experts

   In the United States it is estimated that approximately 15% of all pediatric imaging [48,49] is conducted within dedicated pediatric hospitals or focused sections of pediatric imaging within an adult hospital. Therefore, the vast majority of pediatric imaging occurs primarily within adult focused departments where pediatric imaging is the minority of completed studies. As discussed in Section IV below, pediatric patients cannot simply be treated as if they are small adults. Radiologists and radiologic technologists with limited experience conducting pediatric imaging studies and their pediatric patients should benefit from additional information on pediatric imaging.

   End-users of imaging equipment may assume that the manufacturer's representative or application specialist fully understands the correct application of the imaging product purchased. On many occasions, this is true for adult imaging. However, if the manufacturer of the imaging device has not previously installed one of their units in a dedicated pediatric hospital with sound medical physics support, the manufacturer may not have had the opportunity to develop operational configurations of their equipment specifically designed to image small children.

C. ENHANCE EDUCATION AND USER SUPPORT DURING PEDIATRIC IMAGING

The Alliance has developed numerous presentations and other educational resources for pediatric imaging procedures. Due to rapid advances in technology, end-users of imaging equipment need continual training to understand how to leverage a particular piece of equipment's design features to properly manage radiation dose and image quality. The Alliance has assisted the International Atomic Energy Agency by editing some of its pediatric curriculum for medical physicists. Numerous web-based modules have been created and placed on the IG website on "Enhancing Radiation Protection in Computed Tomography for Children", one for each major equipment manufacturer in 2010. [50-53] In 2013, a three part training web module for radiolo-gists and physicians sponsored by a competitive grant from the US Food and Drug Administration entitled "Image Gently: Enhancing Radiation Protection and Fluoroscopy for Children" was developed. [54]

D. FOSTER THE TAILORING OF IMAGING EQUIPMENT TO THE UNIQUE NEEDS OF PEDIATRIC IMAGING PROCEDURES INCLUDING DEVELOPMENT AND USE OF PEDIATRIC DOSE INDICES.

For the reasons explained in Section IV, imaging equipment tailored to the unique needs of pediatric patients should produce equal or better image quality with the same or less radiation dose to the child. This level of configuration of the imaging equipment is achieved by consultation with the imaging equipment manufacturer's representatives,

physicians who will use the imaging device, and radiolo-gists who will assist the physicians. If available, a medical physicist can help identify potential solutions to specific pediatric imaging needs by serving as an interpreter between clinicians and equipment manufacturer's representatives. [55]

To date, The Alliance has sponsored three summits, two in CT (2008, and 2014) and one in digital radiography, which included equipment design engineers and educators from industry. The summit on digital radiography resulted in the adoption of a standardized Exposure Index (EI) designed to allow radiologic technologists to estimate the radiation dose to the patient. [56] The three CT-based meetings [16,57,58] raised the awareness of the need for a better pediatric patient dose index during CT. In response, the AAPM developed the Size Specific Dose Estimate (SSDE), [59] that estimates the radiation dose to the patient instead of the radiation dose to a phantom ($CTDI_{vol}$). Currently, medical physicists are working with the International Electro-technical Commission (IEC) on behalf of the IGC to develop a new IEC standard that will require the manufacturers to calculate and display SSDE on all their new CT scanners in the future.

E. Provide Guidance to Regulatory or Advisory Agencies Responsible to Maintain/ Improve Pediatric Imaging and/or Radiation Protection

The medical physicist must understand the specific role of the various agencies within their country that regulate the use of ionizing radiation on pediatric patients and should obtain copies of applicable regulations. Advisory agencies develop recommendations. These advisory recommendations, necessary to establish 'a standard of good practice', are optional. However, if a regulatory agency adopts a suggestion from an advisory agency and promul-gates it into a regulation, the regulation becomes mandatory. Individuals involved with the IGC have had the opportunity to offer expert advice and provide suggestions for pediatric specific information into some of these agency's publications of the regulatory/advisory agencies listed below.

1. Examples of advisory agencies

a. *National Council of Radiation Protection and Measurements* (NCRP)

A nonprofit corporation chartered by the United States Congress to collect, analyze, develop, and disseminate information and recommendations about radiation protec-tion, radiation measurements, quantities, and units. [60]

b. *International Council on Radiological Protection and Units* (ICRU)

This advisory agency has a scope similar to the NCRP. However, its international membership includes a larger variety of perspectives on radiation health issues. [61]

c. *International Atomic Energy Agency* (IAEA)

Despite its name, this international advisory agency, located in Vienna, Austria, pub-lishes advisory documents on management of pediatric imaging. For example, in 2014, "Dosimetry in Diagnostic Radiology for Pediatric Patients" was published. [62]

d. *Accrediting Agencies*

Professional organizations may provide accreditation services to end-users of imaging equipment in the United States. The American College of Radiology and The Joint Commission are two accreditation bodies typically with quality standards that a facility must meet to implement and maintain accreditation status. The accrediting agency is not a regulatory agency. However, quality control elements developed by the Accrediting Agency may be adopted as regulations by a given state or may become mandatory if a hospital or site wishes to receive payment for their services from a third party insurance payer. While the accrediting agency has no regulatory authority, if a regulatory body or insurance payer requires a facility to be accredited, the accreditation body's quality control pro-grams must be performed to maintain the accreditation. One member of the IGC was requested by a United States accreditation body to assist in developing quality control elements of their program; as a result, pediatric considerations were added to the program. [63]

2. Examples of regulatory agencies

a. *Conference on Radiation Control Program Directors* (CRCPD)

The CRCPD develops Suggested State Regulations (SSRs) that individual state regulatory programs within the United States can adopt to control the use of ionizing radiation by end-users. Regulatory control is contained within each of the 50 states; a state may adopt or modify the SSRs as written by the CRCPD when promulgating its rules. [64]

b. *Nuclear Regulatory Commission* (NRC)

This United States regulatory agency promulgates regulations that control the use of radioisotopes used for nuclear medicine procedures by end-users.

c. *United States Food and Drug Administra-tion* (FDA)

This body is a national regulatory agency that controls the design and capability of all x-ray producing machines sold within the United States. A manufacturer of imaging equipment must have the design of a given unit approved by the FDA before that type of imaging equipment can be sold in the United States market. A competitive grant was awarded to the IGC by the FDA in 2012, to write guidelines for manufacturers of imaging equipment to be used for pediatric imaging. [65]

d. *International Electro-technical Commis-sion* (IEC)

The IEC develops regulations that control the design and features found on imaging equipment that use ionizing radiation. A manufacturer, which desires to sell its products worldwide, must meet all the stipulations included in applicable IEC standards. One author within the IGC is currently assisting draft of IEC 62B/PT 62985 'Size Specific Dose Estimate (SSDE) on Computed Tomography Units', an IEC standard which will require the calculation and display of SSDE in the future on all CT scanners if approved and adopted when completed.

F. Develop and Implement Quality Control Procedures Specifically for Pediatric Patients

1. Improve existing accreditation programs by including pediatric quality control tests

Accreditation programs are designed to evaluate the quality of imaging at a given clinic or hospital. The more comprehensive programs are designed to evaluate both image quality and the radiation dose required to achieve a specified level of image quality. Sample images and the radiation doses used to produce those samples are typically submitted periodically to the accrediting body for evaluation. To be granted accreditation, the site must achieve pre-determined levels of image quality and radiation dose. Steering committee members of the Alliance have had the opportunity to introduce testing methods specifically designed for pediatric patients on CT scanners in the United States. [63]

2. Provide resources related to diagnostic reference levels for pediatric imaging

Diagnostic Reference Levels (DRLs) estab-lish patient dose levels for various diagnostic imaging exams based on surveys of actual patient doses in multiple facilities typically within a single or region. If the patient's radiation dose exceeds the DRL, the imaging department is strongly encouraged to carefully investigate and identify steps that can be taken to reduce patient radiation doses during subsequent imaging studies. While many European countries have well-established DRLs for most adult and some pediatric examinations, the United States and some third world countries need to develop more complete DRLs. While the pediatric imaging community has made some progress with this goal in abdominal CT [13] and interventional fluoroscopy, [66] much work remains to be done. Hopefully, the further development of a national dose database provided by the American College of Radiology will soon expand its scope beyond CT scans and provide the data necessary to meet this goal.

G. Effective and Efficient Organizational Opera-tions

The IGC continually strives to improve its operations. Additional campaigns may be developed in the future. The Alliance operates by consensus representation and voice to ensure the appropriateness of its proposals. As discussed in greater detail above, it is important for the Alliance to maintain its independence from other select interests, e.g. industry and its desire to sell its products, or organizations with for-profit agendas. At the same time, the Alliance needs to form appropriate alignments with existing resources that aid the dissemination of the Alliance's message, e.g. Radiology info.org, Image Wisely, and international alliances with similar goals.

H. Assess Clinical Impact of Campaign

A real measure of clinical effectiveness of the IGC is just as important as the rollout of numerous campaigns. While some analysis has been completed [32,67,68], it is limited due to the difficulty of establishing quantitative measures that can be accurately determined.

I. Possible Future Goals

1. Smaller, focused topic campaigns that impact more than one pediatric imaging modality will likely be addressed, e.g. appropriate use of gonadal shielding during pediatric imaging, etc.

2. Campaigns with other imaging groups, such as pediatric cardiologists, or orthopedists who use ionizing radiation equipment.
3. Clearer delineation, especially on an international scale, of organizational expertise and responsibility. Given limited resources, duplicate efforts are wasteful. Further discussions between international organizations can help define areas of authority and improved allocation of resources as well as consistent messaging.
4. Constant reassessment of the Alliance's mission and strategic plan with adoption of necessary organizational shifts that continue to provide the greatest opportunity to manage efforts in meeting its mission.

IV. Fundamental Medical Physics of Pediatric Imaging

A. *Team Approach to the Improvement of Pediatric Imaging*

Two independent, yet inter-related approaches are recommended to achieve properly managed patient doses and image quality. First, the design features of the imaging equipment should be configured to reduce radiation dose rates during fluoroscopy and during recording of images (fluorography) left side of Fig. 8. Second, correct operation of the fluoroscope by properly trained operators should reduce fluoroscopy time; the number of fluoroscopic images created. The experienced operator also reduces the number of recorded images, which properly documents the results of the study and allows for correct diagnosis, right side of Fig. 8.

A variety of individuals should work as a team to achieve diagnostic quality images at properly managed radiation doses. End-users should explain their clinical needs to the manufacturer while the manufacturer matches components of their product line and their configuration to these needs. The recommended environment that allows optimum performance of the selected imaging device should be created. [69] After installation of the equipment and completion of agreed upon pediatric modifications/configurations of the unit, a qualified medical physicist should perform extensive functional testing of the imaging device to verify that all technical imaging parameters that affect patient dose are performing in an acceptable manner prior to first clinical use. [70-75] These activities address the left side of Fig. 8.

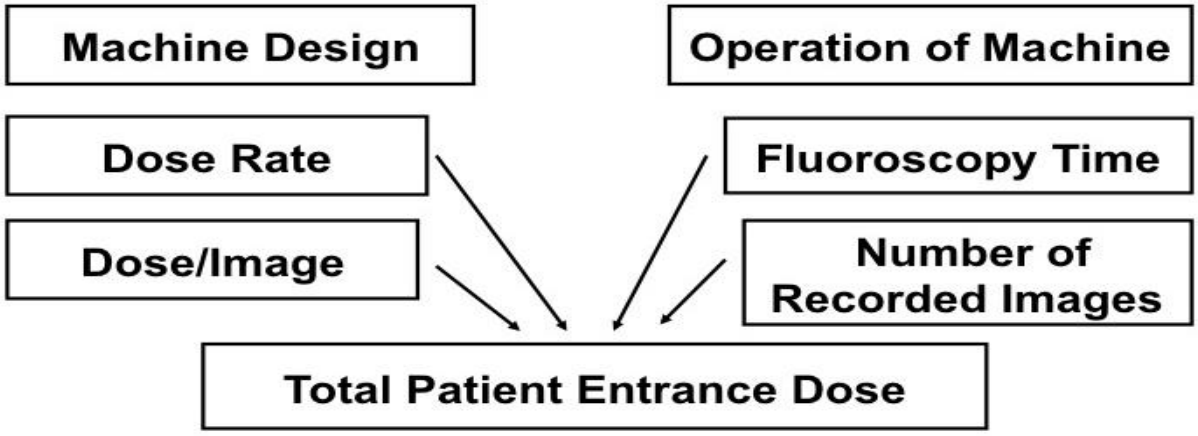

Fig. 8: Total patient entrance dose from a fluoroscope depends on the dose rate during fluoroscopy and dose per recorded image, both factors dependent on the fluoroscope's design and configuration. Total patient entrance dose is also directly related to fluoroscopy time (number of fluoroscopic images) and number of recorded images, which are more dependent on the training and experience of the operator than on the fluoroscope's design and configuration.

Clinical staff in addition to the operator may be involved in ensuring the proper operation of the imaging equipment, right hand side of Fig. 8. [2,76] First, the clinical need and justification of the imaging study involving ionizing radiation should be evaluated. Will the results of the study realistically answer the original clinical question? Should an alternative imaging modality without ionizing radiation be considered first? Answering the clinical question without using ionizing radiation is the most effective method of reducing radiation dose to the patient.

In addition to an understanding of basic physics principles of fluoroscopy, the operator should complete operational training ("buttonology") on every

aspect of fluoroscopic equipment operation. End-users require an ongoing, close, working relationship with their chosen manufacturer. Free exchange of all necessary information is necessary. Positive changes in practice occur when the four groups of individuals in Fig. 9 work effectively together. The manufacturer may need to make design engineers (in addition to product specialists and application specialists) available to communicate to the customer the operational design capabilities of the fluoroscope that can be harnessed to meet clinical objectives. An available qualified medical physicist with experience in pediatric imaging can, through interpretation, help the flow of information between the clinic and industry. This shared knowledge leads to a properly modified and configured fluoroscope for pediatric imaging. The ultimate goal is to perform necessary imaging "with the least amount of radiation required to provide adequate image quality and imaging guidance. Images that are inadequate for diagnosis or for guiding interventions introduce the risk of catastrophic complications." [6]

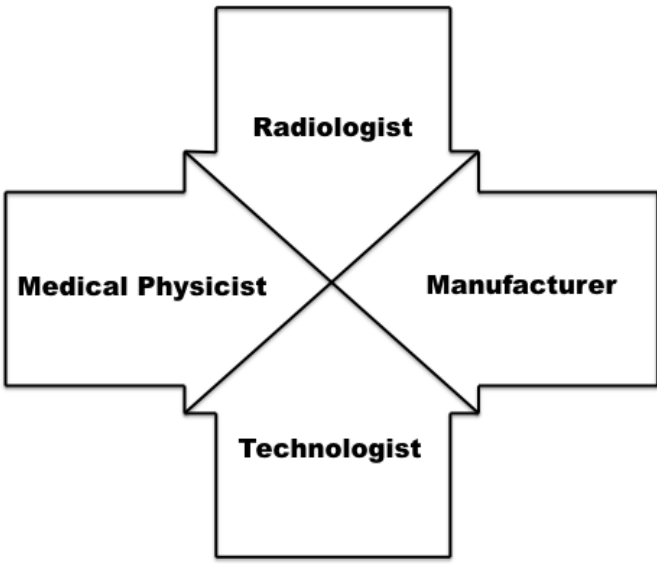

Fig. 9 Pediatric imaging is best optimized when the four groups of individuals shown work effectively together.

B. Image Quality, Patient Dose, and Pediatric Considerations

Children are not small adults. First, their disease states differ from those of adults, which may lead to multiple interventions in the imaging room. For example, neonates and infants may present with a large variety of congenital heart and/or vascular defects or diseases [77] as opposed to coronary artery disease common in adults. These complex pediatric conditions may require as many as ten cardiac catheterizations to manage the disease prior to the patient reaching adulthood[77], which underscores the necessity to manage the radiation dose from each examination. Second, small children may not be able to cooperate during their x-ray examination. The majority of small children are fearful of unfamiliar surroundings, patient staff, the possibility of additional pain, and large pieces of imaging equipment.

1. Radio-sensitivity of Children

Since a child has the majority of their life span ahead of them, the small possibility of a stochastic radiation injury expressed later in the child's life (e.g., radiation induced cancer) is more probable than a deterministic radiation injury (e.g., skin damage). The deterministic injury seldom occurs in a child due to the smaller size of their body, which reduces their entrance skin dose relative to that of an adult. [60]

2. Implications of Patient Size on Radiographic Techniques

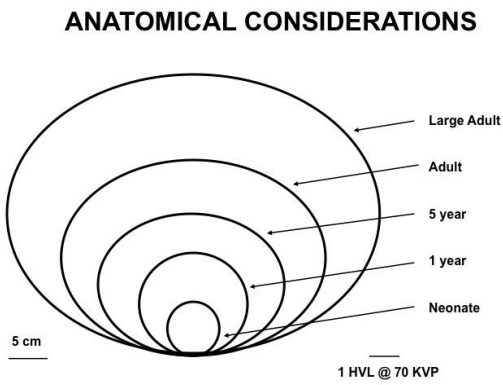

Fig.10 The LAT diameter through the patient's thorax ranges from 5 – 45 cm as a function of age. This range in size (pediatric imaging) requires a change in the required number of x-rays by more than a factor of 8,000 to maintain the same dose to the image receptor provided the voltage used to produce the x-rays remains unchanged.

The small size of a neonate or infant relative to an adult demands a large dynamic range of radiologic technique factors. A neonate has a posterior-anterior [77,78] dimension of approximately 5 cm, while a large adult can have a PA dimension up to 33 cm or more [79,80] as illustrated in Fig.10. The range of tissue path length in the lateral direction is even greater, 5 – 45 cm. If the Half Value Layer (HVL) of tissue is assumed to be approximately 3 cm at 70 kV for fluoroscopic imaging equipment with standard total filtration, this range of patient sizes exceeds 13 HVLs. This requires a dynamic range of radiation per pulse of

greater than 8,000 to minimize the increase in Voltage and reduction of image contrast from the smallest to largest patient!

When imaging the largest adults, producing a sufficient patient entrance flux of radiation to deliver the necessary flux of x-rays at the image receptor is a primary design consideration. When imaging smaller pediatric patients, the need of high radiation flux is dramatically reduced. *This provides the opportunity to select desired x-ray tube voltages/added filtration, reduced pulse widths, or smaller focal spot sizes that either improve image quality, reduce patient dose, or both.* The range of patient sizes depicted in Figure 3 represents the range of patient size within the pediatric population, typically defined as neonates to 21 years of age. If equipment is designed to image children, it is designed for all patients, not just small to large adults. Many imaging units can be altered to reduce patient dose with little or no degradation in clinical image quality. The results of this exercise can be more dramatic than anticipated with the appropriate configuration. [81,82]

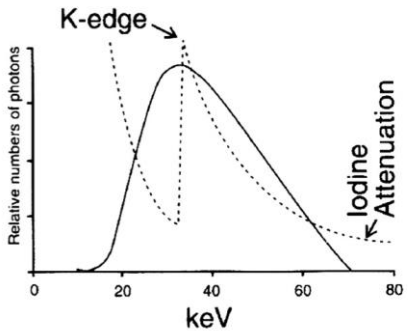

Fig. 11. Iodine Attenuation compared to the effective energy of a 70 kV X-ray Beam Spectrum with 3 mm aluminum total filtration. The effective energy of the x-ray beam spectrum, ~ 30 keV, is well matched to the 33 keV k-edge of iodine. This matching increases the radiopacity of an iodine-filled vessel. Reprinted with permission. [83]

3. Pediatric image quality

Image quality should be tightly controlled in infants and small children to ensure clinically useful images. Small patients have small body parts. For example, the tiny clenched fist of the newborn baby illustrates the size of the patient's tiny heart that the pediatric cardiologist must examine and repair. A sharp image of the patient's anatomy and the smaller devices and hardware used by the pediatric cardiologist or radiologist is extremely important. This requires that sources of unsharpness in the image introduced by the finite size of the focal spot, design of the image receptor, motion of the patient, or geometry of the patient with respect to the location of the image receptor and focal spot must be carefully controlled.

A sharp clinical image must also provide adequate contrast to be clinically useful. Inherent subject contrast of soft tissue structures is limited by the magnitude of the mismatch of the k-shell binding energy of soft tissue (~ 0.5 keV) and the effective energy of the x-ray beam (~ 30 keV), which is necessary to penetrate through the patient's body at a reasonable patient dose. (The effective energy of the x-ray beam, determined by the x-ray tube voltage and added thickness of filter in the beam, should match the k-edge of the contrast media as illustrated in Fig 11.) The limited natural subject contrast is improved by the injection of contrast media (with a k shell binding energy similar to 33 keV [iodine]) into the patient's vascular. Subject contrast created by iodine is a function of the concentration of the iodine in the vessel and the diameter of the vessel [84]. The smaller diameters of the child's vessels require higher concentrations of contrast media to achieve the same subject contrast created by the larger vessels of adults. However, the total volume of injected iodine per patient is limited due to the toxicity of the contrast agent (4 - 6 cm^3/kg of 320 - 350 mg/cc iodine) [77].

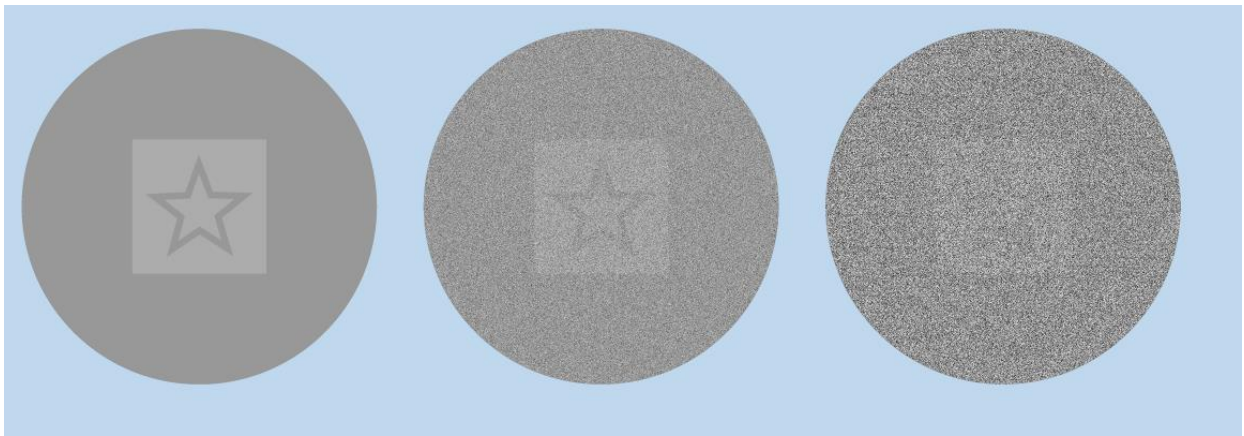

Fig. 12: The image on the left is produced with a radiation dose to the patient more than an order of magnitude greater than the image on the right. The central image is the correct configuration: diagnostic image quality at a properly managed radiation dose

Good low contrast sensitivity in the image is also necessary to distinguish between soft tissue structures within the body. Soft tissue structures are masked by the presence of scatter radiation, which should be controlled with an effective grid. Soft tissue structures are also masked by the quantum mottle in the image as illustrated in Fig 12. As one scans from left to right in the figure, the quantum mottle increases as x-ray flux to the image receptor decreases by more than an order of magnitude. The dose reduction of the right-most image in Fig. 12 is desirable for pediatric imaging, but this large reduction is not clinically acceptable. The elevated quantum mottle in the image would probably prevent an accurate diagnosis; it would probably result in the request for a repeat image. Acceptable pediatric patient doses should be tailored to the imaging task, not an arbitrary dose level. Significant dose reduction may be possible during some high contrast studies where more quantum mottle may be tolerable, but not during low contrast studies. Examples of high contrast studies are a VCUG using iodine or lower GI study using barium contrast agents. Performing angiography of small vessels using iodine is an example of a low contrast study. Reducing radiation dose while ignoring associated degradation of image quality is a relatively simple task, but clinically unacceptable. The correct challenge is to reduce the patient's radiation dose while maintaining diagnostic image quality.

V. Conclusions

Improving the medical care of pediatric patients by properly managing when examinations using ionizing radiation are performed, by properly managing the quality of the clinical images, and by properly managing the associated radiation dose to patients to produce each image is not trivial. Quality pediatric imaging requires attention to detail and effort. Appropriately trained staff members need properly configured imaging equipment to achieve this goal.

Fig. 13 is a recent photograph of the same child on the same beach with the same life jacket in Fig. 1 approximately 8 years earlier. The child has grown to be a pre-teenager instead of a toddler. Image Gently, its methods and programs, described here have also expanded and matured over this time period. Hopefully, medical physicists in all countries striving to improve the care of children locally by developing educational and clinical support activities designed to assist radiologists, radiologic technologists, and representatives of the imaging equipment manufacturer will find these Image Gently programs and resources helpful.

Fig. 13 Same scene, same life jacket and child 8 years after the photograph in Fig. 1

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TECHNOLOGY INNOVATIONS

ULTRASOUND IMAGING GOES ULTRAFAST A CHANGE IN PARADIGM IN MEDICAL ULTRASOUND

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Abstract— **As ultrasonic waves penetrate deep into tissues ultrasound imaging is able to image invisible things by "seeing through tissues" in real time. With the advent of ultrafast ultrasound imaging, the modality can reach thousands of frames per second, much faster than what the human eye can see. A completely new world is revealed as most important physiological processes in the human body occur in this temporal range. This article shows how ultrafast can bring clinical value and change the paradigm in medical ultrasound. From virtual and quantitative palpation to assess tissue stiffness to micro-vascularization imaging, cardiovascular risk assessment and brain functional investigation, ultrafast imaging breaks the traditional barriers of the ultrasound field.**

Keywords— **Ultrasound, Ultrafast Imaging, Shear wave Elastography, Vascularization, Functional Ultrasound.**

I. INTRODUCTION

By filming inside the human body, ultrasound imaging has deeply changed our fundamental understanding and clinical management of pathologies, acting as a virtual human eye that looks at tissue and flow dynamics in real time.

The concept of an ultrasound system is to transform non-audible sound (ultrasound waves) into clinically relevant images of the body. Despite the physics behind it is very well known, ultrasound imaging has been constantly progressing in quality and clinical relevance through technology enablers from other industries. Very schematically, the ultrasound industry has passed through three technological eras [1, 2]:

- *The analogical era (70's and 80's): building the foundations of ultrasound imaging.*

Technically, real time ultrasound imaging has been possible thanks to the manufacturing of efficient piezoelectric materials capable of transforming electrical signal into acoustic waves (and vice versa) and the development of electronic components that are fast enough to process signals in a few microseconds and small enough to fit into transportable volumes;

In the first generation of ultrasound systems, most of the processing, and more particularly the heart of the ultrasound system – the beamforming (or image formation), was performed on analog hardware boards. Despite limited versatility and quality, ultrasound imaging was made possible at an affordable price. Real time analysis of tissue morphology and blood flow revolutionized the medical field such as cardiology or obstetrics;

- *The digital era (90's and 00's): The quintessence of real time imaging*

The move to digital processing started in the late 80s with high quality digital signal processing chips (DSP's) and the significant price reduction of Analog to Digital converters (ADCs) thanks to its democratization in the consumer electronic industry. Ultrasound signals were early digitized and processed numerically to output the final image, enabling new processing techniques that drastically increased the image quality and performances of systems: dynamic beamforming (each pixel data is perfectly realigned and processed), spatial and frequency compounding, second harmonic imaging...

- *The software era (from 10's): from real time to ultrafast imaging.*

In the last decade, the increase in processing power of computer processors and the advent of graphic boards dedicated to massive parallel computing allowed the design of a full software based ultrasound system. The processing – including the beamforming- is now done on a computer reducing the electronic boards to acquisition, digitization and data routing functions.

Coupled with smart techniques to send ultrasound waves in the medium, this architecture pushed the barriers of ultrasound machines, and enabled ultrafast ultrasound

imaging. The body can now be imaged at frame rates 1000 times faster than what the human eye can catch.

Whereas all imaging modalities strongly benefited from the Moore's law [1], the impact of multicore CPU and GPU boards on ultrasound imaging is the most effective. The move from hardware to software beamforming enabled researchers to dramatically change the way ultrasonic waves are transmitted in the human body. Such re-foundation of ultrasound basics paves the way to completely new clinical imaging modes and provides new information and biomarkers for diagnosis.

This article shows how ultrafast imaging is changing the way ultrasound is used, by looking at new phenomena, by displaying new clinically relevant information, by significantly enhancing its performance and clinical impact, by opening new clinical fields to ultrasound and by making the modality safer and easier to use.

The first section explains how ultrafast imaging works. The second section shows how ultrafast ultrasound can be used to discover new properties of the human body. The third section will discuss concrete and potential clinical benefits of these discoveries. The fourth section will present ultrafast perspectives for the next years.

II. IMAGING THE BODY AT ULTRA-HIGH SPEED

To build an ultrafast ultrasound camera, the way ultrasound waves are sent into the body must be rethought. Ultrasound machines are today designed in what is called a serial architecture. The image area is sliced into small vertical bands and the machine successively interrogates those bands by sending focused ultrasound beams.

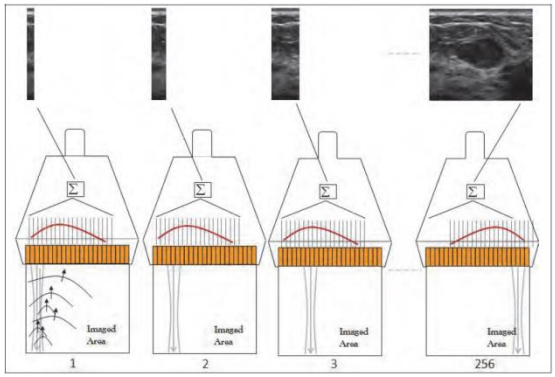

Fig. 1 Conventional ultrasound imaging (from ref [2])

The image is then reconstructed by band, each ultrasound wave getting information from the specific band being insonified. A 2D image is usually reconstructed using a few hundreds of firing beams. The time needed to reconstruct a full image (or volume) is around a few tens of milliseconds, leading to imaging frame rates of a few tens of Hz – perfectly fitting the human eye ability.

This serial design makes perfect sense for ultrasound machines derived from the hardware eras (analogic or digital). The hardware boards were built to compute an image band and this processing was iteratively used for all image bands. Moving to parallel processing of all image lines would require to duplicate the hardware hundreds of time and significantly increase the cost of the system. Despite interesting perspectives shown by academia [3], this move did not make sense from a clinical product standpoint.

The equation is completely different now that software ultrasound machines are technically possible. Parallelization in software is almost for free and a full image or volume could be reconstructed in one shot.

To achieve that, the body should not be insonified anymore by lines but by waves able to cover the whole imaged area. Such waves are either plane waves or divergent waves, propagating over the entire targeted area.

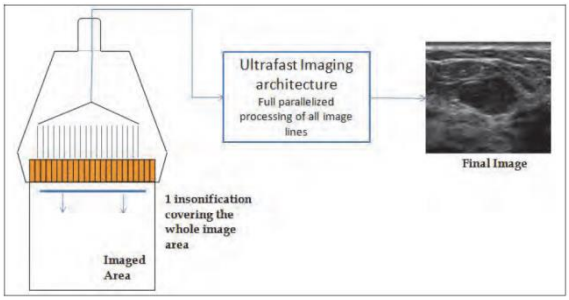

Fig. 2 Basic Principle of Ultrafast Imaging scanners (from ref [2])

On ultrafast machines, each ultrasound wave sent into the body leads to fully reconstructed image of the area of interest. As the wave propagation happens is a few tens of microseconds, frame rates of several thousands of Hz can be reached, way above human eye perception.

This is in perfect analogy with what is done in optics. Conventional cameras reconstruct images line by line, while ultrafast – or high speed – cameras are able to build images in a fully parallelized manner. Today ultrafast cameras can reach billions of images per second, thanks to the much higher speed of propagation of light.

Many concrete applications of such devices exist today such as the monitoring of car crashes to improve car safety, or the recording of object weak movements to better understand their properties or their environment [4].

Similarly we will see that ultrafast ultrasound cameras allow very fine analysis of body's motion leading to clinical breakthroughs in safety and effectiveness.

One of the drawbacks of high-speed cameras is the low image quality, due to weak exposure time. An equivalent problem is faced in ultrasound. Images recovered from flat waves are lower in signal to noise ratio, contrast and resolution compared to classical focused images.

However in the ultrasound world, and contrary to optics, signals are perfectly digitized in time leading to new possibilities to improve ultrafast image quality. The concept

of coherent plane wave compound has been introduced in order to solve this drawback [5]. Instead of reconstructing an image from a single plane wave transmission, several plane waves with different steering angles are sent into the body. Images computed from all steered waves are coherently summed to output a single high quality image. Like in optics, the exposure time is increased, recovering signal over noise but – unlike in optics - the contrast and the resolution are dramatically improved from the coherent summation of steered ultrasound images.

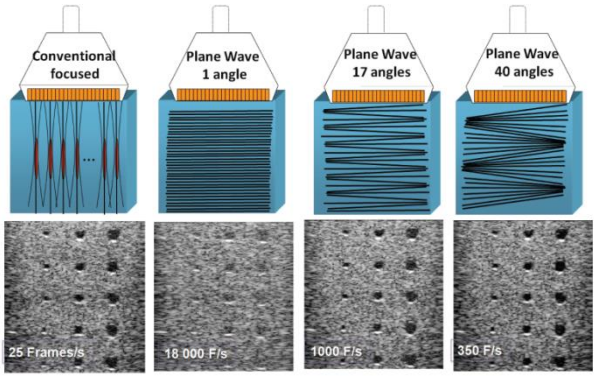

Fig. 3 From conventional line per line imaging to ultrafast coherent compound (from ref [3]))

The beauty of the plane wave compound approach is that with a few tens of angles, very high quality images can be recovered, higher than classical focused images requiring hundreds of firings. Thanks to bi-directional dynamic focusing (in transmit and receive), superb images can then be displayed at much higher frame rate than in a conventional architecture.

In summary, the use of plane wave combined with massive processing parallelization allowed by software platforms enable ultrafast ultrasound imaging.

Very high frame rates can be achieved (up to 20 or 30 kHz) with a limited image quality or ultra-high image quality can be obtained by decreasing the maximum frame rate achievable through the plane wave compounding technique (fig. 3).

There is a continuum of trade-off between frame rate and image quality depending on the number of angles used to compute the final ultrasound frame. The trade-off will be chosen according to the imaging goals.

The Aixplorer scanner from Supersonic Imagine is the first commercially available ultrafast ultrasound system, introduced in 2009. The next section shows concrete examples of how ultrafast imaging can benefit clinical practice on the Aixplorer. Catching small vibrations to measure tissue stiffness, imaging blood pulse to assess cardiovascular risk, imaging of micro-vascularization for pathology characterization.

III. DISCOVERING NEW CLINICAL RELEVANT INFORMATION

The ability to look at phenomena at temporal scale much smaller than what the human eye is able to catch open many perspectives to enrich our understanding of the body. Our ultrafast camera can be used to revisit what classic ultrasound is used to do: image soft tissues, blood flow, or contrast agents. Looking at them at a different time scales reveals new information with significant value for the clinician.

A. Adding a new sense to ultrasound: touch

Ultrasound is originally intended to show tissue morphology in real time. The reference imaging mode, the B mode, display echoes of different intensities depending on tissue ultrasound property, called echogenicity. As a complement to this information, flow information can be derived from ultrasound signals leveraging the Doppler effect of moving red blood cells. The information is displayed as color-coded images, temporal spectra and audio files.

Ultrafast imaging brings an additional sense to ultrasound, in addition to vision (b mode) and hearing (audio Doppler): the sense of touch. With an ultrafast camera it is possible to detect and quantify very subtle and fast tissue motion (a few micrometer displacement) occurring inside the body. This motion, well processed, reveals the inner elastic structure of the analyzed organ. Leveraging these ideas, Shear Wave Elastography (SWE) has been introduced in clinics in 2009 on the Aixplorer scanner to quantify and image in real time tissue stiffness.

- *Shear Wave Elastography: Principles*

To achieve its goal, the ultrasound system will act the same way the physician does when trying to assess tissue stiffness: palpate the organ to feel elasticity contrasts.

In SWE, the palpation relies on a side effect of ultrasound waves: the acoustic radiation force. Like the wind acting on a sail, the ultrasound radiation force pushes the tissue in the direction of the wave propagation. Then, by focusing beams at specific locations deep in tissue it is possible to create virtual fingers remotely palpating tissue at the beam focuses. This concept was introduced by A. Sarvazyan in 1998 [6].

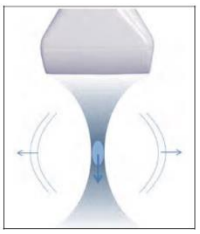

Fig. 1 Acoustic radiation from an ultrasound beam (from ref [3]))

The figure above shows the method to generate a shear wave source inside the body: focus an ultrasound beam using a long pulse: between 100 to 150 µs, 100 times longer than for imaging the tissue.

The virtual fingers will create low frequency mechanical shear waves inside tissues having propagation speeds directly related to tissue stiffness (shear waves propagate slowly in a soft medium and faster in a harder tissue). In a purely elastic tissue, the stiffness is quantified by the Young's modulus E, that can be written $E=3pc^2$, p being the body density (assumed as a constant) and c the shear wave speed.

Contrary to ultrasound waves, shear waves are sensitive to tissue elastic properties and their analysis appears as a smart way to quantify tissue stiffness non-invasively.

However, those waves are very weak (only a few micrometer displacement amplitude) and fast, passing through the image area in a few tens of milliseconds, less than the time required for an ultrasound machine to build a single image.

An ultrafast system is required to properly follow their propagation in tissues. The figure below shows the propagation of a shear wave imaged by the ultrafast scanner at 4000 images/s.

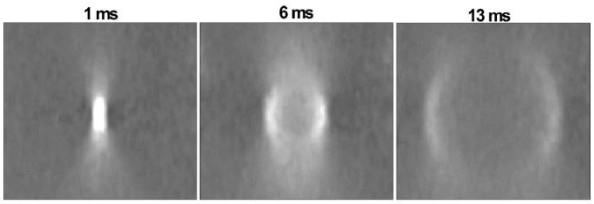

Fig. 2 Shear wave induced by an ultrasound beam focused in the center of the image (from ref [8]))

The tissue elasticity is deduced by measuring at each location the shear wave propagation speed (typically time of flights estimation algorithms are used).

The weakness of the shear wave displacements raises two issues: first it makes the shear wave detection a challenge in real tissue, secondly it limits the distance of propagation of the wave, reducing the explored area (typically to a few millimeters). A trivial solution would be to increase the energy of the ultrasound pushing beams but it raises safety concerns, as the amount of acoustic energy allowed at a given location is limited by international acoustic standards [7]. We found [8] a much smarter way to address this issue by creating a moving shear wave source travelling at a supersonic speed. This is made possible by successively focusing pushing beams at different depths, the beams being moved at a speed higher than the shear wave propagation speed. In such a supersonic regime, and similarly to a supersonic airplane creating an acoustic bang, the shear waves will sum up naturally along a Mach cone to create a higher amplitude plane shear wave as illustrated on the figure below.

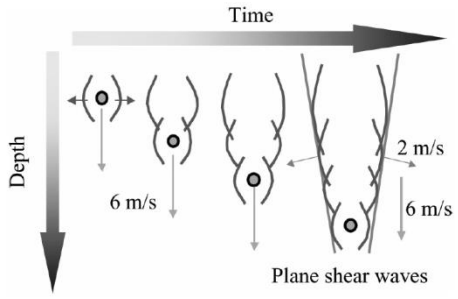

Fig. 3 Supersonic source (from ref [8]))

Thanks to this "bang" effect, the amplitude of the shear wave is multiplied by a factor of 5 to 10 without increasing proportionally the local acoustic power delivered in the medium [9]. With such a method a large shear wave can be generated in the medium able to propagate over several centimeters across tissue.

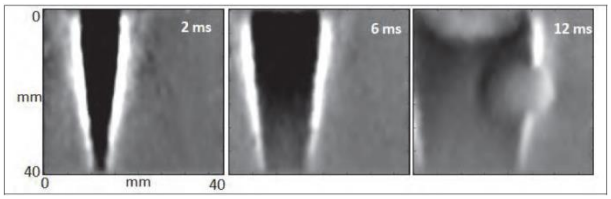

Fig. 4 Plane shear wave along a Mach cone from a supersonic source propagating in a heterogenous phantom (from ref [2]))

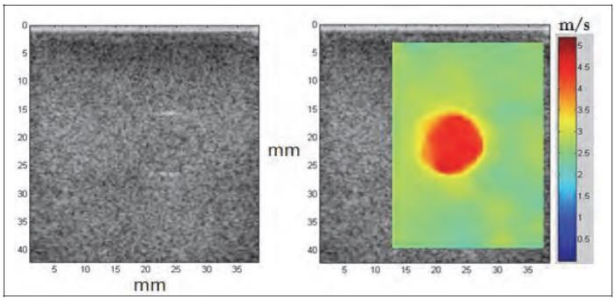

Fig. 5 Map of shear wave velocity deduced from previous movie (ref [2])

To build an image, several supersonic lines laterally separated by a few centimeters (typically 2 to 4) are generated and the deduced elasticity maps is concatenated to build a final elasticity map covering the full image area.

This mode is implemented in real time on the Aixplorer machine and provides quantitative elasticity maps of all organs (Breast, small parts, prostate, MSK, Liver …).

For precise quantification the user can place a Q-box on the image to measure local elasticity values.

In summary, the coupling of radiation force-based supersonic sources and ultrafast imaging allowed the creation of a new imaging mode in ultrasound providing real-time and quantitative elasticity imaging.

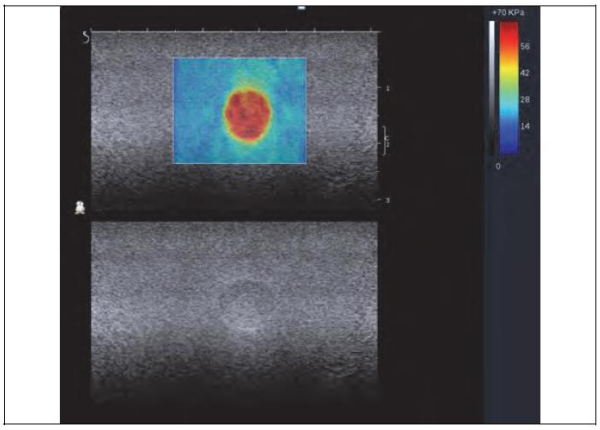

Fig. 6 Shear Wave Elastography mode on Aixplorer (from ref [2]))

- *Shear Wave Elastography: maturity and clinical value*

On Aixplorer, SWE is today a mature mode performing in a robust and a reliable way on most of human organs. It is available in 2D and 3D. It can be used for focal or diffuse disease diagnostic. It is a very powerful tool for therapy monitoring thanks to its quantitative aspect. It can also be used for functional assessment, like in the MSK application for example.

Many clinical studies have been performed since its introduction in 2009 and have proven its robustness and clinical utility. Below some highlights on the main organ studied:

§ On breast, more than 75 peer review clinical articles have been published [10,11]. SWE has been proven to be reproducible with a near perfect intra-observer reproducibility [12]. In the diagnostic workflow it increases ultrasound specificity by 34% without loss in sensitivity when trying to classify BI-RADS 3 and 4a lesions [13]. In the monitoring of therapeutic treatments, it allows early and accurate assessment of chemotherapy efficiency thanks to volumetric implementation for breast.

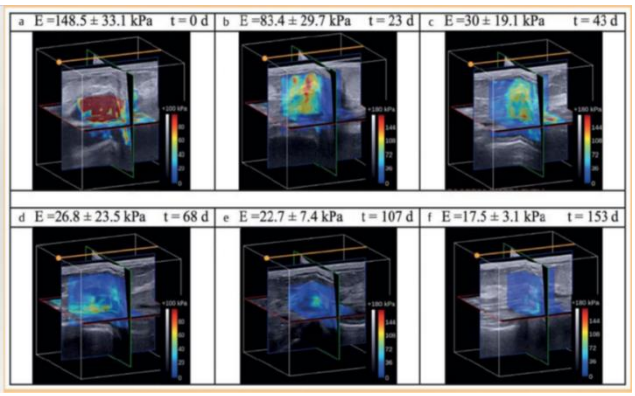

Fig. 7 3D SWE of a lesion treated by chemotherapy at different times

§ On Liver diseases, SWE showed excellent accuracy in detecting severe fibrosis, and exhibited good to excellent performances in staging fibrosis in Hepatitis B, C and NAFDL diseases [14-19]. Cut offs for each etiologies has been found and published. It has also been proven useful in oesophageal varices detection and distinction of compensate from decompensate liver fibrosis through the estimation of spleen elasticity [20].

§ On Prostate, SWE has been proven effective to better target the biopsies (the cancer detection rate being improved by a factor of 3 and showed excellent specificity for lesion characterization [21].

- *Shear Wave Elastography and competition*

SWE was the first real-time quantitative elasticity-imaging mode on the market. Since then all manufacturers have implemented their version of shear wave imaging. Still not relying on ultrafast imaging or supersonic sources these techniques lack of robustness or usability as they need to sacrifice performance. They can either sacrifice the imaging capability (giving only a single point measurement), the real time aspect or the quantitative aspect [22].

From a scientific standpoint the coupling of ultrafast imaging and supersonic sources is the safest and most efficient way to measure elasticity.

§ the safest approach thanks to the supersonic effect that reduces the local acoustic power delivered to the minimum required, staying in compliance with international standards and with ALARA (*as low as reasonably achievable*) principle.

§ the most efficient, as it gives optimal signal to noise ratio and therefore reduces the operator dependency and operation time while providing maximum imaging robustness and stability.

It is highly desirable and probable to see this technique standardized similarly to what happened to the color mode in the 80s/90, the standardization and the extension of the clinical proofs will insert the mode in the mainstream clinical routine of all applications.

- *Shear Wave Elastography: perspectives*

As one elasticity image is computed in a few tens of milliseconds, one potential feature of SWE, unused so far, is to monitor elasticity as function of time. Elasticity of organs can change over time under external or internal solicitation. Dynamic SWE analysis gives another dimension to the understanding of body organs:

§ In the heart, researchers showed that it was possible to monitor evolution of myocardial stiffness while the heart is beating. They measured stiffness at 10 different times during the heart cycle. While diastolic elasticity could help detection of infarct, systolic elasticity is a way to measure heart contractility non-invasively [23]. In the same path, monitoring muscle or tendon stiffness under contraction could help assess their viability and strength and monitor myopathologies [24,25].

§ On external organs, applying a compression hardens them. Quantifying this hardening is a new piece of information to further help characterizing lesions, more particularly small ones where the elastic contrast remains small. Research is going on investigating the possibility of computing hardening maps and assess their clinical relevance.

Finally 3D SWE will provide a unique tool to monitor effectiveness to non invasive or minimally invasive therapies (RF or cryo ablation, Hifu…).

B. Breaking the limits in blood flow imaging.

Blood flow information is assessed today through 2 distinct ultrasound modes. Color flow imaging provides visualization of flow on a color-coded image in real time while PW Doppler gives quantitative and precise flow information at a specific location as a function of time. The existence of two separate modes is a non-sense and a waist of time for the user. And the only reason for that is the technical limitations due to the lack of ultrafast imaging on existing systems. Indeed, properly quantifying blood flow requires high frame rates, typically between 500 and 20000 Hz (the frame rate should be at least twice the Doppler frequency shift induced by the moving red cells). Unreachable for conventional systems these frame rates are only available along a given line where a focused beam is repeatedly fired (PW mode). To get a flow image, compromises are taken and each line is partially sampled during a short duration. These compromises induce many limitations on the color flow imaging mode:

- lack of sensitivity
- Unability to image slow flow
- lack of quantitativeness: only a mean velocity at the central frequency can be estimated.
- Low frame rates of large areas of interest

The PW mode also suffers from limitations

- Availability only at given location
- System dependent spectral broadening due to focused beam geometry inducing bias in the maximum velocity measurements.

Rethinking blood flow imaging with ultrafast is an opportunity to break all these limitations. Using ultrafast frame rates, flow can be correctly sampled over the entire area of interest thus providing highly sensitive and quantitative imaging [26]. The figure below compares sequences of conventional and ultrafast Doppler.

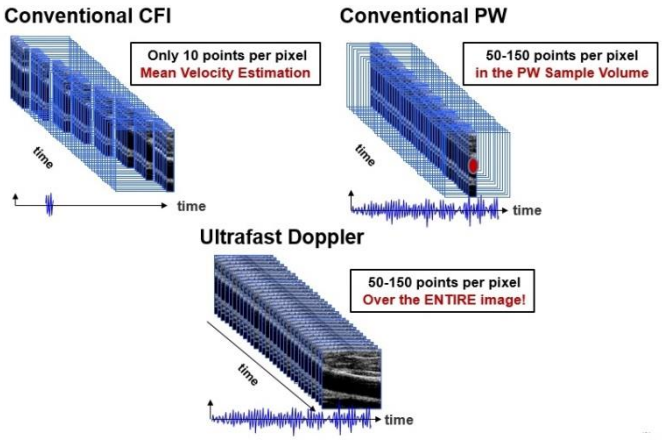

Fig. 8 Doppler mode acquisition sequences

- *Providing quantification anywhere*

As flow is correctly quantified anywhere, launching an acquisition of ultrafast Doppler data allow reconstruction of the color flow images while enabling the possibility to compute PW spectra anywhere on the image [27]. The color imaging frame rate is much higher (typically a factor of 10 is provided) and Doppler signals can be computed from multiple points and compared between them as illustrated on image below.

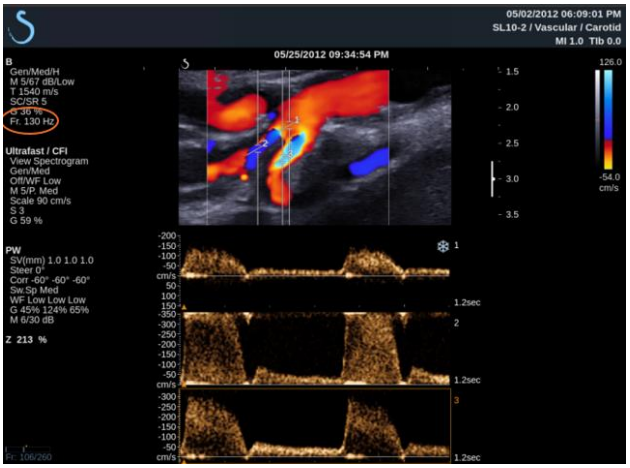

Fig. 9 Ultrafast Doppler of a carotid stenosis (from ref [27])

Comparing multiple spectra from the same acquisition increases diagnostic robustness (the comparison is done on the same plane and same cardiac cycle) and allows a significant gain in scanning time increasing therefore the patient throughput. This is particularly true for carotid and liver scanning.

- *Increasing quantification accuracy*

Doppler quantification is usually performed via spectrum computation of flow signals. The spectrum gives the distribution of Doppler frequencies and therefore the flow velocities at a given location. Most of clinical indicators are based on the maximum velocity measurement or the ratio of maximum velocities (at systole and diastole). However velocity measurements are biased due to geometrical spectral broadening effects. Indeed, a given and constant flow velocity will not give one Doppler frequency as expected but a distribution of Doppler frequencies corresponding to its projection along all angles of the transducer aperture. This artefact depends on the transducer and ultrasound beam geometry and may vary from one manufacturer to the other (literature reported a 20 % uncertainty in the maximum velocity measurements).

Ultrafast Doppler offers the opportunity to avoid this bias by displaying not the spectrum but the distribution of mean velocities over time in a given sample volume. Thanks to the high spatial and temporal resolution, this distribution is much more representative of the true velocity flow pattern [28]. The figure below show an example in the carotid:

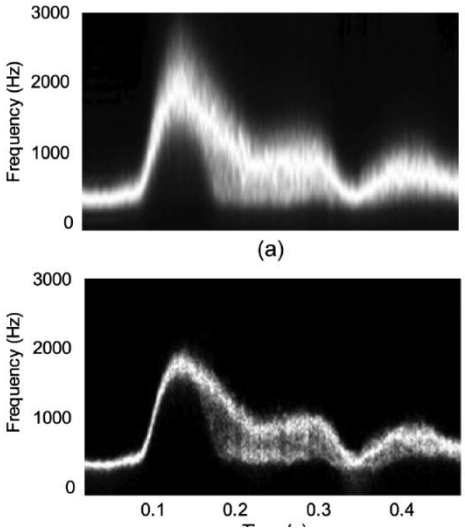

Fig. 10 Classical PW spectrum compared to ultrafast histogram (from ref [28])

Despite its potential clinical impact, this feature is still not available commercially as extensive clinical validation is required to replace maximum velocities cut off in the clinical workflow.

- *Increasing sensitivity and resolution to image micro-vascularization*

Slow flows are today hardly detected by color flow imaging mainly for two reasons. First, the lack of sensitivity and resolution of the mode. Second, because slow flows move at the same speed as tissue and classical recipes (temporal wall filtering) to filter blood from tissue motion do not work anymore;

Ultrafast Doppler is able to overcome those limitations. As for slow flows the sampling rate required in way lower than the maximum capabilities of the ultrafast system (typically 500 Hz for velocities of a few cm/s), the plane wave compound technique can be implemented. Each image is deduced from a set (between 5 and 15 depending on time availability) of several tilted plane waves summed coherently. This significantly enhances the resolution and signal to noise of ultrasound images resulting in a color flow image of very high resolution and sensitivity.

Furthermore, as ultrafast imaging provides simultaneously Doppler data over the full image, smarter filters can be used to separate tissue from flow motion. Conventionally, this separation using temporal filters that assume the flow faster than the tissue. In ultrafast Doppler, the spatial information is used to filter tissue from flow as tissue motion has a much larger spatial coherence than flow motion. Using a filter that use both the temporal and the spatial information allows the extraction of slow flow with speeds similar to tissue's, enhancing the sensitivity of the mode.

Examples below show conventional and ultrafast color images on different pathologies.

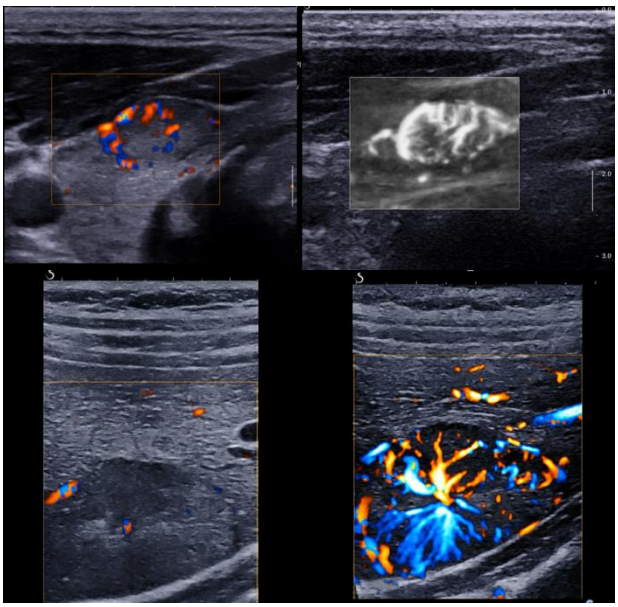

Fig. 11 Example of sensitive ultrafast Doppler (Angio Plus) compared to classical Doppler o clinical cases: thyoid nodule (up) and transplanted kidney (bottom)

Ultrafast Doppler (and its sensitive version called Angio PLUS) was recently introduced. Despite the lack of clinical studies, the first clinical images demonstrate the significant improvement in performance of the mode compared to classical flow imaging opening many clinical perspectives: better lesions characterization, inflammation quantification etc...

- *Perspectives: parametric maps for better and faster workflow*

Leveraging the quantitativeness of ultrafast Doppler, it becomes possible in a single cardiac cycle acquisition to access in all pixels quantitative hemodynamic parameters such as the resistivity or pulsatility indexes, which were estimated up to date at a single location at a time. 2D and soon 3D maps of these parameters could be provided as already demonstrated in the brain of human newborns [29]. Resistivity maps can be used to monitor resistivity variations due to changes of intracranial pressure or controlled hypothermia during the follow up of newborns. It could also provide very informative maps of arterial resistivity in transplanted kidney.

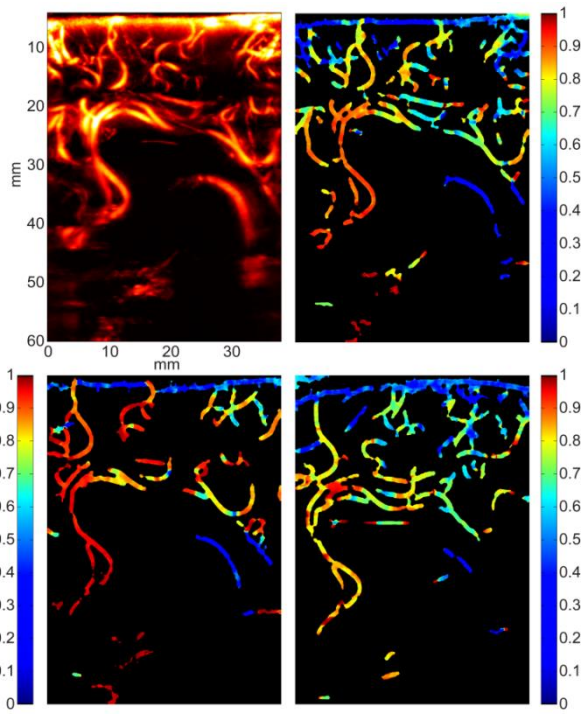

Fig. 12 Changes of resistivity observed in the medial sagittal plane of the human newborn brain during a mild fontanelle compression. Top: the Doppler image and its corresponding resistivity m map at baseline without fontanelle compression. (from ref [29])

C. Recording the living body:

Another way to clinically leverage the ultrafast system is to use it to analyze natural motion occurring in the body. One example is the propagation of the blood flow pulse wave at each heart beat in the arteries. The pulse wave velocity is an established criterion to assess cardiovascular risk. It is usually measured with dedicated tonometry devices (Complior®, Alam Medical and the SphygmoCor, ArtCor Medical) measuring an average value between the carotid and femoral artery. The reproducibility and clinical value of the technique is proven [30]. It suffers from a lack of accuracy as it measures an average speed over many arteries while being a time consuming act (10 - 15 minutes)

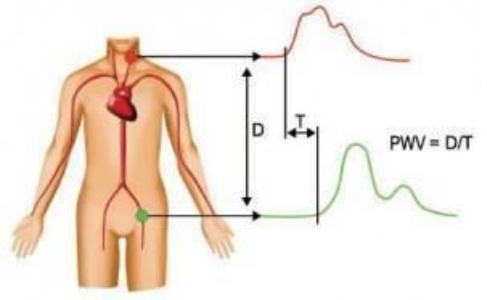

Fig. 13 Classical tonometry measurement methodology (from ref [31]))

Ultrafast imaging allows precise tracking of the pulse wave in vessels and therefore local assessment of pulse wave velocity (PWV) in targeted arteries, such as carotid or aorta. The figure below shows the pulse wave track on the carotid and the velocities estimation derived from the data. Two velocities can be measured: the velocity at artery dilatation and the one at artery retraction (after the blood pulse wave is gone). Interestingly, both velocities can be different, revealing inner elastic and geometric properties of arteries.

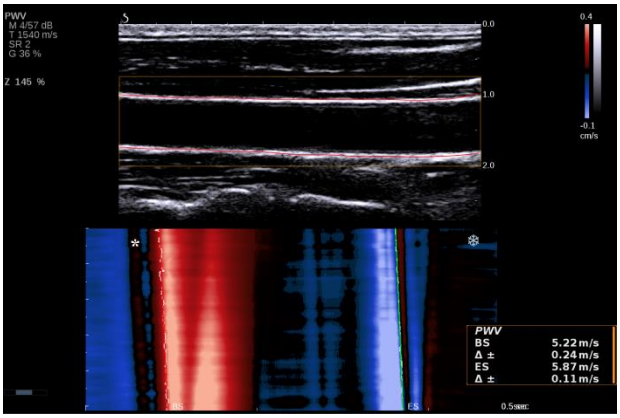

Fig. 14 PWV on Aixplorer

The feature is currently under clinical investigation and comparison with the standards [31]. Its clinical benefit was already demonstrated in the framework of Ehler Danlos pathology, a rare disease affecting Collagen Type III in arteries [32].

IV. PERSPECTIVES FOR ULTRAFAST IMAGING

If ultrafast imaging has already a strong clinical impact in the ultrasound field through applications presented in the previous paragraph, it also opens many other possibilities currently investigated in research that may revolutionize the

use of ultrasound in medicine. We present below an overview of the most promising trends.

A. Exploring human brain activity

The most fascinating impact of ultrafast imaging is probably in neuroscience. At the frontier of physics, biology, computer science and sociology, the quest for understanding the human mind is one of the biggest challenges of the 21st century. So far, brain exploration has been dominated by MRI [33] and more particularly by functional MRI. The use of ultrasound is a challenge in the brain due to the strong attenuation of waves through the skull and is until today dedicated to specific transcranial Doppler exams in vascular.

Interestingly ultrasound could play a role where MRI has limitations: small animals (due to lack of resolution), children (due to confinement requirements) and intra-operative scans. In small animals, the very high sensitivity and resolution of ultrafast Doppler enables for the first time live functional imaging of the brain. The first in vivo experiments were performed on trepanned rats by imaging functional changes of cerebral blow volume (CBV) in the brain micro-vascularization during whisker stimulation [34].

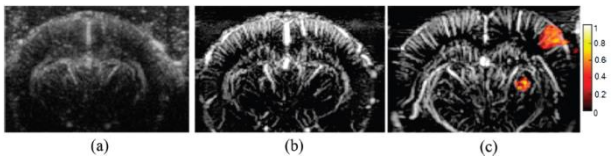

Fig. 15 Functional ultrasound imaging during whisker stimulation a) Doppler, b) Ultrafast Doppler, c) brain activity (from ref [34]))

Similar experiments were performed in intact rats (with skull) using ultrafast Doppler and contrast agents [35]. Functional ultrasound can also be used to monitor brain diseases such as epileptic seizures [34, 36].

Today functional ultrasound can be performed on freely moving small animals by just plugging a small transducer in animal's head [37]. A new field of investigation is here open for research - unreachable by other imaging modalities that require an immobilization of the animal.

Back to clinical diagnosis, functional ultrafast ultrasound can provide a unique bedside neuro-imaging system during neurosurgery for predicting the remodeling of cortical mapping resulting from tumor development. Finally, in newborns, brain activity monitoring is possible through the fontanel window to enable assessment of neonatal seizures and hemorrhage.

Fig. 16 Portable functional brain imaging system (from ref [37])

B. Transforming contrast agents into spy agents

Ultrasound contrast agents are usually injected in the body to increase back-scattered signals from blood flow vascularization. Ultrasound wave makes bubbles resonate at the wave frequency and higher harmonics. The very specific ultrasound signature of bubbles gives access to flow dynamics and can help lesion characterization, in liver for example, or to diagnosis cardiac pathologies.

So far, contrast agents have not been used in the mainstream clinical routine because their clinical benefit does not counterbalance the invasiveness of the technique.

This will not be the case anymore when coupled with ultrafast imaging.

Indeed, ultrafast imaging allows the measurement of the dissolution time of a bubble under high acoustic pressure. The clinical interest of the dissolution time is currently under investigation. It seems strongly correlated to the bubble environment. The figure below shows the difference between bounded and free bubbles in a phantom experiment after a disruption pulse over a few millisecond timescale [38].

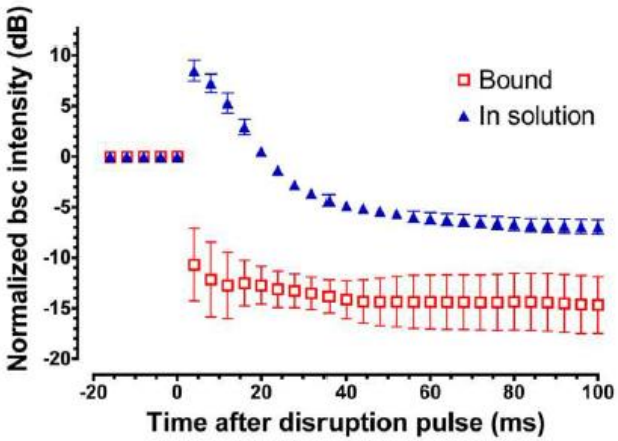

Fig. 17 Dissolution time of bounded and free bubbles in a phantom after a disruption pulse (from ref [38])

Ultrafast bubbles dissolution imaging could help differentiated free bubbles from sticky bubbles and be the first step for ultrafast molecular imaging. It could also be a way to measure intra-vascular pressure while reducing invasiveness to minimum [38,39].

Finally catching bubbles at ultrafast frame rate allows isolation of each bubble signal from the others giving rise to bubble super-localization and what we can call ultrasound microscopy [40].

This has been demsontrated in vitro on a microfluidic setup having channels at least 10 times smaller than the ultrasound resolution, shown on figure below. While the classical ultrasound image blurries all the information, the ultrafast imaging of bubbles allows proper imaging of the channel nerwork, leveraging an increased resolution by at least a factor of 10. This revolutionnary approach, earlier applied in optics and rewarded by the chemistry nobel prize [41], can be applied to ultrasound thanks to ultrafast imaging and is currently under investigation in vivo.

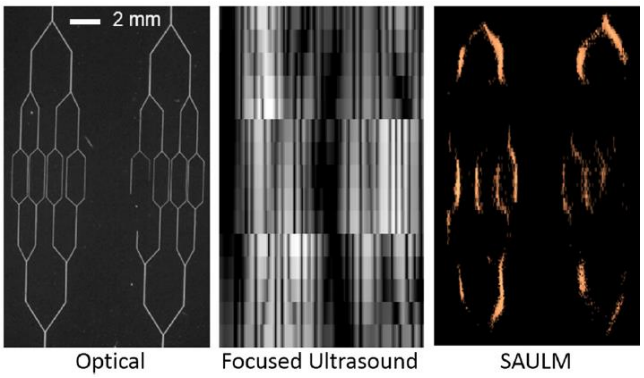

Fig. 18 Optical imaging, ultrasound imaging (center) and ultrasound microscopy (from ref [40])

Given the potential clinical benefit, these three potential applications could give another dimension to ultrasound contrast agents spreading its use in clinical routine.

C. Handheld ultrafast

One of the big trends of ultrasound industry since the 90s is miniaturization. From the big cart used in specific scanning rooms, ultrasound moved to light laptop format used in point of care and emergency. Ultrasound machines are now ready to be embedded on handheld systems, integrated on a tablet or in a probe plugged to a smartphone through usb or wireless connection. Ultrafast imaging will follow that trend. The increasing efficiency of tablet processors will open the road to ultrafast handheld system.

All benefits listed above will be available in the palm of the hand.

The miniaturization will also trigger progress on the road to 4D ultrafast imaging. Expected to be a breakthrough for cardiac imaging, 4D ultrafast still requires another level of technological evolution and miniaturization to be achievable.

V. CONCLUSIONS

With recent technological evolution clinical Ultrasound is currently entering the era of ultrafast imaging. Already bringing significant clinical benefit thanks to SWE mode and ultrafast Doppler, ultrafast imaging breaks the traditional limitations of ultrasound, provides several new applications and opens new avenues for a better understanding and clinical management of the human body.

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HOW TO

QUALITY CONTROL AND PRE-TREATMENT QUALITY ASSURANCE APPLICATION OF EPID (aS1000) FOR FF AND FFF BEAM VMAT PLANS

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Abstract— **Radiotherapy employs high energy radiation for the purpose of cancer treatment. Precise patient positioning is essential with the current use of complicated treatment plans. Portal imaging is often used for pre and during treatment anatomical setup verification. Currently the most advanced and widely used amorphous silicon Electronic portal imaging device (EPID) (aSi 1000) and the TrueBeam linear accelerator (LINAC) from Varian medical systems were used here for the measurements.**

Regular QC (quality control) of the EPID with the use of PTW QC phantom to monitor its performance was performed. Instead of EPIDs main purpose in the department, it was aimed to implement it for a fast and efficient way to perform pre-treatment sophisticated treatment plan QAs (quality assurances). EPIDs spatial resolution and features made them well suited for dosimetric purposes. The treatment plans analyzed include flattened (FF) and flattening filter free (FFF) beams with the TrueBeam LINAC capability of delivering both beam types.

Five VMAT plans with 6MV beam in total having ten arc fields were analyzed using both Eclipse integrated portal dosimetry and external EPIQA software. In addition, four VMAT plans with 6MV FFF beam, in total having nine arc fields were analyzed using EPIQA, since the feature is not supported by Varian Eclipse system currently. The aim of the project was to determine the reliability and comparability of the QA methods.

The evaluations were under acceptable tolerance and as a result it was prevalent that the pretreatment QA methods from both EPIQA and Varian for 6MV beams are comparative and reliable. Further, it was evident that EPIQA system could successfully be implemented for pretreatment 6FFF beam VMAT plan QAs.

Keywords— **EPID (electronic portal imaging), LINAC (linear accelerator), SDD (source detector distance), VMAT (volumetric modulated arc therapy), dosimetry**.

I. Introduction

The use of a megavoltage energy beam for imaging in radiation therapy is called portal imaging (Langmack, 2001) [1]. Portal imaging in radiation therapy is implied to attain the main goal of radiation therapy, which is the delivery of a high conformal radiation dose to the target while sparing the surrounding normal tissue. Although, rigorous patient positioning is followed, with the advancement of collimation and treatment planning systems, uncertainties of exact tumor location are an issue since most treatments take several fractions to complete. The initial and main general objective of portal imaging is geometrical verification of treatment setup or localization to avoid errors and have better accuracy. Localization imaging could be performed before or after treatment, and a small portion of the total dose can be used for the imaging (Antonuk, 2002) [2].

Portal imaging has evolved from the tedious and time-consuming film method to a more convenient and easier aSi EPID (amorphous silicon electronic portal imaging device) method. Currently aSi is the standard, with its better image quality in comparison to the other EPIDs (Matsumoto et al., 2012) [3]. Anatomical landmarks and field borders from reference simulation or DRR (digitally reconstructed radiographs) images are compared with portal images for verification of patient setup and adjustment of patient positioning in accordance with the radiation field.

Quality control assessment of EPID is a necessary task to perform before any portal dosimetric measurements to make sure its reliable performance. A quality control phantom from PTW and its accompanying software called epidSoft are used for the quality control tests, which include mechanical integrity and proper functionality of the EPID.

EPIDs features such as having good spatial resolution and linear response to radiation dose exposure made them a good contender for dosimetric purposes. Apart from image calibration of the portal imager performed to eliminate the nose and to have spatially uniform image, dosimetric calibration of the EPID is necessary before any dosimetric measurement, for relating the delivered dose with the corresponding EPID signal. The conversion of measured field pixel values to observed dose is using a calibration factor (CF) (Tyler et al., 2013) [4]. VMAT (Volumetric Arc Radiotherapy) plans, which are complicated and personalized employ high conformal dose for treatment. QA

of each such plans for a patient is a protocol (Bailey et al., 2011) [5]. In this study, external software for pretreatment portal dosimetry called EPIQA is configured to be used with the Truebeam LINAC. Its performance of plan QA is compared with portal dosimetry system from Varian medical systems for 6MV beam VMAT plans, although both have a different approach of configuration and calculation. Also, QA of 6MV FFF beam plans are demonstrated and analyzed with the Truebeam capability of delivering 6MV FFF and 10MV FFF beams and EPIQAs added feature of pretreatment QA analysis of FFF beam plans.

II. Materials and methods

In the study, the TrueBeam LINAC and the integrated MV-imaging unit (aS1000 EPID) (from Varian medical systems, Palo Alto California, USA) are used for the measurements performed. The LINAC is one of the most advanced system available because of its several ranges of capabilities; including integrated imaging, treatment delivery; real-time treatment tracking and respiratory gating.

The aS1000 EPID detector system is mounted on the robotic support arm called E-arm, which is used for placing the detector to an accurate and reproducible working position, perpendicular to the treatment gantry head. The E arm allows the detector to be positioned at 95 to 180 cm from the radiation focus point (source), and the detector has a 40 x 30 cm^2 active imaging area with the E-arm positioning of the detector at 100 SDD (source-detector distance). The aS1000 has an active imaging area with 1024 x 768 pixel matrix. The EPID has a pixel resolution of 0.39 mm, and it is capable of capturing 14-bit images at 30 fps (frames per second) (Varian Medical Systems, 2006) [6].

Portal imaging is used for verification of treatment setup by relating portal images with relative standard reference imaging (Herman et al., 2001) [7]. There are three ways of acquiring portal images in respect to each treatment fraction, which are before treatment, during treatment and after treatment. Other than monitoring treatment session and setup, during treatment acquisition can be performed for dosimetric purposes with integrated image capture.

A. Quality Control of the EPID

Attaining consistent image quality is required with the use of EPID, so periodic QC of it must be followed. The PTW EPID quality control phantom was used in this project. The Phantom is square shaped having 25 x 25 x 4.8 cm^3 dimensions and 3.8 kg weight (Das et al., 2011) [8]. Detail description on how to make a measurement with the phantom is dealt by Das et al., 2011. The PTW Quality control Phantom has five test elements incorporated in it, which are used for the regular periodic checks made. The Software named epidSoft 2.3 is used for the analysis of the measurements made with the QC phantom (PTW, 2008) [9].

Signal to noise ratio (SNR) which is the measure to define the noise signal from the acquired total signal and Signal linearity are measured with the copper step test elements in the phantom. Six brass blocks are used as test elements to determine the local dependence of linearity. An aluminum test element incorporated in the phantom, resembling the Las Vegas phantom is used for the measurement of low contrast resolution. The 14 line patterned lamella blocks with resolution between 0.167 lp/mm to 3.5 lp/mm in the upper part of the phantom are the test elements to determine the modulation transfer function (high contrast resolution) (Das et al., 2011) [10].

B. Image Calibration of the EPID

Image calibration of the detector involves removal of image background noise (dark field image), correction of detector pixel sensitivity (flood field image) and defective pixel correction. The regular periodic imager calibration is performed, so to have a uniform spatial response from the detector field. Image calibration is performed for all possible energy and dose rate combinations used for image acquisitions to consider all possible detector responses. The background noise should be corrected preferably before every measurement but the pixel sensitivity of the detector, which is corrected by flood field image acquisition, tends to have minimal variation in a month period (Menon and Sloboda, 2004) [11].

C. Portal dosimetry

Profile correction is a necessary task for dosimetric purposes. Profile correction eliminates 5% dosimetric inaccuracy that could arise because of the beam off-axis ratio (Adestam, 2003) [12]. The Varian treatment planning (Eclipse version 11) integrated portal dosimetry uses portal dose image prediction (PDIP) algorithm to attain the theoretical expected measure of all the treatment fields. A verification QA is performed by comparing the actual portal dosimetric measure and the predicted portal dose fluence. The predicted portal dose image is for 2D pretreatment evaluation, and it does not account patient and the treatment table. Further, since currently Varian portal dosimetry does not support the flatting filter free (FFF) beams, treatment plans with FFF beams are to be verified with external software called EPIQA. The software is used for pre-treatment non-transit dosimetric and routine machine QA purposes (EPIQA, 2013) [13]. The software uses an algorithm called GlAas for transforming the integrated image acquired for dosimetric verification purposes to dose map for comparison with the dose map exported from the TPS. A detailed description of the algorithm called GLAaS is given by (Nicolini et al., 2006) [14].

Portal integrated imaging is used for dosimetric measurement purposes or sophisticated treatment plan QAs because the method employs the total prescribed dose for

imaging. Five VMAT plans with 6 MV beam in total having ten arc fields were analyzed using both Eclipse integrated portal dosimetry and external EPIQA software. Non-transmission 2D portal VMAT plan QA performance of both systems are evaluated and compared since they have a different approach to configuration and calculation. Also, four VMAT plans with 6MV FFF beam, in total having nine arc fields were analyzed using EPIQA to demonstrate the EPIQAs capability of pretreatment 2D QA analysis of FFF beams. 6MV FFF beam plan measurement were setup at an extended SDD (source detector distance) of 150cm while for measurement of 6MV plans the standard 100 SDD is used. The reason for using longer SDD for FFF beams is to avoid detector saturation.

III. Results

a. Quality Control of the EPID

The captured single frame QC images of the PTW phantom is saved in Dicom format for analysis use by epidSoft 2.3 software version. The earlier 2.0 version were not able to recognize Dicom format as reported by Pesznyak C, et al. 2009 [15]. The software automatically selects ROI (region of interest) after proper positional calibration to avoid the prevalence of an edge effect on the analysis result. The epidSoft software shows analysis pass and fails based on the user defined range of acceptance. The Figures 1-3 show the analysis plots from epidSoft for PTW QC image acquired with 6MV beam and 3MU dose.

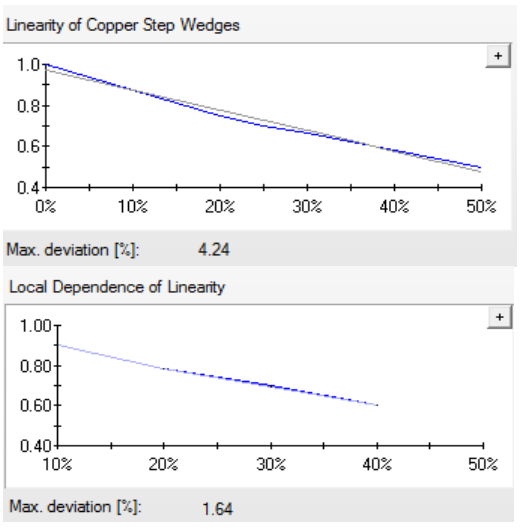


Fig. The linear plot of the copper step wedges showing 4.24% maximum deviation from the regression line (left) and The local dependency of linearity plot showing a maximum deviation of 1.5% from the linear regression (right). For both analysis measures, a maximum deviation of 5% was set as a tolerance.

The Low contrast resolution analysis is presented in numerical and interactive 3D bar graph format, representing the bore holes arrangement in the phantom. For 0.5 contrast difference selection between the holes and their surroundings, the test measurements passed as demonstrated in the figure below.

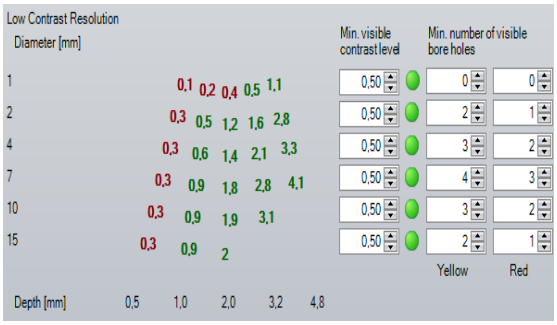


Fig. 2 The Low contrast analysis is depicted above showing 3D plot on the left and numeric representation on the right.

The EPID performance is further evaluated for SNR (signal to noise ratio) and MTF (modulation transfer function) with their assigned test elements in PTW QC phantom. MTF is used for the determination of high contrast resolution of the EPID. The horizontal and vertical MTF analyses were 0.678lp/mm and 0.782lp/mm respectively, which can be used as a baseline for future EPID performance.

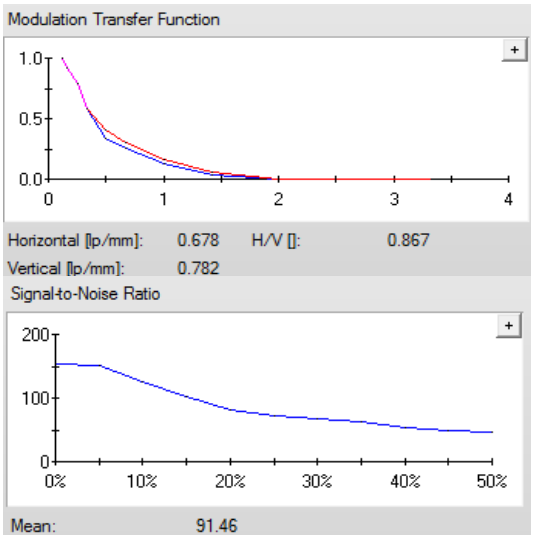


Fig. 3 Modulation transfer function (MTF) plot for all the orientations studied (horizontal and vertical) and Signal to noise ratio (SNR) plot, having a mean value of 91. 46 with lower limit tolerance set to be 50.

PTW QC evaluations of the EPID with epidSoft could be saved and recalled making it possible for statistical comparison and monitoring of the degradation of the detectors over a specified period. As reported by (Das et al.,

2011) [16] the analysis follow-up of aS1000 for a month have not shown a significant verification.

b. *Image Calibration of the EPID*

Image calibrations were performed immediately before any measurement for the most part while carrying out the project. It should be noted that the image calibration task of flood field must be performed at the desired SDD of imaging per beam type. Although, the default SDD for imaging is 100cm, to avoid detector saturation with the use of FFF beams 150cm distance is used, which means the calibration should also be at the defined distance.

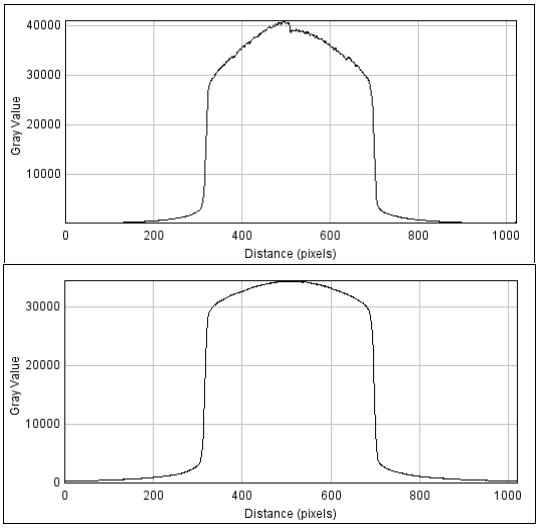


Fig. 4 Horizontal profile plot of 10 x 10 portal dosimetric field acquired with 6MV FFF beam having 50MU dose. The left one show how the profile appears before any Image calibration and the profile to the right is after proper dark field and flood field image calibration of the portal imager for FFF beam.

c. *Portal dosimetry*

Pretreatment 2D portal dosimetry for QA of 5 VMAT treatment plans was performed. The two separate methods from Varian and EPIQA for pretreatment portal 2D QA were evaluated and compared. The tables below depict the results from the analysis measurements of the two separate methods.

Table 1. The gamma analysis (3%, 3mm) made for the evaluation of 5 test VMAT patient plans with external software EPIQA. Each plan has two arc fields, and the table above shows the average analysis values of each arc per plan. Each Arc field evaluation passed the tolerance gamma of 95% since for whole plan to pass each arc field should pass.

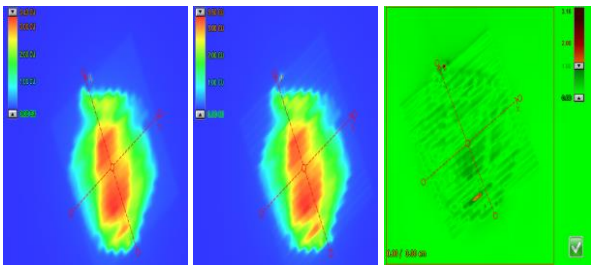
6MV FF beam plans (EPIQA)	Gamma index (3%,3mm)	Mean deviation	Maximum deviation	Standard deviation	Median
1	99.33	0.24	1.70	0.21	0.17
2	99.62	0.22	3.22	0.19	0.16
3	99.62	0.19	2.05	0.16	0.15
4	99.58	0.19	1.91	0.17	0.14
5	99.29	0.22	1.76	0.21	0.18

Table 2. The gamma analysis (3%, 3mm) made for the evaluation of 5 test VMAT patient plans with treatment plan incorporated Varian portal dosimetry. Each plan has two arc fields and the table above shows the average analysis values of each arc per plan. Each Arc field evaluation passed the tolerance gamma of 95% since for whole plan to pass each arc field should pass.

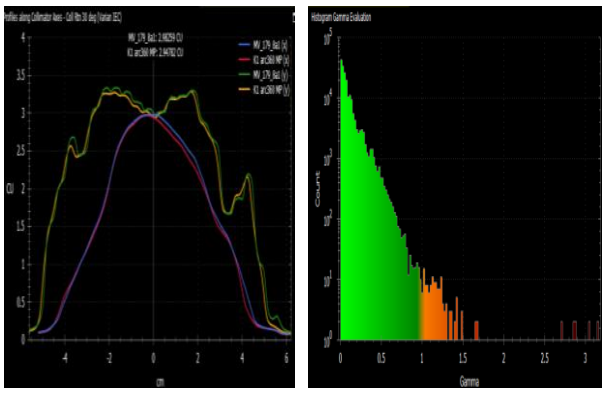
6MV FF beam plans (Varian)	Gamma index (3%, 3mm)	Mean deviation	Maximum deviation	Maximum dose difference (CU)	Mean dose difference (CU)
1	99.7	3.12	0.18	0.49	0.02
2	99.3	3.33	0.19	0.61	0.02
3	99.9	1.9	0.15	0.48	0.02
4	99.9	3.06	0.12	0.89	0.03
5	99.5	2.12	0.19	0.41	0.02

It was evident that the two separate methods had very close analysis results for the chosen treatment plans. Although, since the Varian method is incorporated into the treatment planning system (Eclipse ARIA 11) it was faster to perform the test. Both systems could easily be implemented for a radiotherapy department to have a fast and reliable evaluation of pretreatment plans.

One test plan field of a prostate tumor patient with 6 MV beam energy and 500 MU/min is selected here to show how Varian portal dosimetry appears.



Predicted image Measured image Gamma analysis



Profile plot Histogram

Fig.5. The predicted, the measured, and the gamma analysis are shown from left to right consecutively for one selected field. 99.9% of the field passed the gamma analysis based on the tolerance as shown in the gamma

analysis figure at the middle. Also, the profile agreement between the two compared dose maps of both axises (x and y respectively from the left side) and gamma evaluation histogram plot on the (right most side).

It was possible to perform and demonstrate the portal pretreatment plan QA for 6MV FFF beam plans after the proper configuration of the EPIQA system. The table below shows the analysis made for four such plans and it was evident that the EPIQA supports such task, unlike the Varian portal dosimetry.

Table 3. The gamma analysis (3%, 3mm) made for the evaluation of 4 test VMAT patient plans with EPIQA. Each plan has two-three arc fields, and the table above shows the average analysis values of each arc per plan. Each Arc field evaluation passed the tolerance gamma of 95% since for whole plan to pass each arc field should pass.

6MV FFF beam plans (EPIQA)	Gamma index(3%, 3mm)	Mean deviation	Maximum deviation	Standard deviation	Median
1	99.56	0.29	2	0.23	0.22
2	97.2	0.33	1.55	0.28	0.20
3	98.61	0.30	1.46	0.24	0.25
4	97.94	0.31	1.86	0.23	0.25

One test plan arc field of a lung patient with 6MV FFF beam energy and 14000MU/min dose rate is selected here to show how the image representation for the EPIQA evaluation analysis appears.

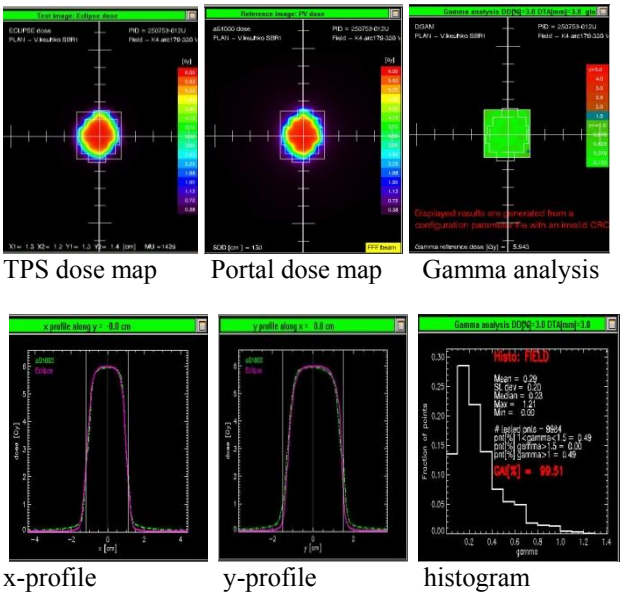


Fig. 6 Gamma analysis and comparison between TPS dose map and the EPIQA converted portal dose map. The Gamma analysis with 3% and 3mm for the first arc passed with 99.51%, which means the gamma index value evaluated was below or equal to 1 for 99.51% of the field under study. Also, the profile agreement between the two compared dose maps of both axises (x and y respectively from the left side) and gamma evaluation histogram plot on the (right most side).

It should be noted that if any one of the evaluated fields fails the gamma evaluation with the set criteria the whole dosimetric QA fails. The rule is valid for both evaluations made with EPIQA and Varian portal dosimetry.

IV. Discussion and Conclusion

EPID development came a long way to the current aSi EPID, which attains better image contrast and resolution in comparison to the other successfully commercialized EPIDs. Periodic quality control monitoring of the EPID performance is an important task. Based on the suggestions from (Herman et al., 2001) [17] daily, monthly, and annual QC checks of different caliber are in order. The PTW QC phantom has several test elements for evaluation of the monthly image quality tests of the EPID. One of the image tests included is MTF, which is used for determining high contrast resolution of the imager. However, since we are using a detector with an already known pixel resolution of 0.39 mm, the MTF evaluation may not be significantly needed. The QC analysis with the use of epidSoft software is not automated, since it involves exporting and importing images after the measurements.

Measurement with the EPID should be strictly confined to the active imaging area to avoid undesired radiation exposure to the surrounding sensitive electronics. As known for a few years that the EPID could potentially be used for dosimetric, and routine machine QA purposes other than patient setup verification, which is its intended initial purpose. With the prevalence of IMRT, VMAT and Rapidarc treatments, which use complicated planning for accurate conformal dose delivery, pretreatment dosimetric QA is a good practice. The accuracy of a treatment dose calculation, precise treatment location, and proper treatment machine functionality are part of the QA test.

In most radiotherapy departments, films and ion chambers are used for 2d dosimetry verifications. However, the EPIDs are also suitable, faster and easier to use for such purposes. Even for in vivo point dose measurements, EPIDs could also be used with an incorporation of complicated back projecting algorithms to give 2d dosimetric data.

The Portal imagers (aS1000) working field size limits measurement of larger field size plans, the issue is more prevalent when measuring at longer SSD than 100cm. For example, FFF beams portal measurement, which requires 150cm SSD to eliminate saturation of the detector.

The portal imager characteristics, which made it appealing for dosimetric purposes are its dosimetric linear response, that it gives reproducible dosimetric response (Green and Vail, 2011) [18] and its negligible memory or ghosting effect of the detector for simultaneous measurements (Greer and Popescu, 2003) [19].

Varian medical systems recently introduced aS1200 EPID to address the measurements issues with aS1000 EPID. The new EPID system integrates a metal plate between the detector and the support arm to remove the

backscatter effect and has larger detector active area of 43 x 43 cm^2 with 1280 x 1280 pixel matrix to support larger field size plan measurements (Varian medical system, 2013) [20].

Pretreatment QA methods from both EPIQA and Varian for 6MV beams are comparative and reliable. The QA evaluations determined the project aim to be correct. Since the measurement results were under acceptable tolerance. Also, EPIQA system showed that it supports pretreatment FFF beam plan QA, which is not currently supported by the Varian portal dosimetry system.

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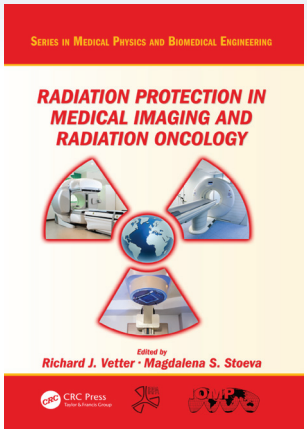

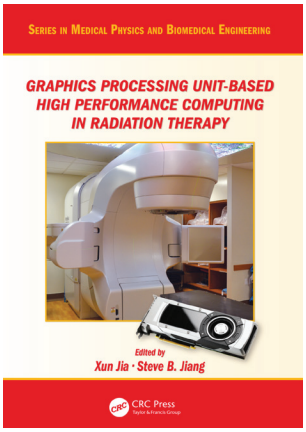

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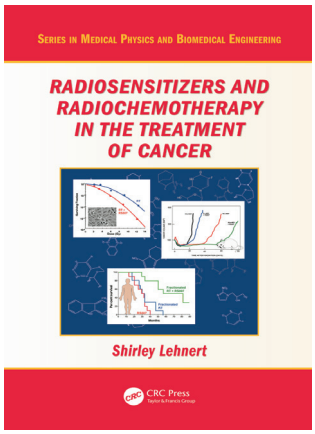

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BOOK REVIEW

RADIATION SHIELDING FOR DIAGNOSTIC RADIOLOGY, 2ND EDITION.

Melissa C. Martin, M.S.

Radiation Shielding Design for Diagnostic Radiology (The British Institute of Radiology. London UK, 2012) is collection of technical information that is intended to be sufficient to enable a physicist to specify and assess the shielding for diagnostic radiology facilities. It has effectively become the United Kingdom diagnostic shielding design standard since its publication in 2000. Diagnostic radiology has seen substantial change since 2000, with the transition from conventional screen-film radiography to digital radiography a key factor driving this change. Computed tomography in particular has seen significant development since 2000. The 2nd Edition of *Radiation Shielding for Diagnostic Radiology* includes revisions to better address these changes. Shielding design for PET/CT suites has also been also added to the 2nd Edition.

The introductory material in Chapter 1 presents fundamental concepts, including dose, types of radiation, occupancy, and workload. Kerma area product (KAP) is recommended as the principle measure of workload, since KAP meters are common in most facilities. If historical KAP data is not available, there are a variety of published sources that can be used to estimate the KAP workload.

The introduction also presents the UK regulations, making the book particularly relevant to physicists in the UK and in other countries with similar regulations. After reviewing the regulations, the authors conclude that shielding for diagnostic radiology rooms can be based solely on the 0.3 mSv per year dose constraint, with occupancy included as appropriate. Notable is their assertion that the UK HSE Approved Code of Practice 7.5 μSv per hour instantaneous dose rate (IDR) constraint need not be considered for diagnostic facilities. This IDR requirement drives primary barrier design for radiotherapy installations, and could have had a major impact on diagnostic shielding if it was the basis for shielding design.

Following the introductory material, Chapter 2 addresses the calculation of unshielded primary and secondary radiation. The use of KAP workload provides a realistic basis for assessing scatter vs. simply designing to the maximum field size. Chapter 2 also addresses tertiary radiation, i.e., radiation that scatters around or over the primary or secondary barriers.

Chapter 3 describes the construction materials that are used to shield radiation, with particular emphasis on the materials and thickness customarily used in the UK. Chapter 4 then addresses the transmission of radiation through the shielding materials. In particular, Archer equation transmission parameters are included for commonly used shielding material in Tables 4.1 and 4.3, for primary and secondary radiation respectively. Chapter 4 recommends basing transmission calculations on the hardened half-value layer of these parameters.

Chapter 5 describes the practical assessment of shielding as performed in the UK. Survey measurements can be performed 0.3 m beyond the barriers, with the diagnostic equipment for which the room was designed serving as the source of radiation. These measurements can then be converted to annual dose based on workload, with the annual dose then compared with the dose constraint. However, Chapter 5 is devoted primarily to an alternative methodology, with a radioisotope placed at an arbitrary location within the room serving as the source of radiation. The objective of this approach is to identify crevices in the room shielding, with the source or the survey meter in some cases in direct contact with the barrier. Evaluating these results is inherently subjective. Since this is a common practice in the UK, it is important for both the physicist and the shielding contractor to be aware if such a survey may be performed, since it may impact the shielding design for the junction between barriers.

Chapter 6 builds on the principles of Chapters 1 through 4 to describe the shielding design for radiographic rooms.

This includes worked examples of the calculations. Since radiographic room shielding must include an assessment of the primary beam component, Chapter 6 introduces the concept of Entrance Surface Dose (ESD) workload, which serves as the workload basis for primary barriers instead of KAP workload. This includes providing a means for estimating ESD workload from the KAP workload, if a direct basis for predicting ESD workload is not readily available. Chapter 6 recommends basing primary barrier calculations on the maximum kV used clinically. For secondary barriers a conservative upper bound to KAP-averaged kV is recommended for transmission calculations. This provides a more realistic energy for secondary barrier calculations than simply designing to the maximum kV.

Following the format of Chapter 6, Chapters 7 through 9 present the shielding design approach for fluoroscopic, CT, and PET/CT suites, respectively. This includes worked examples for each facility type. Chapter 10 then addresses miscellaneous diagnostic rooms that require less shielding (e.g., mammography and dental).

This book is a necessary reference for anyone who designs or assesses diagnostic radiology shielding in the UK or other countries with similar regulations. It is also a useful shielding reference for virtually any country, when used in conjunction with the relevant national or IAEA standards, to provide additional perspective.

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Melissa Martin graduated from UCLA in 1975 with a M.S. in Medical Physics and was certified by the American Board of Radiology in Radiological Physics (Diagnostic, Therapeutic, and Medical Nuclear) in 1979. She became a full time consulting physicist focusing on diagnostic radiology in 1992. Melissa is very active in several professional societies including the American College of Radiology, American Association of Physicists in Medicine, and the Health Physics Society. She is the President-Elect designate of the AAPM, with her term as President-Elect beginning in 2016.

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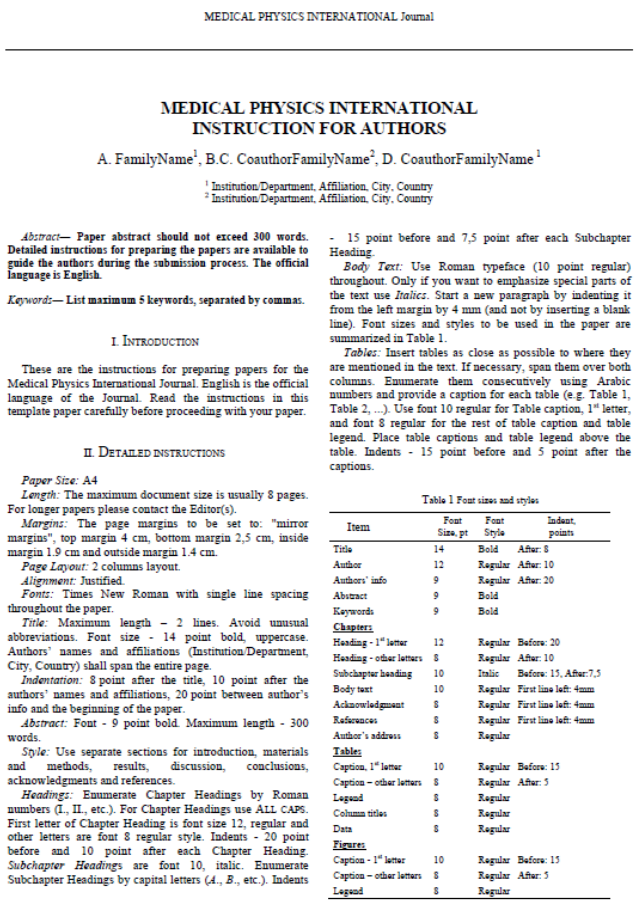

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