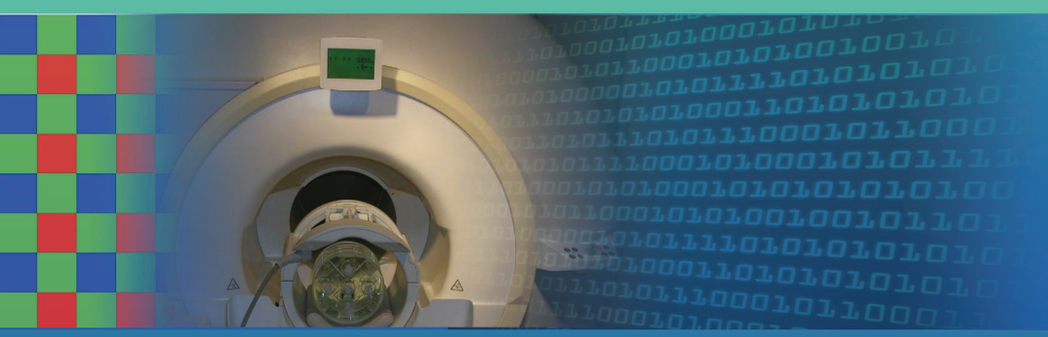
MEDICAL PHYSICS
International



The Journal of the International Organization for Medical Physics

Volume 4, Number 1, April 2016

MPI

MEDICAL PHYSICS INTERNATIONAL

THE JOURNAL OF

THE INTERNATIONAL ORGANIZATION FOR MEDICAL PHYSICS

Volume 4, Number 1, April 2016

MEDICAL PHYSICS INTERNATIONAL

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.

MPI web address: www.mpijournal.org

Published by: The International Organization for Medical Physics (IOMP), web address: www.iomp.org ; post address: IOMP c/o IPEM, 230 Tadcaster Road, York YO24 1ES, UK.

ISSN 2306 - 4609

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Dear Colleagues, on behalf of the 22nd International Conference on Medical Physics Organizing Committee, we are inviting you to participate in the largest International Conference in the profession. ICMP2016 also incorporates 16th AOCMP & 14th SEACOMP Conferences. We shall be delighted to welcome you in Bangkok, and await to receive your proposals for participation at the ICMP2016 Scientific program, its Symposia, Commercial Exhibition and Advanced educational activities. Here is a preliminary list of activities:

International Conference on Medical Physics 2016, Bangkok, Thailand

Mini-Symposia and IOMP School

Title	Speakers
IOMP SCHOOL Day 1: MDCT: Physics, Dosimetry and Radiation Protection	KH Ng , K.Matsubara, J. Damilakis
IOMP SCHOOL Day 2: Dose Tracking and Quality Assurance	M. Rehani, N. Fitousi, V. Tsapaki
European Initiatives on Medical Radiation Protection	J Damilakis, Vi Tsapaki
Room Shielding in Diagnostic Radiology	C A Lewis
Safety in Magnetic Resonance Imaging	S Keevil
Experience Based Lecture of ROC Observer Studies in Diagnostic Medical Physics	J Shiraishi, R Tanaka
Computer Aided Diagnosis and Therapy	H Arimura,et al
The New Era of Medical Physics in Asia	J Shiraishi, R Tanaka
Medical Physic Aspects of Proton Therapy	T Tishitou
Recent Developments in Dosimetry, Treatment Planning and Quality Assurance for Intensity Modulated Proton Therapy	N Sahoo
Robust optimization and robustness quantification in intensity modulated proton therapy	W Liu
Strengthening the Effectiveness and Extent of Medical Physics Education and Training	S Fukuda, ID McLean, B.Healy
Current Status and Future Challenges of Mammography in Asia	H Nishide, Y Kodera, K Tsujioka
Radiation Protection in Dental Radiology	J Vassileva, R Pauwels, IAEA
Women in Medical Physics: Education and Profession	IOMP Women Group
Participation of Women in Medical Physics Scientific Events	IOMP Women Group
Workshop Building Professional Capacities in Developing Countries (IUPAP supported)	Y Pipman, S.D. Sharma, KY Cheung
Comprehensive audits in radiation oncology, diagnostic and interventional radiology	A Meghzifene,A Krisanachinda,WHO,IAEA

IMPORTANT DATES

Registration opens	March 1
Abstract opens	March 15
Mini Symposium ends	May 15
Abstract submission ends	June 15
Abstract acceptance announcements	June 25
Early bird registration ends	July 1
Full text submission ends	Oct 30
Congress and exhibition	Dec 9-12
Opening ceremony and welcome reception	Dec 9

ICMP 2016 President:
Prof. Anchali Krisanachinda (President TMPS)

ICMP2016 Co-Presidents:
Prof. Slavik Tabakov (President IOMP)
Prof. Tae Suk Suh (President AFOMP)

http://www.icmp2016.org/home

Medical Physics Propelling Global Health

ICMP International Conference on Medical Physics
9-12 DECEMBER Bangkok, Thailand 2016

ICMP 2016 Organising Committee (COC):

President TMPS	Anchali Krisanachinda, Thailand
President IOMP	Slavik Tabakov, United Kingdom
President AFOMP	Tae Suk Suh, South Korea
President SEAFOMP	James Lee, Singapore
Secretary General IOMP	Virginia Tsapaki, Greece

International Advisory Committee:

Chair:	Slavik Tabakov, United Kingdom
Co-Chair:	Hu Yi Min, People's Republic of China
Members:	Akio Ogura, Japan
	Franco Milano, Italy
	Ahmed Meghzifene, IAEA
	Agnetta Peralta, Philippines

Scientific/Programme Committee

Co-Chairs:	Geoffrey Ibbott, USA
	Arun Chougule, India
	Howell Round, New Zealand
	Puangpen Tangboonduangjit, Thailand

Educational Committee (IOMP School):

Co-Chairs:	John Damilakis, Greece
	Kwan Hoong Ng, Malaysia
	Shigekazu Fukuda, Japan

Special Activities Committee:

Co-Chairs:	KY Cheung, Hong Kong
	Madan Rehani, USA
	Yakov Pipman, USA

Commercial Exhibition and Marketing

Chair:	Sivalee Suriyapee, Thailand
Co-Chair:	Napapong Pongnapang, Thailand

ICMP2016 Main Topics:

1. Radiation Therapy:
1.2 Particle Beam
1.3 Monte Carlo Simulation
1.4 Clinical Dosimetry
1.5 Image Guided Radiotherapy
1.6 Treatment Planning
2. Radiobiology
3. Diagnostic Imaging
4. Imaging Dosimetry
5. Interventional Radiology
6. Radiation Protection
7. Quality Assurance:
7.1 Diagnostic Radiology
7.2 Radiation Therapy
7.3 Nuclear Medicine
8. Nuclear Medicine
9. Molecular Imaging
10. Magnetic Resonance
11. Ultrasound, Laser, Ultraviolet, Infrared, etc
12. Computer Aided Diagnostic and Therapy
13. e-Learning, Networking and IT
14. Education and Training
15. Professional Development
16. Nanotechnology for Biomedical Applications

Medical Physics Propelling Global Health

EDITORIALS

The Digital Dilemma
Perry Sprawls, Co-Editor

Physicists have overcome a great barrier in clinical medicine by contributing to the development of imaging methods that extending visibility into the human body.

However, a great challenge remains, and even today, we cannot see everything within a patient's body that can contribute to effective diagnosis and guidance of therapeutic procedures. During more than a century since the first x-ray imaging procedures many additional medical imaging modalities and methods have been developed and constantly improved.

The development contributing to what might be considered as "the second revolution in medical imaging" was the introduction of digital computers, associated technologies, and methods for image reconstruction and processing. The modern digitally- based imaging methods have greatly extended the scope of visibility within the body but have also resulted in much more complex procedures. This is because of the many variable parameters that collectively control each imaging procedure. While the goals are generally to optimize visibility for specific clinical objectives and manage risks, it is a complex process requiring extensive knowledge of physics and its application in clinical practice.

This is one of the functions within the expanding role of medical physicists.

Visibility of anatomical structures and pathologic conditions depends on a complex relationship of five specific image quality characteristics: contrast sensitivity, blurring (visibility of detail), noise, artifacts, and geometric or special aspects of the imaged area. While these characteristics apply to all imaging modalities their values and contributing factors are very different.

For the imaging methods that produce digital images, which now include all modalities, the physical structure of the digital image is a major factor in image quality. A major distinction between digital and the earlier analog imaging methods, such as film recorded x-ray images, is that digital imaging is a sampling process in which the patient's body is divided into discrete elements, voxels, and the image is an array of pixels. In virtually all imaging modalities the sample size, voxels and pixels, is an adjustable protocol factor.

The question of optimum sample (voxel and pixel) size for a specific imaging procedure depends on a complex relationship involving clinical requirements, radiation risks, and optimizing with respect to the physical characteristics of the imaging equipment for each of the modalities.

This is the Digital Dilemma faced by the medical imaging profession and addressed within the expanding role of medical physicists as they extend their knowledge and experience in support of the medical imaging procedures within the clinical environment. It requires knowledge and experience beyond the textbook and traditional classroom to include balancing the image quality characteristics with respect to the clinical requirements, and selecting the optimum voxel/pixel or tissue sample size for each clinical procedure.

One of the goals of this journal, Medical Physics International, is to publish and disseminate educational materials and methods using a variety of innovative approaches to develop learning environments for applying physics knowledge to enhance clinical medicine.

Medical Physics International Conferences 2016
Slavik Tabakov, Co-Editor

During this year we see a large number of Medical Physics Conferences – another important parameter for the growth of the profession, fully supported by IOMP and its Regional Organizations:

-The First European Congress on Medical Physics (ECMP, 1-4 September 2016, Athens, Greece) – a new dimension of the regular European Conferences, organized by EFOMP;

-The 7th Latin American Congress on Medical Physics (4 – 7 September 2016, Córdoba, Argentina), organized by ALFIM;

-The First African Conference on Medical Physics, Biomedical Engineering and Sciences (AFROBIOMEDIC 2016, 17 – 21 October 2016, Abuja, Nigeria), co-organised by FAMPO;

-The large regular 22nd International Conference of Medical Physics (ICMP2016, 9-12 December 2016, Bangkok, Thailand), Co-organised by IOMP, AFOMP and SEAFOMP.

Alongside these we also have the large and well attended Annual Conferences of AAPM (Washington, 31 July – 4 August), of IPEM (12-14 September, Manchester, UK), as well as Conferences with International participation in Qatar, Mexico, Sweden, Canada, South Africa, Germany, Vietnam, Bulgaria, Bangladesh, Australia and many others.

I do not remember another year with so many International Conferences on Medical Physics. This active growth will be specially discussed in the IOMP Regional Coordination Board. The enthusiasm of the Organisers should be encouraged and supported. It is also very positive to see that all these Conferences include, alongside their scientific session, special activities supporting Education, Training and Professional development (one of these is the new IOMP SCHOOL activity). Another very important element of the Conferences is that these include many low-and-medium income countries. All this can be seen as one of the results of the focused capacity-building activities of IOMP and its Regional Organisations.

The MPI Journal has also its role for this success, having not only sustained its readership base in the first 3 years since its establishment in 2013, but almost doubling this in the past months (reaching close to 8,000 readers per month)..

IOMP JOURNAL MEDICAL PHYSICS INTERNATIONAL – ACHIEVEMENTS AND STATISTICS OF THE FIRST 3 YEARS

S. Tabakov[1,2]

[1]King's College London, MPI Journal Co-Editor in Chief
[2]President IOMP

The new IOMP Journal Medical Physics International (MPI) was initiated during the summer of 2012 as an official publication of IOMP, devoted to educational and professional issues (Journal ISSN 2306-4609). The first issue of MPI was published during April 2013 as a free access online e-Journal (www.mpijournal.org). Since this time MPI established itself as one of the major Journals of the profession. For the period April 2013 – March 2016 the overall number of downloads from the MPI web site is 179,697. The Journal has a steady number of downloads per month – between 4000 and 6000 in the first two years, and increasing to 8000 for the latest issue (December 2015) – Fig.1.

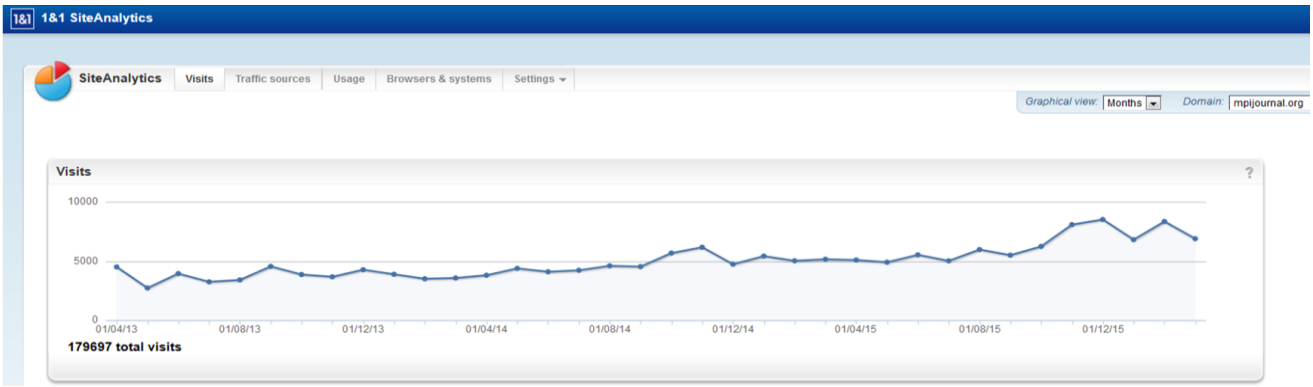

Figure 1 – MPI web site (www.mpijournal.org) statistics of unique visits April 2013 – March 2016

For these 3 years MPI has published 6 issues (two per year) with 60 papers, 29 other publications, and about 2000 abstracts from two Conferences (ICMP2013, Brighton and RPM2015, Varna). In this way the first 6 issues of MPI include 380 pages of articles and 840 pages of Conference abstracts.

The main topics of the MPI Journal are organised in the following areas:

- IOMP Publications
- Professional topics
- Education/Training topics
- Invited lectures
- Collaborating Journals
- Technology Innovation
- Review Articles
- Tutorial Articles an "How to" Articles
- Varia and PhD abstracts
- Conference Proceedings

The Technical Editors of MPI (Dr M Stoeva and Ing. A Cvetkov) created and tested the web site for the MPI Journal www.mpijournal.org, which works with various computer systems (Windows, Mac, Android), as well as with various Internet Browsers.

MPI Journal was created specifically aiming to address various education/training, professional and related issues. The entry pages are indicative of the interest created by the Journal – 72% are direct entry pages (blue); 20% are visits via referring domains (red), and 8% are visits via Search engines (green) – Fig.2.

The very high percentage of direct hits (72%) is a clear indicator for the need of the information published in the MPI Journal.

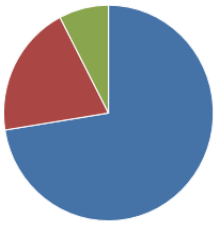

Fig. 2 – Analysis of traffic through www.mpijournal.org

The majority of the papers in MPI have several hundreds of downloads each, while about 1/3 of these have more than 1000 downloads each. These most often downloaded papers (from April 2013 to March 2016) are:

-DOSE MEASUREMENTS IN SMALL FIELDS

-INTRAFRACTIONAL PROSTATE MOTION MANAGEMENT WITH THE CLARITY AUTOSCAN SYSTEM

-ITERATIVE MODEL RECONSTRUCTION: SIMULTANEOUSLY LOWERED COMPUTED TOMOGRAPHY RADIATION DOSE AND IMPROVED IMAGE QUALITY

-A REVIEW OF DIGITAL BREAST TOMOSYNTHESIS

-THE DEVELOPMENT OF MODERN TIME-RESOLVED ANGIOGRAPHIC IMAGING; APPLICATIONS OF UNDERSAMPLED ACQUISITION AND CONSTRAINED RECONSTRUCTION

-INTRODUCTION TO VISION, COLOUR MODELS AND IMAGE COMPRESSION

-RADIATION DOSE OPTIMIZATION TECHNOLOGIES IN MULTIDETECTOR COMPUTED TOMOGRAPHY: A REVIEW

-MEDICAL PHYSICS THESAURUS AND INTERNATIONAL DICTIONARY

-RADIATION PROTECTION OF PATIENTS WEBSITE OF THE IAEA AS A MAJOR RESOURCE FOR MEDICAL PHYSICISTS

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

-IAEA EDUCATION AND TRAINING ACTIVITIES IN MEDICAL PHYSICS

-IMAGE GENTLY CAMPAIGN: MAKING A WORLD OF DIFFERENCE

-ACCREDITATION OF MEDICAL PHYSICS EDUCATIONAL PROGRAMS IN NORTH AMERICA

-EFFECTIVE PHYSICS EDUCATION FOR OPTIMIZING CT IMAGE QUALITY AND DOSE MANAGEMENT WITH OPEN ACCESS RESOURCES

-SAFRON – IMPROVING SAFETY IN RADIOTHERAPY

-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

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

-ULTRASOUND IMAGING GOES ULTRAFAST A CHANGE IN PARADIGM IN MEDICAL ULTRASOUND

The first 4 of the listed papers have more than 10,000 downloads each.

Papers from the past Journals continue to be in high demand. This is a clear sign that they present materials with outstanding educational value. The history-related papers, such as "A HISTORY of IOMP" and "50 OUTSTANDING MEDICAL PHYSICISTS" attract also high interest.

The global use of the latest issue of the MPI Journal (December 2015) is indicative of the development of the profession – as per the 1&1 server statistics:

Usage of MPI issue December 2015 - Geographic Region (by 30 March 2016)	Number of downloads
Asia	5508
Europe	4178
North America	3779
Africa	421
Oceania (mainly AU and NZ)	323
South America (incl. Central America)	267

The Conclusion from the first three years of MPI Journal clearly show that the Journal satisfied a clear need of information related to educational and professional topics. Clearly such a Journal is imperative for a dynamic profession, which uses various e-learning methods, technologies and materials. MPI continues to provide a forum for exchange of educational experience and professional issues and collaborated successfully with the existing Research-orientated Journals in medical physics and with the industry in the field.

Finally, I would like to thank personally and on behalf of the Co-Editor in Chief, Prof. P Sprawls, the MPI Editorial Board and the IOMP ExCom, all authors who submitted papers to the MPI Journal.

COLLABORATING JOURNALS

THE IUPESM JOURNAL "HEALTH AND TECHNOLOGY" – INVITED EDITORIAL

Dear Colleagues, I am Luis Kun the Editor in Chief (EiC) of (Springer's) Health and Technology, the Official Journal of the International Union for Physical and Engineering Sciences in Medicine (IUPESM). Allow me to present a warm welcome to all of you, to "our" Journal.

Dr. Slavik Tabakov, Co-Editor of this Journal of Medical Physics International (MPI) and also the International Organization for Medical Physics (IOMP) President, kindly invited me to submit an Editorial to MPI Journal, so that all of you would have an opportunity to better understand the purpose and vision for this publication, and to send you a direct invitation to actively participate in its life and its growth.

Dr. Lodewijk Bos and I were involved with others, in the planning stages (2010) of this Journal. And from the outset (2011), until his death in July 2014, we both became the co-EiCs of the Journal Health and Technology.

The enclosed LINK should further allow you to read the "Welcome and Introduction," to the Journal' Special Issue on: *"Global Citizen Safety and Security,"* published in August 2014, where you will also find a selection of articles touching many different disciplines. Please read this segment at http://link.springer.com/ article/10.1007/s12553-014-0089-4

In order for all of you (the members of IOMP) to have free access to the Journal, a special URL / link / test account will be arranged and set between IOMP (similarly for IFMBE members) and Springer. You will then access the journal through the webpages of your national society, provided that the national society wishes to make use of this opportunity.

The List of topics of "Health and Technology" includes: quality of health care; patient safety; patient empowerment; disease surveillance and management; e-health; data security; privacy; reliability; management; data mining; knowledge exchange; medical, financial, social, educational and safety aspects of health technologies; social, legal and ethical implications of health technologies; health technology assessment and management; security, efficacy, cost in comparison to the benefit; telemedicine; mhealth; digital homecare; research use of data; public health use of data; physician-patient relationship; social media; patient and genomics; knowledge management; workflow influences (physicians, nurses); health 2.0; vaccines; prevention; wellness; semantic web applications; RFID; Imaging; Picture Archival and Communications Systems; Sensors; Clinical and prevention guidelines; Decision Support; High Performance Computers and Communications; Intelligent agents; Information Assurance; Collaborative Computing; Computer Medical Simulation; Geographical information Systems; Data Access; Medical Informatics; Public Health Informatics; Information Sharing; Common Operating Picture; Global Health Information Systems; Global Information Systems; Data Base Management Systems; Data Warehouses; Electronic Publishing; Educational Tools [INCLUDING Web-enabled Education Tools]; Standards; Interoperability; Education and Training of new tools and techniques; Data, Information, Knowledge and Wisdom Dissemination.

Comments, editorials and papers of course are welcome.

What follows is the Introductory Editorial for Springer's Journal of Health and Technology of August 2011 (printed). Lodewijk Bos and I, were the Editors in Chief and authors.

JUST ANOTHER JOURNAL? NO, A DIFFERENT ONE!

Lodewijk Bos[1], Luis Kun[2]

[1]ICMCC, Utrecht, The netherlands
[2]National Defence University, Washington, DC, USA
Republished from Springer Verlag, DOI 10.1007/s12553-010-0001-9
Published - August 2011, Health Technol. (2011), Volume 1, Issue 1, pp 1-4 - First online: 05 November 2010

Why is Health and Technology not just another journal and why does it call itself different? Because the journal will look at both health and technology in a cross-disciplinary and multidirectional way.

In the context of this journal we define Health Technology as "including drugs, devices, equipment, technical, medical and surgical procedures, the knowledge associated with these in the prevention, diagnosis and treatment of disease as well as in rehabilitation, and the organizational and supportive systems within which care is provided. Included into the definition are the information and communication technologies".

"Health technologies range from single-use devices to the most advanced medical equipment, such as magnetic resonance imaging (MRI) scanners. Technology is used in all types of health facilities, plays a major role in contemporary health care systems and contributes directly to the quality of patient care. It needs to be complemented, however, by good staff training and effective organization of health services where application/use is sought.

Decisions on selecting medical equipment for a health care facility must be supported by evidence and based on clinical needs, financial resources and the local capacity for effective use. Health technology assessment should be used to support more informed decision-making and contribute to the development of national health care services. An efficient HTM programme is needed to keep equipment in good working order with maximum effectiveness in terms of clinical use and running costs." [WHO]

There are many journals covering elements included in this definition, however only very few cover the full width. Recent societal developments, due in large parts to changes in the way we communicate, make it necessary to create a journal with the ambition of being cross-disciplinary—open for all issues and items covered by the above definition—and multidirectional—by any stakeholder for any stakeholder. This approach is not an all-embracing container-for-everything, but a focused and much needed one. Developments in health and technology should be studied, discussed and evaluated from a cross-disciplinary and multidirectional point of view for several reasons:

- Within health sciences specialization is a result of the knowledge explosion and needs to grasp all new phenomena. However, it limits our approach to a patient's condition. A cross-disciplinary approach will increase the diagnostic quality.

-Cooperation in patient's treatment requires an understanding of perspectives from different disciplines. From a patient's point-of-view, there is one patient with one or more complaints, and all available knowledge and experience should be brought together to understand and help the patient. A cross-disciplinary approach will improve cooperation in the chain of health care delivery.

-Technology that supports or enables cross-disciplinary care has to face the challenges of communication between the different disciplines. On the one hand technology enables new ways of communication, like email or web-chats; on the other, technology does not sufficiently support cross-disciplinary communication, e.g. differences in languages, terminologies and coding schemes between primary and secondary care are not yet solved.

-Technology can no longer be seen as just an instrument, it embeds all kinds of assumptions that reflect the way we live or perceive the world. Norms are being built in, and we have to make explicitly clear which values we like to implement. For example, cross-disciplinary exchange of lab-results must include both norm and method. Since communication is based on trust, the receiver must trust the method and understand the interpretation of the sender. Access to information is nowadays supported and regulated by authorization mechanisms. However, for a responsible security officer it is a challenge to maintain these 'rules': they are too embedded in the systems. Our modern technology has become a social construction. Cross-disciplinary approach is needed to design and validate healthcare technology from different perspectives, like ethical, juridical, social, economic and medical, to understand the assumptions and implications.

-The cross-disciplinary approach is not only necessary within the health area. Technologies developed elsewhere

can become a catalyst for change in the way we conduct healthcare as well.

The need for a multidirectional approach comes from a stakeholder analysis. Besides different perspectives, there is the number of people working in healthcare technology all with their proper stake, their proper interest in achieving better care. Government has to deal with conditions for providing good healthcare for a reasonable price for all citizens. Providers and their facilitating partners have to organize healthcare in an economic 'healthy' way. Patients and healthcare professionals have to relate to each other in order to achieve or maintain a status of well-being. Within these three domains (politics, economy and life) each stakeholder has their proper role. The organization of this health and technology eco-system must be studied and discussed explicitly. A multidirectional approach increases the mutual awareness of the broad variety of stakeholders whilst realizing excellent health and technology.

The concept of communication has gone through a major shift in recent history no longer being restricted to humans. Pills, phones, clothes are rapidly becoming monitoring devices, communicating with each other, with systems, with humans and, seemingly, on their own accord.

Ageing and behavior are at the basis of an ever growing number of people who need care and/or cure in any form. This causes a rising demand of resources, human, economic and technical alike, not only in the classically called developed world but also in all other parts of the globe. Increasing economic wellbeing causes both a decline in the number of births and an increase in the number of elderly.

To appropriately deal with these problems we will have to realize, accept and explore our dependency on technology, from process handling to monitoring. Efficiency and error reduction are some of the key arguments used to promote health technologies. In order to achieve those goals, various stakeholders need a basic knowledge about the technology used; at the same time the technology itself has to be safe and efficient.

For all parties involved there are new challenges, following are some examples. Physicians are responsible for the quality of care but will have to accept that providing good healthcare is no longer their sole domain. It depends on versatile, multi-disciplinary teams in which clinical engineers play an important role and warrant adequate quality assurance for the health technologies. To select the appropriate tools, physicians need knowledge of software like electronic health records (EHR), software as a service (SaaS), computerized physician order entry (CPOE); engineers are confronted with the development of new sensor technologies (monitoring) and changing hardware requirements (e.g. direct streaming of MRI data), they have to deal with new equipment performance or training demands, or with the upcoming perception of software being a device (EHR); nurses will have to cover a whole broad spectrum of new technologies, from patient records to barcoded medication distribution. All have to face the developments in telemedicine and mobile health (mHealth).

Patients expect doctors to accept lab tests, X-rays, MRI scans which they did not order themselves, which are performed by other providers than their usual ones and delivered electronically. This causes new constraints concerning trust, interoperability and standards, directly linked to the fact that more parts of the delivery of health care (processes, storage or communication) are being digitized.

Technology has become an essential part of our society. And we slowly discover that almost every aspect of technology influences our health and/or wellbeing. The technologies to transport us, cars, trains, planes, are obvious in this sense and much effort is put into making them as safe as possible under strong pressure from the consumer. Different however is for example the situation in the food industry.

The new ways of communication make information about different fields of science and technology more easily accessible and also much easier to share which enables certain disciplines to be used in alternative ones. The smartphone was not designed for use in the health and medicine areas but is now rapidly becoming an elementary tool. Broadband cabling is changing from an internet browsing enabler to an essential part of telemedicine and digital homecare. Knowledge of chain management in other areas can be used e.g. in the way we distribute food, but also in the manner we manage hospitals. Of course, these alternative uses will have all kinds of implications, not only within the health field but also economically, legally and ethically. These new and "unexpected" relationships will reshape our view of health technologies. But it needs an open mind to be able to see these possibilities. It is amazing to see that we spend so much time, money and discussions on the development of an EHR, whereas a fully functional example already exists and has been in use for many years worldwide, monitoring subjects from before conception till after death, taking into account full family history and environmental aspects: the tags in cows' ears, the cattle register.

Patients are facing a different position as well. Due to the internet and the World Wide Web, their access to information has fundamentally changed with direct consequences to their position not only in their own care and cure path but also in prevention matters. New web and mobile applications are changing the concept of self-management and self-help.

The internet has opened the gates of information, allowing patients not only to consume information, but to add to it their own and, even more important, to add and share their own experience: the way persons act with and react to information. This adds new challenges, especially

in the field of standards (ontologies, semantics), but also for the delivery and quality of information.

Simultaneously patients more consciously come to realize that the basis of information is data, due to access to their own data (EHR) on the one hand and their "active" participation in the gathering of data (telemedicine, mHealth) on the other.

Developments in information and communication technologies (mobile, internet) are changing the role of the patient and causing the relationship between caregiver and care receiver to go through a major paradigm shift, characterized by terms like patient-centered or participatory medicine. Making both patients and providers accept this paradigm shift will be one of the most important challenges we have to face.

New virtualization technologies, genomics and the field of data mining (made easy by digital storage) will lead to personalized medicine with enormous consequences for patients, their caregivers, the pharma industry and technology providers as well as to new approaches in public health. The result of the above-mentioned developments is a society that has the ability to empower people, to iron out differences based on century old informational disparities. The new access to information also enables a new way of communication, helping people to realize that only in the rarest occasions their condition/problem is truly and a hundred percent unique, that there always is another person who has been or is in a similar situation, able to help with their experience; and vice versa. Modern technology allows us to seek and hopefully find this person.

These new technologies will be of essential assistance in achieving a new perception in health and medicine, the patient as a partner in their health and wellbeing related processes by offering them tools to assume that position. This will be enhanced by the many other quickly growing fields like genomics, assistive, smart or gaming technology. This paradigm shift of patients becoming partners will also have consequences in the area of patient safety. First, the patient experience on patient safety must be taken seriously. Instead of statistics, patient safety must be based on patient safety perceptions, *in the end as individually as possible*. Second, to reduce avoidable errors, data must be exchanged and transformed into relevant information, available for both patient and his healthcare providers. Third, new ways of storing and exchanging information will add a whole new dimension to privacy and security, increasing and implementing privacy enhancement technologies.

The new journal Health and Technology

-will assist navigating these new developments.

-will fill gaps that exist in the education of physicians, nurses (e.g. Biomedical informatics), clinical and biomedical engineers as well as medical physicists and many other health care professions.

-will inform about new technologies that create data (like telemedicine, mHealth) but also about technologies that will help both patient and provider to handle the availability of and the access to data and subsequent information, a growing problem.

-will deal with technology concerning both health care and public health with a strong focus on patient safety, quality and ethical aspects.

-will help understand the consequence of a different way and level of access to information and how it affects relationships of both patient and provider.

-will try to explain which societal and ethical shifts are or will have to be made to optimize the structure and organization of our society in concordance with these new developments as well as the economic consequences thereof.

-will play a leading role in easing the ongoing discussion about the influence of (disruptive) technology.

-will pay ample attention to the consequences in policy, workforce, education, training and regulation.

-will give the reader access to newest research, opinions and developments, making them more knowledgeable even outside the areas of their own expertise.

-being the first cross-disciplinary journal it will help to understand how the knowledge society, based on modern technology, influences health in unexpected ways. That the infrastructure of a building can improve health, not only by leaving out asbestos, but by putting in cabling, to name a simple example.

-will look at issues that, on first sight, do not seem related to health.

-last but not least will pay much attention to patient-related aspects of health technology.

Health and Technology will deal with the technology of health, but also with the health of technology.

Health and Technology will be a peer-reviewed journal according to the highest possible standards. We expect our authors to deliver sound, high quality accounts about their experiences or outstanding reports of first rated research, at the same time aiming at the highest achievable standards of accessibility and understandability for both providers and patients not directly involved in their specific area of expertise.

PROFESSIONAL ISSUES

COST OPTIMIZED MEDICAL PHYSICS EDUCATION AND TRAINING: AN INNOVATIVE E&T SCHEME IN MALTA

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Abstract—**Until recently the number of Medical Physicists in Malta was much lower than that recommended by EU institutions. This was impacting the extent, effectiveness, safety and efficiency of clinical services. The University of Malta and the Ministry of Health in Malta embarked on a project to address the issue. The objective was to produce an E&T programme which followed the then developing EU, EFOMP and IAEA recommendations whilst optimizing costs and ensuring future-proofing. We present the innovative scheme, which was part financed by the EU European Social Fund, as a model of academic and public administration cooperation in the service of patients.**

Keywords—**Medical Physics, Education and Training, Curriculum Development, Innovation.**

I. Introduction

Until recently the number of Medical Physicists in Malta was much lower than that advised by European recommendations [1]. This was having a negative impact on the extent, effectiveness, safety and efficiency of clinical services; modern techniques in radiation oncology could not be implemented whilst image quality and radiation doses in diagnostic services were not sufficiently optimized. Academics from the Department of Medical Physics of the University of Malta and public officials from the Ministry for Health in Malta together embarked on a project to address the issue. The objective was to produce a scheme which followed the then developing EU, EFOMP and IAEA recommendations in Medical Physics E&T whilst optimizing costs and ensuring future-proofing [1-3]. Given the impossibility of providing clinical training locally (owing to the very small number of Medical Physicists then available in Malta) it was decided that whilst the Masters in Medical Physics was to be undertaken at the University of Malta, it would be structured in a way as to make overseas training possible. Part EU funding was sought and obtained through the European Union European Social Fund (ESF) for the overseas training by the Ministry for Health.

The scheme was to provide for E&T in the three principal Specialty areas of Medical Physics namely Diagnostic and Interventional Radiology (D&IR), Radiation Oncology (RO) and Nuclear Medicine (NM) [1]. In addition, since in today's rapidly changing and highly competitive world, being a good scientist is not sufficient to achieve professional and clinical goals, it was decided that the Masters programme would include not only the necessary scientific and mathematical content but also the soft skills required for modern professional practice (e.g., leadership, teambuilding, communication, managerial and strategic planning skills) [4, 5].

II. Materials and methods

A review and documentary analysis of European legislation and documentation regarding the role, E&T and human resource requirements of Medical Physicists was carried out [particularly 1-3, 6]. The curricula of established international Medical Physics Masters programmes were scrutinized and elements of good practice identified. European recommendations regarding the structuring of qualifications frameworks [7] and IAEA recommendations regarded clinical training were adopted [8-10]. The scheme was also designed in to serve as a basis for trainees to move seamlessly into developing EU training schemes to Expert level ('Medical Physics Expert')[1, 11].

III. results

The resulting 2.5 year E&T programme is summarized in Table 1 and consists of a 120 ECTS masters course linked to 24 months equivalent of clinical training at an accredited clinical training centre. The study units during the first

academic year are delivered in standard face-to-face small group teaching mode. First semester units are designed to develop the participants as Clinical Physical Scientists and are compulsory for all irrespective of their eventual Major Specialty area. During this semester the participants also experience a month of induction training in *all* Specialty areas. This helps bridge the gap between the physics/engineering backgrounds of the participants and the healthcare milieu whilst exposing them to all possible Major Specialties. At the end of the semester the participants are required to choose their future Major Specialty area.

In the second semester of the first year, participants read towards 20 credits in one Specialty area as Major and 5 credits in each of two Specialty areas as Minors. For example, one can study D&IR as Major whilst taking RO and NM as Minors. This structure ensures that whilst trainees specialize early (in line with EU recommendations given the rapid expansion and increased sophistication of medical device technology [1]), they would also have the necessary background to be able to collaborate with colleagues working in the other specialty areas later on in their careers e.g., by being aware of the critical importance of D&IR in cancer detection, treatment planning and post-therapy patient follow-up. During this semester the participants undergo a month of training in their respective Major Specialty area. This helps them gain direct experience of the clinical applications of Medical Physics in their respective Major Specialty and also in identifying a dissertation project in the same specialty.

The study units in the second year of the Masters complete the transformation of the physicist/engineer into a Healthcare Professional and Clinical Researcher and are heavily training oriented (including the Medical Physics Dissertation and extended case study in the Practices and Procedures study unit *which are both required to be service development oriented*). Theoretical subjects range from the legal and professional to ethical and management issues and health technology assessment; participants are required to permeate their assignments with clinical examples and illustrate the added value which their profession and respective Specialty bring to the broader healthcare system. *The theoretical units are delivered asynchronously via elearning so that the trainees who would then be on full-time clinical training can take the study units at any day/time of the week outside their training schedules.*

Clinical training is carried out at accredited clinical training centres where the training schedules are structured to follow very closely the IAEA training schemes [8-10]. *An eportfolio in the IAEA format is also required*. A 30 ECTS dissertation in the Major Specialty area is required to complete the masters. The subject of the dissertation *must be service development oriented, be carried out at the clinical training center and be of major contribution to the training*. In the case of the first two cohorts the training was carried out at a leading training centre in the UK; however, it is envisaged that future cohorts would be trained locally.

IV. CONCLUSIONS

We have developed an E&T scheme which is attuned to modern Medical Physics curricular developments and curricular delivery and which is sufficiently flexible and innovative to be implemented in other countries. The scheme is cost effective with a total E&T time of only 2.5 years and inherently designed to permit expansion to other specialty areas. Given the tight time-frames, training schedules need to be carefully planned and monitored. A disadvantage for the trainees is that they cannot avail themselves of any extended vacation leave (e.g., no long summer holidays); however, on the other hand they do qualify faster and hence can take up full-time employment earlier (however, duration can be extended to reduce the need for tight scheduling). The process of development of the scheme is presented as a model of cooperation between academia and public administration in the development of a practical curriculum in the service of patients.

ACKNOWLEDGMENT

The project ‘Capacity Building for Medical Physics Services in Malta’ was part-financed by the European Union under the European Social Fund (ESF) Operational Programme II – Cohesion Policy 2007-2013, Empowering People for More Jobs and a Better Quality of Life.

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Table 1 E&T Scheme for entry level Medical Physicists in Malta

Academic Year		**Education Medical Physics Department, University of Malta**				**Clinical Training Ministry for Health**
		MSc Study Units		**Notes**	**ECTS***	**Months**
1	Oct - Jan	The Medical Physicist as *Clinical Physical Scientist*	Biophysics and Basic Biomedical Sciences for Medical Physicists Clinical Medical Devices & Protection from Physical Agents** Principles of Biomedical Signal Processing for Medical Physics Principles of Biomedical Image Processing for Medical Physics Research Methods and Statistics for the Physical and Health Sciences	These study units are core units to be taken by all candidates	10 5 5 5 5	1 month All Specialty Areas. Training delivered locally.
	Feb - May	The Medical Physicist as *Specialist*	Specialty Areas available at present:*** Medical Physics in Radiation Oncology (RO) Medical Physics in Diagnostic and Interventional Radiology (D&IR) Medical Physics in Nuclear Medicine (NM)	Candidates to choose one Specialty Area as Major and two Specialty Areas as Minors****	20, 5, 5	1 month Major Specialty Area. Training delivered locally.
	Jun-Sep		Training only			22 months in Major Specialty Area. In the case of Malta training delivered non-locally for initial cohorts (in the UK) but to be delivered locally in future. However even when locally based training is available individual candidates would still have the option to train non-locally in more advanced training centers (overseas in the case of Malta, however if the scheme is implemented in major states this could mean distant approved training centers within the same country).
2	Oct - May	The Medical Physicist as *Healthcare Professional*	Professional, Ethical, Legislative & European Issues in Medical Physics Clinical Medical Physics Practices and Procedures Service Quality Development, Health Technology Assessment & Innovation in Medical Physics	All three modules delivered online via Moodle. All modules applied to respective Major Specialty Area.	10 10 10	
		The Medical Physicist as *Clinical Researcher*	Medical Physics Dissertation	In Major Specialty Area *and service development oriented*. Carried out at training center and must be of major contribution to the training.	30	
	Jun-Sep		Training only			
3	Oct-Mar		Training only			
Total 2.5 years					**Total 120 ECTS**	**Total 24 months**

* 1 European Credit Transfer and Accumulation System (ECTS) credit is nominally equivalent to 25 hours of student learning of which 5 – 7 are direct teaching when a study-unit is imparted in the standard lecturing mode.
** All physical agents: ionising radiation (includ. radiobiology), magnetic fields, EMF, intense optical etc Greatest emphasis is on ionising radiation.
*** In future more specialty areas will be added e.g., physiological measurement for neurology, cardiology. The scheme is designed for such eventualities.
**** Each Specialty Area of Medical Physics is offered as Major (20 ECTS) and Minor (5 ECTS).

EDUCATIONAL RESOURCES

WINDOWS TO THE WORLD OF MEDICAL IMAGING PHYSICS VISUALS FOR EFFECTIVE AND EFFICIENT LEARNING AND TEACHING

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Abstract— **Modern medical imaging using highly-developed methods and modalities is a complex process with many adjustable factors that determines the characteristics and quality of images. The goal of each clinical procedure should be images that are optimized to provide visibility of the significant anatomical and pathological features to contribute to effective diagnoses and therapeutic procedures. That requires a team of medical imaging professionals, including radiologists, technologists, and physicists, with the knowledge of physics that can be applied to evaluate images and control the complex imaging process. A challenge in medical physics education is that of providing learning activities that contribute to the development of a foundation knowledge rich in sensory/visual concepts that are needed for clinical physics applications in the field of medical imaging. Through the process of *collaborative teaching* medical physics educational programs anywhere in the world are now providing highly-effective learning activities by combining the knowledge, experience, and leadership of local physicists with *Windows to the World* developed and provided by an experienced clinical physicist and educator connected with the internet through the website: www.sprawls.org/PhysicsWindows .**

Keywords – ***Concepts, visuals, image quality, optimization, teaching***

I. INTRODUCTION

Radiology, roentgenology, and the expanding field of medical imaging provides methods for detecting and diagnosing diseases and effects of trauma in addition to providing visualization for the planning and guiding of therapeutic procedures. With the expanding capabilities and complexities of modalities, including MRI, CT, digital radiography and mammography, and radionuclide imaging, the "human factor" is a critical element in the overall imaging system and process. These are the medical imaging professionals including radiologists, radiologists in training, radiographers, technologists, and medical physicists both in their roles as members of the clinical team and as educators for all medical imaging professionals.

An appropriate goal for every imaging procedure is that it be *optimized* to provide visibility of both normal anatomy and pathological conditions and to balance image quality with any potential risks or other competing factors. This is often a complex process because of the many imaging protocol factors that must be considered together to produce an optimized procedure. To achieve this, the medical imaging professionals with responsibility for the clinical procedures must have an appropriate knowledge of the physics of the imaging process and its application within the clinical setting. This includes a comprehensive knowledge of image characteristics, the methods for producing images and the many factors that affect image quality. A major requirement is the ability to analyze and evaluate images in the clinic, determine if they are optimized for specific clinical objectives, and make adjustments of procedure protocols as necessary. This requires a mental knowledge structure consisting primarily of *sensory (visual) concepts* rather than just symbolic elements including words, abbreviations, and mathematical symbols.

A continuing challenge in medical physics education is providing learning experiences that bring medical imaging professionals into the clinical imaging process, with the knowledge to obtain images with the optimized quality characteristics for more effective diagnosis and treatment of diseases along with managing risk and other competing factors.

Windows to the World of Medical Imaging Physics is a web-based resource for medical physics educators and teachers, to use in their classes and other activities to help learners develop more effective knowledge for applying physics to clinical medical imaging.

II. KNOWLEDGE STRUCTURES OF THE PHYSICAL UNIVERSE

Our knowledge of physics is actually a mental representation of the various segments of the physical

universe, with medical physics being the segment of our interest at this time. Knowledge is a complex network of various elements . For a specific field, such as medical physics, there can be very different knowledge structures depending on the learning experiences and *how it was taught*. Two major types and very different knowledge elements are *sensory concepts* and *symbolic representations*. Symbolic representations include *words* used to provide definitions and descriptions and *mathematical symbols* to describe the quantitative characteristics and relationships.

Effective Knowledge Structures: The effectiveness of someone's knowledge is determined by the functions or tasks that they need to perform. An example is the distinction between applying physics to improve medical imaging procedures and that of performing well on academic tests and examinations. That is a major issue facing medical physics education today.

The application of physical principles to control and improve medical imaging procedures and related clinical activities requires a knowledge rich in *visual concepts*. On the other hand, within our academic programs today there is often emphasis on preparing learners for examinations both in the courses being taken and for various professional certifications.

For a specific educational program it is not a question of good or bad, or right or wrong, but that the program must be designed and conducted with learning objectives that relate to the functions the learner/students are expected to perform The success of learners in applying what they have learned to perform specific functions does not depend only on the scope and depth of knowledge, but very much on the types of knowledge structures. This concept is illustrated in Figure 1.

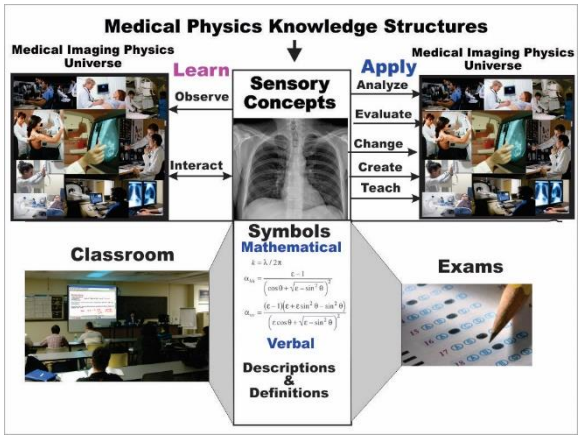

Figure 1. The overall concept relating knowledge structures to both learning and applying.

Knowledge structures for a specific subject, such as medical physics, can be predominantly conceptual, predominantly symbolic, or a combination of both.

For physics knowledge that is to be applied in clinical medical imaging the most effective structure is one that is predominantly conceptual serving as a foundation, with symbolic elements, mathematical and verbal, added to it.

As medical physics educators our greatest challenges and opportunities for the future are developing and conducting learning activities (classroom, small-group, laboratory, clinical, etc.) that will produce the most appropriate knowledge structures.

Every learning activity, especially those in the classroom, has two conflicting characteristics, *effectiveness* and *efficiency*.

Effective Learning Activities: The effectiveness of a learning activity determines the ability of a learner to perform specific functions or tasks. Here we consider two examples. One example is optimizing a CT procedure with respect to quality and dose. Another example is getting a high score on a written examination. An effective learning activity for the first is one that develops knowledge consisting predominantly of visual concepts. For the second, preparing for written examinations, effective learning activities and teaching typically need to emphasize symbolic knowledge, including verbal definitions or descriptions and mathematical symbols and relationships.

A major factor in developing and providing medical physics educational programs and activities is that all medical imaging professionals, including medical physicists, do not need the same type of knowledge structures because they will be performing very different functions and tasks. For example, a radiologist who will be visually evaluating CT image quality and optimizing procedures needs a knowledge rich in visual concepts while a medical physicist calculating the dose for a CT procedure needs a strong symbolic knowledge of the mathematics.

Efficient Learning Activities: The efficiency of providing a learning activity is determined by the cost and effort required. This includes faculty time and effort, availability and cost of resources and materials, availability and access to institutional facilities (especially clinical imaging facilities).

The different types of knowledge structures with respect to their effectiveness and efficiency will now be considered.

III. SYMBOLIC KNOWLEDGE STRUCTURES

Let's continue with the idea that knowledge of physics is a representation, or model, of segments of the physical universe within the human mind. These structures consist of complex networks of concepts and symbols.

Verbal Symbols: Verbal symbols, or words, are the foundation of human communications, both spoken and written. They are essential parts of physics knowledge and teaching when used appropriately.

For some academic fields of study, knowledge consisting primarily of words might be sufficient for the established learning objectives of a course, especially when the learning focuses on memorizing facts and definitions. However, for clinical medical physics, knowledge consisting of words is not sufficient… unless the only objective is to pass a written examination.

There are two major reasons why medical physics education is often "over weighted" with verbal symbolic knowledge. It is *easy to teach* and *easy to test*. It is efficient but the problem is that it is not effective for clinical applications.

It is much easier and efficient to prepare a test or examination based on verbal knowledge such as definitions, descriptions, and facts than testing on conceptual knowledge or ability to apply. This ranges from short tests within courses to major certificating examinations. However, there is an effort with some examinations to move to more of a conceptual and image based approach.

One of our great challenges as medical physics educators is to "teach beyond the test." While preparing our learners to perform well on examinations is necessary the learning objectives and activities should also prepare for the application of physics in the real world of clinical medical imaging.

Teaching physics with words is highly *efficient*. It can be done by lecturing, writing on the board, and showing PowerPoint text. This can occur in a classroom completely separate and isolated from the clinical environment or through web-based activities. It is efficient because it does not require effort or resources to connect the learners to the clinical environment that would be required for higher levels of learning.

Mathematical Symbols and Equations: Physics, including medical physics, is a highly quantitative science. In almost all applications it is necessary to know the values of physical quantities and the relationship to other quantities and factors. These relationships are described with equations or graphs. In virtually all realms of the physical universe, the science of physics can be represented as a quantitative model using mathematical symbols. This is essential knowledge for many applications not only to understand the physical quantities but to use the relationships to determine the values of other quantities by calculations or graphical methods. Here we will use an example. In CT the tissue voxel size is a major factor in image quality and acquisition time. It is determined by a combination of three (3) adjustable protocol factors and the relationship is expressed by Equation 1.

$$V_{mm3} = (FOV_{mm}/M_{voxels})^2 \times t_{mm} \qquad (1)$$

This is necessary knowledge for optimizing image quality when specific values are required. It is easy to teach. Like verbal descriptions discussed previously, learners can memorize the equation, plug in values, perform the calculations, practice by working problems, and perform well on examinations. However, if knowledge is limited just to the mathematical model, what will be missing is a complete and comprehensive understanding of the actual physical reality. What are those various quantities and how do they fit into the overall imaging process? Can the learner visualize the physical items, such as matrix size, or just know it as a mathematical symbol.

As physicists the mathematical model is often our usual representation of the physical universe. It is how we were taught because we were being prepared to become physicists. Mathematics is the tool we use for many functions including analysis, design, modeling, and much more. We could not practice physics without it.

For all who apply knowledge of physics to clinical activities, understanding of the quantitative is important, *but not sufficient*. For example, optimizing a CT imaging protocol in the real world is not done by solving equations. It is done by visualizing the different characteristics of image quality and their relationships.

The most effective knowledge for applied clinical physics is a strong foundation of visual (sensory) concepts onto which the verbal and mathematical knowledge is added. We will now consider how these highly effective knowledge structures can be developed.

IV. SENSORY CONCEPTS

Our fundamental and most significant knowledge of the physical universe (physics) is in the form of *sensory concepts*.

Natural Learning: The learning or development of sensory concepts *occurs naturally* as one experiences the physical universe through the senses, vision, hearing, taste, smell, and feel. This begins early in life well before language capabilities are developed. Our greatest knowledge of the physical universe is in the form of sensory concepts developed throughout life, and most outside of school and formal education.

Application of Knowledge: It is knowledge in the form of *sensory concepts* that is required to effectively interact with our immediate surroundings for functions ranging from selecting the appropriate food items at the market to analyzing and optimizing medical imaging quality. The development of one (selecting food) has occurred naturally as we experienced the market place, especially through the senses of vision, smell, and anticipated taste.

The challenge and opportunity for medical physics educators is to provide learning opportunities for all medical imaging professionals to develop a strong

sensory concept knowledge that will support clinical applications.

The Concept of Sensory Concepts: Water is one of the most common components of the physical universe that we interact with constantly. Our fundamental knowledge of water is in the form of a rather comprehensive set of sensory concepts developed through experiences and interactions with water illustrated in Figure 2.

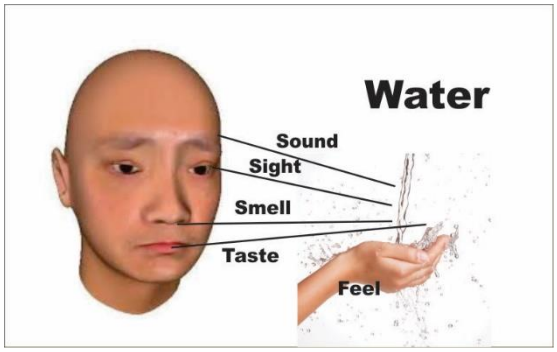

Figure 2. Developing concepts of water by experience through the senses.

A great value of a sensory concept is that it includes many of the characteristics of the physical object. Not only do we have a general concept of water, we have concepts of the individual characteristics, their significance and effects along with sources and perhaps how to make changes. The significance of sensory conceptual knowledge is that it provides for interacting with and controlling the physical objects. For example, if we are washing hands and the water feels too cold we know to adjust the temperature.

Let's now move from water to a medical image characteristic as shown in Figure 3.

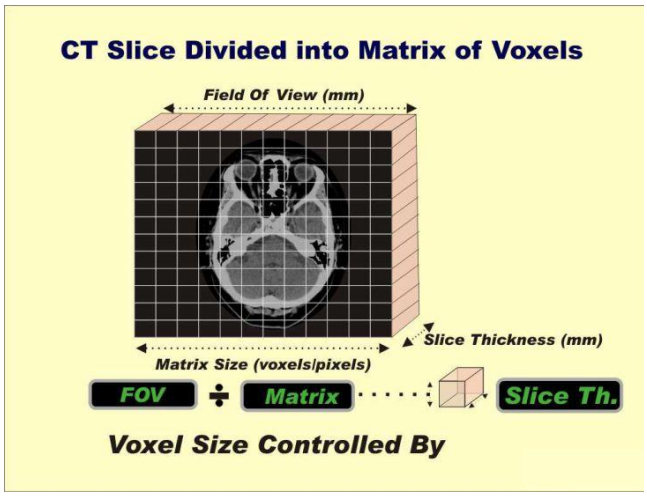

Figure 3. A visual representation of a CT image slice of tissue and the adjustable protocol factors that determine voxel size.

In the various tomographic imaging methods, including CT illustrated here, the size of the tissue voxels is a major contributing factor to several image quality characteristics, especially noise and detail, and must be considered in optimizing protocols.

Here we have the opportunity for comparing two methods of teaching this specific topic to medical imaging professionals. One is the mathematical approach by presenting Equation 1 and working through example calculations. The other is presenting the visual in Figure 3. and guiding the learner in exploring the factors and relationships. Let's continue the comparison in terms of *effectiveness* and *efficiency*. There is no doubt that the visual approach is highly *effective* for developing concepts that support clinical applications. However, it is much less *efficient* for the teacher than just presenting the mathematics because it requires the production or availability of the visual representations.

The significance of knowledge consisting of sensory (especially visual) concepts in fields of study including clinical medical physics is summarized and illustrated in Figure 4.

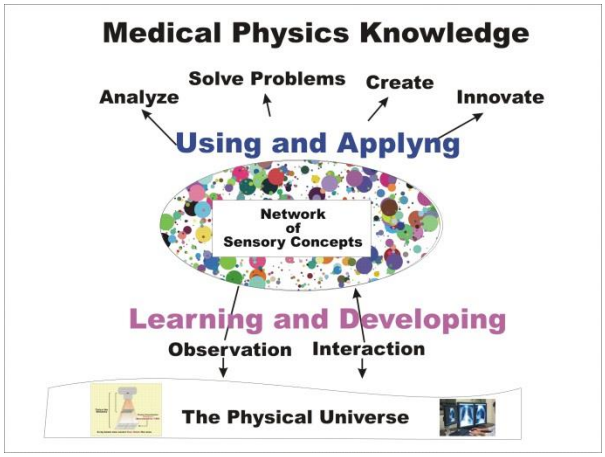

Figure 4 The Development and Application of Knowledge Consisting of Sensory Concept Networks.

Sensory concepts are essential knowledge elements for many physics applications. While learning and developing sensory concepts is a natural human process that occurs as we observe and interact with the physical universe around us, formal educational activities are required to develop the necessary knowledge in fields of study such as medical physics.

V. HIGHLY EFFECTIVE AND EFFICIENT LEARNING ACTIVITIES

A highly-effective learning activity in medical imaging physics is one that develops a comprehensive network of visual concepts. This can be achieved by connecting the learner to the medical imaging procedures and providing guidance by an experienced medical physics educator. While there is value to having these in the clinic with direct access to the equipment, clinical

procedures, and resulting images, it has limitations. It can interfere with clinical activities and cannot accommodate many learners at any one time. While being effective it is generally not very efficient because of many factors including the limited availability and expense of clinical facilities for teaching and it is not practical for large class sizes.

Visualizing the Invisible: Much of the physics universe associated with medical imaging is invisible. This not only includes the radiation that is used to form images but much of the imaging process that occurs at the atomic and microscopic level. There is much more than just seeing the equipment, the patient, and the resulting images. Another challenge in understanding the imaging process is the ability to visualize the sometimes complex relationship among the various factors and their effects on image characteristics and quality. This requires providing learners with resources that can be used to visualize and develop concepts of the invisible.

VI. WINDOWS TO THE WORLD

Let us think about the typical classroom used for medical physics courses. It is in reality like a large box in which we enclose our learners separating them from the real world of clinical medicine and medical physics about which they should be learning.

What is needed are "windows" in the classroom through which selected segments of the physical universe can be viewed.

Now with the availability of digital imaging and graphics technology, the internet and World Wide Web, and the concept of collaborative teaching and shared resources that is now possible as illustrated in Figure 5. The *Windows* project and resources consists of an extensive collection of visual illustrations, for the most part focusing on the elements of the medical imaging process that are not generally visible.

Creation and Development: The visuals or "windows" provided in this project are created by a medical physicist (the author) with extensive experience in both applied clinical physics and education. They are designed to provide visual access--"windows"-- to all aspects of the medical imaging process from the classroom, in textbooks, and online modules. The goal is to contribute to the development of knowledge structures within the learner's mind that will support the application of physics to clinical medical imaging.

Collaborative Teaching: Consider teaching as the process of *helping someone*, the learner, develop appropriate knowledge structures. In some classes this might be in the form of a lecture attempting to transfer knowledge from the brain of the teacher to the brain of the learner. As discussed previously, this is highly efficient but not at all effective, especially for medical physics. Effective teaching requires the opportunity to develop visual representations of the physical process and a network of sensory, usually visual, concepts.

The production of appropriate visuals by individual teachers is not realistic or efficient. It requires great time and effort in addition to extensive experience and insight into the application of physics to the medical imaging procedures.

The process of *collaborative teaching* is increasing both the effectiveness and efficiency of medical imaging physics in virtually all countries of the world. For each class or learning activity the team of collaborating teachers consists of the local teacher working directly with learners and the remote teacher, somewhere in the world, who is creating and providing the visuals. The local teacher meeting with the class is a major contributor to the learning process by organizing and guiding the observation and interaction with the physical universe but also sharing personal experience and knowledge. It can also be an opportunity for the teacher to be a role model demonstrating the valuable contributions of medical physics to clinical medical imaging.

The concept of collaborative teaching using the visuals provided by the *Windows* project is illustrated in Figure 6

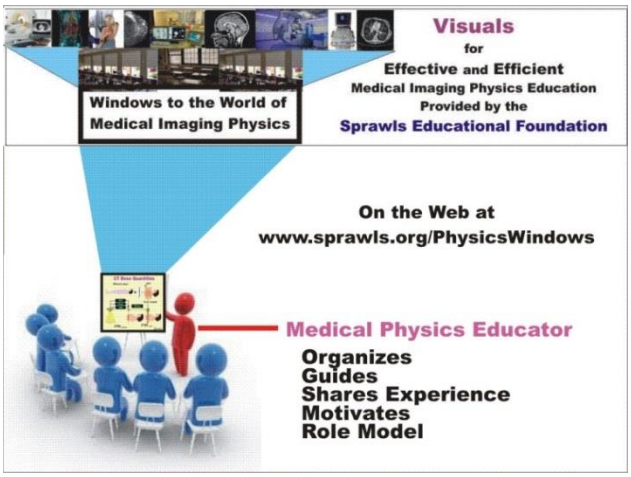

Figure 5. The Windows project brings the world of Medical Physics into the classroom.

Medical physics educators and teachers can now access and use the visuals in their classes and other learning activities by going to:

www.sprawls.org/PhysicsWindows .

VII. CONCLUSION

Medical physics education, specifically in the field of medical imaging, is becoming both more effective and efficient in virtually all countries of the world through the process of collaborative teaching. The local medical physics educators or teachers devote their efforts to organizing and guiding the learning process along with

sharing their knowledge and experience. The visuals provided by the collaborating teacher, connected through the internet, contribute to the development of highly effective visual concepts that are required for clinical applications and as a foundation for additional symbolic knowledge.

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SAFETY IN MAGNETIC RESONANCE IMAGING

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Abstract – MRI is regarded as a safe imaging modality because it does not involve exposure to ionising radiation. However, it has unique hazards of its own, some of which can result in death or serious injury if they are not appropriately managed. This paper discusses the hazards of MRI and their biophysical basis, describes relevant legislation and guidelines, and gives practical advice on managing safety in MRI facilities. Particular attention is drawn to the important roles that medical physicists have in ensuring patient and staff safety.

Keywords – MRI, magnetic resonance imaging, safety, MR safety

I. INTRODUCTION

One of the key advantages of MRI as a medical imaging modality is that it is free of the well-known hazards associated with ionising radiation. On this basis it is often stated, for example in research proposals that come across my desk, that it is a completely 'safe' modality. In fact, MRI involves unique hazards that, if not managed appropriately, can result in death or serious injury to patients or staff: in a sense it actually presents a more serious risk than the long-term stochastic effects arising from ionising radiation exposure. In practice MRI has an excellent safety record, because professionals working in the field, and particularly medical physicists, have developed robust safe working practices to mitigate the risks that exist. In this paper, we will describe the nature and biophysical mechanisms of the hazards encountered in MRI, then consider approaches to risk management and the legislation and guidelines that exist to protect patients, staff and the general public.

II. HAZARDS IN MRI

The hazards encountered in MRI arise primarily from the three types of electromagnetic field (EMF) used in the imaging process: the static magnetic field, gradient magnetic fields that are switched on and off rapidly, and the radiofrequency (RF) field. Each will be considered in turn in this paper. When discussing EMF hazards in this context, it is often helpful to distinguish between *direct* effects arising from interaction between the EMF and the human body and *indirect* effects, in which EMF interacts with some other object in such a way that the object presents a hazard. It is also important of course to distinguish between acute effects of EMF and those that may manifest in the longer term or as a result of prolonged or repeated exposure. MRI hazards that are not related to EMF include those arising from the use of liquefied gases as cryogens in superconducting magnets and those associated with the use of paramagnetic contrast agents, as well as more general health and safety issues (e.g. electrical and mechanical) which will not be discussed in this paper.

III. STATIC MAGNETIC FIELD HAZARDS

The The most obvious hazard in MRI is due to the very strong magnetic field generated by the imaging system. Systems in clinical use are usually based around 1.5 T or 3 T magnets (tesla is the SI unit of magnetic flux density, informally referred to as magnetic field strength in MRI). There are an increasing number of 7 T systems in research centres, and isolated examples of whole body magnets of 9.4 T and 10.5 T. These are superconducting magnets and hence are *always switched on* (unless they are intentionally taken off field for maintenance reasons or in an emergency): unlike ionising radiation modalities, the hazard is always present, even when the MRI facility is closed. These magnetic fields are much stronger than those encountered in other walks of life, and tens of thousands of times stronger than the earth's magnetic field (which has a typical value of 50 μT). A search on the Internet for 'MRI accidents' will yield numerous accounts and images of ferromagnetic objects that have been brought too close to MRI systems and have been pulled towards the scanner by the powerful magnetic field, the so-called projectile effect. Whilst these are often superficially amusing, there is a serious point behind them in that patients and members of staff have been killed or injured in accidents involving ferromagnetic projectiles. The 'index case' of this sort was the death of Michael Colombini, a six year old cancer patient who was killed whilst undergoing MRI in New York State in 2001 when an oxygen cylinder flew into the magnet and struck him in the head [1]. Such tragic accidents are extremely rare, but as recently as 2014 two members of staff were trapped against an MRI magnet for several hours and sustained serious injuries as a result of another oxygen cylinder projectile incident in Mumbai [2].

These indirect effects of the static magnetic field (B_0) arise from translational force (F) and torque (T) exerted on ferromagnetic objects as described by the following equations.

$$\mathbf{T} = \mathbf{m} \times \mathbf{B_0} = mB_0 \sin\varphi\, \hat{\mathbf{n}} \qquad (1)$$

$$\mathbf{F} = \mathbf{m} \cdot \frac{d\mathbf{B_0}}{dz} = \frac{\chi V}{\mu_0} B_0 \frac{dB_0}{dz} \hat{\mathbf{k}} \qquad (2)$$

Where φ is the angle between the object and the magnetic field, μ_0 is the permeability of free space, and the magnetisation **m** of an object of volume V and magnetic susceptibility χ is given by the following equation.

$$\mathbf{m} = \frac{\chi V \mathbf{B_0}}{\mu_0} \qquad (3)$$

Some interesting points arise from this.

- The torque on an object depends on B_0^2 and so is greatest at the centre of the magnet bore.
- The force on an object depends on the product of B_0 and the spatial gradient of the field, so it is actually *zero* at the centre of the bore (where the field is uniform, i.e. $dB_0/dz=0$) and greatest close to the bore opening (see Figure 1).
- On a modern actively-shielded magnet the spatial gradient is very steep, and so the translational force on an object increases sharply as it is brought closer to the magnet, which increases the hazard as compared to older magnet designs.

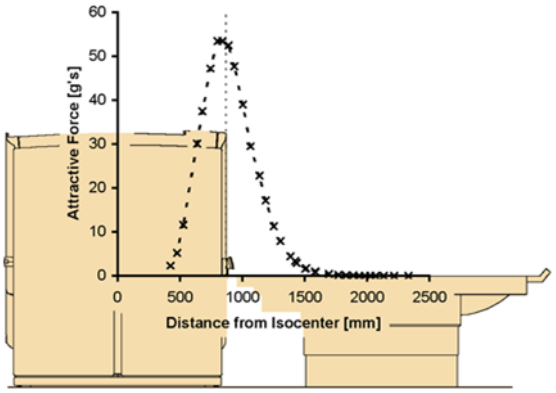


Figure 1. Translational force as a function of distance close to a typical 1.5 T magnet [3].

Many of the precautions in place in MRI facilities, particularly those intended to restrict access to the magnet room, are designed primarily to prevent projectile incidents. However, the static field may also interact with medical devices implanted in patients and staff members, and we will consider this aspect in more detail in Section VI below.

Whilst these indirect effects are of most practical concern, direct effects of human exposure to strong static magnetic fields cannot be excluded, particularly in view of the sparse scientific and epidemiological data on the subject [4, 5]. Since the body contains few ferromagnetic components, acute effects of this type are likely to be due to electric currents induced by motion of conductive tissues in the field rather than to torque or force. Such currents are the only potential direct effect mechanism of concern to the WHO [4].

There are numerous reports of sensory effects such as vertigo, nausea and a metallic taste in the mouth, usually attributed to rapid movement close to MRI magnets. These effects which are transient and believed to be harmless [6, 7]. There is a growing understanding of the underlying biophysical mechanisms [8]. Investigation of reported memory problems among MRI workers (‘mag-lag’) has found no significant effects [9], but recent work has suggested neurobehavioural effects [10], which may result from interaction of the field with the vestibular system [11].

Passage of ions in flowing blood through the magnetic field generates a force on the ions which leads to build-up of an electrical potential across the blood vessel [12]. This effect is greatest in the aorta, and is manifested as an enhanced T-wave in the electrocardiogram (ECG) signal collected from a patient in an MRI scanner (see Figure 2). It has been estimated that at 10 T the current density induced at the sinoatrial node would be approximately 20% of that due to normal cardiac electrical activity [12]. A related cardiovascular effect is the magnetohydrodynamic force opposing the flow of blood through the field. A reduction in flow of 5% has been predicted at 10 T [12], consistent with a compensatory increase in blood pressure which has been measured in human subjects at 8 T [13].

Whilst they are transient and currently of little concern, these sensory, neurobehavioural and cardiovascular effects may well eventually limit the static magnetic field strength that can safely be used for human MRI.

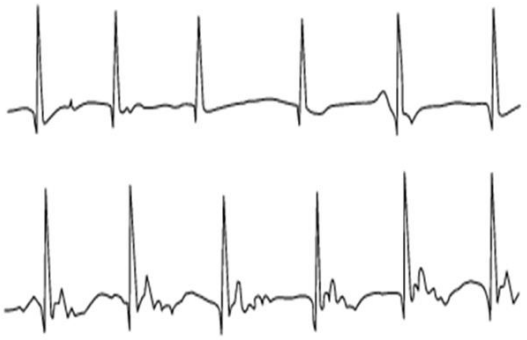


Figure 2. ECG signal collected from patient outside (top) and inside (bottom) an MRI scanner.

Epidemiological studies are currently underway, and others have been proposed, to explore long-term effects of static field exposure. One issue in such studies is how to assess and classify exposure in the absence of routinely-available dosimeters [14, 15].

IV. Switched Gradient Field Hazards

The During MR image acquisition, additional spatially-varying magnetic fields are switched on and off rapidly so facilitate spatial encoding. The resulting time-varying magnetic field (in the hundreds of hertz to kilohertz frequency range) induces an electric field in exposed conductive tissue. This in turn can generate a nerve action potential, leading to *peripheral nerve stimulation* (PNS). At onset, PNS results in a tactile sensation on the skin, but at higher gradient amplitudes and switching rates this escalates to loss of muscle control and eventually severe pain. The

performance of MRI gradients is limited to minimise the occurrence of PNS in patients. Concern is sometimes expressed about the possibility of cardiac ventricular fibrillation, but this could only occur at much higher levels of gradient exposure by which point PNS would have become intolerable to the patient. In some situations, such as interventional MRI, members of staff may be located close to the magnet bore opening during imaging. However, the limits imposed on gradient performance and the rapid fall-off in gradient field amplitude outside the imaging volume means that it is extremely unlikely that these workers would experience PNS.

The passage of electric currents through gradient windings to generate the magnetic fields causes a large force between the windings, and as the gradients are switched on and off the windings vibrate, leading to a loud noise (described as tapping, knocking, chirping, or squeaking, depending on the imaging technique being used). Acoustic noise is a major source of anxiety for patients undergoing MRI (the other being claustrophobia). Sound levels can reach 100 dB or more, requiring patients and any staff or carers remaining in the room during imaging to wear hearing protection in the form of ear plugs and/or ear defenders.

V. Radiofrequency field hazards

The radiofrequency field in MRI is used to excite protons in body tissues so that they subsequently emit a signal which is used to form MR images. The frequency required depends on the magnet field strength, for example 64 MHz at 1.5 T and 128 MHz at 3 T. At these frequencies, the biophysical effect of concern is induction of electric currents, leading to resistive heating of tissues. RF heating is usually expressed in terms of power deposition per unit mass of tissue (specific absorption rate, or SAR). SAR is proportional to B_0^2: this places constraints on the performance, and particularly the imaging speed, of ultra-high field MRI scanners, since the intervals between RF pulses must be longer to keep SAR within acceptable limits. The temperature rise resulting from a given SAR level depends on the thermal properties of the exposed tissues. Some tissues, such as the eyes and the testes, and also the foetus, have relatively poor thermoregulation, and some patients have impaired thermoregulation due to their clinical condition. In order to limit heating, it is important that the MR scanner room is not excessively warm or humid.

Excessive heating of the body can lead to heat stress and heat exhaustion and in certain cases, if heating is sufficiently intense and localised, to RF burns. One possible cause of burns is the formation of current loops within the body due to skin-to-skin contact (e.g. hands touching the sides of the body, see Figure 3). The small surface area at the point of contact leads to a high current density and hence intense local heating. Careful patient set-up and the use of insulating pads can help protect against this.

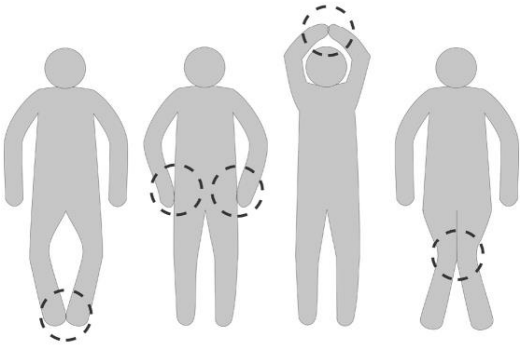


Figure 3. Poor patient set up may lead to formation of current loops and hence to burns.

As well as these direct effects, more serious burns can arise if electrically conductive objects are in contact with the patient during MRI. These can heat significantly, particularly if they are of such a length that they resonate with the RF field, which can lead to temperature rises in excess of 60 ^{o}C. In one incident, a pulse oximeter sensor left attached to a baby's forearm resulted in such severe burns that the limb had to be amputated [16]. In another, a patient with a deep brain stimulator (DBS) in place to treat Parkinson's disease underwent MRI for unrelated reasons and heating of the DBS electrode resulted in permanent right-sided hemiparesis [17] (it is possible to image patients with DBS implants safely in some circumstances if appropriate precautions are taken).

Whilst projectile incidents are the most dramatic form of MRI accident, data from the UK Medicines and Healthcare Products Regulatory Agency (MHRA) shows that RF burns are more commonly reported to the agency by a factor of approximately 2.5 [18].

VI. Implants and ancillary equipment

The safety of implanted medical devices in MRI is a complicated topic because of the plethora of devices available and the need to consider interactions with all three types of EMF. The force and torque exerted by the static magnetic field on devices with ferromagnetic components will depend on the composition and orientation of the implant, and their significance will depend on how strong they are relative to other forces acting on the implant. Fixation of a device to bone usually involves much greater forces than those generated by the magnet, and many devices are safe approximately six weeks after implantation due to ingrowth of tissue. In some clinical situations ingrowth does not occur, for example great caution is exercised over scanning patients with aneurism clips in the brain which, if ferromagnetic, could move and cause a life-threatening bleed. Most aneurism clips now in use are not ferromagnetic, but many MRI centres will not scan patients with these clips in place at all because of the serious consequences of a mistake. Concern is also sometimes expressed about 'magnetic braking': restricted movement of electrically conductive components of artificial heart valves due to induced eddy currents, although the force exerted on

the valve by flowing blood is far greater. RF and gradient field issues with implants usually relate to heating due to induced currents, although these currents can also interfere with the function of electronic implanted devices.

Since the advent of MRI, there has been particular concern about imaging patients with cardiac pacemakers, and a number of deaths have occurred due to inadvertent imaging of such patients [19]. Conversely, it has been argued for some years ago that, with carefully designed protocols, MRI of pacemaker patients can be performed safely [20]. However, as pacemakers were generally regarded as a contraindication for MRI, institutions carrying out this imaging were doing so at their own risk. The first 'MR Conditional' (see Section IX for definition) pacemaker received a CE mark in 2009 and FDA approval in 2010. There are now several models of MR Conditional pacemakers and implantable cardioverter defibrillators (ICDs) on the market. It is safe to image patients with these devices *as long as the manufacturer's conditions are strictly adhered to*. These conditions are contained within the Instructions for Use of the device, and include imaging at 1.5 T only, restrictions on RF and gradient usage, and usually restrictions as to the location of the pacemaker within the patient's body and of the patient within the MRI scanner. More recently, guidelines have been issued for safe use of MRI in patients with non-MR Conditional cardiac devices where clinical need outweighs potential risk [21]. These guidelines explicitly recommend the involvement of the MR Safety Adviser (an older term for MR Safety Expert, i.e. an expert medical physicist, see Section X) in the decision to scan.

As more and more people receive biomedical implants, and the number of people referred for MRI also continues to increase because of the growing range of clinical applications, it is important to strike the right balance and ensure that patients with implants are not unnecessarily denied clinically beneficial MRI examinations. This often requires partnership between a medical practitioner with understanding of the patient's clinical condition and the importance of the MR scan, a senior radiographer or technologist, and a medical physicist who can apply MR physics expertise on a patient-specific basis.

Further information about safe management and screening of patients who may have implants is given in Section X below.

For items of equipment not implanted in the body that might be brought in to the scanner room, concern focuses primarily on the static magnetic field and potential projectile effects. Standards for the testing and labelling of such equipment are discussed below. Many commonly-used items are available in an MR Conditional version (e.g. patient monitoring and anaesthetic equipment, wheelchairs and trolleys). When non-MR Conditional equipment needs to be used in the scanner room, robust precautions are needed. These might include securing the equipment to a wall or putting in place procedures to ensure that it cannot inadvertently be taken too close to the magnet.

VII. Cryogen hazards

Most MRI scanners are based around superconducting magnets. Behind the fibre glass covers of the scanner there is a toroidal vacuum flask containing 1,500-2,000 litres of liquid helium at a temperature of -268.93 ^{o}C (4.2 K). The windings of the magnet itself are immersed in this bath of liquid helium, and so retain their superconductivity. Thanks to efficient refrigeration, the liquid helium boils off extremely slowly. However, some emergency situations (for example a member of staff trapped against the magnet following a projectile incident) may necessitate rapid deactivation of the magnet, which can be achieved by boiling off the liquid helium using a heater located in the cryostat. This is known as a 'quench', and results in elimination of the magnetic field within about 30 s. A quench can also occur spontaneously in some circumstances. A 'quench pipe' connected to the scanner vents the resulting helium gas into a safe area outside the building. It is important that regular checks are carried out on the quench pipe: it has been known for pipes to be blocked by frozen water or nesting animals. If the quench pipe fails, helium may fill the scanner room causing cold burns and asphyxiation. Furthermore, as helium warms from boiling point to room temperature it expands by a factor of 757, so there can be a huge build-up of pressure in the scanner room, which in some cases has caused rooms to explode! MRI scanner rooms are fitted with oxygen level sensors to warn of helium leakage, often linked to extraction fans. It is important to have a means of relieving build-up of pressure in the room, such as an outward-opening door, a pressure relief flap, or a safe way of breaking the glass of the observation window. An exclusion zone (typically 3 m) around the quench pipe outlet is also required.

A quench can be initiated in an emergency by pressing a 'quench button'. There are usually buttons in both the scanner room and the control room. In the Mumbai incident described in Section III [2], it appears that the quench button had for some reason been disconnected, so there was no easy way to deactivate the magnet. In another incident in the UK, the quench button wiring was destroyed by a fire in the MRI suite [22]. It took several weeks to deactivate the magnet, residing in the burn-out shell of the MRI suite, which fortunately was located remotely from the main hospital building.

VIII. Contrast agent hazards

Contrast agents are used in MRI to enhance signal from structures of interest and in some types of functional imaging. Most MRI contrast agents are based on gadolinium, a rare-earth metal with a large paramagnetic moment which has a marked effect on the magnetic properties of body tissues. Gadolinium in its raw state is highly toxic, and consequently the gadolinium ion is attached to a chelate molecule for use as a contrast agent. Gadolinium-based contrast agents (GBCA) have been in clinical use since 1988, and historically have an excellent

safety record with a serious adverse reaction rate of only 0.03% [23]. However, in the late 1990s a new disease entity emerged known as Nephrogenic Systemic Fibrosis (NSF). This results in chronic, progressive and irreversible fibrosis of all body tissues, apart from the brain, and is associated with significant morbidity and mortality. It only occurs in patients with seriously impaired renal function. In 2006, a link was found between NSF and previous exposure to GBCA [24, 25]. It appears that renal failure slows excretion of GBCA from the body, hence increasing the likelihood of transmetallation with zinc or copper resulting in release of toxic gadolinium ions from the chelate. Different GBCA products present different levels of risk, depending on the structure of the chelate molecule. Current advice is not to use high risk agents in patients with serious renal impairment, and to avoid high and repeat doses [26]. With these precautions, few if any new cases of NSF are now occurring [27].

A new GBCA-related problem has come to light very recently. Progressive signal changes seen in certain regions of the brain in patients having repeated MR scans over a period of several years had previously been attributed to disease progression or treatment effects. However, in 2014 it was realised that this effect is actually due to retention of gadolinium in brain tissue, with the magnitude of the signal change strongly correlated with the number of contrast-enhanced scans that a patient has undergone [28]. It is now recognised that administration of certain types of GBCA can lead to accumulation of gadolinium in the brain and bones of patients, including those with normal renal function, persisting for at least 8 years and possibly permanently. It is not known whether this has any clinical significance, but it is clearly a worrying development [29]. To compound matters, it has been found that excreted gadolinium is not eliminated by waste water treatment and that consequently the concentration of anthropogenic gadolinium in bodies of water close to large cities is increasing [30, 31]. In this way, gadolinium is making its way into the drinking water supply.

IX. Legislation, guidelines and standards

Legislation relating to EMF in general and to MRI in particular varies from country to country: a partial list of national regulations is maintained by the WHO [32]. Most countries do not have specific legislation relating to MRI, but MRI activities are subject to generic health and safety law. In the European Union (EU), this means the health and safety framework directive (89/391/EEC) [33], which has been transposed into national law by all EU member states. The provisions of the directive, which for example require employers to perform risk assessments, put safe working practices in place, and provide appropriate training to workers, apply to MRI just as much as to any other occupational setting. There is also now a directive relating specifically to occupational EMF exposure, which must be transposed into member state law by 1st July 2016 [34]. Following a lengthy campaign, with significant input from medical physicists, relating to exposure limits contained in the directive [35], medical MRI activities are excluded from these limits, which would have impacted significantly on clinical and research work (it is important to note that other provisions of the directive continue to apply). However, this exclusion is subject to certain conditions and it remains to be seen how these will be interpreted during legislative transposition and enforcement in different EU member states [36].

The International Commission on Non-ionising Radiation Protection (ICNIRP) has issued guidance on exposure to static magnetic fields [37] and to time varying fields in different frequency ranges [38, 39] and on movement through static fields [40]. There is also ICNIRP guidance on MRI safety specifically [41, 42]. The EMF exposure limits recommended by ICNIRP, which form the basis of those in directive 2013/35/EU [34], incorporate significant safety factors below the thresholds for adverse effects, which is unhelpful and unnecessary in the context of MRI, although the underpinning literature reviews are very useful.

EU legislation relating to medical devices also creates health and safety responsibilities for both manufacturers and users of MRI. MR scanners are medical devices, and so must carry a CE mark indicating conformity with the requirements of the Medical Devices Directive (MDD) [43]. These requirements include that ‘the device must be designed and manufactured in such a way that... they will not compromise the clinical condition or the safety of patients, or the safety and health of users or, where applicable, other persons...’. Conformity is usually demonstrated by satisfying the relevant ‘harmonised standard’, which in the case of MRI is International Electrotechnical Commission (IEC) standard 60601-2-33 [44]. Unusually for a standard of this type, 60601-2-33 includes EMF exposure limits for both patients and workers, the latter being more appropriate in the MRI context than the ICNIRP guidelines discussed earlier. The standard adopts a tiered approach to EMF exposure limitation, with three operating modes defined by exposure thresholds.

- In the ‘Normal Operating Mode’, there is considered to be no risk of ‘physiological stress’ to patients.
- In the ‘First Level Controlled Operating Mode’, the threshold for physiological effects may be approached, and medical supervision is recommended.
- In the Second Level Controlled Operating Mode, there may be significant risk and local regulatory approval is required (e.g., from a research ethics committee), which should explicitly state the permitted levels of exposure.

The limits are summarised in Table 1. The PNS threshold referred to in the gradient exposure limits is the mean threshold for onset of PNS, which may be determined in a group of healthy volunteers.

The MDD is currently undergoing revision. The replacement legislation will take the form of an EU regulation, giving less leeway for variation in member state implementation.

EMF type	Exposure Limits
Static magnetic field	Normal: 3 T 1st level: 8 T 2nd level: > 8 T
Switched gradients	Normal: 80% of PNS threshold 1st level: 100% of PNS threshold
Radiofrequency field (limits on core temperature and whole body SAR averaged over 6 minutes)	Normal: 39 ^{o}C, 2 W kg^{-1} 1st level: 40 ^{o}C, 4 W kg^{-1} 2nd level: > 40 ^{o}C, > 4 W kg^{-1}

Table 1. EMF exposure limits in IEC standard 60601-2-33 ed3.2

Similar medical device legislation exists in many other jurisdictions, for example in the United States MRI is regulated by the Food and Drug Administration (FDA) as a Class II medical device [45].

Another IEC standard, IEC 62570 [46], defines symbols which may be used to label items that might be brought into the MR scanner room to indicate their safety status. The following three safety categories are defined.

- MR Safe - an item that poses no known hazards resulting from exposure to any MR environment. MR Safe items are composed of materials that are electrically nonconductive, nonmetallic, and nonmagnetic.
- MR Conditional - an item with demonstrated safety in the MR environment within defined conditions. At a minimum, address the conditions of the static magnetic field, the switched gradient magnetic field and the radiofrequency fields. Additional conditions, including specific configurations of the item, may be required.
- MR Unsafe - an item which poses unacceptable risks to the patient, medical staff or other persons within the MR environment.

One limitation of these definitions is that the 'MR Conditional' category is extremely broad, covering everything from biomedical implants that can only be exposed to MRI under very carefully controlled conditions (e.g. pacemakers) to non-ferromagnetic wheelchairs and patient trolleys that are technically 'MR Conditional' as they contain electrically conductive components, but clearly by their nature cannot be used in such a way that this presents a hazard.

IEC 62570 is linked to other standards issued by ASTM International that set out procedures for testing devices to establish the conditions under which they may safely be used.

Some individual countries have adopted national guidance on MRI safety. In the UK, the MHRA produces guidance covering issues such as safety infrastructure, safe working practices, worker training, and control of access to MRI facilities [47]. In the Netherlands, safe working guidance was issued in 2008 with the support of the relevant professional bodies and government agencies [48]. The Austrian Standards Institute has developed standards on the role and training of MRI safety officers [49, 50].

X. Safety management and infrastructure: the role of the medical physicist

Several organisations have published recommendations regarding practical aspects of safety management and allocation of safety responsibilities in MRI facilities [47, 51, 52, 53, 54, 55]. Many of these documents refer specifically to the key role of medical physicists with expertise in MRI.

A distinction is generally drawn between the individual with day-to-day operational responsibility for safety in the MRI facility (the Responsible Person [47] or MR Safety Officer (MRSO) [51, 52, 54, 55]), often a senior radiographer or technologist, and an adviser with specialist expertise in magnetic resonance physics (often designated the MR Safety Expert (MRSE) [47, 51, 52, 54, 55]). The EFOMP guidelines [51] indicate that the MRSE should be a medical physicist with appropriate levels of qualification and experience, and ideally with professional accreditation. The IPEM guidelines [52] set out specific knowledge and competences that this individual should have. In guidelines that are intended to extend to the United States, ultimate responsibility for safety is allocated to an MR Medical Director (MRMD) who is a medical doctor [53, 54, 55], reflecting the US legal situation. In other jurisdictions it is generally acknowledged that a medical practitioner has overall responsibility for the care of patients undergoing MRI [47]. Thus responsibility for MR safety should be a partnership, with those with day-to-day clinical and/or management responsibility having a close working relationship with a medical physicist possessing specialist training and expertise. Of course, it is not always practical for MRI facilities to employ a full-time MRSE: it is often more appropriate to contract with a larger centre for these services.

The single most important issue in MR safety is controlling access to the MRI facility, and specifically the scanner room itself. It is important to be able to regulate who has unrestricted access, to ensure that they have appropriate training, and to have procedures in place for

screening of patients, visitor and members of staff who have not had this training. The American College of Radiology (ACR) guidelines [53] recommend establishment of four zones, with proximity to the MR scanner and the concomitant degree of access control increasing from Zone I to Zone IV. In the UK, the MHRA guidelines [47] define the 'MR Environment' (MRE) as the area around the scanner containing the 0.50 mT field contour (this value was adopted historically to guard against interactions with pacemakers) and the 'MR Controlled Access Area' (MRCAA) as a region containing the MR Environment with suitable access control and signage. The MRE is known as the 'Special Environment' in IEC standard 60601-2-33 [44], and usually corresponds to ACR Zone IV (i.e. the scanner room itself); the MRCAA (the same term is used in the IEC standard) corresponds approximately to ACR Zone III (see Figure 4).

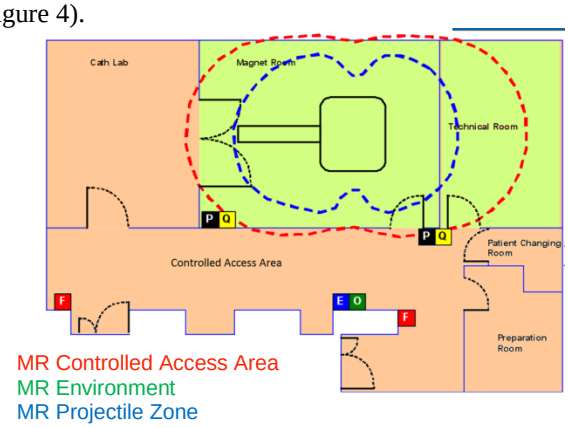
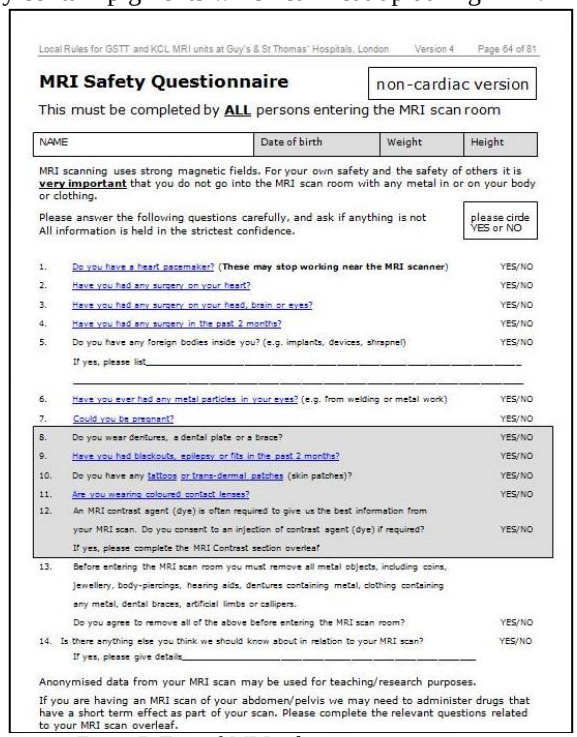


Figure 4. Typical layout of an MRI facility with MRCAA, MRE and MR Projectile Zone defined according to UK MHRA guidelines.

Staff with unrestricted access to the MRCAA/Zone III require appropriate training in MR safety. How this is delivered will vary, but ideally the MRSE/medical physicist should be involved in designing training, if not in its delivery. Such staff may be designated as 'MR Personnel' [53] or 'MR Authorised Personnel' [47], with subcategorization (and hence different training requirements) depending on specific duties and levels of responsibility.

Individuals who do not fall within these categories must be screened for safety before entering the MRCAA/Zone III. It is good practice to screen each patient three times: in writing at the time the patient booking is made, by means of a questionnaire when the patient arrives at the MRI facility, and verbally before the patient is taken into the scanner room. The screening questionnaire is critical, as it provides a lasting record of the screening process that has been undertaken. Details of the questionnaire used will vary between facilities depending on the nature of the work performed, and at our facility for example different forms are in use for different patient groups. An example is shown in Figure 5. In general, the questionnaire will screen for previous surgery (in which devices may have been implanted), for foreign bodes (again focusing on implants, but also metal fragments the removal of which may have to be confirmed by x-ray imaging), and for some perhaps surprising things such as tattoos and contact lenses: these may contain pigments which can heat up during MRI.



Local Rules for GSTT and KCL MRI units at Guy's & St Thomas' Hospitals, London Version 4 Page 64 of 81

MRI Safety Questionnaire non-cardiac version

This must be completed by **ALL** persons entering the MRI scan room

NAME	Date of birth	Weight	Height

MRI scanning uses strong magnetic fields. For your own safety and the safety of others it is **very important** that you do not go into the MRI scan room with any metal in or on your body or clothing.

Please answer the following questions carefully, and ask if anything is not clear. All information is held in the strictest confidence. please circle YES or NO

1. Do you have a heart pacemaker? (**These may stop working near the MRI scanner**) YES/NO
2. Have you had any surgery on your heart? YES/NO
3. Have you had any surgery on your head, brain or eyes? YES/NO
4. Have you had any surgery in the past 2 months? YES/NO
5. Do you have any foreign bodies inside you? (e.g. implants, devices, shrapnel) YES/NO
   If yes, please list_____
6. Have you ever had any metal particles in your eyes? (e.g. from welding or metal work) YES/NO
7. Could you be pregnant? YES/NO
8. Do you wear dentures, a dental plate or a brace? YES/NO
9. Have you had blackouts, epilepsy or fits in the past 2 months? YES/NO
10. Do you have any tattoos or trans-dermal patches (skin patches)? YES/NO
11. Are you wearing coloured contact lenses? YES/NO
12. An MRI contrast agent (dye) is often required to give us the best information from your MRI scan. Do you consent to an injection of contrast agent (dye) if required? YES/NO
    If yes, please complete the MRI Contrast section overleaf
13. Before entering the MRI scan room you must remove all metal objects, including coins, jewellery, body-piercings, hearing aids, dentures containing metal, clothing containing any metal, dental braces, artificial limbs or callipers.
    Do you agree to remove all of the above before entering the MRI scan room? YES/NO
14. Is there anything else you think we should know about in relation to your MRI scan? YES/NO
    If yes, please give details_____

Anonymised data from your MRI scan may be used for teaching/research purposes.

If you are having an MRI scan of your abdomen/pelvis we may need to administer drugs that have a short term effect as part of your scan. Please complete the relevant questions related to your MRI scan overleaf.

Figure 5. Typical MRI safety screening questionnaire.

It is also important to manage the flow of people and equipment within the MRCAA/Zone III to ensure that MR Unsafe equipment is not inadvertently brought into the scanner room. However, there are instances in which this is necessary, a good example being a combined x-ray and MRI ('XMR') interventional suite in which clinical procedures using MR Unsafe equipment are intentionally carried out within the scanner room but at a distance from the scanner itself. In this situation it is useful to designate an additional 'MR Projectile Zone', perhaps at the 3 mT contour [47] (see Figure 4), and essential to adopt rigorous procedures to manage the movement of personnel and devices within the room so as to ensure patient and staff safety [56].

If at the point of referral or during screening it comes to light that a patient has an implant, it is necessary to establish the MR safety status of the device before imaging can go ahead. Ideally, the exact make and model of the implant should be established so that the manufacturer's literature can be consulted. Alternatively an extensive list of devices and implants that have been tested for MRI safety, where appropriate indicating the conditions under which a device is safe in the MRI environment, is available at http://www.mrisafety.com/Default.asp. This is a US resource, but very widely used by the MRI community internationally. In practice, the number of patients with

implants now being referred for MRI is such that 'blanket' policies for particular types of implants are sometimes adopted so that the workload is manageable and efforts can focus on implants presenting a higher level of risk. This needs to be done with considerable caution, and with input from a medical physicist with appropriate expertise and experience.

Each MRI facility should interpret relevant legislation and available safety guidelines in the context of its own practice, installed base of MR equipment and physical layout and encapsulate this in a set of 'local rules'. Where a hospital has multiple MR scanners, it may be appropriate to have a core set of local rules that contain general advice and describe management arrangements applying to all of the facilities and a supplement for each scanner that included local information such as the boundaries of the MRCAA/Zone III and MRE/Zone IV, the location of quench buttons and fire-fighting equipment, and how to obtain assistance in an emergency.

As new applications of MRI continue to develop, and with growing numbers of scanners installed and patients referred every year, it is important that safety standards are maintained at their current high level. The knowledge and expertise of medical physicists is indispensable in this endeavour.

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INVITED PAPER

A REVIEW OF PROTON RADIATION THERAPY AND THE PATH TO WIDESPREAD CLINICAL ADOPTION

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Abstract— **After many years of development, proton therapy is finally reaching the point of mass adoption in clinical practice. Advances in particle accelerator technology and improved dose delivery techniques have provided strong driving forces for expanded use. Pencil beam scanning (PBS) is the generic name for radiation dose delivery to a target volume using individually controlled small pencil beams of accelerated protons. The first proton beam patients were treated with PBS at the PSI facility in Switzerland in 1996, but it took many years for PBS to become available at more facilities. Today, PBS is in routine clinical use in the majority of proton therapy facilities. PBS has truly revolutionized proton therapy, offering increased flexibility in dose shaping and improved dose conformality. Large and non-contiguous targets benefit especially from pencil beam scanning proton therapy, and general utilization has now expanded to almost all sites in the body. The traditional limitations related to range uncertainty have been further reduced with PBS through robust optimization. Treatment plans are now calculated with advanced optimization strategies and dose algorithms, which account for perceived uncertainties. PBS treatment plan deliveries are now robust against changes and uncertainties throughout the entire treatment process. We can now talk about the certainties of PBS proton therapy rather than traditional uncertainties. This certainty provides physicians with vastly improved confidence in the dose delivered to the target. Pencil beam scanning is enabling another paradigm shift, i.e. that we now face the question of which targets will not benefit from proton therapy, rather than the inverse.**

Keywords- **Proton, Radiation Therapy, Pencil Beam Scanning, IMRT, Multi Field Optimization.**

I. INTRODUCTION

After many years of development, proton therapy is finally reaching the point of mass adoption in clinical practice worldwide. This is mainly due to two contributing factors: advances in accelerating technology and advances in delivery techniques. First, technological developments have made proton therapy systems commercially available and allowed these systems to become more compact and less expensive. Second, the clinical realization of pencil beam scanning (PBS) has allowed proton therapy to be more in-line with modern day state-of-the-art intensity modulated x-ray radiation therapy (IMRT) treatments. PBS is the generic name for delivering radiation dose to a target using individually controlled pencil beams of accelerated protons to cover a target in 3 dimensions. The first proton patients were treated with PBS at the Paul Scherrer Institute in Switzerland in 1996, but it took the industry many years to commercialize the system and make it available at more facilities. Today, PBS is in routine clinical use in a majority of proton therapy facilities across the globe. The increased flexibility in dose shaping has enabled improved dose conformation, especially to large and non-contiguous targets, and truly revolutionized proton therapy in the last few years. The general utilization of proton therapy has been expanded to almost all sites in the body, and with robust optimization, which is a practical solution only with PBS, the traditional problems with range uncertainties have been addressed to a greater extent. Using intelligent optimization strategies and computer algorithms, treatment plans are now optimized with the perceived uncertainties in mind, rendering the delivered plans robust against changes and uncertainties in the entire treatment process. We can now talk about the certainties, rather than uncertainties, in PBS proton beam delivery, which provides physicians with vastly improved confidence in the delivered target dose. The largest paradigm shift caused by PBS is that we now are faced with the question of which targets, from a treatment planning perspective, will not benefit from proton therapy, rather than the traditional inverse question.

This review will walk the reader through a brief history of technological developments in radiation therapy, since the first patients were treated with radiation. We will also discuss the latest developments in the clinical utilization of protons and the projected impact

these developments will have on future patients treated with protons.

II. RADIATION THERAPY

In order to understand proton therapy and the way protons are used in clinical practice, a brief summary of external beam radiation therapy, also referred to as tele-radiation therapy, is required. The goal of radiation therapy, since the beginning, was always to increase the therapeutic ratio, which is defined as the ratio between tumor control and normal tissue complications. This means that if we increase tumor control while reducing treatment related complications, we increase the therapeutic ratio. The primary means of reducing complications is to reduce the dose outside the target volume. This is why external beam radiation therapy technology improvements, reviewed in the next section, always aimed at getting a higher dose at depth. The x-ray or gamma beam fluence is attenuated exponentially with depth, which means that the dose delivered by such beams will decrease exponentially with depth. By intersecting several x-ray beams through the target volume, the target will be struck by the radiation beam several times while the healthy tissues are traversed less than the target volume. This results in a higher dose in the target volume relative to the healthy tissues. Protons are used in a similar fashion, except that with proton beams, the radiation stops at the distal end of the target area, so for a specific beam, no dose is delivered beyond the target. In addition, when proton beams of decreasing energy are stacked on top of each other, the primary pristine Bragg peaks are spread out in the beam direction, forming the Spread Out Bragg Peak (SOBP), which has a higher dose at depth than at the entrance, illustrated in figure 1.

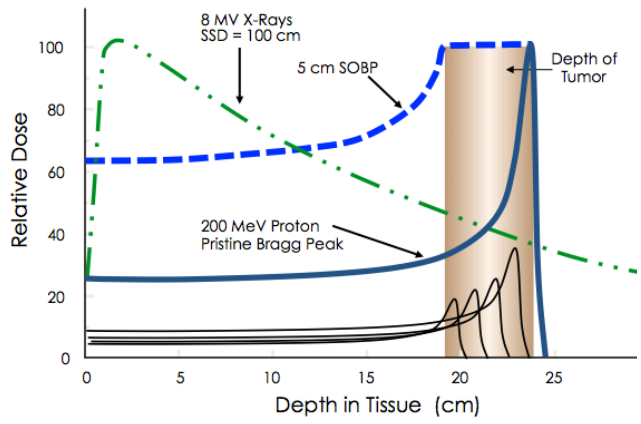

Figure 1. Depth dose curves for an 8 MV x-ray beam (Dash-dot-dot line) and a 200 MeV proton beam (solid lines). The thinner solid lines show Bragg peaks for proximal energy layers stacked onto the deepest energy layer to constitute the Spread Out Bragg Peak (Dashed line) required to cover the target area (shaded).

III. HISTORY OF RADIATION THERAPY

Shortly after the radiation physics discoveries made by Roentgen, Becquerel, and Curie in the early 20th century, the medical and scientific world was quick to adapt radiation for cancer therapy. These early discoveries were low energy radiation, which resulted in high skin dose and the inability to treat deep-seated tumors. In 1913, the only x-ray tube that could penetrate beyond 1 centimeter was the 140 kV 'hot cathode' manufactured by G.E. [1]. At the time, the knowledge of penetration depth of radiation was still in its infancy, and the unit of dose was not officially defined until 1954 [1]. Due to severe skin reactions from these low energy x-rays, Roentgenologists in the 1920's were viewed with skepticism until higher energy x-ray and gamma ray therapies became available [1]. Although radium tele-therapy (gamma radiation, around 1 MeV, from radioactive radium sources) offered increased dose at greater depths, its disadvantages included the large cost of radium, excess exposure to operators, and low dose rate compared to x-ray modalities. Despite the disadvantages, many clinicians were acutely aware of the differences in side effects between low energy x-rays and higher energy tele-therapy gamma rays [1].

Before the onset of the atomic age during World War II, the search for higher energy radiation that could spare more skin and treat greater depths began with the invention of various particle accelerators. Scientists such as Van de Graaff, EO Lawrence, and Coolidge ultimately produced the machines that revolutionized radiation therapy. For example, Coolidge sold his 750 kV 'cascade tube' to various hospitals starting in 1933 [1]. In 1930, Lawrence invented the cyclotron and was awarded the Nobel Prize for his invention. This led to the discovery of the neutron by Chadwick in 1932, when he observed very penetrating radiation produced by the interaction of alpha particles with a Be target [2]. In 1937, not long after the discovery of the neutron, the first neutrons for therapeutic use were produced by bombarding a Be target with 8 MeV deuterons from the cyclotron at the Lawrence Berkeley Laboratory in California [3]. In 1939, the clinical program was transferred to the new dedicated Crocker Medical cyclotron, which could accelerate deuterons to an energy of 16 MeV [4].

Also in 1939, the first cancer patient was treated with 1 MV x-rays using a Van de Graaff generator in Boston [1]. The tubeless betatron followed ten years later, to treat patients with 20-22 MV photons. Higher energy modalities were being developed that ultimately improved skin sparing, depth dose, and dose rate. In the decades to come, cobalt and linear accelerators dominated the market worldwide for therapy units. The Lawrence Berkeley Laboratory (LBL) soon became a large producer of cobalt-60, which would be a source of 1.25 MeV gamma rays for tele-therapy and a reliable dosimetric calibration standard. Higher energy clinical linear

accelerators (LINACs), which could treat up to 8 MV by 1953, and cobalt-60 tele-therapy units proved more clinically advantageous than their kilo-voltage and tele-radium predecessors [1]. At the time of their release, all of these new developments were opposed by their predecessors and often regarded as unnecessary. The General Electric marketing team predicted that only 10 Cobalt units would be sold in the fifties and that 250 KV x-ray units would never be replaced [1].

In 1946, Bob Wilson (a graduate student of Lawrence) published a paper in which he claimed that the properties of fast proton beams made it "possible to irradiate intensely a strictly localized region within the body, with but little skin dose" [5]. In addition, he also claimed that "it will be possible to treat a volume as small as 1.0 cc anywhere in the body and to give that volume several times the dose of any of the neighboring tissue" [5]. These claims and ideas, although many years ahead of the technology in the 1940's, have proven tremendously influential to charged particle therapy.

In 1954, Berkeley treated the first cancer patient with a proton beam. Shortly after, in 1957, Uppsala University built a cyclotron that could produce 185 MeV protons and subsequently treated a patient with their cyclotron [6]. The development of proton therapy gained slow momentum during the sixties and seventies, with pioneering work done primarily at the Harvard Cyclotron laboratory in Cambridge, Massachusetts (USA) and at LBL. In July of 1972, Koehler and Preston stated that "the use of high-energy protons or other heavy charged particles makes possible substantially improved control of the geometric distribution of therapeutic radiations over that obtainable with super-voltage x-rays or electrons" [7]. In these early days, the only way to spread the small proton beam extracted from the accelerator was by means of inserting scatterers in the beam, so the beams were referred to as passively scattered. This technique is essentially three dimensional (3D) proton therapy. This includes other proton modalities, such as double scattering (DS) and uniform scanning (US) systems, which are further explained in section IV. Although passive scatter techniques decreased the integral dose, i.e. the dose outside the target, dramatically, they still suffered from inadequate dose conformality, secondary dose from neutrons, and heavy apertures and compensators that remained problematic. Pencil beam scanning (PBS), first proposed by Kanai in 1980 [8], made it into clinical practice when the first proton patients were treated with PBS at the Paul Scherer institute in Switzerland in 1996. This technique utilizes scanning magnets to steer the beam, along with changing the energy, to deliver individual "spots" of dose at depth.

During the early nineties, a new player emerged in the photon world that would change the face of radiation therapy over the next decade. Intensity Modulated Radiation Therapy (IMRT) was first delivered in 1993 using the NOMOS Peacock MIMiC system utilizing a binary multileaf collimator that could be mounted on a traditional rotating gantry [9]. This technology, termed serial tomotherapy, was adaptable to most commercial linear accelerators. It enabled a relatively easy and low cost transition from 3-dimensional conformal radiation therapy (3DCRT) to a form of intensity modulated therapy. Several treatment machines were developed specifically for IMRT deliveries, such as the helical tomotherapy system which was initially described by Mackie in 1993 [10]. Arc therapy capabilities, first proposed by Yu in 1995 [11], were added to regular IMRT LINACs, to enhance the delivery of x-rays (e.g. VMAT and Rapid Arc) to all kinds of tumors. This resulted in extremely optimized x-ray treatment plans where the high isodose lines are very conformal to the target volumes. The clinical outcomes of patients treated with these new technologies increased dramatically, mainly due to inverse planning techniques and greater conformality, which offered superior normal tissue sparing and the opportunity for dose escalation.

Similar to this x-ray therapy evolution, intensity modulated proton therapy (IMPT) using PBS offered treatment improvements over 3D proton therapy. IMPT has become a clinical reality in many more treatment centers since 2010, when the Hitachi system at MD Anderson, and the IBA system at U-Penn started treating patients with PBS. PBS offers much lower integral dose than traditional x-ray therapy and often more conformal dose distributions for a myriad of cancer types, when compared to x-rays and even 3D proton therapy. The quest for further technological developments is therefore fully supported by the cancer therapy technological advances over the past century.

IV. TECHNOLOGY DEVELOPMENTS

Recent advances in the proton therapy industry are changing the way the technology is used. New techniques in beam delivery, treatment planning, and image guidance are improving the quality of treatments for current treatment sites and opening the door for sites not previously treated with protons. As stated before, the most significant advancement in recent years has been the widespread adoption of PBS delivery techniques. Whereas early proton treatment systems relied on spreading the beam and then shaping it through the use of patient specific apertures and compensators, PBS actively controls a thin pencil beam, steering it to deliver dose in discrete "spots".

Early proton beam delivery methods used double scattering (DS) or "uniform" magnetic scanning (US) to spread the beam over a larger area than necessary and required apertures and compensators to shape the beam laterally and distally. The only beam parameters that could be adjusted were the range and modulation, or width, of the SOBP. Effectively, one could choose how

deep to deliver the beam, conform the distal end to the target with a compensator, and decide how far to pull back the high dose region. By necessity, the shape of the proximal high-dose region would mimic the shape of the distal end, since the dose could only be uniformly modulated, or pulled back. The physics thus give rise to unintended proximal high dose areas outside the target for each individual beam. This effect is mitigated through the use of multiple beams, similar to 3D photon-based techniques.

Likewise, there is no freedom to adjust the width of the beam at different depths since the aperture, which cannot change for a given beam, provides all lateral shaping. These previous delivery techniques did benefit from the physics of protons, which include reduced entrance dose and no exit dose, but were severely limited by lack of freedom in shaping the dose distribution within the patient. Figure 2 illustrates the beam design for traditional proton therapy.

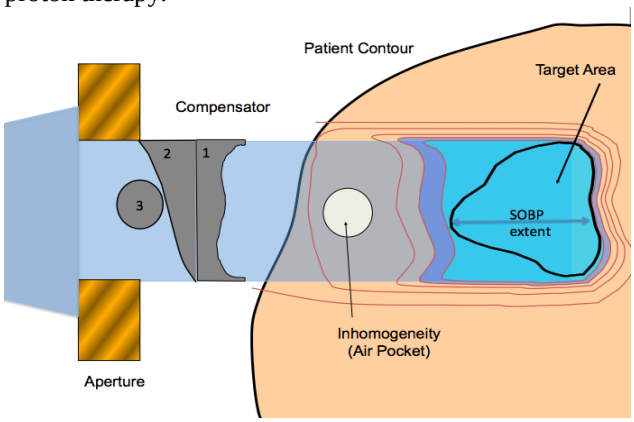

Figure 2. An illustration of traditional proton therapy using DS or US, where the beam is shaped with an aperture and the distal dose is conformed to the target with a compensator that corrects for the distal shape of the target (1), the oblique incidence of the beam (2) and inhomogeneities (3) in the beam path.

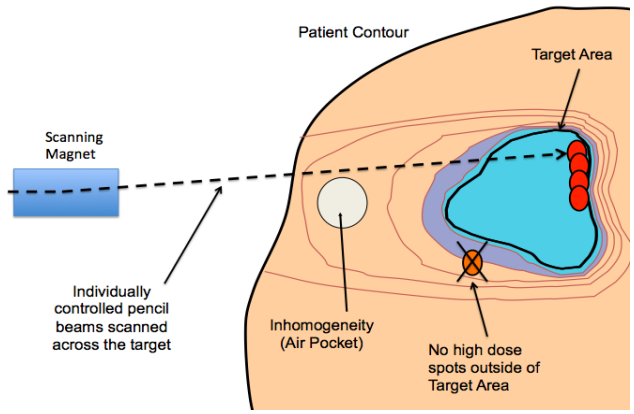

Figure 3. An illustration of the PBS technique. PBS is uses individually controlled small pencil beams of accelerated protons to cover a target in 3 dimensions. The individual pencil beams are scanned off-axis with a fast scanning electro magnet. The beam is stationary at a spot until the desired dose for each spot is delivered.

The advent of pencil beam scanning delivery techniques has overcome these disadvantages. In PBS, the beam is actively steered to deliver dose in discrete "spots" at given depths and lateral offsets. This is illustrated in figure 3.

PBS therefore gives the treatment planner full control over how and where dose is deposited from each beam. Choosing the spot locations allows for changing the beam width with each energy layer. Using this technique, the high dose can conform to both the distal and proximal ends of the target or create a concave shape on the lateral edge of the beam. Compared to 3D proton therapy, PBS allows for improved proximal sparing and does not require apertures and compensators. The only side effect that PBS cannot avoid is that each spot must still deposit its entrance dose. An advantageous clinical application of the proximal sparing of PBS is in the treatment of breast cancer discussed in section VI. A simple single beam comparison between a DS/US and a PBS beam for a target in the brain is shown in figure 4.

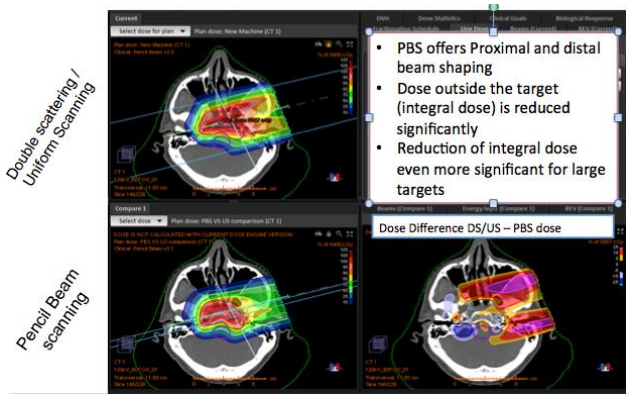

Figure 4. The difference in dose between a single proton beam delivered with DS/US and with PBS. The bottom right panel shows the unnecessary dose delivered outside the target area with US/DS.

The freedom and flexibility provided by PBS opens the door to other advanced planning techniques. In earlier delivery methods, each beam could only deliver a nominally uniform dose, with unintended hot and cold spots resulting from scattering in the patient's anatomy or compensator. With PBS, it is possible, and often sufficient, to mimic this technique, with each field giving a uniform dose to the target; however, this is no longer a requirement. If desired, each beam can be optimized to deliver dose to the target, based on that particular beam's eye view. For example, if a clinical target volume (CTV) wraps around an organ-at-risk (OAR), a right lateral beam may deliver more dose to the near (right hand) side of the CTV, and less dose to the far side, which would require passing through the OAR. The severity of this biasing can be adjusted to any degree the planner prefers.

In addition to new beam delivery technologies, proton treatment planning techniques are progressing. Monte Carlo based dose calculation will soon become

mainstream, allowing more accurate dose calculations for difficult geometries and providing additional information to the treatment planner. Pencil beam dose calculation algorithms for protons have always struggled to model upstream scatter, such as through a thick compensator. With PBS, the problem becomes the range shifter. For most proton therapy systems, there exists a lower energy limit – typically 75 MeV, or approximately 4 cm range in water. Outputting energies lower than this limit would require too much degrader material in the beam path, which would reduce the dose rate and increase the spot size. To mitigate this issue, a range shifter is utilized, as needed. A range shifter is a piece of acrylic placed in the beam, near the patient, that can further degrade the beam to energies low enough for shallow targets, such as breast treatments. The range shifter is positioned outside of the vacuum in the delivery system, so the protons will scatter in air. The air gap is defined as the distance between the range shifter and the patient, and a shorter air gap will scatter the beam less. For large air gaps with a thick range shifter, the algorithm may overestimate the shallow dose. Monte Carlo calculation will greatly improve the accuracy of the dose calculation with upstream scatterers, as well as in the presence of heterogeneities such as air pockets, lung, and metal implants.

One widespread unknown in proton therapy is the relative biological effectiveness (RBE) of protons relative to photons. It has become standard to use a factor of 1.1 [12], so that everyone will be "equally wrong". However, we know that RBE is tied to the Linear Energy Transfer (LET) of the protons at any point in their slowing down process, and the LET varies with energy. It is this variation of LET with energy that actually produces the Bragg peak. With Monte Carlo dose calculations, we can view LET-weighted dose distributions to evaluate what areas might be at risk of elevated biological doses, and hopefully minimize this effect, or at least ensure that it does not occur in sensitive critical structures. Once LET-to-RBE relationships are better established, biologically optimized plans should become possible.

Despite the advanced nature of proton therapy, it has historically trailed the photon world in the development of imaging and patient setup techniques. Respiratory gating is a good example of a technique that is common in photon therapy, but has not yet found widespread use in proton clinics. Cone-beam Computed Tomography (CBCT) is another such technology, but it is now commercially available on all new proton systems and may soon be retrofitted in existing proton treatment rooms. Multiple vendors are now offering CBCT as either an option, or the main imaging modality in the upcoming iterations of their treatment systems. The current industry standard imaging method, 2D orthogonal x-ray images, is largely limited to setup based on bony anatomy and fiducial markers. CBCT is a desirable option, since it can provide improved localization based on the patient surface or soft tissue. Improved confidence in target localization and patient setup may allow target volume margins to be reduced, enabling improved sparing of organs-at-risk.

Another interesting application of periodic CBCT images is the ability to calculate the treatment plan dose on the patient's anatomy in a verified treatment position. Quality assurance CT scans are commonly performed in proton therapy, but currently they require moving the patient to the axial CT scanner and performing a separate setup in the treatment position, without the benefit of image guidance. If the dose could be calculated on the CBCT image acquired in the treatment room, it would increase confidence in the results, as well as avoid additional imaging dose to the patient [13]. The information gained from treatment room CBCT imaging is a valuable tool for physicians in deciding if and when adaptive planning might be required. A further refinement of the process would be real time adaptive planning. This would use deformable registrations and fast treatment planning optimizations to adjust the plan each day for optimal coverage and OAR sparing. At present, however, clinical implementation of this idea in proton therapy is likely years in the future.

In addition to its role in patient setup, imaging technologies may also be applied to verification of delivered dose distribution in the patient. When protons interact with the nuclei of organic molecules in the patient's body, they undergo nuclear interactions and create positron-emitting nuclides, including C-11 and O-15 [14]. If a positron emission tomography (PET) scan is performed on a patient immediately after proton treatment, a PET signal can be seen in the tissue traversed by the proton beam. Converting the PET signal to a meaningful dose estimate is challenging, but useful information can be derived in terms of the beam trajectory and where the beam stopped. Research is ongoing, but this technique already presents an interesting opportunity for in-vivo quality assurance of proton beams.

Another technique that is in the process of being implemented in proton therapy is the detection of prompt gamma rays. Instantaneous discrete energy gamma rays are emitted during proton nuclear interactions with the nuclei in the patient body. Prompt gamma imaging was first mentioned for proton range verification in the medical setting by Jongen and Stichelbaut [15].

Proton radiography is another promising development in proton therapy. X-ray imaging utilizes attenuation information of photons passing through tissue to obtain an x-ray image. A multitude of such x-ray images at known angles with respect to each other is used to reconstruct a 3D CT image. In a similar manner, a series of proton radiographs can be used to reconstruct a proton-computed tomograph (PCT) [16]. The PCT will depict the relative stopping powers of each voxel, and hence of the different tissue types, in the patient's body. An accurate map of the proton stopping powers in the patient's body

is what is missing today to calculate the proton range in the accurately [17].

V. ADVANCES AND EFFICIENCIES IN PBS TREATMENT PLANNING

Traditional treatment planning in proton therapy requires the use of apertures and compensators. Apertures are typically made of brass and are used to limit the field size for each beam. Compensators are made of Lucite or wax and provide distal range conformation for each beam. This range conformation accounts for tissue compensation, as well as distal organ-at-risk (OAR) sparing.

Treatment planning using apertures and compensators is very similar to 3D conventional photon planning. A target is contoured on several slices in the CT scan and beams are chosen to reduce uncertainties and spare normal tissues. Typically, 1-3 beams are sufficient for most proton targets, regardless of the proton modality. Beam angle uncertainties can include immobilization device uncertainty, patient inhomogeneity uncertainty, and target motion uncertainty. These uncertainties must be considered, even in more modern PBS treatment planning. For each beam in a DS or US plan, an aperture is developed by adding a lateral margin around the target. If aggressive sparing is required from a certain beam angle, the aperture can exclude a portion of the target. Margins must also be added proximally and distally to the target, essentially widening the SOBP. This accounts for uncertainties both in the HU-to-stopping-power conversion as well as uncertainties in the compensator design [18, 19]. A beam specific compensator is developed to account for tissue compensation in order to conform the dose to the distal end of the target and for distal OAR sparing. Robust evaluation of a plan is performed, determining if coverage is sufficient if the patient shifts or if the HU-to-stopping-power conversion is slightly off. This includes shifting the isocenter in 6 directions and evaluating a denser and less dense CT. This concept of robust evaluation technically obviates the need for a Planning Target Volume (PTV). In photon therapy, a PTV is typically a uniform margin around the Clinical Target Volume (CTV), to account for patient set up variations. In proton therapy, a beam specific PTV, which includes lateral, distal, and proximal margins, is required. However since each beam will be treated with different energies, the distal and proximal margins will vary per beam, hence a beam specific PTV. The catch 22 situation is that you don't know the beam angles until you do the plan but you need the PTV before you start the plan. This problem is now mitigated with PBS robust optimization, as we will discuss later.

After the plan is approved, the design for each aperture and compensator can be manufactured on or off site. Quality Assurance (QA) should then be performed on each aperture and compensator, prior to treatment. For each patient, there is typically one aperture and compensator pair per beam. If a cone down or an adaptive plan is necessary, new apertures and compensators may need to be designed and manufactured.

With the development of PBS, the need for apertures and compensators practically vanished. PBS offers the ability to place spots precisely within the target for each energy layer, negating the need for an aperture to define the field size (see figure 3 above). Additionally, since each layer can be optimized, there is no need for a compensator. This leads to a very different type of treatment planning for proton therapy that is very similar to IMRT treatment planning i.e. an inverse optimization technique, referred to as inverse planning. The treatment planner instructs the optimizer what targets to treat and what OARs to spare, and the optimizer will choose the number of layers and location and intensity of each spot per layer. What has remained very similar to 3D proton planning is the need for stable and well-characterized immobilization and the need for well thought out beam angles.

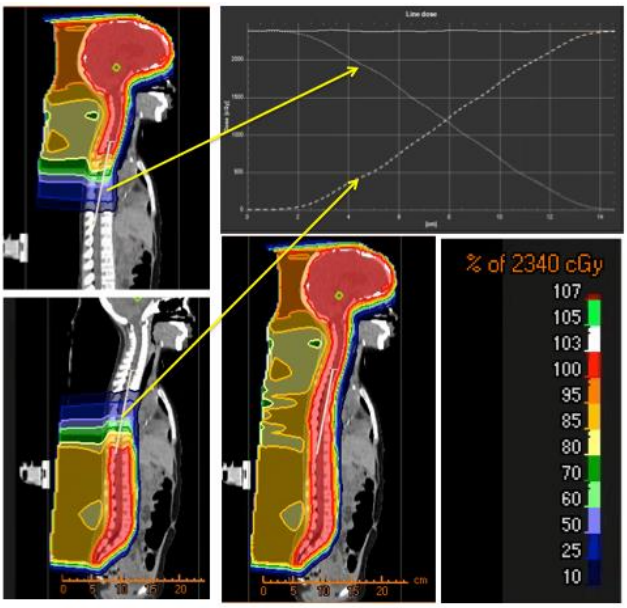

Figure 5. An illustration of the spine junction between two PBS fields for a CSI treatment. The dose gradients for the upper and lower fields, shown in the upper right panel, are tailored to about 1 % per mm, which makes the dose in the junction very insensitive to setup errors.

One of the most advantageous and publicized treatment sites for proton therapy is Cranial Spinal Irradiation (CSI), particularly in pediatrics [20, 21]. One of the challenges of a CSI treatment is accounting for the necessary match line within the treatment field. CSI treatments require match lines due to the large field sizes when treating the brain and entire spine. Another treatment site requiring match lines is head and neck treatments, due to the need for ideal beam angles to avoid

uncertainties and healthy tissues. In 3D proton planning, as in 3D photon planning, match lines require the use of feathering. With the sharp beam edge defined by an aperture, a very precise gap must be left between the beams, causing a significant cold or hot spots in the junction if the gap is not reproduced accurately during treatment. The usual mitigation for this effect is to shift the beam junction, a tedious process requiring at least a second set of fields (and apertures). A further downside is that this tactic leads to extreme sensitivity in the shifting of the patient from one isocenter to the next. Shifting too far could greatly increase the cold spot in the junction, and shifting too little could create a severe hotspot. With the use of PBS treatment planning, a gradient can be developed between abutting fields that can step up and down the dose for each field [22] over a larger distance. This gradient can be made shallow, such as 1% per mm, which will negate the need for a feathering technique and create a more robust treatment, as shown in figure 5. In this treatment, if the patient set-up on a single fraction caused abutting beams to be as much as1 cm closer together than planned, there would be only a 10% hotspot at a point.

In 3D proton planning, weighting can be adjusted between beams; each beam typically treats the entire target. There are more advanced planning techniques, such as Match-Patch and others, which are described well in various texts [23, 6]. This same 3D methodology can be applied in PBS, known as single field optimization (SFO). This means that each beam is optimized as if it were a single field treatment i.e. each beam covers the target with a uniform dose. Another method is multiple field optimization (MFO), which is similar to IMRT in that each beam in the treatment relies on every other beam, i.e. only the sum of all beams will result in uniform target coverage. MFO allows the treatment to better spare OARs, because each field does not have to treat the entire target. Robust planning, explained below, in combination with MFO, can reduce the target dose cloud and improve OAR sparing. One of the most dramatic improvements over 3D proton planning and photon planning is head and neck treatment. MFO PBS can significantly reduce posterior neck and oral cavity low dose irradiation, improve parotid sparing, and maintain robust target coverage, particularly in the match line region in the neck [24].

With some treatment planning systems, we now have the option to plan PBS treatments robustly referred to as robust optimization. This means that the optimizer will evaluate, for each iteration, the effect of an isocenter shift and/or a change in stopping power. The user can designate what robust situations should be considered in the optimization. Ideally, each spot will be positioned to provide the most robust treatment plan. Before robust planning, the method to create a robust plan typically meant treating to a larger target volume (by creating beam specific PTVs), to allow the coverage to drop during a robust evaluation, but still meet the physician's requirements. By optimizing robustly, we can ideally reduce the excess dose cloud on the nominal plan while maintaining robust coverage [25].

As PBS becomes more readily available, it is crucial to ensure the treatment planning process is as efficient as possible. Robust treatment planning improves the robust evaluation process by ensuring that the plan is more likely to pass on all perturbations. Robust treatment planning does not guarantee a robust plan, but if planned properly, can improve plan quality. In proton planning, fewer beams are desirable and it is important that the patient set up and immobilization devices allow for ideal beam angles.

Because protons are more sensitive to changes in patient anatomy and set up, adaptive plans are becoming more and more prevalent in proton therapy. Without the need for apertures and compensators, PBS treatment planning offers the flexibility to create and implement adaptive plans more efficiently. With some treatment planning systems, plans can easily be visualized on a new patient CT to identify the change in dose distribution. Contours can be deformed on to the new CT and an adaptive plan can either be made from scratch or using a template from the original plan. Adaptive plans are conveniently fitted into the workflow for physics and dosimetry, without stressing the system.

Scripting can also provide a measure of efficiency and is offered by many treatment planning software. Treatment sites, such as prostate, are commonly treated with the same opposed lateral beam set up to very similar targets. Treatment planners can initiate a script to create a plan with pre-loaded beams and optimization parameters, significantly reducing time spent on relatively simple plans. This allows the planner to invest more time in high-complexity plans, such as head and neck treatment plans.

Through the progression of treatment planning, from 3D photons to IMRT to 3D protons to PBS, lessons have been learned and passed along the path. For example, the same treatment planning techniques used in IMRT are currently utilized in PBS, and the same patient setup and beam angle considerations used in 3D proton planning are used in PBS today. These insights have led to creating robust PBS treatment plans with stable target coverage and improved OAR sparing, compared to previous methodologies.

VI. CLINICAL ASPECTS

Prior to the clinical realization of pencil beam scanning, the dose from an individual proton beam was conformed to the target by means of apertures and compensators. This limited the utilization of proton breams to small, contiguous targets. Large and non-contiguous targets have been treated in the past, but with

great difficulty and great expense, since manufacturing these large apertures and compensators was expensive and time consuming. Also, by nature of the fixed extent of the SOBP for a specific beam, the high dose volume often extended outside the target area, which in turn increased the integral dose significantly (see figure 2). With PBS, this problem is mitigated since it is now possible to limit the high dose region to the target volume (see figure 3), i.e. not placing spots outside the target volume, and treat large and non-contiguous targets while minimizing the dose outside the target volume. Such targets include, but are not limited to, treatment sites including lymph nodes, such as advanced breast cancers, head and neck cancers and high-risk prostate cancers.

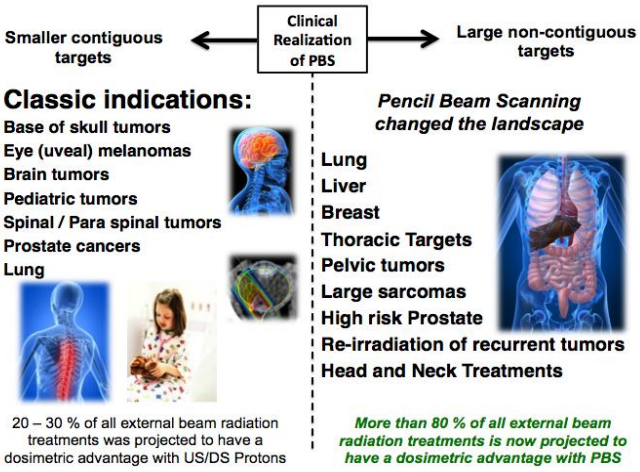

Figure 6. An illustration of the change in the clinical landscape as a result of PBS. It is projected that, with PBS, many more patients will have a dosimetric advantage because large and non-contiguous targets are now added to the list of cancers treated with proton beams.

Figure 6 illustrates the change in the therapeutic landscape with the clinical realization of PBS. On the left side of the dashed line, we list the tumors treated traditionally with 3D proton therapy (DS/US). These sites are referred to as standard indications for proton therapy and were generally accepted as the cases that would benefit most from protons. The improved clinical outcomes for most of these sites have been demonstrated through several clinical studies at legacy proton therapy centers such as LBL and Massachusetts General Hospital (MGH) [23]. On the right side of the dashed line, we list the cancers that are now treated on a daily basis employing PBS. These cases represent the vast majority of sites that are treated with external beam radiation therapy. Based on our clinical experience at the Provision Health Care where we treat patients with both IMRT and PBS, it is estimated that more than 80% of all external beam cases will have a better treatment plan (dosimetric advantage) with PBS than with the most advanced x-ray therapy techniques. The critical point is an improved treatment plan, not necessarily improved clinical outcomes since clinical outcomes depend on many other parameters. However as the history of the technology evolution revealed, it is expected that this will also translate to improved clinical outcomes or an increased therapeutic ratio. In the following sections, we will review how PBS has impacted breast, lung and thoracic, high-risk prostate, and head and neck treatments.

Breast treatments: The breast is a superficial treatment site, with the clinical target volume extending nearly to the skin. However, it is still desirable to achieve some degree of skin sparing. Photon therapy treats with inherent skin sparing due to dose build up. For 3D proton delivery methods, skin sparing is impossible due to the fact that the breast can vary greatly in thickness. With US and DS methods, the beam modulation was fixed by the largest thickness of the target in the beam direction. For the thinner areas of the breast, the beam modulation required by the thick portion would pull the high dose back to the surface of the skin, with no opportunity for skin sparing. With PBS techniques, the whole breast can be treated while keeping the skin surface to approximately 90% of the prescribed dose. The high entrance dose to the skin, when protons are delivered by US and DS techniques, has restricted the use of protons in treating the whole breast. Experience with this technology is reported in breast patients treated post-mastectomy using conventional fractionation [26,27].

Clinical evidence now supports the safety and effectiveness of hypo-fractionated x-ray whole breast radiotherapy in patients with breast cancer [28]. Advantages for hypo-fractionation include patient convenience and decreased patient and healthcare system costs. The Provision Center for Proton Therapy (PCPT) in Knoxville, TN is now using this whole-breast proton treatment technique in patients receiving hypo-fractionated whole breast radiotherapy after partial mastectomy (The so-called Canadian fractionation schema). The prescribed dose is 42.72 Gy_{RBE} in 16 fractions to the whole breast. Typically, a tumor bed boost of 10.00 Gy_{RBE} in 4 fractions follows. Skin sparing is measured as the dose to the proximal 5 mm of the breast. The ultimate goal is to keep the skin dose as close as possible to 90% of the prescription while still covering the CTV, situated just 5 mm beneath the skin surface, with a minimum of 90% of the prescribed dose. Per RTOG, the coverage goal is at least 95% of the target receiving 95% of the prescription dose. Our ongoing experience has shown that patients tolerate treatment well and are able to complete the treatment course without interruption and with minimal side effects, e.g. radio dermatitis. The bigger advantage of PBS for breast cancer treatments is perhaps in cases when the lymph nodes (axillary, internal mammary and supraclavicular nodes) need to be treated [29]. Breast treatments typically utilize one en-face beam at a ±30 degree gantry angle with the patient immobilized in the supine position and the patient's chest angled up by 10 - 15 degrees using a breast

board. A second beam is often used if the nodes cannot be covered robustly with a single beam. A typical dose distribution for an intact breast case and the associated dose volume histograms (DVH) are shown in figure 7.

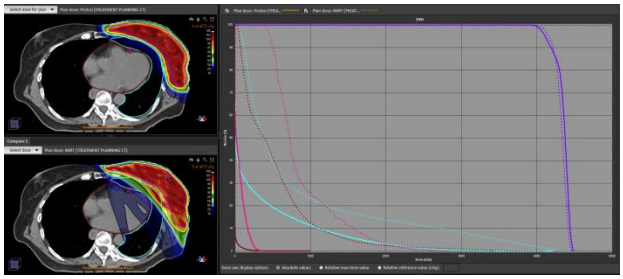

Figure 7. A typical dose distribution for an intact breast case. Top, left: Proton, single beam. Bottom, left: Photon, 7 beam. Right: Dose volume histogram (DVH) comparison, solid: proton, dashed: photon. Purple: Breast CTV, light blue: left lung, pink: LAD, red: heart.

Lung and Thoracic Treatments: The benefits of treating lung and other thoracic lesions with proton therapy are very well documented [30, 31]. These benefits are even greater for centrally located targets where the unwanted dose to the cardiac system can cause significant acute and long-term life threatening complications [32]. The safety aspects of treating moving thoracic lesions with PBS have been debated for some time. However, today it is generally accepted that the dose uncertainties from motion interplay effects between adjacent dose spots and dose layers are mitigated when more than 10 fractions are delivered to a moving target [33]. Modern day PBS beam delivery systems allow for layer repainting, which means the dose in a layer can be subdivided into several sub-layers and can be delivered sequentially before the system proceeds to deliver the next energy layer. Repainting layers between 5 and 25 times is common, which means that the equivalent number of fractions is the fraction count multiplied by the number of repaints. This means e.g. that a 10 fraction hypo-fractionated treatment delivered with 10 repaints will be equivalent to a 100 fraction treatment, from a target motion perspective. This is another huge advantage that PBS offers over IMRT, where this is simply not a practical solution.

Respiration gating for proton beam deliveries are easy, but to determine where the target is at any given moment is not so easy. The other problem with gating, specifically in a multi room proton therapy center, is that it increases the treatment time in a treatment room which adversely affects the throughput in other treatment rooms, since they are receiving the proton beam from the same accelerator. To avoid the need for gating, it is common practice to define an internal target volume (ITV) that covers the entire motion envelope of the gross tumor volume (GTV), and to treat the ITV plus a certain margin to the desired dose. Due to the reduced integral dose with PBS, the volume of lung that receives 20 Gy or less is often significantly less than even a gated photon beam delivery, despite the fact that the ITV is significantly larger than the GTV. The next generation proton therapy systems will allow for much faster inter-room beam switching and beam delivery times, which allow for a more time efficient implementation of respiration gated treatments.

High-Risk Prostate Treatments: High-risk prostate treatments regularly require that a significant portion of the pelvic nodes be treated, in addition to the prostate gland and seminal vesicles. This results in a very complex target shape with the small bowel, bladder, and rectum that must be spared. Comparisons between PBS, planned with robust optimization, and VMAT for the treatment of high-risk prostate cancer have been performed at PCPT to validate the use of PBS (MFO) for high-risk prostate treatments. This study confirmed that robustly planned PBS significantly reduced the dose to normal tissues in the pelvis while maintaining target coverage. Rectum and bladder dose reduction with PBS may improve the therapeutic response beyond the levels accomplished with VMAT [34].

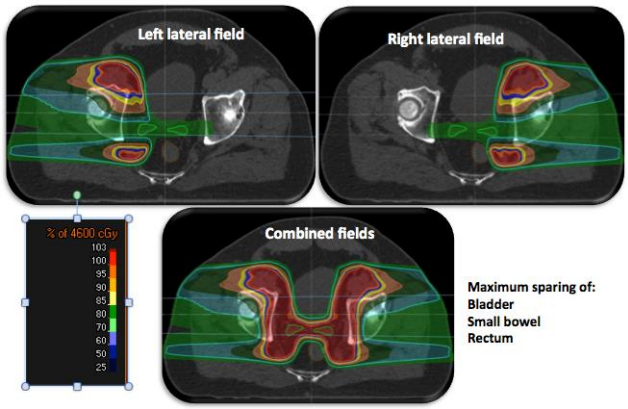

Figure 8. A typical high-risk prostate plan employing two lateral fields. Each lateral field treats the nodes on that respective side and the entire prostate gland. The sum of these two fields constitutes the complex dose map shown in the bottom panel. Red = 46 $Gy_{(RBE)}$, Light green = 36.8 $Gy_{(RBE)}$

Patients with high-risk prostate cancer are now treated on a routine basis at the PCPT facility, targeting the prostate gland, seminal vesicles, and pelvic nodes to a dose of 46 - 50 $Gy_{(RBE)}$, followed by a boost dose to the prostate gland for a cumulative dose of 78 $Gy_{(RBE)}$ using PBS. Most importantly, suspicious or positive nodes can be boosted to a higher dose simultaneously with the prostate boost to dose levels exceeding 60 – 66 Gy_{RBE}, depending on bowel proximity. This is illustrated in figure 8, which shows a treatment plan for a high-risk nodal prostate treatment.

The implementation of PBS also benefits low and intermediate risk prostate patients, but more so for cases where the prostate droops significantly over the rectum

and for patients with a hip replacement. In those cases, PBS allows for shaping the beam over the rectum, which was not possible with DS or US deliveries. The latest long-term outcome (median follow-up time of 5.5 years) data for prostate treatments published by the University of Florida revealed that the 5-year freedom from biochemical progression (FFBP) rates were 99%, 94%, and 74% in low-risk, intermediate-risk, and high-risk patients, respectively [35]. These treatments were performed with DS beam delivery techniques.

Augmenix INC. recently introduced SpaceOAR hydrogel that is inserted between the anterior rectal wall and the prostate, displacing the rectum away from the prostate [36]. The gel insertion typically creates a space, occupied by the gel, ranging between 10 and 15 mm. PBS, together with SpaceOAR, allowed for reducing the volume of rectum receiving 90% of the prostate dose to less than 1%, on average. At PCPT, we have been using SpaceOAR since April 2015 on the majority of prostate patients. This technique further reduced the already low grade 1 and grade 2 toxicities previously experienced by the patients treated without SpaceOAR gel, and has so far totally eliminated any grade 3 acute toxicities.

Head and Neck Treatments: Head and neck (H&N) cancers present one of the most complex shaped and challenging targets to the Radiation Oncologist. In most cases, the lymph nodes on at least one side of the neck, and often on both sides of the neck, need to be treated to doses higher than 60 Gy. Several dosimetric studies were conducted to evaluate the feasibility of using PBS for these cancers [37, 38, 39]. A general consensus is that in treating oropharyngel cancers, PBS reduces normal tissue exposure in particular the posterior pharynx and oral cavity without sacrificing target coverage. Treating patients for H&N cancers at many proton therapy institutions with PBS revealed that these dosimetric advantages appeared to translate into lower rates of acute treatment-related toxicity including mucositis, dysgeusia, and nausea, compared with IMRT [37, 38, 39]. Our own experience at PCPT, predominantly treating bilateral neck, is that the patients tolerate the H&N treatments generally well with acute toxicity not too dissimilar to IMRT but with more rapid and complete recovery of swallowing function, taste and saliva. Weight loss during treatment does occur and often requires adaptive plans, which are relatively easy with PBS.

VII. COST EFFECTIVE PROTON THERAPY FACILITIES

One of the main hurdles that proton therapy facilities had to overcome is cost. The cost of these facilities was often driven by the size of the equipment and the time it took to develop a facility. During recent years, several companies embarked on developing more compact systems that can be pre-assembled in a factory and installed on-site, requiring shorter installation times. Mevion, INC developed a compact single room system, where the accelerator is mounted on a rotating gantry. IBA, INC developed a dedicated single room system employing a limited angle gantry plus a dedicated cyclotron. Protom and Hitachi developed similar limited angle gantries, but they use synchrotrons to accelerate the protons. The legacy large systems that were initially developed by Varian, IBA, Sumitomo, and Mitsubishi are still commercially available and are typically purchased by the larger academic institutions. Although they are legacy by design, they are equipped with the latest technologies, e.g. CBCT and PBS.

The use of superconducting technologies entered the field of proton therapy in the early 2000's when the first superconducting isochronous cyclotron was built by ACCEL technologies (Acquired by Varian in 2005). Since then, several companies have started to develop superconducting synchrocyclotrons to reduce the size and cost of the accelerator. The most pertinent example is the MEVION synchrocyclotron, weighing less than 20 tons. Table 1 lists common commercial cyclotrons and synchrocyclotrons. The IBA C230 machine is a room temperature isochronous cyclotron and has been installed in the majority of the IBA facilities worldwide.

Table 1. Commercial cyclotrons for hadron therapy

	Mevion S250	IBA S2C2	Varian ProBeam	IBA C230
Type	SC Syn	SC Syn	SC Iso	NC Iso
Size (m)	1.8	2.5	3.1	4.3
Mass (tons)	20	<50	<90	250
Energy (MeV)	250	230	250	235
Peak B field	8.90	~6.56	<4	2.2
Power (kW)			≤115	320

SC: Superconducting, Syn: Synchrocyclotron, Iso: Isochronous

ProNova Solutions is the newest proton therapy system manufacturer and is developing a compact system employing superconducting magnets on a 360-degree rotating gantry that reduces the sizes of the gantry by almost a factor of three, compared to the legacy gantries. The ProNova system is based on beam line technologies developed at the Indiana University Cyclotron Facility [40]. This system employs separate energy modification systems for each room, making the treatment rooms independent from the main beam production system and allows for rapid (< 3 msec.) beam switching between treatment rooms.

The Provision Center for Proton Therapy (PCPT) is a state-of-the-art proton therapy facility equipped with the legacy IBA system comprising of three proton therapy rooms. PCPT also purchased the first ProNova SC360 system, which has been installed in the same building as

the IBA system. The SC360 system is going through final FDA testing and submission process, as of writing. PCPT is planning to start patient treatments using the SC360 system by the end of 2016, after the 510K clearance has been obtained from the FDA. A layout drawing of the PCPT building is shown in Figure 9. The difference in footprint between the legacy IBA system and the ProNova system is apparent in this figure.

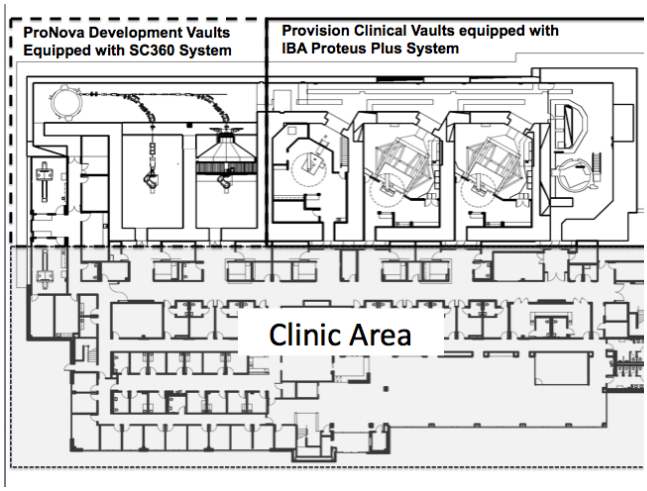

Figure 9. A layout of the first floor of the PCPT building, showing the IBA Proteus Plus system (Solid lines) and the ProNova SC360 system (Dashed line). The clinic area, containing the exam rooms and patient changing and waiting areas, are indicated with the gray shaded area.

VIII. The Future of Proton Therapy

The future of proton therapy is very promising. The immediate positive impact that PBS has had on the clinical landscape is beyond reproach. Although this was evident since the first patients were treated at the Paul Scherrer Institute (PSI) in 1996 [41], it became more evident when PBS became a clinical reality in many more treatment centers across the globe. The clinical teams at the University Medical Center in Groningen (UMCG) in the Netherlands, under the leadership of Dr. Hans Langendijk, realized the advantages that PBS can bring to their clinical program. They undertook an intensive investigation into the need for proton therapy at the UMCG, doing retrospective analyses of normal tissue complication probabilities that occurred in several cohorts of patients treated at the UMCG [42]. Figure 10 shows a bar graph (reproduced with permission from Dr. Langendijk) of the projected future utilization of a PBS based proton therapy system at UMCG, which is now under construction [42]. It is interesting to note that 75% of PBS utilization is for prevention of complications and secondary cancers. Only 20% of the cases they plan to treat will aim at improving local control, while only 5% will be for standard indications. The standard indications are more or less what proton therapy has been used for until the clinical realization of PBS. In other words, the standard indications in figure 10 represent the same indications listed on the left side of the dashed line in figure 6. This means that the potential clinical benefit of PBS is far beyond what was expected or predicted in the earlier days of proton therapy.

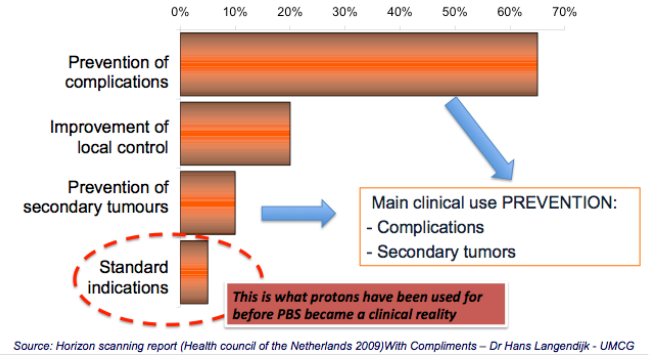

Figure 10. The projected clinical utilization of the UMCG proton therapy facility that is now under construction in Groningen, the Netherlands (Reproduced with permission from Dr. H Langendijk).

IX. Conclusions

Wilson first proposed the use of accelerated protons for radiation therapy purposes in 1946 [5] and the first patients were treated with protons in 1954 at the LBL [6]. After many years of dedicated work from many people in the field of particle radiation therapy, we finally reached a stage to declare that proton therapy is now ready for mass adoption in the clinical practice. This adoption is happening at a rapid pace. Arthur Schopenhauer (1788-1860) stated that all truth passes through three stages. First, it is ridiculed, second it is violently opposed and third it is accepted as being self-evident. It is our opinion that the clinical realization of PBS, together with many technological advances, made it possible for proton therapy to advance to the third stage of Schopenhauer's hierarchy. We will continue to see a near exponential growth in the number of proton therapy treatment vaults over the next decades. This growth in proton utilization will, in turn, allow for reducing the costs and construction times even further. The clinical realization of PBS allows for exploiting the full potential of accelerated proton beams in the pursuit of increasing the therapeutic ratio. It is the opinion of the authors that PBS will have an even more significant impact on cancer treatment outcomes than the introduction of IMRT had to-date. Bringing PBS to mass clinical adoption is a true testimony of the importance of the radiation therapy technology evolution that started with Roentgen's discovery of x-rays in 1896.

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TECHNOLOGY INNOVATIONS

REFERENCE DETECTOR FOR SMALL FIELDS – THE T-REF CHAMBER

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Abstract— **This work takes a closer look at one of the more practical aspects of small field dosimetry: where can a reference detector be placed for profile and percentage depth dose (PDD) measurements? One possible solution to this problem is to use a large-area plane-parallel transmission chamber. In this work, such a chamber – the new T-REF chamber of PTW – is presented and analyzed. A close look is taken at the ease of use of the chamber, at the range of usable field sizes, at perturbation effects, at the signal strength and quality, and at the influence of vibrations that might be transmitted by the motors of the water phantom.**

The T-REF chamber proved to be easy to use and as long as the minimum distance of 20 cm above the water surface was respected, no perturbations were seen in PDD measurements. In profiles no deviations between different distances to the water surface and no perturbations in the out-of-field-fractions were seen. There was no influence of vibrations and the reference signal of the chamber was highly stable. Its signal to noise ratio (SNR) even exceeded that of a classical Semiflex 0.125 cm³ chamber placed in a corner of the field. To help the user in choosing the correct range of the electrometer, an examplary range-table is provided.

Keywords— **Small field dosimetry, water phantom, transmission reference detector, DAP chamber, T-REF**

I. INTRODUCTION

In dosimetry PDDs and profiles are commonly measured using a second detector obtaining a reference signal to make sure that instabilities or drifts of the linac output cannot falsify the measurements. The signal of the field detector is divided by the reference signal and the outcome is used as measurement result. The common procedure is a positioning of the reference detector in a corner of the field by mounting it on the water phantom. If the field size is big enough, e.g. 10 cm x 10 cm, the disturbance by the reference chamber does not influence the signal of the field chamber. But for field sizes below roughly 2 cm x 2 cm placing a reference detector in the field without disturbing the measurement becomes difficult. There is not enough space for placing a reference detector in, e.g., a corner of the field. The measurement would be interfered with the shadow, caused by the reference detector [12]. For solving these problems there are different possibilities.

Modern linear accelerators (linacs) usually deliver a stable signal so maybe it could be possible to measure every relative measurement without reference detector and rely on the stability of the linac output. The second possibility would be to place a standard ionisation chamber (farmer type, semi flexible etc.) nearby but outside of the field. A third technique is to take a big flat chamber and use it as transmission detector.

The disadvantages of the measurement without reference detector are that the measuring time can be a bit longer and the physicist has to rely on the stability of the linac. Many clinics do not have the newest generation of linacs or although it is new, the linac might exhibit signal drifts and need servicing. These drifts are often not noticed because the output in monitor units is still perfectly stable, only the output over time drifts. Hence, many physicists would like to measure with a reference detector even when using a very modern linac. The technique of placing the chamber outside the field also has drawbacks, because of the bad signal to noise ratio (for more details concerning signal to noise ratio see [12] and [13]). The disadvantage of a transmission detector is that the beam will be modified in a way. Furthermore, if the detector is linac-head mounted, the signal might drift, caused by the high temperature differences between linac head and detector and by the changing temperatures of the head itself.

In this article PTW wants to present a chamber which is not affected by these problems in small fields. The T-REF chamber is a flat, thin transmission reference chamber with a large diameter that has been optimized for a very low areal density in order to perturb the beam as little as possible. The detector is vented, air filled and has a nominal volume of 10.5 cm³. It is brought into the beam above the water surface and provides a reference signal while the beam transmits through the chamber.

The T-REF chamber is mounted to the water tank and hence is not in contact with the linac head. This prevents instabilities of the reference signal that might arise because of the elevated and non-constant temperature of the linac

head. As the result of the measurement is the signal of the field chamber divided by the signal of the reference chamber, such temperature-induced drifts would deteriorate the measured curves.

This work embraces different subjects for characterizing the performance of the T-REF chamber.

- Is it trivial to bring the chamber in position? There are some tools for mounting the chamber to the water phantom that need to be checked for usability. The motor of the water tank might cause light vibrations, the impact will be studied.
- What is the maximum field size one can apply to the T-REF chamber?
- Another thing to test is the influence of the presence of the chamber. Does the T-REF chamber influence the curve measured by the field chamber? Measurements were performed with and without the chamber to test for this influence.
- Perturbations induced by the presence of the chamber should decrease when the distance between water surface and chamber is increased. We studied this distance behavior to test at which minimum distance no perturbation is deducible in the scans.
- The current measured by the T-REF chamber depends on the field size and the dose rate. It can be shown that this relation is linear.

II. Methods and Materials

In this work, we tested the T-REF chamber which can be used as reference detector in small field relative dosimetry. There are diverse reasons for introducing a new transmission measurement technique. For determining the behavior of the T-REF chamber it is important to know all the technical aspects of the chamber itself and of the used materials.

A. The detector and materials for measurements

The T-REF chamber consists of a holder for the water tank and a waterproof detector cable. The detector itself is a plane parallel air vented chamber with the following specifications:

- Nominal volume: 10.5 cm³
- Vented, waterproof (not for use in deep depths)
- Nominal response: 325 nC/Gy (at ^{60}Co free in air)
- Entrance window: 0.1 mm varnish, 0.5 mm PMMA, 0.02 mm graphite
- Total window area density: 72 mg/cm²
- Sensitive volume: radius 40.8 mm, depth 2 mm
- Guard ring width 1.1 mm
- Chamber voltage: ± (300…500) V, nominal: +400 V

The chamber is mounted on the edge of the water tank. By the use of an acrylic glass rod and a holder, the chamber can be brought in position.

The materials used to investigate the characteristics of the T-REF chamber were:

Water phantom: MP3, MP3-XS (PTW-Freiburg, Lörracher Strasse 7, 79115 Freiburg, Germany)
Two-channel electrometer: TANDEM T10011 (PTW-Freiburg)
Linac: SIEMENS Oncor (SIEMENS, Erlangen, Germany), Varian Truebeam (Varian Associates, Palo Alto, CA), Elekta Synergy (Elekta, Crawley, United Kingdom)
Field detector: microDiamond 60019 (PTW-Freiburg), Dosimetry Diode E 60017 (PTW-Freiburg)
Reference detector: T-REF chamber 34091 (PTW-Freiburg), Semiflex 0.125 cm³ 31010 (PTW-Freiburg)

The measurement of percentage depth dose curves (PDD) and profiles (TBA scans) were implemented with the MEPHYSTO mc² software of PTW.

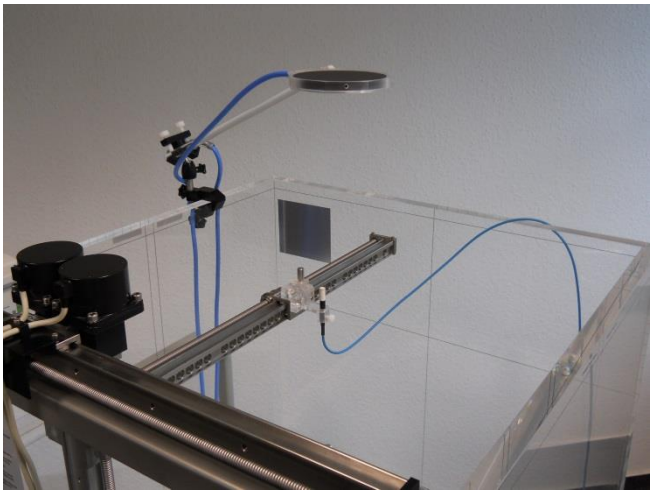
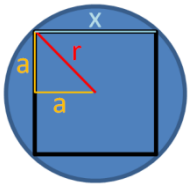


Figure 3: The T-REF chamber is mounted on the edge of the water tank and can be brought into the beam via an acrylic glass rod and holder.

B. Maximum square field size

Fieldsizes can be considered as small when they are ≤ 40 mm x 40 mm [14]. The radius of the T-REF chamber is 40.8 mm. Consequently, the maximum field size that fits on the chamber area is

$$x^2 = 4a^2 = 2r^2 \quad (1)$$
$$= 57.7mm \times 57.7mm$$



The T-REF chamber is mounted above the water surface, i.e. closer to the linac source than the isocenter. Following the theorem of intersecting lines, the maximum

isocenter field size can be calculated. For the minimum distance to the water surface (see chapter III.C) or DSD (detector surface distance) of 20 cm the resulting isocenter field size is 56 % larger.

C. Possible perturbation

Two main effects could lead to a perturbation of the beam. The first one is a partial build up effect together with the scattered radiation which occur from the material of the T-REF chamber and might disturb the beam a little. When in-air photons enter matter that has a higher density than air, one can observe a build-up effect, which leads to the known shape of a PDD curve, see e.g. [15]. When photons traverse the T-REF chamber, a partial build-up takes place. Due to the very low areal density, this effect is only weak. For large distances to the water surface (large DSD), the secondary electrons created in the T-REF chamber will be scattered out of the beam, hence it is expected that the partial build-up effect will not be visible if the DSD is large enough. For small DSDs, the T-REF chamber could lead to an increased surface dose. This is studied in this work by positioning the chamber in different DSDs and subsequently measuring PDDs. The expected result will be a non-measurable influence of those effects from a defined minimum DSD because the build-up radiation will be scattered out.

The second effect is the beam hardening. This effect occurs when the lower energy photons are absorbed by some material which is interposed. Because of the low areal density of the chamber, it is expected that this effect will not be visible.

Measurements with and without T-REF chamber were implemented for studying those effects.

D. The influence of inaccurate positioning and vibrations during measurement

The T-REF chamber is essentially a DAP-chamber (dose area product). Since the DAP is independent from the distance, small variations in the distance to the water surface can be tolerated and should not lead to differences in the signal.

Field sizes of small fields are mostly smaller than 4 cm x 4 cm and thus much smaller than the area of the sensitive volume of the T-REF chamber. Therefore small lateral shifts are also expected not to pose a problem. We expect that the signal is very stable during operating the MP3 water tank, despite the possible vibrations that might be introduced by the water tank motor.

III. Results and Discussion

A. Mounting

The T-REF chamber can be easily mounted on the edge of the water phantom. The acrylic glass rod with the holder enables a continuous positioning without increments. On the flat area on the top of the chamber it is possible to read the SSD value, which is projected on it by the linac. The physicist can either use the SSD projection or a ruler for positioning the chamber at the wanted distance to the water surface. Thus, the positioning is not difficult and does not require a high precision because the T-REF chamber operates on the principle of a DAP chamber. For that reason the position in z-direction is not that important and the adjusting can be done quick and easy as long as the user makes sure that the DSD is at least 20 cm.

B. Maximum square field size

The maximum field size in different DSD can be calculated following the theorem of intersecting lines (see

Table 1). For the minimum distance of the T-REF chamber (upper edge of the chamber) to the water surface (see chapter III.C) of 20 cm the space for a square field is about 56 % larger, what corresponds to a field size of 72 mm x 72 mm. When an uncertainty of positioning of ±6 mm would be included, a field size of 65 mm x 65 mm can easily be irradiated. In Figure 7 of chapter III.C it is shown that distances from20 cm on don't result in different relative measurement curves.

Table 1 Maximum square field size following the theorem of intersecting lines

DSD [cm]	Space for length of square field [%]	Space for square field [%]	resulting length of square field [mm]
0	100.0	100	57.70
10	111.1	123.5	64.11
20	**125.0**	**156.3**	**72.12**
25	133.3	177.8	76.93
30	142.9	204.1	82.43
40	166.7	277.8	96.17
50	200	400	115.40

Thus the T-REF chamber can be placed at a distance to the water surface of e.g. 30 cm. This results in a maximum field size of about 75 mm x 75 mm. When measuring profiles (see Figure 4) for a field size of 4 cm x 4 cm, the out-of-field-fraction is 1.5 cm (37.5 % of field size) for DSD = 20 cm and 2 cm (50 % of field size) for DSD = 30 cm.

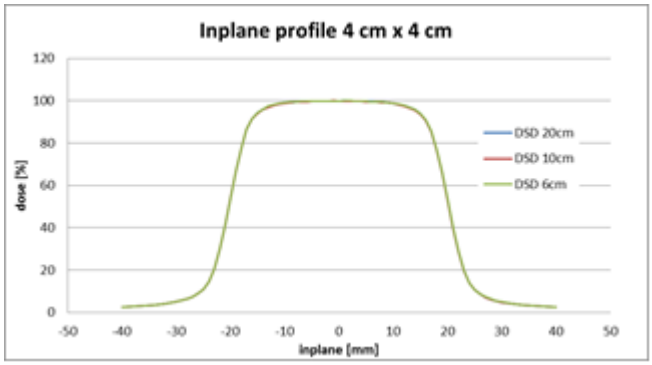


Figure 4: inplane profile 4 cm x 4 cm, 6 MV at three different DSDs (6 cm, 10 cm, 20 cm). No differences are found in the out-of-field-fraction of the curves.

In Figure 4 profile measurements for different DSDs are shown. In all cases, no influence from the guard ring or edge of the T-REF chamber is visible. Hence, the chamber can safely be used for profile measurements in small fields.

C. Perturbation from the chamber

The influence of the T-REF chamber's presence has been investigated by taking measurements with a 60019 microDiamond as field detector: first with the T-REF chamber between linac head and water surface (three different distances to the water surface: 20 cm, 22 cm and 24 cm) and secondly without presence of the T-REF chamber. A field size of 4 cm x 4 cm was chosen. Then the field signal was visualized by measuring PDDs with the focus on deviations between presence and absence of the reference chamber.

It is hard to see any differences between the different PDDs (see Figure 5). This means the perturbation is minimal and can be ignored for relative measurements, if the underlying circumstances are correct (e.g. minimum distance to water surface). The reason for the small perturbation is the very low areal density of the chamber and that the minimum distance to the water surface was maintained.

If the T-REF chamber is placed relatively close to the water surface, the partial build up can be seen in the first millimeters of the PDD because of a larger contribution of dose production. For larger DSDs, when the way through the air is long enough, these lower energy photons and secondary electrons will be scattered out of the beam. Hence for a large-enough DSD, the partial build-up effect should no longer be visible in the PDD measurements. In Figure 6 this effect can be observed. For distances from 8 cm to 18 cm there are effects, which show a light influence for the first few millimeters of the PDD.

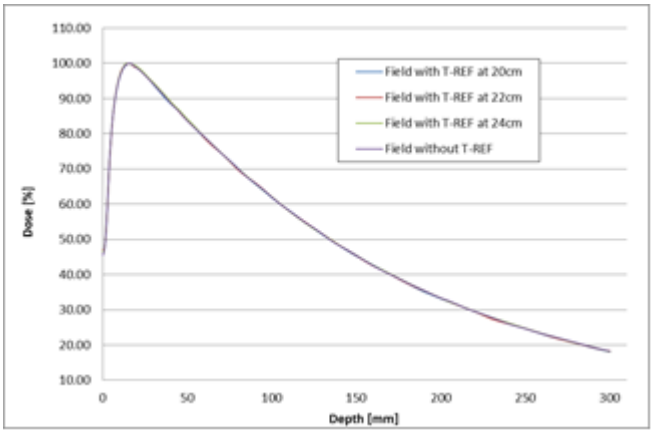


Figure 5: Field size 4 cm x4 cm, 6MV, field detector 60019. The PDDs shown here shall indicate the influence of the presence of the T-REF chamber. The curves are smoothed and are not divided by the reference signal. It is clear that the influence is very small. The relative depth dose curves of the three different DSDs of the T-REF chamber and one where a Semiflex 0.125 cm³ was used as reference lie very well on top of each other. The positioning of the Semiflex chamber followed the normal procedure of placing it into a corner of the field.

Above 20 cm no influence is observable in the Data (see Figure 7). This leads to the fact that the physicist has a free choice in positioning the T-REF chamber, as long as he respects the minimum distance to the water surface of 20 cm.

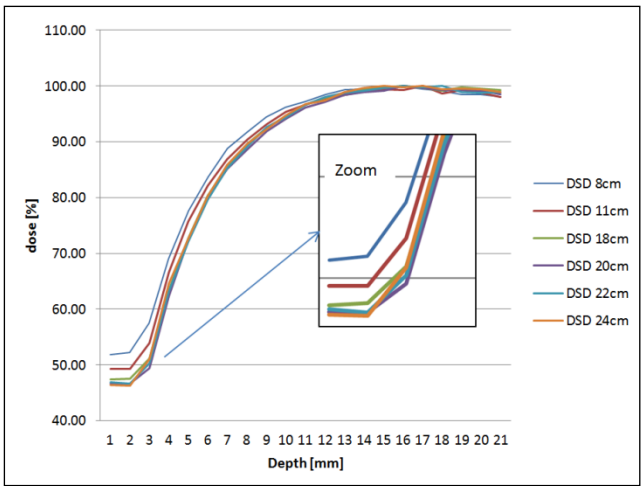


Figure 6: PDDs measured in 4 cm x4 cm, SIEMENS Oncor 6MV. The distance-to-water-dependence is clearly visible in the onset of the PDDs.

For larger distances of the T-REF chamber larger fields can be applied. In Table 1 the factor of field size increase can be seen. For a DSD of 40 cm, which is close to the linac head, field sizes of almost 10 cm x 10 cm can be applied. But for these field sizes a standard Semiflex chamber in the corner of the field can be sufficient, whereby the signal to noise ratio would be slightly worse.

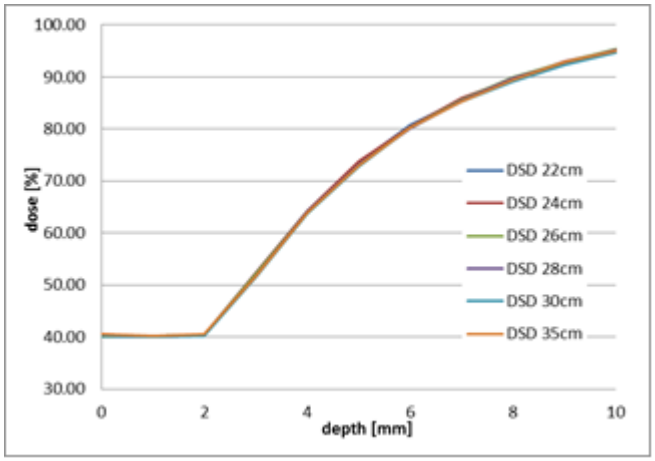


Figure 7: 2 cm x 2 cm, Electa Synergy 6MV, Different distances from minimum to 35 cm

D. Different approaches for measuring the reference signal compared with the T-REF chamber

For the standard technique of measuring the reference signal, a thimble chamber, here the Semiflex 0.125 cm² 31010 is placed in the corner of the field. In **Error! Reference source not found.** the relative noise of the reference measurement in a 4 cm x 4 cm field is easy to see because of a high resolution of the axis from 98 % to 102 %. When comparing this measurement with one of the T-REF chamber in Figure 9, which was placed in the beam as a transmission chamber, the difference in the noise becomes clear. In the PDDs there are no observable differences. This excellent signal to noise ratio is one of the advantages of the T-REF chamber. It follows from Figure 9 that the vibrations caused by the motor of the water phantom do not influence the reference signal.

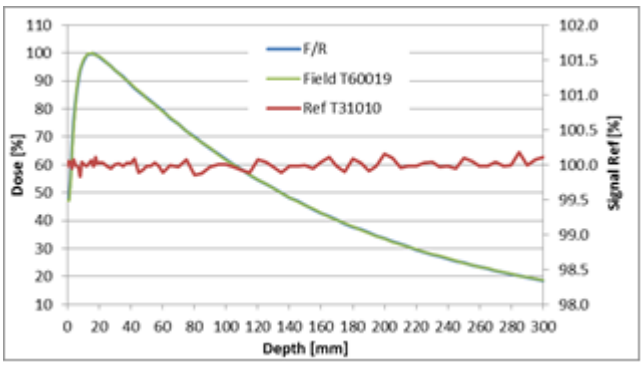


Figure 8: PDD measurements, 4 cm x 4 cm, field detector 60019, Varian Truebeam 6MV: a Semiflex 0.125 cm³ used as reference chamber. Measuring time per data point 0.5s.

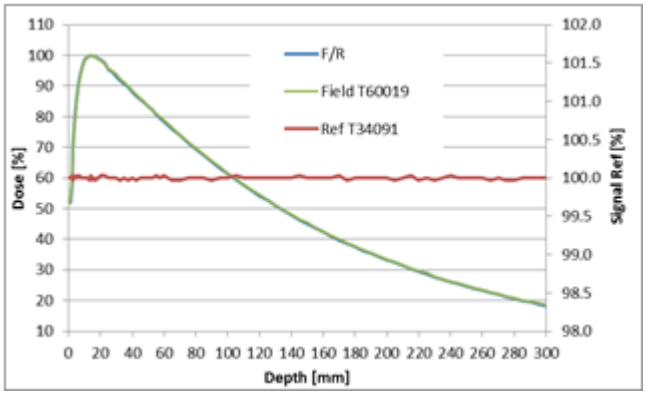


Figure 9: PDD measurements, 4 cm x 4 cm, field detector 60019, Varian Truebeam 6MV: a T-REF chamber used as reference chamber. Measuring time per data point 0.5s.

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E. The current magnitude of the reference signal

One further investigation was whether and how the measuring current of the T-REF chamber depends on the field size and on the dose rate. Because the T-REF chamber measures one value over the whole area, one could assume that the relation "the bigger the field, the larger the measurement current" is linear with the field area (in cm²).

Here for 300 MU/min (approx. 3 Gy/min) and 6MV the following field sizes were tested: 1x1, 2x2, 3x3 and 4x4 [cm x cm]. As can be seen from the data table (see Figure 10), the signal indeed increased linearly with the field size. From these data points the other dose rates and field sizes were calculated. The two-channel electrometer of PTW, TANDEM, has three range settings: LOW, MEDIUM and HIGH. They are defined as follows:

Table 2: Range setting of PTW TANDEM

Range	[A]
LOW	5.0E-12 … 1.0E-9
MEDIUM	50.0E-12 … 10.0E-9
HIGH	500.0E-12 … 100.0E-9

dose rate [MU/Min]	Length of quadratic field [cm] 0.3	0.5	1	2
100	2.8E-12	7.7E-12	30.9E-12	123.7E-12
200	5.6E-12	15.5E-12	61.9E-12	247.5E-12
300	8.4E-12	23.2E-12	*92.8E-12*	*371.2E-12*
400	11.1E-12	30.9E-12	123.7E-12	494.9E-12
500	13.9E-12	38.7E-12	154.7E-12	618.7E-12
600	16.7E-12	46.4E-12	185.6E-12	742.4E-12
1000	27.8E-12	77.3E-12	309.3E-12	1.2E-9
1200	33.4E-12	92.8E-12	371.2E-12	1.5E-9
1400	39.0E-12	108.3E-12	433.1E-12	1.7E-9
2400	66.8E-12	185.6E-12	742.4E-12	3.0E-9

	3	4	5	6
100	289.2E-12	533.7E-12	773.3E-12	1.1E-9
200	578.5E-12	1.1E-9	1.5E-9	2.2E-9
300	*867.7E-12*	*1.6E-9*	2.3E-9	3.3E-9
400	1.2E-9	2.1E-9	3.1E-9	4.5E-9
500	1.4E-9	2.7E-9	3.9E-9	5.6E-9
600	1.7E-9	3.2E-9	4.6E-9	6.7E-9
1000	2.9E-9	5.3E-9	7.7E-9	11.1E-9
1200	3.5E-9	6.4E-9	9.3E-9	13.4E-9
1400	4.0E-9	7.5E-9	10.8E-9	15.6E-9
2400	6.9E-9	12.8E-9	18.6E-9	26.7E-9

LOW MEDIUM HIGH

Figure 10: Currents of T-REF chamber dependent of field size and dose rate in [A]

For small fields up to 2 cm x 2 cm and dose rates up to 600 MU/min the range LOW can be kept as default. For larger field sized and higher dose rates MEDIUM will be more suitable. If the user is not sure about the settings the indication for the ideal range can be watched in the PTW-tbaScan interface of MEPHYSTO mc² software. If the signal bar is filled out by 2/3 the setting is perfect. If it is lower than 1/3 or 1/4 the user might set a lower range and vice versa.

IV. Conclusions

In this work, the new PTW T-REF chamber was characterized in a clinical environment. This chamber provides a solution to the problem of where to put the reference chamber for small field PDD and profile measurements. The chamber proved to be fast and easy to mount, and as long as the minimum distance of 20 cm above the water surface was maintained, no perturbation due to the use of the transmission chamber could be seen in the curves measured for this work, neither for PDDs, nor for profiles. The range of usable field sizes was provided and covers the entire range of use for small field measurements. No influence from vibrations from the motors of the water phantom could be deduced in the measurements, as was expected for a DAP-type reference detector. Indeed, the signal to noise ratio of the T-REF chamber proved to be excellent, exceeding that of a classical Semiflex 0.125 cm³ chamber in the corner of the irradiation field. Because the chamber is mounted to the water phantom and not to the linac head, there are no temperature drifts which might influence the reference signal. Care must be taken by the user to correctly set the range of the electrometer of the channel to be used with the T-REF chamber. An exemplary table was provided which shows the range setting for a TANDEM electrometer in use at field sizes of 0.3 cm x 0.3 cm up to 6 cm x 6 cm.

Acknowledgment

I would like to thank Alexandra Friedrich for helping to provide measuring data and Heiko Karle and Sascha Großmann who permitted us to use their linacs. Additionally I want to give thanks to my colleagues Jan Würfel and Rafael Kranzer for providing data and for helpful discussions about reference detectors.

Conflict of interest statement

The Author is employee of PTW-Freiburg.

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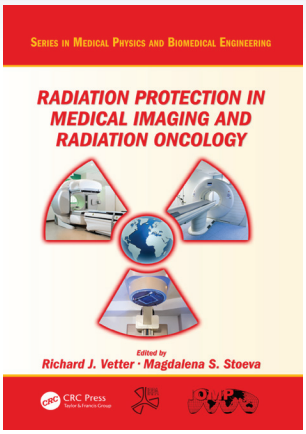

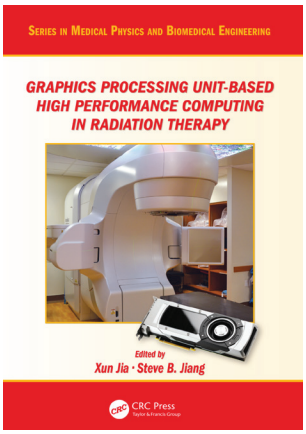

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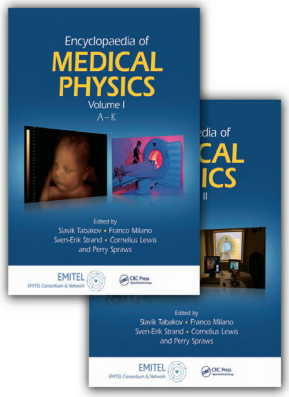

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BOOK REVIEW

INNOVATIONS AND ADVANCES IN ELECTRONIC PUBLISHING: A BRIEF OVERVIEW

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[1] IOP Publishing, Bristol, United Kingdom

Abstract— **Electronic publishing, specifically electronic books (referred to as ebooks), continues to evolve as reading and learning habits alter. Publishers have innovated their practices and workflows to incorporate the changing technologies in publishing. In doing so, production practices and access to content has undergone advances to keep up with these changes. The result is evident in the final product, and this paper briefly explains the transmission of content, the production process, and how ebooks are accessed.**

Keywords— **XML workflow, ebooks, multimedia, PoD**

I. Introduction

There have been many studies and scholarly articles on electronic publishing expressing opinion and usage statistics. This paper offers a general overview of electronic publishing, ebooks in particular, focusing on what is important for potential authors and readers to note as they produce and consume information. Additionally, how authors send materials, how the production is completed, and hence how the content is then available to the readers will be the primary points covered in this paper.

According to a 2015 editorial from *The Washington Post*, as demand for ebooks rises, libraries are responding; nationwide, spending on ebooks has grown from 1.7 percent of public library budgets in 2010 to 7.6 percent in 2014 [1]. As the demand grows, publishers must innovate and there are some key ways they are doing this.

II. Submitting material

All proposals and manuscripts are submitted in MS Word or LaTeX, the most widely used programs. If possible, it is also requested that PDFs are provided.

Materials can be sent via email but it is often much easier (for manuscripts especially) to utilize file sharing services such as Dropbox or We Transfer. If an author is not familiar with these services, an ftp site can be provided and the files can simply be uploaded to the site.

If it is more convenient, the author can also send in CDs, DVDs, or USB drives containing the content. All figures can be submitted separately as long as it is identified in the manuscript where the figures should be placed.

III. Production

Traditional production processes were centered on the use of Word and In Design, whereas more publishers are now taking the leap into full XML production workflows often supported and integrated with an accompanying content management system for their book production.

The primary advantage of an XML workflow is that it allows the creation of multiple formats from a single source - HTML, PDF and EPUB are all created from the same XML. Using XML also gives publishers the opportunity to do more with the book content in the future such as enhanced searching, enriched content (like embedded multimedia and interactive elements, and MathML: See Fig.1) and greater integration with journals content on a single online platform. All of which, for a publisher of STEM content, needs to be fully embraced to

enhance the reader experience and further the capacity for learning.

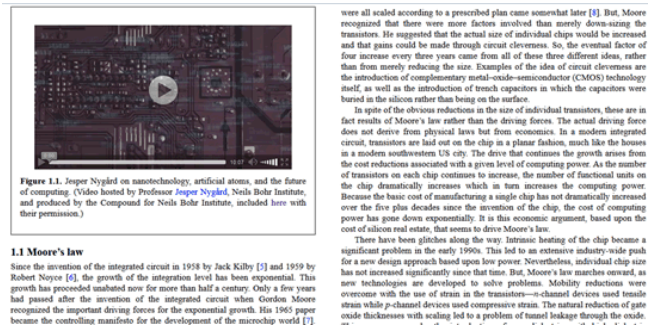

Figure 1.1. Jesper Nygård on nanotechnology, artificial atoms, and the future of computing. (Video hosted by Professor Jesper Nygård, Neils Bohr Institute, and produced by the Compound for Neils Bohr Institute, included here with their permission.)

1.1 Moore's law

Since the invention of the integrated circuit in 1958 by Jack Kilby [5] and 1959 by Robert Noyce [6], the growth of the integration level has been exponential. This growth has proceeded unabated now for more than half a century. Only a few years had passed after the invention of the integrated circuit when Gordon Moore recognized the important driving forces for the exponential growth. His 1965 paper became the controlling manifesto for the development of the microchip world [7].

were all scaled according to a prescribed plan came somewhat later [8]. But, Moore recognized that there were more factors involved than merely down-sizing the transistors. He suggested that the actual size of individual chips would be increased and that gains could be made through circuit cleverness. So, the eventual factor of four increase every three years came from all of these three different ideas, rather than from merely reducing the size. Examples of the idea of circuit cleverness are the introduction of complementary metal–oxide–semiconductor (CMOS) technology itself, as well as the introduction of trench capacitors in which the capacitors were buried in the silicon rather than being on the surface.

In spite of the obvious reductions in the size of individual transistors, these are in fact results of Moore's law rather than the driving forces. The actual driving force does not derive from physical laws but from economics. In a modern integrated circuit, transistors are laid out on the chip in a planar fashion, much like the houses in a modern southwestern US city. The drive that continues the growth arises from the cost reductions associated with a given level of computing power. As the number of transistors on each chip continues to increase, the number of functional units on the chip dramatically increases which in turn increases the computing power. Because the basic cost of manufacturing a single chip has not dramatically increased over the five plus decades since the invention of the chip, the cost of computing power has gone down exponentially. It is this economic argument, based upon the cost of silicon real estate, that seems to drive Moore's law.

There have been glitches along the way. Intrinsic heating of the chip became a significant problem in the early 1990s. This led to an extensive industry-wide push for a new design approach based upon low power. Nevertheless, individual chip size has not increased significantly since that time. But, Moore's law marches onward, as new technologies are developed to solve problems. Mobility reductions were overcome with the use of strain in the transistors—*n*-channel devices used tensile strain while *p*-channel devices used compressive strain. The natural reduction of gate oxide thicknesses with scaling led to a problem of tunnel leakage through the oxide.

Fig. 1 Screenshot of embedded ePub video

There now seems to be a movement towards a 'Digital First' publication model, allowing publishers to actively commission books that take advantage of and feature these new technologies, like the embedded multimedia and reflowable content display in ePub3 for example, and enhanced mathematical equation rendering using the MathML feature across all formats. However, having books produced in XML also means that future developments that are implemented (content enrichment, integration, etc.) can be applied to books that are already published, and not just new books, allowing for maximum flexibility in published output. This, however, seems to be where many publishers differ on the definition of an ebook – with some prepared to consider a digitized print PDF as fulfilling this brief, whereas others taking the next step considering the ePub as the true, modern ebook format, with all its value-adding inbuilt features and technical possibilities for enrichment and user interaction.

Physical book printing has evolved as well with many publishers now choosing to operate on a PoD (Print-on-demand) basis instead of printing vast quantities and storing for distribution and sale as done previously. This arrangement increases the production flexibility further, allowing books to be produced not only with a digital first audience in mind, but producing print PDF files for those who still require a physical book (on an 'on demand' basis). It also chimes nicely with the model of 'Digital First', where e-formats take precedence and print is very much a secondary offering.

It's also worth noting that the above mentioned processes, when done right, can all contribute significantly to reducing the overall time to market, from traditional production times of anywhere between 6-12 months down to as little 12 weeks in some publishing companies.

IV. Access

Ebooks have traditionally tended to be produced and considered as digitized web PDFs (with somewhat limited functionality beyond making the PDF viewable in electronic form). However, it is now becoming more standard to produce ebooks in HTML, ePub, and even Mobi format (which is what Amazon uses for their readers) to better serve the needs of the readers as noted above. These formats offer the publisher distinct opportunities to enhance technical and display elements of the book and its contents, and generally enrich reader experience across the widest variety of e-readers. Modern ebooks tend to be produced in HTML, ePub3, Mobi, and PDF formats (or combinations thereof by different publishers), and these are most commonly created at chapter level only; however, some publishers now create these files at whole book level for reader download.

In terms of accessing ebooks' content, institutional subscribers have a number of access options to read ebooks from long standing, industry standard methods like username & password and IP address authentication, to federated search login authentication like Shibboleth and ATHENS. Individual users still tend to access ebooks by individual purchase and order print-on-demand copies direct from a publisher or through a retailer site, or choose to download in their preferred e-format (where available by publisher) to their e-reader device. Digital formats (individually purchased) are usually bound by DRM on the ebook and would be unable to share across devices, however some publishers choose not to impose this restriction and operate a 'DRM Free' policy, allowing the purchaser to use the content as they wish post-purchase. Many of these books also carry digital watermarking, which restricts the amount of text available to copy to clipboard, but again, some choose not to impose this.

In terms of book types, some publishers offer individual purchase at both whole book and chapter specific levels, however at present the whole book print purchase option is still most common across many publishers and retailers.

V. Conclusions

In order for publishers to be successful and serve the needs of their readers, attention must be paid to the ever-evolving capabilities of electronic publishing. Ebooks in particular offer a way to showcase advances in epublishing and will continue to innovate with the changing technologies. It would be easy to imagine as formats become ever more sophisticated in what they offer, that publishers will choose to take advantage of these possibilities, and that the ebook will become as much interactive and sensory as it will be informative and educational. As these technologies develop, it's

foreseeable that user behavior may too change to take advantage of these new features and ways of learning, but it's as yet unclear whether reader demand for new ways of learning and flexible reading will influence publishers to produce the ebook as a primary format, or whether publishers following this path will actually change user behavior.

Good reference articles for ebook production:

- JEP - XML Production Workflows? Start with the Web... http://quod.lib.umich.edu/j/jep/3336451.0013.106?view=text;rgn=main

- O'Reilly ToC - The Agile Upside of XML http://toc.oreilly.com/2011/10/xml-publisher-workflow-ebook-design.html

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PhD THESES

APPLICATION OF MDCT TECHNIQUES IN DIAGNOSING RETROPERITONEAL EXTRARENAL MASSES

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I. INTRODUCTION

MDCT allows accurate assessment of retroperitoneal structures, which is the key to accurate diagnosis, early detection and monitoring of pathological processes in the area. With the advancement of software capabilities and speed of modern appliances, MDCT is now the method of choice for diagnosing retroperitoneal diseases.

The retroperitoneum is a space that can be affected by inflammation of the large bowel, appendix, pancreas, infections of tuberculosis of the spine (cold abscess), malakoplakia, haemorrhage, retroperitoneal benign cysts, idiopathic retroperitoneal fibrosis and others.

II. OBJECTIVES

The objective of this study is make a retrospective analysis and data comparison of examination data from the last 3 years. A 2 stage analysis is undertaken – analysis of the clinical and the physical aspects of the examinations. The main objective of the clinical analysis is to evaluate the role of MDCT as a primary diagnostic method for retroperitoneal masses, while the physical aspect of the study is targeting an assessment of the patient dose and a comparison of the results with European reference values in order to achieve an MDCT dose optimization.

III. MATERIALS AND METHODS

The diagnostic equipment used during the examinations consists of 2 multi-detector scanners – 16 and 64 slice, with individual peripheral collimation of 0,25 and central 0,65. The total detector collimation is 1,5 mm, x-ray beam – 20 mm, gentry rotation 0,5 sec and pitch 0,98.

Our experience is based on 20 cases – 15 men and 5 women at the age between 21 and 80, the method of choice is MDCT. We have 12 cases of retroperitoneal hematoma, 3 cases of pancreatic carcinoma, 5 cases of adrenal adenoma (Fig. 1, 2, 3).

The primary tumors of the retroperitoneum can arise from the adrenal glands, retroperitoneal lymph nodes (malignant lymphomas) and other tissues. Retroperitoneal soft tissue sarcomas are also shown in this field - liposarcoma, malignant fibrous histiocytoma, leiomyosarcoma, rhabdomyosarcoma, fibrosarcoma, vascular tumors, peripheral nerve tumors, synovial sarcoma, extraskeletal osteosarcoma. Retroperitoneal germline tumors and metastasis of gonadal tumors can also be established. Primary retroperitoneal tumors are rare. Men and women suffer equally at all ages. Malignant mesodermal tumors of the retroperitoneum are: liposarcoma, fibrosarcoma, lymphosarcoma, reticulosarcoma, rhabdomyosarcomas, hemangioendothelioma, fibromiosarcoma, etc. Retroperitoneal tumors are often massive and can infiltrate neighboring organs and/or vital structures, making them difficult to resect.

Primary benign tumors of mesenchymal origin are benign or malignant. Benign tumors are: lipoma, leiomyoma, fibroma, rhabdomyoma, lymphangioma, hemangioma, xanthogranuloma and others. Tumors of neurogenic origin are: benign schwannoma, neurinoma with capsule, ganglioneurinoma, sympaticoblastoma and neuroblastoma. The third group is represented by dysontogenic retroperitoneum tumors, benign form of teratoma, which is rare and chondroma.

Metastatic tumors in the retroperitoneal space can appear from neighbor tissues or through lymph. Symptoms of retroperitoneal neoplasms are unclear, caused by compression and obstruction of organs.

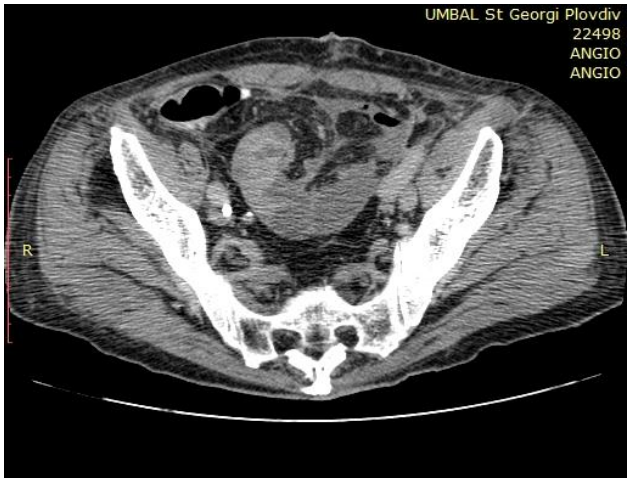

Fig. 1. Kidney variety and cancer

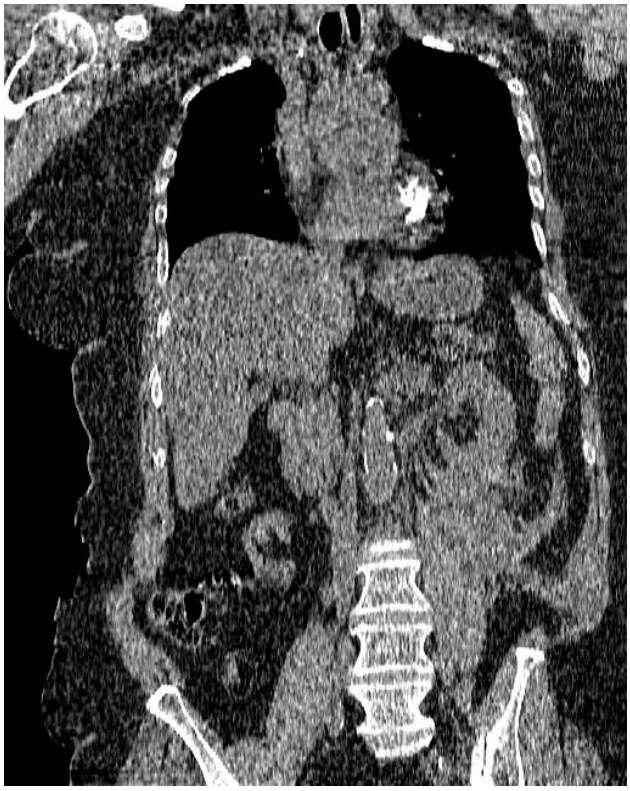

Fig. 2. Retroperitoneal hematoma

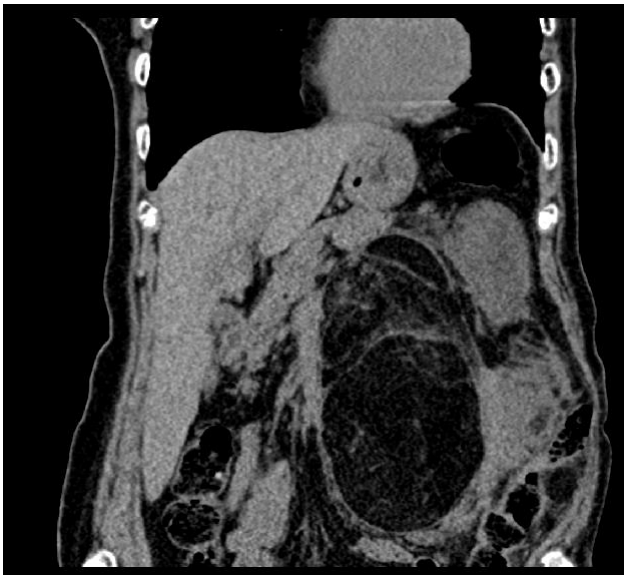

Fig. 3. Retroperitoneal liposarcoma

IV. CONCLUSION

MDCT is still the method of choice in specifying and characterization of retroperitoneal masses. It can easily specify pseudotumors and other anatomical variations and provides levels of attenuation, which confirms the presence of fluid in the cysts or fatty tissue in angiolipomas.

MDCT outlines exactly pararenal space and retroperitoneum, exact analysis of retroperitoneal masses requires the use of intravenous contrast. The continuing development improved detection, characterization and staging of extrarenal tumors and allows high quality multilayer reconstruction, required in surgery planning, especially with the increased use of laparoscopic and robotic surgery.

The diagnostic value and the role of MDCT as a method of choice in retroperitoneal masses are indisputable, while at the same time this presents a large risk factor due to the increased patient dose. Unnecessary exposure of patients may arise from the improperly selected and not individually tuned exposure parameters.

THE LEADING ROLE OF COMPUTER TOMOGRAPHY FOR THE DIAGNOSE OF KRUKENBERG TUMOR WITH A TYPICAL SYMPTOMATOLOGY

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I. INTRODUCTION

The first description of this type of tumor was made in 1896 by Friedrich Krukenberg.

There is a renaissance and expanded discussion of the subject in articles posted over the recent year. There is no uniformity as regards to the incidence of the disease. The figures vary from 0,16 % in 100000 people to 10% (1, 2). In addition to the known primary foci in the stomach and the column, the formation of Krukenberg tumor occurs in some primary locations in the lung, mammary glands, pancreas, etc. (3, 4). There are reports that highlight the difficult differentiation between the Krukenberg tumor and primary ovarian tumor (5, 6, 7). What is sought are the most appropriate CT reports as well as the characteristic CT image and the clinical presentation of the course (8, 9). In the bibliography available we found no report for the launch of the clinical presentation of Krukenberg tumor with haematuria.

II. OBJECTIVE

The objective of this examination is to analyze both the clinical and the physical aspects of the examination and findings of this rare disease. The main objective of the clinical analysis is to evaluate the role of CT as a diagnostic method for Krukenberg tumors, while the physical aspect of the study is targeting an assessment of the patient dose and a comparison of the results with European reference values in order to achieve an CT dose optimization.

III. RESULTS

The diagnostic equipment used during the examinations consists of 2 multi-detector scanners – 16 and 64 slice, with individual peripheral collimation of 0,25 and central 0,65. The total detector collimation is 1,5 mm, x-ray beam – 20 mm, gentry rotation 0,5 sec and pitch 0,98.

We report a female patient, aged 48, whose disease onset occurred with haematuria and load in the low back. Hydronephrosis of the right kidney and hydroureter without establishing the reason for the change were found upon an ultrasound scan of the abdominal area. The anamnestic data showed that subtotal resection of the stomach and duodenum was performed with latero-lateral anastomosis with jejunum on the occasion of histologically established gastric carcinoma 16 months ago. When a preventive gynecological examination and transvaginal ultrasound scan were performed, a cyst in the right ovary was found subject to ultrasound scan. CT scan of abdomen and pelvis was carried out with intravenous contrast enhancing performed with oral contrasting. From the scan: a multi-chamber formation of irregular shape was found which size was 50/48 mm originating from the right ovary (fig.1).

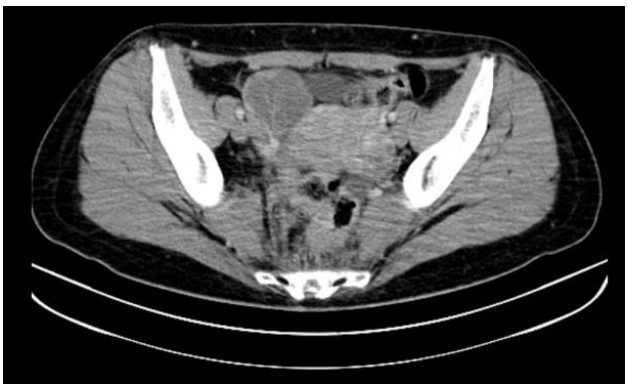

Fig. 1. A multi-chamber formation of irregular shape

This formation extends to the wall of the sigmoid colon, transverse colon and the lower third of the right ureter (fig. 2).

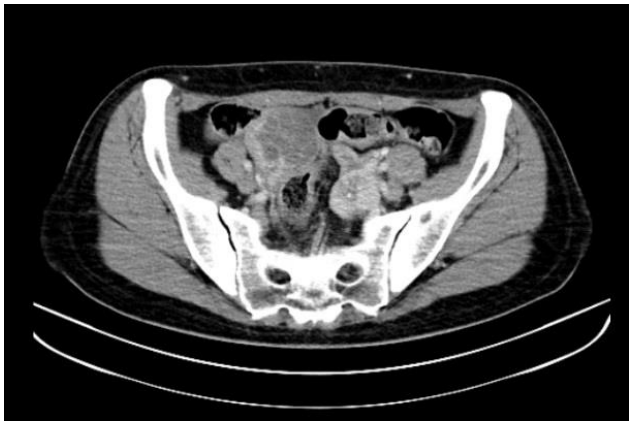

Fig. 2. Extension of the formation

The formation has a highly variable density from the center to the periphery from 56HE to 17 HE and unevenly thick walls of non-sharp contours and density of 60HE at the native exam. Contrast agent passes through the wall to 75HE and through the cyst itself - to 68HE. The right kidney is hydronephrotic with delayed release of contrast agent at the 4th hour and hydroureter up to the upper two thirds of the ureter (fig. 3).

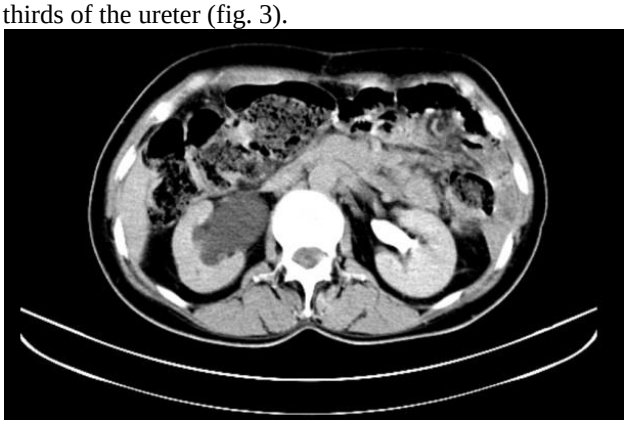

Fig. 3. A view of the hydronephrotic right kidney

The distal and intramural part of the ureter are intact. Parenchymal cyst was found in the right kidney, 13 mm and density of 4HE. The liver is of normal size and density with the presence of a simple cyst in the right lobe, size 58/43 mm. An enlarged uterus. No involved lymph nodes are observed. Other parenchymal organs do not show signs of deviation. After the surgical intervention Krukenberg tumor was found histologically.

IV. CONCLUSION

The case raises interest because of its atypical clinical presentation starting with only hematuria, which has become an occasion to identify the cause for its occurrence - an advanced Krukenberg tumor complicated with hydronephrosis and hydroureter.

An optimization of the examination protocols is needed in order to reduce patient dose in this very sensitive body area.

V. REFERENCES

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CONFERENCES

THE EUROPEAN CONGRESS OF MEDICAL PHYSICS (ECMP): A BIENNIAL EVENT TO CONNECT MEDICAL PHYSICISTS IN EUROPE AND BEYOND

Prof. John Damilakis

EFOMP President,
President of the 1st ECMP

The European Congress of Medical Physics (ECMP) is a biennial event, rotating among various countries in Europe. The congress is held at the end of August or in September. The 1st ECMP is organized in Athens, September 1-4, 2016.

The ECMP in a nutshell

The ECMP is organized by a Congress Program Committee (CPC) in cooperation with a Local Organizing Committee (LOC). The CPC comprises a Chair and 6 members. The European Federation of Organizations for Medical Physics (EFOMP) designates the chair of the CPC. EFOMP's board nominates 5 members and the host society nominates 1 member. Members nominated by EFOMP who have served 3 times are replaced by EFOMP, unless they become chair. The CPC establishes a Scientific Board to develop the scientific programme and scientific activities of the congress. It is the role of the Scientific Board to select and invite speakers, review and evaluate the papers submitted and inform authors about the decision of the review process. The CPC is responsible for global public relations and communications, industry relations and fundraising at a European level and promotion of the congress through EFOMP channels.

The host national member organization establishes the LOC. The LOC comprises a chair and 6 members. The chair of the LOC is designated by the host society. The host society nominates 5 LOC members and EFOMP nominates 1 member. The LOC is responsible for the choice of the venue, social events, the preparation, printing and distribution of preliminary announcements and flyers for the promotion of the congress, the printing and the distribution of preliminary and final programs and proceedings, registration and hotel accommodation processes and the development and updating of the ECMP website. The LOC is responsible for local/regional fundraising and marketing and local/regional public relations and communications.

The 1st ECMP

The 1st European Congress of Medical Physics (ECMP) will be held in Athens, Greece, September 1-4, 2016. The scientific program of this congress has a number of excited symposia related to the scientific, professional and educational activities of our profession. The program features the latest research in Medical Physics including the physics and technology of diagnostic and interventional radiology, nuclear medicine and radiation therapy. For more information about ECMP please click on https://www.ecmp2016.org/

ECMP's major role in the international Medical Physics community has been to gather colleagues from all over Europe and beyond and to offer them an inspiring environment to define common goals. Their diverse cultural background has been the basis for innovation and vision. The 1st ECMP introduces the initiative entitled 'ECMP welcomes'. The ECMP CPC invites a national Medical Physics society to organize three 90 minute scientific, educational or professional sessions to present facts about Medical Physics in their country and share knowledge and expertise with other European colleagues. This initiative will emphasize the importance of looking beyond national borders, it'll broaden horizons and enhance relationship between European Medical Physics societies. 'ECMP welcomes Italy' at ECMP in Athens. Italy has been selected in order to honor the commitment of Italian medical physicists within the EFOMP. Italian Medical Physics has achieved significant scientific success over the last years and will certainly offer attendees interesting insights. This initiative will be continued and expanded at future congresses.

ECMP provides a unique opportunity for all participants to exchange ideas and share their knowledge and experience. Besides scientific programme, delegates will enjoy sightseeing and archaeological sites in Athens. Early September is an excellent time to come to Greece. Congress participants and accompanying persons will be able to enjoy the sunny weather and beautiful beaches in Attica or take a cruise to the Greek islands before or after the ECMP.

Oct. 17 - 21, 2016 AFROBIOMEDIC 2016 Abuja, Nigeria

1st African Conference on Medical Physics, Biomedical Engineering & Sciences

AFROBIOMEDIC 2016 is the premier inter-disciplinary and international forum for exchange of ideas on all aspects of medical physics, biomedical engineering and sciences as they affect the continent of Africa.

AFROBIOMEDI 2016 is a great academic event organized by the medical physics, biomedical engineering and biomedical sciences communities in Nigeria for the African medical physics, biomedical engineering and sciences and supported by the International Organization for Medical Physics (IOMP) and International Federation for Medical and Biological Engineering (IFMBE). The conference will provide platform to share the latest information on global health challenges, advanced technologies and innovative applications. And it will cover comprehensive areas at the cutting edge of Medical Physics, Biomedical Engineering and Biomedical Sciences as it affects the African region. Several hundreds of participants from all over Africa and the world are expected to attend this conference.

The conference central theme is "Appropriate Biomedical Technology for Africa" and further details about this premier event are on the conference website – www.afrobiomedic2016.org . The conference is to be held at the Nigerian federal capital city of Abuja between 17th and 21st October, 2016.

The organizers of the conference include among others – Federation of African Medical Physics Organizations (FAMPO), African Union of Biomedical Engineering and Sciences (AUBES), Nigerian Association of Medical Physicists (NAMP), Nigeria Society of Biomedical Sciences and Association of Biomedical Engineers and Technologists of Nigeria (NABET).

The conference is also anticipated to be co-sponsored by the American Association of Physicists in Medicine (AAPM), the Medical Physicists Without Borders (MPWB) as well as the International Atomic Energy Agency (IAEA).

The Medical Physics related tracks to be covered include – Global Health and Evidence-based Medicine, Medical Imaging and Devices, Radiation Oncology, Cancer Research and Treatment, Dosimetry and Radiation Protection, Clinical Engineering, Physics and Patient Safety, Education and Professional Activities as well as Gender in Medical Physics, Biomedical Engineering and Sciences.

Taofeeq A. IGE (Ph.D.)
Co-Chair MP
AFROBIOMEDIC 2016 (igetaofeeq@yahoo.com)

The Latin American Congress on Medical Physics (ALFIM) and Argentine Congress of Medical Physics Setting Regional Actions for Medical Physics

Simone Kodlulovich Renha, ALFIM President
Gustavo Sanchez, SAFIM President and President of the 13th SAFIM Congress

We are very pleased to inform that the 7th Latin American Congress on Medical Physics and 13th Argentine Congress of Medical Physics will be held at the Portal del Lago Convention Centre, Villa Carlos Paz, Argentina, September 4-7, 2016. (ALFIM 2016)

Seeking to provide a great and successful scientific event to the medical physicists of our region, the Latin American Association of Medical Physics (ALFIM) and the Argentinean Society of Medical Physics (SAFIM) have joined forces to host this international event.

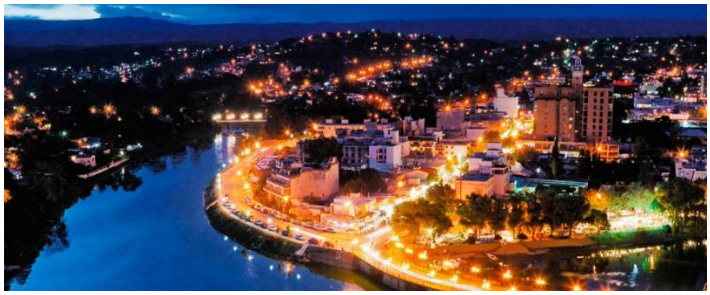
As in the past, this conference, which is the triennial focal event of ALFIM, is aimed at professionals involved in Medical Physics throughout Latin America. In addition to Medical Physicists it is expected to attract other Physicists, Radiation Therapy and Imaging physicians, Technologists and Dosimetrists, Biologists, Regulators, Academics, and other related professionals. The aim is to carry out discussions among all players in the health system and together find solutions for common problems.

The program includes lectures, panel discussions, breakout sessions, refresher courses and workshops in various areas of Medical Physics and it will benefit from the significant participation of national and international guests. (http://www.alfim2016.com/en/)

The Congress offers an exceptional opportunity to showcase the breadth and caliber of medical physics from around the world and it welcomes everyone who is working in these fields or has an interest in them. This event, bringing together the medical physicists of the region enables us to establish new partnerships in scientific projects, it allows sharing experiences that contribute greatly to the development of our work and promote the integration of new medical physicists into the scientific community. In addition to enriching our knowledge, we have the pleasure to meet again our old friends and make many new ones.

To hold this event, the congress organizers have chosen a very pleasant environment. Villa Carlos Paz is a nice town located in the north of the province of Córdoba, right in the heart of Argentina. It is located in the Punilla Valley, on the western slope of the Sierras Chicas and on the southern shore of the San Roque Lake. It is traversed by the San Antonio River, and provides a truly exceptional venue, with accommodations and tourism opportunities nearby. It is a major tourist destination at the national level, favored by its proximity (36 km) to the city of Córdoba, the capital of the province and the second largest city in Argentina.

On behalf of ALFIM and SAFIM, we are pleased to extend our welcome and are looking forward to your unique participation.



UNIVERSITÀ DEGLI STUDI DI TRIESTE

The Abdus Salam International Centre for Theoretical Physics

IAEA

Trieste University Hospital

MASTER'S OF ADVANCED STUDIES IN MEDICAL PHYSICS

2017 – 2018

The Abdus Salam International Centre for Theoretical Physics (ICTP) and the University of Trieste, Italy announce the fourth Master's Programme in Medical Physics (MMP), a two-year training programme in the field of Medical Physics, under the patronage of the Trieste University Hospital.

The programme will be held from 1 January 2017 until 31 December 2018 and will lead to an Advanced Studies Master's Degree in Medical Physics. The first year will be spent in Trieste, Italy, while the second year will be dedicated to clinical professional training in a medical physics department of a hospital in the programme's training network. Courses are held in English.

The Master's Programme is designed to provide young promising graduates in physics or equivalent (mainly from developing countries that are members of the United Nations, UNESCO or IAEA) with post-graduate theoretical and clinical training suitable to be recognised as Clinical Medical Physicists in their countries.

FIRST YEAR PROGRAMME:

Anatomy and physiology as applied to medical physics - Radiobiology - Radiation physics - Radiation dosimetry - Physics of nuclear medicine - Medical physics imaging fundamentals - Physics of diagnostic and interventional radiology (X rays, US, MRI, Hybrid systems) - Physics of radiation oncology - Radiation protection - Information Technology in medical physics - Medical statistics

IN TOTAL 332 HOURS OF LESSONS AND 228 HOURS OF GUIDED EXERCISES

SECOND YEAR PROGRAMME:

Clinical training in radiotherapy, diagnostic and interventional radiology, nuclear medicine and radiation protection in a Medical physics department of a hospital of the clinical network (Italy and other nearby countries)

IN TOTAL 1600 HOURS

The minimum qualification for applicants is a degree equivalent to a M.Sc. in Physics or related fields. Candidates who have received their degree outside Italy must obtain a *"Dichiarazione di Valore"* from the Italian Embassy in their country, testifying that their curriculum studiorum is equivalent to the Italian *"Laurea specialistica"* (12 years of primary and secondary school and a University study allowing to enter in a PhD programme). The selection of candidates will be based on their university performance, research activity and professional experience in the field. Adequate proficiency in the English language is required. The maximum number of students admitted is 30.

A limited number of full or partial scholarships will be awarded to successful candidates from developing countries, thanks to the support of the IAEA, IOMP and ICTP.

More information on the selection procedure and scholarships can be found at:

https://e-applications.ictp.it/applicant/login/2917

To apply online: https://e-applications.ictp.it/applicant/login/2917

Application deadline: 15 May 2016

For more information please visit the programme website: http://www.ictp.it/programmes/mmp.aspx

INFORMATION FOR AUTHORS

PUBLICATION OF DOCTORAL THESIS AND DISSERTATION ABSTRACTS

A special feature of Medical Physics International (on line at www.mpijournal.org) is the publication of thesis and dissertation abstracts for recent graduates, specifically those receiving doctoral degrees in medical physics or closely related fields in 2010 or later. This is an opportunity for recent graduates to inform the global medical physics community about their research and special interests.

Abstracts should be submitted by the author along with a letter/message requesting and giving permission for publication, stating the field of study, the degree that was received, and the date of graduation. The abstracts must be in English and no longer than 2 pages (using the MPI manuscript template) and can include color images and illustrations. The abstract document should contain the thesis title, author's name, and the institution granting the degree.

Complete information on manuscript preparation is available in the INSTRUCTIONS FOR AUTHORS section of the online journal: www.mpijournal.org.

For publication in the next edition abstracts must be submitted not later than /august 1, 2014.

INSTRUCTIONS FOR AUTHORS

The goal of the new IOMP Journal Medical Physics International (http://mpijournal.org) is to publish manuscripts that will enhance medical physics education and professional development on a global basis. There is a special emphasis on general review articles, reports on specific educational methods, programs, and resources. In general, this will be limited to resources that are available at no cost to medical physicists and related professionals in all countries of the world. Information on commercial educational products and services can be published as paid advertisements. Research reports are not published unless the subject is educational methodology or activities relating to professional development. High-quality review articles that are comprehensive and describe significant developments in medical physics and related technology are encouraged. These will become part of a series providing a record of the history and heritage of the medical physics profession.

A special feature of the IOMP MPI Journal will be the publication of thesis and dissertation abstracts for will be the publication of thesis and dissertation abstracts for recent doctoral graduates, specifically those receiving their doctoral degrees in medical physics (or closely related fields) in 2010 or later.

MANUSCRIPT STYLE

Manuscripts shall be in English and submitted in WORD. Either American or British spelling can be used but it must be the same throughout the manuscript. Authors for whom English is not their first language are encouraged to have their manuscripts edited and checked for appropriate grammar and spelling. Manuscripts can be up to 10 journal pages (approximately 8000 words reduced by the space occupied by tables and illustrations) and should include an unstructured abstract of no more than 100 words.

The style should follow the template that can be downloaded from the website at:

http://mpijournal.org/authors_submitapaper.aspx

ILLUSTRATIONS SPECIAL REQUIREMENTS

Illustrations can be inserted into the manuscript for the review process but must be submitted as individual files when a manuscript is accepted for publication.

The use of high-quality color visuals is encouraged. Any published visuals will be available to readers to use in their educational activities without additional approvals.

REFERENCE WEBSITES

Websites that relate to the manuscript topic and are sources for additional supporting information should be included and linked from within the article or as references.

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Only persons who have made substantial contributions to the manuscript or the work described in the manuscript shall be listed as authors. All persons who have contributed to the preparation of the manuscript or the work through technical assistance, writing assistance, financial support shall be listed in an acknowledgements section.

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When they submit a manuscript, whether an article or a letter, authors are responsible for recognizing and disclosing financial and other conflicts of interest that might bias their work. They should acknowledge in the manuscript all financial support for the work and other financial or personal connections to the work.

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Authors considering the development of a manuscript for a Review Article can first submit a brief proposal to the editors. This should include the title, list of authors, an abstract, and other supporting information that is appropriate. After review of the proposal the editors will consider issuing an invitation for a manuscript. When the manuscript is received it will go through the usual peer-review process.

MEDICAL PHYSICS INTERNATIONAL
INSTRUCTION FOR AUTHORS

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[1] Institution/Department, Affiliation, City, Country
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Abstract— **Paper abstract should not exceed 300 words. Detailed instructions for preparing the papers are available to guide the authors during the submission process. The official language is English.**

Keywords— **List maximum 5 keywords, separated by commas.**

I. INTRODUCTION

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

II. DETAILED INSTRUCTIONS

Paper Size: A4

Length: The maximum document size is usually 8 pages. For longer papers please contact the Editor(s).

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

Page Layout: 2 columns layout.

Alignment: Justified.

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

Title: Maximum length – 2 lines. Avoid unusual abbreviations. Font size - 14 point bold, uppercase. Authors' names and affiliations (Institution/Department, City, Country) shall span the entire page.

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

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

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

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

Body Text: Use Roman typeface (10 point regular) throughout. Only if you want to emphasize special parts of the text use *Italics*. Start a new paragraph by indenting it from the left margin by 4 mm (and not by inserting a blank line). Font sizes and styles to be used in the paper are summarized in Table 1.

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

Table 1 Font sizes and styles

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

Figures: Insert figures where appropriate as close as possible to where they are mentioned in the text. If necessary, span them over both columns. Enumerate them consecutively using Arabic numbers and provide a caption for each figure (e.g. Fig. 1, Fig. 2, …). Use font 10 regular for Figure caption, 1st letter, and font 8 regular for the rest of figure caption and figure legend. Place figure legend beneath figures. Indents - 15 point before and 5 point after the captions. Figures are going to be reproduced in color in the electronic versions of the Journal, but may be printed in grayscale or black & white.

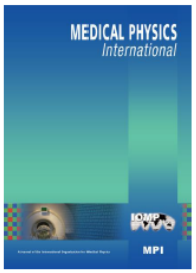

Fig. 1 Medical Physics International Journal

Equations: Write the equation in equation editor. Enumerate equations consecutively using Arabic numbers

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

$$X = A \times e^{at} + 2lkt \quad (2)$$

Items/Bullets: In case you need to itemize parts of your text, use either bullets or numbers, as shown below:

- First item
- Second item

1. Numbered first item
2. Numbered second item

References: Use Arabic numbers in square brackets to number references in such order as they appear in the text. List them in numerical order as presented under the heading 'REFERENCES'. Examples of citations for Journal articles [1], books [2], the Digital Object Identifier (DOI) of the cited literature [3], Proceedings papers [4] and electronic publications [5].

III. CONCLUSIONS

Send your papers only in electronic form. Papers to be submitted prior the deadline. Check the on-line Editorial Process section for more information on Paper Submission and Review process.

ACKNOWLEDGMENT

Format the Acknowledgment headlines without numbering.

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The list of References should only include papers that are cited in the text and that have been published or accepted for publication. Citations in the text should be identified by numbers in square brackets and the list of references at the end of the paper should be numbered according to the order of appearance in the text.

Cited papers that have been accepted for publication should be included in the list of references with the name of the journal and marked as ''in press''. The author is responsible for the accuracy of the references. Journal titles should be abbreviated according to Engineering Index Inc. References with correct punctuation.

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