MEDICAL PHYSICS
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A Journal of the International Organization for Medical Physics

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MPI

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

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WELCOME ADDRESS TO MEDICAL PHYSICS INTERNATIONAL

FROM THE IOMP PRESIDENT

Kin Yin Cheung

Hong Kong SAR, PR China, President IOMP

It is my great pleasure seeing the launching of the official IOMP journal "*Medical Physics International* (MPI)". The idea of establishing its own journal has occasionally been raised within IOMP over the years. It was during the World Congress in Medical Physics and Biomedical Engineering 2012 (WC2012) held in Beijing that the idea was raised at Council. A small task group led by Vice-President, Dr. Slavik Tabakov was established shortly thereafter to explore the feasibility of establishing an international journal.

Through the great efforts in the planning and preparation of Dr. Tabakov and his team members, the Medical Physics International (MPI) is finally off the ground. I would like to congratulate Dr. Tabakov and his team for a job well done. 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. Such a resource of information will be very valuable and important for all IOMP members.

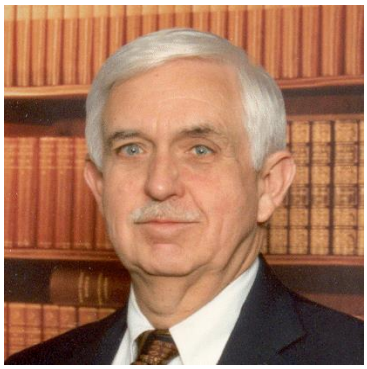
Every medical physicist is welcome to make use of this platform either as an author, a reader or a reviewer and contribute to the advancement of medical physics. Articles published in MPI will be read by 19,000 or more medical physicists practicing in more than 80 countries in different parts of the world. With this large network of readership, the MPI will likely become one of the most popular and reputable journals in our profession. IOMP is charged with the mission "To advance medical physics practice worldwide by disseminating scientific and technical information, fostering the educational and professional development of medical physics and promoting the highest quality medical services for patients." MPI, being an open access journal is one of the initiatives taken by IOMP aiming at accomplishing this mission.

I would like to thank the co-editors, Dr. Slavik Tabakov and Dr. Perry Sprawls and members of the editorial board for the successful launching of MPI and their efforts and commitments in running the journal.

EDITORIAL

Perry Sprawls

Atlanta, USA, Co-Editor Medical Physics International



The medical physics profession is rapidly becoming a connected global community and this journal, Medical Physics International, will be serving as a very active node in that network. There are many issues and activities relating to medical physics that benefit from communicating and sharing. Many other journals and conferences provide for the publication and presentation of research reports and results, and that will not be an activity of this journal.

In principle we will be filling some of the voids especially relating to professional development, education methodology and resources, practical applied physics, and the preservation of our history and heritage.

One of the dynamics that has a major effect on the medical physics profession is the rapid development of both medical imaging and therapeutic technology and methods and the growing deployment in virtually every country in the world.

This is creating a special need for physics education-specifically the physics knowledge and experience to support clinical procedures in both diagnostic imaging and therapy. This is not the physics knowledge recorded in textbooks and provided in traditional medical physics educational programs. It is the knowledge derived from present-day experience with the new technologies and methods.

Medical physicists and our clinical colleagues around the world will benefit when this experience and knowledge is shared. For us as a profession that is not only a challenge but an opportunity.

A specific goal of Medical Physics International is to connect our global community especially with the sharing of experience and educational resources.

EDITORIAL

Slavik D Tabakov

Dept. Medical Engineering and Physics, King's College London, UK, Vice-President IOMP, Co-Editor Medical Physics International

During the last 15 years the number of medical physicists globally increased with some 40%. This is directly linked with the increased attention to medical physics education and training. Alongside with the established education and new training schemes of USA and UK, many other countries opened new educational activities in the field. Following the first International Conference on Medical Physics Education (Budapest 1994) medical physics courses in Europe doubled, especially in Eastern Europe; the rapid development of such courses in Asia is clearly seen in the myriad of regional Conferences; ALFIM in Latin America puts its emphasis in education; IOMP is now helping FAMPO to start a program for professional development in Africa, etc.

Several EU projects, supported also by EFOMP and IOMP, developed new e-learning materials, now used in many countries, as well as the first e-Encyclopaedia of Medical Physics with Multilingual Dictionary of terms, used currently by almost 9000 colleagues per month. The collaboration between IOMP and the publisher Taylor & Francis opened a new book Series in Medical Physics and Biomedical Engineering.

All these activities show a growing emphasis on professional and education activities and this way the creation of the new professional Journal of the IOMP Medical Physics International (MPI) was a logical consequence of this line of events, triggered at the World Congress in Beijing (WC2012).

The quick start of the Journal was possible with the full support of the IOMP Executive Committee and the President Prof. KY Cheung, and with the hard work of the Editorial Board, specially mentioning the web site created by the Technical Editors. The fact that this first issue was compiled only for 3 months shows also the appreciation of the medical physics community.

Medical Physics is a very dynamic profession. Its rapid growth is supported by the need of healthcare, but at the same time this creates tension for the workforce to constantly follow the new developments. MPI Journal will invite educational papers describing new methods and equipment in a way useful for teaching. The educational resources will also include publications from leading Laboratories and industry about their newest developments.

Medical Physics is both innovative and practical profession. A number of very useful methods with direct practical application are being constantly developed. The MPI Journal will present a forum for sharing such expertise, which can also be very useful for the practical training of young medical physicists.

Support for the professional development of existing and new medical physics societies is another MPI focus. The current IOMP achievement in this field – the inclusion of medical physicists in the International Classification for Standard Occupations – is a milestone for the professional recognition in many countries. MPI will share information and provide guidance in the field as well.

Alongside professional and educational information, MPI will also publish PhD abstracts, and Conference proceedings, thus creating an information hub for quick orientation in the leading trends of the profession. The second issue of the MPI will include the abstracts of the International Conference on Medical Physics ICMP2013, Brighton, UK, celebrating the 50th anniversary of the IOMP.

All MPI information will be available free on Internet and we believe that the new Journal will soon become not only the voice of the IOMP, but also a global media for medical physicists.

IOMP

PROFESSIONAL AND EDUCATIONAL ACTIVITIES

BENEFITS TO MEDICAL PHYSICS FROM THE RECENT INCLUSION OF MEDICAL PHYSICISTS IN THE INTERNATIONAL CLASSIFICATION OF STANDARD OCCUPATIONS (ICSO-08)

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Abstract- The occupation of 'Medical Physicist' is explicitly included for the first time in the latest version of the International Standard Classification of Occupations (ISCO-08), published by the International Labour Organisation (ILO), under Unit Group 2111 'Physicists and Astronomers'. Both the structure of the Standard and the background to the inclusion of medical physicists are briefly explained. ILO decided not to classify medical physicists under Sub-major Group 22 'Health Professionals' primarily as classification under Unit Group 2111 best fits the conceptual model of ISCO as the basis of knowledge required for medical physics is physics. However ILO recognises that medical physicists work in health services and this is reflected in the inclusion of two notes, one under Unit Group 2111 stating "…..medical physicists are considered to be an integral part of the health work force alongside those occupations classified in sub-major group 22, Health professionals….." and a second one under Sub-major Group 22 Heath Professionals. The two main benefits of inclusion of medical physicists in the Standard are reviewed – these are the value for the development of medical physics services, particularly in developing countries, of the formal recognition of medical physics as a profession, and in the collection data on the number of physicists in the health services in different countries.

Keywords- medical, physicist, ILO, ISCO- 08, classification.

INTRODUCTION

The International Standard Classification of Occupations (ISCO) is a tool for organizing jobs into clearly defined groups according to the tasks and duties of the jobs. One of its main aims is to provide a basis for international reporting, comparison and exchange of statistical and administrative data about occupations. It is prepared and revised by the International Labour Organization, a United Nations agency [1].

The International Organisation for Medical Physics (IOMP) represents the worldwide medical physics community and has as one of its objectives the advancement healthcare by the adequate provision of medical physics services [2]. Whilst not a primary purpose, ISCO is used by some governments and employers to determine the status and other factors, such as salaries, of a particular occupational group. The inclusion of the occupation 'medical physicist' in ISCO, included in the latest version of the classification for the first time, is of significance to the profession of medical physics, particularly in some countries where the medical physicist profession is not formally recognized by either the government or health authorities.

ILO AND ISCO-08

The International Labour Organization (ILO) has a tripartite structure bringing together representatives of governments, employers and workers [1]. The ILO Department of Statistics to provide users within and outside the ILO with relevant, timely and reliable labour statistics, to develop international standards for better measurement of labour issues and enhanced international comparability, and to help member States develop and improve their labour statistics.

The ILO is custodian of the International Standard Classification of Occupations (ISCO) and responsible for its maintenance, updating and revision [3]. ISCO is a tool for organizing jobs into a clearly defined set of groups according to the tasks and duties undertaken in the job. Its main aims are to provide:

- a basis for the international reporting, comparison and exchange of statistical and administrative data about occupations;
- a model for the development of national and regional classifications of occupations; and
- a system that can be used directly in countries that have not developed their own national classifications.

The International Standard Classification of Occupations 2008 (ISCO-08) is the latest version of the classification and it is a four-level hierarchically structured classification that covers all jobs in the world. ISCO-08 is fully supported by the international community as an accepted standard for international labour statistics [3]. It allows the production of relatively detailed internationally comparable data. Many countries are now updating their national classification either based on ISCO-08 or to improve alignment with the new international statistical standard.

ISCO-08 classifies jobs into 436 unit groups. These unit groups are aggregated into 130 minor groups, 43 sub-major groups and 10 major groups, based on their similarity in terms of the skill level and skill specialization required for the jobs[3].

The main groups of interest to the medical physics are illustrated in Figure 1. Major Group 2 'Professionals' is divided into 6 sub-major groups, two of which are 'Science and Engineering Professionals' and 'Health Professionals'. The former has as one of its minor groups 'Physical and Earth Sciences Professionals which in turn has 'Physicists and Astronomers' as a unit group. 'Health Professionals' has as one minor unit 'Other Health Professionals', which itself has 'Health Professionals Not Elsewhere Classified' elsewhere as one of its unit groups.

The framework of ISCO is based on two main concepts – *job* and *skill*. A job is 'a set of tasks and duties performed …by one person..'. *Occupation* refers to the kind of work performed in a job. Skill is defined as the ability to carry out the tasks and duties of a given job and two dimensions of skill are used to arrange occupations into groups. These are skill level and skill specialization and one of the measures of skill level is the level of formal education. Four broad skill levels are a used in ISCO-08 and Major Group 2 contains only occupations at the highest ISCO skill level – skill level 4[3].

BACKGROUND TO INCLUSION OF MEDICAL PHYSICISTS IN ISCO-08

The classification system is infrequently updated – approximately every 20 years; the previous one being in 1988 (ISCO-88) which did not include any mention of medical physicists or medical physics. In 1995 the President of International Organization for Medical Physics (IOMP), Keith Boddy, formally wrote to ILO requesting the specific inclusion of medical physics as profession in the next revision ISCO [4]. Over the next two decades officers of IOMP, together with other individuals and organisations, engaged in dialogue with ILO [5-8]. ILO twice consulted member countries. After the first consultation ILO concluded that medical physicists were not sufficiently numerous to justify a separate unit group.

The second consultation focused on where medical physics should be included in the classification and responses were equally divided between including medical physics under 'Physicists and Astronomers' and under 'Health Professionals'. IOMP, and others, proposed that medical physicists should be classified under 'Health Professionals [5, 7] and in the classification system of a number of countries medical physicists have been classified under 'Health Professionals' [8].The ILO finally decided in favour of classification under 'Physicists and Astronomers' for the following two main reasons [9]:

- Since the basis of knowledge required for medical physics is physics, it is consistent with the ISCO conceptual model to include them in the same Unit group as other physicists.
- The view that medical physicists should be classified as health professionals because they work in the health system was not accepted as ISCO is not a classification of industrial activities.

Following further discussions involving IOMP two notes were added to ISCO-08 clarifying the position of medical physicists in relation other health professions and the list of tasks under 'Physicists and Astronomers' was extended and modified to include tasks typically undertaken by medical physicists [3].

THE INCLUSION OF MEDICAL PHYSICISTS IN ISCO-08

'Medical physicist' is classified in ISCO-08 as an example of an occupation which comes under unit group 2111 'Physicists and Astronomers'. Medical physicists are also listed in Volume 2 of ISCO-08 'Index of occupational titles' [10]. The list of tasks undertaken by 'Physicists and Astronomers' include tasks undertaken by medical physicists, such as *'ensuring the safe and effective delivery of radiation (ionising and non-ionising) to patients to achieve a diagnostic or therapeutic result as prescribed by a medical practitioner',* as well as the more general tasks undertaken by many different physics professions, including '*conducting research and improving or developing concepts, theories, instrumentation, software and operational methods related to physics and astronomy*. Appendix 1 reproduces the full text of this unit group [11].

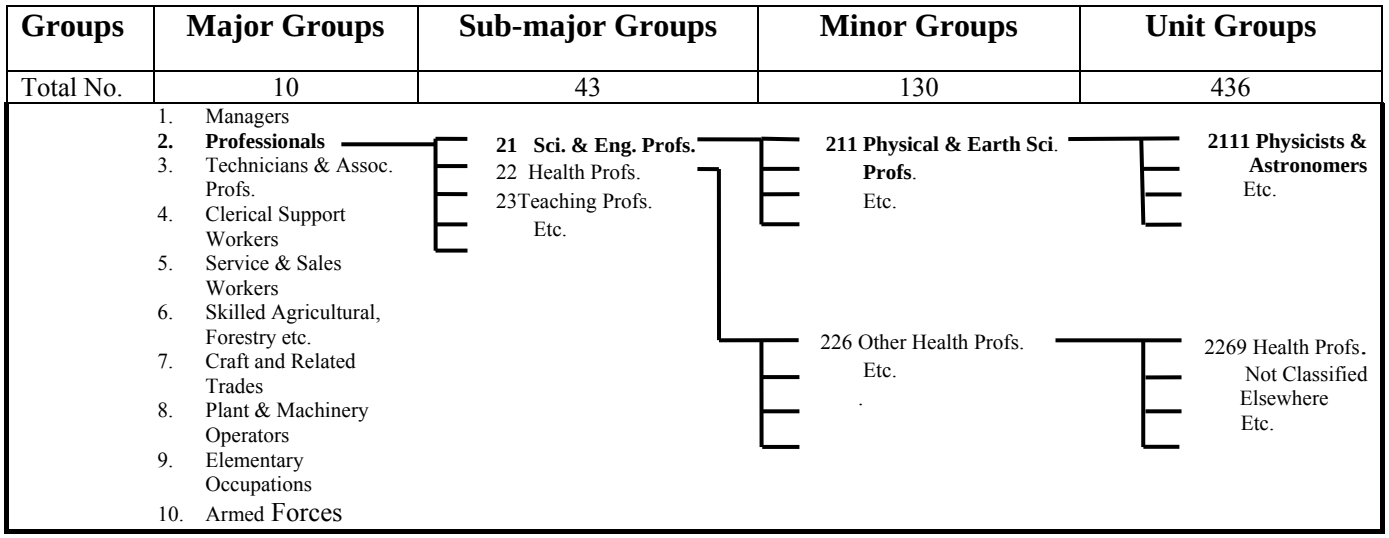

Figure1. Illustration of structure of ISCO-08 and specific groups relevant to medical physics

As noted there were discussions as to whether medical physicists should be included under sub-major group 'Health Professionals'. To recognize that medical physicists work in health care and alongside other professions classified under 'Health Professionals' the ISCO-08 has a note at the end of unit group 2111 'Physicists and Astronomers' which includes the statement '*…medical physicists are considered to be an integral part of the health work force alongside those occupations classified in sub-major group22, Health professionals..*'.See Appendix 1 for full text. This is reinforced by a note under sub-major group 22 'Health Professionals' which states *'In using ISCO in applications that seek to identify, describe or measure the health work force, it should be noted that a number of professions considered to be a part of the health work force are classified in groups other than sub-major group 22, Health professionals. Such occupations include but are not restricted to: addictions counsellors, biomedical engineers, clinical psychologists and medical physicists.'*[11].

BENEFITS OF INCLUSION OF MEDICAL PHYSICISTS IN ISCO-08

The inclusion of medical physicists in ISCO-08 achieves the original objective of the International Organization for Medical Physics and others in confirming the status of medical physics as a profession alongside other health professions such as medical doctors. In some countries specific jobs are opened only if the profession exists in ISCO [5].Ministries of Health, health employers, medical physics organizations, and individual medical physicists can refer to ISCO-08 to ensure medical physicists are correctly classified and accorded the appropriate recognition, status and salary. A related benefit is that the recognition of medical physicists should assist in ensuring the correct staffing of medical physicists when establishing new healthcare infrastructure, particularly in developing countries.

A benefit from inclusion of medical physicists under Unit Group 2111 'Physicists and Astronomers' is the collection of data on employment of medical physicists in healthcare. If medical physicists had been classified under '226 Other Health Professionals' then only the total

number of 'Other Health Professionals' would be recorded. Their inclusion in group 2111 allows them to be identifiable in data cross-tabulated by occupation and administrative data on the health service work force using ISCO-08, as there are no other professionals classified under group 2111 who are employed in healthcare.

DISCUSSION

The IOMP argued over many years that medical physicists should be classified under 'Health Professionals [5, 7]. However the disadvantages of classifying medical physicists Sub-major Group 21 'Science and Engineering Professionals' have been considerably mitigated by the inclusion of tasks specific to medical physics in the overall list of tasks of physicists and astronomers and also by the notes under both groups 2111 'Physicists and Astronomers' and 226 'Other Health Professionals' emphasising that medical physicists are integral part of the healthcare workforce alongside other healthcare professionals [13].

Biomedical engineers are treated in a similar fashion to medical physicists in ISCO-08, listed as one of the occupations classified under Unit Group 2149 'Engineering Professionals not Classified Elsewhere'. Neither group is likely to attain sufficient size to be considered as a separate unit group on its own. It should be noted that medical physics technicians and biomedical engineering technicians (and similar occupations) that do not meet the classification requirements for medical physicists and biomedical engineers will normally be classified under Major Group 3 'Technicians and Associated Professionals'. Also medical physicists and biomedical engineers employed by universities will be classified under Minor Group 231 'University and Higher Education Teachers'. A separate unit group including medical physicists, biomedical engineers and other comparable healthcare professions, such as physiological scientists and biochemists, might achieve the requisite size and a case prepared, if considered desirable by the professions involved, for inclusion of such a group as a new unit group under Sub-major Group 22 'Health Professionals' and submitted to ILO.

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APPENDIX 1

2111 PHYSICISTS AND ASTRONOMERS

Physicists and astronomers conduct research and improve or develop concepts, theories and operational methods concerning matter, space, time, energy, forces and fields and the interrelationship between these physical phenomena. They apply scientific knowledge relating to physics and astronomy in industrial, medical, military or other fields.

Tasks include -

(a) conducting research and improving or developing concepts, theories, instrumentation, software and operational methods related to physics and astronomy;

(b) conducting experiments, tests and analyses on the structure and properties of matter in fields such as mechanics, thermodynamics, electronics, communications, power generation and distribution, aerodynamics, optics and lasers, remote sensing, medicine, sonics, magnetism, and nuclear physics;

(c) evaluating results of investigations and experiments and expressing conclusions, mainly using mathematical techniques and models;

(d) applying principles, techniques and processes to develop or improve industrial, medical, military and other practical applications of the principles and techniques of physics or astronomy;

(e) ensuring the safe and effective delivery of radiation (ionising and non-ionising) to patients to achieve a diagnostic or therapeutic result as prescribed by a medical practitioner;

(f) ensuring the accurate measurement and characterization of physical quantities used in medical applications;

(g) testing, commissioning and evaluating equipment used in applications such as imaging, medical treatment and dosimetry;

(h) advising and consulting with medical practitioners and other health care professionals in optimizing the balance between the beneficial and deleterious effects of radiation;

(i) observing, analysing and interpreting celestial phenomena and developing methods, numerical models and techniques to extend knowledge of fields such as navigation, satellite communication, space exploration, celestial bodies and cosmic radiation;

(j) developing, implementing and maintaining standards and protocols for the measurement of physical phenomena and for the use of nuclear technology in industrial and medical applications;

(k) preparing scientific papers and reports.

Examples of the occupations classified here:

- Astronomer
- Medical Physicist
- Nuclear Physicist
- Physicist

Some related occupations classified elsewhere:

- Specialist physician (nuclear medicine) - 2212
- Radiation oncologist - 2212
- Radiologist - 2212
- Radiographer - 3211

Notes

It should be noted that, while they are appropriately classified in this unit group with other physicists, medical physicists are considered to be an integral part of the health work force alongside those occupations classified in sub-major group 22, Health Professionals and others classified in a number of other unit groups in major group 2, Professionals.

IOMP MODEL CURRICULUM FOR POSTGRADUATE (MSc-LEVEL) EDUCATION PROGRAMME ON MEDICAL PHYSICS

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Abstract— The IOMP project for Model Curriculum for Medical Physics Education was completed in 2012. It aims to present guidance on the organisation of post-graduate (MSc level) courses. The project presents several models for this: modular, distributed, mixed, topical and e-Learning. The advantages/disadvantages of these models are discussed from the point of view of specificity in the country. The project also suggests topics for the Curriculum and indicative percentage of these, as well as introduces criteria and method for IOMP Validation of MSc courses in Medical Physics..

Keywords— Education, MSc Curriculum in Medical Physics, Accreditation of MSc courses.

INTRODUCTION

The expansion of Medical Physics as a profession requires dedicated academic programs for the education and training of the young colleagues. At this time many countries do not have guidance on how to develop their education programmes. The experience in other countries provides the foundation for a project to produce a very useful Guide for development of new programs.

The Model Curriculum (Model Teaching programme) project was a spin off activity of the World Conference on Physics and Sustainable Development (November 2005, Durban, South Africa). It was supported both by the IUPAP (International Union of Pure and Applied Physics) and the IOMP (International Organization for Medical Physics). The project was discussed at the IOMP Education and Training Committee (ETC, 2006) and resulted in the formation of Work Group of experts (the authors of the article), which had a meeting during the EMITEL Conference in ICTP, Trieste, October 2008 and a number of Internet discussions. Being all active educators, the authors gathered expertise from countries with advanced Medical Physics education, as well as from countries which successfully developed their current education on this subject. This paper presents an overview of the main issues addressed by the Model Curriculum project. These include:

- Overall number of classroom contact and self-reading hours;
- MSc project and thesis;
- Structure of the Curriculum and Models of content delivery;
- Entry requirements and students' assessment;
- Principles of validation of courses/programs;
- Indicative content of the Curriculum.

OVERALL NUMBER OF CONTACT AND SELF-READING HOURS

Medical Physics education is usually provided at the Master level (final University year). In general, the total number of learning hours associated with a postgraduate (MSc-level) educational programme (also called University MSc course) include:

- Contact hours (lectures, seminars, tutorial, labs and practical exercises);
- Self-study hours (reading specified books an web-based resources and preparation for course works / exams);
- MSc project related hours (including the research and the writing of the MSc thesis)

The total number of contact hours (lectures, seminars and labs) in a postgraduate (MSc-level) education programme can vary according to the local University requirements and the level of self-reading requested by students. There are two educational models representing the approximate lower and upper limits of contact hours.

In case of high self-reading expectation, the overall contact hours could be of the order of 300 – 400 hours. However in this case each lecture hour has to be complemented by at least 2 hours additional self study (depending on the difficulty of the subject). This model requires the existence of a good reference list and the

availability of a library with the necessary resources, either in print or online. To satisfy the simultaneous study of at least half of the student group (at a time). This model also requires good student testing during the delivery of education.

At the other extreme (when minimal self-study is expected) the overall contact hours could be of the order of 800-900 hours. This model is useful for Regions or Universities, where the libraries are not rich in resources, and most of the information is expected to be delivered during the lectures and labs. In this model the main resource which students have for preparation for exams is their lecture notes.

When distributing the contact hours, one needs to build a good proportion for labs and other practical hours. Their proportion could be estimated as ¼ of all contact hours.

It should be emphasised, that contrary to some other University courses, attendance to Medical Physics lectures should be regarded as essential, and coursework delivery as obligatory. These requirements are very important for our dynamic profession, where books and other sources become out of date quickly.

As a rough estimate, the sum of class contact and self-reading hours of an MSc programme in Medical Physics would be around 1100-1300 (including time for the examination and feedback tutorials).

MSC PROJECT AND THESIS

The MSc project (or Diploma work) and related thesis is of great importance for the assessment of students' ability to apply the acquired knowledge into practice. This research element of the education element should follow the above-described taught element. The nature of Medical Physics education allows for minimal overlap between these two elements and the MSc projects should follow after the completion of the educational modules. It would be advisable the subject of the MSc project to be linked to a real practical problem.

The volume of the MSc thesis is often given as around 15000 words, but this should not be a strict requirement, as different theses would produce results which would include elements which can not be measured this way (for example programming, drawings, etc.). However the thesis is expected to be "publication-like" – i.e. including all major elements of a typical research paper: Introduction; Literature search; Materials and Methods; Results; Discussion; Conclusion; Reference list.

The difficulty of the project should be related to the approximate time, which the student is expected to devote to it. In many Universities this time is around 500-700 hours.

This MSc project time, added to the time for contact and self-reading above, would give an indicative overall length of the postgraduate (MSc-level) education programme of approximately 1700-1900 hours. Again, variations related to local requirements could significantly change this figure. Normally this length would be delivered either within one-two academic year (full time studies) or in two-three academic years (part time studies). Some local regulations could require longer study time - e.g. 2 years for full time MSc programme. Similarly the taught element of the full-time programme could be extended over 1 whole year, and the MSc project could be developed over the second year (during which the student can have also some exposure to the real practice of the profession). Respectively such delivery of the programme could extend the Part-time delivery and completion up to 4 years.

STRUCTURE OF THE CURRICULUM AND MODEL OF TEACHING DELIVERY

The MSc programme could be delivered either as a condensed full-time academic activity (most often over one year), or as a distributed part-time academic activity (most often over two years). Its organisation should be based on a progressive structure, as many of the topics require background from other previous topics. From this point of view a very suitable model for Medical Physics Education is the modular model. One module is a finite element of the studies, with separate assessment (for example Radiation Protection Module). Its length varies, but is often 30-40 contact hours.

In this model each subject from the educational structure is delivered in a condensed period of time (over 1-2 weeks). The model is very effective in regions, where the concentration of lecturers is not sufficient. The model allows for various lecturers to be called from other Universities (or cities and countries). The disadvantage of this model is related to the fact that when students miss certain element (due to illness, or other reason) they would have great difficulty to be in pace with the group.

A variation of the modular model is distributed delivery of lectures on different subjects, while keeping the logical link between them. This model is more convenient for the students, but puts great pressure on the organisation, as a missing lecture (due to lecturer's illness or other reason) could disrupt the logical line of knowledge delivery.

Perhaps a suitable balance between these two possibilities provides a good solution, which is used in a number of Universities. This balance could be based on mainly distributed delivery of the basic topics (for which one University could find local lecturers) and fully modular

delivery of the special topics (what would require invited external faculty of lecturers).

Obviously this method of delivery must be based on grouping the subjects (modules) in two main categories – general topics (which all students will study) and topical modules (from which the student will select a limited number, depending on their interest). Later an example model for a curriculum with its modules is described.

Other organizations of the delivery (by subject) are also possible - for example – Imaging group of modules, which would form a package including the physics principles, the medical application, the relevant equipment and its method of operations, various measurements and safety issues, etc. This however is very difficult to be applied in a small country, where the lecturers are often scattered in various cities and institutions. The advantage of this organisation is related to the better learning and examination of students. This method of delivery is suitable for a large (and rich) University, which can afford to organise solely an MSc programme in Medical Physics (and even such University would need a number of honorary lecturers).

In most other cases the University issuing the degree must have agreements with other Universities (where some lecturers work and/or suitable laboratories exist). These inter-university agreements are vital for the organisation of MSc courses in small countries. A model suitable for smaller countries (and Universities) is collecting a faculty of lecturers (from other cities or countries) and maintaining a local Education Centre (which in principle could be not just for one country, but for a whole region). This model can have variations.

One variation could be all students to be registered at their own University (which can be different from the University hosting the Education Centre) and attend all optional lectures at this Centre (which in this case is the meeting point of students and lecturers). In this case the Centre should have honorary contracts with the host University. It is assumed that the students could attend the basic lectures at their own University. When the students complete the taught element of the programme they could develop their MSc project in their own University, and graduate from it. This model is cost-effective, but will depend heavily on the inter-university agreements (between the hosting University and the other Universities sending students to it).

Alternatively, the students can register with the University, where the Centre is established, complete all taught element there (basic and optional modules), then develop their MSc project in the Education Centre and graduate from the host University. This education delivery requires good investment in the foundation of the Centre (for equipment, laboratories, teaching room, etc). Its advantage is that in this case all teaching and research are in the host University (assuming the countries sending students have educational agreement with the host country). A plus of this mod-el is that with time the host University will have a number of its own graduates to take part in the education process, what in future would decrease the cost for invited faculty.

ON-LINE STUDIES

The number of students following on-line courses and other e-Learning initiatives increased over the past 10 years. Most authors support blended delivery of e-Learning and classical learning [7, 8]. Contemporary web technology (e.g. Skype) allows for direct lecturing from distance, supported with specific on-line materials. Own development of bespoke e-Learning materials is very expensive, however a number of suitable and well used such materials exists on Internet [e.g. 9, 10, 11]. Their use however has to be specified in the Programme description/handbook. In such case the home University (offering e-Learning degree) has to agree on the use of these materials (blended with their own education) and has to consider inclusion of on-line teachers in the Programme Faculty of the MSc course (if appropriate). e-Learning is most suitable for remote areas, but its delivery without contact with real practising lecturers is not recommended. The best results of e-Learning are usually for further education of junior specialists, who already work in Medical Physics Departments as technicians, or similar. This way they have the necessary contact with the profession, as well as supervisors for their MSc projects.

ENTRY REQUIREMENTS

A normal entry requirement would be undergraduate degree (BSc-level) in Physics, Engineering or other relevant subject (based on minimum 3 years University education). The variation of undergraduate programmes and courses is enormous and the entry level should be decided for every single case. When this level is doubtful, an extra preparatory period (approximately one term) could be added. During this period the student will have to pass additional elements on Physics, Research methods and Human Physiology&Anatomy. If such model is used, we could expect that the Full Time delivery would extend over minimum of 2 years (e.g. 1/2 year preparatory + one year taught element + ½ year research project). Such education course could build very sound educational base and could include elements of further practical training (what

otherwise would be difficult to organise as a separate activity).

Due to the variety of University undergraduate programmes, it is not possible to advice on specific entry requirements. Selecting students with an interview is always advisable, as this way the selecting panel could agree on the acceptable entry level, type of questions, etc.

STUDENTS' ASSESSMENT

As usual standard written exams (2 to 3 hours exam writing time) are required for passing the educational modules. The percentage which the exam mark takes from the overall module mark is advisable to vary between 60 and 80%. This way the remaining 40-20% are for course work to assess the progressive build-up of Medical Physics knowledge (coursework in a form of essay on a subject, small design project, a set of tasks, etc given and assessed during the semester). The dynamics of our profession and the structure of knowledge does not allow for missing coursework (or any other type of home work). This work should be structured to be answerable in approx. 8 hours (by an average student). The course work has to be assessed and feedback given to the students before the exam.

Due to the relative difficulty of the Medical Physics exams, it is advisable for these to be distributed in two exam sessions (after each substantial term). At least 3 days revision time should be given in-between exams. In case of modular delivery the exam could follow directly the end of the module. It is a good practice for the exam questions to be confidentially agreed not only by the respective lecturers, but also by an External Examiner, who is from another University (or at least is not involved in the course delivery).

The pass mark of each module is to be decided by the University, but it should not be below 40% (assuming 100% is the maximum mark) for each element of the assessment - written exam and course work. Many Universities require for the minimal sum pass mark to be 50% and the written exam to be assessed by two examiners.

Assessment of the MSc thesis (or Diploma work) includes normally an oral exam (viva voce), where the student has to defend his/her project/hypothesis and answers the questions of the examiners. The number of examiners in the panel can vary according to local requirement. Normally the pass mark for MSc thesis is 50%. This mark should include approx 70-80% from the theses assessment and 30-20% from the actual oral exam presentation. A good practice can be introducing an Interim MSc exam (approx. 1 month after the beginning of the MSc research work), where the student presents his/her idea, initial literature search, expected results and working plan. This Interim exam can be assessed with 10% from the total MSc thesis mark, but could give an early feedback to the student for the development of his/her re-search and could prepare him for the final oral examination.

SUGGESTION FOR THE MODULES OF THE PROGRAMME

The syllabi of modules of the Model Curriculum include the main components necessary for initiating practice in the profession. However due to the dynamic development and expansion of the profession these have to be regularly updated. The Model Curriculum is based on a number of publications, collected over the last 15 years at special Conferences, Workshops and Seminars [1-8].

Based on these an indicative suggestion for the main modules in a MSc-level programme in Medical Physics (plus their % of contact hours) can be presented as:

Basic modules:
Basis of Human Physiology and Anatomy ~10%
Basis of Radiation Physics ~10%
Research Methods ~10%
Radiation Protection and Hospital Safety ~10%

Topical modules:
Medical Imaging Physics and Equipment 1 ~10%
(non-ionizing radiation - MRI, Ultrasound)
Medical Imaging Physics and Equipment 2 ~10%
(ionizing radiation – X-ray, Nuclear Medicine)
Radiotherapy Physics and Equipment ~15%
Other optional modules could also be included.

MSc project work ~ 25%

INDICATIVE OUTLINE OF THE SYLLABI OF THE MODULES

Basic modules

Basis of Human Physiology and Anatomy ~10%

This module aim is to give to students background for their further studies and to help them in their future work with medical colleagues. From this point of view it is advisable for this module to be placed at the beginning of the teaching programme. It could have internal structure based on sub-modules (approx. 2 to 4 hours each), according to the main systems in the body (with emphasis on physiology). In principle it can be delivered as 5 to 8

days full time module. The lecturer(s) could use one of the many existing textbooks on the subject (suitable adapted medical physicists). For example a suitable book could be "Introduction to the Human Body" by Tortora and Grabowski.

Basis of Radiation Physics ~10%

This module aims are to provide suitable background of the basic physics of the ionising and non-ionising radiations used for medical diagnostic or therapeutic purposes. The module will need some initial reminder of the radiation concept; fields and photons; the origin of different types of ionising radiation; the interactions of radiation with living organisms. The module may follow elements of existing Physics education, but has to include laboratories on Radiation measurement and has to include more detail about:

- Photon interactions: Elastic scattering, Rayleigh scattering, Compton scattering, photo-electric absorption, pair production. Interaction cross sections, and dependence on energy and atomic number. Absorption and attenuation coefficients.
- Particle interactions : Interaction of charged particles with matter; Electron-electron collisions, delta rays, polarisation effect, radiative losses; Heavy charged particles, Bragg peak. Stopping power and dependence on energy, atomic number, density.

Elastic scattering. Range.

- Radiation measurements: Concepts of fluence, absorbed dose, exposure, kerma.

Methods of radiation detection: gas detectors, scintillation detectors, semiconductor detectors, thermoluminescence detectors, photographic film.

- Ultrasound: Acoustic propagation and interaction. Pulses and diffraction. The pulse-echo principle. Doppler effect. Acoustic properties of human tissues. Transducers.
- Electromagnetic radiation: Sources of radiation, interaction, hazards and medical applications for each: Lasers, Radiofrequency, Microwave, Infra-Red, Visible and Ultra-Violet.

Research Methods ~10%

The aim of this module is to introduce the basic principles of research methodology, related project planning and ethical issues; the practical applications of modern data processing in medicine (medical signals and image processing), including statistical techniques relevant to medical data. The module may include also study/application of relevant software (e.g. MatLab, SPSS, etc). The module may follow elements of existing Signal/Image Processing education and has to include more detail about:

- One dimensional signal processing : Sampling: Nyquist, aliasing, quantization;

Spectral analysis: DFT, FFT, Hilbert, Hartley, Hough; Correlation and Convolution;

Various Filtering methods.

- Two dimensional signal processing: Image perception and quality, Spatial frequencies; Image Enhancement and Restoration: Point operations, Pixel group processing, Global operations, etc; Image analysis: Segmentation, Morphological processing, Feature extraction, etc; Image compression; Foundation of backprojection reconstruction; Image transfer and archiving systems.
- Statistical methods: Frequency distribution and summary measures; Sampling distribution; Hypothesis testing; Analysis of variance; Basis of Time series; Regression.

Radiation Protection and Hospital Safety ~10%

This module aims to provide the theoretical background of the radiological protection requirements (ionising and non-ionising radiation), as well as fundamentals of general hospital safety. The module may follow existing national methods for Risk assessment and has to include more detail about:

- Biological effects of ionising radiation; Dose response – relationships and factors affecting dose response; Quantities used in protection: Quality Factor, Equivalent Dose, Effective Dose; Background radiation; Organisations concerned with radiation protection (e.g. ICRP, IAEA, etc); Framework for radiation protection; Development of recommendations; National legislation concerning medical use of radiation; Personnel monitoring; Dose control for patients; Strategies for patient dose reduction.
- Ultra-Violet radiation: Biological effects, Measurement, Maximum Permissible Exposure; Monitoring and protection
- Microwaves and Radiofrequency (including MRI): Classification, Biological effects, Measurement, Maximum Permissible Exposure; Monitoring and protection.
- Lasers: Types of lasers and classification of hazard, Biological effects; Measurement, Maximum Permissible Exposure, Monitoring and protection.
- Ultrasound: Classification, Biological effects, Monitoring and protection.

Topical modules:

Medical Imaging Physics and Equipment 1 ~10%
(non-ionizing radiation - MRI, Ultrasound)

This module aims to educate students in the physics of medical imaging with non-ionizing radiation (MRI and Ultrasound). Due to the rapid development of these imaging modalities (especially MRI) the module is expected to adapt

regularly to the progress in these fields. The main parts of this module have to include more detail about:

- Magnetic Resonance Imaging

Physics of MRI; MRI Instrumentation; K-space; Different MR imaging methods; Pulse sequences; MR Contrast and Image quality; Health and Safety; MR Spectroscopy; Flow imaging; Perfusion, Diffusion and Functional MRI; Three dimensional reconstruction; Clinical applications of MRI; Image artefacts; Inter-relationship between medical imaging techniques.

- Ultrasound Imaging

US wave motion and propagation; Acoustic properties of biological media; Acoustic radiation fields; Safety measures; Transducers; A-mode; B-scanning; Doppler Ultrasound; Image artefacts; Blood flow measurements; Measurement of acoustic power; Clinical applications of US imaging; Image artefacts; Inter-relationship between medical imaging techniques.

Medical Imaging Physics and Equipment 2 ~10% (ionizing radiation – X-ray, Nuclear Medicine)

This module aims to educate students in the physics of medical imaging with ionising radiation (X-ray and Nuclear Medicine Imaging). Due to the rapid development of these imaging modalities the module is expected to adapt regularly to the progress in these fields. The main parts of this module have to include more detail about:

- Diagnostic Radiology

X-rays production and equipment; Interaction of X-rays with matter; Radiological image quality; X-ray detectors: Film, Image Intensifier, Storage phosphor, Flat panel; Scatter radiation and filtering; X-Ray Computed Tomography; Scanner configurations; Reconstruction types; CT image display, windowing, CT numbers; X-ray patient dosimetry and protection; Optimization techniques; Clinical applications; Image artefacts; Inter-relationship between medical imaging techniques.

- Nuclear Medicine Imaging

Radionuclides and production of Radiopharmaceuticals; Disease-specific radiopharmaceuticals; Radiation protection in Nuclear Medicine; Image quality and noise; Nuclear Medicine instrumentation and quality control: Gamma camera, SPECT, PET, SPECT/PET-CT, etc; Optimization techniques; General imaging principles, cardiac imaging, multigated studies, first pass studies, renal studies, modelling; Image artefacts; Inter-relationship between medical imaging techniques.

Radiotherapy Physics and Equipment ~15%

This module aims to provides the necessary background for the support of Radiotherapy Physics activities. Due to the rapid development of this field the module is expected to adapt regularly to the Radiotherapy progress. The main parts of this module have to include more detail about:

Interaction of radiation with tissues; Radiobiology in Radiotherapy; Radiotherapy dosimetry; External beam radiation and treatment planning; Megavoltage Linear Accelerator; Radiobiology in Radiotherapy; Radiotherapy with particle beams; Brachytherpay: High dose rate (HDR) treatments; Low dose rate (LDR) permanent implants; Beam models and planning tools; Treatment room design, machine commissioning and networking; Imaging in Radiotherapy; Quality management in Radiotherapy; Principles of Clinical application.

VALIDATION OF THE PROGRAMME

Usually a small country will have no experience in setting and accrediting a suitable post-graduate programme (course) in Medical Physics. Validating the programme by an experienced body will assure the local University (or Ministry of Education) that this programme is in line with the international standards. Additionally, the fact that the MSc graduates will work in Hospital environment (indirectly involved with patient health), makes the external validation an important element of the educational process.

IOMP has significant expertise allowing the provision of validation of such post-graduate programmes in Medical Physics and has set up of a special Validation and Accreditation Panel (VAP) of experts to the ETC Committee. This Panel (or sub-committee) could not only assess and validate the programmes, but could also provide External Examiners and suggest suitable lecturers. The activities, terms and internal rules of the VAP are still in discussion. It is expected Validation activities of the IOMP to be implemented during the period 2011-2012. These will include: Validation requirements; Application Form, Validation Procedure and Validation Certificate (all to be found at the IOMP web site at implementation stage).

CONCLUSION

The project for Medical Physics Model Curriculum, was developed by leading specialists and approved by the IOMP ETC. It presents a background for initiation of new MSc courses. Part of the project has been used in the new IAEA Project Post-graduate medical physics academic programmes

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2006-2009

Dr Anchali Krisanachinda, Thailand, Chair; Dr Cornelius Lewis, UK, Secretary; Dr HJ Kim, S Korea; Dr C.M. Pathak, India; Dr Ana Cecilia Pedrosa de Azevedo, Brazil

Dr William Rae, S Africa; Dr Adel Mustafa, USA

Validation& Accreditation Panel: Dr Slavik Tabakov, UK, Chair; Dr Ervin Podgorsak, Canada; Dr Anchali Krisanachinda, Thailand; Dr Cornelius Lewis, UK; Dr Perry Sprawls, USA

2009-2012

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Validation& Accreditation Panel: same as in 2006-09

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ACCREDITATION OF MEDICAL PHYSICS EDUCATIONAL PROGRAMS IN NORTH AMERICA

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Abstract- The purpose of this paper is to provide the reader with a description of the accreditation process for medical physics educational programs in North America by the Commission on Accreditation of Medical Physics Educational Programs (CAMPEP). Forty graduate programs and 65 residency programs are currently accredited. Programs desiring accreditation must prepare a Self-Study document, which is reviewed by an appropriate CAMPEP Review Committee. Following approval of the Self-Study, a site visit team visits the program and prepares a recommendation to the Review Committee. After discussion and vote by the Review Committee, the documentation is forwarded to the Board of Directors for final approval. Accreditation is for up to five years and is renewable. The introduction of the accreditation process has resulted in an increase in the passing rate in the American Board of Radiology certification examinations for candidates completing accredited educational programs.

Running title - Accreditation of North American medical physics programs

Keywords- accreditation, education, medical physics

INTRODUCTION

Accreditation is defined as "a process whereby a professional association or nongovernmental agency grants recognition to a school or health care institution for demonstrated ability to meet predetermined criteria for established standards." [1] In North America, medical physics graduate programs, residency programs, and continuing education programs are accredited by the Commission on Accreditation of Medical Physics Educational Programs (CAMPEP). The stated mission of CAMPEP is "to promote consistent quality education of medical physicists by evaluating and accrediting Graduate, Residency and Continuing Education programs that meet high standards established by CAMPEP in collaboration with its sponsoring organizations." [2]

The purpose of this paper is to provide the reader with a description of accreditation of medical physics educational programs in North America. We shall begin with a brief history of the accreditation process for medical physics educational programs, and follow this with a description of the process by which CAMPEP accredits both graduate programs and residency programs.

HISTORY OF THE ACCREDITATION PROCESS

Accreditation of medical physics educational programs in North America began in the 1970s as an informal process of educational review administered by the American Association of Physicists in Medicine (AAPM). The first programs accredited by this mechanism were the medical physics graduate programs at the University of Oklahoma and the University of Colorado. In the 1980s the accreditation process became more formalized as a "service" offered by the AAPM through an AAPM-controlled entity named the Commission on Accreditation of Educational Programs for Medical Physicists. The first graduate programs to gain accreditation through this more formal process were the programs in medical physics at Wayne State University (1988), The University of Wisconsin (1988), The University of Texas – Houston (1989) and McGill University (1993). At this time, concern over liability caused the AAPM to transfer the accreditation process to an independent body, and CAMPEP was officially formed and incorporated in Illinois in 1994. CAMPEP was initially sponsored by three organizations in the United States, the AAPM, the American College of Radiology (ACR), and the American College of Medical Physics (ACMP). The Canadian College of Physicists in Medicine (CCPM) joined the list of sponsors in 2001, and was replaced by the Canadian Organization of Medical Physics (COMP) in 2010. In 2012, after the ACMP was incorporated into the AAPM, the Radiological Society of North America (RSNA) and the American Society for Radiation Oncology (ASTRO) joined as sponsors. The first continuing education programs were accredited in 1995 and the first residency program accredited was the program at the Washington University School of Medicine (1997).

The need for medical physics educational programs to become accredited became more critical in 2002, when the American Board of Radiology (ABR) mandated that all medical physicists desiring to take the certification

examination in any of the branches of radiological (medical) physics on or after 2012 had to have completed a CAMPEP-accredited graduate or residency program. This requirement was amended at the request of the AAPM to require that medical physicists who wished to take the certification examination on or after 2014 must have completed a CAMPEP-accredited residency. Similarly the CCPM requires that after 2016 applicants for their radiation oncology physics certification examination will be admitted only if they have completed a CAMPEP-accredited graduate or residency program. These mandates have generated a significant increase in the number of graduate and residency programs seeking accreditation by CAMPEP. Figure 1 shows the increase in the number of accredited graduate and residency programs in recent years. As of January 1, 2013, there are 40 CAMPEP-accredited graduate programs and 65 CAMPEP-accredited residency programs, with 8 graduate programs and 12 residency programs in the process of initial accreditation.

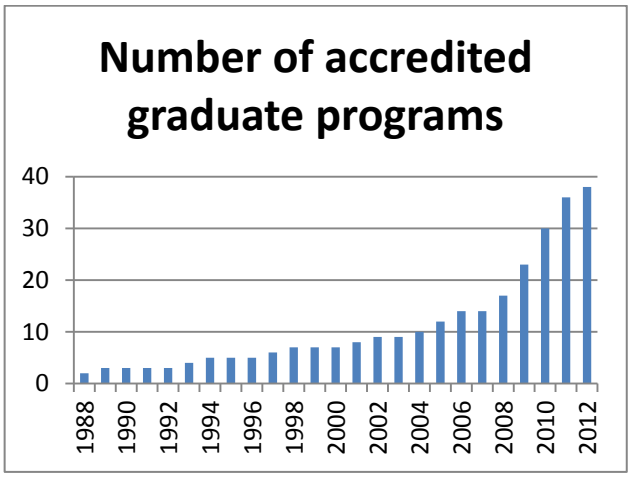

Figure 1. Growth in number of CAMPEP-accredited graduate programs (1988-2012)

Although the overwhelming majority of educational programs accredited by CAMPEP are in the United States or Canada, a few programs in other countries have recognized the potential advantages of CAMPEP accreditation, and have sought and achieved accredited status.

CAMPEP is currently in the process of acquiring accreditation itself from the United States-based Council for Higher Education Accreditation (CHEA). Recognition by CHEA affirms that the standards and processes of the accrediting organization are consistent with the academic quality, improvement and accountability expectations that CHEA has established [3]. Among the criteria for CHEA recognition that CAMPEP must satisfy are that CAMPEP has written procedures that publicly describe the accreditation process, and has policies that include a self-evaluation of the program along with an on-site review by a visiting team. CAMPEP's Policies and Procedures Manual is available on the CAMPEP website [2], and a written Self-Study and Site Visit constitute a major portion of CAMPEP's process for accrediting an educational program.

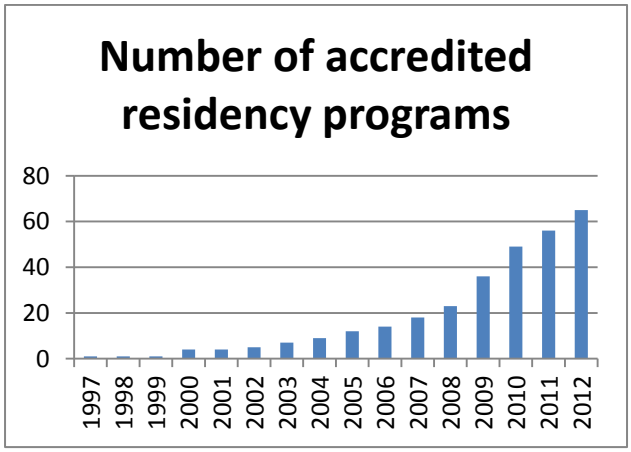

Figure 2. Growth in number of CAMPEP-accredited residency programs (1997-2012)

Presently, the CAMPEP application for CHEA recognition is under review; we anticipate CAMPEP's application will be reviewed at the next CHEA Board meeting, which will take place in November 2013, with a decision announced in January 2014. In August, 2013, representatives of CHEA will attend a meeting of the CAMPEP Board of Directors.

THE CAMPEP ACCREDITATION PROCESS

The process by which an educational program becomes accredited begins when a Program Director (PD) submits a Self-Study document. Templates for the Self-Study are available to the PD on the CAMPEP website [2]. The template for graduate programs is somewhat different from that for residency programs, although there are substantial similarities between them. The Self-Study consists of several parts (seven for graduate programs, eight for residency programs) and five appendices. The first part, the Program Goal and Objectives, simply requires that the educational program state its objectives. The second part is the Program Evolution and History. In this section, the PD provides a brief history of the program's history, including faculty, staff, and students. An institution preparing a Self-Study to renew its accreditation is also required to list in this section all significant changes in the program since the previous Self-Study. These changes are described in more detail in the appropriate section of the Self-Study guidelines.

Table 1: Membership of the CAMPEP Board of Directors and CAMPEP officers, Officers: President, Vice-President, Secretary/Treasurer

Sponsoring Organization								
Year	**AAPM**		**ACMP**		**ACR**		**COMP(CCPM prior to 2010)**	
1994	B Paliwal	RL Tanner	L Rothenberg	ES Sternick	-	-	-	-
1995	B Paliwal	RL Tanner	L Rothenberg	ES Sternick	GD Frey	J Trueblood	-	-
1996	B Paliwal	RL Tanner	L Rothenberg	ES Sternick	GD Frey	J Trueblood	-	-
1997	B Paliwal	CA Kelsey	L Rothenberg	ES Sternick	GD Frey	J Trueblood	-	-
1998	B Paliwal	CA Kelsey	L Rothenberg	ES Sternick	GD Frey	J Trueblood	-	-
1999	B Paliwal	CA Kelsey	L Rothenberg	ES Sternick	GD Frey	J Trueblood	-	-
2000	B Paliwal	CA Kelsey	L Rothenberg	E McCullough	GD Frey	J Trueblood	-	-
2001	PJ Biggs	CA Kelsey	JB Smathers	E McCullough	GD Frey	M McKetty	BG Clark	P Dunscombe
2002	PJ Biggs	P Steward	JB Smathers	E McCullough	RA Geise	M McKetty	BG Clark	P Dunscombe
2003	PJ Biggs	P Steward	JB Smathers	E McCullough	RA Geise	M McKetty	BG Clark	P Dunscombe
2004	PJ Biggs	P Steward	JB Smathers	JCH Chu	RA Geise	M McKetty	BG Clark	P Dunscombe
2005	PJ Biggs	P Steward	JB Smathers	JCH Chu	RA Geise	M McKetty	BG Clark	P Dunscombe
2006	PJ Biggs	P Steward	JB Smathers	JD Hazle	RA Geise	M McKetty	BG Clark	P Dunscombe
2007	R Maughan	P Steward	TD Solberg	JD Hazle	GD Clarke	M McKetty	E Podgorsak	P Dunscombe
2008	R Maughan	W Hendee	TD Solberg	JD Hazle	GD Clarke	M McKetty	E Podgorsak	P Dunscombe
2009	R Maughan	W Hendee	TD Solberg	JD Hazle	GD Clarke	C Coffey	E Podgorsak	BG Fallone
2010	R Maughan	W Hendee	TD Solberg	JD Hazle	GD Clarke	C Coffey	W Beckham	BG Fallone
2011	R Maughan	W Hendee	TD Solberg	JD Hazle	GD Clarke	C Coffey	W Beckham	BG Fallone

Year	**AAPM**		**ACR**		**ASTRO**		**COMP**		**RSNA**	
2012	R Maughan	W Hendee	GD Clarke	C Coffey	TD Solberg	J Buatti	W Beckham	BG Fallone	M Giger	D Balfe
2013	J Prisciandaro	W Hendee	EF Jackson	C Coffey	J Antolak	J Buatti	W Beckham	BG Fallone	M Giger	D Balfe

Table 2: Review Committee Leadership

Year	**Graduate**	**Residency**	**Continuing Education**
1994	Gary T Barnes	Kenneth R Hogstrom	-
1995	Gary T Barnes	Kenneth R Hogstrom	-
1996	Gary T Barnes	Kenneth R Hogstrom	Perry Sprawls
1997	Richard L Morin	Kenneth R Hogstrom	Perry Sprawls
1998	Richard L Morin	Kenneth R Hogstrom	E Russell Ritenour
1999	Paul M DeLuca	Richard G Lane	E Russell Ritenour
2000	Paul M DeLuca	Richard G Lane	E Russell Ritenour
2001	Paul M DeLuca	Richard G Lane	E Russell Ritenour
2002	Paul M DeLuca	Richard G Lane	E Russell Ritenour
2003	Richard L Maughan	Eric E Klein	Bruce R Thomadsen
2004	Richard L Maughan	Eric E Klein	Bruce R Thomadsen
2005	Richard L Maughan	Eric E Klein	Bruce R Thomadsen
2006	Richard L Maughan	Bruce J Gerbi	Bruce R Thomadsen
2007	Edward F Jackson	Bruce J Gerbi	Bruce R Thomadsen
2008	Edward F Jackson	Bruce J Gerbi	Bruce R Thomadsen
2009	Edward F Jackson	Bruce J Gerbi	Bruce R Thomadsen
2010	Edward F Jackson	Bruce J Gerbi	Bruce R Thomadsen
2011	Edward F Jackson	Bruce J Gerbi	Bruce R Thomadsen
2012	Edward F Jackson	Bruce J Gerbi	Steven J Goetsch
2013	Brenda G Clark	Chester Reft	Steven J Goetsch

The next part of the Self-Study is the Program Structure and Governance. This part allows the CAMPEP reviewers to assess the stability and continuity of the organizational structure in which the training program is conducted.

The fourth section of the Self-Study describes the educational requirements for the program. In the case of graduate programs, this would be the program's curriculum. The curriculum for graduate programs must be consistent at a minimum with the recommendations presented in AAPM Report 197 "Academic Program Recommendations for Graduate Degrees in Medical Physics."[4] Sample academic plans also must be provided along with the process by which the institution approves the curriculum and course content. For residency programs, this section includes a listing of the clinical rotations that constitute the training schedule, along with the didactic prerequisites required for a candidate to enter a residency program. The elements of clinical training should be consistent at a minimum with recommendations presented in AAPM Report 90, "Essentials and Guidelines for Hospital-Based Medical Physics Residency Training Programs." [5]

The fifth section of the Self-Study addresses the trainees in the educational program, the students and residents. Application materials need to be described along with admission requirements. CAMPEP requires that students entering a medical physics graduate program have either an undergraduate degree in physics or a degree in physical science or engineering with a physics minor (three upper-level undergraduate courses in physics or their equivalent), while individuals entering a residency program after January 1, 2014, have either a degree from a CAMPEP-accredited graduate program or a PhD in physics, physical sciences, or engineering, together with successful completion of the didactic courses identified in AAPM Report 197S, "The Essential Medical Physics Didactic Elements for Physicists Entering the Profession through an Alternative Pathway."[6]

The sixth section of the Self-Study for residency programs addresses program administration. The administrative structure of the program must be well-defined, with a clear description of the responsibilities of the Program Director and the Residency Program Committee. Sometimes residency programs span multiple institutions and departments, in which case the roles of each component institution must be clearly explained. Extensive record keeping is required of residency programs, and the applicant institution must identify these records and how they may be accessed.

The next section of the Self-Study asks the applying institution to identify its resources. Resources include faculty and staff and their roles in the educational program, availability and extent of funding for students and residents, and a description of the facilities available to the students and residents.

The final section of the Self-Study asks the applicant program to summarize the program's strengths and needs as perceived by the program staff, and to elucidate the goals that, if achieved, would improve the program by capitalizing on its strengths and addressing its needs.

The main body of text of the Self-Study is followed by a series of Appendices, including letters of invitation and institutional commitments, documentation of institutional accreditation, summaries of the various components of the educational curriculum (course summaries for graduate programs and clinical rotation summaries for residency programs), lists of program graduates for the past 10 years if the program has been in existence for a while, and biographical sketches of faculty and staff along with identification of their roles in the educational program.

Once the Self-Study and the application fee are received by CAMPEP, the Chair of the appropriate review committee, the Graduate Education Program Review Committee (GEPRC) or the Residency Education Program Review Committee (REPRC), assigns two reviewers to review the Self-Study. In some cases the review is accepted by the reviewers, while in other cases the reviewers require further clarification of the Self-Study, sometimes necessitating several rounds of review.

After the Self-Study has been accepted by the reviewers, a site visit is scheduled. The purpose of the site visit is to examine selected areas of the program identified in the self-study review where questions may exist; to meet and talk personally with faculty members, students, and administrative officials; to observe the adequacy of facilities; to assess the aptitude and commitment of students and faculty; to observe the general educational and scientific environment at the institution; and to obtain any additional data required for evaluation. The site visit typically takes 1½ to 2 days. During this time, the review team meets with the Program Director, faculty and staff, trainees, and administrative officials.

At the conclusion of the site visit, the review team prepares a final report and makes a recommendation for or against accreditation to the appropriate review committee. The possible actions are as follows:

Initial accreditation: A program may be granted initial accreditation for a period of three years. If the program submits acceptable annual reports during the first three years of accreditation, the program accreditation may be extended to five years on the recommendation of the appropriate review committee and granted by the President upon recommendation by the Chair of the review committee.

Provisional accreditation: New educational programs that have yet to graduate one student or resident may be granted provisional accreditation for a period less than

three years. These programs are required to provide evidence of graduation of their first student or resident, or remediation as appropriate in which case Initial Accreditation will be granted.

Deferred accreditation: This action may be appropriate for programs that are found to be non-compliant with CAMPEP standards for accreditation, in order to allow an adequate period of time for the institution to implement planned or suggested improvements in the program. This action postpones a final decision until specific additional information is provided which brings the program into compliance with CAMPEP standards.

Withheld accreditation: This action is appropriate for programs that are found to be non- compliant to CAMPEP standards for accreditation, and it does not appear that program changes could be achieved within a reasonable period of time to qualify for accreditation. After this decision, should accreditation be pursued, a new application would be required including the appropriate fee.

The final report with an appropriate accreditation recommendation is distributed to all members of the review committee for consideration. After agreement is reached by the review committee, a recommendation on accreditation is submitted to the Board of Directors. If the Board concurs in a recommendation for accreditation, the accreditation status is conferred on the program.

Programs are required to submit annual reports. In the report, the program is required to identify any changes in the program or key personnel. Programs are asked to identify actively enrolled students or residents, those who have completed the program and those who have left the program prior to completion. Sometimes additional data are requested for statistical purposes.

At the beginning of the last year of a program's accreditation, the program is requested to submit an updated Self-Study to CAMPEP along with the renewal fee. The renewal Self-Study is reviewed in the same manner as the initial application for accreditation. If the application is for reaccreditation following an initial accreditation, or if a site visit was performed for the previous reaccreditation, a site visit is not necessary. If a site visit is required, it is conducted in the same manner as the site visit associated with the initial application for accreditation. After the appropriate review committee has approved the application for reaccreditation, the Chair of the review committee forwards the recommendation to the Board.

Examination statistics for the 2012 oral ABR certification examination for medical physicists have demonstrated that completion of a CAMPEP-accredited residency program significantly increases the passing rate. In 2012, 390 individuals took the Oral ABR Examination in one of the three branches of medical physics, with a passing rate of 56%. Of these individuals taking the examination, 47 had completed a CAMPEP-accredited residency program. The passing rate for these individuals was 87%. [7] Clearly, successfully completing a CAMPEP-accredited residency program substantially increases the probabilitythat an individual will pass the ABR examination.

CONCLUSION

Accreditation of medical physics educational programs in North America is provided by the Commission on Accreditation of Medical Physics Educational Programs (CAMPEP). CAMPEP has a well-defined process for programs that wish to undergo accreditation. If programs that are currently under review successfully achieve accreditation, there will be almost 50 graduate programs and 80 residency programs holding CAMPEP accreditation. Successful completion of an accredited educational program has been shown to increase the probability that a medical physicist will pass the American Board of Radiology certification examination in medical physics.

ACKNOWLEDGMENTS

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THE IMPACT OF THE ICTP COLLEGE ON MEDICAL PHYSICS FOR THE ESTABLISHMENT OF MEDICAL PHYSICS IN DEVELOPING COUNTRIES

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Abstract- The regular College on Medical Physics at ICTP (the Abdus Salam International Centre for Theoretical Physics), Trieste, Italy, has been a strong support for the development of medical physics in developing countries. Additionally ICTP has participated in several medical physics education/training projects and has hosted several International Conferences in this field. Recent feedback assessment shows significant (66%) increase of participants knowledge. During its more than 20 years history the college has educated more than 1000 young medical physics colleagues from developing countries.

Keywords- Education, training, developing countries.

INTRODUCTION

The International College on Medical Physics (CMP) at ICTP (the Abdus Salam International Centre for Theoretical Physics) in Trieste, Italy has operated for more than 20 years. Although ICTP does not have a permanent Research Activity in the field of Medical Physics, a very vigorous training and Conference activity takes place. It started with an International Conference on the Applications of Physics to Medicine and Biology in 1982 (organised by Giorgio Alberi). Another successful Conference and several Workshops were organised in the following years, demonstrating the need for Medical Physics education for the developing countries. This convinced ICTP to expand their training activities with Medical Physics. The first College on Medical Physics took place in 1988 (a 4 week activity with the participation of 68 scientists from developing countries). The regular series of Colleges begun in 1992 and continues to run on a regular basis (usually bi-annually). During the period the ICTP has educated more than a 1000 young medical physicists mainly from developing countries. From the beginning corner stones for the ICTP involvement in Medical Physics were Luciano Bertocchi (then Deputy Director of ICTP) and Anna Benini (then IAEA Officer). Additionally, a number of prominent professionals were engaged with the College on Medical Physics, including John Cameron (USA), Sergio Mascarenhas (Brazil), Perry Sprawls (USA) and Slavik Tabakov (UK). The current Co-Directors include also Franco Milano (Italy) and George D Frey (USA), while the Hospital training is organised by Mario De Denaro.

MEDICAL PHYSICS COLLEGES AT ICTP

The transfer of knowledge and experience to the developing countries is a major objective of the College. Each participant receives a full set of lecturing materials, including Power Point slides, e-Learning materials, access to web sites, etc. These have triggered tens of Medical Physics activities and courses in the developing countries and helped hundreds of colleagues from these countries to practice the profession. Due to this reason CMP is always one of the most over-subscribed training activities of the ICTP – see Figure 1.

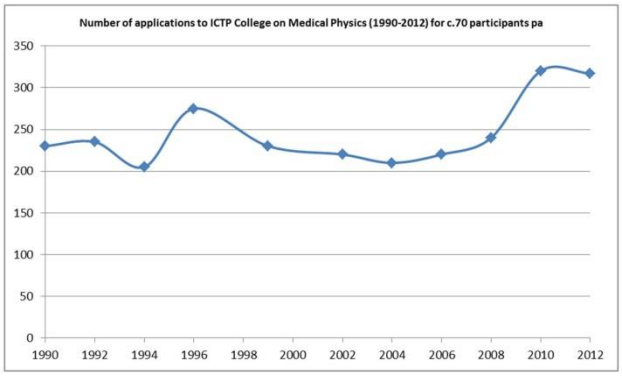

Figure 1. Applications to ICTP College on Medical Physic

CMP usually accepts colleagues from 30 to 40 developing countries. It is known that in general, physicists from these countries have good educational foundations in general physics. The College builds on

this foundation by providing education on the recent advances in medical physics. Participants of previous Colleges on Medical Physics have demonstrated its great value as they have formed a significant medical physics infrastructure in their countries.

ACTIVITIES AND EFFECTIVENESS OF THE ICTP COLLEGE ON MEDICAL PHYSICS

Some areas of Applied Physics in medicine (especially Radiotherapy physics) are covered by specific courses provided by various institutions, organizations, and agencies, however there are not sufficient courses, available elsewhere, which cover Physics of Medical Imaging. Additionally very few of those include training on the practical application and optimization. Because of this the CMP emphasis during the last decade is on Medical Imaging Physics.

The effectiveness of the 2010 and 2012 Colleges (both with focus on Digital Imaging) was assessed with 3 Questionnaires – collecting feedback on the College Organisation, syllabus, knowledge transfer and suggestions. The results of these questionnaires showed significant effectiveness in increasing the knowledge of participants. In brief while the student's estimate of their knowledge prior to the College was with a mean of 45%, after the College it was with a mean of 75%. This regular feedback is also used for modifying the programme for each following College. This approach to improve the Curriculum with the active participation of the students has been one of the successes of CMP.

The increased interest of ICTP in Medical Physics led to its inclusion in several international projects. Most notable are EMERALD, EMIT and EMITEL. The first two developed e-Learning training materials in physics of: X-ray Diagnostic Radiology, Nuclear Medicine, Radiotherapy, MRI and Ultrasound Imaging. EMERALD was not only the first e-learning in medical physics, but introduced one of the first ever e-books. Currently each participant receives a free set of these materials. In connection with these training materials ICTP hosted three International Conferences (in 1998, 2003 and 2008) – these were the first international Conferences on medical physics training. The importance of the above projects can be judged by the fact that in December 2004 the EMIT project received the inaugural European Union "Leonardo da Vinci" award.

The Conference in 2008, related to project EMITEL, introduced the first e-Encyclopaedia of Medical Physics (currently used by some 9000 colleagues each month). This Conference established a good relationship of ICTP with IOMP (also a partner in EMITEL). Recently IOMP supported other medical physics activities of the ICTP.

Apart from the regular CMP in Trieste, ICTP initiated similar courses in other countries. The first Regional College on Medical Physics was conducted in Mumbai, India during November 2007. The first week was devoted to The Physics and Technology of Medical Imaging and the second week to The Physics and Technology of Radiation Therapy. Perry Sprawls and S.D.Sharma were the Academic Directors and the College was also supported by the ICTP, and the Bhabha Atomic Research Centre (BARC), Mumbai, India. Additional co-sponsors were the American Association of Physicists in Medicine (AAPM) and the Association of Medical Physicists in India (AMPI).

ICTP operates under the aegis of UNESCO and IAEA and naturally alongside the CMP, hosts many IAEA Workshops and Symposia. In 2005 ICTP was the Co-Organiser of the World Conference "Physics and Sustainable Development" in Durban, South Africa, where one of the main directions for applied physics in the XXI century was voted to be Physics in Medicine.

ICTP also supports Medical Physics research in a similar way to other scientific areas. This is through two programs for individuals: The Associate Members and the Programme of Research and Training in Italian Laboratories. Associate Members are scientists from developing countries who are given the opportunity of spending periods of up to three months, three times during their appointment, to use the Centre's facilities and to conduct research. So far some 50 scientists have been appointed as Associate members in medical physics.

The programme of Research and Training in Italian Laboratories - TRIL - gives the opportunity to experimental scientists to spend periods of time up to one year joining a group in an Italian laboratory. In the area of Medical Physics 48 Italian laboratories offer this opportunity, and a total of 97 scientists were trained so far.

CONCLUSION

During its long history the College on Medical Physics at ICTP has introduced successful educational models and has helped many colleagues from less developed countries to begin/stabilise their medical physics activities. Many colleagues from these countries see ICTP as one of their first encounters with the profession and IOMP has always shown high appreciation and support for this international impact of the ICTP for the developing countries.

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MEDICAL PHYSICS ORGANIZATIONS

MEDICAL PHYSICS EDUCATION AND TRAINING IN LATIN AMERICA: CURRENT STATUS AND CHALLENGES

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Abstract — Due to economic development in many Latin America countries, advanced diagnosis and treatment techniques are being constantly implemented. As a consequence, the need for qualified medical physicists has increased significantly. By acting as the interface between physics and medicine, the medical physicist can improve the effectiveness of both diagnostic and therapeutic medical radiation procedures. An analysis was made in Latin America countries to evaluate the education and training status of medical physics, mainly regarding the availability of courses, and certification and accreditation processes. Data was collected in collaboration with National Medical Physics Associations and Regulatory Bodies. The results indicated that even in radiotherapy where most of the efforts in education and training were initially concentrated, the number of physicists remains insufficient; the problem is worse in nuclear medicine and radiology where the number of both theoretical and practical courses is insufficient to meet the actual demand. It was also observed that most LA countries don't have a proper framework to apply international recommendations. The Medical Physics Associations in Latin America are very concerned about the potential consequences for patients and staff involved in medical radiation procedures. An action plan should be implemented urgently in Latin America, including setting minimum requirements for academic qualifications, continuing training and professional development, and a standard process for medical physicist accreditation which can be accepted in any country of the region. These actions might initiate a strengthening of medical physics in Latin America.

Keywords—Medical Physics, education and training, certification, Latin America

INTRODUCTION

Latin America (LA) is composed of 20 countries: Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Ecuador, El Salvador, Guatemala, Haiti, Honduras, México, Nicaragua, Panamá, Paraguay, Peru, Republican Dominican, Uruguay and Venezuela. The total area is approximately 21,069,501 km², representing approximately 3.9% of Earth's surface, or about 14.1 % of its land area. In 2010, its population was estimated at more than 588 million inhabitants, representing 8.5% of the world population.

Despite wide differences in population, economy and health care assistance among constituent countries, some problems are similar throughout the region (Table 1).

In Table 1, it can be observed that for many countries there is no correlation between gross domestic product (GDP) and respective health care level. Cuba has a low GDP but their health care system provides a level I assistance for the population. On the other hand, although there has been significant economic development in Brazil and Chile, the health care remains at level II. This data suggests that the distribution of investment by governments does not always prioritise the health system.

The main problem remains the education and training of health professionals. Although new diagnosis and treatment techniques such as Computed Tomography (CT), Intensity-Modulated Radiation Therapy (IMRT), Positron Emission Tomography (PET), and Functional Magnetic Resonance Imaging (FMRI), amongst others, are being implemented in the region, investment in appropriately qualified staff for facilities providing such techniques are still deficient.

As member states of the United Nations and according to Pan American Health Organization (PAHO) resolution [4], Latin America countries have to be prepared to implement the IAEA General Safety Requirements - GSR Part 3 [5]. However, the requirements regarding the duties of medical physicists, and their qualification, training and competence, are not included in the legislation and consequently have not been implemented in most countries. The problem is more significant in nuclear medicine and diagnostic radiology

where historically the medical physicist has not been considered essential and has therefore not been accepted as much as in radiotherapy.

However, in the last decade, only a few countries have established medical physics courses to provide formal education, training and experience of clinical practice for different areas. In general these courses are not accredited and don't follow any standard or a minimum curriculum to ensure that they provide for the current needs of medical physics.

In order to obtain an overview of the current situation, the aim of this study was to verify the main aspects that affect the current status of medical physics education and training in Latin America region.

Table 1: Latin America countries social and economic characteristics * *No data*

Country	Population Thousands (2010) [1]	Physicians ratio 10,000 hab. [1]	Per capita GDP U$ (2011) [2]	Health Care Level (UNSCEAR) [3]
Argentina	40,412	32.1 (2004)	9162	I
Bolivia	9,93	4.9 (2008)	1978	II
Brazil	194,946	16.0 (2007)	10716	II
Chile	17,114	9.3 (2004)	11888	II
Colombia	46,295	15.0 (2008)	6223	II
Costa Rica	4,659	18.6 (2009)	7704	II
Cuba	11,258	66.3 (2008)	5704	I
Dominican Republic	9,927	13.2 (2008)	5195	II
Ecuador	14,465	16.2 (2007)	4073	I
El Salvador	6,193	20.1 (2008)	3426	II
Guatemala	14,389	9.9 (2008)	2882	III
Haiti	*	*	*	*
Honduras	7,601	3.0 (2008)	2026	III
Mexico	113,423	14.0 (2006)	9101	II
Nicaragua	5,788	16.4 (2003)	1132	II
Panama	3,517	13.4 (2008)	7614	I
Paraguay	6,455	13.0 (2008)	2771	II
Peru	29,077	9.2 (2009)	5411	II
Uruguay	3,369	29.0 (2009)	11952	I
Venezuela	28,98	13.0 (2007)	13503	I

MATERIALS AND METHODS

During 2011-2012, a questionnaire was prepared and sent to the medical physics associations or, where an association was not established, a representative of the national regulatory body was invited to participate. The countries which collaborated were: Argentina, Brazil, Costa Rica, Colombia, Chile, Ecuador, El Salvador, Guatemala, México, Nicaragua, Peru, Panamá, Republic Dominican, Uruguay and Venezuela. Although there are 20 countries in Latin America, in this survey it was only possible to obtain the data from 19 countries, and furthermore the responses from some countries were not complete.

The main topics were: status of medical physicist recognition, legislation, number of installations and equipment per area, education and training, beyond certification and accreditation program.

RESULTS

Despite the difficulty in obtaining all the relevant information, the responses to the questionnaires were received by mail. It must be emphasised that this data was considered properly provided by the participants.

Because some of the information sent by the participants was incomplete, the results were collated and are discussed below.

The number of medical physicists in each country is presented in Figure1 where it can be seen that 8 countries, 40% of the total, have no registered or certified medical physicists.

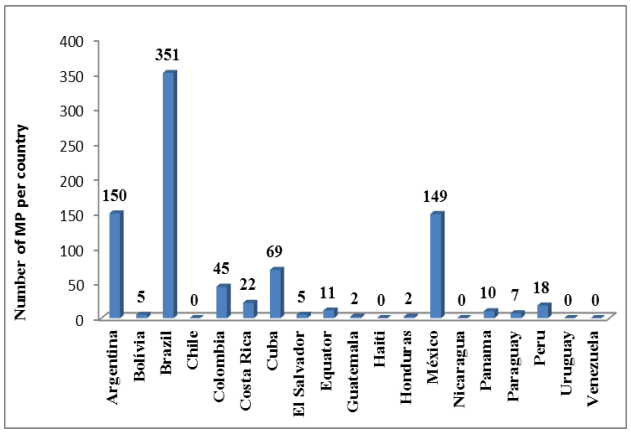

Figure 2. Number of Medical Physicists for each LA country.

As expected, the distribution by specialty confirms that there is an obligation established by law or regulation of the availability and qualification of medical physicists in radiotherapy, which does not happen in other areas. It can be seen from Figure 2 that 72% of medical physicists are working in radiotherapy, where the risk has always been considered higher than diagnostic radiology and nuclear medicine. However, due to the complexity of newer equipment, plus the need for individualised dosimetry studies and radiation protection reasons, the work of this

professional is also essential for the proper performance of a service in the other applications of ionising radiation.

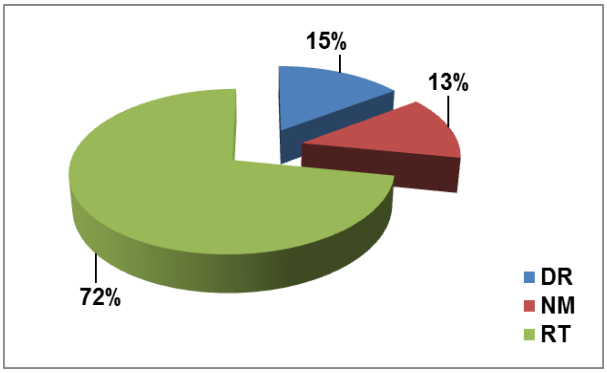

Figure 2. Number of Medical Physicists for each specialty: Diagnostic Radiology (DR), Nuclear Medicine (NM), Radiotherapy (RT)

Considering the number of medical physicists certified in each country it can be concluded that there isn't a formal process of regulation of the profession, or even a certification scheme established in each country. However, one fundamental problem is the lack of available basic training for medical physicists, even at undergraduate level. Figure 3 shows the degree courses for each country, where it can be seen that undergraduate courses in Medical Physics are established only in Argentina, Brazil, Nicaragua, Uruguay and Venezuela, totalling 25% of the participating countries.

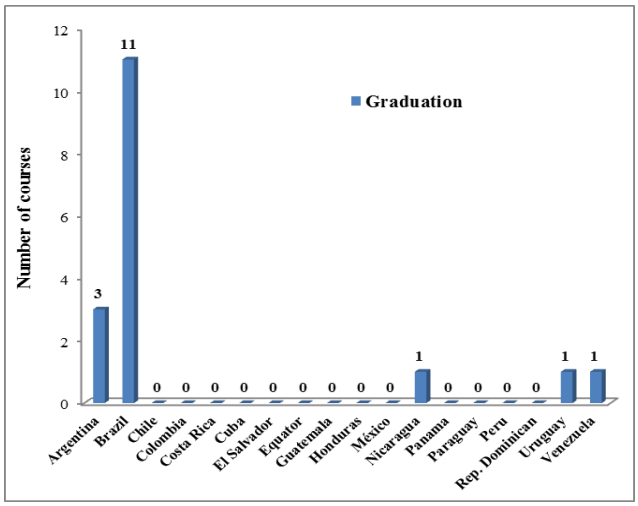

Figure 3. Number of Medical Physics courses for each LA country.

This information is rather contradictory when compared to the number of medical physicists available in each country, as shown in Figure 2. For example, there are courses in Nicaragua, but no certificated medical physicists. There is also the issue of recognition of the profession in each country –for example in Brazil, where there are 323 trained and certificated medical physicists, but the profession is not yet recognised by the Ministry of Labour.

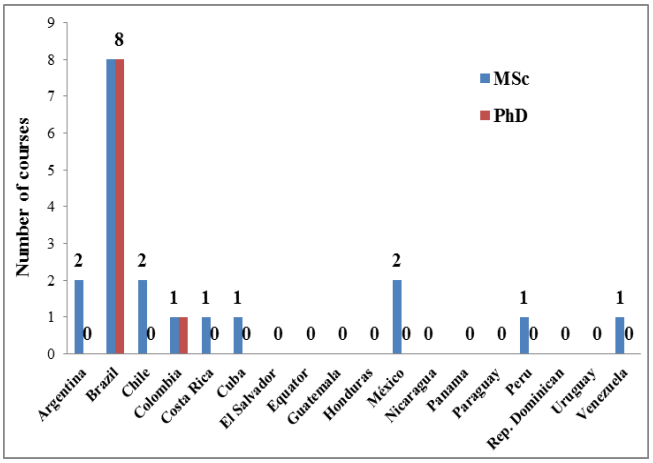

Figure 4. Number of Medical Physics post-graduation courses for each LA country

In the absence of courses in their own countries, many professionals, looking to get specialization, have to go abroad where there are postgraduate courses already established. Figure 4 shows the Master of Science (MSc) and PhD degree courses available in the region. It can be seen that in some countries, such as Peru or Chile, there are MSc and PhD courses but no undergraduate courses.

Another problem is the need for clinical practice training that is fundamental to the development of medical physicist competence. Only a few hospitals and clinics are now accredited to provide this training; Figure 5 shows the number of practical training placements available annually for each country.

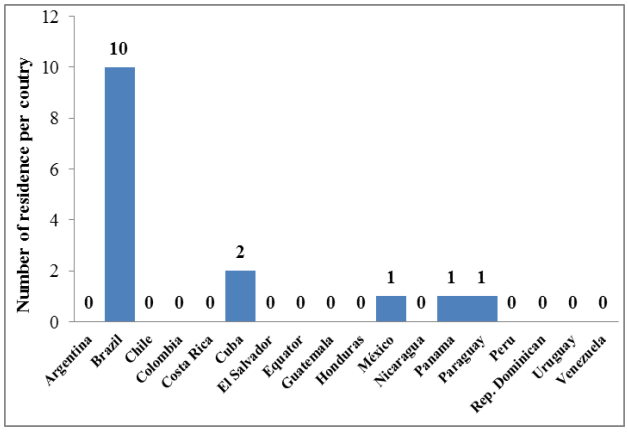

Figure 5. Number of hospitals and clinics providing clinical practice training in Medical Physics

Even in Brazil, where there are at least 10 accredited hospitals for clinical training, the number of hours of practice differs greatly from place to place. Moreover, the annual number of vacancies is not enough to meet the demand, as shown in Table 2.

Table 2: Placements for MP clinical practice training available in Brazil.

Institution	Period (hours)	Annual vacancies
1	3380	6
2	3900	3
3	3940	2
4	3840	2
5	4000	1
6	1920	2
7	1920	1
8	3800	1
9	3800	3
10	6240	1

It should be recognised the role of associations in labor regulation and certification of the professionals. Figure 6 shows the percentage of countries that have a Medical Physics Association, an established certification process and the recognition by law of Medical Physics as a professional.

It can be seen that 50% of the countries have a Medical Physics Association in place, but a professional accreditation process is only established in 17% of them. To corroborate with this, recognition of the profession is not established for most of the countries - only 11% of the countries have adequate legislation providing such recognition.

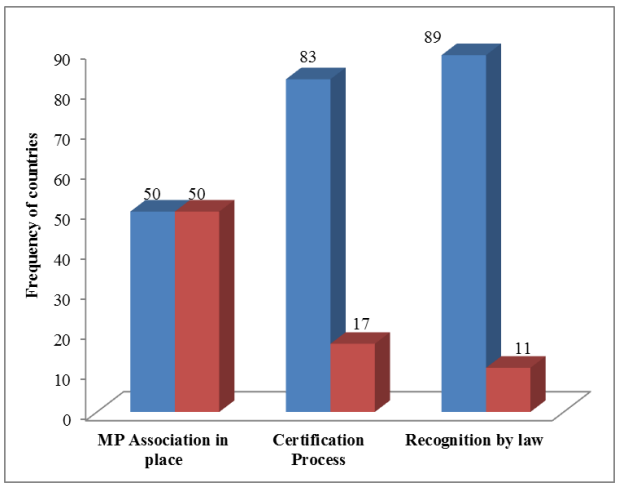

Figure 6. Frequency of: MP Association established in LA countries (formal and informal); countries with established certification process; countries where the MP professional is recognised by law.

CONCLUSIONS

There are several problems to be addressed in order to improve the situation of the profession of medical physicist in LA. ALFIM would like to start convening the Class Associations to work together in defining a comprehensive plan of action.

The proposal is the establishment of the following parameters:

- Legislation;
- Regulatory requirements;
- Educational;
- Certification Process.

Participation of the Education, Labour, and Health ministries of each country is paramount to the success of this plan.

None of these subjects have a lower importance and must all be treated simultaneously. The establishment of minimum requirements for a syllabus, and the required number of hours of theory and clinical practice training is considered to be a good start.

Knowledge of the situation in other regions and already-established models such as that recently published by the European Community will be used to establish policies for the LA region.

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The authors would like to thank the Medical Physics Associations and Regulatory Bodies that participated in this work.

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ELECTRONIC MEDICAL PHYSICS WORLD - A RESOURCE FOR GLOBAL EDUCATION

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Abstract— The International Organization for Medical Physics (IOMP) represents nearly 20,000 medical physicists worldwide and 82 adhering national member organizations. The mission of IOMP is to advance medical physics practice worldwide. The following article presents the official Bulletin of the IOMP – electronic Medical Physics World (eMPW).

Initially started as an IOMP Bulletin, eMPW turned recently into an educational and scientific resource of global value not only for Medical Physicists, but also Medical Doctors, Radiology Technicians and related specialties. It went a major renovation very recently, the new format of is already distributed in a number of international conferences around the world.

The interdisciplinary area of Medical Physics develops in parallel with other major medical and technological specialties. Providing a good level of communication and disseminating the most recent advances in Medical Physics is one of the major tasks conducted by eMPW. The main contributions of eMPW are in the areas of education, training, scientific and professional activities, expanding the links with the related professions. eMPW is targeting a wider popularity by providing scientific and educational content meant not only for Medical Physicists, but also Medical Doctors and Radiology Technicians.

Keywords— eMPW, renovation, IOMP, education, medical physics

INTRODUCTION

The International Organization for Medical Physics (IOMP) was formed in January 1963 initially with four (4) affiliated national member organizations [1]. The Organization currently has a membership of 82 national members representing nearly 20,000 medical physicists worldwide. The Organization is affiliated to IUPESM, IUPAP and ICSU and is officially connected to IFMBE. According to the Statutes of the Organization its aims are to organize international co-operation in medical physics and to promote communication between the various branches of medical physics and allied subjects, to contribute to the advancement of medical physics in all its aspects and finally to advise on the formation of National Committees for Medical Physics in those countries which lack such organization. Very recently, IOMP introduced its first official journal, Medical Physics International (MPI). Apart of these journals, IOMP publishes, twice yearly, a bulletin that is sent to every medical physicist via the National Organizations. This is the Medical Physics World (MPW) which was founded in 1984 as the official bulletin of IOMP. Recently MPW was upgraded to electronic Medical Physics World (eMPW) [2]. Throughout the years, MPW and eMPW have both played a significant the role as one of the main informational resources for IOMP, reaching medical physicists around the world and providing them with the latest updates at organizational and scientific level.

MATERIALS AND METHODS

eMPW initially started as an IOMP Bulletin. As the years went by, eMPW turned into an educational and scientific resource of global value not only for Medical Physicists, but also Medical Doctors, Radiology Technicians and related specialties. Taking into account that the interdisciplinary area of Medical Physics develops in parallel with other major medical and technological specialties, the need to provide a good level of communication and disseminating the most recent advances in Medical Physics is apparent. Therefore, this is one of the major tasks conducted by eMPW. The main contributions of eMPW are in the areas of education, training, scientific and professional activities, expanding the links with the related professions. eMPW is targeting a wider population by providing scientific and

educational content meant not only for Medical Physicists, but also Medical Doctors and Radiology Technicians

Throughout its almost 30 years of existence, MPW and later eMPW has been chaired by some of the leading professionals in the field of Medical Physics & Engineering., mostly from the United States of America (USA). The first editor was Dr Lawrence Lanzl in 1984, succeeded by Dr Colin Orton in 1986, Dr Richard Maughan in 1988, Dr Bhudatt Pasllwall and Dr Azam Niroomand-Rad in 1994, Dr Ishmael Parsai in 2000 and Dr Donald Frey in 2009. In the World Conference of Medical Physics in Beijing in May 2012 a new editor was elected for the eMPW and currently the editorial board consists of the following distinguished scientists around the world: Virginia Tsapaki, Greece as the Chair Editor, Magdalena Stoeva, Bulgaria who is the Associate Editor, Dr Ibrahim Duhaini, Qatar, who also serves as the Calendar Editor of the bulletin, Dr KY Cheung, Korea, Dr Slavik Tabakov, UK, Dr Madan Rehan, Austria, Dr Anchali Krisanachinda, Thailand, Dr Tae Suk Suh, China and finally Dr A.W.K Kyere, Ghana. For the first time ever in MPW history a non USA editor leads the IOMP bulletin. One of the first decisions of the new board was to completely redesign the layout of the eMPW in order to become more appealing and modern.

RESULTS

The editorial team is very proud to present the brand new version of the eMPW. Figure 1 shows the front page of the July issue with a picture of the opening ceremony of the World Congress on Medical Physics and Biomedical Engineering 2012, Beijing, China. Although being primarily an electronic publication for dissemination through IOMP website, it is intended to be partially printed and distributed in important conferences around the world including the European Congress of Radiology (ECR) and other radiological and medical conferences. It must be noted that the July 2012 issue is already not only presented but also distributed in 4 large conferences around the world in less than 6 months. These conferences are: 1) the annual meeting of American Association of Medical Physicists (AAMP) in Charlotte, USA, 2) the European Conference on Medical Physics in Sofia, Bulgaria, 3) the Balkan conference of radiologists and 4) the Asia-Oceania Congress of Medical Physics in Chiang Mai, Thailand. The links to IOMP webpage having the new issues are sent to all IOMP member countries. It is also sent to various international bodies such as the World Health Organization (WHO), International Atomic Energy Agency (IAEA), etc.

The December 2012 issue is already in the website and sent to all IOMP members. Figure 2 shows the front page of this bulletin. It must be noted that the world puzzle contains images of medical physicists at work both in developed and in developing countries, scientists at medical physics conferences, as well as the logos not only of the regional organizations but also of the collaborating organizations with IOMP. The editorial board would like to thank all the people who kindly permitted the use of these images and strongly encourages medical physicists, radiation protection workers, biomedical engineers and other relevant scientists around the world to send their images in order to be placed in one of the future issues of EMPW.

The specific issue is going to be printed and distributed in the European Conference of Radiology in March 2013, which is held every year in Vienna, Austria. This conference is one of the largest medical meetings in Europe and the second-largest radiological meeting in the world. The attendees of the conference span all areas of the radiology arena such as radiology professionals, radiographers, industry representatives, and press reporters for both the medical and consumer press. For the first time ever, IOMP will have a dedicated booth in ECR, where a lot of information together with the latest issue of eMPW will be circulated. Some of the IOMP officers as well as members of the IOMP committees who were planning to attend the ECR conference kindly offered their help to man the IOMP booth in order to explain to the visitors of the booth, the mission and objectives of IOMP.

For the near future, the editorial board has the intension to print and distribute the July 2013 issue in the 20th International Conference on Medical Physics and Biomedical engineering (ICMP) which is going to be held in Brighton, UK from 1st - 4th September 2013. The conference is hosted, on behalf of the IOMP, by the Institute of Physics and Engineering in Medicine and will celebrate the 50th Anniversary of the foundation of the International Organization for Medical Physics (IOMP) [3]. This issue will focus on the initiatives taken by national member organizations as well as regional organizations to celebrate the International Day of Medical Physics (IDMP) [4]. This is one of the initiatives taken by IOMP to raise the profile of the Medical Physics profession to the public. This will be an annual event aiming to draw the attention of the global community but also to generate sufficient momentum to ensure its continuity in the future. November 7, the birthday of Marie Sklodowska-Curie has been named by IOMP as the International Day of Medical Physics. A special Task Group has been set up by IOMP in planning and coordinating a series of professional, educational and scientific activities to mark this meaningful day in 2013. The intension is to bring together as many medical physicists as possible from all over the world to participate in this exercise. The editorial board of eMPW intends to publish all these individual events.

As far as content is concerned, the year 2012 issues contain reports of the IOMP officers and chairs of the various IOMP committees, reports from regional organizations, policy statements of the IOMP as well as

scientific papers. The 20113 July issue preparation has already started with a significant contribution from Africa focusing on "Medical Physics and the Challenges in Africa". The editorial board strongly encourages reports from member organizations on educational , professional or scientific issues with special emphasis in developing countries.

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Figure 1. The front page of the new eMPW.

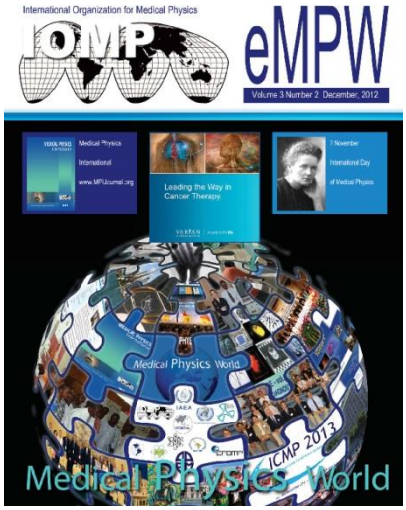

Figure 2. The front page of the eMPW December issue.

Deadlines for submission of material relating to scientific, research, educational or professional subjects are April 1 and October 1 for publication of July and December, respectively. The feedback of readers is always greatly appreciated. Comments or suggestions can be sent to the editor for consideration (virginia@otenet.gr), as the editorial board believes that they would facilitate to the improved communication between IOMP and its members.

CONCLUSIONS

Quoting the mission of IOMP": "advance medical physics practice worldwide by disseminating scientific and technical information, fostering the educational and professional development of medical physicists, and promoting the highest quality medical services for patients", the eMPW team will work so that the eMPW becomes the IOMP tool for accomplishing this mission.

ACKNOWLEDGMENT

The authors of this paper (the editorial board) would like to acknowledge the valuable help of Dr Ishmael Parsai who facilitated enormously the process for smoothly moving to the new renovated version of the eMPW.

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EDUCATIONAL RESOURCES

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

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Abstract- The radiation protection of patients (RPOP) website of the IAEA (http://rpop.iaea.org) has been one of the major resource that medical physics professionals have utilized in the last few years. The website was established in Sept 2006 and has grown to be at top website of the world in the area of medical radiation protection. Besides conventional area of practice that medical physicists are involved in, the website also provides extensive material on radiation protection in use of fluoroscopy outside radiology in gastroenterology, urology, orthopedic surgery, protection in dentistry, in hybrid imaging, bone mineral densitometry and also material relevant for referring physicians. The website provides training material as power point slides for free download and posters on radiation protection in fluoroscopy and computed tomography. This paper describes thinking behind development of this website, purpose and orientation, how search optimization was performed to enable appearance on first page of search (like Google search), performance indicators and results achieved.

Keywords- Website management, Search optimization, radiation protection, patient protection, medical radiation protection, IAEA RPOP website

INTRODUCTION

Way back in 2004 during a meeting of the Steering Panel of the International Action Plan on Radiological Protection of Patients (IAPRPOP) of the IAEA [1], it was deemed appropriate to initiate actions for a website dedicated on this topic. No website in the world at that time was able to provide information on:

1. Radiation doses to patients in diagnostic radiological procedures
2. What actions are needed to optimize patient doses while maintaining image quality or clinical purpose
3. Which radiological medical procedures are associated with radiation risks that cannot be ignored, what are risks and how to deal with them
4. Specialized training material for various professionals

During the planning phase, issues that needed careful attention were:

a) Should the new website be a resource to let people know what the organization does or it be a scientific resource to meet needs of users?

b) Should it have dominant orientation towards regulators or hospital professionals?

With these in background, the path we followed is as given below:

ORIENTATION TO PURPOSE

Most websites are directed at letting visitors know what the organization or company does. Whereas it was a unique opportunity to be beneficiary based. Radiation protection of patients neither reflects an organization nor is a subject like radiology, medical physics, radiation oncology… There is a purpose in the name itself. If there are few billions of patients who undergo radiological examinations each year, how the website can make a difference to them. Just by providing information that concerns some thousands of regulators or medical physicists, one cannot achieve safety of billions of patients. That provided answers to above two questions. There were many issues pertaining to the mandate of the IAEA and if the website should provide information only for health professionals who have responsibilities assigned under the Standards [2] or extend to information for patients. Many times the purpose (safety) gets lost as tools and how to use tools take over and mask the purpose. Rules become more important than the purpose

for which rules were made. Although these debates took away lot of time, fortunately we kept track of the purpose and started with information for health professionals first and in subsequent years for patients.

Another important decision making point was when we were ready with training material and had to decide if we should make them available as power point slides or as pdf. Fear that .ppt slides will be modified by people and may then contain wrong information that can tarnish the image of the IAEA had to be dealt with to allow more weightage to the benefits of providing flexibility to users and making training material more useful than the pdf. In those years it was not common to make available .ppt files on websites and we were among the first ones to take bold step and make available huge training material for free download.

Many home pages tend to be too crowded. We were conscious that we need to keep home page somewhat cleaner with lesser information. At the same time we wanted specialist audiences to be seen on home page, such as interventional cardiologists, children, pregnant patients, training material and Member States. We also decided to add rolling texts on "Did you know?" to make home page attractive. Besides conventional area of practice that medical physicists are involved in, the website also provides extensive material on radiation protection in use of fluoroscopy outside radiology in gastroenterology, urology, orthopedic surgery, protection in dentistry, in hybrid imaging, bone mineral densitometry and also material relevant for referring physicians.

After launching website in Sept 2006, an important issue was how will people find us?. It was not possible to coin a catchy short name to add to domain iaea.org. The trends in web were getting directed towards "search". Remembering URLs, navigating information pages through home page were becoming less important than reaching directly through search engine. We decided to keep short abbreviated name rpop to represent radiation protection of patients. Although no one knew this but we felt that with time it will become popular.

SEARCH OPTIMIZATION

The guiding principles were that the person should not find himself lost in a sea of information, should be able to reach the site dealing with information he is seeking in a matter of seconds.

Our emphasis was on search optimization such that addition of commonly used terms for subject of the website could lead people to first page and on top of first page of search results. No one likes to go to second page of search. After a month or so of starting website, on adding "radiation protection of patients" in Google search, I could spot our website only on page 34. Thus it was a big challenge to bring on page one. It required lot of research. Most business organizations like hotel, travel industry etc have to pay significant amount to Google to bring them on first page of Google search which we could not do, being Governmental organization. We had to create meta tags to search terms, to headings, sub-headings in content pages, search which terms are used by visitors to website to reach us and enhance material pertaining to those terms.

UPDATES

Many websites are initiated enthusiastically but not updated regularly. Our emphasis was to update the website such that just by looking at the home page, one gets a feel that the website is current. We wanted our website to be a resource that people look onto when they have to find the status of a controversial subject or happenings in the field. Latest News provided the column for this. Latest literature column was created to bring to the attention of visitors a snap shot of important papers published in the field and upcoming events is primarily an area for events of IAEA or organizations involved in IAPRPOP.

CONTENTS

It is very easy to provide long answers with lot of information, but more difficult to provide short answers with only meaningful information. There is lot of information available in world from different sources, some times conflicting. People get confused and they are looking for information from an authentic source, which they can rely upon and quote. Our objective was to meet this need. Guidelines that were prepared for contents were:

1. The questions should be catchy, inviting attention and be practically oriented as the audience is largely medical professionals rather than physicists
2. The questions should be so framed that the first line of the answer can give a feel of answer. There is need to keep in mind that the readers are busy, they should just get feel in fisrt line itself. Those interested to read more will go through full text of answer.
3. The answers should be short and crisp, invariably not exceeding 7 lines, at most 10. If more detailed information is absolutely essential, it should be provided through hyperlink (to another question, another heading with response or to another source within the website or to external website) rather than extending the same question to more than 10 lines.
4. References should be in following hierarchy a) publication of international organisations such as ICRP,

UNSCEAR, WHO, EC etc. b) statements of professional bodies in authentic publications c) international journals of repute.

5. Dynamic content with reasonable frequency of updates
6. Meeting the needs of grass roots rather than confining to professional societies or organizations
7. Mega Mall concept- all under one roof

PERFORMANCE INDICATORS AND RESULTS ACHIEVED

There are a number of performance indicators for a website. Initially we had access to only reverse proxy for hit statistics but then when Google Analytics started to become popular in 2008-2009, we switched over to it. It provides statistics on visits, geographic distribution.

Fig. 1 gives visits and page views on RPOP website in last five years. There has been continuous increase in visits and the growth rate in visit has been 27 to 53 % per year during 2008-2012 (Table 1).

Fig. 2 depicts download statistics of training material that has been made available for free download as power point slides in different areas [3]. In recent years translated material into Spanish and Russian been added and data for these languages is also included. Overall there have been more than 30,000 downloads of training material every year for the last 3 years (Table 2).

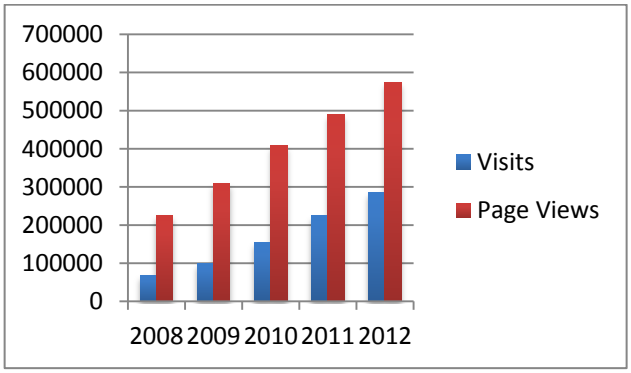

Figure 1. Visits and page views on RPOP website in last five years

Our vision has been to make a difference in the world where more than 3.6 billion diagnostic X ray examinations are conducted every year [4,5,6,7]. In that respect, while training courses, training material and website are powerful resources, still they do not have possibility to affect billions of examinations. To extend outreach further we have developed posters and made them available for free download on website [8]. These posters can be downloaded freely from website and can be printed in any size without affecting quality. They have been translated into 18 languages so far.

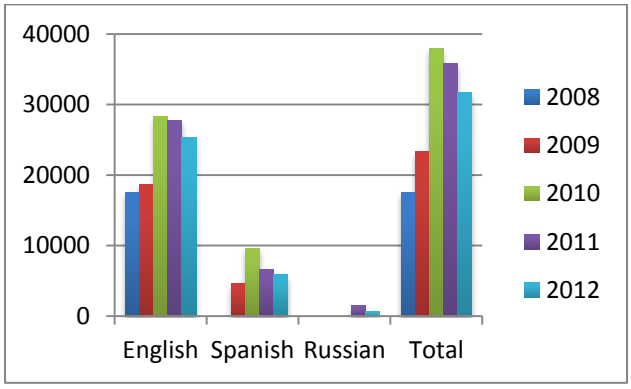

Figure 2. Download statistics of training material in different languages from RPOP website

Top ten search key words in last few years are listed in Table 3 and top ten countries visiting RPOP website are listed in Table 4. The shift as a result of making website available in Spanish language is visible in Table 4.

Table 1: Growth rates of visits on RPOP website

Year	Visits	Growth rate
2008	**67,641**	**NA**
2009	**100,393**	**48.42%**
2010	**153,475**	**52.87%**
2011	**223,739**	**45.78%**
2012	**285,753**	**27.72%**

Table 2: Top Downloads every year

Topic		2012	2011	2010	2009	2008
Training Material	Total	31693	35753	37945	23296	17496
	English	25270	27759	28327	18723	17496
	Spanish	5819	6563	9618	4573	NA
	Russian	604	1431	NA	NA	NA
Posters	Total	11101	422	NA	NA	NA
	English	10135	405	NA	NA	NA
	Others	966	17	NA	NA	NA

Table 3: Top ten search keywords

Year	Keywords
2012	Eritema, fluoroscopy, digital radiography, dental radiology, erythema, ct colonography, radiography, what is erythema, colonography
2011	Fluoroscopy, erythema, digital radiography, what is erythema, dental radiology, radiography, ct colonography, interventional cardiology, upcoming events
2010	Fluoroscopy, digital radiography, dental radiology, what is erythema, ct colonography, interventional cardiology, digital radiology, upcoming events, radiography
2009	Fluoroscopy, digital radiography, dental radiology, digital radiology, what is erythema, interventional cardiology, upcoming events, iaea workshop justification, radiography
2008	Fluoroscopy, digital radiography, dental radiology, digital radiology, interventional cardiology, paediatric radiography, radiotherapy and pregnancy, therapeutic nuclear medicine, iaea training

Table 4: Top ten countries of visit

Year	Keywords
2012	United States, United Kingdom, Spain, Mexico, Canada, India, Colombia, Argentina, Australia, Chile
2011	United States, United Kingdom, India, Canada, Australia, Spain, Malaysia, Philippines, Japan, Brazil
2010	United States, United Kingdom, Canada, India, Australia, Malaysia, Spain, Philippines, Germany, Japan
2009	United States, United Kingdom, Canada, India, Australia, Germany, Spain, Malaysia, Croatia, Belgium
2008	United States, United Kingdom, Canada, Mexico, Australia, India, Spain, Malaysia, Italy, Philippines

VII. HOW CAN ONE CONTRIBUTE?

The website provides feedback mechanism and has links with social media. A large number of medical physicist have contributed voluntarily to translation of posters into many languages and to some part of the website. Many medical physicists have contributed to development of training material and contents of the website and there is always need for further contribution by professionals. The expert panel, which reviews contents before they are uploaded, has many medical physicists. Medical physicists are primary users and contributors to the contents. The training material as provided on the website is routinely used by many thousands of medical physicists, the world over, for training purpose. The feedback provided has helped to improve material.

ACKNOWLEDGMENTS

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FREE EDUCATIONAL RESOURCE: MEDICAL PHYSICS CLINICAL SKILLS WORKBOOK FOR THERAPY PHYSICS

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Abstract: A Medical Physics Clinical Skills Workbook for Therapy Physics was developed by Rosalind Franklin University (RFUMS) and employed as part of their clinical practicum course. The workbook is now accessible from both the AAPM website and RFUMS website. This paper describes the workbook and presents student outcome data which indicate that use of the workbook facilitated student learning.

Keywords: Clinical Education, Clinical Skills, Therapy Physics, Workbook.

INTRODUCTION

Rosalind Franklin University (RFUMS) is excited to announce the availability of its Medical Physics Clinical Skills Workbook for Therapy Physics. It may be accessed free of charge for nonprofit educational purposes via the following link: http://www.rosalindfranklin.edu/chp/MRP/ClinicalSkills Workbook.aspx

It may also be accessed from the American Association of Physicists in Medicine (AAPM) website in the "Educators Resource Guide": http://www.aapm.org/education/ERG/GRADED/ or from the Rosalind Franklin University website: under "College of Health Professions", select "Medical Radiation Physics"; under "Department Links", select "Clinical Skills Workbook".

BACKGROUND

Rosalind Franklin University's Medical Physics Clinical Skills Workbook for Therapy Physics was initially developed as a guide for medical physics master's degree students in a clinical practicum course. Although the workbook was only partially completed at the time, the workbook and structured clinical practicum course together merited an award for "Excellence in Educational Innovation" at the 2010 AAPM national meeting in Philadelphia. [1,2] This early work was described in detail in an article in Electronic Medical Physics World,

http://www.iomp.org/sites/default/files/mp_world_vol_1_number_2.pdf [3]

Since that time, the workbook has been finalized. It is designed to serve as a companion text for any beginning medical physics student or resident who is new to the clinical setting and whose objective is to learn to safely, competently, and appropriately practice clinical medical physics.

What makes the workbook unique is that it does not tell the student how to do things. Instead it poses many questions and outlines various exercises to elucidate each topic. For true and accurate learning to occur, the student must discuss the answers to the workbook questions with a knowledgeable clinical practitioner/preceptor; this step is essential to a correct and comprehensive understanding of the material. By serving as a framework for what things should be understood and mastered in the clinical setting, the workbook's questions and exercises aid the student in learning how to think like a practicing medical physicist.

METHODS

In order to provide comprehensive but manageable coverage of important topics in therapy physics practice, the content of the workbook was divided into modules and units. These are listed in Table 1. The topics included are based in part on the following guidance documents of the AAPM:

- AAPM Report No. 90, "Essentials and Guidelines for Hospital-Based Medical Physics Residency Training Programs, Report of the Subcommittee on Residency Training and Promotion of the Education and Training of Medical Physicists Committee of the AAPM Education Council", August 2006, [4]
- AAPM Report No. 197, "Academic Program Recommendations for Graduate Degrees in Medical Physics, Report of the Education and Training of Medical Physicists Committee", April 2009, [5] and

• AAPM Report No. 79, "Academic Program Recommendations for Graduate Degrees in Medical Physics, A Report of the Education and Training of Medical Physicists Committee", November 2002. [6]

TABLE 1: List of Modules and Units in Rosalind Franklin University's Medical Physics Clinical Skills Workbook for Therapy Physics

Module I: Basic Clinical Skills in Radiotherapy
Unit 1: The Clinical Environment
Unit 2: Simulation
Unit 3: Clinical Conduct
Unit 4: Chart Checking
Unit 5: Record and Verify Systems
Unit 6: Basic Radiation Safety
Module II: Quality Assurance in Radiation Oncology
Unit 1: Linear Accelerator Quality Assurance
Unit 2: Acceptance Testing and Commissioning
Unit 3: Measurement Equipment QA
Unit 4: CT Simulator QA
Unit 5: Portal Imaging and kV X-ray Imaging QA
Unit 6: Cone-beam CT QA
Unit 7: PET-CT QA
Unit 8: HDR QA
Unit 9: Software System QA
Unit 10: Prevention of Technology-Related Errors
Module III: Treatment Planning
Unit 1: Prerequisites for Treatment Planning
Unit 2: Mark and Start Cases
Unit 3: 3D-Conformal Planning
Unit 4: IMRT Planning
Unit 5: Protocols
Unit 6: Secondary Monitor Unit (MU) checks
Unit 7: Block Cutting
Unit 8: Diodes / TLD
Unit 9: Beam Data Collection, Modeling, and Commissioning
Module IV: Special Procedures
Unit 1: Radiosurgery
Unit 2: LDR Brachytherapy
Unit 3: HDR Brachytherapy
Unit 4: TBI Electrons and Photons
Unit 5: IGRT methods
Unit 6: Rotational Therapy
Unit 7: Proton Therapy
Module V: Health Physics
Unit 1: Radiation Safety
Unit 2: Instrumentation for Health Physics Measurements
Unit 3: Shielding Calculations
Unit 4: Isotope Procedures

Each unit begins with a list of applicable references, although the student is instructed to supplement these by seeking out additional and updated guidance documents for each topic. Next, unit objectives summarize measurable learning goals. Most units are subdivided into tasks, consisting of various questions and exercises designed to guide the student through the topic material. For the more fundamental sections in the workbook, the student is led more methodically (e.g. analyzing in detail each step of a clinical process); as the student progresses, the questions become more open-ended and require a greater facility with clinical problem-solving skills (e.g. designing one's own form or method, which may differ from their preceptors').

The workbook's table of contents and several of the included references in the document are hyper-linked to aid the student in quickly accessing relevant material. Because the workbook was originally designed as part of a structured clinical practicum course, it contains a copy of the practicum course syllabus (as an appendix), as well as various forms for student use.

Chief among these forms is the comprehensive Clinical Competency List. This tool can be employed to track student progress through the workbook topics. At Rosalind Franklin, preceptors were asked to regularly re-assess the student's level of familiarity with each item (i.e. at the end of each academic quarter). The scores ranged from "1" ("observation only") through "4" ("competent"). In the final version of the workbook, the goal set for the medical physics master's degree students was to achieve scores of "3" ("competent with supervision") or "4" ("competent") in at least 80% of the items by graduation. No items were allowed to be left blank (a score of "0"). Certain items were designated as "core concepts": for these items, students were required to achieve a "3" or a "4". If this workbook were to be applied in the residency setting, an appropriate goal could be to expect scores of "4" ("competent") in at least 90% of the items, and "3" ("competent with supervision") for the remaining 10% of the items. In addition to quarterly competency lists, students were required to keep a composite competency list which tracked their scores over multiple quarters.

Besides completing the questions and exercises in the workbook, students were expected to document every clinical task which they observed or in which they participated by writing a thorough procedure in their own words. These documents were reviewed for accuracy and adequate detail by both the preceptor and university faculty. The optimum procedures included enough detail to allow someone unfamiliar with the process to accomplish the task. Besides giving the students practice in writing such documents, the procedures often proved helpful to the clinical staff at the various rotation sites.

Students further documented their time in the clinic by keeping detailed attendance sheets which listed their tasks each day. Preceptor-signed attendance sheets and Clinical Competency Lists have been used by students as proof of their clinical education and experience. Students were also required to gain practice in explaining medical physics topics to the clinical staff by preparing and delivering power-point presentations at their rotation sites. This often had the added advantage of providing an opportunity for radiation therapists to earn continuing education credits.

From time to time, students found themselves confronted with competency list items that could not be accomplished at their current clinical rotation site. In some cases, certain clinics did not have the equipment or simply did not perform the procedure specified by the workbook. In these cases, the students were instructed to address the topic as a "thought experiment". They were told to imagine that the lead physicist or physician had approached them and asked them to be ready to perform the procedure in a few weeks. They would need to consult guidance documents, perhaps gather information from vendors, plan how they would be ready for the procedure, decide what measurements they would make, determine how exactly they would make those measurements, and address how they would know that everything was correct and prepared for the patient's treatment. They would then be required to write up their proposed procedure and review it with their preceptor.

EVALUATION AND DISCUSSION

Early drafts of the workbook were implemented in the medical physics clinical practicum course at Rosalind Franklin in 2008. These initial drafts included only certain sections. Over time, as the workbook became increasingly comprehensive, composite competency list scores at graduation were evaluated to assess the benefit of a workbook-based structured clinical practicum course compared with the previous "follow and learn" method.

The RFUMS Medical Radiation Physics master's degree is a two-year (7 quarter) didactic program which includes clinical practicum work in 6 of the quarters. It is important to note that the 2009 graduating class used the workbook for only three of their six clinical quarters. The 2010, 2011, and 2012 graduating classes used the workbook for all six clinical quarters. However, beginning with the 2011 class, students were told that their goal should be either "3" ("competent with supervision") or "4" ("competent"); either of these would be viewed as equally successful in terms of the graduation requirements for the master's degree.

Figures 1, 2, and 3 present histograms of the composite competency list scores for the 2009, 2010, and 2011 graduating classes. The scores are expressed as a percentage and are shown for each student. This data indicates that the students using the clinical skills workbook employed in the context of a structured practicum course (the classes of 2010 and 2011) achieved higher composite competency list scores at graduation than the students who did not have these resources for their entire clinical experience (the class of 2009).

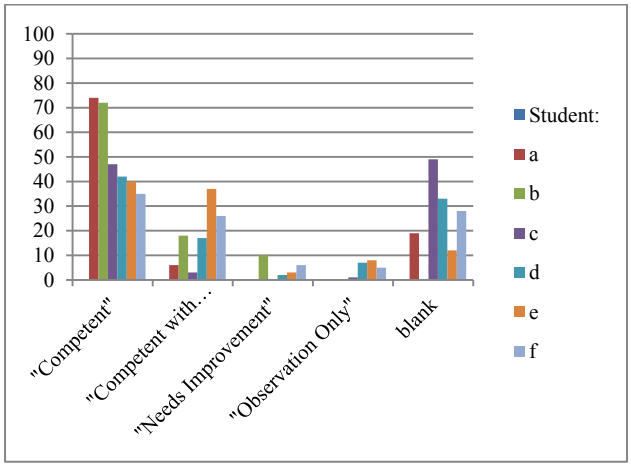

Fig. 1 Histogram Representation of Percentage Composite Competency List Scores at Graduation for 2009 Graduates: these students used the traditional "follow and learn" method for their first 3 quarters in the clinic, and used the workbook in the context of a structured clinical practicum course for their second 3 quarters in the clinic.

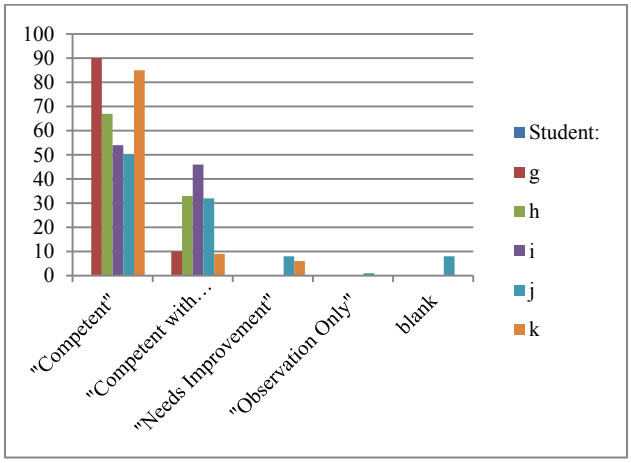

Fig. 2 Histogram Representation of Percentage Composite Competency List Scores at Graduation for 2010 Graduates: these students used the workbook in the context of a structured clinical practicum course for all 6 quarters in the clinic.

In Figure 4, because students were advised that their goal should be either "3" ("competent with supervision") or "4" ("competent"), each students' competency list scores of "3" and "4" were combined, and data for all three graduating years are shown on the same histogram. In Figure 5, the data of Figure 4 was used to calculate mean percentages of composite competency list scores at graduation for each class.

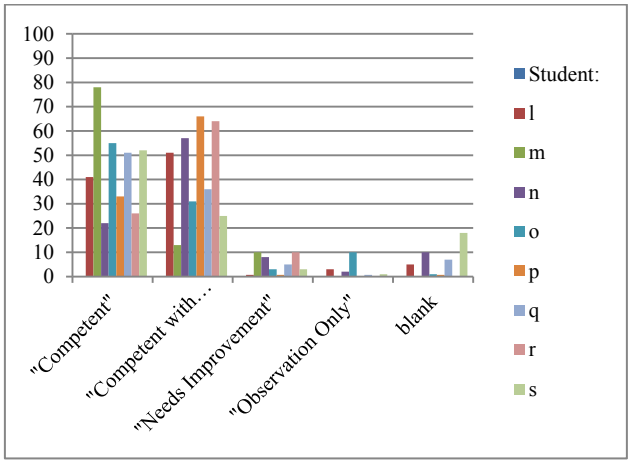

Fig. 3 Histogram Representation of Percentage Composite Competency List Scores at Graduation for 2011 Graduates: these students used the workbook in the context of a structured clinical practicum course for all 6 quarters in the clinic, but were told that their goal should be either a score of "3" ("competent with supervision") or "4" (competent") for each item in the competency list.

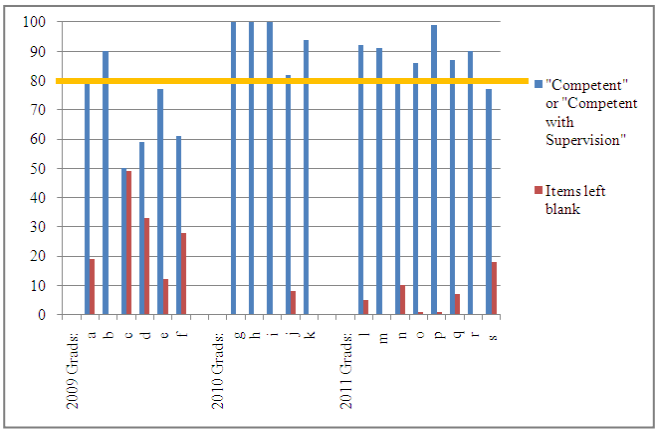

Fig. 4 Comparison of 3 Graduating Classes (2009, 2010, & 2011): Histogram representation of percentage composite competency list scores at graduation combining scores of "3" ("competent with supervision") and "4" ("competent"). The yellow line represents 80% of the items in the competency list.

In Figure 6, a mean score for each student was calculated from their composite competency list at graduation, taking into account the individual scores for all items, with each item having received a score of "4" ("competent"), "3" ("competent with supervision"), "2" ("needs improvement"), "1" ("observation only"), or "0" (blank). From this data, overall mean scores were then computed for each class. The yellow line represents an overall mean score at graduation of "3" or "competent with supervision".

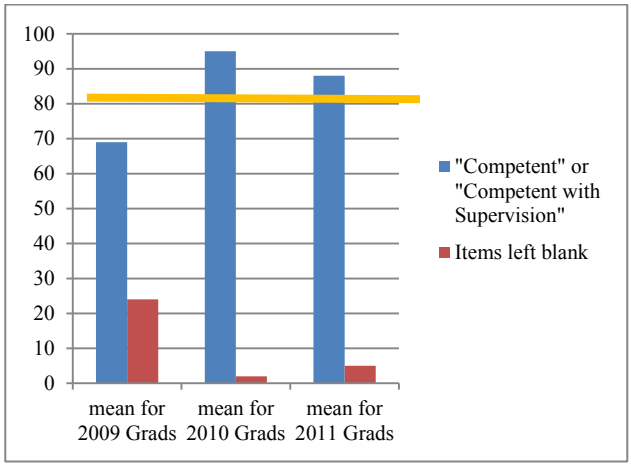

Fig. 5 Comparison of 3 Graduating Classes (2009, 2010, & 2011): Histogram representation of mean percentages of composite competency list scores at graduation calculated for each class. The yellow line represents 80% of the items in the competency list.

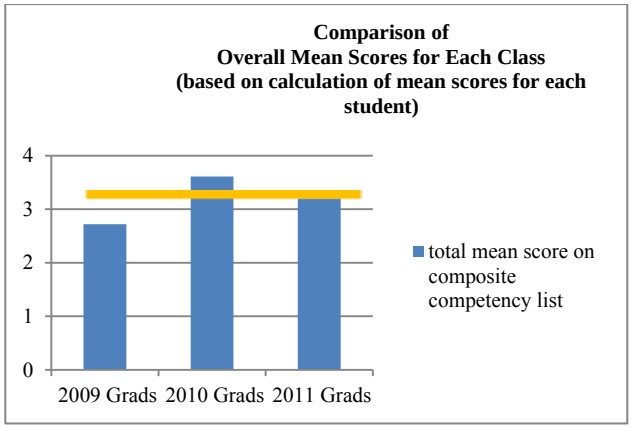

Fig. 6 Comparison of 3 Graduating Classes (2009, 2010, & 2011): For each student, a mean score was computed from their composite competency list at graduation, taking into account the individual scores for all items (each item having received a "4", "3", "2", "1" or "0"). From this data, overall mean scores were computed for each class. The yellow line represents an overall mean score at graduation of "3" or "competent with supervision".

Based in part on this data, the 2012 graduating class was required to achieve a minimum score of "3" ("competent with supervision") for at least 80% of the items in the competency list, and no items were allowed to be left blank. Also, certain items were designated as "core competencies"; these were required to be completed with a score of "3" or "4". It should be noted that the 2012 graduating students did meet all of these requirements. However, the class was deemed too small for accurate analysis of the data and hence was not included here.

In addition to examining student composite competency list scores, a per-item analysis was performed by computing the mean score for each competency list item for each graduating class. This enabled added emphasis to be given in the next year to items that did not achieve a mean score of "3" in the previous year. A per-quarter analysis of this same data for each class revealed a large variability because of the small number of students. Similarly, there was not enough data to accurately seek a correlation between competency list scores and final clinical oral exam scores. However, if more data were accrued, these analyses could prove helpful. Also, it could be insightful to aggregate and re-sort the data from each quarter by clinical site. This could allow a quantitative assessment to be made of the strengths and weaknesses of each site/preceptor combination, and hence assist in future student clinical placements.

Even though the data presented here is based on a small population (19 students total spanning 3 graduating classes), the workbook was judged sufficiently valuable to recently merit wider availability through the AAPM website (under "Medical Physics Graduate Education" in the "Educators Resource Guide", found beneath the heading "Education") and through the Rosalind Franklin University website. The workbook may be used free of charge for non-profit educational purposes. To make potential users aware of the workbook's availability, the links to the websites were sent to directors of CAMPEP-approved medical physics academic programs and residencies. It is the author's hope that the workbook will benefit many future students in various clinical settings.

CONCLUSIONS

The Rosalind Franklin experience with the clinical skills workbook employed in the context of a structured practicum course indicates that the workbook aided master's degree students in successfully mastering tasks which comprise therapy medical physics practice. The workbook provided a framework outlining important topics and guided students in acquiring the critical reasoning and problem-solving skills necessary for the clinical setting. In addition, the workbook's competency list provided a method of assessment.

This workbook can easily serve as a companion guide for any medical physics student or resident who is working closely with a knowledgeable preceptor/mentor and who seeks to learn to safely, competently and appropriately practice clinical therapy physics.

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

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Abstract: **The most effective optimization of CT image quality and related radiation dose management requires a clinical imaging staff with knowledge of the physics principles that apply to the imaging process. This knowledge can be developed through a combination of learning activities, including classroom discussions, but a critical requirement is guided learning activities associated with the clinical imaging procedures. A program is described for including physics education within clinical activities, especially for trainees, and online open access resources are provided to enhance the process.**

Keywords: **Computed Tomography, Physics Education, Image Quality, Radiation Dose Management.**

INTRODUCTION

Computed tomography (CT) is now one of the most effective and valuable imaging methods for medical diagnosis and guiding therapeutic procedures. With the continuing advances in technology there is the capability to produce images with characteristics that can be optimized for a wide range of clinical purposes. Also, there is the need to manage the radiation dose for each patient and balance it with respect to the image quality requirements. This is achieved by adjusting the protocol factors for each procedure. Developing an optimized protocol requires knowledge of the clinical requirements, the design and functional characteristics of the equipment, and especially the physical principles and physics that is the foundation of the CT imaging process. There is a significant challenge in providing the medical professionals who have responsibility for and who conduct CT procedures with the appropriate knowledge of physics that can be applied to enhance the effectiveness and safety of CT. A model of a collaborative approach to providing this education, on a global basis, is described along with the online resources that are open access and can be used in any CT program.

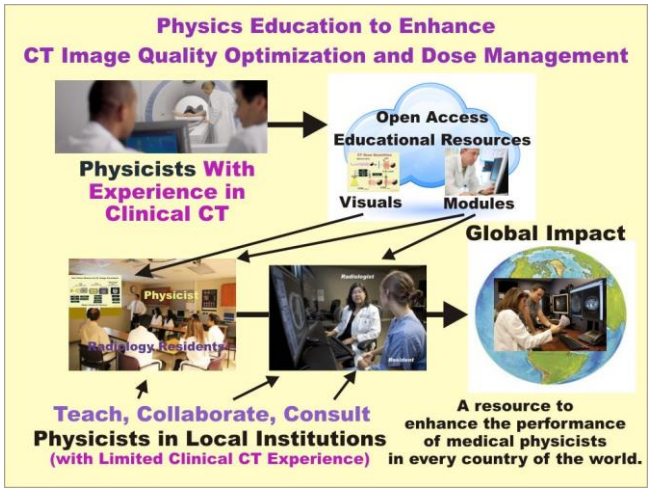

Figure 1. The model of a program to provide physics education to support clinical CT procedures.

CONTROLLING THE CT PROCEDURE

There are two major factors that can be controlled in each CT procedure as illustrated in Figure 1. One is the characteristics and quality of the image and the other is the radiation dose delivered to the patient. The direct control of these by the medical staff is through the adjustment of the imaging protocol which is the complex combination of quite a few individual protocol factors.

A. Technology. The imaging capabilities and ability to manage radiation dose that are available in a specific clinic depend on the design characteristics of the CT equipment. With the continuing development and innovations there is generally the opportunity to produce higher quality images and to do it with a reduced radiation dose to the patient. However, this can only be achieved if the staff is capable of developing and using protocols that are optimized for each.

B. Science. Physics is the fundamental science of CT. The imaging process and the design of the technology are based on physics principles. That is the knowledge used by physicists and engineers in the

continuing development of CT technology. However, of equal significance is the knowledge of physics required by the medical professionals who conduct imaging procedures. This is the knowledge that must be applied in the intelligent selection, adjustment, and optimization of imaging protocols.

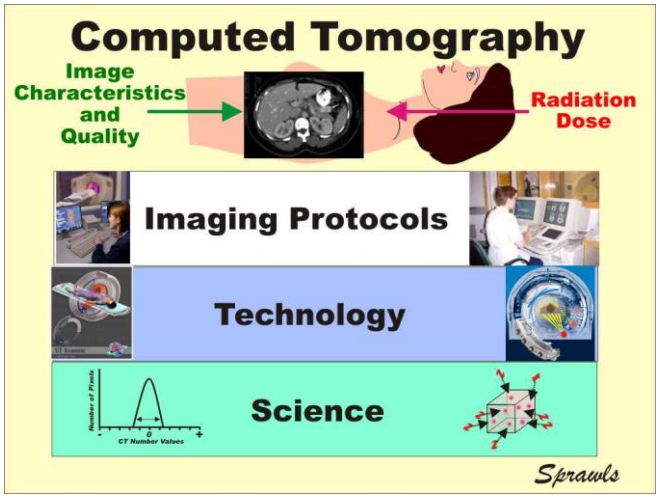

Figure 2. The major factors that determine image quality and dose to the patient.

PHYSICS KNOWLEDGE STRUCTURES

Knowledge of physics is actually a mental representation of various components of the physical universe, depending on the specific areas of study and experience, medical physics being the one that is our interest at this time. Physics knowledge structures consist of a complex combination of elements including images, words, and mathematical quantities. The organization of these elements contributes to a higher level of knowledge in the form of principles, concepts, and the ability to analyze conditions and apply the knowledge to innovate and produce solutions to a variety of questions or problems.

A. Appropriate Knowledge Structures. The physics knowledge structure that is appropriate for an individual depends on the work or functions that they are to perform. The knowledge structure needed by physicists and engineers who develop CT technology, new methods and procedures, and evaluate quality and performance is very different from that needed by the medical imaging staff conducting clinical procedures.

B. Physicists and Engineers: They need a strong quantitative (mathematical) understanding of both the physics and technology in order to innovate, develop, and analyze new possibilities. This also applies to the clinical medical physicist who evaluates image quality, system performance, and plays a major role in radiation dose management. This knowledge comes from physics and engineering study, typically at the graduate level, and practical and applied experience.

C. Medical Imaging Professionals: This is the team of professionals who have responsibility for and conduct the CT imaging procedures. They include radiologists, trainees (residents and fellows), and technologists who operate the equipment. They need a physics knowledge structure that applies to their functions. It needs to give them insight into and an understanding of the CT process with which they can interact. To a great extent it needs to make what is generally an "invisible world" visible so that useful knowledge structures can be formed and used.

VISUALIZATION

A major factor in providing effective medical physics education, especially for medical imaging professionals, is to enable them to visualize the imaging process and especially the relationships among the various components and elements. This helps form mental knowledge structures of the CT process that go beyond just seeing the equipment and the images. Here we have two examples.

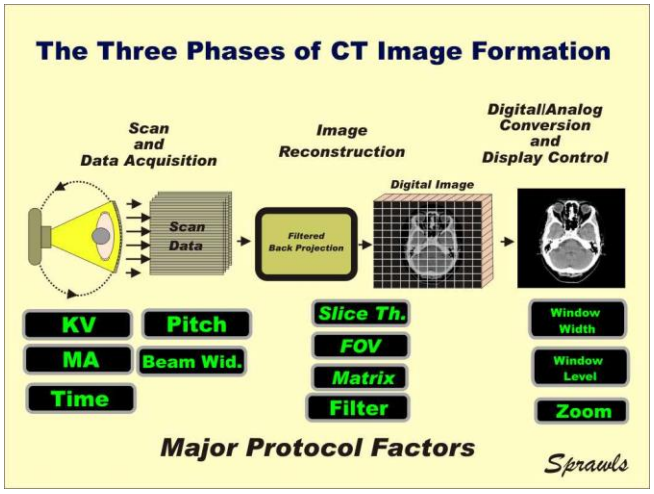

Figure 3. The three phases of the CT imaging process and the major protocol factors associated with each.

This visual provides a comprehensive view of the CT process and shows where it is possible to interact and control the characteristics and quality of the images. This is the type of knowledge that cannot be conveyed by words alone or mathematical equations.

One of the most difficult topics for many to understand is the different quantities that are used to express radiation dose, their relationships, and the factors that control them. That is all brought together in this one visual.

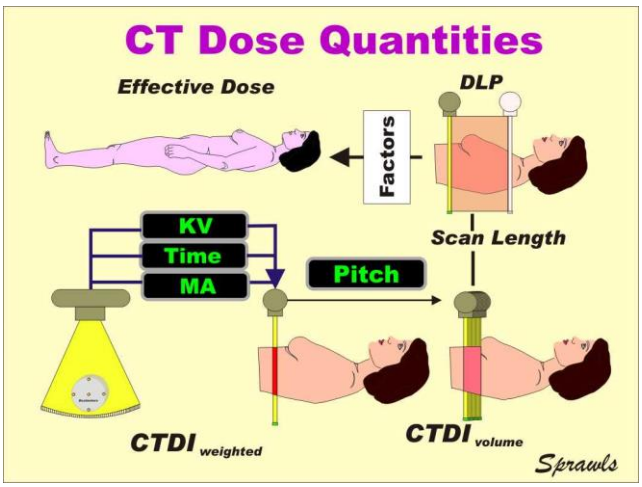

Figure 4. The relationship of the various radiation dose quantities used in CT.

LEARNING AND TEACHING PHYSICS

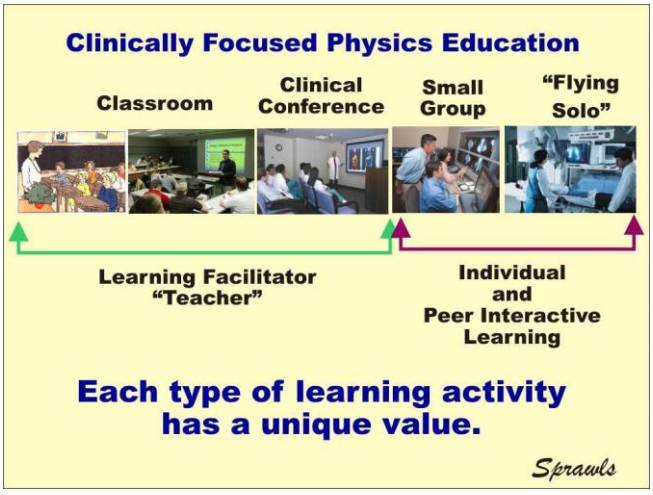

Figure 5. The series of learning activities that contributes to physics knowledge that can be applied to clinical imaging.

Knowledge of physics, and especially medical physics, is developed through a series of learning activities ranging from classroom to direct clinical experience as shown here.

A major objective of medical physics education for medical imaging professionals is to enable them to apply physics principles in the control and optimization of the imaging process, such as CT. The different types of learning activities have their advantages and values but also their limitations and challenges. The goal is to provide a combination of activities that produce the desired results.

A. Classroom and Conference Presentation.

Both of these obstacles can be overcome to a great extent by the use of the web-based resources provided here. These are visuals for classroom/conference presentations and discussions (Ref. 1) and a module (Ref. 2) to support both classroom learning and as a review and reference during clinical activities.

The Visuals can be used by medical physicists, even without significant CT experience, to conduct classes and conference discussions on the physics that is the foundation of CT. They are used in the context of *Collaborative Teaching* where the physicist conducting the class or conference discussion uses his knowledge and experience in general and radiation physics in combination with the Visuals prepared by a collaborator, in this case the author, who has extensive experience in the physics of clinical CT. A significant value of the visuals is that they provide a highly-effective connection between the classroom and the clinical CT process. It enables the learners to develop mental knowledge structures that will support their clinical activities, specifically analyzing images and optimizing procedures.

The online module can be assigned to the learners, rather than a traditional textbook, for additional study, review, and reference.

LEARNING PHYSICS IN THE CLINIC

The clinical environment where the learner is actually participating in CT procedures provides an excellent opportunity for learning physics. The great advantage of this, compared to the traditional classroom is that there is direct observation and interaction with the equipment, the images, and the procedures. Here the learning experience can be directed by the experienced clinical radiology faculty. The online module is used as a review as the learner begins a clinical CT rotation and as a reference as questions come up and during discussions with the clinical faculty.

While it is important to produce images of superior quality, it is also important for trainees to understand the cost of radiation dose when evaluating CT images. Despite the increased focus on radiation dose, few radiologists routinely examine the CT dose report on every patient, especially when the images are of good quality. It is important that radiology trainees be aware of the principle of As Low As Reasonably Achievable (ALARA). While images should be of diagnostic quality, some noise should be expected for most exams if the radiation dose is considered. Discussing the dose report routinely raises awareness of CT dose and its relationship to image quality and also reinforces concepts of CTDIvol, DLP, and effective dose with the increasing complexity of newer scanners.

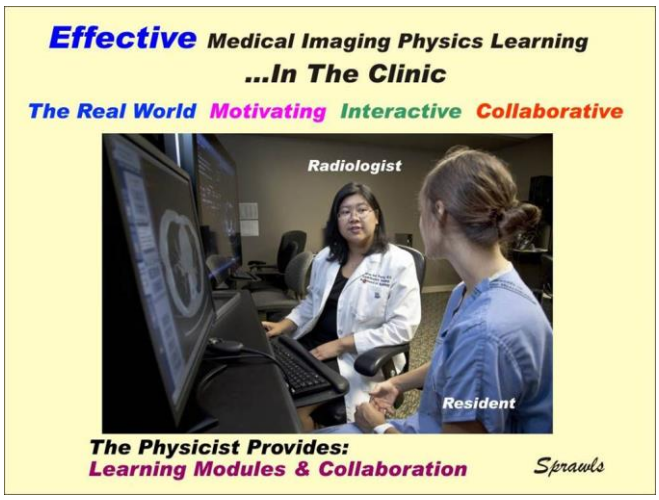

Figure 6. Advantages of physics education in the CT clinic.

A The Need for Clinically Focused Physics Education.

It is also essential to understand how to implement dose saving techniques including automatic tube current, tube potential selection, and iterative reconstruction. Adjusting these parameters can be confusing, particularly when dealing with multiple scanner platforms which employ different quality reference standards. Also, while these techniques can be of great benefit when used properly, radiologists and technologists need to be aware of the pitfalls. For instance, as tube current modulation is based on the scout image, the tube current will be defaulted to the maximum if the patient is scanned beyond the region included on the scout.

In the age of digital imaging, radiologists have less contact with technologists and imaging equipment in daily practice. Reviewing physics in the clinical setting can help trainees learn to rectify suboptimal images and become more aware of radiation dose. Discussing real life examples reinforces these concepts and makes them less abstract.

B Providing Clinically Focused Physics Education.

Suboptimal images present an opportunity to discuss imaging parameters (tube current, tube potential, rotation speed, and pitch) as it relates to image quality and dose specific for that patient. This can be especially instructive when there is a prior comparison exam using a different technique. Trainees can also be shown the effects of poor patient positioning, which can result in suboptimal image quality and higher dose to the patient. The presence of artifacts may prompt a discussion on the purpose of daily and periodic quality control. Radiologists need to be able to distinguish between equipment artifacts, noise, a poorly positioned patient, and operator error. The objective, for a trainee, should be to provide a comprehensive physics learning experience during a clinical rotation. This begins with the study of the online module followed by a discussion with a physicist if available, reviewing and answering questions as needed. As clinical cases are interpreted the radiologist can address image quality and procedure issues and ask questions of the trainee. This is a more effective learning experience if a plan is followed that includes specific topics to discuss and related questions. The plan can be developed as a collaborative effort between the radiologist and physicist. The objective for the clinical staff is to review and enrich their knowledge of physics as it applies to CT by studying the online module in the context of continuing education.

CONCLUSION

The optimization of CT imaging procedures to produce maximum image quality and clinical information along with effective dose management requires knowledge of applied physics principles by the medical professionals with responsibility for the CT procedures. The development of an effective educational program needs to combine the advantages and values of different types of learning activities with a special emphasis on "clinically-focused" activities where the trainee/learner is actively involved with the imaging process. Medical physicists affiliated with radiology educational programs and clinical CT activities can contribute to the process by using open access resources for both classroom and in-the-clinic learning activities. The two authors, one a physicist (PS) and one a radiologist (P-ATG) are finding this collaborative and clinically-focused educational model to be very effective especially for radiology resident and fellow training. It has added a new dimension to more traditional medical physics education.

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INTRODUCTION TO VISION, COLOUR MODELS AND IMAGE COMPRESSION

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Abstract— The paper presents an introduction to the human vision and perception of colours. Short examples are given for spatial resolution of a normal eye and its colour sensitivity. Several colour models are briefly presented with emphasis on Hue Saturation Value (HSV) model. The concept of the latter is shown as underpinning the implementation of digital image compression. Elements of the paper can be used as introductory to various educational modules/courses on medical imaging.

Keywords— human vision, colour models, image compression, medical imaging educational resources

TRICHROMATIC COLOUR REPRESENTATION

Colour theory is in the focus of imaging sciences from the time of Leonardo da Vinci. Some milestones include Isaac Newton's Theory of Colours (in Opticks, 1704), Michel Eugène Chevreul's Law of Simultaneous Color Contrast (1839), Young–Helmholtz Trichromatic Colour Vision Theory (1850) [1], and James Clerk Maxwell's Colour triangle (1860). These fundamental scientific works were supplemented by works of philosophers and artists such as Goethe (Theory of Colours, 1810), Schopenhauer's On Vision and Colors, and importantly, Albert Munsell's artistic Color System and Notation (1912) [2].

The complexity of the Colour theory is based on the mix of scientific (light), physiological (vision) and psychophysical (perception) components [3]. Initially Newton's discovery that colours could be created by mixing of colour primaries led to selection of three "pure" or "primary" colours, which were accepted as Red, Yellow and Blue (RYB Colour model). Goethe also adopts these "primary" colours and today many artists and painters consider the RYB as "primary". In parallel Thomas Young suggested that the eye includes three specific colour receptors (1802) and later (1850) Hermann von Helmholtz developed these ideas further to suggest that these three types of photoreceptors (later named cone cells) could be classified as short-preferring (blue), middle-preferring (green), and long-preferring (red), as per their response to various light wavelengths. This established the RGB colour model, used extensively at present. The actual cone cells in human retina were described one century later by Gunnar Svaetichin (1956) [4].

Most of those pioneers accepted that the mix of three primary colours can reproduce all colours in the light spectrum. Any departures from this assumption were explained with the impurity of the primary colorants (dyes) used. Today we know that 3 primary colours can only create a limited number of colours (a gamut). This number is smaller than the human eye can perceive, but is more than sufficient for reproduction of colour in prints, monitors, etc. The trichromatic theory led to the use of the RGB model for television and John Baird created the first colour TV transmission (1928) using Red, Green and Blue emitting phosphors [5]. This established the RGB as the technical "primary" colours.

The fact that active displays (projecting light, as TV monitors) add various proportions of Red, Green and Blue light intensity to form a specific colour from the gamut, led to naming these colours "additive". The addition of all three colours in their maximal intensity will produce almost white light. In contrast, pigments which absorb these specific RGB colours from the spectrum of the light they reflect, were named "subtractive" colours. The subtractive colours of Red, Green and Blue are respectively Cyan, Magenta and Yellow (CMY) – see Figure 3. These are sometimes called "subtractive primaries", or "secondaries", or incorrectly "negatives" (following the photographic white-black analogy). Light reflected from maximal concentration of CMY pigments will be almost black as its RGB components will be absorbed by the pigments. The CMY subtractive colour model is used for colour printing, but black (K) is added as a separate pigment (to avoid use of too much colour pigment ink) – the so called CMYK model.

The need of better colour digital printouts (more colour nuances) required the inclusion of additional subtractive colours (e.g. light cyan, light magenta) forming a six-colour printing (aka CMYKLcLm), while the additive colours remained almost unchanged. Today all colour digital monitors form their colour pixels by three active elements with Red, Green and Blue glass filters over their emitting area, and similarly the photosensors of most digital photo camerasare covered with similar RGB glass filters – the Bayer filter. This filter includes 50% Green and 25% for each Red and Blue to reflect the increased sensitivity of human eye to green light [6] – see Figure 1.

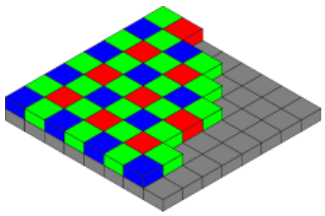


Figure 1. Bayer filter (image cited from [32])

COLOUR SENSITIVITY AND RESOLUTION OF THE HUMAN EYE

The discovery of the light sensitivity of the cone cells and rod cells in the human eye retina (G. Wald & P. Brown at Harvard, and E MacNichol, W Marks & W Dobelle at John Hopkins, 1964) placed the RGB model on more solid scientific background [7,8]. Although the photoreceptors of the retina had been known since the 19 century and the light-sensitive protein rhodopsin had been discovered by Franz Boll in 1876, the more detailed understanding of colour perception needed some 100 years further research. Despite this, the visual perception and the colour processing in the human brain are still not well understood.

What we know currently is that the three types of cone cells in the retina of the human eye have the following response to light [9]:

- Blue sensitive cone cells (aka S cones, for Short) with peak sensitivity around 420-440 nm
- Green sensitive cone cells (aka M cones, for Medium) with peak sensitivity around 534-555 nm
- Red sensitive cone cells (aka L cones, for Long) with peak sensitivity around 564-580 nm

The other type of photosensors in the retina - the rod cells - have sensitivity between Blue and Green (but closer to Green) with peak at about 498 nm – see Figure 2. The rods are very sensitive to light (about 100 times more sensitive than cones) and provide vision at low intensity levels (twilight and night vision) [10].

The rods in the human retina are about 120 million, compared with cones, which are about 6 million in total. The cones are mainly concentrated in the macula of the retina and are larger than rods (cone diameter is c. 0.006 mm, while rod diameter is c. 0.002 mm) [12]. The distribution of the cone cells is roughly accepted as 64% reds, 32% greens and 2% blues (also, their distribution in the retina is not homogeneous) [13]. Due to this reason the maximum sensitivity of the human eye is in the region of the green-yellow colour. As the cones are responsible for perception of the high-resolution images, the representation and transmission of colour is directly related not only to the visual contrast resolution, but also to the spatial resolution.

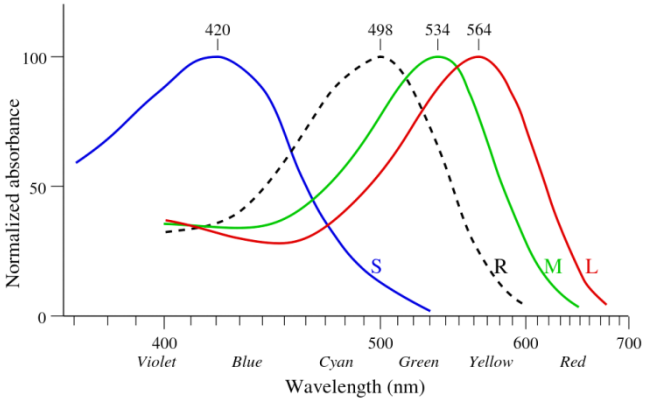


Figure 2. Response of cone cells (S, M, L) and rod cells (R) to light wavelength (image cited from [10], based on [11])

If we take a rough example [14] of reading text from 50 cm distance (book to eye lens) and assume c. 2 cm distance from the eye lens to the retina, the observed text (image) will be minimized 25 times over the retina. Projecting the size of the cone (0.006mm) over the text, will present an object of 0.006x25=0.150 mm (i.e. a pair will be 0.3 mm). This object size corresponds to 3.33 lp/mm (line pairs per mm). For printing, about 170 such objects will be displayed over 1 inch – i.e. 170 dots per inch (dpi). This indicative example gives an estimate of the minimal acceptable spatial resolution (without zoom or optical magnification) of observed printouts or films with normal eye at 50 cm. However the vision acuity depends on the observation distance. Usually the visual acuity is expressed in cycles per degree (cpd), this taking into consideration the viewing angle (and the distance from the object). As every optical system, human eye has its Modulation Transfer Function (MTF), its Contrast Sensitivity, Subjective Quality Factor, etc – for more information on the subject see [15].

The colour sensitivity of the human eye depends on various parameters, most notably the luminance. Usually it is accepted that a normal untrained eye could distinguish between 150 and 250 different grey shades, while the number of distinguishable colours in this case can be from 100,000 to several millions [16]. As medical imaging relies mainly on grey scale images, research has shown that a well trained eye could distinguish around 870 just noticeable differences (JND) of grey [17]. The pixels of contemporary digital medical images use 16 bits, of which usually 12 bits are used to record the image contrast, and the other 4 bits are used for supporting information (for example text or graphs displayed over the image). The 12 bits present 4096 levels of grey (2^{12}) what is more than enough for the human vision. A special Windowing technique is applied to adjust this large number of grey levels to the less-sensitive human eye [18]. Historically the selection of 4096 grey levels has

been based on the early CT scanners, where the difference between CT numbers of air and water has been accepted as 1000, while the most absorbent bones are up to 3 times this absorption difference, thus forming a CT number scale from -1000 through 0 (water) to +3000. The practice has shown that 4096 levels of grey are also sufficient for various densitometric measurements (measurement the optical density of the pixel, corresponding to the radiation absorption of the respective voxel from the anatomical object).

COLOUR MODELS IN IMAGE TRANSMISSION AND PROCESSING

The transfer from black/white (B/W) to colour television in mid-20th century led to a different way of colour representation. The TV engineers at that time decided that if they would transfer separately a signal related to light intensity and signal related to the colour, a TV monitor could reproduce respectively either B/W image or colour image. This is how another colour model was introduced – YUV, where the light intensity Y (aka "luma" signal, used for B/W images) was separated from the two colour (aka "chrome") signals U and V. This separation, applied to analogue TV transmission, used information from all three RGB colour signals to form the Y signal and a specific formula to form U and V [18]. The matrix below shows a typical conversion from RGB to YUV – here Y varies from 0 to 1 (as RGB), while U and V vary from minus to plus values (U: -0.436 to +0.436 and V: -0.615 to +0.615) [20].

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.147 & -0.289 & 0.436 \\ 0.615 & -0.515 & -0.100 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

The YUV colour model has been used for analog PAL and analog NTSC TV signals (in some cases the model have some variations in calculation of the three components). Importantly the YUV model allowed reduction of the bandwidth in the TV transmission of the two "chroma" signals – i.e. allowed transmission of reduced number of colours, without significant compromise of the colour perception of the eye [19].

The introduction of digital imaging opened new horizons to image processing, compression and transmission. The necessity of more colours in the imaging information required a new presentation of the colour space. This was solved by a new technical application of the artistic colour scheme. This breakthrough was realised by Dr Alvy Ray Smith (with degrees both in Arts and Computer Science), who introduced the HSV colour model in the mid-1970. This is how he describes the development of the HSV model [21]:

"One of my best friends showed me his paint program at this new place called Xerox PARC. I knew this was exactly what I was looking for, a combination of art and computers. I got hired on as an artist to show off Dick Shoup's SuperPaint program (software and hardware). Now I can tell you the story of HSV.

Early in my encounter with SuperPaint I went to Dick and asked him what the algorithm was for converting the natural video color space of RGB to HSB (as I called it at first and as it is still called in Photoshop), which we artists use. I told him that I couldn't figure out how to make pink, say, with RGB, but for artists it was easy: choose red paint, add white paint to it to lighten it to pink. Easy! I also used brown as another example. Again I couldn't figure out how to make brown from RGB. But for artists it's easy: choose an orange red hue and darken it with black. Easy! That's when Dick informed me that no such algorithm existed.

So I started working on the algorithm. It had to exist obviously. So by the next morning I had it. I got to it by standing the RGB cube up on its main diagonal (the one from black to white), looking at it down that axis. That's where the hexagon comes from. The rest of it I just worked out so as to have a hue circle (like in a paint store), although the "circle" was a hexagon in this case. I thought first about a double-ended cone then rejected it as just a little more complex than a single-ended cone. (In those days every extra step cost.) That's it. What was wonderful about it was that it was VERY simple, which mattered a lot. So I coded it and inserted it into Dick's program. In short it took only a day to do the whole thing.

Then I spent years explaining to people that, despite its axes names, it wasn't REALLY a perceptually based system. That's when I stopped calling it Hue Saturation Brightness. The B axis was clearly NOT brightness. It was the amount of black, or Value as artists call it. And I insisted that it be called HSV after that."

The actual RGB to HSV transformation is described in SIGGRAPH 78 Conference Proceedings, Aug 1978 [23]. It should be mentioned that this transformation did not require expensive software techniques (very important in these early days of image processing).

The transfer of the artistic understanding of colours into the technical world revolutionised digital imaging as, although the immediate visual result is not intuitive, it allows new ways for image compression where significant reduction of image file size is achieved with minimal disturbance of the visual perception. This new concept founded the digital paint systems and opened new ways for digital image processing.

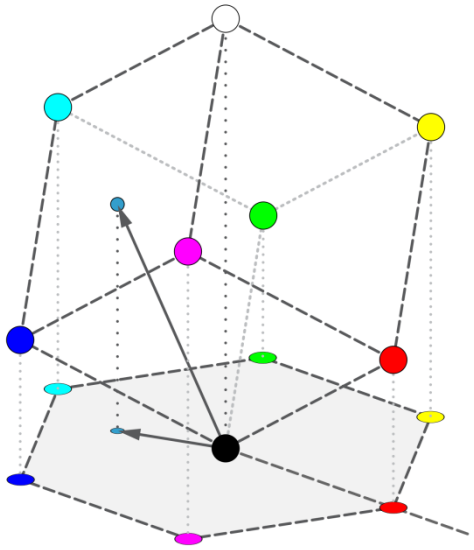


Figure 3. The figure is used to support Dr A R Smith description - projection of the RGB cube (with its CMY values, opposite their respective "additive" colours) into a hexagon (image cited from [22])

In 1982 the TV colour model also moved to digital with the YCbCr presentation of colour space, defined in the ITU-R BT.601-5 and ITU-R BT.709-5 standards of the International Telecommunication Union (ITU) [24]. YUV and YCbCr are similar, but YCbCr applies to digital systems, while YUV is for analogue TV systems.

COLOUR MODELS AND DIGITAL IMAGE COMPRESSION

When the RGB model is used, each colour could be presented in a coordinate system, where each of the "primary" RGB colours varies from zero to maximum value (e.g. from 0 to 1, or from 0% to 100%, or from 0 to 255 brightness levels, etc). The method is precise but requires lots of memory (full size of the image file) to describe the RGB coordinates of each colour from the light spectrum. Additionally, the RGB (or its subtractive CMY model) is not intuitive (i.e. not exactly related to the way humans perceive a colour). The image below (Figure 4) illustrates the difference between the two presentations of colour in RGB and HSV models, resulting from using Matlab for

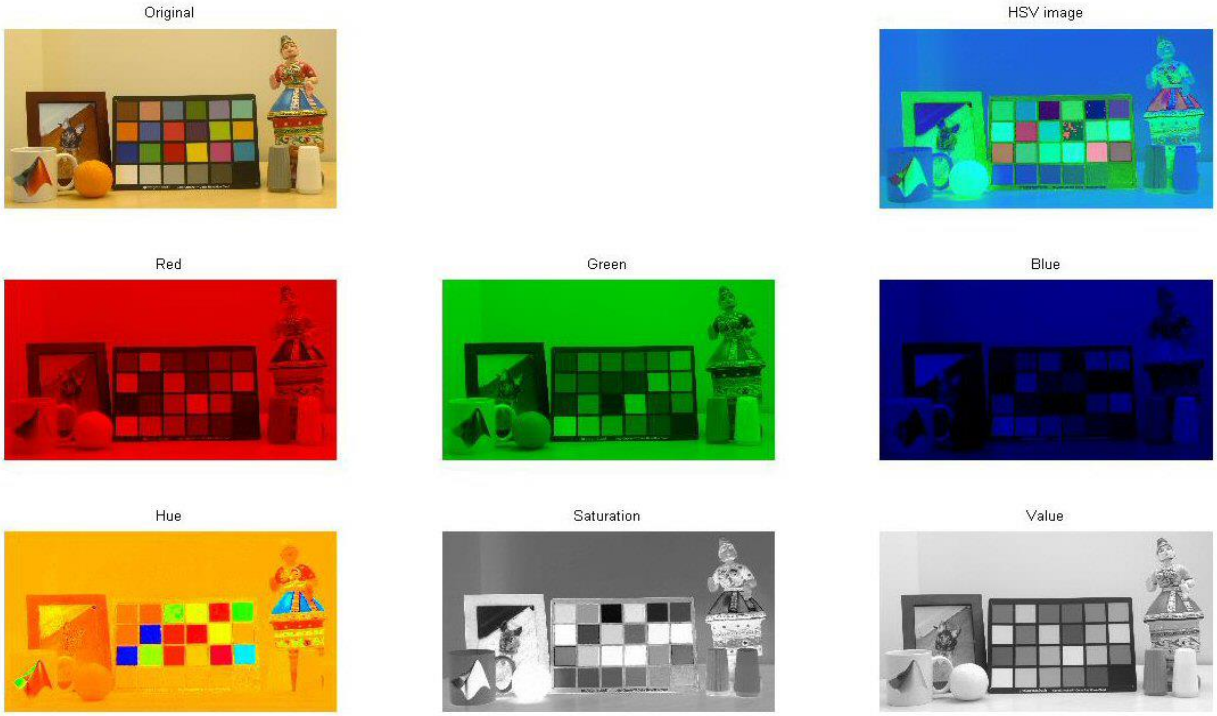


Figure 4. Illustration of the use of MatLab for decomposition of colour image – original image is decomposed to RGB and HSV (image courtesy to Dr A De Stefano).

decomposition of image colour [25].
The HSV model applies a measure of the light intensity (Volume – V); measure of the colour wavelength (Hue – H); measure of the amount of colour (Saturation – S). This model, although also not intuitive, is closer to the way of human perception and understanding of colours [25] – see Figure 5. Due to this it forms the background of the artistic system for colour production by mixing of paints. Even so, the HSV is usually not applied as an absolute colour model, but mainly as a method to encode the RGB information .

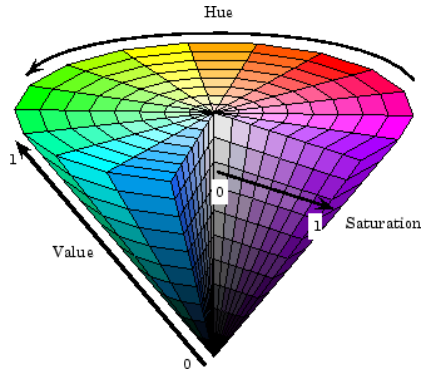


Figure 5. The cone of the HSV Colour Space (image cited from [26])

As explained above, the human eye is very sensitive to changes of image brightness (light intensity, Value), while it is less sensitive to change in chrominance. This means that, depending on the image, the visual data includes redundant information (psycho-visual redundancy) [27]. This redundancy allows to present the eye with full information related to Intensity (V), and with only limited information about the Hue and Saturation (usually only half of the "chroma" channels). This reduction of visual information does not change significantly the visual perception of the colours, but the image file size is significantly reduced. This way the colour model with separate Intensity/Value and "Chroma" channels forms the base of various image compression algorithms, which include certain loss of visual information.

The main compression steps of one of those widely used lossy algorithms – JPEG [28, 29] – includes (as per Figure 6) transforming the RGB image components into HSV (or similar colour model as YCbCr), thus forming three image files. These files are treated differently – the Value/Intensity file remains unchanged, while the two "chroma" files are reduced to half volume each (colour downsampling). The image components are then divided into small sections (e.g. 8x8 pixels) and each section is transformed in the frequency space through Direct Cosine Transformation (DCT). This transformation separates the high and low spatial frequencies in the image, thus allowing at the next stages (Quantisation and Encoding) some high frequencies to be discarded without significant loss of spatial resolution. This allows for application of user-defined 'image compression quality factor' (removing different percentage of the high spatial frequencies) – the higher the quality factor, the more high spatial frequencies will be preserved (but the larger will be the file). During the encoding the system selects the accuracy with which image components with different spatial frequencies are presented (e.g. low frequency components, which bring more visual information, are stored with higher accuracy). This final stage reflects the specificity of human vision to detect small variation in light intensity (brightness) over large areas (i.e. at lower spatial frequencies) [30].

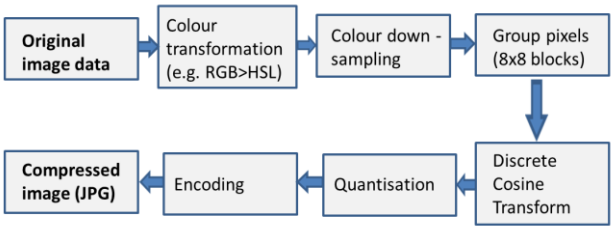


Figure 6. Simplified steps of the JPEG compression process

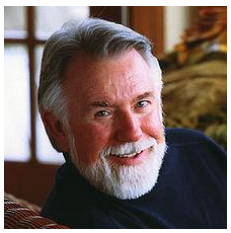
One very important moment in the compression process is to distinguish the relevant information, which should be preserved and this is a very difficult process, especially for medical images where clinically useful data must be carried with high resolution [31]. Once the compressed image is transmitted (or stored) with significant reduction of file size, its further re-visualisation requires all steps back through decoding and transformation into RGB in order to be presented to the final display monitor.

CONCLUSION

Different image compression algorithms apply different methods for reduction the image data file and not all algorithms are suitable for medical imaging. However all these methods are based on the fact that human vision has specificities which allow an image to deliver the necessary information with fewer resources. The process of transforming/encoding of the image colour space (resulting in acceptable reduction of information) requires good knowledge of the visual perception and imaging science, plus lateral thinking and creativity. Without a doubt the ideas behind the digital HSV colour model and algorithm are milestones of digital imaging. One field where these ideas are used is medical physics, but one could find them in various areas of life.

Information about human vision and perception of images/colours is essential for medical imaging, but this is a

subject discussed in many different fields – from physiology to photography, and is rarely found in one place. Some useful References on the subject are given below. Elements from this Education Resource can be used in various introductory lectures to modules covering the physics of medical imaging.



Dr Alvy Ray Smith

Cofounded two successful startups: Pixar and Altamira (sold to Microsoft). Was present at the beginning of computer graphics at Lucasfilm and the New York Institute of Technology. Was the first Graphics Fellow at Microsoft. Received two technical Academy Awards for the alpha channel concept and for digital paint systems. Invented, directed, originated, or otherwise instrumental in the following developments: first full-color paint program, HSV (aka HSB) color model, alpha channel and image sprites, Genesis Demo in Star Trek II: The Wrath of Khan, first Academy-Award winning computer-generated short Tin Toy, first computer-generated film Toy Story, Academy-Award winning Disney animation production system CAPS, and the Visible Human Project of the National Library of Medicine. Was a star witness in a trial that successfully invalidated five patents that threatened Adobe Photoshop. Has PhD from Stanford University and honorary doctorate from New Mexico State University. Is a member of the National Academy of Engineering. Has published widely in theoretical computer science and computer graphics, and holds four patents. Retired in 2000 to devote time to the emerging artform of digital photography and to scholarly genealogy, to which he has contributed two award-winning books and half a dozen learned journal papers. He is Trustee Emeritus of the New England Historic Genealogical Society, Boston, and a Fellow of the American Society of Genealogists. He is now writing a book on the biography of the pixel. For more see <alvyray.com>.

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PRACTICAL AND APPLIED MEDICAL PHYSICS

TWO TECHNIQUES TO FACILITATE QUALITY ASSURANCES PROCEDURES ON MEDICAL IMAGING

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Abstract— Two methods to facilitate quality assurance indices computation are described. The first is an algorithm to automatically determine the position of the test objects centre on the image. The second allows using the image achieved for computing SNR and uniformity to also compute geometric distortion and linearity indices. These methods make possible the concurrent calculation of several quality assurance parameters without user intervention and facilitating the tests repeatability.

INTRODUCTION

In clinical environment the time available for physicists to perform quality assurance (QA) and quality control (QC) tests is limited by several factors. It is not scope of this work to discuss why and if this is right. The reality is that QA tests are often carried out in very short slots of time or out of clinical service hours. To facilitate this, many medical centres in the last years have implemented programs reducing dramatically the time needed on the scanners and leaving the majority of the computation for post-processing. In this work we describe two basic methods aimed to facilitate the computation of QA indices during post-processing. The author does not claim to be the inventor of these new methods. There are many excellent texts and publications describing quality assurance methods in different modality and using different test objects [1]. The scope of this work is to disseminate two basic techniques because these may be of large interest even though already used in some centres. We tested these methods using IQWorks™ and Matlab™ [2-4].

The first problem we addressed is that during a QA session unfortunately it is very difficult to place the test object exactly in the centre of the field of view. As a consequence the user, not knowing where the test object is located on the image, needs to select manually (during the post-processing) the position of the regions of interest (ROIs) used to compute indices such as SNR and uniformity. This operation is time consuming and reduces the repeatability of the tests. We proposed an algorithm able to automatically select on the image the centre of test objects having circular or squared section independently from where this is on the image.

The second problem we consider is that the computation of geometric distortion and linearity indices requires additional machine (scanner) time and post processing because a specific test object is used. In this work a method is introduced to evaluate geometric distortion and linearity from the image achieved using the cylindrical or spherical test object already used to compute SNR and uniformity.

METHODS

a) Preliminary screening

The aim of this subsection is to emphasize that in some particular cases before using automatic tools it is important to perform some preliminary operations.

i) Firstly for the efficiency of automatic techniques it is fundamental to eliminate from the medical image all features not related to image quality that may affect the efficiency of the automatic techniques, such as labels including clinical information and vertical and horizontal rulers. Often this is also required for security and data protection reasons. This operation can in theory be performed using text recognition algorithms but the use of Dicom editors, such as EFilmTM, is suggested.

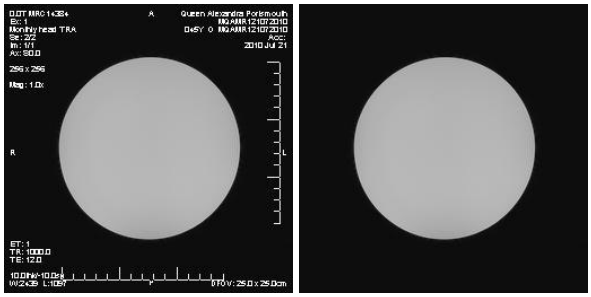

Figure 3. Elimination of labels containing medical information.

ii) Secondly it is essential to select the part of the image that is relevant to the analysis, deleting for example frames. Specific automatic algorithms for this purpose are available but again the manual cropping using Matlab™ or Dicom editors may be more efficient and it is recommended.

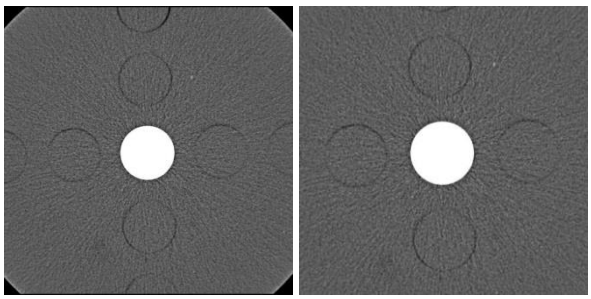

Figure 2.Elimination of framing not containing image quality information.

iii) Finally in some particular cases it is also required to optimise the image in order to achieve the best performances from the automatic technique. For example, image rotation may be required when using a phantom not having a circular section. For this purpose the use of an image editor is recommended.

Fig. 3. Elimination of unwanted rotation.

b) Automatic selection of test object centre

In order to calculate automatically the centre of the phantom, the general algorithm includes 6 main steps.

i) the first step is to compute the vertical and horizontal line profiles X(n) (blue) and Y(n) (green) of pixel values over the image. For the efficiency of the algorithm, these profiles do not need to be passing through the image centre but only to cross the test object in at least two points.

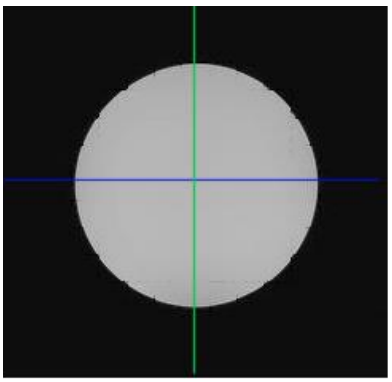

Figure 4. Selection of profiles along X and Y directions.

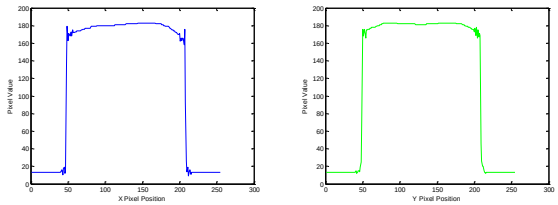

Figure 5.Pixel values profiles.

ii) The second step is to differentiate the pixel values of the line profiles. This creates two new vectors Xd(n) and Yd(n) where the value at each point is achieved from the expression

(1) $X_d(n)=X(n+1)-X(n)$ and $Y_d(n)=Y(n+1)-Y(n)$

The new vectors $X_d(n)$ and $Y_d(n)$ will have length of one element shorter than the original vectors.

iii) The third step is to compute the absolute values of the two difference vectors. This identifies the locations where there are edges.

(2) $X_{ad}(n)=abs(X_d(n))$ and $Y_{ad}(n)=abs(Y_d(n))$

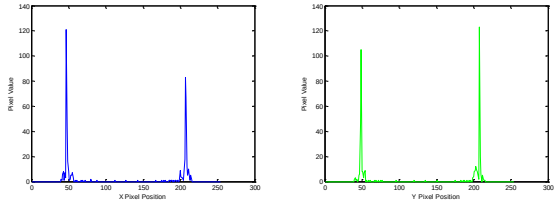

Figure 6.Edges location.

iv) The fourth step is to select the values where these absolute values are above an established threshold T. This will generate two vectors $V_x(i)$ and $V_y(j)$ of indefinite length including all the positions along the line profile where the corresponding $X_{ad}(n)$ and $Y_{ad}(n)$ are larger than T

(3) $V_x(i)$ i: $X_{ad}(i)>T$ and $V_y((j)$ j: $Y_{ad}(j)>T$

The threshold value T depends on the contrast between pixel values produced by the test object and background. This threshold selection does not need to be repeated at each test and can be used for the same medical modality. One simple way to select the threshold in advance is to note the pixel values inside and outside the test object and to use as threshold value as half of the difference.

v) The fifth step is to select the positions corresponding to first and last element of the vectors $V_x(i)$ and $V_y(j)$. This is required when test objects including internal sections are used. This operation will identify the specific edges of the test object.

(4) $V_{x1}=V_x(1)$; $V_{x2}=V_x(last)$ and $V_{j1}=V_y(1)$; $V_{y2}=V_y(last)$

vi) Finally the last step is to select the position corresponding to the middle points between the edges. In the presence of odd values some rounding may be required.

(5)$C_x=V_{x1}+((V_{x2}-V_{x1})/2)$ & $C_y=V_{y1}+((V_{y2}-V_{y1})/2)$

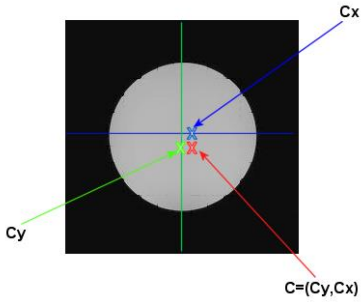

Figure 7.Selection of the centre of the test object.

The point having coordinates $C=(C_y,C_x)$ represents the centre of the test object on the image. The regions of interest needed to perform the quality assurance program can be consequentially positioned using this information in order to be sure that they are appropriately located inside or outside the area corresponding to the test object.

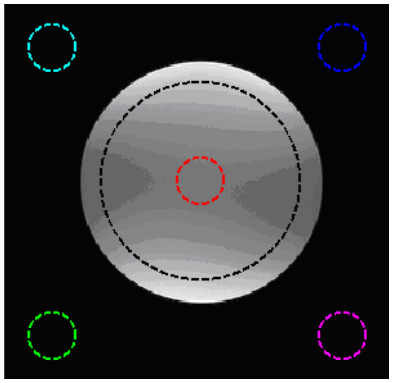

Fig 8.Region of interest location for SNR and integral uniformity.

c) Computation of the geometric linearity and distortion using a non-specific phantom

To compute the geometric distortion and linearity during a quality assurance program often specific test objects are used and the manual intervention of the user is required. Here we propose an alternative method which can be applied when the test object used is known to have circular section. The method does not require any user intervention.

The algorithm implemented essentially repeats the procedure used for selecting the centre using image profiles and selecting the positions where these profiles cross the test object. The assumption made in this case is that each line profile passes through the centre of the test object.

The general outline of the algorithm is as follows:

i) Identify the centre of the test object using the procedure seen in section b).

ii) Compute the image profiles of the pixel values passing through the centre of the test object along several directions. The accuracy of the method depends on the number of directions used. In our implementation we used 16 directions.

iii) Compute for each line profile the coordinates of the edges and therefore the distances between the edges (diameters).

(6) D(k) k=1…12

iv) Compute the geometric distortion using the expression

(7) $G_d=Std(D(k))/Mean(D(k))$

The geometric linearity can also be evaluated having information concerning pixel resolution and nominal size of the test object.

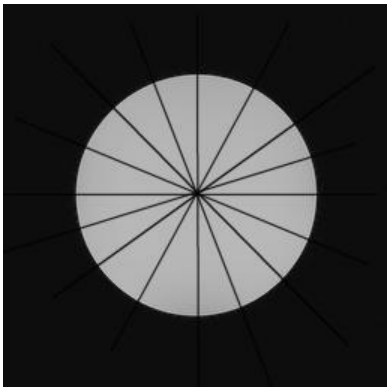

Figure 9.Line profiles for 16 directions (0º (horizontal), 11º, 23º, 34º, 45º, 56º, 68º, 79º, 90º (vertical), 101º, 113º, 124º, 135º, 146º, 158º, 169º) to compute geometric distortion and linearity.

CONCLUSIONS

We present two practical methods intended to speed up the QA indices computation. The first allows the automatic selection of the centre of the test object. This way ROIs needed for SNR and uniformity computation can be placed automatically and the parameters calculated without any user intervention. The second method results in a relevant time-saving by allowing the computation of geometric distortion and linearity indices to be made simultaneously with SNR and uniformity (and again without the manual intervention of the user).

We assessed these methods for CT and MR modalities in the Portsmouth Hospital Trust, comparing the results with those achieved using the manual ROIs selection and the ad hoc geometric distortion phantom [5]. For MR QA a comparison has also been performed between results achieved in several MR 5 medical centres situated on the south coast of England [4]. All these results show perfect consistency and repeatability. The methods are currently used during quarterly QA sessions for CT and MR.

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INNOVATIONS IN MEDICAL PHYSICS

APPLICATIONS AND TECHNOLOGY

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

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Abstract—Prior to the introduction of DSA, time-resolved X-ray angiography required film changers and darkrooms and provided an awkward mechanism for interventional radiology. DSA stimulated the development of the field of interventional radiology providing greater convenience and safety. Time resolved angiography was then extended to MRA using undersampled acquisition techniques such as TRICKS and VIPR. This was followed by the development of constrained reconstruction such as HYPR which, when combined with VIPR, provided undersampling factors of 800 relative to the traditional Nyquist requirements. The HYPR concept was subsequently applied to a broad range of medical imaging applications often offering an order of magnitude improvement in dose or acquisition speed. The success of the concepts of underampling and constrained reconstruction has led to what has been referred to as the Post-Nyquist Era of medical imaging. The concept of undersampling has recently been extended to DSA which now includes a non–time-resolved 3D DSA capability using rotational C-arm acquisition and cone beam reconstruction. By modifying the acquisition to include time-dependent projection information, it has been possible to develop 4D DSA which provides time-resolved DSA volumes up to 300 times faster than with sequential C-arm rotations. Relative to CTA, which requires exposure for each time frame, 4D DSA obtains up to 300 time-resolved volumes following a single C-arm rotation and a single contrast injection. Using similar ideas, 4D Fluoroscopy is under development and will provide a new interventional capability by providing views previously unobtainable due to C-arm geometrical constraints. This promises to increase the speed and safety of interventional procedures. The extension of undersampled acquisition and constrained reconstruction using iterative reconstruction techniques promises to further extend the possibilities for angiographic as well as other medical imaging applications.

Keywords— angiography, time-resolved, constrained reconstruction, undersampled acquisition, 4D DSA

INTRODUCTION

This article will trace the history of the development of modern angiographic imaging techniques beginning with X-ray DSA then continuing with time resolved MRA and then returning to the current version of DSA that now provides full 4D capabilities. Many groups have made important contributions to this process and we confess in advance that this article will be heavily influenced by our own recollections and may overemphasize the work with which we are most familiar.

The first angiogram in a human patient was obtained by Egas Moniz using a direct needle injection into the carotid artery [1]. The isolation of the vasculature was greatly improved by the introduction of film subtraction angiography by Ziedses des Plantes [2] who quite amazingly introduced this concept and the concept of tomography in the same PhD dissertation in 1934. The concept of subtraction is one that pervades all future developments in MRA and DSA. An illustration of Ziedses des Plantes film subtraction technique is shown in Figure 1.

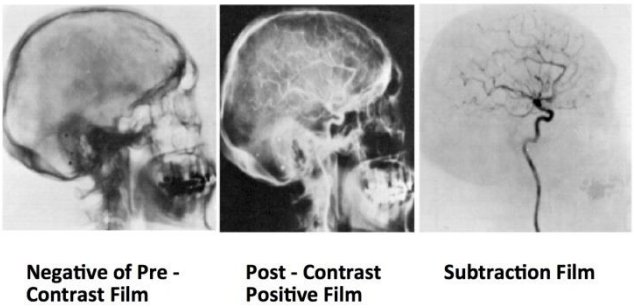

Figure 1. Illustration of Ziedses des Plantes film subtraction technique.

Film subtraction angiography was commonly used for interventional procedures, which relied on rapid film changers, and required devices to be left in the patient while films were processed in a darkroom.

Film subtraction angiography remained the standard well into the 1970s where excellent image quality was obtained but remained time consuming and ill-suited to real time intervention.

Generalized Subtraction Imaging

$$I(x, y,z,E,t) - I(x + \Delta x, y + \Delta y,z + \Delta z,E + \Delta E,t + \Delta t) =$$

$(dI/dx)^* \Delta x + (dI/dy)^* \Delta y$	2D spatial processing
$+(dI/dE)^* \Delta E +$	Dual energy
$+(dI/dt)\, \Delta t +$	DSA
$+(dI/dz)\, \Delta z$	Tomography/CT
$+(d^2I/dEdz)\Delta E \Delta t$	Dual energy CT
$+ (d^2I/dEdt)\, \Delta E \Delta t$	Dual energy DSA
$+ (d^2I/dzdt)\Delta z \Delta t$	CTA, 4D DSA
$+ (d^3I/dEdzdt)\, \Delta E \Delta t \Delta z$	Dual energy 4D DSA

Figure 2. Taylor series expansion showing potential imaging modalities obtainable using X-rays.

In 1973 we discussed the concept of generalized subtraction imaging [3] and described the various potential imaging modalities that might be implemented using first, second and third order image subtraction involving differences in the spatial variables, energy and time. The imaging modalities categorized in this way are shown in Figure 2.

The terms in Figure 2 did not describe how the various modalities could be implemented and for example, certainly did not describe CT or DSA. However, with our recent demonstration of the feasibility of dual energy 4D DSA, essentially all of the modalities predicted by the terms in Figure 2 have now been implemented.

During the early 1970s our group at the University of Wisconsin was concerned with dual energy imaging (the dI/dE term) [4]. We were using quasi-monoenergetic x-ray spectra, which peaked above and below the k-edge of iodine as shown in Figure 3.

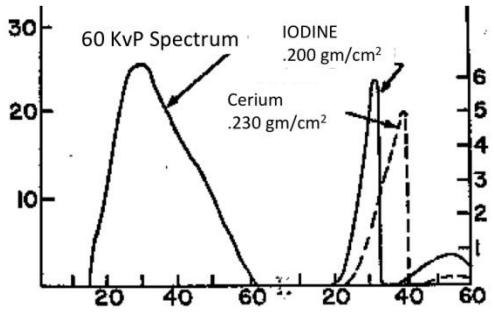

Figure 3. Formation of quasi-monoenergetic beams using filtration.

The idea for dual energy imaging was to perform a weighted subtraction of images formed from the two spectra in order to cancel bone or tissue and isolate iodine. Initially the subtraction was performed using a series of two silicon target storage tubes, the first that performed a difference image and the second that integrated the results [5]. The sensitivity of the subtraction apparatus is illustrated in our first subtraction experiment that consisted of a periodic insertion of a tongue depressor and piece of paper into the imaging field. This is illustrated in Figure 4.

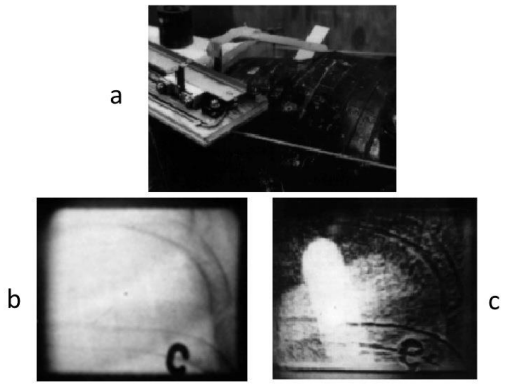

Figure 4. Enhancement of periodic x-ray contrast using dual storage tube apparatus. Figure 3a shows the apparatus. 3b shows the unsubtracted image. 3C shows the integrated subtraction result.

The storage tube apparatus was used to image periodic contrasts produced by a rotating filter that generated the spectra shown in Figure 3

Although the method was sensitive to small amounts of iodine, it required the careful balancing of several analog parameters to achieve the correct subtraction weighting. Because of this, X-ray exposures had to be repeated frequently.

Just prior to the development of DSA the group at Toulouse [6] reported excellent film subtraction results using intravenous injections and improved film techniques as shown in Figure 5

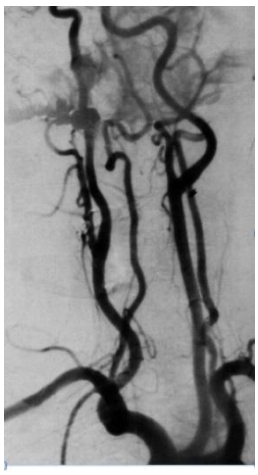

Figure 5. Intravenous film subtraction angiography-Ducos de Lahitte et al. 1979.

About the same time Ovitt, Nudelman, Capp and others at the University of Arizona [7] and Brennecke and Heintzen from the Kiel Kinderklinic [8] reported off-line digital processing of angiograms using time subtraction. Their early results are shown in Figures 6 and Figure 7.

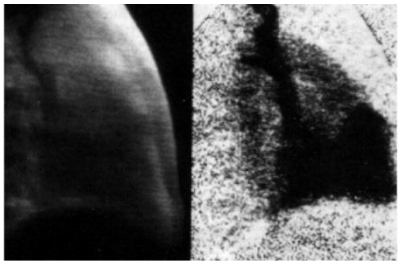

Figure 6. Subtracted pediatric left ventriculogram from Brennecke and Heintzen, 1976.

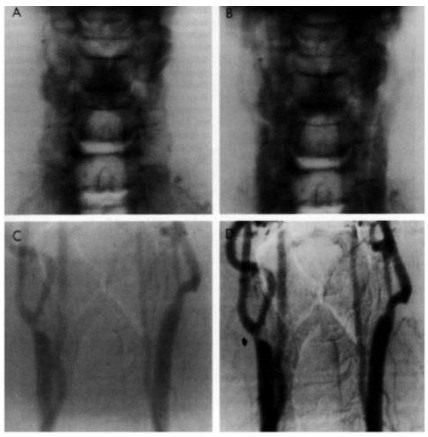

Figure 7. Offline digital subtraction angiograms showing pre-injection (upper left), post injection (upper right), subtraction lower left) and enhanced subtraction (lower right) From Ovitt et al, 1977.

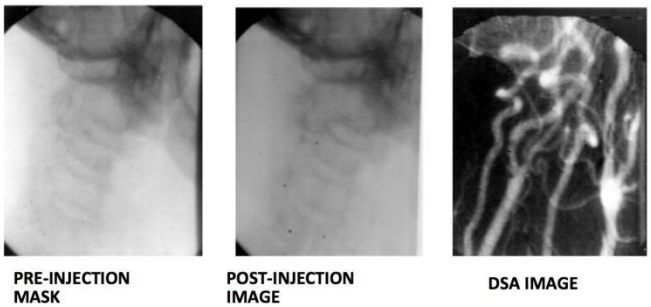

Figure 8. Real time DSA. University of Wisconsin, 1978.

These results inspired our group to modify our dual energy real time digital processor to facilitate implementation of time subtraction angiography [9-13]. An early result is shown in Figure 8.

At the time of the commercial introduction of DSA at the Dallas RSNA in 1980, it was hoped that all diagnostic angiography could be done using DSA with intravenous injections. Within two years there were thirty companies manufacturing DSA equipment. However, it soon became evident that due to artery/vein overlap and limited signal to noise ratio more consistent results were obtained when the real time DSA apparatus was used with arterial injections. These injections were now possible with smaller catheters and smaller iodine doses than used with film angiography. Complication rates rapidly decreased using the new DSA technique that greatly facilitated the development of interventional radiology [14].

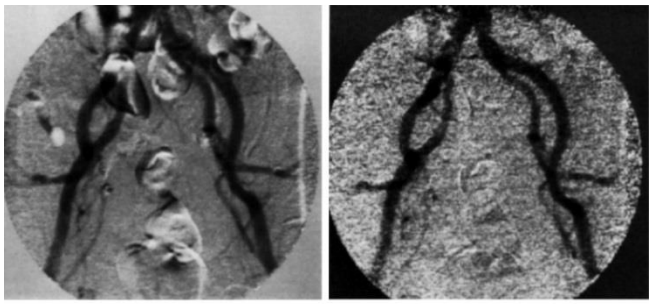

Figure 9. Comparison of time subtraction DSA and hybrid energy/time subtraction DSA

We briefly considered another generalized image subtraction term called hybrid energy/time subtraction ($d^2I/dEdt$) and incorrectly reasoned that since the temporal subtraction would remove non-vascular anatomy, there was no need for energy subtraction. However it was recognized by Brody[15] that this method could be used as a means of removing soft tissue artifacts from DSA exams in which soft tissue swallowing artifacts or misregistration due to bowel peristalsis could degrade image quality. This mode was subsequently introduced commercially but was eventually abandoned due to the poor signal to noise ratio obtained with the second order subtraction. An example of energy/time subtraction is shown in Figure 9.

It is interesting to note that with the improved SNR provided by the constrained reconstruction techniques as well as the arbitrary views permitted by the 4D DSA technique that will be described later, the most significant problems of these early intravenous techniques have been overcome.

The origin of the constrained reconstruction and undersampled acquisition techniques that made 4D DSA possible were initially developed within the context of our studies in MR angiography.

MAGNETIC RESONANCE ANGIOGRAPHY

In 1993 Prince [16] introduced the gadolinium-enhanced MRA method. Although excellent 3D images could be obtained with intravenous gadolinium injections, the timing of the data acquisition was a major problem. If the central portions of k-space were obtained prior to or after peak arterial opacification there could be significant problems with signal dropout or venous contamination in the single image volumes that were typically acquired in a time of about 30 seconds. Additionally, the single image acquisition techniques did not provide dynamic information.

Several methods were developed to try to time the data acquisition. These included the use of test boluses [17], region of interest signal detection [18], and the use of 2D MR fluoroscopy [19, 20]. Because peak opacification of various vessels may occur at different points in time, none of these methods were completely satisfactory.

Attempts to obtain dynamic image series in MRA were done using Keyhole imaging [21] in which the central portion of k-space was repeatedly acquired and combined with high spatial frequency information acquired at the end of the examination. While this provided some sense of the vascular dynamics, high spatial frequency information was prematurely displayed throughout the examination. Several investigators had been exploring variable rate k-space sampling in non-contrast-enhanced MRA applications [22]. We applied these principles to MRA in the TRICKS method (time resolved imaging of contrast kinetics) in 1996 [23,24]. In this technique, during the passage of the contrast material, data from the center of k-space were acquired alternately with data from the peripheral regions of k-space so that there was a new central k-space contrast weighting for each of several time frames as in keyhole imaging. However after several central k-space samples were obtained there would be a new complete sampling of outer k-space. This resulted in an acceleration factor of four relative to the conventional static examination and provided central k-space sampling throughout the bolus, reducing the need to carefully time the acquisition relative to the contrast arrival.

Figure 10 shows an early TRICKS examination that clearly showed the passage of contrast through the cerebral vasculature. Although spatial and temporal resolution were limited by the use of conventional Cartesian acquisition and the time consuming phase

encoding process, TRICKS represented a significant MRA breakthrough and thirteen years after its introduction remains the most widely used technique for time resolved MRA.

In an effort to achieve greater degree of acceleration relative to the traditional acquisitions prescribed to obey the Nyquist theorem we began to investigate the use of radial k-space acquisition, the technique originally used by Lauterbur. The radial approach had been abandoned in favor of Cartesian acquisition because of gradient imperfections that made it difficult to pass through the center of k-space on each acquisition and a fifty percent increase in the number of acquisitions relative to Cartesian acquisition required to satisfy the Nyquist theorem.

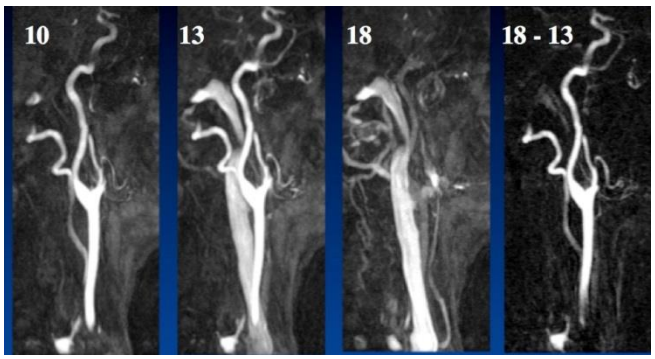

Figure 10. TRICKS examination showing time frames 10, 13 and 18. On the right frame 18 containing the jugular vein has been subtracted for frame 13 to isolate the arterial phase.

Scheffler and Hennig [25] demonstrated that radial acquisition could be used for small field of view imaging and demonstrated that in radial acquisition, when angular undersampling was done, the point spread function maintained high resolution in the central portion but showed radial streak artifacts in the peripheral regions. The size of the adequately supported small field of view decreased with the amount of angular undersampling.

In 2000 our laboratory began its study of radially acquired MRA. This was motivated by our desire to speed up the MRA acquisition by eliminating the time consuming phase- encoding process associated with Cartesian imaging. Peters [26] investigated the use of radial sampling in 2D and found that for the purposes of full field-of-view angiography a factor of four undersampling could be used with tolerable artifacts. For the same acquisition time as Cartesian a factor of four resolution increase was realized in the phase encoding direction.

We then realized that if undersampling were performed in a 3D acquisition, the artifacts would have a full 3D angular range in which to disperse. We implemented a technique called VIPR [27] (vastly undersampled imaging with projections) and found that excellent MR angiograms could be achieved with a factor of about 30 violation of the Nyquist theorem. Figure 11 shows the VIPR k-space acquisition consisting of radial projections all passing through the center of k-space and an early VIPR examination using a phase contrast pulse sequence (PC VIPR). Note the absence of significant artifacts.

PC VIPR permits voxel sizes an order of magnitude smaller than can be achieved in the same time as with Cartesian acquisition. This has permitted the measurement of pressure gradients using the Navier-Stokes equations, estimates of wall shear stress and, when implemented with cardiac gating, has provided dynamic flow information that can be viewed from arbitrary angles greatly simplifying applications such as those used pediatric cardiology [28-32].

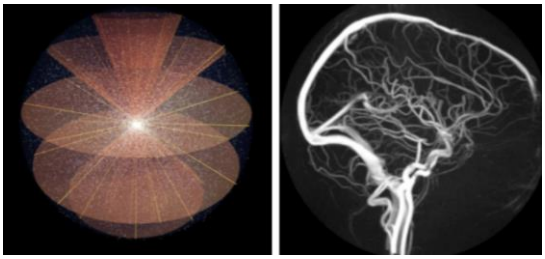

Figure 11. VIPR k-space trajectory and an early PC VIPR examination using an undersampling factor of 36.

Another significant advance in connection with accelerated MRA was the application of constrained reconstruction techniques to reduce undersampling artifacts and to increase SNR. Constrained reconstruction had been reported in MR by Lauterbur's group as early in 1993 [33]. This and the more recent KT-Blast and KT-Sense techniques [34] used the idea of a training image to constrain the reconstruction of time frames. While at the 2006 ISMRM meeting, during the process of thinking about training images we heard a plenary lecture by Jeurgen Hennig in which he reminded us that if the vessel configuration were known in advance and the vessel filling proceeded according to a well defined contrast curve, a complete 4D angiographic reconstruction could be performed by acquiring a single k-space point or single projection for each time frame.

We began to wonder how many projections would be required if the situation were not quite the same as in the Hennig example. We began to imagine a training image depicting the eligible vascular voxels and single projection information being backprojected and deposited only in the predefined vascular space. This constrained back projection was significantly different from

conventional filtered back projection used for CT reconstruction. We found that a surprisingly small number of projections were required to obtain highly accelerated dynamic MRA sequences. This approach was called HYPR for "highly constrained back projection" [35].

An improved version of HYPR that limits the deposition of information to the local region in which it belongs is called HYPR-LR [36]. In this method a composite constraining image is formed from a series of undersampled time frame acquisitions in which the projection angles are interleaved. For a long acquisition this results in a fairly well sampled composite image that can be used to constrain the reconstruction of individual time frames. The individual time frame data are convolved to provide a series of temporal weighting images. These are multiplied by the constraining image resulting in a time frame having nearly the same SNR as the constraining image and nearly the full resolution of the constraining image even though the resolution and SNR associated with the acquired time frame data would be limited. This sort of approach woud have provided adequate SNR for the old hybrid X-ray time/energy approach shown in Figure 9.

Figure 12 shows time resolved MRA frames acquired using a 2D Stack of Stars geometry in which radial imaging is used in-plane and one dimension of phase encoding is used in the slice direction. These are compared to conventional filtered back projection. In spite of an acceleration factor of 50, the HYPR images are far cleaner. Sixteen projections instead of the Nyquist designated 800 projections were used.

The combination of VIPR and HYPR have led to acceleration factors as large as 800 [37] as illustrated in Figure 13. In this application called Hybrid HYPR/VIPR MRA the composite image is formed in a separately acquired examination, typically lasting a few minutes. In Figure 13 the composite was formed with PC VIPR and was used to constrain the reonstruction of highly undersampled VIPR time frames. Again, the SNR and spatial resolution of the composite image is transferred to the time frames. This approach greatly reduces the traditional tradeoff between spatial and temporal resolution.

Compressed sensing can add modest acceleration factors by removing streaks in undersampled acquisitions and can be used in conjunction with more highly accelerated techniques like Hybrid HYPR VIPR. Parallel imaging has been used to accelerate the TRICKS techniques and the use of 2D parallel imaging has been used to facilitate accelerations on the order of 40 in the Cartesian CAPR technique [38].

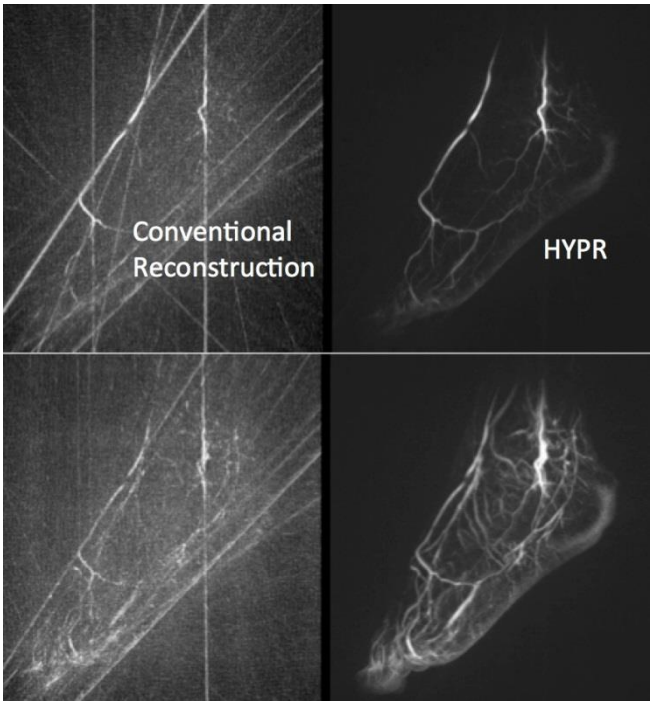

Figure 12. Comparison of conventional filtered back projection and HYPR reconstuction using a factor of 50 fewer than the Nyquist requirement. (Courtesu of Oliver Wieben).

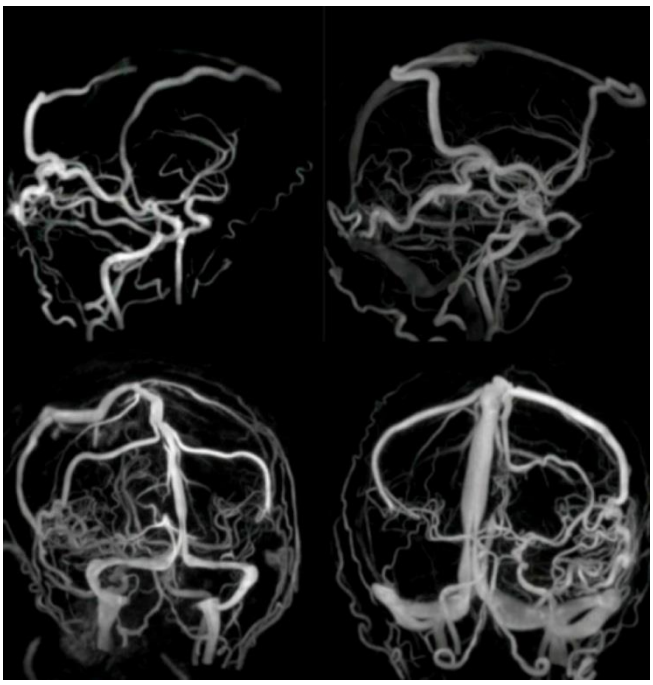

Figure 13. Hybrid HYPR VIPR MRA rotating time frames using an acceleration factor of 800 relative to conventional 3D radial Nyquist acquisition.

Figure 14 summarizes the MRA acceleration methods that have occurred since TRICKS.

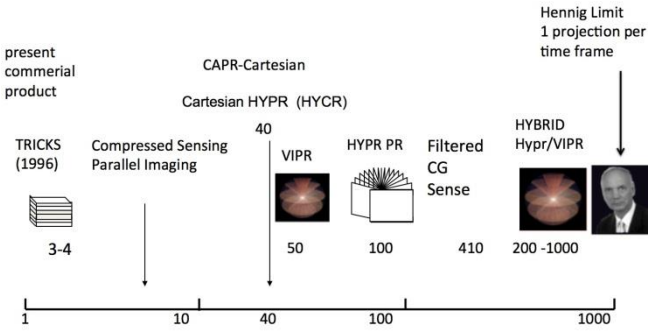

Figure 14. Acceleration Methods for Dynamic MRA

Ultimately, the optimal combination of all available techniques will move us closer to the Hennig limit of obtaining images with almost no data at all.

4D DSA

Commercial DSA systems have evolved from the original single plane projection systems to rotating C-arm systems that provide what is essentially a 3D CTA reconstruction of the vasculature providing a 3D DSA image which statically represents the average opacification of the vessels during the C-arm rotation [39,40]. The rotational 3D DSA image is traditionally acquired in an equilibrium phase in which all vessels are well opacified in all projections. This provides the optimal 3D reconstruction. However, we discovered that if inflow is permitted in the early stages of rotation, the 3D reconstruction can provide an adequate constraining image that can be used to help reconstruct time dependent information provided by each of the projections obtained during the rotation [41[. This ultimately provides 3D volumes at the projection frame rate, typically 15-30 fps. Assuming a ten second gantry rotation, this provides 300 rather than one 3D volume during the passage of the contrast. The result is a 4D DSA display in which arbitrary view angles can be used at any point in time and a time series that can be observed at any chosen angle. This greatly reduces the vascular overlap problems that were experienced in the earlty attempts to do intravenous DSA.

The basic idea is illustrated in Figure 15**.**

As indicated in Figure 15, once the 4D volumes have been reconstructed, any time frame can be viewed from arbitrary angles. This provides considerable flexibility in the study of the vasculature by providing views that may not be normally obtainable with the C-arm.

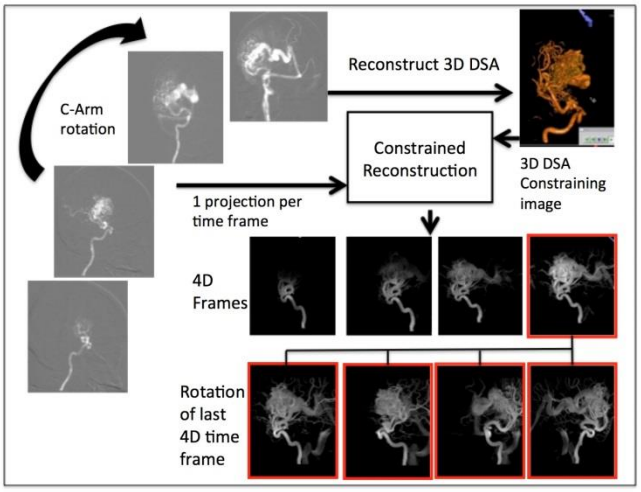

Figure 15. Schematic representation of 4D DSA

Figure 16 illustrates the effect of the constrained reconstruction on the SNR of the 4D DSA images. The image on the left is one of the acquired projections. This is compared with a corresponding 4D DSA frame (middle) and the 3D DSA constraining image (right).

Figure 17 shows MIPS through a series of 3D volumes in the case of an AVM. In this case each voxel has been colored to indicate the time of arrival of the contrast material. In addition to the temporal variations in the contrast intensity the color-coding provides quantitative information. It should be realized that although just two views are shown, any arbitrary view angle is available without additional gantry rotation. The view on the right represents a view in which the X-rays would have had to traverse from head to foot, a view not practical in a single 2D projection acquisition.

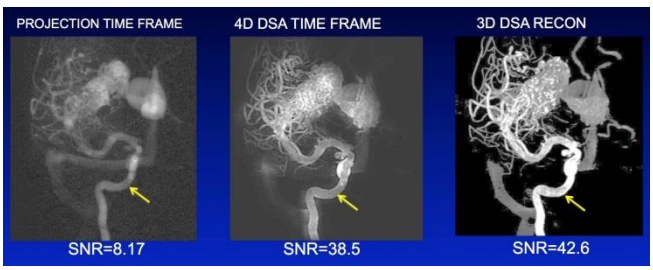

Figure 16. SNR comparison. Most of the SNR of the constraining image is transferred to the individual 4D DSA time frames so relative to the acquired projections, 4D DSA provides significantly higher SNR at all angles.

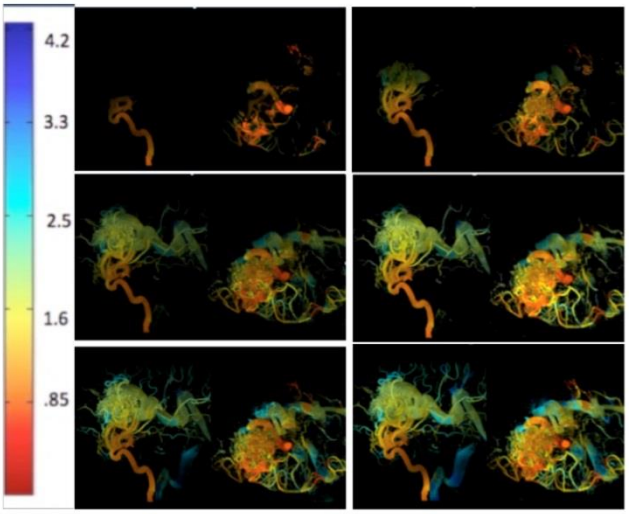

Figure 17. Time series of color coded 4D DSA time frames. The time series on the right is not obtainable using standard 2D acquisition techniques.

Figure 18 illustrates the simplification provided by 4D DSA in the evaluation of vessels following intravenous contrast injection. The 3D DSA volume (upper left) is complex and contains areteries and veins. The vessels of interest are easily seen in one of the arterial phase 4D DSA time frames (lower left). Twenty minutes were spent trying to see the vessels of interest by looking at cut planes (right) through the 3D DSA volume. The process was cumbursome and not very sucessful due to the fact that the vessels do not stay in discrete planes.

Figure 19 compares the temporal and spatial resolution of competing methods for time-resolved angiography. Conventional DSA has excellent temporal resolution but the voxel size is very large since displayed information is a projection through the whole volume. This has been demonstrated to produce lower contrast in small vessels compared with the MIP projections that can be used with 4D DSA.

Current MRA tehniques have significantly lower temporal resolution than 4D DSA although HYPR MRA does provide frame rates of 2-3 per second with sub-millimeter isotropic resolution.

CTA can provide frame rates of 2-3 per second with voxel sizes of about 0.1 mm^3. This is an order of magnitude slower than 4D DSA when images are constructed at 30 fps.

When 4D DSA volumes are reconstructed at 512^3 spatial resolution is comparable to CTA. However, the flat panel detectors used for 4D DSA have higher resolution than discrete CT detectors and can in principle support reconstrution at 1024^2, potentially providing an order of magnitude increase in spatial resolution relative to CTA.

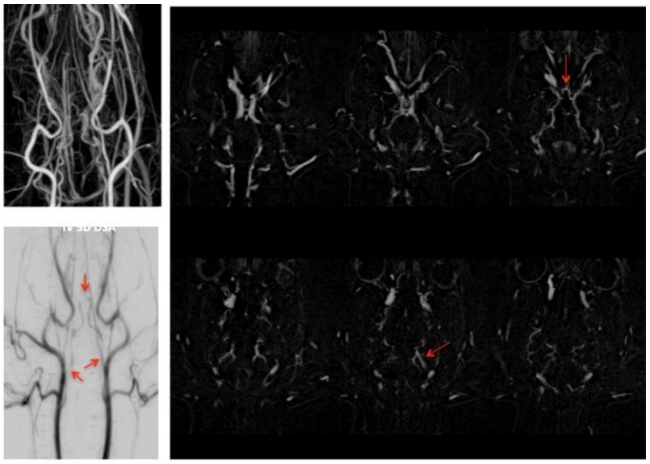

Figure 18. Comparison of vessel identifacation in 3D vs 4D DSA.

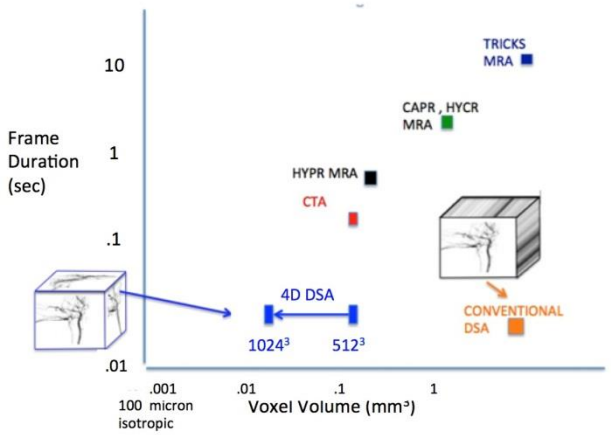

Figure 19. Spatial and temporal characteristics of competing time-resolved angiographic modalities,

Another significant difference beteeen CTA and 4D DSA, not shown in Figure 19, concerns the X-ray dose required for a dynamic series. In the case of 4D DSA all temporal frames are acquired with a single C-Arm rotation using a single X-ray dose. For a CTA time series containing 30 time frames, the dose would have to be repeated 30 times. Although the CTA data could eventually be subjected to something like HYPR processing which has been reported to reduce time resolved CT dose by perhaps 5, there remains an order of magnitude difference in the required dose for a time resolved 4D DSA exam and a time-resolved CTA exam.

So far 4D DSA has primarily been applied for neuroangiography where motion is minimal. For abdominal imaging, as was realized in the early days of DSA, there is a high probability of soft tissue artifacts. This was the motivation for the implementation of the hybrid energy/time method listed in Figure 2. We have simulated the expected image quality that would be generated by the third order tomographic energy/time term ($d^3I/dEdtdz$) which we call dual energy 4D DSA.

In the absence of energy switching capabilities on our C-arm system we performed two nearly identical injections and performed C-arm rotational acquisitions at 60 and 125 kVp. The projections from these two acquisitions were given weightings corresponding to soft tissue subtraction and were reconstructed using the standard 4D DSA algorithm. The results of this simulation are shown in Figure 20. Shown are the 4D DSA results at 60 kVp and 125 kVp, the tissue subtracted dual energy 4D DSA result and a series of selected 4D DSA time frames. The simulation does not test the tissue subtraction capabilities since there was no motion in the head. However, the SNR that remains after the tomographic energy/time subtraction is displayed in the time frames and appears to be adequate and certainly a large improvement over the SNR in Figure 9.

4D FLUOROSCOPY

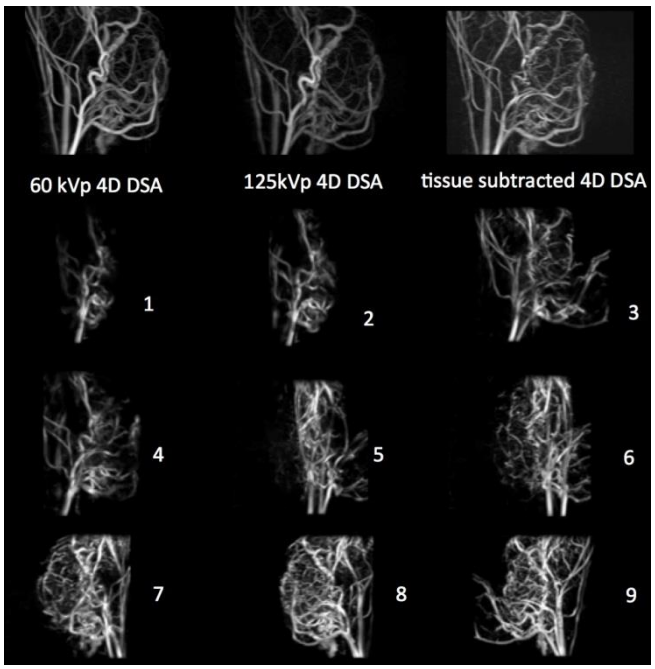

Figure 20. Simulation of dual energy 4D DSA.

During interventional procedures it is important to have an adequate view of the pathology and its relationship to the various interventional devices being employed. Even with bi-plane fluoroscopy it is sometimes not possible to acquire adequate views and the procedure is aborted and the patient is sent to surgery.

Using principles similar to those of 4D DSA we have been able to embed a 4D representation of the interventional device in the 3D space of the rotational DSA reconstruction and to view the device from arbitrary angles, including those normally unavailable, without gantry motion. So far this has been done retrospectively but will soon be available in real time. There is much validation that must still be done in terms of the accuracy of the representation of the device and means for dealing with potential motion. There is also additional algorithm development in progress to accommodate the many situations that arise during interventions such as the insertion of a coil into an aneursym already a containing a significant amount of coil.

The general idea of 4D fluoroscopy is shown in figure 21 where a coil is being inserted into an aneurysm. Shown are several points in time with one fixed angle and another rotating view. In practice the clinician could choose the optimal view angle from the 3D DSA study and then view the reconstructed 4D fluoro images at that angle. An endoscopic viewing mode is being developed and should assist with device placement when one of multiple intravascular openings must be chosen for device insertion.

DISCUSSION AND CONCLUSIONS

The evolution of DSA from the traditional method introduced in 1980 to the 4D version presented here has taken more thn 30 years. It has benefitted from the work done on the development of 3D DSA rotational angiography and the undersampled acquisition and constrained reonstruction principles learned in the course of developing accelerated MRA.

During our development of undersampled and constrained MRA tehniques there was much skepticism because our methods were consider intuitive, ad hoc and without mathematical justification. The extreme violations of the Nyquist theorem were a cause for considerable concern. However, shortly after our development of VIPR, Emmanuel Candes and colleagues from Cal Tech published what we consider to be a new Nyquist theorem [44,43] that proves that in the case of sparse data sets such as we have in angiography a good reconstruction of a image matrix with n^3 elements does not require n^3 data samples. Instead the required number is significantly less and depends on the number of non-zero voxels in the image volume. This theorem provides some insight into why the methods we had developed were successful.

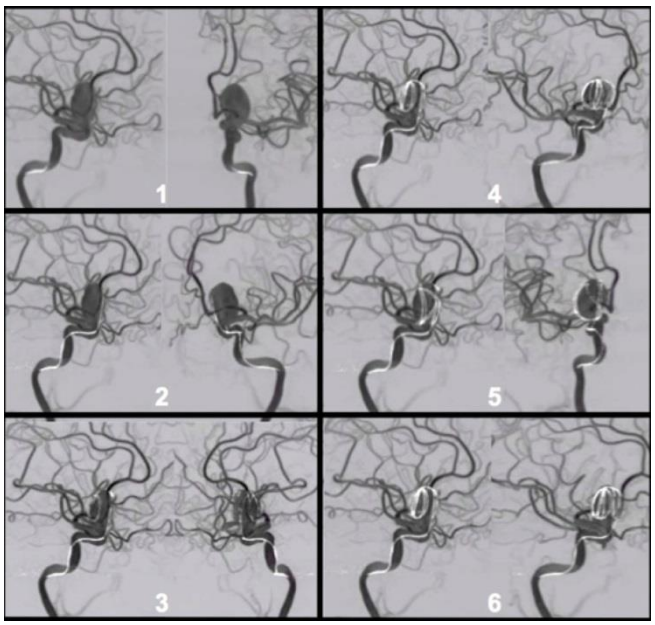

Figure 21. Demonstration of 4D fluoroscopy using retrospective processing of two bi-plane fluoroscopic views.

The use of undersampling and constrained reconstruction are likely to have implications in a broad range of medical imaging applications. The use of VIPR has enabled the development of ultrashort echo time imaging that provides a new means of imaging short T2* behavior [43] and has led to practical flow imaging in pediatric cardiology and other applications. Significant increases in SNR, reduced radiation dose and accelerated acquisition have been reported using HYPR processing in time-resolved CT [45-47], Photacoustic tomography [48], time resolved PET imaging [49,50], MR spectroscopy [51], and diffusion tensor imaging [52] There are now more advanced techniques than HYPR which incorporate iterative reconstruction and the methods generally associated with compressed sensing [53,54] These may provide some increase in the accelerations reported here.

The development of 4D DSA is an example of why it is useful to reexamine old techniques in view of new technology that has arisen. It is also important to look at advances in all imaging areas in order to seek tools that might be useful for any contemplated advance in any particular area. The development of 4D DSA made use of advances in CTA, MRA, and the general principles of undersampled acquisition and constrained imaging learned in the course of the development of ultrafast time-resolved MRA.

We would like to emphasize again that this arricle reflects the developments with which the author is most familiar. Any major advance in imaging depends heavily on the excellent body of work done by other investigators. In the case of DSA the introduction of digital electronic technology was a key factor. For the ultimate development of ultrafast time-resolved MRA, the introduction of gadolinium techniques [16], the development of techniques leading to the generation of high quality non-time-resolved scans [19,20], and prior work on constrained reconstruction [33,34] were important developments. Significant advances in MR hardware were contributed by industry. The development of 4D DSA relied heavily on the development of cone beam C-arm angiographic reconstruction [39,40].

It has been a privelege to work in the field of medical imaging for the past four decades. We believe that in the future medical imaging will continue to be an exciting and productive area of research.

ACKNOWLEDGEMENTS

In addition to the many graduate students including people like Robert Kruger and Stephen Riederer who worked with us during the development of DSA, we would like to acknowledge some of the radiologists who have played important roles in the development of the angiographic technques described in this paper. Dr. Joseph Sackett, Andrew Crummy, Charlie Strother and Pat Turski were key contributors to the original DSA technique. Dr. Strother is the co-inventor of 4D DSA and has provided both the inspiration for the technique and the expertise for its implementation into a clinically useable modality. Dr Tom Grist and Dr Turski have inspired the development of many time-resolved MRA methods.

We would like to acknowlege forty years of continuous funding, initially from NSF and then NIH. Our early DSA work was also supported by Phillips. All of the MRA work was supported in part by General Electric and the recent 4D DSA work has been done in collaboration with Siemens who have also contributed funding.

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INTRAFRACTIONAL PROSTATE MOTION MANAGEMENT WITH THE CLARITY AUTOSCAN SYSTEM

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Abstract— Intrafractional motion of the prostate can be significant, and its management is of particular importance for hypofractionated regimes and stereotactic ablative radiotherapy (SABR). In this paper, we describe the Clarity Autoscan with Monitoring system and its use of non-invasive soft tissue imaging to monitor prostate motion during the course of radiotherapy. The system uses a 4D autoscan ultrasound probe to image the prostate through the acoustic window of the perineum. We discuss this imaging technique, as well as the algorithms used to track the prostate during treatment. We measure the accuracy of the tracking algorithm with a motion phantom and find it to be -0.2 ± 0.2 mm, 0.2 ± 0.4 mm and -0.0 ± 0.2 mm in the A/P, L/R and S/I directions, respectively.

Keywords— radiotherapy, prostate, motion management, intrafractional motion, ultrasound.

INTRODUCTION

Interfractional image guidance for external beam radiotherapy of the prostate has emerged as an integral part of conformal and intensity modulated radiation therapy (IMRT) treatments. The prostate position can vary substantially between the initial simulation and each day of treatment, and thus can benefit dosimetrically from pre-treatment corrections [1]. Fiducial-based planar x-ray methods (kilovoltage [2] or megavoltage [3]), tomographic CT (cone-beam [4] or conventional [5]), transabdominal ultrasound (TAUS) [6,7] and electromagnetic beacons have been used for this purpose [8].

The magnitude of intrafractional corrections is on average smaller than interfractional motion. Large excursions greater than 1 cm may occur in some fractions, although the dosimetric advantage of corrections is diminished when averaged over a conventional fractionation regime [9,10]. Although it can be argued that it is important to ensure that dose is correctly delivered to the target even under conventional fractionation, the real advantage to intrafractional motion corrections emerges for hypofractionated regimes and stereotactic ablative radiotherapy (SABR) treatments.

Various technologies have been reported for prostate motion management. Stereoscopic x-ray imaging with kilovoltage (kV) x-rays acquires two planar projections using digital x-ray detectors placed in orthogonal directions around the patient. Since planar x-ray imaging cannot visualize soft tissue, fiducials are implanted within the prostate with needles inserted transperineally under transrectal ultrasound guidance. Stereoscopic kV imaging is commonly used for interfractional patient positioning. For intrafractional correction, however, the extra imaging dose limits the sampling rate, for example one image per 30 seconds [11].

Some research articles have explored using the megavoltage (MV) energy treatment beam to track fiducials in the prostate. The images are acquired with an electronic portal imaging device (EPID). The advantage of this technique is that no additional imaging dose is delivered, since the treatment beam is already being used for treatment delivery.

One limitation of the MV tracking technique is that motion of the prostate is only known in the direction perpendicular to the beam at any moment in time (the direction of the beam changes throughout treatment, either step-wise or continuously). To circumvent this, assumptions are made about the prostate motion – *e.g.*, that it is confined to the sagittal plane, and that motion in the anterio-posterior direction is proportional to motion in the superior-inferior direction. For this reason, this technique is approximate only and is considered as a *failure detection strategy – i.e.*, an indication that there is a high probability that the prostate has moved outside of tolerance. Detection of failure would then warrant a more precise localization measurement to effectuate a correction with, for example, cone-beam CT or stereoscopic imaging [12,13].

Another limitation of MV imaging to measure intrafractional motion is that for IMRT treatments, the aperture of the treatment beam may not encompass all or any fiducials at any given point in time. There is thus a certain fraction of dose delivery where the tracking is lost. This technique has not to our knowledge been implemented commercially to date.

Another technique to monitor intrafractional motion is the use of transponders (beacons) which are implanted in the prostate, their positions tracked in time using an array of alternating current magnetic coils to generate a resonant response. This concept is used by the Calypso

System (Varian Medical Systems, Palo Alto, CA) [8]. In this solution, the detecting array is placed above the patient and is tracked with three optical cameras calibrated to the room isocenter.

In the Calypso beacon technique, individual beacons 8 mm × 2 mm in size are inserted into the prostate via needles through the perineum under transrectal ultrasound guidance. A minimum of 2 beacons, preferably 3 or more, are used for a given patient. Comparison of the beacon centroid to its position in the planning CT is used to first align the patient for interfractional motion. During treatment delivery, the centroid of the implanted beacons are monitored at high temporal frequency. This technique has been used successfully for intrafractional motion of the prostate. Some limitations include the invasiveness of the procedure, as beacons are generally larger than conventional fiducials used with x-ray imaging; beacon cost; lack of soft tissue information; and MRI artifacts [14] in post-treatment follow-up.

As motion management of the prostate gains importance, particularly for SABR and hypofractionated regimes, intrafractional monitoring of soft-tissue without the need for implanted fiducials or additional radiation dose could have significant benefits. One potential technique would be an integrated MRI-linac, which would give excellent soft tissue definition throughout the treatment. This technology is being developed [15] and has promise to become the gold standard for motion management.

Ultrasound is another non-invasive and non-ionizing imaging technology which has potential benefits such as lower cost than MRI, while retaining excellent soft tissue definition of the prostate. This paper investigates the use of ultrasound for prostate motion management, with a focus on describing the implementation and use of the *Clarity Autoscan with Monitoring* system which has been designed for this purpose.

ULTRASOUND SYSTEMS FOR IMAGE GUIDANCE

Ultrasound has been commonly used for pre-treatment interfractional corrections. The BAT system (Best Medical, Springfield, Virginia) uses transabdominal ultrasound (TAUS) to image the prostate in two near-orthogonal slices through the prostate; the orientation of the slices are known with respect to the treatment room [6]. The prostate contour from the treatment plan is visually matched to the prostate as seen on the ultrasound images, and the resulting prostate shift is corrected with a translation of the treatment couch.

The Sonarray System (Varian Medical Systems, Palo Alto, CA) acquires a freehand sweep of the ultrasound probe to generate a multitude of slices through the prostate, while simultaneously tracking the position and orientation of each slice with respect to the isocenter room coordinates [16]. The slices are reconstructed into a 3D voxel image in room coordinates to be used for alignment purposes. As with the BAT system, the prostate contour from the CT treatment plan is matched to the ultrasound image to measure and correct for prostate displacement.

AAPM Task Group 154, *Quality Assurance for ultrasound-guided radiotherapy*, recommends that ultrasound image guidance use an ultrasound image as reference rather than a CT treatment planning contour [17]. This allows comparison of the same modality from simulation to treatment, eliminating the judgment required to align ultrasound and CT images.

The Clarity System (Elekta, Stockholm, Sweden) uses TAUS imaging of the prostate to acquire a freehand sweep in both the CT-sim and treatment rooms. The Clarity tracking system detects an array of infrared reflectors affixed to the probe handle throughout the sweep. The sweeps are reconstructed to generate 3D ultrasound images in each room. Ultrasound images acquired prior to each treatment are compared to reference ultrasound images from CT-Sim to calculate and correct for interfractional prostate motion. This intramodality comparison has been shown to be more accurate than the intermodality method of comparing ultrasound to CT [7]. The Clarity System has also been extended to other treatment sites such as breast [18,19]. In the remainder of this article, we will describe the extension of the Clarity System to monitoring intrafractional motion; this system will be referred to as *Clarity Autoscan with Monitoring*.

The ultrasound-based systems described above rely on TAUS techniques for external beam radiotherapy image guidance. TAUS uses the acoustic window of the bladder to obtain prostate images. Limitations include the necessity of bladder filling as well as shadowing of the prostatic apex in some patients by the pubic symphisis. TAUS is not well-suited to intrafractional motion monitoring, as the probe lies in the radiation path of typical prostate treatment beam arrangements.

ALTERNATIVE ULTRASOUND TECHNIQUES

Transrectal ultrasound (TRUS) is seen as the gold standard of ultrasound techniques for measuring prostate volumes. TRUS, however, is not practical for external beam radiotherapy due to the proximity of the probe to the prostate, deformation of the prostate by the probe, as well as patient acceptability during multiple fractions.

Transperineal ultrasound (TPUS) is not a well- known technique for prostate imaging and is primarily used for patients that cannot tolerate TRUS. It is an interesting

candidate for intrafractional motion detection, however, since the probe lies between the patient's legs and is thus outside of the radiation path. It also has the potential for high image quality due to the short path between the perineum and the prostate.

Rathaus *et al* [20] have studied TPUS imaging in 80 patients with benign prostatic hyperplasia, and compared the measured prostatic volume with the actual weight of the surgically removed gland and found good correlation between the two (0.89). They used an approximate ellipsoidal formula to calculate volume since they did not have 3D images, which can reduce the accuracy of their prostate volume calculations. They experienced technical difficulties in approximately 10% of patients which had prominent pubic bones, due to the acoustic shadows from these bones. This should not present any issues for motion management for this subset of patients as long as there is sufficient prostate in the image to track motion.

Griffiths *et al* [21] have compared TRUS with TPUS in 287 healthy men. They used the ellipsoidal approximation for prostate volume since they did not have 3D ultrasound. When considering TRUS as the gold standard, they found excellent volume agreement with minimal downward bias (-3.7%) for total prostate volume. They had a technical failure rate of 13.6% for TPUS, similar to that experienced by Rauthaus *et al*.

In a study of 50 patients, Terris *et al* [22] were able to obtain good TPUS visualization of the prostate in 96% (transverse plane) and 90% (sagittal plane). Using a 2D spheroid approximation for volume, they found that prostate volumes correlated well between TRUS and TPUS (r = 0.876). They found that TPUS was able to identify some intraprostatic findings (*e.g.*, calcification and cysts), but not suspicious hypoechoic lesions. They expect that large prostatic tumors could be detected with TPUS, but that it may not be able to detect smaller tumors. Any visualization of tumors would be an added benefit to treatment planning but not a requirement for monitoring the prostate position.

AUTOSCAN IMAGE ACQUISITION

The Clarity System for interfractional image guidance uses a reconstructed sweep from a tracked 2D ultrasound probe to form 3D images. Although this is adequate for pre-treatment corrections, it is not practical for intrafractional motion management as the therapist is not present in the treatment room during radiation beam delivery. An automatically scanning probe, or *autoscan probe*, is therefore a necessity for this application.

The *Clarity Autoscan* system has integrated a mechanically-scanned autoscan probe for this purpose. The probe consists of a 2D probe within housing, with motorized control of the sweeping motion. The probe is able to scan a complete 75º sweep in 0.5 seconds. The patient does not sense any motion other than a slight vibration, as all motion is internal to the probe housing.

The autoscan probe has an integrated homing sensor which triggers as it passes through the center. This allows every sweep to be checked for geometrical accuracy, which is critically important for this application.

The autoscan probe is housed within an *Autoscan Probe Kit* (ASPK), shown in Fig 1. The ASPK consists of a base plate, which can be indexed to the CT and treatment room couches. The Autoscan probe is attached to the base and allows positioning and locking of the probe for TPUS scanning, as well as incorporating a fine adjust mechanism. An array of 4 infrared reflective makers are affixed to the probe so that its position and orientation can be detected by the Tracking System.

CALIBRATION

Figure 1Autoscan Probe Kit for transperineal ultrasound of the prostate

The Clarity Autoscan System must be calibrated to the coordinate system of the CT and treatment room, respectively. This provides a relationship between each ultrasound pixel and their corresponding position in room coordinates. We may define the following four coordinate systems: **R** is the room coordinate system, **T** is the coordinate system of the tracker, **F** is the coordinate system of a given 2D ultrasound frame, and **P** is the probe coordinate system defined by the definition of the reflective marker array attached to its handle. As illustrated in Fig. 2, a pixel in ultrasound "frame" coordinates $\boldsymbol{r}_{\mathrm{F}}$ can be transformed to room coordinates $\boldsymbol{r}_R$ by the equation

$$\boldsymbol{r}_R = {}^{R}\boldsymbol{T}_{T}\,{}^{T}\boldsymbol{T}_{P}\,{}^{P}\boldsymbol{T}_{F}\boldsymbol{r}_{F} \qquad (1)$$

where ${}^{P}\boldsymbol{T}_{F}$ is the 4×4 frame-to-probe transformation matrix, ${}^{T}\boldsymbol{T}_{P}$ is the probe-to-tracker transformation matrix, and ${}^{R}\boldsymbol{T}_{T}$ is the tracker-to-room transformation matrix. *Room calibration* and *probe calibration* are defined as finding the transformations ${}^{R}\boldsymbol{T}_{T}$ and ${}^{P}\boldsymbol{T}_{F}$, respectively. The former is static as long as the isocenter and tracking system do not change, and the latter as long as the markers affixed to the probe's handle maintain a constant relationship.

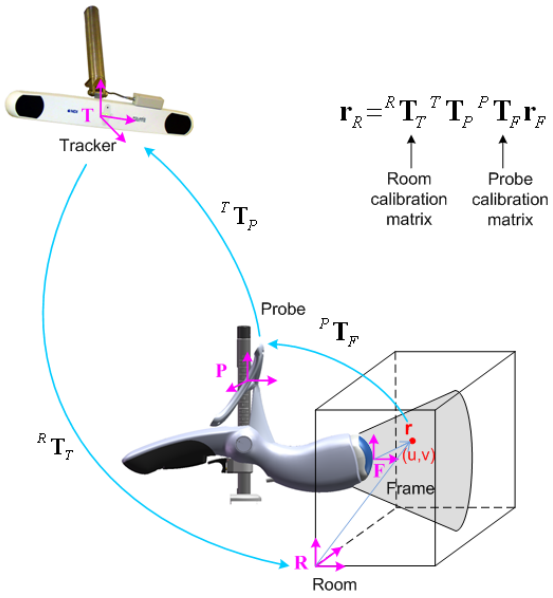

Figure 2. Schematic diagram illustrating coordinate transformations for calibration

The frame-to-probe matrix can be further broken down into the components

$$ {}^{P}\boldsymbol{Tr}_{F} = {}^{P}\boldsymbol{T}_{C}\boldsymbol{T}_{S}\,{}^{C}\boldsymbol{Tr}_{F}(i) \qquad (2) $$

where the frame-to-center rotation matrix ${}^{C}\boldsymbol{T}_{F}(i)$ defines the rotation of the frame relative to the probe as a function of indexed motor position i, $\boldsymbol{T}_{S}$ is a scaling matrix and ${}^{P}\boldsymbol{T}_{C}$ is the center-to-probe transformation, which defines the relationship between the central frame when the probe is at its center position and the marker array affixed to the probe handle.

Room Calibration is defined by aligning etchings on the Clarity calibration phantom (Fig. 3) to the isocentric room lasers, and pressing a *Calibrate* button on-screen. The tracking system then detects infrared markers affixed to the front plate of the phantom, and and since the relationship between these markers and the etchings on the phantom is known, the room calibration matrix can be calculated.

The probe calibration procedure is performed by acquiring a 3D image of the calibration phantom with the autoscan probe. The phantom contains rods and spheres at known positions; the positions are known *a priori* but are adjusted by measurements of the distances on a CT phantom. The rods and spheres are automatically detected in the ultrasound images, and an optimization algorithm is used to find the optimal ${}^{P}\boldsymbol{T}_{F}$ that best fits the detected positions to their known positions in the phantom. This is saved in the Clarity System as the probe calibration, which along with the room calibration is used to convert all ultrasound images (frames) along with their tracking system readings ${}^{T}\boldsymbol{T}_{P}$ into room coordinates using Equation (1).

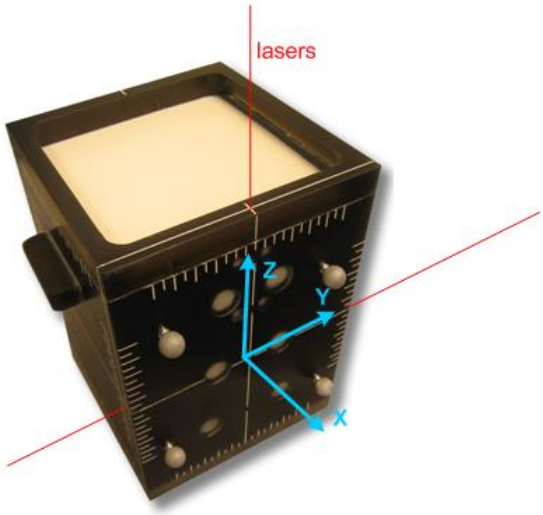

Figure 3 Clarity phantom used for calibration

Calibration is performed upon installation, and in theory would not change unless a) the probe were deformed, b) the camera moved relative to isocenter, or c) the isocentric coordinate system were moved. This is verified daily by a Quality Control (QC) procedure which consists of scanning a sphere in the Clarity phantom and comparing its detected location with its location as measured on CT. Calibration may be repeated in the event the QC is out of tolerance.

IMAGING ACCURACY AND PRECISION

In order to validate accuracy and precision of the calibrated Autoscan image acquisition process, we used the Clarity phantom which has embedded sphere and rod structures at known positions that can be visualized on both CT and ultrasound.

CT and Clarity Autoscan images of the phantom were successively acquired and registered as per clinical workflow. Since the systems are calibrated to each other, structures in the phantom should be aligned in the fused images. We validated this by reviewing the resulting fusions (Fig. 4) in the Clarity Workstation for three successive scans with different probe and phantom combinations. All structures were visually validated to be within 1 mm of each other on both modalities.

To quantify the precision, we scanned the same phantom 32 times, automatically segmented the phantom sphere in each scan, and calculated the resulting structure centroid for each scan. The 95% prediction interval for the centroid position were found to be ±0.4 mm, ±0.7 mm and ±0.5 mm, and the standard deviations 0.1 mm, 0.2 mm and 0.1 mm in the SUP/INF, RT/LT and ANT/POST directions, respectively. A histogram of the results is shown in Fig. 5.

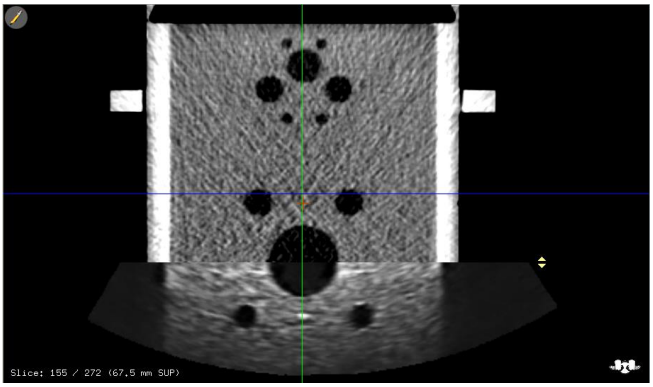

Figure 4. Registered CT and Clarity Autoscan images on the same phantom for validation of registration

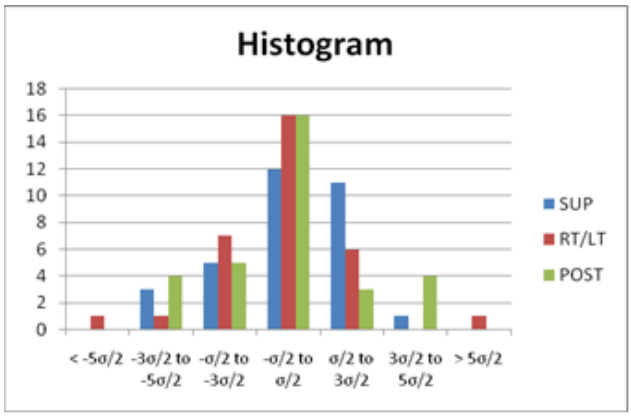

Figure 5. Histogram of precision measurements

INTRAFRACTION PROSTATE MONITORING

In order to monitor the prostate during treatment, the autoscan probe must continually sweep through a sector which includes the prostate. The ultrasound frame-rate is on the order of 45 Hz, depending on the imaging parameters used. The relationship between the angular spacing between frames $\Delta\theta$, the total sweep time T_{sweep}, the maximum sweep angle $\Delta\theta_{sweep}$ and the ultrasound frame rate F is given by

$$T_{sweep}\Delta\theta = \frac{\Delta\theta_{sweep}}{F} \quad . \qquad (3)$$

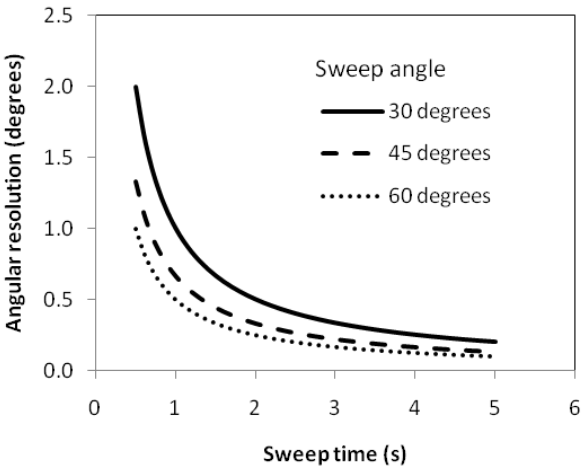

Figure 6. Theoretical plot showing relationship between angular resolution and sweep time for different sweep angles, assuming an ultrasound frame rate of 45 Hz.

It can be seen that there is a trade-off between the sweep time and resolution as defined by the angular spacing. The relationship, assuming a frame rate of 45 Hz, is plotted in Fig. 6. From the graph, a 45º sweep with an angular resolution of 0.3º would lead to a 2.5 second sweep time.

Although the maximum sweep angle is possible with the autoscan probe, we have found that a 45 º is a good trade-off to obtain sufficient coverage of the prostate for TPUS imaging. Assuming a typical prostate depth of 5 cm, this would lead to a resolution of 0.9 mm at the middle at the depth of the prostate. From the graph, the sweep time for this scenario would be approximately 1 second.

Even if a high monitoring sampling is possible, clinical use of prostate motion management during external beam radiotherapy generally compensates for drifts and stable excursions rather than chase transient peaks. We have thus implemented a slower sweep time of 2.5 seconds to gain higher resolution soft tissue imaging - a 0.4º angular

resolution which would result in a 0.35 mm resolution at 5 cm depth.

In the Clarity Autoscan with Monitoring system, a full pre-treatment sweep is first acquired, and the images reconstructed and displayed to the user. This image is then compared to the simulation 3D ultrasound image to calculate a couch shift to correct for interfractional prostate motion. The system then goes into a *monitoring* phase, where the ultrasound sweeps back and forth continuously. The first sweep is used as a reference for monitoring. The image is continuously refreshed as the autoscan probe sweeps the region of interest.

An intensity-based image-to-image registration finds an optimal fit between the current image and the monitoring reference image. The algorithm uses normalized cross-correlation as the cost-function, and uses pixels within a 2 cm boundary surrounding the prostate for the comparison. The registration is constrained to 6 degrees of freedom, *i.e.*, translations and rotations with no deformations.

Image-to-image registrations are most commonly performed in rectilinear coordinate systems. For the current monitoring application, the ultrasound sweeps are acquired in a cylindrical coordinate system (Fig. 7). To reduce calculation time, we skip the step of reconstruction in the monitoring algorithm and directly register images in cylindrical coordinates [23]. The calculation time for each registration is approximately 0.7 seconds. Rather than wait for a full sweep, the calculation is applied in succession on each partially updated image.

The registration algorithm calculates a correlation score for each iteration. This score would be 1 for a perfectly correlated fit, and 0 for a completely uncorrelated fit. We have chosen a cut-off based on training data; the user is alerted to verify the registration on-screen if the correlation is below the threshold. This provides an additional safety measure.

During monitoring, the user is presented with sagittal and coronal views, as well as the current live image, as shown in Fig. 8. Each view shows a contour overlay of the prostate as calculated by the registration. Graphs showing the motion in each Cartesian direction are plotted, as when thresholds are exceeded. The system provides an alert when the threshold has been exceeded by a certain amount of time. The therapist would then interrupt the treatment, perform a couch correction, and resume treatment. Thresholds in each direction, as well as time-out-of-threshold values, are pre-determined by the physician prior to the first treatment fraction.

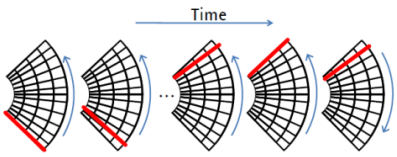

Figure 7. Cylindrical coordinate system geometry

PHANTOM MEASUREMENTS

In order to validate the prostate monitoring algorithm, a commercially available multimodality pelvic phantom (CIRS), modified with an extra acoustic window on one side to accommodate TPUS scanning geometry, was placed on a robotic translation stage (Velmex, Bloomfield, NY), as shown in Fig 9. The autoscan probe was set up to continuously acquire images of the phantom. A reflective marker array was affixed to the top of the phantom to record the actual motion of the phantom with the Clarity tracking system.

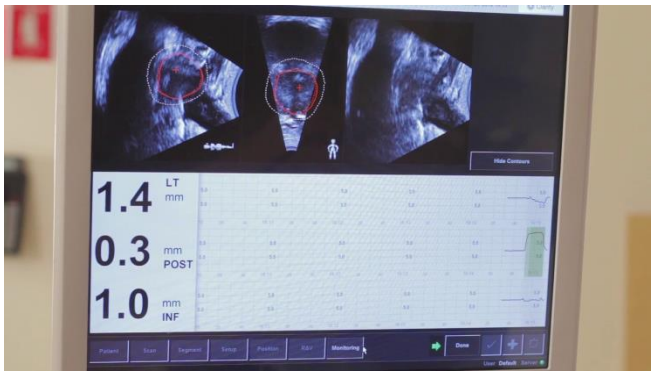

Figure 8. Clarity Monitoring screen

The robotic stage was programmed with motion patterns, and the prostate structure was tracked with Clarity to quantify the differences between the calculated and programmed time sequences. Motion in the A/P and L/R plane was measured differently than that in the S/I direction due to the practical issue of maintaining contact between the probe and the phantom as the phantom is moved. For the former, a rectangular wave was programmed with ±10 mm in the A/P direction and ±5 mm in the L/R direction. Each step was held for a duration of 10 minutes, and run 5 times in a row for a total of 10 minutes. For the S/I motion, a gel pad was used between the phantom and the probe to maintain contact, and the motion amplitude was limited to ±4 mm.

The results are shown in Fig. 10 for the A/P and L/R directions, and in Fig. 11 for the S/I direction. The mean and standard deviation of the differences are -0.2 ± 0.2 mm, 0.2 ± 0.4 mm and -0.0 ± 0.2 mm in the A/P, L/R and S/I directions, respectively. The calculated versus programmed motion was within 1 mm 95% of the time.

Abramowitz *et al* [24] also performed measurements with the Clarity Autoscan system at the University of Miami. They used a motorized phantom with an embedded prostate-like structure submerged in a liquid. While Clarity tracked the structure, the Calypso System (Varian Medical Systems, Palo Alto, CA) tracked beacons affixed to an external stem that followed the same motion as the prostate structure. They programmed 7 series of clinical prostate motion datasets from the literature, and found excellent agreement between Calypso and Clarity.

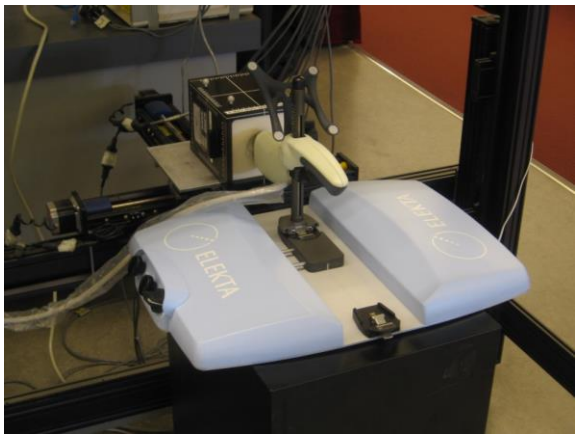

Figure 9.Experimental set-up for phantom measurements

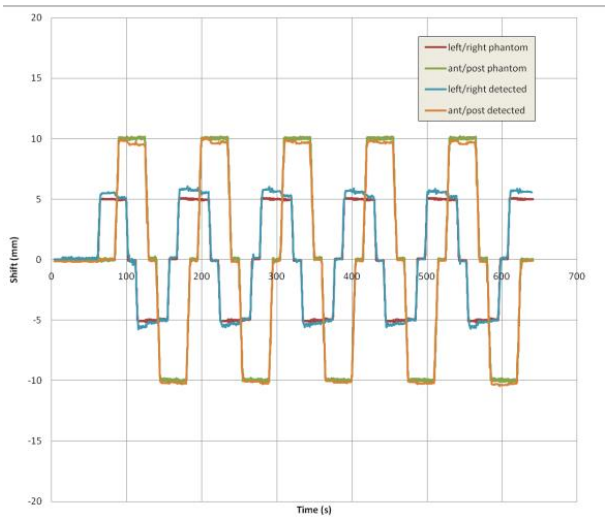

Figure 10. Comparison of programmed versus calculated motion in A/P and L/R directions

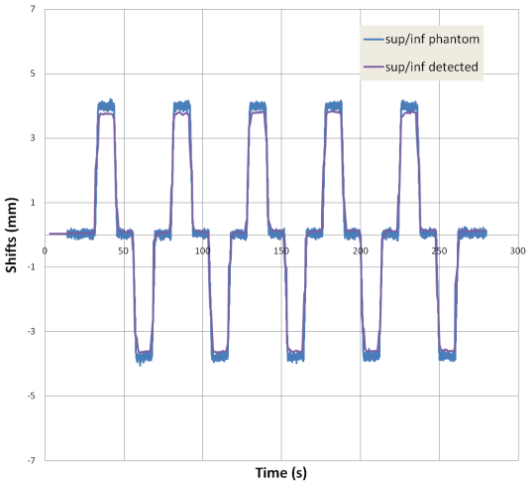

Figure 11. Comparison of programmed versus calculated motion in S/I directions

PATIENT IMAGING

Wallace *et al* [25] studied the use of Clarity Autoscan transperineal imaging on a series of 15 patients. They acquired autoscan TPUS as well as freehand TAUS images for each patient during the CT simulation process. Image quality of prostate borders for TPUS was similar for TAUS except for a dramatically improved visualization of the prostatic apex. Rectum and penile bulb visualization was much improved over TPUS, whereas the bladder was better visualized under TAUS. Example images acquired during the study are shown in Figs 12 and 13.

Abramowitz *et al* [26] collected data during external beam radiotherapy treatments for prostate cancer for 62 fractions. They found that the tracking algorithm accurately tracked observed intrafractional prostate motion throughout the series.

Further comparative clinical studies are ongoing and will be presented by the principal investigators in separate manuscripts.

CONCLUSION

We present a system for intrafractional prostate motion management during external beam radiotherapy. The system relies on soft tissue imaging of the prostate with transperineal ultrasound without the need for implanted fiducials or extra imaging dose. A calibration algorithm has been described which brings the imaging data in the isocentric treatment coordinates, and a registration algorithm is described which successfully tracks the prostate during treatment. Accuracy and precision of imaging, as well as the prostate monitoring algorithm, are found to be less than 1 mm in each direction. Future work will investigate intrafractional monitoring of surrounding critical structures, as well as extension to other anatomical treatment sites.

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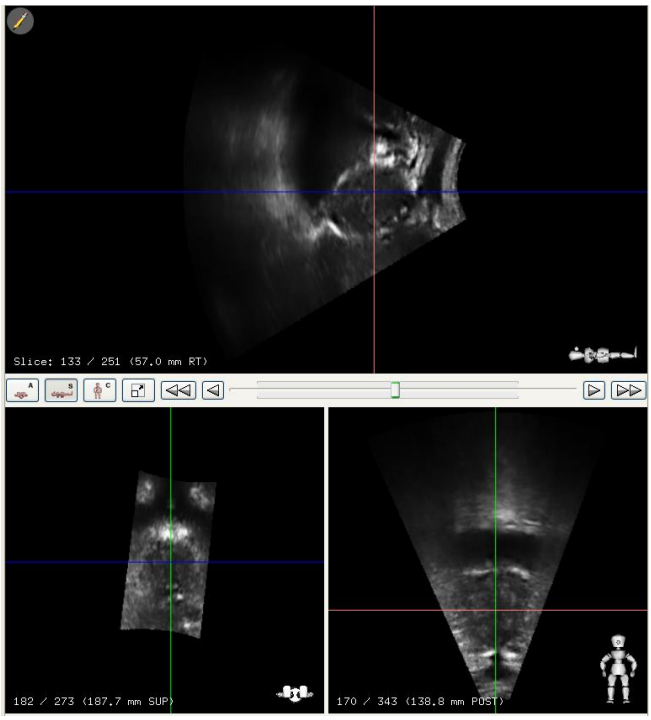

Figure 12. Clarity Autoscan image of the prostate for a sample patient

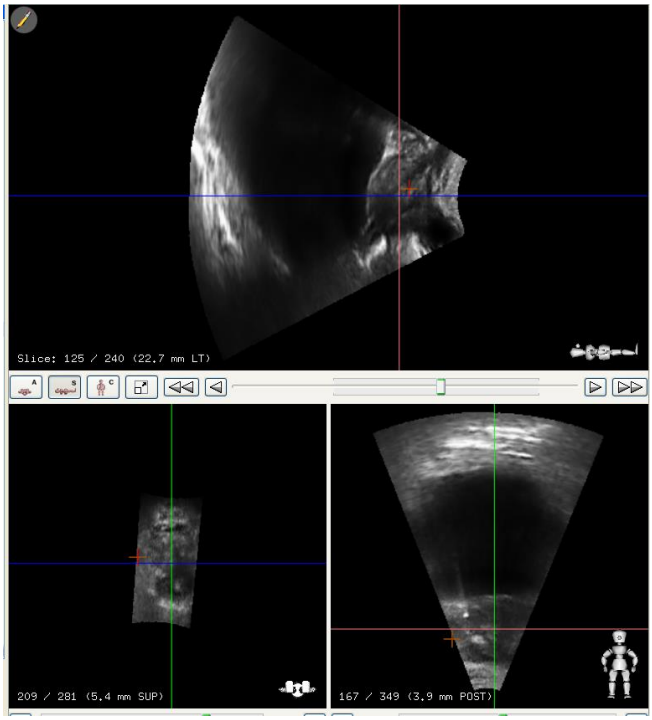

Figure 13. Clarity Autoscan image of the prostate for a sample patient

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DOSE MEASUREMENTS IN SMALL FIELDS

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Abstract— A rapidly increasing number of teletherapy treatment modalities, e.g. intensity modulated radiation therapy (IMRT), volumetric arc therapy (VMAT) or stereotactic radiosurgery (SRS), is capable of applying small irradiation fields. Field sizes can be as small as 1 cm x 1 cm or below. The main physical and measurement related effects to consider when performing dose measurements in small fields will be introduced. Subsequently, a detailed description is given on how to decide which detector to choose for the measurements and how to perform the measurement.

Keywords— small field dosimetry, detector choice, practical dosimetry, stereotactic therapy fields

INTRODUCTION

An increasing number of teletherapy treatment techniques make use of small and very small radiation fields, for example, stereotactic radiosurgery (SRS), intensity modulated radiation therapy (IMRT) or volumetric arc therapy (VMAT). Using small radiation fields allows the dose to be placed very precisely in the target volume and at the same time to spare healthy tissue which may be in close vicinity. All in all, there is an increasing demand to characterize small fields in dosimetry.

At the same time, small field dosimetry is more demanding than dosimetry of classical field sizes. New physical aspects, such as the volume averaging effect or the lack of secondary electron equilibrium start to play a non-negligible role and the approximations of classical radiation physics, such as the bragg-gray conditions tend to be valid to a lesser extend compared to larger fields. Precise dosimetry in small fields is still a matter of scientific research; international standards are being developed but not ready yet, e.g. [1].

PHYSICAL AND MEASUREMENT RELATED ASPECTS OF SMALL FIELDS

The volume averaging effect

Any detector will average the dose over its volume. If the dose varies over the volume of the detector, this averaging can yield a different signal compared to the signal an infinitesimally small detector would measure in the center of the area of the large detector. This so called *volume averaging effect*, or short *volume effect* leads to two distinct aspects: (i) the dose in the center of a small field is underestimated – important for output factor[1] measurement and reference dosimetry, and (ii) the penumbra is washed out – important for profile scanning [2]. In general, the volume effect is proportional to the curvature (i.e. second derivative) of the dose profile but *not* to the gradient; this is illustrated in Figure 1, see also [3].

Calculation example: to get a feeling for the volume effect, an ideal circular detector in an ideal circular 2D Gaussian field can be assumed. Then, the average signal over the detector area can be calculated and compared to the value in the center of the Gaussian. For a 20 mm FWHM[2] Gaussian dose profile with a 5 mm diameter detector, the resulting volume correction factor is 1.02. In this example, the detector diameter is four times smaller than the field diameter and this leads to 2 % deviation due to volume averaging. This can be formulated as a rough rule: if the detector width is at least four times smaller than the field width, the volume effect will only be a few percent.

In summary, the volume averaging effect can lead to:

- Dose underestimation when measuring output factors in small fields
- Blurring of the penumbra in profile measurements

The safest way to avoid the volume effect, is to choose a detector which is small enough. Another possibility is to partially correct the volume effect by deconvolution techniques [4–7]. This way the good energy response of an ionization chamber can be preserved and the penumbra still reasonably well characterized.

The volume averaging effect in combination with CAX normalization

As explained in the last section, the volume averaging effect can lead to a reduced signal in the center of a field when there is a non-zero field curvature over the detector volume. In most cases, measured profiles are normalized to their central axis (CAX) value. By doing so, the entire curve is multiplied by one factor, $k_{Vol} > 1$.

[1] Also called *total scattering factor*.
[2] Full Width at Half Maximum

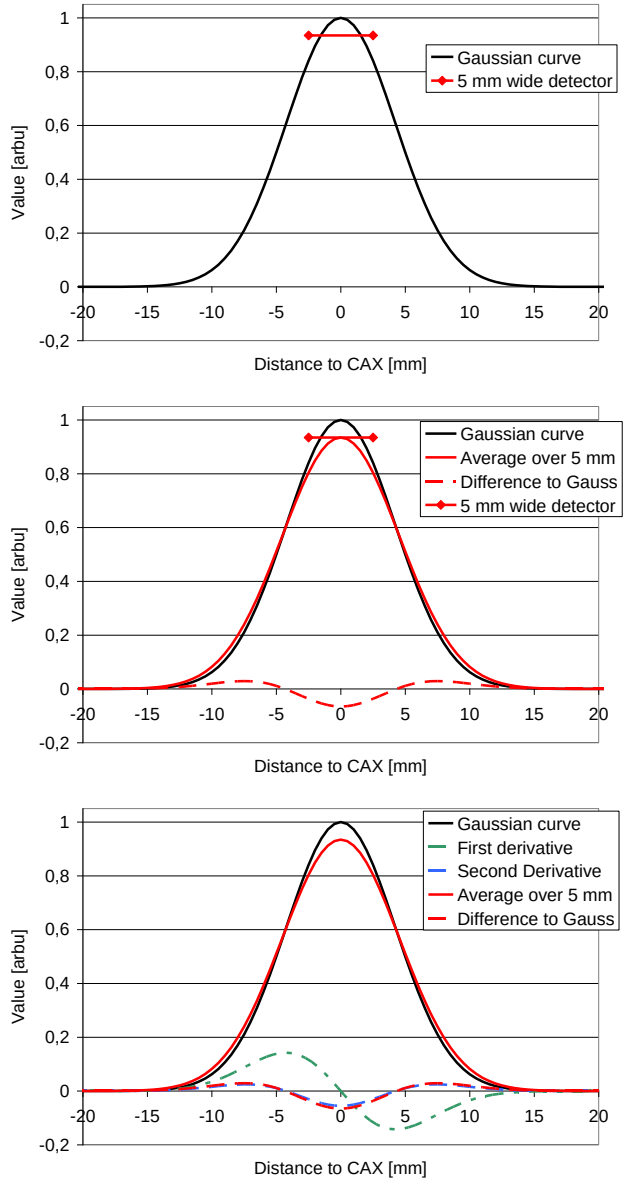

Figure 1. Gaussian curve (solid black) as approximation of a small field profile to illustrate the effects of volume averaging. This is a purely 1D example which leads to the same principle effects but at a different magnitude compared to a full 2D treatment. **Top:** if the size of the detector is larger than the distance in which the field will vary noticeably, a volume averaging effect is expected. **Middle:** the solid red curve represents what a detector would measure when a volume effect is present. The deviation between the two curves in global % is displayed as dashed red line. **Bottom:** in this plot the first (dash-dotted green) and second (dashed blue) derivative of the Gaussian curve are shown. Clearly, the difference curve and the second derivative are proportional to each other. Note, in the high-gradient region at roughly ±4 mm, no volume effect is present – both the difference curve and the second derivative pass through zero.

Since this factor is applied to the entire curve, it also increases the dose in the outer penumbra and out-of-field region. In addition, due to the signal increase in the penumbra, the 50 % isodose moves outwards, i.e. the apparent field size increases. This last effect is only due to the CAX normalization, the original dose measurement exhibits no volume effect at the 50 % isodose because the curvature is zero there, see Figure 1.

In Figure 2, the described effects are presented for a 1 cm x 1 cm field measured with a diamond detector (T60003, PTW-Freiburg, Lörracher Strasse 7, 79115 Freiburg, Germany) and a considerably larger semiflex 0.125 cm³ chamber (T31010, PTW-Freiburg) on an Elekta Synergy SLi18 linac (Elekta, Crawley, UK). Due to the CAX normalization the volume effect in the field center is set to zero but increases outside of the 50 % isodose.

In summary, the volume effect in the field center in combination with CAX normalization can lead to:

- The field appears larger than it is
- The dose outside of the main field is increased in addition to the volume effect alone as described in section 00. See bottom Figure 2.

The low and high energy response

The energy response of any detector should be classified into two parts. (i) The response to photon radiation in the kV energy range and (ii) the response in the MV range. Silicon, for example, exhibits a relatively strong energy dependence in the low-energy range because the ratio of the mass energy absorption coefficients of silicon over water changes considerably in that energy range [8, 9]. On the other hand, Silicon exhibits a relatively low energy dependence in the high-energy range because a slow variation of the mass stopping power ratio of silicon over water in the MeV energy range [9–11]. The kV-energy dependence is especially important when low-energy scattered radiation is present; this is the case in large radiation fields [12, 13].

Hence, for small field dosimetry the kV-energy dependence is of comparatively minor importance. In [14], the use of non-shielded silicon diode detectors is recommended for very small fields.

Signal noise and attainable speed of the measurement

When performing dose measurements, there are several possible sources of noise. The following four are usually the most important ones: (i) quantum noise of the radiation itself, see e.g. [15], (ii) electromagnetic disturbance from the linac environment (iii) noise of the amplifier input of the dosemeter and (iv) noise of the voltage source of the dosemeter.

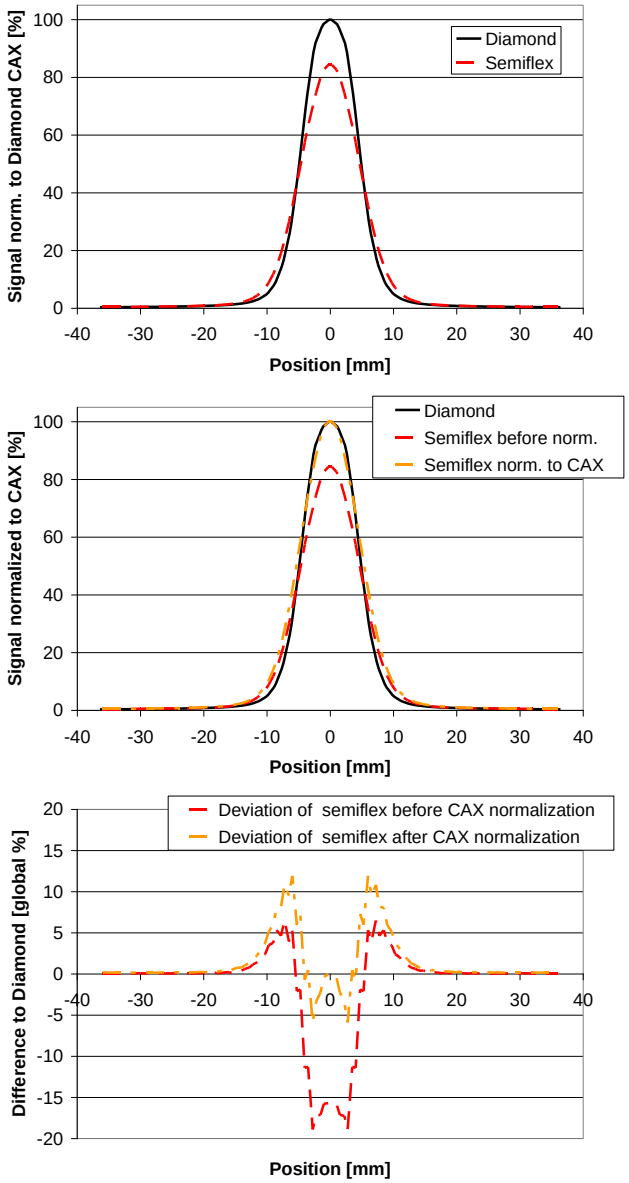

Figure 2. Smoothed profile of a 1 cm x 1 cm field measured with a diamond detector (solid black) and a 0.125 cm³ semiflex chamber (dashed red) on an Elekta Synergy linac. **Top:** both signals have been normalized to the CAX of the diamond detector. The volume effect of the semiflex chamber is clearly visible and leads to a 15.7 % signal loss. **Middle:** each signal has been normalized to its own CAX value, i.e. the entire measurement of the semiflex chamber has been multiplied by 1.19 (dashed orange). Due to this multiplication, the 50 % isodose of the semiflex measurement seems to lie further outward than in the original measurement where both detectors correctly measure the dose at 50 % isodose. In addition, the dose outside of the field is overestimated by the factor of 1.19. This increases the deviation due to the volume effect outside of the main field as can be seen in the **bottom graph**, where the difference between semiflex and diamond curves before and after CAX normalization is displayed in global %.

When using a high-quality dosemeter and detector, the noise from the amplifier, voltage source and electromagnetic disturbance only contribute very little to the cumulative noise. In this case, quantum noise is the most important contribution. Quantum noise measurements have been performed in Co-60 radiation and at a SIEMENS Primus linac (SIEMENS, Erlangen, Germany) [16–18].

At first, one might assume that noise is only a function of the *response* of the detector. But this is not the case. The magnitude of the quantum noise mainly depends on the detector *volume* and *material*. For example, the quantum noise of a PinPoint chamber (type 31014, PTW-Freiburg) is a lot less than the noise of a Diode E (T60017, PTW-Freiburg), even though the response of the diode is 22.5 times higher [18]. If only detectors of the same material are compared, e.g. only diamonds or only air-filled ionization chambers, quantum noise usually reduces with increasing volume and response [18].

Quantum noise follows Poissonian statistics. Hence, in contrast to many other sources of noise, quantum noise is a function of the signal [18, 19]:

$$\text{Quantum noise} = \sqrt{\text{Signal}} \tag{4}$$

When measuring relative data, e.g. profiles or output factors, the signal and hence also the noise are normalized to the signal itself. This yields the relative quantum noise:

$$\text{Relative quantum noise} = \frac{1}{\sqrt{\text{Signal}}} \tag{5}$$

Hence, the lower the signal, the higher the relative noise. The extent of noise in the signal plays a role in the attainable speed of the measurement. The lower the noise, the faster the signals can be recorded. Ionization chambers typically exhibit less quantum noise than diodes.

Depending on the quality of the dosemeter, amplifier and voltage source noise may add to the quantum noise. In that case an ionization chamber measurement might exhibit more noise than necessary.

Detector positioning in the field center

Small fields typically show no plateau in the field center. Hence exact detector positioning in the center of the field is a lot more important than in dosimetry of larger fields. The detector should be aligned to the field center by measuring profiles in shallow and large depths [14].

Using a reference detector

When measuring profiles, PDD curves, or TPR data, it is common practice to place a reference detector in the corner of the radiation field to correct for fluctuations of the linac output. In small fields there is not enough space to place such a reference detector inside the field. One possible

solution for this problem is to use the linac monitor chamber as a reference detector. Unfortunately this signal is usually not accessible. Alternatively, the measurement can be performed without reference detector or by use of a very high response detector which is placed outside of the field [14]. When measuring without reference detector, it has to be assured that the output of the linac is stable in time, e.g. by measuring the profile multiple times. In this case, the linac fluctuations will be source of noise. A high quality but slow alternative is measuring step by step, irradiating a fixed number of MUs at each detector position.

Using a reference detector outside the field: The dose rate outside the primary beam is usually very low, typically a few percent of the primary signal. As described in section 0.0 the relative noise of weak signals will be a lot higher than in the field. Since the result of the measurement is the field signal divided by the reference signal, this will increase the noise of the measurement. To prevent this, a reference detector with a very low quantum noise should be chosen, e.g. a large ionization chamber. The effect is shown in Figure 3, where the signal of a 0.125 cm³ chamber (type 31010, PTW-Freiburg) is displayed, placing the reference detector inside and outside a 4 cm x 4 cm irradiation field of a Varian Clinac iX (Varian Associates, Palo Alto, CA). Clearly, the signal quality is greatly reduced when simply placing the reference detector outside of the field. The situation improves when using the 22.5 times larger Farmer chamber (type 30013, PTW-Freiburg) but the noise still increases. Using the standard deviation as a noise measure and equation (2), the expected noise can be calculated as a function of the signal. For the data in Figure 3, the signal – and hence the volume – of the reference detector has to be increased by a factor of four to reach the noise level of the semiflex chamber in the field. The calculated standard deviations are presented in

Table 2. This is only one single example. The calculated minimum volume depends on the field size and distance from the field edge. A larger chamber is needed when the field size is smaller or when the distance to the beam edge is increased.

Table 2 Standard deviation, as a measure of noise of the signals shown in Figure 3. "Ouside" signifies 3 cm outside of the beam edge as defined by the light field.

Chamber type	**Volume [cm³]**	**In the field or outside?**	**Noise (= standard deviation) [%]**
PTW 31010	0.125	Inside	0,12
PTW 31010	0.125	Outside	0,62
PTW 30013	0.6	Outside	0,29
Hypothetical	2.4	Outside	0,15

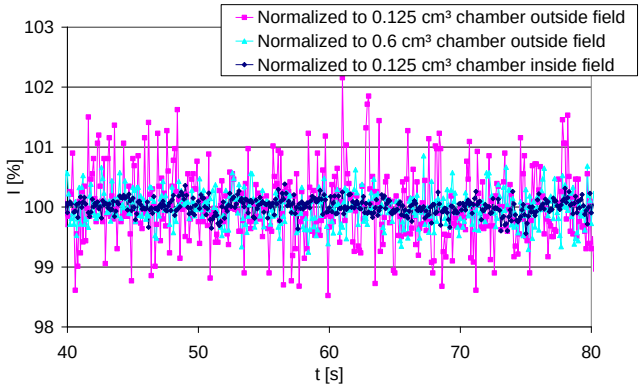

Figure 3. Signal of a 0.125 cm³ chamber in a 4x4 cm² field at roughly 1.5 Gy/min, at 10 cm depth in water. The integration time for each data point is 100 ms. For this measurement, a 0.125 cm³ reference detector has been placed inside the field (blue diamonds) and 3 cm outside the field (magenta squares). For comparison, the result when referencing to a 0.6 cm³ Farmer chamber, located outside the field, is also displayed (cyan triangles).

In summary, the possible options are:

- Using the monitor chamber of the linac
- Ensuring that the linac is stable and measuring without reference
- Using a reference chamber outside of the beam but with a volume well larger than 2.4 cm³. It should be placed as close as possible to the beam edge. The chamber should be pre-irradiated before use outside of the beam.
- Irradiating a fixed number of MUs at each detector position

Dose rate dependence

Some detectors exhibit a dose rate dependence, i.e. the response of the detector can change when the dose rate changes. Depending on the detector in question, this may be a reaction to the changing linac frequency, average dose rate, or dose per pulse. In this article, *dose rate dependence* will be used as general term to describe all three aspects. For air-filled ionization chambers the effects are well understood and can easily be corrected. Nonetheless this correction can be quite time-consuming and for many small field detectors, data on their dose rate dependence is sparse. It is worthwhile to address the question on how much effect a dose rate dependence actually has on the results. When performing reference dosimetry, the dose rate dependence is usually corrected. Hence we are left with its effect on relative measurements only; for example output factors, profiles or PDDs.

Mathematically, the following three operations are done when performing a relative dose measurement:

1. A quantity proportional to dose is measured while changing one parameter of the setup. This parameter can be depth, distance from the CAX, field size or some other parameter.

2. The entire measurement is normalized to one data point of the same measurement, e.g. the value on the CAX. In practice this means, the entire curve is multiplied with one numerical factor.
3. The entire measured curve is displayed as relative values, either in % or as factor where 1 is the normalization value.

In fact, the second and third step is equivalent to calibrating the detector to the conditions valid at the normalization point. After normalization, by definition, the value at this position is exact. Hence, in the flat field part, the profile is in very good approximation not influenced by a dose rate dependence. The more the actual signal deviates from the signal at the normalization point, the stronger can the influence of a dose rate dependence be. At the same time, the absolute deviation is also small at low signals because the signal itself is low. All in all, after the signal is normalized at 100 %, a deviation due to dose rate dependence is best visible at the 50 % dose level. This is illustrated for an idealized profile in Figure 4. The only physical assumptions that are needed for the data are that the dose rate dependence is linear with the dose per pulse and that the saturation loss is maximal at the highest dose per pulse. These assumptions are reasonable for ionization chambers [20].

As explained above, the error vanishes at the normalization point on the CAX. This is clearly visible in the bottom part of Figure 4. In the low dose region the error tends to very small values because we look at global % values. These are small when the signal is small. The highest deviation of the normalized curve is in the penumbra because the signal is relatively far away from the normalization value but still high enough to yield an observable global % difference value.

In summary, the normalization procedure leads to:

- The maximum deviation in global % is only 1/4th of the saturation loss at the normalization point
- This maximum deviation is located in the penumbra
- The deviation changes sign

The same estimation can be performed for PDD curves, where the maximum deviation is also 1/4th and located at the 50 % dose value of the curve.

Similar considerations hold for the measurement of output factors. In most cases, the signal range without changing the detector will be roughly 70 to 120 % of the signal at the normalization point. The maximum deviation is hence a bit less than the 1/4th of the maximum signal deviation encountered in profile and PDD measurements.

Ionization chambers and diamond detectors tend to exhibit a loss of response at high dose rates while for diodes the opposite behavior is possible [21].

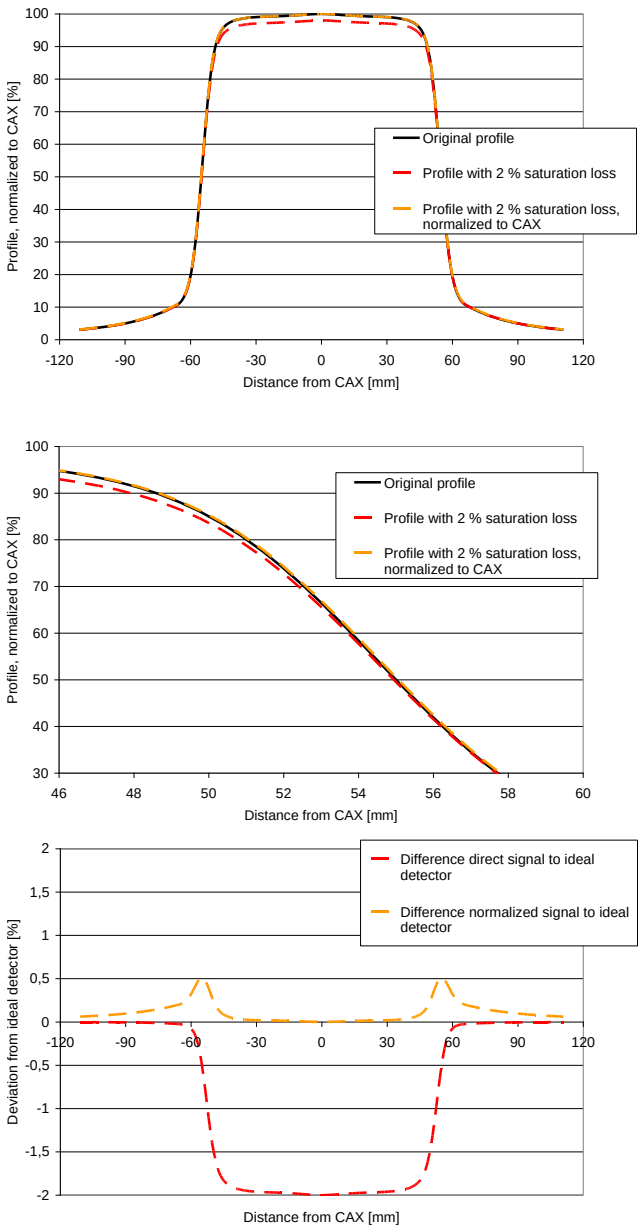

Figure 4. Theoretical profile of a 11 cm x 11 cm field measured by an ideal detector (solid black), a detector exhibiting a dose rate dependent saturation loss of up to 2 % (dashed red) and of the signal normalized to the CAX value (dashed orange). **Top:** full profile, **middle:** zoom into the upper right part of the profile and **bottom:** difference in global % between the curves.

Non-linear relation between field size defined by the collimators and field size defined as 50 % isodose

In large fields, there is a one to one correspondence between the field size set by the collimators and the actual field size. In small fields, the focus can be partly obscured by the collimator blocks. This leads to the field size – as defined by the 50 % isodose – to reduce faster than the

collimator opening. Hence the relation between field size set on the collimators and the actual field size can become non-linear for very small fields [22].

In the case of source occlusion, the actual shape of the field may depend on the size and shape of the focal spot. The shape of the focal spot might vary in time or if a different linac model of the same type is used. In these cases, the field shape will also vary. [22]

Lack of secondary electron equilibrium

As soon as the distance to the closest field edge is smaller than the travel distance of scattered secondary electrons, equilibrium of secondary electrons breaks down. As a rough estimation the range of laterally scattered secondary electrons is similar to the depth of the dose maximum of a PDD in 10 cm x 10 cm. Precise data is given in [23]. Some of the assumptions of classical dosimetry break down when lateral electron equilibrium is not given. The electron energy distribution over the volume of an air-filled ionization chamber is, for example, not constant in contrast to equilibrium conditions. The consequences of lack of secondary electron equilibrium are still in scientific discussion, see e.g. [14].

Correction factors from literature

Recently, many articles have been published providing correction factors for certain detectors, e.g. [1, 3, 24–27]. When using these factors, care has to be taken to adapt them to the dosimetry protocol employed because the precise value of these factors may depend on the specific protocol used. For example, the value of the beam quality correction factor k_Q is different in TRS 398 [28] and DIN 6800-2 [29], and TG-51 [30] uses a different measure for the radiation quality. k_{Vol} may depend on the specific linac model in question as the precise shape of the beam depends on the size of the focal spot of the electrons on the target [14, 22].

Other aspects

High density detectors: many small field detectors are solid state detectors, e.g. silicon diodes or diamond detectors. These are high density materials, of 2.3 and 3.5 g/cm³ density, respectively [3, 26]. Recently, some publications claim an influence of the density of the detector material on the measurement in small fields [26, 31].

Cable and stem effects: due to the very small volume of microchambers of less than 0.1 cm³, stem and cable irradiation effects are a lot stronger than for standard ionization chambers. To be on the safe side it is reasonable to perform a polarity correction. To reduce the influence of the cable, it can be mounted in a way that the irradiated cable length changes as little as possible during the measurement. For example, the chamber can be mounted in axial orientation – this will, by the way, also increase the spatial resolution in most cases. When purchasing such a chamber it is important to watch for the water equivalence, e.g. a steel electrode is not preferable [14].

FFF beams: often, therapy systems using small fields are flattening filter free (FFF) linacs. The field is then never flat in the field center, even for large fields. A Farmer chamber might already show a volume effect in any field size [32]. In addition, the dose per pulse values and dose rate can be elevated for FFF linacs.

Penumbra more important: in general, when working with small fields, it is more important to precisely characterize the penumbra and out-of-field region. When many small fields are added up, a comparatively large fraction of the dose stems from the penumbra, and for field sizes roughly below 3 cm x 3 cm, the field consists almost only of penumbra [22]. The penumbra width, e.g. the spatial distance between 80 and 20 % dose, is smaller in small fields. This increases the curvature and hence the volume effect in the penumbra region.

Electron and photon spectrum can change with field size: in small fields, the energy spectrum of the primary photons and secondary electrons can change with the field size. For some examples see [14].

Divergence of the beam: divergence of the beam can, via the volume effect, lead to a slight overestimation of 1 % in a PDD measurement deep in the water [26]. Because of the small opening angle of small field beams, this effect is relatively weak.

HOW TO CHOOSE THE DETECTOR

Choosing the correct detector for small field measurements is not an easy task. There are no simple rules or standard detectors. Some insight into the physics of small fields is needed, and it has to be considered what exactly should be measured. Then a compromise between all requirements has to be found. The following chapter shall give a guideline for the decision process.

Detector types

In large fields, air-filled ionization chambers are usually the first choice. In small field dosimetry different types of detectors are in use.

Medium-sized vented air-filled ionization chambers show a very good water equivalence in the kV energy range. The MV energy dependence can be corrected by applying k_Q values from literature. Their volume is in the order of 0.1 to 1.0 cm³. The only disadvantage of these chambers is their relatively large volume which can lead to a volume effect. Depending on the model in question, these chambers can be used down to field sizes of 3x3 cm² [33].

Small-size vented air-filled ionization chambers, sometimes referred to as *microchambers* or *pinpoint*

chambers, show a good water equivalence in the kV energy range and their MV energy dependence can also be corrected using k_Q values from literature or from the manufacturer. Due to the very small volume of less than 0.1 cm³ of these chambers, stem and cable effects, e.g. the polarity effect, become more important than for larger ionization chambers, especially when used in a wide range of field sizes. When used in axial orientation, i.e. the chamber axis facing in the direction of the focus, the spatial resolution of these chamber can be as good as 2 mm [33]. Be careful not to use a microchamber employing a steel electrode, this will lead to a stronger energy dependence [14].

Silicon diodes are solid state detectors and currently the smallest detectors available on the market. They are usually not subject to the volume effect except in extremely small fields [26, 31, 34]. Usually, silicon detectors exhibit a directional dependence and a strong energy dependence for kV energy photons. When used in small fields, the kV energy response is of minor importance, hence unshielded silicon diodes can be used in small field dosimetry and are often the detector of choice [14]. The MV energy dependence is better than for air but still non-zero. To measure reference doses, the detector needs to be cross calibrated in conditions as close as possible to the envisaged operating conditions, e.g. in a 4 cm x 4 cm field at the same radiation quality.

Diamond detectors are a very advantageous combination of the required properties of a small field detector. Diamond basically has no MV energy dependence – the ratio of the mass stopping power of carbon to water is constant in the MeV range [10] – and the kV energy response is very good. In addition, the angular response is very homogeneous. Diamonds may exhibit a weak dose rate dependence [35], which can be corrected.

Plastic scintillation detectors read out a relatively weak optical signal, hence they tend to exhibit a very strong noise [36, 37] and need very long integration times. In addition, the temperature dependence is quite high [38]. It is challenging to control the Cherenkov part of the signal in the light guide which can lead to relatively strong cable irradiation effects [39].

Detector selection criteria

To choose a suitable detector, it is first of all necessary to determine the basic requirements. These are:

- What is the minimum field size required?
- What is the maximum field size required?
- What has to be measured?
  - → Output factors or reference doses according to a dosimetry protocol
  - → Relative doses (profiles and PDDs)
- Is it an option to use more than one detector?

Once decided upon the requirements, these can be cross-checked against the technical data of the detectors to see which detectors are the most suitable. Usually, a choice of more than one detectors is possible. Then, the following criteria can help to decide which detector to take in the end. Often, the best results can be obtained using a combination of two or more detectors.

Reference dosimetry: if the task is to measure absolute doses using reference dosimetry, then a calibrated detector is needed as well as a dosimetry protocol, publication or manufacturer specification providing correction factors. To date, this is only possible for air-filled ionization chambers.

Penumbra precision: the smaller the detector, the more accurate is the characterization of the penumbra.

Out-of-field dose precision: outside of the field, the kV fraction of the radiation is strongly increased. If a precise measurement of dose outside of the field is desired, a detector featuring a low kV energy dependence should be chosen. In case this is a relatively large chamber, a volume effect in the field center in combination with CAX normalization can lead to an overestimated out-of-field and outer penumbra dose – independent of the kV response.

Dose stability: diodes reduce their response with accumulated dose. For profile, PDD and TPR measurements, this is usually not a problem, the diode must only be stable during each scan. To measure output factors, it must be ensured that the diode is cross calibrated often enough. Air-filled ionization chambers and diamond detectors are in general very stable with accumulated dose.

Dose rate independence: most detectors, will show a slight dose rate dependence. For relative dose measurements, this usually only leads to a small uncertainty as shown in section 0, but it should be considered before performing the measurement. For air-filled ionization chambers, the dose per pulse dependence can be calculated and corrected [20, 28–30].

MV energy response: In very small fields, the energy spectrum of the secondary electrons slightly changes with field size [14]. To be safe from this effect it is good to choose a detector with a low MV energy dependence.

kV energy response: If the fraction of kV radiation in the photon spectrum is expected to vary during a measurement, a detector featuring a low kV energy dependence should be chosen. This is, e.g., the case when measuring in large and small fields with the same detector (output factors) or when high precision is required for in-field dose as well as out-of-field dose (profiles). If the deconvolution technique is used, an ionization chamber might be a good option.

Speed of measurement: As described above, when using high quality equipment, quantum noise will most probably be the main source of noise in the measurement. Choosing a detector with a low quantum noise can save measurement time. Very low quantum noise can be expected from ionization chambers, medium noise from

high-response diodes (roughly above 100 nC/Gy), relatively high quantum noise from low response diodes (roughly below 100 nC/Gy) and highest quantum noise from scintillation detectors [18, 36, 37].

Other aspects to consider

Quality of the dosemeter: the measuring equipment does not only consist of the detector. In addition, a water phantom and a dosemeter are required. If the response of the detector is low, a very high quality dosemeter is mandatory. It is worthwhile to have a close look at signal noise and zero drift of the dosemeter at the lower bound of the current or charge measurement range. The quality of a dosemeter can be checked by applying a precisely defined current or charge to the input [40].

Quality of the water scanning system: due to the high gradients encountered in small field dosimetry, the requirements on accuracy and precision of the position of the water phantom are higher compared to large field measurements.

HOW TO PERFORM THE MEASUREMENT

Reference dose and output factor measurement

By „*reference dose*" this article refers to measuring dose using a calibrated detector in the center of a radiation field [9]. Sometimes, this is also referred to as *absolute dose measurement*. The best way to measure reference dose depends on the field size. If the field size is large enough to allow the use of an air-filled ionization chamber the direct application of one of the international dosimetry protocols, e.g. [28–30], is the best approach. If correction factors of the chamber are not contained in the dosimetry protocol, the information can often be obtained from the manufacturer or from publications.

For field sizes ≥ 4 cm x 4 cm: a medium sized air-filled ionization chamber can be used, e.g. a 0.125 cm³ semiflex chamber. The dose can be directly measured according to a dosimetry protocol.

For field sizes of 2 cm x 2 cm to 4 cm x 4 cm: either a microchamber can be used, following one of the dosimetry protocols, or a small field detector can be cross calibrated against a medium sized air-filled ionization chamber in a relatively small field of 4 cm x 4 cm to 5 cm x 5 cm.

For field sizes below 2 cm x 2 cm: for very small fields a detector that is small enough to exclude the volume effect has to be selected. This detector should be cross-calibrated against a medium sized air-filled ionization chamber in a relatively small field of 4 cm x 4 cm to 5 cm x 5 cm.

Output factors: to measure output factors, all correction factors that neither depend on dose rate or field size can be neglected because it is a relative dose measurement. Other corrections, such as polarity, volume effect, or dose per pulse can be applied to increase the accuracy of the measurement. Before deciding for which field sizes to take which detector, the kV energy dependence of each detector should be considered.

How to perform the cross-calibration:

The cross-calibration is done in a phantom for each radiation quality. It should be performed in two steps in a field of 4 cm x 4 cm or 5 cm x 5 cm:

1. Use a medium-size vented ionization chamber, e.g. a semiflex 0.125 cm³ chamber, to determine the dose D_{ref} for the radiation quality and depth of interest. Use one of the international or national dosimetry protocols, e.g. [28–30].
2. Replace the medium-size ionization chamber by the small-size detector to be cross-calibrated. Make sure the effective points of measurement are located at the same depth. The orientation of the small field detector should be the same as in the consecutive use. Apply the same number of monitor units as before and determine the reading D_{small} of the small-size detector. The cross-calibration factor for the small-size detector is the ratio D_{ref}/D_{small}.

After cross-calibration, the small-size detector can be used in fields smaller than the cross-calibration field and at different depths, but always at the same radiation quality and detector orientation.

Relative dose measurement

When performing relative dose measurements, several details have to be considered.

The detector should be well centered in the field. Since small fields often do not have a dose plateau in their center, detector positioning needs to be done with great care. The positioning should be checked by measuring profiles in shallow and also in large depths. Otherwise the detector might "walk out of the beam" when moved downwards in the water.

The volume effect should be excluded. The detector has to be small enough to exclude the volume effect. This is especially important when measuring output factors where the volume effect can lead to a serious underestimation of the dose value [14]. A volume effect in the field center can lead to overestimation of the field size and out-of-field dose as explained in section 0. A volume effect in the penumbra can partly be corrected by deconvolution.

The integration time should be chosen sufficiently long. Small field detectors often exhibit a higher level of quantum noise than ionization chambers used for larger fields. The integration time per data point has to be chosen long enough to keep the noise in a reasonable limit. To reduce noise by half, the integration time has to be increased

by a factor of four [19]. Some water scanning systems may automatically smooth the signals. To tell how much noise is on the signal, this smoothing must be turned off.

The use of the reference detector has to be considered. Either the reference detector has to be placed outside the field or the measurement has to be performed without reference detector. For the first option, a large chamber must be used or very long integration times chosen, otherwise the noise of the signal will strongly increase. When measuring without reference it must be assured that the linac output is stable in time.

Other details to consider

Concerning the spatial resolution of the measurement, film would be a good choice as relative small field detector. When considering the use of film, it must be kept in mind that the energy response and dose range of radiographic films is not very good and the result depends on the development of the film. Radiochromic films have a very good energy response but need a relatively high dose to develop. In addition, the response of radiochromic films can vary by a few per cent over the area of the film and there are batch to batch variations. Note also, the results of film dosimetry are always somewhat handling dependent [14].

Most examples and figures in this article refer to square fields. If the field is circular, the field edge of the square field can approximately be replaced by the field diameter of the circular field.

If the field is rectangular, the short field edge is more important than the long field edge.

When working with a FFF linac, the field is never flat in the center and the dose per pulse values are elevated.

SUMMARY

Dosimetry in small fields poses new challenges for medical physicists. Positional accuracy is very important, the volume effect should be excluded as much as possible and some of the common measurement methods, e.g., where to put the reference detector in scanning measurements, have to be reconsidered. Reference dose and output factors can be measured by cross calibration in field sizes in the order of 4 cm x 4 cm to 5 cm x 5 cm.

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CONFLICT OF INTEREST STATEMENT

The Author is employee of PTW-Freiburg.

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HISTORY AND HERITAGE

SOME REMARKS ON THE ROLE OF MARIA SKŁODOWSKA-CURIE IN THE DEVELOPMENT OF THE FIRST POLISH CENTRE FOR RADIUM TREATMENT

Oskar A. Chomicki

Former President of IOMP (2000-2003)

Maria Skłodowska-Curie (1867–1934), after graduating from secondary school in the 1880s, left for France in 1891, as it was impossible to continue her education in Warsaw. The city was at the time occupied by tsarist Russia, as a result of the „partitions" of Poland done by Prussia, Russia and Austria at the end of the 18th century. In Paris, she studied at Sorbonne University, where from 1904 she headed the laboratory and from 1906 (after the death of her husband, Pierre Curie) she was chair of the Radioactivity Department. As result of her joint research with her husband on radioactivity emitted by the mineral uranium and thorium, in 1898, they discovered two new radioactive elements, polonium and radium. For this achievement, they received the Nobel Prize in Physics in 1903 (along with Becquerel). In 1911, Maria alone received a second Nobel Prize, this time in chemistry, for her research on the chemical and physical properties and methods of isolating, purifying and measuring the activity of polonium and radium.

During her whole life, Maria Skłodowska-Curie had very close ties to her native country Poland. She herself jokingly expressed her opinions when telling a story at the meeting of the International Committee of Intellectual Cooperation in 1921: Representatives of three countries took part in a free literary competition on the role and importance of elephant. The Englishman's story was entitled: "My adventures while shooting elephants in South Africa", the Frenchman was more concerned with "The sexual and erotic life of elephants", while the Polish approach was invariably "The elephants versus Poland's national independence", which seemed quite understandable in the light of over 120 years of the above-mentioned partition of Poland. Maria's story became proverbial and came to express the unmistakably Polish tendency to see everything in terms of Polish interests.

It is not surprising then that in 1913 Maria became the official (and later honorary) director of the Radiological Laboratory at the Warsaw Scientific Society, established to do research on the properties of radium. In 1921, in an independent Poland, she not only gifted 100 mg of radium bromide to the Radiological Laboratory, as well as 1000 dollars, gathered by Polish organizations in the USA, but also wrote a detailed construction plan for the Radium Institute in Warsaw, to model the Parisian Institut du Radium. Her priority was to closely link clinical activity to research. At the time, it was a pioneer idea to suggest doctors should cooperate with representatives of the sciences: physicists, chemists, and biologists. As she wrote herself, "Radium therapy in such a novel area needs to be based on a strong foundation, which is physico-chemical research on new bodies; if this is absent, the theory becomes empirical or a routine, indiscriminately using popular methods which often contain basic errors."

After gaining independence after World War 1 on the basis of the Versailles Treaty and as a result of victory in the Polish-Soviet war of 1920, Poland was a poor country, especially ruined by military activity that had taken place within its boundaries. Poland needed gigantic efforts to consolidate the three separate parts of the country, a division that was inherited from 127 years of partitions. This obstacle in the fields of science and medicine was overcome thanks to a special and deep understanding of the importance of radium treatments, as well as support from the most famous and popular Polish pianist of all times, Ignacy Jan Paderewski (1860-1941), who was instrumental in collecting money in the USA, as well as the then President of the Polish Republic, Stanisław Wojciechowski,

and in 1921, the Radium Institute Society was created. It was spearheaded by Maria's sister, Dr. Bronisława Dłuska, and other members included the most prominent representatives of Polish academia. A few years later, this Society, along with the newly-created Polish Committee to Fight Cancer, raised funds and material donations in order to buy the land and finance the construction of the Radium Institute in Warsaw, which exists until this day. In the declaration we read: „ Poland cannot be indifferent, but should honour her brilliant Daughter in a manner worthy of a great Nation. The Polish Committee to Fight Cancer turns to the whole of Polish Society to request donations for the Polish National Gift. This gift should become the Radium Institute named after Maria Skłodowska-Curie".

Figure 1. The opening of the clinical department of the Radium Institute in May 1932. Maria Skłodowska-Curie is seen in the centre of the picture planting a tree (with the shovel) in the front of the Institute building.

The response from Polish society to this appeal was instantaneous and extremely generous – over 2 million zloty (the equivalent of 400, 000 dollars at the time) were collected, which was an enormous amount. This, along with help from the government, enabled the planning and construction of a modern complex by Polish engineers, with guidance from Maria Curie herself and French specialists from Paris. The complex consisted of four separate buildings: 1) A clinical building with specialist consulting-rooms and a hospital ward for radium patients, 2) X-ray therapy, (3) A biology and physics research building, and (4) preparation of radiological sources. The ceremony of laying the foundation stone under the Institute took place on June 7, 1925, while the construction itself took 6 years. It is worth mentioning the beautiful statue of Maria Skłodowska-Curie, created by well-known Polish sculptress Ludwika Nitschowa, in the park surrounding the Institute. Incredibly enough, the statue, and the Institute itself, survived the complete destruction of Warsaw during World War 2, and still stands to this day.

From the very beginning, Maria Skłodowska-Curie actively advocated for creating a Physics Department or Physics Laboratory at the Radium Institute, for instance writing to one of the most famous Polish physicists of the time, Professor Stefan Pieńkowski from the Physics Institute at Warsaw University, „We will create, in the building's laboratories, a physics and chemistry centre, strictly scientific, which will be dedicated to research on resolving the most interesting issues of biology. They would relate to the basics of metrology, which, as for now, leaves much to be desired. I expect that you will be interested in this project, which seems to me to be in harmony with the scope of research done in your Institute, and that you will want to take part in its execution, by helping to start the project by suggesting employees from among your own co-workers (Translation from Polish).

As a result, one of Professor Pieńkowski's colleagues, Dr. Cezary Pawłowski (1895-1981), became the director of the future Physics Laboratory, after undergoing a 4-year 'apprenticeship' with Maria Curie in Paris in the years 1927-1931. As he wrote: „As a future director, I was surrounded by the special care of our great scholar, who devoted much of her valuable time to discussing the results of my research."

Dr. Franciszek Łukaszczyk (1897-1956), who was also educated in Paris as well as Berlin and Hamburg, became the Director of the Institute.

Most importantly, the Institute's activities depended on possessing radium. For that reason, as the above-mentioned Dr. Pawłowski writes: „Maria Skłodowska-Curie did not waste any time in her efforts to gain the necessary amount of radium for the Warsaw Radium Institute to be able to start research and treatment of cancer. However, acquiring this valuable element in the required amount exceeded the financial possibilities of the newly-recovering nation. In order to successfully gain radium for her native country, Maria Skłodowska-Curie turned to the well-known American journalist, Mrs. Meloney for help. Thanks to the campaign for the purchase of radium that she organised among Polish Americans and friends of Poland, enough money was collected to buy 1 gram of this element. "

Bearing in mind the experience from May 1921, when Maria along with her daughters journeyed through the USA collecting money to buy a gram of radium for the Institut du Radium in Paris, in 1929, Marie Meloney (nicknamed „Missy") invited Marie Curie once again to the USA. With the collected funds, and with the support of the US President, Herbert Hoover (1874-1964), 1033,21 mg of radium was purchased at a specially lowered price from the Belgian company „Union Minière du Haut Katanga". This was offered to the Radium Institute in Warsaw and marked with the code MSR (short for: Maria Skłodowska's Radium).

At the Radium Institute, the radium for clinical purposes was used only in the form of tubes and needles. The

activities and dimensions of these applicators followed the so-called Paris system of dosage adopted at the Institute.

The opening of the clinical department of the Radium Institute took place on May 29, 1932. The ceremony was attended by Maria Curie (who came especially from Paris for the event), Dr. Regaud and Prof. Marie, Director of the Chemistry Institute of Paris University. From the US, attendees included a delegation from Polish women's societies and Marie Maloney (who in the meantime received from the Polish government the Cross of Merit), and numerous Polish government officials and representatives of academia also attended the event. In her speech, Maria Curie expressed admiration for the opening of the clinical department of the Institute, but at the same time also called for quick construction of the Physics Laboratory. As she said, "Therapy should be constantly linked to research, without which it can make no progress. The search for pure knowledge is one of the essential needs of humanity. So I hope that opening the scientific laboratories foreseen for the Institute will take place soon after opening the medical section".

Maria Curie's efforts to connect clinical practice with research were greatly supported by earlier-mentioned Bronisława Dłuska (1865-1939), as well as, of course, Dr. Cezary Pawłowski. Construction of the laboratory building was finished in 1934, the year Maria Curie died, but even at the beginning of the year Dr. Pawłowski wrote in a letter to Maria: „The approaching opening of the laboratories in the Radium Institute gives me the courage to write a letter in which I plan to give the general outlines of the state of the current preparations, as well as indicate the direction of future works. At the same time, I kindly request your comments on this plan." In this same letter, Dr. Pawłowski writes: „ Research in the Physics Institute of the RI will mainly concern the effect of radioactivity on matter. The whole body of work will go in three directions: (1) research close to the biological direction, which aims to analyse the effect of radioactivity on matter in a state close to those which are in the [human] organism, and especially in the colloidal state, (2) research of a purely physical character will be related to the forced transformation the nucleus of atoms, (3) research of a measurement nature will be done at the Institute at the request of different public and private institutions and would be the analysis of the radioactivity of minerals, mineral waters, radioactive materials' standardization, etc.

The building of the research laboratories, with the section dedicated to the Physics Laboratory, was opened in its final shape at the end of 1934, while the Laboratory itself did not become active until February 1936. Following the suggestions of Maria Skłodowska-Curie, the Physics Laboratory was to be dedicated to research on physics issues in the area of Roentgen radiation and atomic radiation, which have their application in biology and medicine.

Within the Physics Laboratory in 1937, also following the suggestions of Maria Curie, the Measurement Laboratory was created. It consisted of the X-ray Showroom and the Laboratory of Measurements of Radioactive Bodies. The research scope of these Laboratories included (according to the later published memories of Dr. C. Pawłowski):

(1) Determination of the efficiency and the radiation distribution of X-ray tubes;
(2) Investigation of phantom scattered radiation;
(3) Radiation exposure (determination of current and total doses);
(4) Investigation of X-ray tube shielding properties;
(5) Determination of scattered radiation in X-ray, research and clinical departments;
(6) Investigation of X-ray and radium radiation shielding materials and curtains;
7) Investigation of X-ray radiation quality and that of X-ray filters;
(8) Determination of dose equivalents of radium, thorium and other radioactive elements;
(9) Calibration and service of X-ray dosimeters;
(10) Determination of leak-tightness of radium tubes and needles;
(11) Radiation contamination monitoring;
(12) Design and investigation of radiation protection devices in radiological laboratories;
(13) Investigation of shielding devices; and
(14) Search for lost radium tubes.

In the Laboratory, there was also a mechanical workshop and glass workshop, since much of the equipment was to be constructed within the institute itself. The Physics Laboratory had its own optical darkroom, because in research on ionizing radiation, the photographical method was the most frequently used.

Unfortunately, the premature death of Maria Skłodowska-Curie did not permit her to follow the development of the Radium Institute in Warsaw. Shortly after her last visit to Poland at the beginning of 1934, she died at the Sancellemoz Sanatorium in Passy, in Haute-Savoie, from aplastic anaemia contracted from her long-term exposure to radiation, on July 4 1934. She was buried in Sceaux, next to her husband Pierre. Sixty years later, in 1995, as a token of appreciation for their merit, Pierre and Maria were place in the Panthéon in Paris. In this way, Maria Skłodowska-Curie became the only woman scholar to gain this honour.

There is no doubt that thanks to the unfailing dedication to the creation and development of the Radium Institute, Maria Skłodowska-Curie played a dominant role in the history of radium treatment in Poland, especially in its beginning phases.

At the end, it should be said that unfortunately the brilliant development of the Physics Laboratory, and also

the Radium Institute itself, was interrupted by World War 2. It should be mentioned here that immediately preceding the war, Dr. Pawłowski, who was concerned about the fate of radium, buried all equipment with radium in the garden of the institute, hiding at the same time in a safe place the research and measurement equipment of the Physics Laboratory.

After the war, the Radium Institute was rebuilt, and Dr. Cezary Pawłowski headed the Physics Laboratory until 1953, raising a new generation of medical physicists, the most famous of whom was the recently deceased Prof. Barbara Gwiazdowska (1928-2011). For many years, she headed the Department of Medical Physics at the Maria Skłodowska-Curie Oncology Centre in Warsaw, which Department was the direct descendant, or rather continuation, of the historical Physics Laboratory of the Radium Institute.

This article is based in a large part on the publication entitled Historia Zakładu Fizyki Instytutu Onkologii w Warszawie w okresie kierownic-twa Prof. Cezarego Pawłowskiego [History of the Physics Department of the Oncology Institute in Warsaw under Professor Cezary Pawłowski], written by B. Gwiazdowska and others, included in Pol J Med. Phys Eng 2007; 13(4) 183-238).

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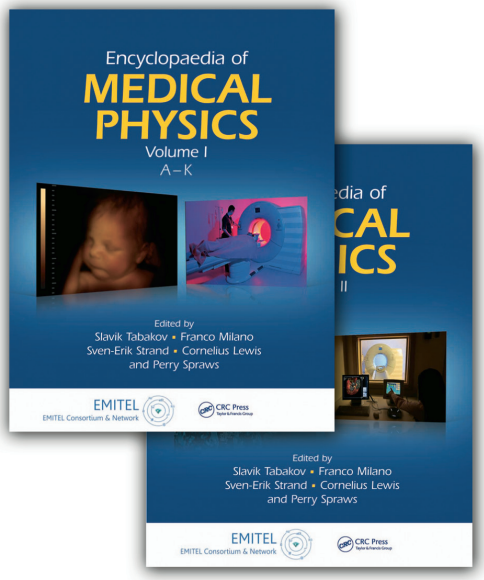

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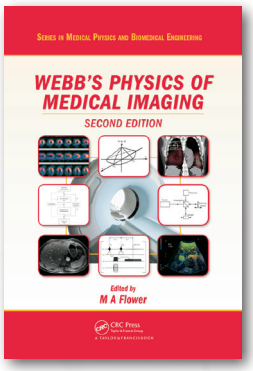

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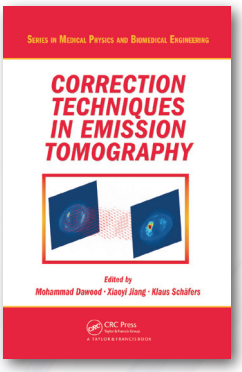

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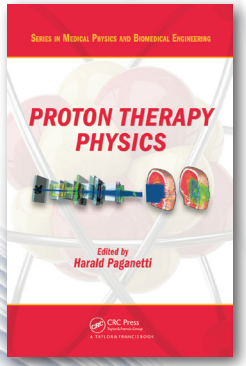

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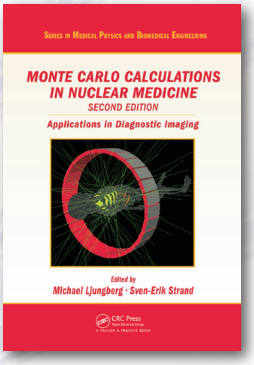

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THE 20TH INTERNATIONAL CONFERENCE ON MEDICAL PHYSICS

P. Sharp

President of ICMP13, President of EFOMP, University of Aberdeen, UK

***Abstract*— The 20th International Conference on Medical Physics, ICMP2013, Brighton, UK (1-4 September 2013) celebrates the 50th anniversary of the IOMP.**

***Keywords*— International Conference, IOMP, EFOMP, IPEM.**

INTRODUCTION

In January1963 four national physics societies, from the UK, Canada, Sweden and the USA, got together to form the IOMP. Their first international conference, the ICMP, was held in Harrogate, UK in 1965 and so it is fitting that IOMP has returned to the UK to celebrate its 50th birthday.

THE PROGRAMME

There is always a temptation, given the history behind this particular conference, to concentrate on what has been achieved in medical physics over the past 50 years. While one should not ignore the work of those who have gone before us, it is even more important to look to the future. So the theme chosen for this meeting is 'New Horizons - Global and Scientific'.

In an age where teleconferencing and virtual meetings are increasingly popular one might ask whether it is really necessary to bring people together in a conference centre for 4 days. The future of medical physics and bioengineering depends on identifying where scientific opportunities might lie both within our own spheres of physics and engineering but also in work coming out of other disciplines. Conferences offer a less pressurized environment in which one has the opportunity not only to listen to a variety of speakers but also to socialize with them, to explore new ideas and possibly set up new collaborations.

So will the conference provide a scientifically stimulating programme? Well to a certain extent that depends on you the reader. Bring along your latest work and see what others think about it and maybe you will end up with some new ideas. Abstracts can now be submitted on-line, details are available from the conference website, www.icmp2013.org. The programme covers most areas, ranging from particle radiotherapy to gregarious MRI. As is usual, the proffered papers will be interspersed with plenary lectures, our speakers include Molly Stevens, Professor of Biomedical Materials and Regenerative Medicine at Imperial College, London who has recently been recognised by the TR100, a compilation of the top innovators, under the age of 35, who are transforming technology - and the world - with their work.

On the Sunday, before the official opening ceremony, there will be a number of workshops including thermal imaging cameras, shielding and technology enhanced education in medical physics. There will be a programme on Medical Physics in Africa reflecting IOMP's interest in fostering medical physics in that continent.

While history should not dominate our thinking, it is important for us to acknowledge and advertise what we have achieved. The Opening Ceremony will have a lecture given by Colin Orton. In the entrance hall there will be posters celebrating the influential physicists from around the world, nominated by the national medical physics societies.

What makes Medical Physics different from many other areas of physics is that the end product of our activity benefits patients. We serve the public. So it is fitting that on the Opening Day we should encourage the public to visit the conference. The HPA lecture, aimed at school children and

those young at heart, will be given by Peter Marsden from UCLH. We are also planning an area where children can engage with our sort of science.

Two other ingredients go to making up a good conference: a comprehensive commercial exhibition and a good social programme. Already a number of leading companies have agreed to display their latest products.

Why Brighton and, anyway, where is it? These might be questions that spring to mind. Well it is on the South Coast of England and has excellent rail and road connections both to international airports and to London – but only for your post-conference sightseeing. What Brighton also offers is superb Regency architecture, a long beach and the weather, and perhaps the sea, should be warm in September. Brighton is famed for its lively night-life both for the younger and older members. So we can guarantee a good social programme, ranging from a traditional Fish and Chip supper on Brighton's famous pier to a walking tour through part of a Victorian sewer.

So book the date, 1st-4th September, into your diary and join us at Brighton for ICMP 2013.

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RISK OF MEDICAL IMAGING – AN IOMP POLICY STATEMENT

William R Hendee

Rochester, MN, USA, Editor J. Medical Physics, Chair IOMP Science Committee

Over the past few years papers have appeared in the scientific literature that predict thousands of cancers and cancer deaths each year in populations of patients receiving medical imaging procedures (primarily computed tomography) employing ionizing radiation. The predictions in these papers are computed by estimating very small and hypothetical risks at low radiation doses and multiplying these speculative estimates by large numbers of patients experiencing medical imaging. The public media use these papers to develop print and electronic news releases that raise anxiety in parents, families and patients, at times causing them to delay or defer needed imaging procedures. Decisions to delay or defer examinations constitute real risks to patients, as contrasted with the hypothetical risks presented in the papers.

Professional organizations, including the American Association of Physicists in Medicine and the Health Physics Society, have developed policy positions in an effort to illuminate the controversy over the risks of low-level radiation exposures (see URLs in the supporting documents and additional readings). Scientific advisory groups such as the International Commission on Radiological Protection, the National Council on Radiation Protection and Measurements, and the United Nations Scientific Committee on the Effects of Atomic Radiation have also addressed the controversy (see URLs in the supporting documents and additional readings). Now the International Organization for Medical Physics, representing 80 national and six regional medical physics organizations and 18,000 medical physicists worldwide, has developed its own policy statement which is reproduced below. One can only hope that the policy statements issued by these knowledgeable organizations will have some deterrent influence on the continued propagation of unsupportable cancer risk estimates related to medical imaging procedures conducted with minimum doses of radiation consistent with high quality studies.

POLICY STATEMENT

This policy statement, prepared by the IOMP Science Committee, addresses predictions of induced cancers and cancer deaths in a population of patients exposed to low doses (<100 mSv) of ionizing radiation during medical imaging procedures.

- Prospective estimates of cancers and cancer deaths induced by medical radiation should include a statement that the estimates are highly speculative because of various random and systematic uncertainties embedded in them. These uncertainties include dosimetric uncertainties; epidemiological and methodological uncertainties; uncertainties from low statistical power and precision in epidemiology studies of radiation risk; uncertainties in modeling radiation risk data; generalization of risk estimates across different populations; and reliance of epidemiological studies on observational rather than experimental data. Such uncertainties cause predictions of radiation-induced cancers and cancer deaths to be susceptible to biases and confounding influences that are unidentifiable.

- Paragraph A86 of Report 103 of the International Commission on Radiological Protection (ICRP) states that "There is, however, general agreement that epidemiological methods used for the estimation of cancer risk do not have the power to directly reveal cancer risks in the dose range up to around 100 mSv." Further, UNSCEAR Report A-67-46, approved in May, 2012, states that "The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) does not recommend multiplying very low doses by large numbers of individuals to estimate numbers of radiation-induced health effects within a population exposed to incremental doses at levels equivalent to or lower than natural background levels."

- Predictions of radiation-induced cancers and cancer deaths from medical imaging procedures should be accompanied by estimates of reductions in patient morbidity, mortality and cost resulting from the same medical imaging procedures.

- If effective dose is used to generate predictions of cancers and cancer deaths, a statement should be included that the ICRP has expressed caution in the use of effective dose for purposes of estimating risks to individuals or

populations exposed to ionizing radiation. Paragraph 151 of ICRP Report 103 states: "The use of effective dose for assessing the exposure of patients has severe limitations that must be considered when quantifying medical exposure," and "The assessment and interpretation of effective dose from medical exposure of patients is very problematic when organs and tissues receive only partial exposure or a very heterogeneous exposure which is the case especially with x-ray diagnostics."

SUPPORTING DOCUMENTS AND ADDITIONAL READING

- National Research Council, Health risks from exposure to low levels of ionizing radiation: BEIR VII – Phase 2, Committee to Assess Health Risks from Exposure to Low Levels of Ionizing Radiation, Washington, DC, National Academies Press, 2006.

- The 2007 recommendations of the International Commission on Radiological Protection. ICRP publication 103. Ann ICRP 2007; 37 (2-4) 1-332.

- Health Physics Society. Position statement of the Health Physics Society. Radiation risk in perspective. July, 2010. http://hps.org/documents/risk_ps010-2.pdf.

- American Association of Physicists in Medicine. Position statement of the American Association of Physicists in Medicine. Radiation risks from medical imaging procedures. December, 2011, affirmed November, 2012. http://www.aapm.org/org/policies/details.asp?id=318&type=PP

- W. Hendee, M. O'Connor. Radiation risks of medical imaging: Separating fact from fantasy. Radiology 2012, 264:2 312-321.

- United Nations Scientific Committee on the Effects of Atomic Radiation. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation. 59th session (May 21-25, 2012). General Assembly Official Records. 67th session, Supplement No. 46. http://daccess-dds-ny.un.org/doc/UNDOC/GEN/V12/553/85/PDF/V1255385.pdf?OpenElement

- P. Zanzonico, M. Stabin. Benefits of medical radiation exposures. Health Physics Society. http://hps.org/hpspublications/articles/Benefitsofmedradexposures.html

- National Council on Radiation Protection and Measurements. Uncertainties in the Estimation of Radiation Risks and Probability of Disease Causation. NCRP Report 171. National Council on Radiation Protection and Measurements. Bethesda, MD. 2012. http://www.ncrponline.org/Publications/Press_Releases/171press.html

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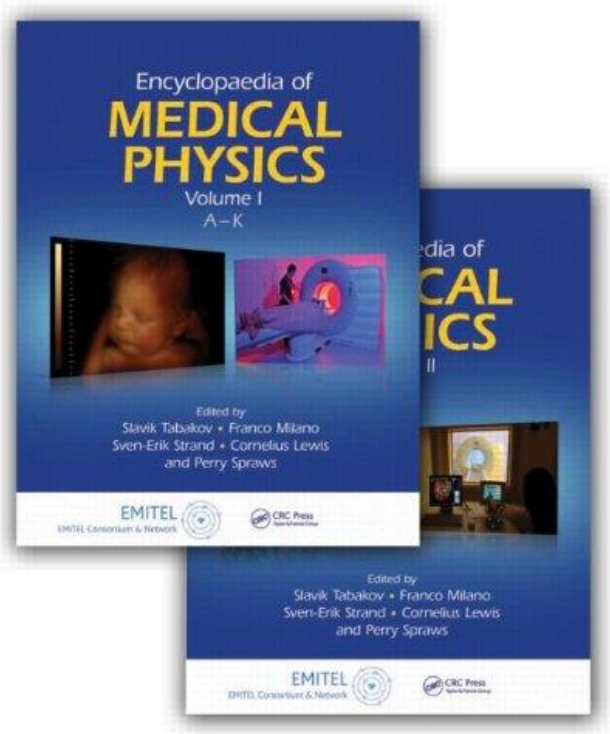
BOOK REVIEW

ENCYCLOPAEDIA OF MEDICAL PHYSICS

G. Donald Frey, Ph.D.

Professor of Radiology, The Medical University of South Carolina, USA



Encyclopaedia of Medical Physics. . Editors of the printed version are S Tabakov, F Milano, S-E Strand, C Lewis, and P Sprawls. Published by CRC Press. The 820 pages are printed in two hard-cover volumes with the topics arranged in alphabetical order. There is an extensive index that is useful in finding materials on specific topics. The content covers 7 categories – Physics of: X-ray Diagnostic Radiology, Nuclear Medicine; Radiotherapy; Magnetic Resonance Imaging; Ultrasound Imaging; Radiation Protection and General terms.

The printed version was developed from the online Multilingual Dictionary and e-Encyclopaedia EMITEL available at www.emitel2.eu. The on-line Encyclopaedia development included the work of some 100 specialists from 25 countries. This website also includes a Thesaurus of c. 3000 terms, translated to 29 languages (c. 98,000 entries). There are c. 2900 articles with over 2000 illustrations. The online version is open access and can be searched by specific topics.

The printed edition will be of special value to education programs as a resource and reference for both faculty and students. One of its major features is that it gives a comprehensive coverage of the field of medical physics combined in one high-quality publication. Students especially will find it both interesting and helpful in "seeing the big picture" of medical physics and as an introduction to its many topics, as provided by many of the leading medical physicists of the world.

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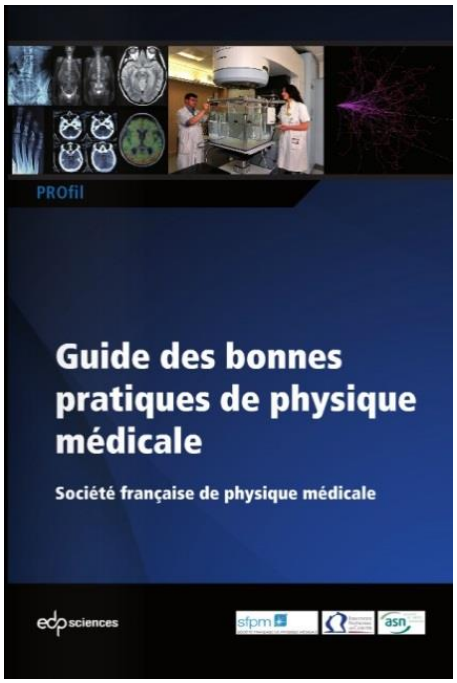
BOOK REVIEW

SOCIETÉ FRANÇAISE DE PHYSIQUE MÉDICALE (DOMINIQUE LE DU, JEAN-CLAUDE ROSENWALD) "GUIDE DES BONNES PRATIQUES DE PHYSIQUE MÉDICALE" FRANCE : EDP SCIENCES, 2012, 247PP, €20, 978-2-7598-0744-4

Dr Delphine Darios

Dept. Medical Physics, Guys and St Thomas' Hospital NHS Foundation Trust, London, UK



This book is the first reference guide for physicists using ionising radiation for diagnosis and therapeutic purposes (radiotherapy, nuclear medicine, radiology, etc…) in France. It provides general guidance on good professional practice regarding patient safety and includes recommendations regarding the quality management and application of security and patient safety rules in the day to day job. However, this book does not address good practices regarding the radiation protection of members of staff.

This guide contains three chapters. The first chapter refers to the training requirements to become medical physicist in France and includes good professional conduct guidance. The second chapter addresses the principles of quality management and security during acceptance and commissioning of new equipment but also while performing dosimetry tasks. The third chapter presents good practice recommendations for each type of work carried out by physicists such as, specification of new equipment, acceptance and commissioning of new equipment, quality assurance, management of errors and incidents, clinical works, etc…

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PhD ABSTRACTS

PUBLICATION OF DOCTORAL THESIS AND DISSERTATION ABSTRACTS

A special feature of the new IOMP Journal Medical Physics International (http://mpijournal.org/) 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.

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 abstract document should contain the thesis title, author's name, supervisor(s) name, the year and the institution granting the degree.

The abstracts must be in English and no longer than 2 pages (using the template of the Journal) and can include color images and illustrations. Medical Physics International is open access so abstracts will be available for reading and reference by medical physicists on a global basis. The first issue of the Journal will publish approved abstracts without cost to the authors.

The deadline for receiving abstracts to be considered for publication in the Medical Physics International Journal will be during each mid-March and mid-July.

Submissions should be by e-mail to: slavik.tabakov@emerald2.co.uk

Additional information, if needed, can be obtained from the Co-editors of Medical Physics International, Slavik Tabakov, Ph.D. or Perry Sprawls, Ph.D. sprawls@emory.edu.

RESPIRATORY MOTION CORRECTION IN PET/CT IMAGING

P. J. Schleyer [1]

[1] Doctor of Philosophy, The University of London, 2012

Supervisors: P.K. Marsden [2], M.J. O'Doherty [2]

[2] Division of Imaging Sciences and Biomedical Imaging, King's College London

In dual modality PET-CT imaging, respiratory motion can introduce blurring in PET images and create a spatial mismatch between the PET and CT datasets. Attenuation correction errors can result from this mismatch, which can produce severe artefacts that potentially alter the clinical interpretation of the images. Various approaches of reducing these effects have been developed. Many involve respiratory gated acquisitions which generally require a measure of the respiratory cycle throughout imaging.

In this work, a retrospective respiratory gating technique was developed for both PET and CT which extracts the respiratory cycle from the acquired data itself, removing the requirement for hardware that measures respiration. This data-driven gating method was validated with phantom and patient data, and compared with a hardware based approach of gating. Extensions to the method facilitated the gating of multi-bed position, 3D clinical PET scans. Finally, 60 Ammonia cardiac PET/CT images were used to compare several different approaches of reducing respiratory induced attenuation correction errors and motion blur.

The data-driven respiratory gating method accurately substituted a hardware based approach, and no significant difference was found between images gated with either methods. Gating 11 clinical 3D whole body PET images validated the extended data-driven gating methods and demonstrated successful combination of separate PET bed-positions. All evaluated approaches to reduce respiratory motion artefacts in cardiac imaging demonstrated an average improvement in PET-CT alignment. However, cases were found where alignment worsened and artefacts resulted. Fewer and less severe cases were produced when the 4D attenuation correction data was created from a 3D helical CT and PET derived motion fields. Full motion correction produced a small effect on average, however in this case no detrimental effects were found.

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ADVANCED TECHNIQUES FOR CARDIOVASCULAR MAGNETIC RESONANCE IMAGING IN CASES OF IRREGULAR MOTION

Christoph Kolbitsch [1]

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy of King's College London, London, United Kingdom, 2012

Supervisors: Tobias Schaeffter[1], Claudia Prieto[1]

[1] King's College London, Division of Imaging Sciences and Biomedical Engineering, London, UK

Magnetic resonance imaging (MRI) has recently been shown to provide valuable information for image-guided ablation therapy used to treat patients suffering from cardiac arrhythmia. This requires isotropic high resolution anatomical information about complex structures such as atria and pulmonary veins. In addition, the visualisation of fibrotic tissue in the myocardium can be important for treatment planning and assessment.

One of the main challenges to obtaining images with a high isotropic resolution is respiratory motion. Although a wide range of different methods to minimise respiratory motion artefacts has been presented, irregular breathing can still lead to unacceptably long scan times and scan abortions. Respiratory motion in patients must also be taken into consideration during the ablation procedure to ensure accurate image guidance. Furthermore, arrhythmia leads to pathological changes in the electrical excitation of the heart. This can cause irregular heart beat variations and result in very long scan times for the functional assessment of the heart in patients suffering from arrhythmia.

This thesis presents new MRI methods which overcome these problems and allow for the characterisation and compensation of physiological motion even in patients with highly irregular respiratory and cardiac cycles.

A new high resolution 3D whole-heart acquisition scheme is introduced. It reduces scan times by 36% in both volunteers and patients with irregular breathing motion due to a higher respiratory navigator efficiency compared to a commonly used respiratory gating method. Furthermore, this approach not only yields anatomical information but also provides additional respiratory motion information without an increase in scan time. This information can be used to assess, and compensate for, respiratory motion during ablation procedures. This method was also modified for 3D high resolution assessment of myocardial scar tissue which led to a 60.8% increase in navigator efficiency in heart failure patients with irregular breathing.

Furthermore, a novel technique to assess cardiac function without ECG using image-based navigation is presented. This allows for a synchronised multi-slice acquisition of the heart without the need of an external ECG and could provide new methods to address arrhythmic heart beats.

In conclusion, the approaches detailed in this thesis provide imaging methods which may not only be beneficial for patients suffering from arrhythmia but also improve the accuracy, outcome and procedure time of other percutaneous procedures.

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INFORMATION FOR AUTHORS

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.

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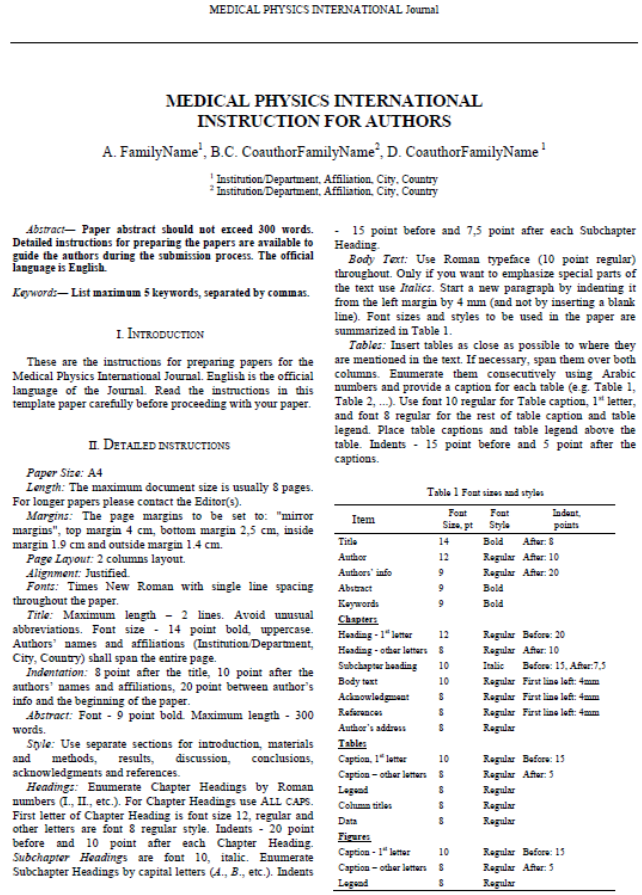

MEDICAL PHYSICS INTERNATIONAL Journal

MEDICAL PHYSICS INTERNATIONAL INSTRUCTION FOR AUTHORS

A. FamilyName[1], B.C. CoauthorFamilyName[2], D. CoauthorFamilyName [1]

[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.**

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Paper Size: A4
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Margins: The page margins to be set to: "mirror margins", top margin 4 cm, bottom margin 2,5 cm, inside margin 1.9 cm and outside margin 1.4 cm.
Page Layout: 2 columns layout.
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.
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Style: Use separate sections for introduction, materials and methods, results, discussion, conclusions, acknowledgments and references.
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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	

MEDICAL PHYSICS INTERNATIONAL Journal

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Fig. 1 Medical Physics International Journal

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

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

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

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1. Numbered first item
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III. Conclusions

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1. LeadingAuthor A, CoAuthor B, CoAuthor C et al. (2012) Paper Title. Journal 111:220–230
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3. LeadingAuthor A, CoAuthor B, CoAuthor C (2012) Paper Title. Journal 111:330–340 DOI 123456789
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