Review Article

ROLE & RESPONSIBILITIES OF MEDICAL PHYSICIST IN RADIATION ONCOLOGY - A REVIEW

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(Bang. Onc. J. 2009; 4 (2) : 72-81)

Introduction

A Medical Physicist is a professionally qualified person with specialist education and training in the concepts and techniques of applying physics in medicine. Medical physicists are concerned with three areas of service delivery: clinical service and consultation, research and development, and teaching. Medical physicists are essential for the proper provision of Medical Imaging, in the Treatment of Disease, Physiological measurement techniques, Quality and Standards in Patient & Staff Safety, and Medical Computing and mathematics.[1]

"In radiotherapy, the physicist who has given special study to this field is a full partner with the therapist, not only in the development of the science, but in the day-to-day treatment of patients" - Ralston Paterson, CBE, MC (1897-1981).

Radiation therapy has always been, from its early days and throughout its development, associated with physics. Radiation oncology is a branch of medicine that uses various types of radiation to treat and control cancer. The foundation of radiation oncology is based on the interaction between matter and energy. Beginning with the discovery of x-rays in 1895 by Wilhelm Roentgen, the role of the physicist has been critical in understanding how radiation interacts with matter. With the discovery of radioactivity by Henri Becquerel in 1896 and the separation of radium by Marie and Pierre Curie in 1898, it became known that certain materials also emitted radiation. Almost immediately the hazards and biological effects of x-rays and radioactive materials became apparent. In 1903, Alexander Graham Bell was one of many who suggested that radiation might be used to treat malignancies. Since the turn of the 20th century, radiation has been a part of medicine. The medical application of x-rays and radioactivity has given rise to the discipline of Medical Physics. The physics capabilities for producing man-made isotopes, developed on a wider scale in the 1950s, have revolutionized brachytherapy, and in recent years the development of modern imaging techniques such as computed tomography (CT scanning), ultrasound, magnetic resonance imaging (MRI), together with computing technology, have contributed much to improvements in tumor diagnosis and localization, precision of treatment planning, as well as to the accuracy of radiation delivery to the tumor volume. Most developed radiotherapy centres have physical scientists in their supporting teams. In very broad terms the role of physicists in radiotherapy is to provide the necessary scientific expertise and back-up service in all aspects of the usage of radiation beams in clinical practice. The radiotherapists, in prescribing the dosage in the management of patients, rely on the data provided by physicists. To ensure that the physics data are accurate and reliable is probably the most important responsibility associated with the physicist's work in this field. The medical physicist helps to translate the science of radiation physics into the clinical treatment of cancer. Physicists are involved in a wide spectrum of radiotherapy activities encompassing external beam therapy, brachytherapy, treatment planning and computing, dosimetry and quality assurance, servicing of treatment machines and associated equipment, radiation protection, development and research, workshop activities, sealed sources laboratory, CT scanning, magnetic resonance and other imaging techniques, staff training and teaching, and liaison with medical, radiographic and technical staff.[2]

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The aim of this article is not to describe the physical principles of any of the radiotherapy methods or techniques but to focus the reader's attention merely on the scope of the physicist's involvement in radiation treatment delivery system.

External beam therapy[2]

The radiation beams produced by megavoltage machines such as cobalt-60 or linear accelerators are the most frequently used form of radiation in radiotherapy treatments. The physics and technology involved is much more sophisticated than that concerned with orthovoltage therapy, and con-sequently a large proportion of the physicist's time is devoted to this area of radiotherapy.

Among the tasks performed by physicists, the most important are:

1. Acquisition of data concerning radiation beam physical characteristics
2. Quality assurance tests of beam parameters and equipment performance
3. Computing and treatment planning
4. Contribution to development of treatment techniques.
5. Radiation protection.

The main function of physicists in dosimetry is to acquire, preferably by measurements, as much infor-mation as possible about the physical characteristics of the radiation beams employed in their radiotherapy centre. It is necessary for the physicist to have the appro-priate equipment and instrumentation to perform the required dosimetry. It is also recommended that he has access, preferably direct, to computer facilities so that meaningful physical and mathematical evalua-tion of treatment plans agreed with the radiotherapist may be rapidly performed prior to the initiation of radiation therapy.

Dosimetric activities can conveniently be divided into three distinct groups:

(1) Dosimetry on new treatment facility and acceptance tests.

(2) Long-term quality assurance tests

(3) Development dosimetry.

A new treatment facility

The involvement of physicists in the external beam therapy starts at the time of the decision by the hospital authority to purchase and install a radiation facility. This decision should be made with the advice of a physicist, whose responsibility in this task would be to help in the choosing of the equipment to suit the local requirement. The physicist's role is also to plan the installation from the radiation protection point of view and to survey the installation after completion so that it complies with the official radiation protec-tion rules and law as well as meeting the general safety law. It is the physicist's function to certify that the therapy equipment is performing according to specification after it is installed. The decision to accept the machine is based on tests which are designed to confirm that the installed machine con-forms to the specifications agreed between the radiotherapy centre and the manufacturer prior to the purchase. A typical list of acceptance tests for a linear accelerator would have to include confirmation of beam energy, check of the radiation output level, check of dose measuring channels, determination of beam symmetry and flatness, spot checks on central axis dose distribution and beam penumbra, beam alignment checks with isocentre and light indicators, test of collimating system performance and verifica-tion of the radiation leakage level through the treat-ment head. On the basis of such checks, the physicist would advise the radiotherapy department whether the machine is conforming to their requirement. Having accepted the equipment, the physics depart-ment would then continue measuring the beam's physical characteristics in the widest possible sense with emphasis on achieving high accuracy of the measured data. This second stage of dosimetry would deal with measurements which go far beyond the equipment acceptance tests and would be designed to look at the physical parameters of the radiation beam in greater detail.

The first parameters which the physicist needs to determine are the beam quality or energy, and the radiation distribution pattern which the beam produces in the absorbing medium.

Centres which have neutron beam facilities, particularly those produced by a cyclotron, require strong scientific supporting teams to deal with the complexity of this treatment technique.

Quality assurance tests

Once detailed data on beam characteristics and equipment performance have been obtained during the initial dosimetry, it is necessary to monitor these parameters in the continuing use of the treatment machine. This is achieved by quality assurance. The need for a quality assurance programme to ensure that cancer patients are treated adequately and with procedures and equipment which are safe and operate correctly, is undisputed. The physicist's role in the radiotherapy quality assurance programme is to ensure that the radiation beam parameters and equipment performance guarantee the delivery of a correct dose to the target volume. To achieve this a carefully designed pro-gramme of tests is performed. These are carried out periodically throughout the use of radiotherapy facilities. How many parameters are checked and how often, depends on the quality assurance programme agreed, but some parameters are relatively stable and need not be checked frequently.

Development dosimetry

Dosimetry concerned with developments in radiotherapy is an almost never-ending occupation for a physicist. Physicists are required therefore to investigate by individual dosimetry any newly proposed technique so that the radiotherapist will feel confident in using it. Furthermore, treatment techniques undergo a continuous evolution. Even a technique well documented and developed in one centre can rarely be adopted for use in another centre without having to carry out some dosimetry to account for differ-ences for equipment, accessories, performance in setting-up method and treatment planning facilities. Some sophisticated treatment methods require the full time involvement of a physicist. The classic example of this is the computer- controlled tracking technique[3] known also as conformation therapy.

Brachytherapy

Brachytherapy presents physicists with problems very different from those encountered in external beam therapy. These arise from the fact that brachytherapy sources are usually small in size and that the radiation intensity around them varies rapidly with distance. For these reasons the dosimetry in Brachytherapy is very difficult. A serious problem in brachytherapy is radiation protection since, unlike a beam from a linear accelerator (linac) or a cobalt unit, the radiation beam from a nuclide cannot be switched off, and this presents a particularly serious environmental radia-tion hazard during handling of sources, clinical use and storage. A considerable amount of physicists' time is devoted to radiation protection. The situation in Brachytherapy physics was, in addition, further aggravated by the proposed changes in general dosimetry. Consequently, the new Brachytherapy dosage systems had to assimilate also the switch-over from exposure (Roentgen) to the concept of the absorbed dose (rad and Gray and the new unit of activity-Becquerel). The reader can be assured that those physicists who were involved in Brachytherapy in the last 15 years were not left idle. As soon as computers were introduced into medicine, physicists found them to be useful for solv-ing problems in brachytherapy physics. One of the most tedious tasks in this field used to be the calcula-tion of radiation distribution around the sources. The computing technology has created an opportunity for calculating distributions in more detail and in many planes around the sources deposited in tissue. To facilitate this, mathematical calculation models have been proposed. A considerable problem in brachytherapy physics used to be the correlation between the sources' geometry and the anatomy of the patient. It is much easier now with the use of CT scanner images.[4]

Remote afterloading

Concern about radiation protection of the personnel involved in the use of sealed sources, particularly for the treatment of carcinoma of the cervix and the uterus where a large number of hospital staff was exposed to radiation, stimulated interest in the development of afterloading techniques.

Involvement in treatment planning

Treatment planning is a multidisciplinary activity involving staff from all the professions working in radiotherapy: medical, scientific, radiographic, technical, nursing and other related specialties. Successful planning of treatment depends on a unique contribution from each of these groups, and equally on effective communication and harmonious cooperation between them. The involvement of the medical staff in treatment planning is more precisely

defined than that of physicists or radiographers. The current experience shows that the scope and demar-cation of activities of the two latter groups may vary considerably from hospital to hospital depending on local requirements and concepts of responsibilities. The discussion in this chapter will be confined to the role which the physicist plays in the treatment planning procedures.

Radiotherapy planning is conducted through several distinct phases. The physicist may make a profound contribution to most and these include:

1. Consultations with radiotherapists as to the general approach to the treatment planning for a given patient
2. Collection of basic patient information
3. Radiation field planning and isodose distribu-tion charting
4. Monitoring of settings, treatment time and other treatment data calculations
5. Treatment implementation
6. Verification dosimetry during treatments.

The physicist's familiarity with the radiation beam physical characteristics and their limitations is often useful to the radiotherapist when he is considering a choice of approach to treating a given case. This applies to radiations of all types, whether generated by a machine or a sealed source. Consultations are particularly important in unconventional cases where the technique of usage of beams or sealed sources is not so obvious.

Most of the patient data collection and treatment simulation procedures are based on high technology imaging techniques, and physicists have the responsi-bility to ensure that the operational parameters of these methods are physically correct. This is impor-tant because the localization, simulation or scanning geometry must be perfectly matched to the distribu-tion calculation geometry and to the geometry of the therapy unit on which the actual treatment will be carried out. Many of these problems are minimized if CT scanning images of the patient's appropriate cross-sections can be directly utilized during treat-ment planning. CT images give a precise description of the patient's cross-section and provide most useful information about internal structures provided the scanner is calibrated appropriately, and that the calibration is stable with time.

From this point of view, the role of physicists in this area of radiotherapy activities has changed consider-ably with the development of computers. It is the task of the physicist to follow new developments in that area of physics which has application to treatment planning and to ensure that these are implemented in his own centre. In practice, the routine treatment planning schemes as programmed on the computer cannot always be invoked, and special calculations or special treatment techniques must be developed. These may be simple or complex and often require considerable physics input.[2]

The implementation of the actual radiotherapy treatment is in the hands of the radiographers, and the physicist's role in this area is confined to devising techniques leading to reducing errors in setting-up and delivering the radiation. Among the approaches considered is the fully automated treatment technique[3], which is available in very few centres because of the cost of the equipment. More accessible are partially automated systems in the form of computer-controlled setting and recording of the various machine parameters (beam size, beam orientation, dose delivered). These systems are still a subject of practical assessment.The physicist's involvement does not finish at the time of treatment implementation but extends to dose verification which may take place during actual treatment. Among the methods available to physicists for dose verification on patients are ionization chamber, thermoluminescent dosimetry (TLD) and semi-conductor detectors.

Computing in radiotherapy

It is difficult today to imagine modern radiotherapy and physics departments working without computing facilities. During the past decade the application of computers has increased considerably due to larger availability and lower cost of the hardware and wide-spread knowledge, particularly among physicists, of handling and using computers. Among the applica--tions in radiotherapy the most important is that of computation of radiation distribution charts or so -called treatment plans. Other applications include treatment verification, acquisition of patient's anatomical data, record keeping and analysis of treatment results. Applications in treatment automa-tion are developing slowly.

Computation of radiation distribution charts

Physicists take a deep interest in computing concerned with acquisition of radiation beam data and computation of radiation distribution in both exter-nal beam therapy and brachvtherapy. To be complete and satisfactory, a computerized planning system should be able to take into account all possible parameters which affect the calculated distribution. It should be able to deal with irregularities of the patient surface, with in homogeneities, wedges, various field weighting, fields of unusual shape or elongation, static or rotational beams. These features should be available for both photons and electrons. With the computer's ability to produce different plans very rapidly many existing systems have facilities to consider alternative treat-ment parameters and to produce an 'optimum plan'. The treatment planning system described by Redpath,Vickery and Duncan[5] contains an optimization facility which, for a given combination of beam directions and sizes, finds the optimum weights and wedges for the beams, based on the criterion of uniformity of dose throughout the tumour volume.The computer methods for treatment planning are now being taken one step further towards three-dimensional (3-D) treatment planning. In the past 15 years physicists have put a consider-able effort into the development of computational methods in treatment planning and this is still continuing.

Computed tomography in radiotherapy

When the potential of CT in radiotherapy was realized, physicists started to work on the utilization of the CT images for the purpose of treatment planning. This led to the development of CT-linked treatment Planning systems based on a computer. Such a system has a facility to use the CT-obtained data for displaying the images on the console of the treatment planning system and for calculating the radiation dose distribution taking into account the patient's outline and tissue inhomogeneities in the irradiated volume. When the CT-aided treatment planning computer completes its calculations a more accurate dose distri-bution chart is produced in which the dose to the tumour and to the surrounding normal tissue (for example the spinal cord) is predicted with a higher degree of accuracy compared to other methods.[2]

Radiation protection

Each Authority in the UK Health Service must be served by an appropriately qualified and experienced physicist to act as a radiological protection adviser(RPA).The physicist, who is the RPA, is responsible for advice on all aspects of radia-tion protection, from planning new facilities to modifications of the existing ones. He must ensure that the environment is regular surveyed and that the staff expose to radiation from external sources is systematically monitored, preferably on an individual basis. If the radiation survey indicates that persons may, under normal working conditions, receive doses in excess of the level reasonable in the circumstances for the particular type of work, the RPA must indicate the measures to be adopted to rectify the situation. The RP A's responsibilities involve all areas of radiotherapy activities. Radiation protection, in general, has two aspects; advisory and dosimetric, and physicists play an active role in both.[2]

Protection in external beam therapy

The physicist's task in external beam therapy is probably the simplest of all the tasks which he performs. The focal issue in this area of radiotherapy is the proper design of treatment room facilities at the time of equipment installation. Once the room for a treatment machine is suitably designed most of the problems of staff protection are solved. This is, how-ever, not simple especially in the case of megavoltage installations. Room design for a linear accelerator has for example to be based on calculations which give consideration to all possible therapy beam orien--tations, scatter generated in the patient, in walls, floor and ceilings and to the leakage of radiation through the shielding around the radiation target (treatment head). At energies above 15 MeV, neut-ron production may become significant in magnitude and needs to be considered. The crucial areas in the design are the maze entrance and the machine control panel room which are heavily occupied by staff, particularly radiographers. A good practice in the design of these areas would be to aim to achieve radiation levels not in excess of one tenth of the per-mitted exposure. A large amount of expense is involved in the construction of suitably protected megavoltage treatment facilities, which are vital for the safety of all the staff. The physics calculations and advice therefore carry a considerable degree of responsibility.The success of the design must be checked by a thorough survey of radiation levels in the whole of the environment of the newly installed machine. Proper documentation of this work must be made and held for future reference and inspections by the authorities who control the implementation of the radiation protection measures.If the radiotherapy centre is equipped with a cobalt-60 or caesium-137 external beam machine, there will be a need to exchange the sources for new ones every few years when their activity is low. This work must be carried out by an experienced company and under a strict radiation protection survey. A great deal of thought must be given to such an opera-tion prior to the source exchange.[2]

Protection in Brachytherapy

In contrast to the external therapy facilities where the radiation protection requirements must be already resolved at the time of building an appropriately designed room to house the equipment, radiation protection in brachytherapy is concentrated on the minimization of unwanted exposure during the usage of the sealed sources. Brachytherapy thus requires attention from this point of view all the time.The central area for brachytherapy activities is the radioactive sealed sources laboratory which has to be appropriately designed to provide the storage, clean-ing, handling facilities and sources inventory. It is a duty of the physicist to design such facilities to the highest possible safety standards. Physicists must be conversant with the code of prac-tice and other regulations or any other legal require-ments concerning the use of radioactive sources.[2]

Research and development (R and D), teaching

As in any other field of medicine or science, radiotherapy would not make any progress unless an appropriate effort is put into research and develop-ment. Similarly, the physics underlying radiotherapy must be developing in parallel. There are several aspects of the R and D activities in which physicists are involved [2]:

1. Research on various aspects of ionizing radia-tion characteristics, on dosimetry, on inter- action processes of radiation with matter and the effect of ionizing radiation on tissue and cells.
2. Development and/or assimilation of new improved treatment methods and techniques for clinical use.
3. Assimilation of research and development results which are produced in other radiotherapy and physics centres.
4. Assimilation of national or international recommendations currently concerning the best practice in physics and radiation dosimetry.
5. Interchange of information of research and development results through meetings and publications.

The duties of the medical physicist in radiation oncology are summarised in the following table [6] under the following headings :

* Radiation dosimetry and Quality assurance
* Treatment planning and Treatment
* Acquisition of new equipment and maintenance of equipment.
* Teaching and training
* Research and development
* Management

Duty	Frequency of performing duty (where applicable)
1 RADIATION DOSIMETRY AND QUALITY ASSURANCE	
1.1 **Dosimeters**	
1. Acquisition of a suitable dosemeter or dosemeters	
2. Sending of the dosemeter to the CSIR for calibration	Yearly
3. Testing of the calibration stability of the dosemeter	Monthly
1.2 **Linear accelerators**	
1. Implementing of the AAPM TG21 protocol for absolute dose measurement of the x-ray and electron beams	
2. Absolute measurement of dose for all available x-ray and electron energies applying the TG21 protocol	At installation of a new
3. Testing of the symmetry and flatness of the x-ray and electron beams	accelerator
4. Comparative dose measurements of the available x-ray and electron energies (e.g. with diode detectors)	Weekly
5. Acceptance tests and the accumulation of dose data commissioning of a new linear accelerator	Monthly
6. Mechanical, optical and geometrical quality assurance tests (e.g. testing of beam sizes, isocentre, collimator rotation, vertical couch movement, correspondence of light and radiation beam, alignment of LASERS, etc.)	Daily
1.3 **Cobalt Units**	
1. Absolute measurement of absorbed dose	
2. Acceptance tests and collection of dose data when commissioning of a new cobalt unit	
3. Mechanical, optical and geometrical quality assurance tests (e.g. testing of beam sizes, isocentre, collimator rotation, vertical couch movement, correspondence of light and radiation beam, alignment of LASERS, etc.)	Monthly
1.4 **Low energy x-ray unit (maximum beam quality 300 kV)**	
1. Absolute measurement of dose	
2. Mechanical and geometrical quality assurance	Weekly
1.5 **Afterloading unit**	
1. Absolute measurement of dose	Weekly
2. Quality assurance tests	Monthly
3. Replacement of the radioactive source or sources and the accompanying tests as required by the specific afterloading unit	
1.6 **Simulator**	
1. Acceptance tests at commissioning of a new simulator	As required by
2. Quality assurance (mechanical, optical and geometrical tests e.g. tests for beam size, isocentre, collimator rotation)	the type of source

Duty	Frequency of performing duty (where applicable)
1.7 **CT Scanner**	Weekly
1. Quality assurance (image quality, alignment of LASER-beams, couch movements, etc.)	
1.8 **Unsealed radionuclide therapy**	
1. Determination of the activity of unsealed radionuclides and the administration of these nuclides in specific cases (e.g. oral administration)	Weekly
2 PLANNING AND TREATMENT	
1. Acceptance and commissioning of a treatment planning system.	
2. Input of beam data into the treatment planning computer and verification of beam data of the various treatment units (cobalt unit, linear accelerator, afterloading unit).	
3. Quality assurance and management of software on the planning computer.	Monthly
4. Assistance in calculating dose distributions for individual patients.	Daily
5. Consultation with regard to the localization procedures, simulation of planned treatments and the design and manufacturing of special devices for specific patients.	
6. Inspection and verification of the treatment plan for **each patient** before commencement of treatment.	Weekly
7. Absorbed dose measurement for individual patients as required.	
8. Verification of the absorbed dose which is prescribed by performing in vivo dosimetry on **individual patients**.	
9. Calculation of dose distributions for patients receiving brac hytherapy with sealed radioactive sources.	
10. Participate in the design and manufacture of devices e.g. shielding block by the radiotherapy laboratory and a ^{192}Ir wire cutter by the workshop.	
3 ACQUISITION OF NEW EQUIPMENT AND MAINTENANCE OF EQUIPMENT	
1. Writing specifications for new equipment after consultation with radiation oncologists and radiographers.	
2. Evaluation of tenders submitted and drafting of recommendations for purchasing of equipment after consultation with radiation oncologists and radiographers.	
3. Commissioning and acceptance of equipment as well as the training of staff in the use of equipment.	
4. Management and supervision of the maintenance of equipment.	
4 TEACHING AND TRAINING	
4.1 The medical physicist participates in the formal academic teaching and practical training of the following students:	
1. Post-graduate and in-service training of medical physics students.	
2. Physicians specialising in radiation oncology.	
3. Radiography students.	

Duty	Frequency of performing duty (where applicable)
4. Radiation technology students.	
4.2 Teaching radiation protection to radiation workers.	
4.3 Training in the use of new equipment.	
5 RESEARCH AND DEVELOPMENT	
5.1 Independent research and development in medical physics aspects of radiation oncology.	
5.2 Participation in the research and development projects of the radiation oncologists.	
6 MANAGEMENT	
The management functions of the medical physicist include:	
6.1 Managing the medical physics department.	
6.2 Managing the workshop.	
6.3 Managing the radiation technology laboratory.	
6.4 Drafting the budget for the medical physics department as well as the equipment budget for the Department of Radiation Oncology (if requested).	
6.5 Act as member of the management team of the Department of Radiation Oncology.	

Conclusion

For more than a century, physicists have worked side by side with their physician and technologist colleagues to exploit the diagnostic and therapeutic uses of radiation for the benefit of patients. Today, physicists play a fundamental role in medical imaging and radiation oncology. Tasked with the critical function of assuring the safety, appropriateness and effectiveness of radiation-based clinical procedures, their current role far exceeds past contributions to patient care and wellbeing. Clinical medical physicists are a very important part of the radiation oncology team. Their primary role is to assure that the highest level of quality care is maintained. The medical physics group design and implement the quality assurance program in radiation oncology. They are responsible for selecting and specifying the types of equipment that are used in radiation therapy. After new equipment is installed, the medical physicist assures that the equipment meets or exceeds specifications. Once the equipment is accepted, the physicist is responsible for commissioning the equipment, which involves taking enough measurements so that the equipment can be used clinically. Measurement data must also be transferred to other computer systems so that patient treatments can be planned. The medical physicist is frequently consulted by the radiation oncologist to help design a treatment that is difficult or unusual. A physicist is responsible for doing the quality assurance of every treatment plan before it starts. He or she checks that the planned information has been correctly transferred to the machine, that the plan agrees with the physicians prescription, that beam-on times are correct for each treatment field, and that all information is consistent, understandable, and well-documented. Bridging the gap between physics and medicine, medical physicists have facilitated the introduction of technologies such as CT, MRI, PET, linacs and many other innovations that have revolutionized the way medicine is practiced. In the field of radiation oncology, the clinical role of the physicist was greatly enhanced by the advent of Co-60 ã-ray and megavoltage (1–25MV) X-ray beams in the latter part of the last century. Such beams require much greater attention to dosimetry and computation in treatment planning, because visible indicators of treatment progress are eliminated.

The medical physicists also instructs radiation oncology residents, physics residents and graduate students, dosimetrists, nurses, and radiation therapists on the subject of radiation physics. Most of the physicists are also involved in specific areas of research, some basic research, others clinical or translational research.

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