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Review

Medical physics in radiotherapy: The importance of preserving clinical responsibilities and expanding the profession's role in research, education, and quality control

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ABSTRACT

Medical physicists have long had an integral role in radiotherapy. In recent decades, medical physicists have slowly but surely stepped back from direct clinical responsibilities in planning radiotherapy treatments while medical dosimetrists have assumed more responsibility. In this article, I argue against this gradual withdrawal from routine therapy planning. It is essential that physicists be involved, at least to some extent, in treatment planning and clinical dosimetry for each and every patient; otherwise, physicists can no longer be considered clinical specialists. More importantly, this withdrawal could negatively impact treatment quality and patient safety. Medical physicists must have a sound understanding of human anatomy and physiology in order to be competent partners to radiation oncologists. In addition, they must possess a thorough knowledge of the physics of radiation as it interacts with body tissues, and also understand the limitations of the algorithms used in radiotherapy. Medical physicists should also take the lead in evaluating emerging challenges in quality and safety of radiotherapy. In this sense, the input of physicists in clinical audits and risk assessment is crucial. The way forward is to proactively take the necessary steps to maintain and advance our important role in clinical medicine.

1. Introduction

In recent decades, medical physicists have slowly become further removed from direct clinical responsibilities in planning radiotherapy treatments. This change has been more prominent in countries in Western and Northern Europe, somewhat less evident in Southern Europe, and only marginal in Eastern Europe.

Previously, physicists handled all aspects of the treatment planning from start to finish. Over time, however, this model has steadily given way to a new structure in which other

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specialists and technicians (primarily medical dosimetrists and technologists) have assumed many of these responsibilities. While the reasons for this transformation are many and varied, medical physicists themselves are undoubtedly at least partly responsible.

Not everyone agrees with the notion that medical physicists have become too distanced from clinical work. Bortfeld and Jeraj[1] argue that the real problem in medical physics is not insufficient clinical involvement, but rather that the research and academic aspects of the profession are weakening. Despite these arguments, I contend that there has indeed been a shift in the responsibilities of medical physicists.

One of the primary reasons that medical physics has become ever more distanced from its original, clinical role—in which the physicist was closely involved in treating patients—is the emergence of advanced technologies and the challenges that these technologies present. The work of medical physicists in the clinical setting has become increasingly less clinical. This is particularly evident in radiotherapy, where physicists were once responsible for developing treatment plans for all patients, but now have a more supervisory role in treatment planning. This change has altered how physicists are perceived by other members of the clinical staff, and it might even have a negative impact on the job positioning of physicists in the hospital, where the most important responsibilities are considered those that directly relate to patient care and treatment.

In the present article, I describe how and why this shift in responsibilities has occurred, and I explain how it has affected the profession of medical physics. I argue that it is essential that medical physicists maintain their clinical involvement because the specialized knowledge that physicists possess cannot be easily replaced by technicians or radiation oncologists, nor by specialized software run on advanced computers. In the long run, if medical physicists do not take steps now to alter current trends, we run the risk of irreparably harming the profession.

2. Historical background

The discipline of radiation oncology has changed tremendously since the discovery of the therapeutic value of X-rays around the turn of the 20th century. While contributions to the advance of radiotherapy have come from experts from a variety of fields—including clinicians and biologists—it seems safe to say that the innovations of physicists have been essential.[2,3]

From the very beginning, physics has had an important role in radiotherapy.[4] The early discoveries of the value of ionizing radiation in the treatment of cancer were made by eminent physicists such as Wilhelm Roentgen, and Marie and Pierre Curie. As a result, physicists were closely involved in developing radiotherapy treatments and protocols. The typical job titles of these early physicists—e.g., radiation physicist, clinical physicist, and medical physicist in radiotherapy—underscore their importance. The physicist was a key member of the treatment team and, more importantly, was involved in every case without exception.

Until the advent of computerized treatment planning and the sophisticated imaging methods made possible by computers, these early physicists performed most of their planning tasks manually. Consequently, developing an individualized treatment plan was not only time-consuming (early sources, such as kilo-voltage X-ray units, were not automated and required that the physicist perform frequent dosimetry and output dose checks), but also highly challenging. In order to create an effective treatment plan, it was necessary for the physicist to have an adequate understanding of both biology and anatomy, in addition to the ability to visualize patient anatomy in three dimensions. Moreover, technological limitations meant that physicists had to configure the beams and calculate the doses using only the topographic measurements of the outer contours of the patient's body and orthogonal X-ray images. In this pre-computer era, the dose calculation algorithms were quite simple, so much so that dose distributions could be calculated manually or with the aid of a calculator or calculating machine.

Despite the evident limitations of these now outdated methods, they had one very important advantage that has since been lost: because physicists were obliged to perform dose calculations manually, they developed a strong understanding of the limitations of the algorithms and formulas used to calculate the dose. Through experience, medical physicists knew instinctively that any type of body slope or inhomogeneity had to be corrected for. Of course, this is not to say that we should lament the passing of the old methods, nor that we should return to using them; rather, this example shows that we need to think about whether and what kinds of hands-on computational approaches should be included in training physicists, as such methods still have educational value.

The interaction between ionizing radiation and the human body is complex, in large part because a variety of different phenomena can affect the dose. In the past, it was widely understood that the person who performed the dose calculations and beam configurations needed to possess extensive knowledge of the physical interaction between radiation and matter. Moreover, these early physicists had to be able to measure the delivered doses to calibrate the therapeutic sources and to assure that the correct dose was delivered in vivo. Given the complexities involved, this work could only be performed by highly-trained individuals who had studied physics at the master's or Ph.D. level.[3,5] This means that, in radiotherapy hospitals, the role and position of the medical physicists was closely associated with the daily clinical activity of treatment planning, although the profession of medical physics in radiotherapy was not formally recognized in some countries. However, as we shall see, that scenario has changed.

3. Medical physics in the 21st century

As technological developments continue to revolutionize radiation oncology, the role of medical physicists has also evolved.[1,3] However, some believe that some of these changes are not entirely positive, and we may need to steer a modified course. For instance, in many countries, the focus of medical physicists has become extremely narrow, with an emphasis on improving specific skills at the expense of a broader role for medical physicists. In other words, it seems that greater emphasis is placed on improving physicists' technical ability rather than their overall knowledge and skill. To some degree, this supports the conclusions of Bortfeld and Jeray,[1] who argue that the greater concern is research activity. However, as I argue in this paper, withdrawal from routine clinical obligations might also be a serious drawback of these changes.

Recently, The Lancet[6] published a series of papers about the contributions of physics to human health. As Knight[7] state in their contribution to the Lancet series, medical physicists have long been involved in transferring laboratory discoveries into valuable tools that have helped to improve health care. Examples of such technologies include computed tomography, positron emission tomography, and linear accelerators. Those same authors also point out the need to support research in physics, particularly with regard to medical applications. Over time, radiotherapy delivery machines (linear accelerators, etc.) and imaging units (CT, MRI, etc.) have become ever more sophisticated, as have the computerized treatment planning systems needed to operate these technologies. These advances have undoubtedly changed the role of physicists in the treatment planning process. For instance, inner body structures are now scanned by CT and the data is transferred directly to the planning system, thus eliminating the need for what is commonly called "manual dose calculation". Similarly, the complexity of dose distribution algorithms (due to the many cross-sections) requires the use of high-speed computer calculations, and thus manual dose calculation is no longer feasible. Similarly, the algorithms used in these computerized planning systems have become increasingly accurate, but with a corresponding increase in complexity. Daily routine treatment planning is performed on a computer, and it is the computer which performs the complex dose calculations and optimizations based on a physicist's pre-designed beam setup. As a result, this gives the perception that a less qualified person is perfectly able to perform routine treatment planning. In fact, in many departments, this job is performed by dosimetrists.

Another downside of the highly sophisticated algorithms used to calculate and optimize treatment plan calculations is that they are less easily understood by the people who design the treatment plan, regardless of whether these are medical physicists or other professionals. Over time, algorithm development has become a highly specialized domain of a sub-group of medical physicists, who read and publish in scientific journals and attend conferences on this subject. As a result, the person who prepares individual treatment plans and whose responsibilities are primarily clinical has less need to possess a comprehensive understanding of the more theoretical aspects of these algorithms. Considering that in-depth knowledge of the algorithms and their limitations is no longer necessary for daily planning, and that physicists are subject to inevitable time demands and constraints, do we dare to claim that specific expertise in physics is no longer needed for treatment plan preparation? Or perhaps that planning can be split between the person who prepares the plan (not a physicist) and the person (a physicist) who verifies and accepts the plan? Neither solution seems satisfactory because even though accepting a treatment plan implies a certain responsibility, this does not allow the person to develop sufficient expertise given that creating a plan and accepting a plan are two very different tasks. As a result, over time, the person who prepares the plan is likely to become more expert than the person whose only role is to check and accept or reject the plan. In short, medical physicists should design treatment plans, not merely check them.

Undoubtedly, an important reason behind the decrease in actual clinical work (i.e., dosimetry and treatment plan design) for medical physicists has been the development and introduction of new equipment and procedures such as intensity-modulated radiotherapy (IMRT) and image-guided RT (IGRT). These technologies and techniques require extraordinary amounts of time for quality assurance and dosimetry.[8–12] The routine duties of physicists in quality control, commissioning of equipment, and performing of acceptance tests became much more complicated tasks when organ motion and size variability became important. This new task presented a challenge to medical physicists while routine treatment planning, by contrast, began to look comparatively simple. The question that arose is this: to what extent should routine clinical treatment planning be delegated to dosimetrists? These newer techniques now occupy a large portion of physicists' time, to the exclusion of other tasks. This change has opened the door for dosimetrists and technologists to replace medical physicists in routine planning. Of course, we cannot overlook a related argument: that it is too expensive to train a qualified medical physicist (which requires a Master's degree in physics plus a postgraduate residency programme in the clinic) if his/her primary role is to prepare standardized treatment plans.

A bigger threat to the profession may be the large changes that can be seen on the far horizon. What were once clearly-defined boundaries between the various medical disciplines are becoming increasingly blurred, and this is true for diagnosis, treatment, and management. Numerous therapies are now available (or soon will be) to allow specialists from fields other than oncology to treat cancer patients. The use of radioactive particles to treat tumours using catheters, high-intensity focused ultrasound, electromagnetic wave ablation, and photodynamic therapy and nanoparticles[13] are just some challenges to the existing paradigm.

The uncertainty and turf battles will only become more intense, and medical physicists will not be spared. This raises an important question: how do medical physicists fit into this rapidly changing scenario? In addition to the new technologies already mentioned, we must also consider the molecular revolution that is underway. Are we prepared to explore the newer technologies such as nanotechnology? And are university curricula being adapted quickly enough to respond to changing needs? The following sections of this paper address such questions in detail. I explore numerous issues associated with various aspects of the professional profile of medical physicists today. Finally, I describe the dangers that threaten to diminish the important role and status of medical physics.

4. Clinical obligation—the evolving roles in radiotherapy planning

In the context of this article, the biggest change in medical physics is the shift of routine treatment planning responsibilities from physicists to medical dosimetrists. In the early days of radiotherapy, the role of technicians (or nurses) was to position patients in the treatment unit, set up the parameters according to the treatment plan, and to deliver the radiotherapy. Originally, the staff members that performed these duties were called electroradiologists, radiographers, or radiotherapy technicians. Training was typically a 2–3 year course at professional schools (i.e., not university level) after graduation from high school. Some of these technicians began to assist medical physicists in treatment planning, and, over time, ultimately came to specialize in treatment planning under the supervision of medical physicists. These new technicians specializing in dosimetry have come to be known as medical dosimetrists and in many countries they now perform most of the day-to-day treatment planning for patients. This process has accelerated in recent years as many universities have launched bachelor's and even master's degree courses dedicated to training radiation technicians (technologists) to meet new demands.[14,15] However, given the many differences between countries and regions, it is difficult to draw a general picture of the situation regarding who performs treatment planning and the degree of involvement of radiation oncologists, medical physicists, and dosimetrist/technologists.

The emergence of this new figure has changed the role of medical physicists in treatment planning, whose responsibilities are now of a more supervisory nature. Physicists spend less time developing treatment plans for individual patients and more time performing other tasks. In fact, in much of Western Europe, medical physicists no longer carry out simple radiotherapy planning, as this is performed by dosimetrists or assistants. In contrast, physicists in Eastern European countries continue to design routine treatment plans.[16,17] In some centres, for example, designing treatment plans is almost exclusively performed by dosimetrists, with the plan checked by the radiation oncologist (with only minimal involvement of the physicists). Given that the interaction of ionizing radiation with a body is a complex process requiring a strong understanding of physics—knowledge which can only be obtained through university-level physics courses—the complete exclusion of physicists from treatment planning is wholly inappropriate and is most definitely not a positive change, as I discuss in the paragraphs that follow.

The gradual elimination of medical physicists from treatment planning might also affect the quality and safety of routine procedures. In all medical specialities, safety is always prioritized over cost. There is no doubt that having a physicist perform treatment planning for each patient is more expensive; however, just as the important role of highly-qualified nurses has not eliminated the need for physicians to directly care for individual patients, so too with medical physicists. If computerized planning systems allow physicists to withdraw from routine planning, does that imply that some more advanced computer system—such as artificial intelligence—will eventually replace medical doctors, so that a less qualified person could perform routine patient visits while the role of the doctor is merely supervisory?

As in many other specialties, the driving forces behind these changes are financial and political pressures to optimize limited resources in health care. Curiously, if we consider the overall cost of cancer treatment—which includes surgery, radiotherapy and chemotherapy—the cost of physics expertise accounts for only a small fraction of the expense. This implies that efforts to reduce costs should focus on other areas, as treatment can still be cost-effective even when physicists play an important role in performing or accepting the individual treatment plan.

Another important concern is that the increasingly limited clinical role for physicists could impair the ability of the next generation of medical physicists to respond to new technologies. However, we need be concerned not only with the research aspects of the profession, but also with providing career opportunities in the clinic. If the opportunities for physicists become increasingly narrow, university students will have less interest in pursuing radiotherapy physics after graduating from the university.

5. Education

In the not-too-distant past, medical physicists were recruited from graduates who attended university degree programmes (in most cases, 5-year degrees) in physics. Depending on the country, these physics courses may have provided some training in the application of physics in medicine, and some may have even included a focus on radiation aspects. Thus, upon graduation (master degree), the graduates possessed extensive knowledge in physics and joined a medical physics team where they would be trained in medical physics.[18,19] However, times have changed and, in many countries, universities have increasing autonomy in defining the curricular content, and thus the background training in physics may be stronger or weaker depending on the university and country. For some jobs, especially clinical ones, public safety requires that the staff involved have clearly defined competences and skills.

Another important point is related to the recent Bologna Agreement.[20,21] Under the changes implemented through the Bologna Agreement, all degree programmes (with the exception of medicine and few other specialities) are to be split into Bachelor's and Master's degrees. Theoretically, then, a student could obtain a Bachelor's degree in one field (e.g., engineering or even a field further removed from physics) but then go on to do an M.S. degree in Physics. This implies that students from fields other than physics may graduate from these Master's programmes, and will thus not be as well prepared in physics as previous generations who had completed a traditional, 5-year undergraduate course in physics.

This new situation accentuates the need for intensive, high-quality post-graduate training in the field. However, in a number of countries, the requirements to work in clinical radiotherapy or to enter a residency programme are not clearly defined and they vary from country to country.[22] As a result, there is some doubt as to whether a Bachelor's degree in physics is sufficient or whether a Master's is required, or whether the combination of a Bachelor's degree in a related field (e.g., engineering) combined with an M.S. in physics is sufficient. At the moment, these are questions open for debate.

The impact of Bologna Agreement on the education and training of medical physicists has been discussed in detail by Edualdo and Olsen in their follow up to the European

Federation of Organizations for Medical Physics (EFOMP) policy statement no. 12.[23] This statement supports the positive results of the Bologna process, whose first step (bachelor level) equips the physicist with basic knowledge in physics, mathematics and other relevant topics in natural science. In the second step, medical physics related topics should ideally be taught in master courses, while the usual postgraduate training of at least 2 years should be undertaken in a hospital setting. EFOMP recommendations suggest that only completion of these three steps would allow a student to gain the appropriate knowledge and competencies, and this should be confirmed by inclusion in a National Register. That policy statement is very clear and practical. It accepts the existing reality that, in some countries, medical physicists are recruited from graduates of engineering or related fields, but it stresses the necessity that all students obtain a master's degree in medical physics. However, we must remain cautious given that the Bologna process initiated deregulation in higher education. Training in medical physics is not regulated, and this means that, in many countries, the content of bachelor's and master's curricula is not regulated by any national bodies. As a consequence, universities are free to choose the content they offer and allow the market to decide which model is most appealing. This approach is stands in stark contrast to medical studies, in which the curricular content is regulated by various professional and state bodies.

An important document has been recently published by the EC in which key competencies and qualifications of the Medical Physics Expert (MPE) are defined.[24] Although this work has been carried out under the umbrella of Radiation Protection Section, its content goes beyond safety issues and highlights the importance of a foundation in physics in undergraduate education and postgraduate training in a clinical setting. It quotes a term "or equivalent" for each educational component, and extensively defines the particular meanings of each "equivalent". Although this effort reflects existing diversity in educational background, it somehow confirms the doubts raised here regarding whether current specifications of educational standards for medical physicist are too loose and vague.

The new Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionizing radiation (EC BSS) lays out in great detail the responsibilities and competencies of MPEs as they relate to radiation protection and the significant role of dosimetry as set out in article 83, while treatment planning receives much less attention.[25]

Both of the aforementioned EC documents stress the importance of medical physicists in the clinical setting, although the emphasis is placed on safety-related aspects in radiotherapy. Safety is no doubt important, but more emphasis needs to be placed on the clinical competencies and professional training of MPEs.

6. Postgraduate residency

In many countries, residency programmes (similar to those in medical specialities) have been introduced to assure that medical physicists possess the requisite knowledge and competencies to carry out work in clinical physics for radiotherapy. Thus, in many (though not all) countries, physicists must complete a 2–3 year residency programme under the supervision of an experienced and certified tutor, followed by a comprehensive exam, in order to become certified in medical physics. In some countries these programmes are managed by governmental agencies. For instance, in Poland, this process is regulated by the Medical Centre of Postgraduate Education (in Polish, the *Centrum Medyczne Kształcenia Podyplomowego*; CMKP) and the diploma is awarded by the state.[5,19] In other countries, private entities—including professional bodies or societies (e.g., the Society of Medical Physicists)—award certificates and evaluate courses developed by different hospitals.[22,26]

These residency programmes highlight the need for a strong understanding of physics, particularly as it relates to medicine and biology—in other words, medical physics.[3,22,26,27] Despite the importance of medicine and biology in the field of medical physics, it is worth noting that the focus of such training programmes is, properly, on physics and not medicine. This is an important point, as we are not training medical doctors but rather medical physicists. The medical physicist must first and foremost thoroughly understand all aspects involving the interaction between ionizing radiation and matter, and then, more specifically, how radiation interacts with human tissues and the body. As the job involves not only dose calculations but also measurements, medical physicists must have a thorough understanding of dosimetric methods and the limitations thereof.

The rapid technological advances of recent years have brought us effective yet highly complex of dose delivery methods (e.g., IGRT, IMRT, VMAT, Tomotherapy, etc.) that require a thorough understanding of the principles underlying these technologies. While radiation oncologists do not need to possess such a strong theoretical understanding of these technologies, physicists do. This is a key difference between these two professions, especially because this knowledge is essential to evaluating the limitations of the various dose delivery methods.[9,12,28]

For non-specialists, it is easy to suppose that the role of the medical physicist is simply to use the computer (i.e., the treatment planning system) to shape the isodose curves to provide maximum tumour coverage while complying with the constraints to healthy tissues. Certainly, this is part of the job, but this task is only valuable (and safe) when the person performing it possesses a comprehensive understanding of the processes the various body tissues and organs undergo as radiation passes through and interacts with the tissues. This complex interaction between radiation and human cells and organisms will invariably cause both desired and undesired effects, just as occurs with many medications.

Treatment planning systems have an inherent limitation that is directly related to the limitations of the algorithms that model interaction with the body. Even though computers are more powerful than ever and can perform nearly instantaneous dose calculations, they are still governed by an algorithm that has been developed by humans—in most cases, by medical physicists. The crucial point is that the planning system is not a black box that anybody can use to produce the optimal beam configuration. A thorough knowledge of physics is needed to support this work, and this knowledge can only be gained through university education combined with formal training (i.e., the residency period) and experience. Of course, it is clear that modern software has made the process of fitting the dose to the tumour much easier nowadays, with far fewer difficulties than in the past. The use of templates make this task easier and this is why the dosimetrists and technologists, who do not typically possess a strong background in physics, are able to perform this task in routine cases.[14,22] Nevertheless, to assure patient safety and treatment effectiveness, it is essential that physicists regularly check the simple treatment plans prepared by dosimetrists. For more sophisticated plans, such as those that use IMRT and IGRT techniques, the physicist should actually perform the calculations. However, there appears to be a growing belief that dosimetrists can also perform calculations for sophisticated plans, with the physicist limited to providing final approval of the plan. In my view, verification and approval is far less valuable—in terms of reliability—than actually performing the primary calculation and for this reason I strongly believe that physicists should continue performing this highly complex task.

7. Collaboration and overlap between specialists

To this point, I have argued that medical physicists should be closely involved in developing and implementing radiotherapy treatments. However, we must recognize that there is, inevitably, a certain amount of overlap in the work performed by the various specialists (technicians, dosimetrists, radiation oncologists, and medical physicists) who work in radiotherapy.[11,14,16] Indeed, treatment planning can be done by any of these figures, and in high-resource European countries, technicians/dosimetrists and physicists perform treatment planning in equal shares (42.8%). In contrast, the bulk (85%) of treatment planning in medium and low-resource countries is performed by medical physicists. A similar contrast is seen in quality assurance, in which low and medium-resource European countries rely on physicists to perform this task in 90% of cases, whereas this percentage drops to 67% in high-resource countries.[29,30]

Notwithstanding this situation, I believe that it is important to clearly define the role of all specialists in order to minimize overlap, and to avoid encroachment. Certainly, changes can be made as appropriate, as roles can be expanded, reduced, or simply altered. However, it is better to do so with forethought rather than after the fact.

8. Involvement in academics

Academic work usually refers to both teaching and research. At some universities, academic positions include both components and both are mandatory for staff faculty. Other universities, in contrast, allow their academic staff to concentrate primarily on either research or teaching, a variation on traditional professorial obligations, which typically involve both areas.

Academic work (teaching or research) used to be considered essential only in academic institutions or at university radiotherapy clinics. Medical physicists who work in community hospitals may not want to be involved in teaching or research and may prefer to focus mostly on the clinical aspects of their work. While clinical medical physicists are often not involved in teaching university students, their work typically includes supervising trainees. Physicists must supervise and train not only new medical physicists, but also dosimetrists and radiotherapy technologists. In addition, during residency, most radiation oncologists will spend at least some time observing the work of physicists.

Depending on the speciality, students or trainees may require varying levels of supervision. For instance, undergraduate physics courses may include material on medical radiation physics, and thus any practical components of such courses will require greater staff involvement—in other words, a greater time commitment. These supervisory and training aspects are time-consuming and this must be accounted for when determining appropriate staffing levels. In addition, the training process should include elements of self-training (more or less formalized continuing medical education) in order for the physicists to learn to use new technologies and techniques.

Although many physicists are not involved in conventional research, it is important to emphasize the fact that clinical physicists have long played an important role in developing new treatment methods—both in the past and present—and such efforts could certainly be called "research". Today, given that the role of physicists in routine treatment planning has been reduced, involvement in research and teaching activities might improve the job profile and should, therefore, be valued highly. However, this is not always the case. If teaching and research activities are included in the job profile, then the institution needs to have a policy in place to govern the work of staff involved in these activities, and to provide suitable financial compensation for their work.[16,29] Typically, teaching forms part of the physicist's clinical duties and thus, clearly, physicists with teaching obligations cannot perform the same amount of work as those without such obligations.

Research in medical physics is extremely important component in fostering development of new technologies and elevating the job profile.[1,3,31] For this reason, in most developed countries, professional and scientific organizations have been created to promote the development of medical physics. Affiliating medical physics departments with academic institutions creates opportunities for staff to participate in implementing new advances, but this is insufficient. Usually, the workload in clinically-oriented departments is high, thus precluding physicists from dedicating much (if any) time to research. Positions that allow physicists to split their time between research and clinical work are important to help quickly transfer scientific results to clinical practice. However, it seems that the most efficient way of fostering scientific advances is through temporary, full-time research positions financed by grants which require achievement of clearly specified scientific objectives. In Poland and certain other countries, such positions in the field of physics are not popular, as most people prefer more permanent positions that mainly focus on clinical work, with only a small percentage of time dedicated to research activities.

9. Quality control and quality assurance

Quality control (QC) and assurance (QA) is becoming ever more important in light of the increasing complexity of modern radiotherapy delivery and the high doses. Patient safety is a high priority, and among the best ways to assure safety is to implement strong, consistent protocols. In recent years, the European Union has implemented measures whose aim is to harmonise medical procedures and training throughout its member countries.[25] The idea is not only to increase quality and safety, but to assure similar quality levels for radiotherapy treatments throughout Europe. These initiatives are leading, inevitably, to a standardization in radiotherapy planning and delivery. QA & QC are the important duty of the medical physics department. In most large hospitals, one staff member is designated as the quality officer. The quality officer could be a physicist or oncologist, or even a specialist such as public health. Similar, the quality officer may be a member of the department, or simply work as an outside consultant. Nowadays, "quality" has a much wider meaning than it did in the past. However, the main aim of quality remains the same as always: to offer the best medical care.[31,32]

One aspect of quality that is often overlooked is the role of nurses. Nurses have an important function in optimizing patient care and improving therapeutic outcomes. However, as described previously, the roles of the various staff members must be precisely defined to avoid overlap.

Finally, in many countries, particularly in Eastern and Central Europe, radiation oncologists and physicists are often asked to perform much of the routine clerical work associated with their other duties. However, this takes time from their more important clinical work and can thus have a negative impact on quality. For this reason, appropriate clerical staffing is an important requirement.

An emerging area of QA is risk assessment, reporting and analysis of near misses and adverse error-events.[33] This concept, which is well-known in industry, involves QA of new radiotherapy tools, and this is largely the domain of medical physicists. Moreover, this area is now the focus of EC recommendations.[34] Implementation of such analyses and activities, which will shortly be mandated in all radiotherapy departments will create job opportunities for medical physicists.

10. Clinical audits

Clinical audits are considered more effective than quality control audits (ISO 9000) in harmonizing radiotherapy delivery.[35] Clinical audits differ greatly from the formal controls carried out by radiation protection or other government institutions. Medical staff members are more receptive to clinical audits, mostly because the auditing team is comprised of peers (e.g., radiation oncologists, physicists, and radiation technicians) rather than administrative personnel. In addition, properly performed clinical audits evaluate clinical activity (how the work is conducted) in greater depth than is done in quality control audits (which usually focus only on record verification). Professionals with clinical expertise are essential to the clinical audit process because only these professionals really know how the procedure should be performed. Given their hands-on knowledge of the radiotherapy process, clinical physicists are ideal candidates to take part in clinical audits—and this could be a key area of interest in the future. Together with the radiation oncologists and the technicians who actually run the machines, physicists are best able to judge the many procedures involved in radiotherapy planning and delivery. Moreover, given that a dosimetry audit should also be performed as part of the clinical audit, it is obvious that the role of the physicist is predominant (although dosimetrists can also provide valuable input).

While clinical audits are still relatively uncommon in some EU countries, the International Atomic Energy Association (IAEA) has been performing clinical audits for many years now under the acronym QUATRO.[36] In fact, the EU recently (2009) published clinical audit guidelines that should be incorporated into the laws of all individual EU countries.[35]

11. Radiation protection of patients

Medical physicists also have another obligation: radiation protection for patients. Although policies have long existed to protect staff, patient protection to avoid accidental and unintended exposure is also extremely important. Radiotherapy is generally a safe procedure, but considering public concerns about the effects of radiation, even small accidents with minor injuries receive much attention in the press. For this reason, the EU has consolidated the existing legal framework and passed a new Basic Safety Standards directive that obliges all EU member countries to implement regulations to prevent unintended patient exposure and to evaluate risks.[25] The new BSS directly addresses the role of medical physicists in these standards, specifically calling for the active participation of these specialists in the process, and physicists are considered indispensible for preventing and rectifying situations that might put either the staff or patients at risk. Interestingly, in some countries, regulation do not require that the radiation protection officer (RPO) be a medical physicist, or even that the RPO have a university degree.

12. Conclusions

Medical physics has a long and storied tradition in radiotherapy, and it is important that the clinical team not lose sight of that fact. Sophisticated treatment planning systems make it easy to forget that the people who designed the algorithms and truly understand these systems are mainly medical physicists. It is essential that physicists continue to be involved in performing treatment planning and clinical dosimetry. Such an approach is not intended to exclude radiotherapy technicians, especially those with advanced training (i.e., an M.S. degree). It is clear that technicians have an important role to play. However, it is imperative that certain clinical key responsibilities be performed by the profession of medical physics.

As physicists, we must possess a thorough understanding of human anatomy and physiology in order to be competent and equal partners to our clinical colleagues, the radiation oncologists. However, unlike our physician colleagues, we must also have a comprehensive knowledge of the physics of radiation as it interacts with body tissues and understand the limitations of the algorithms used in radiotherapy. Without such knowledge, we cannot hope to be treated as equals and to fully participate in clinical treatment planning. We must be confident in our knowledge, competence, and skills and be able to defend and sustain our opinions when discussing the best technological approach to each particular clinical situation.

Medical physicists should also take the lead in evaluating emerging challenges associated with radiotherapy quality and safety. They must be involved in clinical audits and risk assessment. Education has a crucial role in medical physics. Physicists need proper and consistent education before joining a medical physics department, and thereafter both postgraduate education and life-long continuous education are essential as well.

The way forward is to be proactive in our approach to the profession, to carefully consider our own role, and to take the necessary steps to promote our profession to its rightful place in clinical medicine.

Conflict of interest

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REFERENCES

1. Bortfeld T, Jeraj R. The physical basis and future of radiation therapy. *Br J Radiol* 2011;**84**:485–98.
2. Bernier J, Hall EJ, Giaccia A. Radiation oncology: a century of achievements. *Nat Rev Cancer* 2004;**4**:737–47.
3. Thwaites DI, Malicki J. Physics and technology in ESTRO and in Radiotherapy and Oncology: past, present and into the 4th dimension. *Radiother Oncol* 2011;**100**:327–32.
4. Webb S. The contribution, history, impact and future of physics in medicine. *Acta Oncol* 2009;**48**:169–77.
5. Kosicka G, Malicki J. Status of a medical physicist in Poland and verification of foreign professional qualifications. *Zeszyty Naukowe WCO, Lett Oncol Sci* 2013;**10**(3):72–6.
6. Horton R. Offline: why physics is special. *Lancet* 2012;**21**(379):1472.
7. Knight P. Physics and medicine—two tips for a long and happy marriage. *Lancet* 2012;**21**(379):1463–4.
8. Malicki J, Litoborski M, Bogusz-Czerniewicz M, Swieżewski A. Cost-effectiveness of the modifications in the quality assurance system in radiotherapy in the example of in-vivo dosimetry. *Phys Med* 2009;**25**:201–6.
9. Rogelj P, Hudej R, Petric P. Distance deviation measure of contouring variability. *Radiol Oncol* 2013;**47**(1):86–96.
10. Grau C, Borras JM, Malicki J, et al. Radiotherapy capacity in Europe. *Lancet Oncol* 2013;**14**:e196–8.
11. Barbera L, Jackson LD, Schulze K, et al. Performance of different radiotherapy workload models. *Int J Radiat Oncol Biol Phys* 2003;**55**:1143–9.
12. Piotrowski T, Kaźmierska J, Sokołowski A, et al. Impact of the spinal cord position uncertainty on the dose received during head and neck helical tomotherapy. *J Med Imaging Radiat Oncol* 2013;**57**:503–11.
13. Prijic S, Sersa G. Magnetic nanoparticles as targeted delivery systems in oncology. *Radiol Oncol* 2011;**45**:1–16.
14. Janaszczyk A, Bogusz-Czerniewicz M. Comparison of curricula in radiation technology in the field of radiotherapy in selected European Union countries. *Rep Pract Oncol Radiother* 2011;**16**:189–97.
15. Coffey M, Degerfält J, Osztavics A, van Hedel J, Vandevelde G. Revised European core curriculum for RTs. *Radiother Oncol* 2004;**70**:137–58.
16. Malicki J. Staffing for quality: overview. In: Pawlicki T, Dunscombe P, Mundt A, Scalliet P, editors. *Quality and safety in radiotherapy*. Taylor & Francis; 2010., ISBN 978-1-4398-0436-0.
17. Pötter R, Eriksen JG, Beavis AW, et al. Competencies in radiation oncology: a new approach for education and training of professionals for Radiotherapy and Oncology in Europe. *Radiother Oncol* 2012;**103**:1–4.
18. EFOMP policy statement no. 10. Recommended guidelines on national schemes for continuing professional development of medical physicists. *Phys Med* 2001;**XVII**(2):97–101.
19. Malicki J, Gwiazdowska B, Waligórski M. Training of medical physicist and formal requirements of radiotherapy departments related to expertise in medical physics. Proceedings of the 10th biennial ESTRO conference on physics and radiation technology for clinical radiotherapy. *Radiother Oncol* 2009;**92**(S1):156.
20. Bologna agreement in 199 aiming to be implemented by 2010 – uzupełnić.
21. Hensen P. The “Bologna Process” in European higher education: impact of bachelor’s and master’s degrees on German medical education. *Teach Learn Med* 2010;**22**:142–7.
22. Stefanoyiannis AP, Christofides S, Psichis K, et al. The education and training of clinical medical physicists in 25 European, 2 North American and 2 Australasian countries: similarities and differences. *Phys Med* 2012;**28**:183–90.
23. Eudaldo T, Olsen K. The European federation of organisations for medical physics policy statement no. 12. The present status of Medical Physics Education and Training in Europe New perspectives and EFOMP recommendations. *Phys Med* 2010;**26**:1–5.
24. European Guidelines on Medical Physics Expert. *European Commission. Directorate-General for Energy. Radiation protection no. 174*; 2014.
25. Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom. *Off J Eur Union* 2014;**57**(17):L13.
26. Del Guerra A, Bardies M, Belcari N, et al. Curriculum for education and training of medical physicists in nuclear medicine: recommendations from the EANM Physics Committee, the EANM Dosimetry Committee and EFOMP. *Phys Med* 2013;**29**:139–62.
27. Eriksen JG, Beavis AW, Coffey MA, et al. The updated ESTRO core curricula 2011 for clinicians, medical physicists and RTTs in radiotherapy/radiation oncology. *Radiother Oncol* 2012;**103**:103–8.
28. Malicki J. The importance of accurate treatment planning, delivery, and dose verification. *Rep Pract Oncol Radiother* 2012;**17**:63–5.

29. Slotman BJ, Cottier B, Bentzen SM, Heeren G, Lievens Y, van den Bogaert W. Overview of national guidelines for infrastructure and staffing of radiotherapy ESTRO-QUARTS: work package 1. *Radiother Oncol* 2005;**75**:349.E1–6.
30. Bentzen SM, Heeren G, Cottier B, et al. Towards evidence-based guidelines for radiotherapy infrastructure and staffing needs in Europe: the ESTRO QUARTS project. *Radiother Oncol* 2005;**75**:355–65.
31. Valentini V, Bourhis J, Hollywood D. ESTRO 2012 strategy meeting: vision for radiation oncology. *Radiother Oncol* 2012;**103**:99–102.
32. Malicka A. Analysis of a patient environment during stay in a hospital. *Zesz Nauk Polit Pozn Arch Urban* 2012;**28**: 81–96.
33. Malicki J, Bly B, Bulot M, et al. Patient safety in external beam radiotherapy – Guidelines on risk assessment and analysis of adverse error-events and near misses: Introducing the ACCIRAD project. *Radiother Oncol* 2014, http://dx.doi.org/10.1016/j.radonc.2014.08.011. Available online 19 September.
34. *Patient safety in external beam radiotherapy – guidelines on risk assessment and analysis of adverse events and near misses*; 2013. www.accirad.eu
35. Radiation protection no. 159. European Commission guidelines on clinical audit for medical radiological practices (diagnostic radiology, nuclear medicine and radiotherapy). 2009 Directorate-General for Energy and Transport Directorate H – Nuclear Energy, Unit H.4. http://ec.europa.eu/energy/nuclear/radiation_protection/doc/publication/159.pdf
36. *Comprehensive audits of radiotherapy practices: a tool for quality improvement: Quality Assurance Team for Radiation Oncology (QUATRO)*. Vienna: International Atomic Energy Agency; 2007. http://www.pub.iaea.org/MTCD/publications/PDF/Pub_web.pdf1297