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Editorial

Adapting training for medical physicists to match future trends in radiation oncology☆

1. Introduction

Radiation oncology is a field with constantly evolving technological developments, both with respect to planning and delivering treatment, and it is therefore essential to adapt the training in medical physics to these changes. Automation is increasingly being introduced into radiation oncology processes, and hence there is greater reliance on computing capability and power. We are learning how to better predict treatment outcomes and the risks of morbidity and treatment failures by modelling with available data we already have. In radiation oncology much of our ability to predict and measure outcomes is based on imaging and the quantitative information it can give us. However, the field is also diversifying and increasing in complexity and therefore we will also need leaders who have a vision to progress as effectively as possible, who are prepared in a constructive way with the other disciplines, learning how to cope with change and new knowledge whilst maintaining physics knowledge. Future training will need to consider how this can best be incorporated to ensure that the education of medical physicists in radiation oncology is most effective in this continually developing field [1–3], see footnote. Here we consider some of the topics which might need to be incorporated to optimally equip the next generation to be the most effective radiation oncology physicists of the future.

2. Imaging

In recent years, radiation oncology has been making more and more use of complex 3D- and 4D imaging technologies, such as computed tomography (CT), magnetic resonance imaging (MRI) and positron emission tomography (PET) to improve treatment planning and radiation delivery [4,5]. Even though CT-based planning is considered standard of care today, a multitude of research programs has been and currently still is under investigation to unravel the full potential of modern imaging technologies. These focus on accurate target volume delineation, daily target volume assessment and offline or online adaptation, as well as for response assessment and adaptation before, during and after fractionated radiation therapy [6]. Several recent studies have shown the potential of using CT, MRI and PET imaging for improving target volume delineation for radiotherapy treatment planning [7,8]. Multi-parametric imaging information from PET/CT or PET/MRI contains different layers of information which can be combined using novel machine learning methods to automatically generate target volumes in a robust manner [9,10]. Furthermore, plan adaptation according to daily position of target volume and organs at risk (OAR) can be effectively performed using cone beam CT (CBCT) or MRI available at the treatment machine [11]. Depending on the anatomical position, 4D-imaging to account for intra-fraction motion may be required to provide the technology for online adaptive image-guided radiation therapy [12–15]. Finally, a number of studies have identified multi-parametric functional imaging as an ideal tool to assess dedicated molecular biomarkers containing information about biological characteristics or response prognosis with respect to outcome [16–19]. Here, quantitative imaging methods are required to ensure multi-centre comparability of data and guarantee a robust basis for future interventions based on those biomarkers, such as dose painting [20–22].

Imaging plays already today a major role in radiation oncology contouring, treatment planning and response prediction [23,24]. Consequently, errors in image acquisition and quantification may have direct impact on the accuracy of radiation oncology application and delivery. Therefore, it is extremely important to standardize image acquisition protocols, image analysis tools and methodologies used to integrate imaging information into treatment planning and delivery [25–27]. Integrating basic education and knowledge about modern imaging technology, physics principles of image formation and acquisition as well as state of the art tools for image post-processing and analysis will be crucial in the training of future medical physicists specialized in radiation oncology.

3. Computational methods and automation

Undoubtedly, technology and physics have been at the basis of most of the major breakthroughs in radiation oncology in previous decades. Some of the most important advances were intensity modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT) with inverse planning, and novel image-guided (IGRT) approaches, first with electronic portal imaging devices and CBCT and currently also with integrated MR-linac systems. Advanced dose calculation algorithms have been developed for highly accurate dose calculations in patients, and as for most technological successes, computational innovations have been of major importance. In the 1980's Anders Brahme and co-workers developed the principles of IMRT [28,29]. Initially, clinical applications seemed far away as the required inverse planning

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☆ At the ESTRO 38 meeting in Milan in April 2019 the physics track held a debate entitled 'In 10 years, physics will need different training to include more….'. The aim was to horizon scan and look at the different key topics which physicists of the future would need to be better trained in. Five debaters put forward their cases for more training in imaging, automation, biological modelling and big data, management and leadership and finally argue that a solid understanding of fundamental physics is now even more important than ever. The idea for this paper stemmed from the arguments and discussions put forward during that debate.

was computationally too expensive for clinical use. However, developments in optimization and delivery techniques paved the way for mainstream adoption, facilitated by developments in computer hardware and software, from the mid 1990's [30].

Currently there are many new exciting research areas in radiation oncology physics with indispensable computational components that will definitively further revolutionize radiotherapy, probably even more than before. These include automation of treatment planning [31], adaptive radiotherapy, MR-linac systems [32], biological and functional imaging [33], dose painting [34], radiomics [35], dosiomics [36], and predictive modelling [37]. There is also a wide range of topics investigated with artificial intelligence (neural networks, deep learning [38,39]), including segmentation of tumors and OARs [40], pseudo-CT generation from MRI [41], dose prediction for treatment planning [42], patient-specific quality assurance [43], real-time respiratory motion prediction [44], and prediction of treatment response [45].

Results of these novel computational developments are already entering the clinics. There are excellent opportunities for medical physicists to contribute to the research. However, more in-depth training in computational radiotherapy physics for young physicists will become mandatory in order to avoid a clearly undesired introduction and clinical use of new applications as black boxes. It is impossible to predict in what directions the computational research will move and what will in the end be successful in terms of clinical use and what will not. For this reason it is important that the required training in computational methods is broad, i.e. it should not have full focus on only a single radiotherapy field such as imaging or planning.

4. Biological modelling and big data

Thorough knowledge of the radiation dose response for tumours and involved normal tissues is the foundation of all radiation oncology practice [46]. The dose response curves are the result of radiobiological modelling studies, which depend on the collection of solid clinical data (with information about the treatment such as doses and volumes and other factors for the x axis, and patient outcomes on the y axis). This is an inter-disciplinary research area where physics meets biology, clinics and statistics, and where medical physicists play a major role. Obviously, these curves also depend on what we typically consider as 'classical' medical physics: Our efforts in the field of radiation dosimetry ensure that the data points behind these curves are correctly positioned on the x-axis. Also, classical medical physics research to develop new treatment strategies are important as they define the position of these curves relative to each other, and they are also important since new modalities might have 'new' biology (e.g. spatial effects in normal tissues [47–49], radio-biological effect studies for protons [50].

Medical physicists clearly have a natural 'talent' for data analysis, i.e. we have the appropriate background, to be the professional group in radiation oncology that takes responsibility for this. We can describe relations with equations i.e. models with tunable parameters, that can be fitted to data. We can perform computer simulations to explore models, or we can fit data to models using complex methods. It is important that medical physicists acquire knowledge and practical experience in analysis of the real-life data that radiation oncology and medical physics is so full of, in their basic physics training.

Recent and current radiobiological modelling studies are trying to expand on the relative simplistic approaches of the previous tumour control probability (TCP) and normal tissue complication probability (NTCP) models. It is being recognized that dose and volume alone (such as in the classical LKB NTCP model) are insufficient to predict risk with good precision at the individual level [51]. Other factors need to be taken into account, while we are also expanding the dose/volume parameters to reflect that they are not static, but that they are changing intra and inter-fractionally [52]. This is an exciting area for medical physics research.

We are entering into the era of 'big data', with potentially huge changes for radiation oncology. The 'big data' push has the potential to considerably widen our knowledge of dose response relations by making treatment and outcome data from large number of patients (both inside and outside clinical trials) available for predictive modelling building. However, there are also challenges for us in this field. 'Data mining' is often spoken of, as if the data was already lying around waiting for us. However, the more appropriate term is probably 'data farming', since it requires a lot from us to actually obtain data that can be analysed in a meaningful way [53]. A large number of big data initiatives are available [54] many being institution specific, while others are groups of centres treating certain diagnoses (e.g. pediatric cancers) or large groups such as the Radiogenomics consortium, involving more than 100 institutions. However, challenges exist in terms of responsibilities and the legal issues surrounding data sharing.

There are therefore considerable changes ahead for scientists and physicists involved in model development. However, there are also changes for those that will use these models. The focus on personalized medicine might change the way we use predictive models, from being an internal tool, to being part of a decision-support systems that will be used by professionals together with patients. Big data or radiomics based models will require a new level of standardization, well beyond using the same definitions of target volumes and the same normal tissues delineation protocols. In particular, this relates to a number of aspects of imaging, including endpoints derived from quantitative imaging. Radiobiological models based on radiomics and/or big data are already available [55], and as such, they are already here ready to use. Medical physicists should maintain a strong involvement in the field of big data, primarily for the benefit of the radiation oncology patients we are treating, but through that also for the benefit of our medical physics profession.

5. Leadership

Medical physicists will only have the capacity to define our own professional role, if we are properly positioned to do so. In this regard, our professional future may depend on having professionals from our field in key leadership positions within the health care field and even in government bodies. This is crucial, as only medical physicists are fully aware of the critical importance of our speciality in the treatment of cancer, which is why we must be closely involved in decision-making about the future of our discipline [56].

Having medical physicists in key leadership positions would be highly beneficial to the field, as these professionals would have the ability to influence the allocation of human, financial, and technological resources and in defining the role of medical physicists. If we wish to have a say in discussions of the future role of medical physicists, it is essential not only to train these specialists, but also to foster a greater interest in becoming involved in management [57].

Given the need to develop a future generation of leaders willing and able to assume positions of importance within hospital management or governmental and non-governmental health care bodies, the question is how to achieve this. Clearly, the first step is to incorporate management and leadership skills training (including communication skills) into the graduate and/or postgraduate curriculum. Professional bodies should also provide training opportunities for both new and experienced professionals. We also need to begin to speak openly among ourselves about these aims, and to develop a support system to foster the development of new leaders.

Hence a major training–related need is to develop strong management and leadership skills among the next generation of medical physicists, which would allow these professional to assume leadership roles in the broader health care field. This will allow medical physicists to obtain leadership positions in the health care field, where they can be visible advocates for our profession to positively influence the direction of this field. To ensure the future of our field, it is essential that we provide quality training in management, leadership, and communication skills.

6. Fundamental physics

Fundamental physics skills, which once were considered the most obvious pillars of medical radiation physics, do not seem to go through the same renaissance as these above-mentioned topics. However, there is urgency for understanding how to correctly use the new technologies and software from radiation delivery equipment (often coupled with imaging equipment) to treatment planning software to quality assurance packages. This together with the requirement to perform both professionally and effectively enhances the importance of medical radiation physics competence together with solid fundamental physics skills as an ever-crucial component of the education path of the future.

The development of Stereotactic Body Radiation Therapy (SBRT) in the early 1990's, is one of the iconic examples of the perfect match between physics skills and radiation therapy [58]. An analytical study of the SBRT geometry, the ability to provide a conformal heterogeneous dose distribution, the set-up and reproducibility issues solved by the stereotactic body frame with the repeated use of CT images are just some of the features of a main paradigm shift in radiation oncology.

Another example of radiation therapy science where physics knowledge has been fundamental and will continue to be a main requirement is in treatment planning. Even though as clinical users we do not need to know all details about algorithms, the understanding of a good accelerator model together with the understanding of the main features of various algorithms (e.g. the collapsed cone algorithm, linear Boltzmann transport equation solvers or Monte Carlo algorithms) is crucial. This will make the difference not only in how we best select and use treatment planning systems but also in how we assess their performance in quality assurance procedures [59] and in the way we teach others how to use them.

Proton and particle therapy, which is now becoming routine in several centres, represents another field where several skills are required, underpinned by fundamental physics knowledge. The possibilities given by proton and particle therapy are multiple, summarized by the energy deposition characteristics of protons, which can provide clinically favourable dose distributions in comparison with photons, including considerable reduction of integral dose [60]. The field is complex and still in need of further development not least in imaging, treatment planning, treatment delivery and delivery technology, in all of which technological and physical components are essential [61,62].

Other innovative steps in radiation therapy are already under preparation; as an example a non-rotating hadron therapy gantry which bends the treatment beam without the need to rotate the structure is under development at CERN [63]. It is premature to predict the outcome of this project, but the relevance of how different competencies in physics mutually interact to produce new ideas has to be kept in mind. Therefore, skills in fundamental physics continues to be an important component of training of medical physicists in radiation oncology, thus maintaining a thorough understanding of radiation fields and the interaction with human tissues.

7. Discussion

The correct and safe use of the complex equipment and technology that are available in radiation oncology departments requires several skills. The radiation oncology world is continuously influenced by the developments in contemporary sciences, from software science to artificial intelligence, to computational methods, to imaging science, beyond the increased knowledge brought about by decades of experience and data analysis in the field. Additionally, the increased complexity in organization issues, not limited to the radiation oncology service, has also made managing skills a specific discipline which requires to be understood in order to run a department effectively.

The field of health care, including radiation oncology is expected to experience significant changes in the coming decade. All associated professionals, but particularly those in medical physics, in which technology plays a crucial role, must be prepared to adapt to these changes, which will require extensive, ongoing training in many areas. In the context of medical physics education and training, it is important to consider that medical physicists in different environments have different roles [64]. The majority of medical physicists are doing routine clinical work in hospitals. The training and professional development needs of these medical physicists are very likely going to be different from the ones doing full-time, 'cutting-edge' research [64]. The challenges of being closely involved in research while staying close to the clinic has also been discussed recently [65]. Obviously, it is also important to consider that these things are not static. A medical physicist today is not doing the same tasks as he or she did ten years ago, and these changes will continue in the future. The core curriculum for training of Medical Physicists in Radiation Oncology in Europe was first published in 2004 [1], was updated in 2011 [2] and soon the process of a further revision will be started. The new core curriculum will need to reflect these changes and be ready for the future.

Imaging plays a key role in diagnosing, treating and following up for cancer treated with radiotherapy and the use of imaging will only expand. Furthermore, the use of quantitative imaging is still in its infancy and this is an area where physicists will play a vital role. Automation is an area which is expanding across all walks of life, not just radiation oncology; however it is already clear that it will play a big role in streamlining and standardising treatment. Biological modelling and big data will allow us to take the field of radiotherapy much further towards personalisation with the ability to more accurately predict outcomes for individual patients before treatment commences. Leadership skills are becoming more and more recognised as crucial in getting the best from the workforce in terms of their development and the ability to identify the key strategies which will take the field forward effectively. It is also important to ensure that the profession has a high profile in order to best communicate with other disciplines where the medical physicists can play a priority role. However, whilst considering all these changes, we must not lose sight of the fact that physics underpins most of radiation oncology in one way and another and therefore ensuring that our profession maintains and attracts the strongest physicists will ensure the success of our discipline.

It is impossible to be a master of all the topics debated here, so a key factor in building and training the most effective workforce of the future will be in determining which skills will be needed by everyone and what should be specialised topics which need training at a higher level. The revision of the core curriculum should take this dilemma into account and try to future proof the training to address these issues.

From the arguments given above the future of radiation oncology is exciting and there is expansion in a wide range of different areas. The role of medical physicists is as crucial as ever and the training must reflect the different skills which will be needed to contribute to both the research and the clinical implementation of the techniques of the future.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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