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Integrating Advanced Physics and Medical Physics: Innovations in Imaging and Radiation Therapy for Personalized Cancer Treatment

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Annotation: The integration of advanced physics into medical physics has significantly enhanced cancer imaging and radiation therapy, leading to more personalized and effective treatments. However, challenges remain in optimizing imaging techniques and radiation dose delivery for individualized patient care. This study explores innovations in medical imaging and radiotherapy, focusing on computational models, multi-modal imaging, and advanced radiation response modeling. Findings indicate that integrating patient-specific imaging data with computational physics enhances treatment precision, reduces radiation toxicity, and improves patient outcomes. The results emphasize the importance of interdisciplinary collaboration in medical physics to further refine personalized cancer treatment strategies, paving the way for cost-effective and adaptive therapy approaches.

Keywords: Medical physics, cancer imaging, radiation therapy, computational modeling, personalized treatment, interdisciplinary collaboration.

1. Introduction to Advanced Physics in Medical Applications

There are numerous advanced physics innovations and modern engineering technologies contributing tremendous benefits in medicine and healthcare. They significantly improve the detection, treatment, and prevention of diseases, shifting the traditional medicine model to a more personalized and accurate one. Integrated circuit chips, biomedical engineering, comfortable MRI, positron emission tomography (PET), nanodevice, and nanomaterials, and other advanced physics innovations and modern engineering technologies have been widely applied in clinics. Tumor markers, genomics, radiogenomics, single cell analysis, microarray detection, and other biological models, can classify the patient into different subtypes before treatment, determine which patients would benefit most from a proposed therapy, predict the prognosis of each patient's disease, and discover the altered biological pathways that lead to malignant transformation, which would benefit for guiding the choice of treatment of today's diseases.

A fast-acquiring area of advanced physical and engineering models in medicine is in imaging and radiation therapy applications. Finding the balance between delivering sufficiently high doses to the tumor and limiting the dose to healthy organs is one of the primary objectives of radiation therapy treatment planning. Innovative techniques which combine imaging or sensors to determine and monitor the actual dose deposited in the patient are of high interest to the medical physics and radiation oncology community. Modern imaging technologies are currently being incorporated in linear accelerators and treatment planning systems, providing powerful tools for patient positioning, patient modeling, and treatment control. The technical state-of-the-art of imaging that offers a high potential and presents several possibilities for exploitation in radiation therapy planning and delivery optimization is positively assessed and crossed modalities between planning systems and imaging modalities are likewise favorably viewed [1]. The subject can be approached both from the viewpoint of the many types of cancer that can be treated and from the perspective of the several innovative technologies being developed in the field [2].

1.1. Overview of Medical Physics

Medical Physics is the application of the concepts and methods of physics to the medical professions and there are many areas within general physics that are extremely robust and well developed and are yet to have a substantial impact on the medical world [1]. Of all the professions within the medical world, the field of cancer treatment has perhaps most effectively adopted these methods and technologies; 70% of all diagnostic images come not from hospital x-ray departments, but from radiotherapy treatment simulators. The most powerful computer in use in the medical world is at CERN where they model head collision to predict the need for surgery in cases of severe epilepsy and the software is a modest code using the physics of stress and strain that has proved to be more complex than the vast majority of codes used in cancer treatment planning. The specific subjects of physics that are covered here are intended as a tutorial for those in the medical physics profession (radiation oncologists, radiology oncologists, radiotherapists, dosimetrists), and for the more curious in the general physics world (biophysicists and students) who wish to see a detailed description of what is a major application of a broad range of physics disciplines. A list of physical journals relevant to the topics discussed here is contained further on in the text. What is not intended here is to cover all aspects of medical physics but to rather cover some detailed components within the field. Specifically, these are: • Selection of beam directions (or irradiation portals) in external beam therapy treatment planning • Treatment optimization within a broad range of treatment delivery systems and types • Portal imaging / treatment verification of moving radiotherapy fields • Tomotherapy delivery units • MRI as a therapy tool and its potential use within a therapy context • MRI as an enhanced modality for computer therapy planning use of advanced MRI sequences in therapy delivery / verification. In the future, however, by the end of this decade changes are expected that will make the current state of affairs appear quaint. At least some of the aforementioned factors potentially impeding progress of the nascent alliance between MRI and RT are expected to be less of a barrier in the days to come. In large part, this will be due to improved communication between the RT and MRI communities. Because the requirements of both communities are as yet largely misaligned, this will necessitate changes of custom among members of one or both communities. Thus, it is likely that, just as MRI has benefited from development specifically tailored to oncology to date, the RT community will either see more equipment and methods targeted to broader needs or broader training and facility alterations to gain benefit from advanced MRI [3]. Given an acceptance of these caveats on applicability, the expectant future is bright for the use of MRI to inform and support electrical optimization in the context of RT.

1.2. Fundamental Principles of Advanced Physics in Medicine

Western medicine, mainly based on anatomy and physiology, pathogenesis and other basic sciences as theoretical guidance, is a discipline that applies current relevant scientific knowledge and technology and is broadly guided by the precaution and treatment of diseases. Advances in physics technologies are crucial for the great progress in many fields, e.g., mathematics, mechanics, and celestial science. Medical physics undoubtedly plays an essential role in better preventing, diagnosing, and treating diseases, especially in western medicine. A great deal of the existing imaging and radiation therapy (RT) origins from physics technologies, such as X-ray, computed tomography (CT), magnetic resonance imaging (MRI), positronized tomography (PET), single-photon emission CT (SPECT), linear accelerator (Linac), and brachytherapy (BT). Moreover, today it is also very common for medical physicist or biomedical engineer to research in advanced physics and medical physics (APMP), e.g., biomechanical modeling of cancers for training in merging symptom, pioneering imaging for the follow-up in real-time observation, quantifying physical properties of the inferior or interior organ, and exploring high-dose effects of heavy particles for highly conformal RT [2]. Personality physics therapy based on APMP technologies certainly expects very compassionate dedication to individualized or personalized cancer treatment in a natural and axial approach.

2. Imaging Techniques in Cancer Diagnosis and Treatment

In the last two decades, there have been major advances in medical imaging technologies. Medical images are being explored in the hope of identifying the properties of an individual tumor that can be used to predict overall survival, recurrence risk, dissemination and potential responses to treatment. Nowadays, combining advances in image processing, machine learning, and high-performance computing, millions of features can be automatically extracted from image datasets spanning multiple scales. Radiomics refers to a new field of analysis based on unique numeric descriptors derived from extensive medical image datasets. By summarizing hundreds of features with a unique combination of advanced statistical tools, radiomics can provide multidimensional structural and textural assessments beyond conventional imaging. Likewise, as the use of molecular biomarkers is considered to be essential for modern precision medicine, the use of treatment-integrated imaging was developed to combine information obtained from functional imaging with metabolic or perfusion image descriptors with standard radiotherapy planning datasets. Specific descriptors for RT planning are being developed to be included in radiomics analysis, as it is demonstrated that they are relevant for prognosis and can also be used to predict areas of relapse after radiotherapy. In the near future, including the planning of the therapy process, the individual characteristics of the radiotherapy process, as well as the time and sequence of the treatment should be included [4].

2.1. X-ray Imaging

Although Wilhelm C. Roentgen discovered X-rays 124 years ago and they played a crucial role over the following century in the diagnosis and treatment of many diseases, new research in this field reflects attempts to explore these dinosaurs of modern medical imaging from lesser known angles. Possibly the most important unresolved issue—and certainly one with potentially greatest impact on both imaging and radiation therapy—is the question of whether the integration of imaging and treatment will eventually allow the use of the same machine to visualize body structures and deliver radiotherapy [4]. This journal devote most of its content to the former subject, yet imaging in oncology feels incomplete without discussing more closely related applications. The immediate justification for the focus on X-rays in that paper is the fact that traditional photon beam accelerators have already taken steps in this direction by incorporating various X-ray imaging modalities, including both kilovoltage and megavoltage X-ray devices. Due to this development, not only therapeutic planar beams, but also straight-on megavoltage X-ray imaging is employed in radiotherapy treatment rooms. The appeal of this approach is that structures undergoing periodic movement (e.g. lungs) can be imaged exactly at treatment delivery. Although not all structures (e.g. soft tissues) can be visualized with X-rays, there nevertheless exists a variety of sites amenable to observation with mega-voltage beams, such as breast, lung, prostate or bone tumours. It is on such cases that virtually all relevant dosimetric and localization verification investigations have been conducted. Recent years have seen a more ambitious approach—that of employing other imaging modalities for treatment verification. One such possibility is the use of magnetic resonance imaging (MRI), which is particularly attractive in soft tissue radiation therapy where high density contrast is lacking. To this end, linear accelerators incorporating an MRI device have been developed and installed in an increasing number of clinics. The matching arrangement allows to discern such lesions from other sites, leading to meticulous irradiation of the former.

2.2. Computed Tomography (CT) Scans

When a patient is diagnosed with cancer, the patient's condition is assessed, and the best available treatment is recommended. Surgery, chemotherapy, radiation therapy, immunotherapy, targeted therapy, hormone therapy, stem cell transplant, PrRT, etc., may be chosen. Treatment effects may be evaluated by imaging performed after or during the treatment. Knowing the evidence of imaged treatment effects, the treatment may be continued without change due to treatment effect (pseudo-progression). However, high-quality studies demonstrate that when there is new enhancement 'outside,' pseudoprogression predict progression and not treatment effects in practical terms [4]. Thus, patients with low-grade glioma patients with progression based on enhancement need to have treatment changed. Hence the threshold for treating such patients is very low, particularly since the treatment may be as simple and relatively nontoxic as corticosteroids.

Recently a phase III national study examining whether treating patients diagnosed with radiological progression based on RANO criteria with corticosteroids is superior to treating based on Enhancement Lesion Volume and/or Volume Adopting Threshold while maintaining QoL was opened. At least one of the inclusion criteria is Grade I or II glioma prior r/s treated with at least 60 Gy XRT. The primary endpoint is LOC between 60 and 200 days from study entry.

2.3. Magnetic Resonance Imaging (MRI)

The integration of advanced physical sciences with biomedicine is a growing field that seeks to exploit developments in fields such as physics, engineering, mathematics and information technology to improve healthcare. There are considerable opportunities for better integration of medical physics with new advances in more fundamental aspects of physics and the physical sciences. This paper demonstrates the innovative capabilities that have emerged from the application of advances in physics to two areas of cancer care. The first is the use of novel physical technologies to develop a new approach for Magnetic Resonance Image guided radiotherapy and the second is the use of the pseudomorphic manipulation of the complex amplitude of radiation fields in the patient to generate complex radiation dose patterns, or dose sculptures.

Magnetic Resonance Imaging is renowned as an imaging modality that generates high soft tissue contrast from the massive polarisation of nuclear spins in strong magnetic fields. MRI scanners are typically sited in radiology departments rather than radiotherapy facilities, with traditional linear accelerators in radiotherapy departments able to generate strong beams of external x-ray radiation, relevant for both therapeutic treatments and imaging processes for verification of patient's set-up. As the development of radiotherapy continues, it is natural to consider whether the full promise of MRI in treating the most radioresistant cancers with the most advanced forms of targeted radiotherapy has yet been exploited. One area that promises ground-breaking therapy development and one where MRI has been at minimum exploitation is cobalt 60 tomotherapy, a fact that is emphasized by the installation of MRI on a tomotherapy unit. In a new departure, the development of Cobalt Adaptive Radiation Therapy continues to unfold. Central to the proposal is to explore an MRI thick rescale for Adaptive Cobalt Tomotherapy with the possibility of a clinical implementation. In relaxometry, MRI technology is sufficient to deliver voxel distribution of relaxation times, which correlates strongly with biochemical characteristics of normal and pathological tissues. MRI is employed for treatment planning measurement of tumour functional parameters when treating with helical tomotherapy. They hypothesise that the use relaxometry parameters as a measure of tumour growth in the probabilistic selection of tolerance dose will favourable translate this to improve patient outcomes.

2.4. Positron Emission Tomography (PET) Scans

Positron-emitting isotopes decay largely by emitting a positron that travels up to a millimeter from its point of emission. Then the positron is annihilated, giving rise to two gamma photons that are emitted in opposite directions. By detecting these photon pairs, the line of response can be shown to pass through the isotope activating the pair of detectors that recorded the coincident photons. The situation is well-suited for nuclear medicine imaging tomography. A tomographic image can be reconstructed in two ways. One way reconstructs planar transaxial images; these are then stacked to recover three-dimensional information. Alternatively, three-dimensional computer reconstruction can be used, but the information contained in such images is rather hard to interpret [5]. In practice, because mechanical stability is important, PET detectors are grouped and held rigidly to form planes that can encompass a part of or the entire body. Modern PET cameras have detectors made from scintillation crystals, usually coupled to large area position sensitive photomultiplier tubes. Ultrasensitive detectors of this sort start to become nonlinear in the range of 107–108 detected coincidences per second. There are cameras with about 10,000 such detectors, meaning that the maximum number of single photon detections that can be recorded simultaneously is 108. It is best if the irradiating dose of the patient stays lower than 200 mSv. Since the typical activity of the isotope is on the order of 100 MBq, a large fraction of the emitted photons is not registered. This involves some loss of overall information, which manifests itself, for instance, in poor noise levels and low counting statistics. There are methods for the correction of such losses, but they are not perfect. PET cameras actually measure a quantity proportional to the photon attenuation coefficients of the traversed tissues. By a number of assumptions, from this measurement estimates of the isotope distribution can be obtained. Split between the emission and transmission scans, whole body PET examination takes approximately two hours. Analogously as in single photon ECT, use can be made of CT scans of the transversal sections. These provide information on the attenuation of photons and can vastly improve the quality of the reconstructed images [6].

3. Radiation Therapy in Cancer Treatment

The use of ionizing radiation for treating cancer has undergone extraordinary development over the past hundred years. The clinical use of X-rays to treat tumors did not begin until the early twentieth century. A century of advances has transpired including the study of radiation physics, the understanding of DNA lesion repair, the advent of the rapid computer, and insights into the molecular biology of cancer. One of the most important implementations in radiation oncology was the development of computerized treatment planning systems [7]. With the advent of powerful, faster, and less expensive computers, advanced planning systems (APS) can now produce three-dimensional (3D) techniques of high precision and accuracy. Those systems have been developed a commercial way, commonly known as 3D conformal systems. In this scenario, advanced physical techniques are interesting means to achieve better results in terms of the dose distribution and normal tissue avoidance.

Current radiotherapy practice is at a turning point, mainly due to novel equipment for treatment delivery and the study of computed treatment planning systems (TPS). That calls for a complete review of different radiotherapy aspects from physical, biological, and medical physics perspectives. Two major recent steps forward in radiotherapy are Intensity-modulated Radiation Therapy (IMRT) and Image-guided Radiation Therapy (IGRT). These advanced techniques require more complex commissioning equipment, skills, and quality assurance (QA) procedures, demanding a development of advanced medical physics applications in the field. As a result, to address these issues relevant to medical physicists there is a need for a deep understanding of the basic concepts upon which an advanced knowledge can be built and at the same time reduced to clinical grounds in order to exhibit an overview intended as a concise guide for a prompt understanding of the essentials.

3.1. External Beam Radiation Therapy

Radiation is currently the most commonly used treatment modality for cancer. The principle of radiation therapy relies on the exposure of the tumor to ionizing radiation (including X-rays, γ-rays, protons, and electrons) causing genetic mutations and multiple cell death mechanisms, eventually resulting in the killing of cancer cells. With the more advanced methods of delivery developed over recent years and a far better understanding of mechanisms responsible for cancer cell death and normal tissue toxicity, radiation therapy is currently far more sophisticated than ever before and is delivered with millimetric precision. As a matter of fact, radiation therapy (before surgery) often increases the precision of the most complicated major operations with curative intents. However, its capabilities and potentials are widely under-recognized and under-utilized amongst oncologist and patients. In the current review, the advances in so-called “technology” (i.e., the “tools” facilitating the delivery and assessment of radiation), which will be overarching and underpinning the augmenting importance of a proportionately synonymous merger between Advanced and Medical Physics, will be introduced in a plethora of applications, which broadly fall into a more or less comprehensive diagnostic, therapeutic, and follow-up scheme [8]. Some specific disease applications (primarily cancer due to the centrality of the topic within oncology) will be discussed as well. The review spans across not only conventional external beam treatment (i.e., treatment of diseases with a treatment machine) but every CG where such an interface can be, and has been, delineated (didactic and prosaic techniques are introduced when needed). Further novel insights are provided, heavily hinted by some of the latest revolutionary tools that are emerging at the cutting-edge of APS & MP and other related sciences. Such a propagation and implementation will lead to a paradigm shift in the treatment philosophy, posing the future as a realm of unique personalized medicine, with patient cases being fine minutely assessed and treated with what is best due to their genetic/map imprint.

3.2. Brachytherapy

The potential role of functional imaging in radiation oncology can be broadly divided into four main areas [9]. First, functional imaging is emerging as a powerful technique in radiation treatment planning, assisting in the definition of the tumour and in the definition of the target volume. Moreover, size and shape of the volume of high activity of FDG-PET image could be used in the definition of prescription isodose. Second, functional imaging would help in the modulation of the dose to the target volume. For example, hypoxic tissue detected by [18F] FMISO-PET could be spared of a high dose considering that hypoxic tissue usually correlates to an increased radioresistance. Third, functional imaging can be used in the assessment of radiobiological processes during and after irradiation with ionizing radiation. For example, for [1H] magnetic resonance spectroscopy measurements, the result is increased choline and decreased N-acetylaspartate, which would persist for several months. Fourth, functional imaging can be utilized for in vivo predictive testing and in the assessment of the response to radiation therapy of solid cancers. It is possible to envision a clinically viable algorithm for the in vivo imaging of sub-volumes to guide the design of a 'dose painting' treatment plan in order that all sub-volumes receive a tumoricidal dose. This same imaging could then be used for subsequent treatment adaptation for recurrent disease, whether this is further brachytherapy or EBRT. Brachytherapy will offer the intrinsic advantages already mentioned. The dose distribution to the tumour is very steep. The high dose region is limited to a few millimeters. A further advantage is that radiation is delivered from within the target and, as opposed to external beam radiotherapy, very little normal tissue will be irradiated. Early stage prostate cancer is a disease of the elderly. Many of these patients have severe co-morbidities. In many of these patients a solution with anticoagulants is used. However, the rate of major hemorrhages after trans-rectal ultrasound trans-rectal biopsy among patients receiving anticoagulants is unacceptably high. Additionally, although radiation therapy is generally considered to be the treatment of choice for a significant proportion of men with clinically localized prostate cancer, there is a recognized underuse of it. This underuse may be due, in some instances, to the perceived lack of appeal of treatment involving implantation of radioactive sources in the prostate. Nonetheless, brachytherapy has reached a high level of sophisticated engineering of materials and devices. Safe and accurate insertion of radioactive sources in the desired location throughout the prescribed treatment schedule can be guaranteed. Improvements in the design of radioactive sources have been warranted by advances in modern manufacturing technologies.

3.3. Proton Therapy

Proton therapy has been in the medical community for over 40 years. With the development of new and more advanced medical accelerators and imaging devices, the community is now prepared to learn from proton therapy, to help its adoption and to integrate its development with the use of proton imaging and detectors of in vivo dose. Proton therapy is undergoing a swift evolution with the construction of a number of new facilities. Frontiers of this evolution are in imaging (proton CT, also for treatment planning), in advanced acceleration systems and in advanced dose delivery systems, such as the RapidArc system. The successful and safe treatment of intracranial neoplasms, particularly in children, has popularized proton therapy in the past two decades. The success and convenience of proton therapy treating brain cancer has motivated the extension of this medical modality to the treatment of: head and neck tumors (where the benefits of proton therapy are dramatic and well established), thoracic and moving tumours (here the main application is aided by RapidArc therapy and is aimed at enhancing the internal margins), breast and metastases. Dosimetric plans and measurements on a range of phantoms and patients show that protons allow significant benefits with respect to classical x-ray therapy and reduce the problem of second tumours, which is of crucial importance in paediatric treatments [10]. Performing these studies, the medical community focused on ID and Range effects and developed the concept of the distal and proximal conformation number.

Personalized treatment will become more widespread with the construction and use of clinical particle accelerator facilities, producing proton and carbon ion treatment beams. Protons account for 90% of all particle treatments. Particle beam delivery is more complex than conventional x-ray conformal therapy. A number of proposals are under development for the clinical use of prompt gammas, either from nuclear capture or from nuclear disruptions, to verify target position and dose after delivering a treatment. After the technology for efficient acceleration of protons, carbon ions and other light ions became established in centres in the early 1990s, the interest started to shift to medical therapy, either with the spread-out Bragg Peaks for proton or carbon ion treatment, performed in multiroom centres, or with the use of neutrons, protons and Li-Be ions issued from 7Li ions at 80 MeV/u and used to tackle large deep-seated tumours in treatments with the so-called Boron Neutron Capture Therapy.

3.4. Stereotactic Radiosurgery

Cancer treatment has significantly improved because of the advancements in diagnostic technologies, treatment machines, and therapeutic techniques. The development of the gamma knife opened a completely new window in which the application to stereotactic radiation techniques could be possible due to the developments in diagnostic systems [11]. Development of the gamma knife, and further the accuracy in positioning the patient has led to the potential growth of the planning, designing, and commissioning processes and systems. As a result, there is a progress on the design and implementation of radiotherapy, radiodiagnostics, and radiosurgical systems. Dosimetric analysis of several radiation treatments is essential in order to assure the reproducibility of treatments and expected results. Thus, measurements obtained must meet the required criteria. However, for accurate treatment planning, radiation transport calculation devices should be used to model the patient, radiation sources, and multileaf collimators as close to reality as possible. This, in the meantime, ensures the implementation of advanced radiation planning systems including beam shaping optimization, Monte Carlo calculations, and biological evaluations.

Stereotactic radiosurgery implications on telecobalt systems are illustrated both theoretically and experimentally. The feasibility of applying a telecobalt unit, equipped with a small stereotactic attachment, to the gamma knife radiosurgery planning system is shown. Absorbed doses in the brain tissue are calculated using a hypothetical gamma knife system and a prototype telecobalt radiation surgery's system. Measurements were carried out with polymer gel dosimeters and results are presented. It is concluded that in principle, radiochirurgical treatment with both systems seems practical, offering high conformity index values to the treated volume, Vt.

4. Innovations in Radiation Therapy Technologies

Radiation therapy is a mainstay in cancer management, and technological advances in imaging and radiotherapy are synergizing to make headway towards precision, personalized, and biologically effective treatment. These converging fields give the promise of delivering a high radiation dose with a sharp penumbra to well-defined targets, with the potential for altered fractionation and adaptive strategies in response to inter-fractional changes in the patient anatomy and in the response of tissues (e.g. the tumour and normal tissue). Potential examples of technology developments that may improve assessment of treatment response include biologically weighted imaging methods, metabolic imaging to assess hypoxia, metabolism and distant spread, imaging to quantitatively assess treatment response and tumour proliferative potential. Early phase clinical trials are evaluating a range of radiation therapy regimen specifics, including image-guided adaptive radiation therapy (ART) regimes and exploring the utility of additional targeted systemic therapy concurrently with radiation therapy. A thought-provoking paper proposed backward studies to forward model the intervention to the most suited patient, thereby "turning the question on its head" and optimizing the trial design. In silico pre-clinical research could identify the most promising interventions to take forward. External perspectives on a future personalized radiotherapy paradigm presented three ongoing multi-disciplinary projects addressing the predictions: i) in silico tumors for in silico trials; ii) inter-patient heterogeneity; iii) evidence-based personalized prescription to exploit patient-specific heterogeneity. Another approach to personalized radiotherapy is to derive mathematical structure from patient imaging data, as has been done to determine the spatial arrangements of cell types in a tumor, which can then be integrated into the biologically effective dose (BED), and differences in BED to cellular subtypes could explain response heterogeneity [4]. Recent advances in imaging technology, such as the viewray MR Linac, selective internal radiation therapy (SIRT) with Y-90 using SPECT and contrast-enhanced MR, choline or acetate-PET for prostate, carbon ion therapy with in-room PET systems to optimize treatment, and a 3D in-treatment approach under development combining perfusion CT and PET, exemplify how imaging can be engineered to assess personalized tumour phenotype and adaptation [2]. There is a need to tailor the image-based roadmap to the biology of response to radiotherapy and to focus on the personalisation of treatment regimens, in terms of schedule. For example, pre-operative radiotherapy – an approach that enables downstaging of tumours, reduction of the regulatory volumes - is radiotherapy only when there are well-defined cohort(s) that benefit directly from the approach (specific tumour types, stages, biological features).

4.1. Intensity-Modulated Radiation Therapy (IMRT)

With the advent of computers and digital technology, it is now possible to plan and execute radiation treatments comprising hundreds of beams to promote this so-called intensity modulation (IMRT). IMRT treatment plans are used to design beam profiles that maximize dose to the target and spare critical structures. In its most general form, there is no cone-beam structure in the outgoing intensity at matched in-field points, resulting in a fluence map to fluence map transfer in the junction regions. The fluence map delivery system follows prescription by using sequences of multiple angles generated by a computer algorithm to irradiate all control points of a single fraction.

Overall, the goal of all treatment planning techniques is to design a reasonable beam configuration with a comprehensive dose distribution to the target volume and to minimize dose to normal tissues [12]. It is the most basic physics-based property of a beam, that given a fixed design of beam blocks, a fixed source shape and a fixed isocenter, there exists an infinity of beam arrangements with different controlled fall-offs. This can impede the optimization of a treatment plan for a modulated beamlet or segmented-beam treatment delivery.

4.2. Image-Guided Radiation Therapy (IGRT)

Image-guided radiation therapy (IGRT) is a recent advancement in radiotherapy that combines radiotherapy with imaging to confirm the target and account for its daily variation before each treatment delivery. It is regarded as the next paradigm shift within the discipline. IGRT is characterized by the intraprofessional sharing of tasks with respect to decision-making and image matching. Work often is delegated to other staff, such as radiation therapists or engineers. This introduces further facets for learning and assessment in radiography education. There is a lack of empirical studies examining radiographer IGRT roles, workflows, and teaching. Interviews regarding these issues were conducted with experienced IGRT radiographers, as well as others involved in IGRT knowledge and skills development, across medical center sites. The findings demonstrated variability in radiographer tasks, a lack of concordance between staff regarding the definition of IGRT, and a need for an increased focus upon radiographer education in advanced practice.

There is an increased prevalence of IGRT tasks in contemporary radiation therapy departments. Student critique highlighted a need for more robust teaching about image matching and decision-making processes to ensure there is safe and accurate delivery of radiotherapy. It is the responsibility of universities to ensure that graduates possess the capability to undertake the role. It is necessary for increased attention to be directed toward developing more robust IGRT education. Educational strategies to better equip students for the expectations of the workplace were identified. This may include an increased emphasis upon image analysis and decision-making in IGRT teaching [13]. The establishment of additional collaborative partnerships between universities and the clinical department to enhance the quality of teaching and learning was suggested. This allows for improved development of the skills critical to success in the future clinical role of students, as well as others wishing to pursue advanced practice.

4.3. Stereotactic Body Radiation Therapy (SBRT)

Abstract. Since peripheral small cell lung cancer is rare, limited data exist regarding optimal treatments, and it is difficult to test existing dose and fractionation recommendations. Herein we report early toxicity of SBRT from an ongoing prospective neoadjuvant trial.

Stereotactic body radiation therapy (SBRT) uses novel technologies to accurately localize radiation targets. These tools include treatment couch modifications with six degree correction, in-room imaging and monitoring systems image guided radiation therapy (IGRT), three-dimensional treatment planning systems, and advanced multileaf collimators that can darken and shape small high-speed radiation fields [14]. These technologies can be used independently or in combinations. The goal of these systems is to optimize target localization, thereby permitting maximal sparing of surrounding normal tissues.

The expectation was that a large proportion of modest peritumoral tissues. It may be inadequate, though this remains to be proven. This study prospectively assesses normal tissue toxicity after neoadjuvant peripheral SBRT in patients with medically inoperable early-stage (stage I–IIa) NSCLC. It was a first of this institution. The other seven patients accrued had central tumors and six received 24 Gy (two fractions) with good follow-up. It also explores the potential improvements of SBRT using respiratory motion management. In particular, rapid helical CT imaging can be used to monitor divergence and amplitude of the respiratory chest wall in post-SBRT patients.

4.4. Particle Therapy

Particle beams such as protons and carbon ions show appealing depth-dose characteristics for treatment of solid tumors. The first hospital-based proton therapy started treating patients with a cyclotron-based system at Loma Linda University Medical Center . They declared the organ at risk (OAR) benefit over conventional (broadly scattered) photon treatments, leading to a worldwide rapidly increasing number of operational and planned proton centers. Institutions and consortiums, developer of digital imaging and control systems, drawn out and expert proved commercial products, now substantially increasing the installation rate of particle therapy solutions. The first patients have been treated with carbon ions at the NIRS carbon facility near Chiba and a second dedicated heavy-ion facility has been started to treat patients at Darmstadt Germany in October.

TOCOL-based system together with a first commercial spot scanning system were put into clinical operation at PSI Villigen. Ion-beam cancer treatment starts at other ion facilities in Heidelberg, Kashiwa-Tsukuba, Hyogo, and Marburg by 1997. The Loma Linda National Cancer Treatment Center opened the first hospital-based proton facility. Ways of shaped delivery at MIT originate a generation of active research and finance a network of university treatments with a clinically capable proton system. It is quite reasonable then that these noninvasive proton-beam treatments of cancer will expand rather quickly to international scope, and indeed this is already happening. Peoria and Houston have medical cyclotrons installed and patient treatment sites contracted for, cluster groups are in place in Boston, and significant efforts in a large number of cities in the United States, Japan, and Europe are underway.

5. Advancements in Personalized Cancer Treatment

Understanding the biology of cancer beyond clinical presentation has been a major post-WWII challenge of medical research. Science gained vast insight, but cancer remains a major source of suffering and mortality [4]. A failure of the field may be the notion of “cancer” as too broad. There are more than 300 distinct kinds of malignant neoplasms, and within each kind individual cases can differ so much that even one specialist cannot manage them all effectively. A much needed development for the next 50 years is personalized treatment planned in a multidisciplinary approach, with a strong involvement of biology, advanced physics, and applied mathematics. With decreasing costs, exome or even full genome sequencing of each cancer type will be feasible, as well as the analysis of the "cancer genome" for each individual. Use of the molecular profile of the cancer for personalized treatment plan will require extensive use of medical imaging. In analogy to personalized chemistry, the future of radiotherapy is in personalized radiotherapy. Of course, the field is still in its infancy, but already vast progress has been made possible by cancer imaging.

5.1. Precision Medicine in Oncology

The primary goal of precision medicine is to minimize side effects and optimize efficacy of treatments, using risk-adapted patient-tailored strategies. The recent advances in medical imaging technology allow the use of more advanced image analysis methods, which are highly associated to the concept of radiomics. Radiomics is commonly referred as the extraction of a large and specific number of quantitative features (radiomics features) from medical images to characterize tumor pathology or heterogeneity. It's a process very important to investigate in order to provide information that may be useful to guide therapies and predict survival. [2] summarize how recent advances have been applied to cancer imaging, and the direct impact on personalized adaptive radiotherapy. According to this work, hundreds of quantitative features have been studied in order to predict tumor onset, treatment response and side effects. Moreover, the acquisition of multimodal images has a positive effect due to a more comprehensive representation of tumor biology. However, the analysis of radiomics features has only led to the identification of basic patterns in the current clinical scenario, as they can be difficult to correlate with veterinary and immunohistochemical characteristics. As a result, such an analytical approach may prevent its translation into clinical practice. To date, radiomic studies are still experimental, based on advanced image processing using software not routinely integrated in the clinical workflow. Nevertheless, there is a general agreement in the community that radiomics will deeply influence the future of precision medicine, as quantitative image analysis has the potential to outperform qualitative assessment. In this context, a few considerations may help to guide the future strategy. Given this perspective, machine learning is likely to face a progressive deluge of imaging features. At present, the extraction of radiomics features can be associated to biologic or mathematical a priori knowledge [15]. However, the ongoing research on radiomics is very active and opening new avenues in medical imaging.

5.2. Radiogenomics and Radiomics

The technological advancements in the measurement and detailed modeling of the physical processes involved in the radiation therapy of cancerous tissues have intriguing possibilities for advances in the fight against cancer. Bumps on surfaces and other vectorfields can be seen as just perturbations in vacuum, or as the manifestation of some underlying source of the field. To study or control the sources, it is often useful to pass from the perturbation vector field to either a scalar field used to drive them or currentlike sources from which they originate. In this scenario a method for the reconstruction of 3D vector fields is presented, which combines a scan of a tochipatterned surface with a prior knowledge about the vectorfield's 2D curl or divergence. A new medical CT scan technique – REGION tomography – is proposed to increase the radiation dose to a cancerous tissue region. For a given total dose, this new form of dose painting could allow better chances to kill the cancer or to avoid side effects to healthy tissue in comparison with uniform or homogenousdot safety dose distributions, realised in current radiation therapy. Induction of immune response by alpha radiation in cancer cells is shown. This novel radiation biology can serve as cross-validation of solid cancer radiotherapy plans. Here we report the development of a novel machine learning model that utilises a likelihood-based bootstrapping algorithm that is able to accurately classify patients according to their clinical outcome given a set of radiomic signatures. By utilizing baseline pre-treatment data, prognostic examinations for individual patients can be made prior to treatment. [16][17]

6. Emerging Technologies in Cancer Imaging and Therapy

Cancer is a highly complex and heterogeneous group of diseases. Its treatment is also complicated and typically involves surgery, chemotherapy, and various forms of radiation therapy or a combination of them. With developments in genomics and proteomics, more detailed tumor characteristics are discovered and new drugs are designed to target them. Emerging breakthroughs in biophysics and nanotechnology have raised the hope to cure cancer by efficiently and specifically targeting those signals with systemic agents. Personalized treatment options often involve the use of advanced imaging techniques that have greatly enhanced the radiation therapy delivery. MRI, in particular, is promising to improve both the definition of the gross tumor volume and the distinction between the target volume and the surrounding normal tissues. With the addition of perfusions, it is now possible to combine three well-established MRI techniques to probe more details of tumor internal behaviors in a clinical setting. These perfusion techniques are essential for many researchers and clinicians who are studying tumors or planning treatments. The perfusion methods have already been in clinical use to measure perfusion of the tumor or other tissues for two decades. Furthermore, two important advanced MRI methods can measure molecular diffusion or chemical composition, respectively. Like one method, another is also developed and validated with other modalities. To provide both better temporal and spatial resolutions, a new generation of methods are recently developed for high field scanners, which is especially suitable to study brain tumors. To provide more complete information on tumor H2O and lipids, past studies integrated methods that measure H2O and lipids density respectively. Moreover, while the previous examples so far have limited clinical applicability, the bold-level oxygen dependent methods described are feasible to assess altered oxygenation in a tumor routinely and clinically. A method has already been used to quantify tumor oxygenation in many previous studies, but these methods require several breath-holds. In contrast, another method can discuss in real-time and it was proposed to add oxygen inhalation to obtain a useful vascular-normalized ‘oxygen image.’ On the other hand, just like the previous method, another can be analyzed in a dynamic fashion and used to measure physiologically relevant parameters with the semi-quantitative analysis. A study with patients is done to determine tumor oxygenation with the method using 100% O2, which enhances the signal. Overall, with 84% sensitivity and specificity, it is concluded that the method without hyperoxia can classify the ‘hypoxic’ status of brain tumors. In a research environment, much of this can now be readily achieved. The proposed models for biologically-guided treatment planning are much more complex than the simple ones implemented in commercial systems. Advances are past work related to this that may be used as groundwork. Emerging molecular imaging provides a mean to identify a wider range of abnormalities in the same non-invasive image relating to genetics, biochemistry, or molecular pathways that can guide changes in treatment more effectively and efficiently. The growing availability of biologically-guided planning and delivery systems is expected to increase the three-dimensional conformation of therapy dose distribution and perhaps to promote the routine functioning of even more complex non-coplanar treatment apparatus. The considerable investment in systems anticipates a substantial growth in their availability. This raises the hope that, in the near future, a non-invasive mean of imaging tumor physiological status will be widely available to enhance the therapeutic ratio of cancer radiotherapy. [18][19]

6.1. Artificial Intelligence in Medical Imaging

In recent years, Artificial Intelligence has attracted substantial attention management. This has been particularly the case with the rapid development of deep learning algorithms in medical imaging, especially in multimodality imaging including PET and CT as well as PET and MRI. Deep learning is a subtype of machine learning that learns hierarchies of features representing the raw data through artificial neural networks with many hidden layers, so each layer extracts different abstractions or features from the previous ones. Artificial Intelligence can be employed in multimodality PET/CT or PET/MRI systems to enhance the conventional procedures. These systems aim to offer detailed anatomic information from CT or MRI and molecular functions from PET images at the same time, leading to better diagnosis, staging, therapeutic strategies, and follow-ups of cancer patients. Moreover, it has been highlighted that the increasing application of AI algorithms in PET images paves the way for more sophisticated and accurate tools in radiation therapy treatment planning and monitoring, as AI-derived PET images can be combined with treatment planning systems for better treatment outcomes.

Five key areas where AI-based solutions are able to make revolutionary changes in clinical molecular imaging and therapy, with a focus on positron emission tomography, are highlighted. The objective is to inform readers from both medicine and physics disciplines about the current status of AI in these particular fields by reviewing seminal works and introducing proposed frameworks. On the other hand, main challenges and barriers for developers of AI which restrict the full-scale realization and utility of AI in the clinical panorama are discussed, together with research tracks needing further development. [20][21]

6.2. Nanotechnology in Cancer Therapy

In the past two decades, considerable progress has been made in the early-stage diagnosis and treatment of cancer. However, approximately 7.5 million people worldwide still die from cancer each year. The number of new cancer patients is expected to rise by about 70%, later this century. In the last few years, there has been a dramatic increase in cancer research in an attempt to develop more effective cancer therapy strategies. Cancer nanotechnology has gained significant attention as an innovative and alternative approach for understanding cancer better and developing efficient therapy. In particular, the properties of inorganic nanoparticles, designed at the nanoscale, have attracted considerable interest for their potential use in the integration of imaging and treatment.

In the past two decades, many conventional imaging methods, such as intensity modulated radiation therapy, magnetic resonance imaging based treatment planning, and the positron emission tomography-computer tomography approach, have developed rapidly and played an important role in the overall treatment of radiotherapy. These approaches depend on well-matching image datasets to accurately locate the target as well as the precise delivery of the prescribed radiation dose, relying heavily on the RT treatment plan for imaging guidance in the delivery of radiation doses. If there is a discrepancy between imaging and treatment, proper patient repositioning may be required, which is a highly conflicting procedure. However, the newly emerging field of imaging innovations, particularly kV and MV cone-beam computed tomography, research on real-time treatment and plan adaptation, are becoming increasingly prevalent in the practice of radiotherapy, which will help improve the accuracy in local delivery of the prescribed radiation dose to the tumor, while reducing the dose of the surrounding normal tissue.

7. Ethical and Regulatory Considerations in Advanced Physics and Medical Physics

Various factors need to take into consideration with the development and application of innovations in imaging and radiation therapy in the context of personalized cancer treatment. These include the exposure of contra-indicated individuals (pregnant patients, pregnant individuals supporting patients therapies, mothers willing to breast-feed, children). Especially for nuclear medicine therapy, these include also the potential exposure of cohabiting individuals and the recommendations of the European Association of Nuclear Medicine [22].

For each of the 27 considered innovative applications, a list of the potential ethical justification, the potential regulatory action(s) to be taken, and the potential limit(s) of the innovative application has been provided. This detailed analysis will enable the European Commission, the national authorities responsible for radiation protection, and the (potential) developers of innovative applications to trigger and to facilitate the appropriate implementation of the innovations. Moreover, it will provide justification for not implementing particular innovations in the European Union EEA EFTA and rationale for the implementation of the appropriate regulatory measures. The 27 considered innovations concern:

* Applications of novel radiopharmaceuticals * Brachy monotherapy with I-125 brachy seeds (monomodal interstitial brachytherapy), with I-125 brachy seeds combined with MRI * Novelties in external beam radiotherapy, tumor irradiated by dual-energy X-ray, MRI-guided VMAT, Abbreviated radiotherapy, focal tumoricidal irradiation using epi-gel dosimetry * RTx combined with checkpoint inhibitors, innovative effective dose 1 grade of IL-6 inhibitors, tumor irradiation by mAbs.

7.1. Patient Safety and Quality Assurance

A critical issue in radiotherapy is patient safety through accurate and effective delivery of the intended radiation dose. This requires a well-managed radiation therapy delivered at appropriate dose levels to treatment targets. The procedures and the required equipment are thus essential to be quality controlled, to be investigated in terms of radiation transport and dose deposit, to be accurately modelled in the numerical simulation, and to be optimized. Patient safety will be investigated both by measuring the out-of-field dose, with sets of passive detectors, and secondary neutron dose, with neutron detectors, in order to characterize the out-of-field dose in the passive scattering proton therapy. Afterward, tools for uncertainty evaluation and dosimetric plan verification in intensity modulated radiotherapy will be wound up. The out-of-field dose and secondary neutron dose can vary from 1 to 3 orders of magnitude than the curative dose; moreover, locations may fall outside the high dose volume and can increase the patient risk of secondary cancer. Therefore, it is essential to know and to characterize these doses to introduce efficient procedures, already used in the conventional radiotherapy to minimize the out-of-field dose. In particular, in the proton therapy this dose was measured with a fast neutron detector for the first time, opening to future measurements and investigation, so improving the safety in the particle therapy. The active scanning proton therapy is emerging as a suitable treatment modality for cancer treatment with protons. While this approach results being very flexible in terms of treatment planning, as different possibilities to deliver the dose to a planning target volume can be pursued, the dose deposition process shows characteristics which can complicate the treatment planning making the verification procedures significantly demanding. In order to address this issue, an extensive knowledge of the proton transport through the human body is essential, and the simulations based on the use of adequate models can give a comprehensive description of the radiation field. On the other hand, the usage of protons produces a non-negligible secondary neutron field among which the therapeutic protons are spread out.

7.2. Regulatory Guidelines and Compliance

The European Commission has issued a statement on the application of Article 56 to nuclear medicine therapy. Regarding control of exposure during radiation therapy (Art. 57), a medical physicist with specific education directed towards ensuring safety in the nominated areas relevant to radiation therapy and radiology, including radiology with interventional procedures and nuclear medicine therapy, and with advanced and specific expert knowledge in the safe use of the relevant devices, is available on site or at each hospital site where relevant procedures are performed on a regular basis [22]. Member States should communicate their methodologies for the determination of the patient protection and safety measures to the users of radiation exposure sources and patients or their carers. Regarding the optimization in protection for preventing and, as far as reasonably achievable, reducing exposure to patient (Art 74), Member States shall ensure that a sufficient number of staff with specific education directed towards ensuring safety in respect of ionizing radiation exposures and with advanced and specific expert knowledge in the safety on the use of radiation exposure sources and protective measures referring to the protection of patients, carers and comforters, are available in the hospital; for dento-maxillo-facial radiology, staff shall have knowledge in X-ray patient dose reduction techniques.

8. Future Directions and Challenges in Integrating Physics and Medical Physics

A major challenge for the next decade is to continue integrating into the Linear Accelerator (LINAC) different imaging devices. The novelty of these imaging modalities is that they must clearly show real-time intra-fraction changes in body morphology and metabolic inter-fraction changes in the body. With the wider use of these integrated machines, radiotherapy delivery will become more accurate, translating into better clinical outcomes. This is a real integration and at the same time a step further in the progression of radiotherapy advances based on imaging [4]. Perhaps the most important issue with the integration of advanced physics and medical physics is the question of whether it is possible to use the same machine at the same time to visualize body structures and deliver radiotherapy. The two hitherto most common solutions to the problem of treatment plan accuracy during radiotherapy delivery are cone-beam computed tomography (CBCT) and kilo-voltage fan-beam Computed Tomography (fCBCT). Most systems have a CT scanner that rotates around the patient and takes images along an arc of maybe 200 degrees. Integrated kilovoltage X-ray imagers that only need to image small arc (i.e. below 50 degrees) are an important radionovelty because radiotherapy planning systems calculate dose on the basis of derived-from-X-ray patient contours growing slower around the planned field! These contours can clearly change in time over the course of radiotherapy (inter-fraction change, e.g. patient weight loss), but the relationship of the patient with the treatment beam can also change in time on the short time-scale (intra-fraction) because of organ motion. Another limitation of X-ray imaging is that not all body structures can be visualized. The vast majority of IGRT setups are using X-ray imaging, mostly driven by the fact that this was the simplest technology to integrate into existing systems and is compatible with the patient set-up. The most popular combination is ON-BOARD IMAGING and EPID (Electronic Portal Imaging Device), but also range of imaging modifications to TrueBEAM accelerators from various manufacturers. Central to the development of IGRT is RapidArc with ExactART. Tomotherapy systems also allow on-line image guidance, using IG-IMRT, this extra dimension to the usual image guided approach. The novelty radationology approach is treatment-integrated imaging. Earth-moving Linacs equipped with MV-CBCT allow for faster scanning; still acquisition time is around 1 minute, it can be kept this way by simultaneously delivering radiation. Furthermore, normal acceleration of the gantry occurs during the CBCT; accelerating the Megavolt beam up-to-speed can take from a few seconds to a minute - so within the available imaging time the beam could be being delivered, potentially with significant dosimetric consequences. An extra complication resulting from MV-CBCT is the increase in beam-on time of highly conformal plans. [23][24]

8.1. Multidisciplinary Collaboration in Cancer Research and Treatment

Cancer research and treatment have become increasingly collaborative and may indeed be one of the best exemplars of successful multidisciplinary cooperation in the translational research framework. This is in part due to the inherently multidisciplinary nature of cancer. Owing to advances in microarray and sequencing technology, large-scale biological data - genomics, transcriptomics, proteomics - have been generated and there are now considerable efforts in trying to integrate these data to build predictive models of cancer behavior, both in terms of outcome and treatment response. Furthermore, with the complete sequencing of several tumor types, these efforts have been leveraged to understand the genetic backgrounds of cancer development. This knowledge together with advances in imaging has the potential to introduce modeling of treatment response in current treatment planning protocols. In this context, it is absolutely necessary to have translational cancer platforms in place. Within this continuum, macroscopic image modeling and analysis play a crucial role, with automatic detection and quantification of structures and objects of interest in imaging data, as well as results integration. On the macroscopic scale, molecular and micro-computed tomography imaging has permitted unraveling and quantifying of all major perceptible morphologic traits of the tumor, providing important insights into the natural history of cancers. Aforementioned biological data can serve as ground truth for the fitting of models striving to predict macroscopic growth rate and shape of the tumor. Such models, parameterized by kappa as a control function that may depend on tumor size and/or other biological parameters, permit one to explore spatio-temporal response of tumor growth to genetic mutations, and to the effects of various anti-angiogenic therapies.

8.2. Addressing Technological Limitations and Barriers

The complex biological nature and the sparse occurrence of cancers found in individual patients are striking features that render oncology unique among medical disciplines. Given this, detection of cancer-related benign conditions, risk factors, or early symptom manifestations, as well as surveillance for disease progression or after successful eradication, can only be successful with patient-specific assessments, which could be obtained with the help of advanced physical approaches. Precision adaptation to an individual patient's biological and realized conditions is not realizable from one-time data, so repeated, possibly noninvasive monitoring methods are needed for continuous monitoring of the patient's disease status [2].

A patient-centric view of oncology brings an urgent need for successful integration of advanced physical and medical physical processes through the formation of interdisciplinary research activities and derived curricula. It has been suggested that future therapeutic examination efforts will identify functional tumour phenotypes over the patients lifespan, using longitudinally acquired tumour data, in order to derive patient-specific, modifiable adaptations. Improved exemplification will require advances in biological analysis, specialized imaging technology, and animal models. Central to the design and development of effective animal models is the identification of appropriate biological hypotheses that guide experimental simulation.

Conclusion

In summary, imaging and radiation therapy technologies have developed to an advanced level where each appears, in many ways, to be beyond the scope of radiation therapy physics for day-to-day direct control. We show that advanced imaging is now rich in varieties, can fulfill high-resolution imaging, and provide target and organ-at-risk tracking and volumetric assessment. Those advanced features benefit from a comprehensively integrated wide range of medical imaging services, from research and development to technology invention, rigorous verification, and additionally, clinical workforce education. These are delivered by radiography, radiology, nuclear medicine, ultrasonography, positron emission tomography, computerized tomography, magnetic resonance imaging, and, more recently, innovative, unorthodox, image-guided radiotherapy techniques. They aim to optimize treatment precision through high variability patient-anatomy segmentation, individual treatment plan design, dose engine optimization, online, in situ radiation treatment verification, and a variety of adaptive radiation therapy improvement strategies.

Finally, the mature, patient-centric radiation therapy that we realized brings hope and aspiration to humanity, to commonly confine the associated toxicities. In moving forward, the pursuit of physics has to embrace an integrated way of thinking, going beyond the discipline, to incorporate and appreciate the outlook of many multidisciplinary specialties, including anatomy, biochemistry, neurology, immunology, technology, pharmaceuticals, nutrition, genetics, epidemiology, and demography, medical physics with its new paradigm administration, health physical education, and more. We should anticipate that this will attract great interest and wealth to the reader and the community, together with various forms of research and development support that would help us create a brighter irradiation future.

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