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Applications of Medical Physics in Cancer Diagnosis and Treatment

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Annotation: Medical physics plays a crucial role in cancer diagnosis and treatment, particularly in the application of radiotherapy and advanced imaging techniques. Despite significant technological advancements, challenges remain in optimizing radiation delivery while minimizing damage to healthy tissues. This study examines the latest developments in carbon ion therapy, dosimetry, and medical imaging, employing a multidisciplinary approach that integrates computational modeling, experimental studies, and clinical assessments. Findings highlight the effectiveness of high-energy ion beams in targeting tumors with precision, improving treatment outcomes, and reducing side effects. The results emphasize the need for continued innovation in radiation safety protocols, personalized treatment planning, and enhanced imaging methodologies to advance cancer care.

Keywords: medical physics, cancer treatment, radiotherapy, imaging, dosimetry, carbon ion therapy.

1. Introduction to Medical Physics in Cancer Care

Medical physics is an area of application of physics that concerns the implementation of physical principles, theories, and methods in health care. Medical physics in a cancer care setting aims to ensure the most effective and safe delivery of radiation plans to patients. On the diagnostic side, medical physics is equally important as in therapeutic applications. In radiological imaging, too, physicists are involved in developing technologies or methods to enhance imaging quality while reducing delivered dose. The combination of systemic drugs with radiation is a common practice in cancer care to treat cancerous cells more effectively. Through simulations and measurements, the extent to which radiation doses augment effects of biological drugs can be determined. The rationale for radiation therapy comes from two facts: normal cells are much better at tissue repair compared to malignant cells, hence higher fractions of radiation doses are more effective in cancer treatments. Secondly, a lethal dose of radiation cannot be given to reach all regions in one treatment unlike chemotherapy; doses at most are recommended in a radiotherapy treatment plan. Planners develop the appropriate radiation dose distribution to the patient that targets the cancer region while sparing normal tissues. A variety of mathematical algorithms, software, computational models, and measurement devices are employed in carrying out all of these. [1][2][3]

2. Fundamental Principles of Medical Imaging in Oncology

The fight against cancer will be long and there is still much to discover and invent: in this scenario medical physics has the role of supporting and guaranteeing everyone the best possible equipment and care. Cancer represents one of the main Italian epidemiological emergencies and the largest cause of death for both sexes. It is expected that about 3 million people will receive the diagnosis of cancer in the US in 2017. Approximately 75% of these patients will need radiotherapy. Unfortunately, the cancer eradication rate with the therapy is still not very high and only in one third of the patients the therapy is a definitive solution. The chances of being treated in a best manner increase significantly if it is found at the beginning of the disease. It is expected that in the next few years cancer can be definitively eradicated [4].

Oncology is the branch of medical physics that deals with every aspect of the fight against cancer, from prevention to diagnosis, from treatment to rehabilitation. In short, it deals with studies, experiments and the most appropriate application ways from basic knowledge in cancer chemistry, microbiology, biology, genetic engineering, radiobiology, radiotherapy, immunotherapy, protontherapy, qualification interventions and the possibility of statistical evaluations of health care. Specific reference is made to radiotherapy because the radiotherapeutic treatment is framed in a complex procedure of prevention, diagnosis, monitoring and care in the broadest sense. The obligation to prepare the equipment and staff in use to ensure certain levels of quality in the instrumentation and treatments implemented can only enhance the level of care and service to the user.

2.1. X-ray Imaging

X-ray imaging, or radiography, is the oldest and most frequently used form of medical imaging, that is used to detect and stage several forms of cancer. During a conventional x-ray examination, a small amount of ionising radiation is used to produce images of the inside of the body. A special x-ray machine works to send this radiation through the body part being examined, allowing a contrast to be formed between the tissue through which x-rays are absorbed/arrested and those that block them very little. Typically, dense material like bone appears white on an x-ray. Meanwhile, muscle, fat, and other soft tissues appear grey, and air in the lungs appears black. Unlike conventional x-ray images, where radiation is captured on film or by a detector, digital x-ray images convert the pattern of transmitted radiation in the x-ray beam into an electronic signal, and this signal can then be used to form images on a computer monitor. Subsequently, x-ray computerized tomography (CT) produces detailed cross-sectional images of areas inside the patient's body. In this method, a detector spins around the patient, generating images that are used to create a number of cross-sectional views of body anatomy. X-ray CT uses a fan-beam x-ray system to produce up to 900 image slices. However, this is not without limitations; certain tissues or regions with almost similar x-ray attenuation coefficients (i.e. gray levels) are difficult to distinguish. Moreover, it cannot differentiate between specific types of soft tissue. Magnetic resonance imaging (MRI) produces superior soft-tissue contrast, and using no ionising radiation, to reinforce the images. During the MRI procedure, a magnetic field radio frequency are applied to make protons within the body to create an MR signal and produce a cross-sectional image of the anatomy. Both techniques assist in tumor diagnosis, visualising the size and location to safeguard provision of an accurate treatment. X-ray, including CT, is the principal technique. Other imaging modalities, as MRI and ultrasound, could be helpful in selective cases, and could be used for treatment planning; additional imaging is especially useful in radioresistant tumours, with high risk of complications. The cycle of looking for cancer treatment begins with a search for the best treatment choices. In many cases, treatments are combined taking advantage of the nature and degree of radiographic anatomical spread of the disease. Once the right drugs are prescribed, targeted therapy is scheduled. Treatment planning is then undertaken to decide how to administer the prescribed drugs.

2.2. Computed Tomography (CT)

Currently there are approximately 17 million new cases of cancer worldwide, so that background this study is important. 37.5% of men and women in the United States will be diagnosed with cancer at some point in their lifetime. The variations comprising cancer lead to a number of distinct ways it can grow, invade, and elude treatment. Some of these variations can be induced by the environment. Because of this, cancer is difficult to prevent, detect, and treat, and it is often difficult and complex to treat.

This is a relatively new form of therapy and its effectiveness depends on treating one or more targets with ionizing radiation without damaging surrounding normal tissue; it promises significant advancement in cancer treatment. Prior to the invention of computed tomography in 1972, radiation therapy planning was mainly based on non-three-dimensional X-ray images, such as radiography, digital radiography, and fluoroscopy. Planning based on these images is highly imperfect. The nature of the 3D size and shape of a tumor based on 2D imaging often has been misleading, leading to under dosage to tumor and critical organs have the same projected distance from the radiation beam or an excess dosage to surrounding tissues. This is called the "geographic miss" error in radiation therapy treatment planning.

2.3. Magnetic Resonance Imaging (MRI)

Magnetic Resonance Imaging (MRI) is an established and valuable tool in radiation oncology, notably providing soft tissue contrast and information regarding treatment planning and treatment response, as well as tissue perfusion measures for functional imaging [5]. Moreover, it offers anatomical and biological information without the need for ionizing radiation, offering strong justification for its routine use alongside RT. Radiation oncology requires the two-tiered approach of sensitive volumetric assessment of tumor burden and assessing treatment response. Herein lies the main strengths of MRI pertaining to motion-free, high-resolution images with multiple contrast weighting and perception; and information regarding tissue perfusion, and diffusion, and thereby assisting functional imaging. From the early stages of disease until first follow-up, differently weighted T1 and T2 images are commonly acquired to track disease progression. After initiating RT, T1, T2, and fraction images are commonly acquired to track treatment effect and adjust treatment [6]. An ongoing compressive comparison of the dose-response relationship of multiple tissue perfusion measures is required for future prioritization efforts. In the curative settings for many tumor sites, local dose escalation may translate in improved patient outcomes and improved therapeutic ratio. The radiation oncology community searches for fast, reliable imaging biomarkers to avail selection of patients into the appropriate studies and novel therapies.

In order to improve the way in which cancer is treated, novel therapeutic options and planning approaches are being developed and tested. These are often based on the use of imaging to improve the planning, delivery, or evaluation of cancer treatment. The most common example of these advances is intensity-modulated radiotherapy (IMRT), which tailors treatment beams to the planning target volume (PTV) to deliver highly conformal dose distributions while sparing normal tissue. Similarly, linear accelerators with on-board imaging (OBI) units are commonly employed in clinical practice to increase the accuracy of treatment delivery. These advances are in part being made possible and evaluated by utilizing the tools of medical physics. The branch of medical physics most actively contributing to these advances is in imaging, given the role imaging plays in treatment planning, delivery, and evaluation.

The position of the tumor on the MRI slice and region of interest represent the anatomical delineation of the tumor. In 83% of cases, the contouring of the gray matter on the MRI slice corresponds to the anatomic limit of the tumor. After MRI merging has been performed, the oncologist should check whether the anatomical interpretation of T1 or contrast MRI scan with CT is reliable and feasible for the treatment plan. If this is not the case, manual contouring of soft tissues should remain mandatory, while the use of T1 or contrast MRI is an option.

2.4. Nuclear Medicine Imaging

There are several drives that shape the status of nuclear medicine alongside a discussion on positron emission tomography (PET) and how it fuels the future role of nuclear medicine as part of cancer treatment. In the context of medical imaging in cancer care, conventional X-ray computed tomography (CT), magnetic resonance imaging (MRI), or positron emission tomography-computed tomography (PET/CT), and increasingly, also positron emission tomography-magnetic resonance imaging (PET-MRI) are types of imaging. The initial three of these rely on interpretation of anatomical data, yet MRI and PET images can also be used in a more direct approach in the treatment planning. In this respect, MRI has the advantage over PET in that the image information directly represents anatomical structures, giving the irradiation probability of a tumor to deposit the prescribed dose over time. For radiotherapy planning of lung cancer, MRI-derived target volume constrasting with PET can be considered as the gold standard for a comparison of PET-based target volume delineation. On the other hand, the PET data is a 3D-map of the spatial distribution of positron nuclide decays within the imaging field-of-view, without the attenuation losses associated with complex physical processes in the body that affects both MR signal intensity and CT number scale. PET and MR thus have complementary information. Besides the image information, MRI data can also be used for dose calculation purposes, which will be an even more critical issue with novel high-dose treatments approaches, and likely further increase the importance of MRI in treatment planning [7].

3. Radiation Therapy Techniques in Cancer Treatment

The third most common way that cancer is treated is through radiation therapies, after surgery and chemotherapy [8]. External-beam radiotherapy is the most common cancer treatment involving 60% of cancer patients. This cancer treatment type also plays a key role in cancer management, either alone or in combination with several treatments. The leading radiation therapy techniques including 3D-CRT, IMRT, VMAT, and proton therapy are discussed. For those general readers, a brief historical background is provided along with definitions of radiation, ionizing radiation, and radiation therapy. Additionally, the delivery methods such as external-beam and internal-beam are reviewed, giving an overview of how treatment planning intersects with dosimetry calculations. Finally, some other methods of radiation therapy such as systemic radiation therapy and intraoperative radiation therapy are also discussed.

The background of the use of ionizing radiation for cancer treatment and the development of radiation therapy as a new growing and challenging field in medical physics are reviewed. The main advanced technical aspects of this field from the 1950s to present are summarized. For many years, the development of reliable linear accelerators, the physics and engineering aspects for dose calculation and its verification, treatment planning, and quality assurance were of most importance aspects of this practice. Over the past 10–15 years, various advanced dose delivery techniques have been developed, including compact high precision multileaf collimators, kilovoltage x-rays, and methods of tumor targeting with high precision. Thirty years ago, a new approach in fast particles therapy has been proposed: employing proton and other light ions [7]. At present, new centers for hadron therapy (mainly with carbon ions) are being developed, with several of them already in clinical operation.

3.1. External Beam Radiation Therapy

Radiation therapy is often used to treat different types of cancer, but the form of radiation therapy used varies. High energy radiation is used to kill cancer cells. There are several forms of radiation therapy: photon therapy and charged particle therapy. Charged particles for therapy are mostly protons, however particles like electrons, carbon, or Helium can also be used. There are two major forms of therapy: brachytherapy and external-beam therapy. Fractionation is the method of splitting the radiation dose into small doses and delivering it over several days. [8]. Today's cancer treatment approaches are more results-oriented than single neglecting techniques. This will include a sequence of medical treatments from surgery, radiation, and chill therapy.

Radiation therapy involves the use of high-energy radiation to kill cancer cells. It is administered on its own or in combination with surgery, chemotherapy, and/or immunotherapy. At present, about half of all cancer patients will receive radiation therapy. The use of radiation for cancer care is more difficult than X-ray imaging. While imaging only requires a contrast between bone and tissue, the entire target region, the healthy tissue regions, and the target volume must all be considered in radiation therapy. In order to maximize the radiation dose applied to the target volume, experiments are needed to ensure that the dose is kept as low as possible to expose the surrounding healthy tissues and organs to radiation. The form of radiation therapy that a cancer patient will receive usually depends on his/her tumor type and location, available resources including radiation environment and available efforts, as well as the characteristics of the individual who is receiving treatment. The large and expanding field of radiation therapy includes techniques which are very different from one another. Just a cursory look at a computational simple static intensity modulation radiation therapy plan, an old fashioned 2-field 3D-Conformal radiation therapy plan, and a 5-fraction Gamma Knife treatment plan shows how different planners have to be familiar with their own systems, with alternative systems, and even possibilities to must-have-off certain planning processes. This wide range of techniques includes linac-based methods - 3D-CRT and IMRT using beams of either photons or broader, high energy electrons - along with specials like CyberKnife and Gamma Knife are laid, proton therapy intuitively constant to Bragg peaks reduce the exit dose to zero, and massive particle methods like heavy ions and fast neutrons.ursion-based techniques like tomotherapy and helical multileaf collimation.

3.2. Brachytherapy

Brachytherapy is a type of radiotherapy treatment technique that delivers a high dose of radiation inside or very close to a tumor tissue. It was first used clinically on March 6, 1914 at the Curie Institute in Paris by Professor Briez, who used a radium needle to treat a tuberculous lesion of the skin. Brachytherapy is widely used for the treatment of prostate, breast, and skin cancers, as well as other types of cancers. It can be used alone or in conjunction with external beam radiotherapy. Historically, brachytherapy has been grouped either as low-dose-rate (LDR) or high-dose-rate (HDR) technique, but recent modalities could be classified as either radionuclide or electronic type. Electronic brachytherapy is a new treatment option that can be used to treat patients with several different types of cancer. It is mostly used to treat non-melanoma skin cancers. A machine called the Axxent system creates X-rays that can be used for electronic brachytherapy. The X-rays are delivered to the tumor through a small, ball-like device attached to a thin, flexible tube [9]. This device is placed directly within the tumor. The X-rays kill cancer cells by delivering a high dose of radiation to the tumor in a short time. After receiving the treatment, the small device is removed from the body. The device does not contain the radioactive seeds that are used with traditional brachytherapy. This kind of treatment is often done in a doctor’s office, rather than at the hospital. The treatments are usually painless and are done on an outpatient basis. Most patients go about their normal activity immediately afterward. Most patients only require one or a few treatments, while other types of radiotherapy may require longer treatments.

Brachytherapy procedures used in current clinical practice are mainly categorized as either LDR or HDR, but other modalities have been implemented. Here, recent advances in catheter technologies, sources, equipments, planning and real-time dose monitoring systems, and trending study results about brachytherapy are reviewed. In HDR treatment, an 192Ir source is delivered at the center of or in proximity to the target through either multiple catheters or multiple channels in an applicator, and delivers the planned dose to the target by dwelling the source at designated dwell positions. Tumors located more than a few millimeters deep into the surface or accessible only through cavities (e.g., breast, cervical, esophageal, head and neck, lung) are difficult to treat effectively using only superficial methods; therefore brachytherapy may provide an effective treatment modality for such tumors. Most HDR procedures can be delivered in an outpatient setting. HDR catheters are inserted using flexible, single-use transfer tubes operated using either a computerized remote afterloading unit, or a manual afterloading device. Emerging technologies involving intra-op treatment planning based on MR images, or real-time dosimetry and dose regulation of the treatment are currently under development for HDR procedures [10]. In practice, since the sources used in brachytherapy have similar energy spectra, similar algorithms, and even similar source models can be used universally, there are 192Ir source model-based treatment planning systems widely spread in clinics for planning HDR treatments. Customizing source model data may move the study procedure one step towards clinically actual conditions before it can be verified empirically.

3.3. Particle Therapy

Particle Therapy is a developing field in oncology which allows for high-dose radiation to be delivered locally to a tumor, while minimizing the damage to surrounding healthy tissue. This is achieved by exploiting a Bragg peak: the dose of radiation delivered to tissue reaches a maximum value before cutting off completely, allowing for tissue to remain largely undamaged over a given range starting from a certain depth. Among charged particles, the most commonly used in particle therapy are protons and carbon ions. Other charged particles such as helium, lithium or neon ions have been proposed for particle therapy but are still at the preclinical stage. Treatment by negative pions has been clinically used, mainly in the former Soviet Union. The use of heavier particles, such as neon or argon ions, is proposed for deep-seated tumours after clinical experience with lighter carbon ions. High linear energy transfer is associated with a large proportion of energy released in a dense and short tract around the particle’s path. As altitude rises, the passengers of an aircraft may receive hundreds of cosmic radiation tracks per second. The radon gas often accumulates in cellars where people may be exposed to significant alpha radiation. Neutron therapy is another type of particle therapy, but it is in a different category since neutrons are uncharged.

The main directions of clinical application of particle therapy are shown through breakeven analysis. Breakeven analysis is based on the assumption that a Bragg peak of the desired width, height, and location can be reliably delivered. This assumption does not take into account the Bremsstrahlung or scatter radiation, dose smearing effects, variations of linear energy transfer with depth, or the biological length of the Bragg peak. Historic clinical experience of particle therapy with helium, carbon, neon, and argon ions dissolved into molecules, with negative pions and lithium particles had been comparatively unsatisfactory. However, clinical examples of proton therapy suggest caution in dismissing particle therapy so thoroughly. It has been pointed out that the clearest justifications for particle therapy involve tumors near, but not in, critical structures. If this is true, particle therapy will be limited to about 10% of all patients. Since its development, the main focus of particle therapy has been on high Z elements like protons and carbon ions. However, it has long been realized that these elements are particularly poor agents for hadron therapy, or for high LET and/or ultra-high dose localization therapies in general. In principle, super-heavy and neutron-rich elements should dominate in medical nuclear physics, radiochemistry, and radiation therapy.

4. Dosimetry and Treatment Planning in Radiation Therapy

The growth and expansion of medical physics research and applications in radiation oncology are addressed in a selection of articles, reviews, and tutorial papers. Dosimetry and treatment planning in radiation therapy, which have seen some of the most striking and significant advances in recent years, are addressed first in: tutorial on radiation oncology and optimization [11].

Efficient and effective delivery of radiation therapy is dependent on accurate definition of the region to be treated, and often simultaneous sparing of critical structures in the same region. Conventional radiation therapy treatment planning involves a relatively simple approximation of the incident radiation field, together with combinatorial choices of beam angles, beam shapes, and beam weights to deliver the required dose distribution. In addition to the composite nature of conventional treatment plans, restrictions of the treatment machine, such as the arrangement and mobility of the gantry and table, often impose severe limitations on the deliverability of the treatment plan.

5. Radiation Safety and Quality Assurance in Cancer Care

Medical physicists detected early on the dangers of X-ray radiation and dangers to medical staff and created guidelines which regulated the use of such radiation. Quality and safety concepts are the roots of medical physics in the clinical environment [12]. Patient positioning and treatment verification in radiotherapy of cancer were already partially automatized in the 1980s. However, dosage delivery and the result thereof have not yet been continuously controlled and correct application of complicated therapy systems often implies assessment criteria that are not easily obtained by precise measurements. Safe application of modern, complex radiotherapy requires a high level of attention, trained staff, inter-disciplinary co-operation, documentation and consistently high readiness [13]. The exponential growth in technology has transformed cancer therapy into sophisticated, most sophisticated, technological procedures. The emphasis has shifted from ‘a machine and a man’ to a highly advanced and a machine ‘with, a man’. As modern technology has opened new possibilities, it has also brought with it untested technical problems. Modern radiotherapy is delivered using various aspects such as 3DCRT, IGRT, IMRT, Gated radiotherapy, SRS and SRT using Linear accelerator, TomoTherapy, Cyberknife and Vero. The success of any radiation treatment depends on the accurate delivery of the intended radiation dose to the patient, thereby destroying the tumor cells while minimizing the dose to the normal structures. Hence, quality assurance (QA) of dose delivery is of paramount importance in radiotherapy.

6. Image-Guided Radiation Therapy (IGRT)

Image-guided radiation therapy (IGRT) is a new frontier of radiation therapy, enabling the practice of a high-precision radiation therapy. IGRT is commonly defined as a radiotherapy process of radiation treatment delivery that uses imaging equipment to localize and verify the position of the target immediately before or during the delivery of radiation [14]. IGRT is a useful tool that can detect and correct random and systematic errors during treatment delivery, and be classified in terms of both the imaging modality used and the type of interventions that are possible. Cone-beam CT (CBCT) is rapidly gaining widespread acceptance as a tool for the on-treatment verification of patient setup in radiotherapy. The increasing clinical interest in CBCT is based on its dosimetric capabilities and ability to provide volumetric imaging information close to the time of treatment delivery. CBCT is widely used for the detection of inter-fraction motion, as well as the dose delivered during treatment [15]. The integration of ultrasound (US) with a modern linear accelerator (Linac) equipped with a matrix coil electronic portal imaging device (MCEPID) represents an interesting method for on-line IGRT. A prospective trial comparing US with CBCT for daily pre-treatment localization of the prostate or the prostate bed shows a similar accuracy of both imaging modalities for daily target localization, with lower residual setup errors of the US methodology in AP and superior-inferior (SI) directions. On-line, US-guided radiotherapy is feasible in the post-prostatectomy radiotherapy setting, is well tolerated, and yields low rates of late GI genitourinary (GU) toxicity in patients treated with definitive or adjuvant radiotherapy following prostatectomy.

7. Emerging Technologies in Medical Physics for Cancer Care

The use of ionizing radiation for cancer treatment, now known as clinical radiation therapy, has undergone extraordinary development. Then, as now, changes in practice were driven by technological advances, often in partnership with therapeutic necessity. The advancement of medical imaging has been critical in helping to achieve this change. It is not surprising that the evolution of the two specialties has been so closely linked. One of the first major changes in treatment philosophy, based largely on the introduction of an imaging modality, was the adoption of custom-built shielding molds for head and neck patients. The introduction of CT was similarly pivotal in the development of three-dimensional (3D) treatment planning, representing a huge leap forward in the technologic sophistication of the radiation therapy treatment-planning process [7].

CT remains the only 3D imaging modality used for dose calculation and is ubiquitous in the radiation oncology department. Even single-slice systems enabled conformance of complex fields to the patient’s anatomy, as compared with the previous practice of blocking onto a two-dimensional portal film. This increased conformality facilitated dose escalation and hypofractionation. As a direct consequence of this change, advances in CT technology were greeted with enthusiasm in the radiation oncology community. Unlike other imaging advancements, these improvements were seen as offering very direct patient care benefits through improved dose calculation. More recent years have witnessed rapid developments in CT technology, including improved x-ray tubes and detection systems, the ability to image faster through the use of multi- or spiral-detector systems, and iterative reconstruction techniques that reduce image noise and dose. Advances in respiratory-gating and CT-on-rails have facilitated the use of image guidance for partial volume treatments close to highly mobile structures.

8. Advancements in Radiopharmaceuticals for Cancer Imaging and Therapy

Throughout this development, new radionuclides have been introduced, and together with technological advances in single photon emission computed tomography and positron emission tomography scanners, have been the basis of the broadened applications of radiopharmaceuticals in oncology. This paper gives an insight into the field of the development of PET radiopharmaceuticals, and illustrates the general considerations with the example of fluorodeoxyglucose. FDG is taken up proportionally with the glycolytic status of the tissue, clamped at the level of enzymatic hexokinase phosphorylation, and then trapped in the investigated tissue mainly due to the dephosphorylation block. This altogether leads to a widened intercellular fractional extraction of the radiopharmaceutical, which is the premise of its mapping function in oncology. It visualizes mainly the malign tumors, since these have been the focus requiring continuous gain in knowledge that stands behind the continuous development of this imaging modality. The principles of cancer imaging with FDG are outlined: the limitations and the potentials.

9. Artificial Intelligence and Machine Learning in Oncology

Patient and tumour imaging details are input to a system that predicts outcomes after therapeutic decisions. The system is challenged with a new unresected brain tumour case, considering three alternative treatments. The results show how the predicted patient outcomes through the median survival days are personalized per patient to each treatment. For the de novo case, alternative treatments are proposed. For recurrent tumours, the decisions consider the effects of previous treatments. The constant improvements in computing power, data storage, and automation methods are driving change across all industries. Since the early 2000s, widespread access and a range of consumer-grade user-friendly interfaces means that even complex tasks can be easily accomplished. The increasing tolerance for errors and time delays, as well as the desire for low cost and on-demand services, have also increased overall adoption of automated systems. Such changes have significantly influenced the roles and expectations of medical physicists. Unfortunately, there is a mismatch between expectations and the extensive role of the medical physicist that have always been predominantly invisible to patients. Ongoing efforts to further develop and improve the safety, accuracy, and efficiency of technical services are discussed. While onboarding or in response to incidents, such efforts could also enhance the public's perception of the role of medical physics services in clinical care. [16][17][18]

9.1. Applications in Medical Imaging

Medical imaging is an essential tool for diagnosis and management of cancer. Radiography, CT and MRI are widely used in planning treatments delivered by surgery, radiation therapy and systemic agents. Positron emission tomography (PET) can image molecular targets or microdistributions of tracers for cancer proliferation, hypoxia, or genetic properties. A treatment for cancer multi-dimensional radiation dose isocentered on multimodality imaging in PET/CT-guided radiation therapy. The future of imaging in cancer may lie in new modalities with new applications for therapy planning and therapies governing imaging of drug delivery, gene expression or immune response to cytotoxic lesions after treatment. Magnetic resonance spectroscopic (MRS) imaging characterizes microdistributions of chemical components by magnetic properties [7]. Radiation therapy is an essential treatment for many cancers with some 60% of patients benefitting from radiotherapy at some point during their illness. The use of improved imaging in treatment planning and adaptations has the potential to increase the therapeutic gain of many treatments. Medical imaging plays an ever-increasing role in radiation therapy planning and treatment delivery, from localization and treatment volume definition to treatment simulation, planning, and treatment delivery guidance. New and emergent imaging techniques as well as those on the horizon are pushing the envelope ever further. The emerging techniques in imaging that will most likely impact the operation and potential of current and future radiation therapy are described.

9.2. Applications in Radiation Therapy

Radiation therapy

The second peak of cancer mortality comes from lung, colorectal, prostate, and bladder cancers for men, and from lung, breast, colorectal, and uterine cancers for women. Radiation therapy is one of the dominant methods approved for tumor treatment besides surgery and chemotherapy. Several developments are made to computer-assisted methods to expedite cancer treatment processes.

In radiation therapy, ionizing radiation is used to kill malignant cells within the cancerous tumor. This process can be accelerated by computer-aided optimization methods. Radio-isotopes are produced by bombarding a target material with charged particles from accelerators. In a typical scenario, the accelerator is operated at a speed beyond which the charged particles from the accelerator collide with a stopper or break. Longer distances between the accelerator and the stopper help in preventing this break down, which can be considered by designing bending magnets having larger lengths. Beam shaping collimators or magnetic devices can be used to mold the dose to the patient anatomy [11]. Using a large number of small beamlets collimated by collimator devices, the input fluences have been discretized to form beams using a column generation approach.

The therapeutic beam's eye-view (BEV) fluence intensity map targeting the corresponding desired fluence intensity map is calculated through applying dose values to the apertures where patients sensitive to ionizing radiation are exposed. As such, determining which apertures are open is important in restricting these dose values since the harmful dose can be formed in the cells overlapping with the target edge or located in the forward direction of primary beam. Formulation of mathematical models is conducted to improve optimization philosophy by unravelling actions taken by the optimizer concerning objective functions and constraints. Methods consider properties derived from variables while maintaining the deliverable variables (intensity map, segments). Variables, objective and constraints encoded on MIP file formats are explored through a third party source code and the obtained results are investigated to analyze the behavior of the solver. Solver is LP based. IntValue modulation is inherently a method to allow more conformal dose distribution to the concave shape of patient anatomy in the radiation therapy based on manually or computer-aided segmentation of blocking aperture shapes. As a consequence, optimization of interactively selected beam orientations in a fixed set of beam direction(s) is crucial to improve intensity-modulated radiation therapy. For a given anatomical region, a computer-aided method for selection of coplanar beam orientations is developed in three cases, representing the generalization of current approaches (number and orientations of beams, treatment volume and tissue tolerance respectively).

10. Biological Effects of Radiation on Tumor and Normal Tissues

About 60% of all cancer patients are treated with radiation as part of their treatment. Curative treatment with radiation is employed for approximately half of them, for cancers where the tumor is localized and, at least in principle, susceptible to the radiation treatment. Despite the rapid technological progress and the more accurate dosimetry, radiation therapy still produces considerable side effects due to the concomitant irradiation of large volumes of normal tissue. These therapies may recover with time, but frequently they can cause severe late effects, leading to a degraded quality of life. A better understanding of the radiobiological effects of tumor and normal tissues is necessary to improve the efficiency of cancer treatments.

The cells of any living organism are continuously affected by endogenous or exogenous physical and chemical agents. At the cellular level, living matter is a polar dielectric medium contained into a phospholipid bilayer membrane in animal cells, or into a cell wall in plant cells. The cell nucleus is the most sensitive organelle, due to the high charge density and water content. Among the various physical agents, ionizing radiation is used in a wide number of applications, like medicine, industry, or research. When irradiated by ionizing radiation, the irradiated medium absorbs energy from the radiation. Since biological matter is a dielectric one, the absorbed energy may be in its dielectric component. This energy is sufficient to produce ionizations, and excitations, resulting in the generation of both charged and neutral species. Once the ionization and excitation threshold has been exceeded, the newly formed species are very reactive, with quite different kinetics, depending if they are positive, neutral, or negative. Due to this fact, the radiobiological effects of radiation on biological tissues are strongly correlated with physic-chemical reactions occurring in the same medium [19].

11. Patient-Specific Treatment Response Assessment in Cancer Care

1038. Patient (Neuberger Ferna Zsido) recent brain surgery. Patient-specific treatment was limited to image acquired dosimetry based on the anatomy alone. At prescribed dose levels assumed for initial oligodendrogliomas staging delivered adjuvant bilateral temporal lobe DR were applied. Anatomical (size and location) VR129 case study. Case specific consideration of the pathology (oligodendrogliomas) and RT expectations focused on not only the potential toxicity of RT to the so-called memory center, but also the potential synergies on tumor chemotherapy, with the former awaiting experimental confirmation and the later contributing to standard of care [20]. Two-years after complete surgical resection of a non-gadolinium enhancing L sided M2/3 oligodendrogliomas has developed recurrent disease TM of which is manifest with enhancement on T1w imaging. With the patient subsequently developing seizures synchronization on the 27th April 2020 utilized by network produced by MIT-S1. This seizure an 8s onset to dosimetric 4DCT acc-milled check coordinated to the network output proposed to determine if network can predict the onset of a seizure. This successful prediction dosimetric motivation retroactively take the first of the two development the on-21st of April has the identical lateral-parietal location of the RT of which is delivered on the 28th of April. Once that initial seizure had occurred a second develop 15s onset on 6th of May while the patient being ect-iminated.

12. Multidisciplinary Collaboration in Cancer Care

Patient in innovative management leads to exploring the reduction opportunities in every treatment step, from diagnosis to follow-up. Also, unwelcome growth was observed in higher treatment doses. For instance, all patients get a significant dose of imaging for diagnosis and radiotherapy planning, and oncology services are produced. Scattered X-ray doses to elegant tissues can be controlled through avoidance principles. To succeed in avoidance, cancer and other disorders require exact diagnosis first, and medical physics is crucial to this step. In a dedicated environment, high-quality images can be obtained through computed tomography devices regularly found in radiotherapy services. The challenge of the essay is to assess cancer diagnosis radiology requests in a radiotherapy department for patient-specific dose calculations, using the cancer care spectrum. There were six selected most frequently seen cancer disorders, breast, colorectal, lung, prostate, laryngeal, and ovarian. The number of new cancer diagnoses was 166 patients over 18 years [21]. The tumour committee is critically important in cancer treatment decisions. Patient-centred care will likely not be achieved without clear guidelines that affect the optimal cancer care path. On the other hand, appropriate patient management will be influenced unnecessary regimens in unwonted locations by the lack of coordinated care. Roundtables from 148 institutions have been identified for this study. A 9-question survey was forwarded to an intellectual committee.

12.1. Radiation Oncologists and Medical Physicists

Radiation oncologists and medical physicists are medical scientists who specialize in fighting and killing various cancers in patients. Radiation oncologists administer cancer treatment that uses targeted radiation therapy. They use advanced technology, such as magnetic resonance imaging, to select the site and plan the volume of radiation dose it will take to kill the tumor [11]. Those plans are typed into a computer workstation where medical physicists use a Monte Carlo code program to simulate the radiation beam impingement. A dose-volume histogram is then computed to see where the planned dose is to be administered to cancer and to what extent. Radiation oncologists then look at a variety of statistical cancer related targets to optimize the radiation dose delivery. Medical physicists focus on optimizing the treatment plan that radiation oncologists prescribe to deliver to a currently hopeless cancer patient. Optimization methods include linear programming, constrained least-squares optimization (of dose and barrier functions), and sequential least-squares quadratic programming (reoptimization of fluence intensity vectors for fixed MLC shapes minimizing dose to OARs). Nonlinear optimization methods are mostly feasible; quasi-Newton and simulated annealing methods succeed with beamlet-based optimization.

12.2. Radiation Therapists and Dosimetrists

Radiation therapists are responsible for patient treatment; they position patients for treatment, deliver the radiation as prescribed by the radiation oncologist, and counsel patients about the treatment procedure. To deliver the correct radiation dose to the patient, it is necessary to care for daily patient positioning. A new tool has been developed to estimate the daily positioning error with a simple method with the regular immobilization device by simply counting the time of each operation. Radiation therapists and physicists can monitor the temporal accumulated positioning errors and adjust the margin if necessary. This framework allows the delivery of a more tightly focused dose to the tumor, which results in higher tumor doses and a lower dose to surrounding normal tissues [22]. Dosimetrists are the unlicensed complement of the medical physicists in the treatment radiotherapy group; they calculate the proper radiation dose to be delivered after the prescription from the radiation oncologist. A successful sophisticated verification process for the dose validation process has been developed to enhance their performance. A total of 383 measurements were conducted on 25 patients. Two head-and-neck patients were randomly selected for each week. For each selected patient, the wallpaper dosimeter attached to the mouth has been constructed, the treatment delivered, the actual dose was measured, and after the completion of all measurements, the dose from the XVMC also was made. During the six-month experiment, the dosimetrists prevented 15 cases of overdosage and 9 cases of underdosage, 90% of which were about 5-10 percentage differences of deviation. The results show that after implementing the sophisticated verification process model, dosimetrists can significantly improve their work performance.

12.3. Oncologists and Surgeons

Oncologists offer the primary line of treatment in cases of cancer, while surgeons play a significant role at various times in the diagnostic and therapeutic management process. The strategic positioning of both these types of medical experts is discussed and the various parameters under the control of each specialty that could potentially be integrated are examined [4]. In particular, investigations of the surgical parameters most likely to affect radiotherapy outcomes and the oncological parameters most likely to affect surgery outcomes are presented. In the context of these examples, the technical issues of creating space at the interdisciplinary border are discussed [11].

With this pile-up of increasing referrals, specialist oncological and surgical expertise will be restricted to the most severe cases, with the effect that no clinical expert will be in a position to follow the patient right through the disease from presentation to resolution or, where diagnosed late, to death. This problem is merely one of scale. Other drivers lie in the need for special equipment, techniques, and personnel to treat successfully many forms of cancer with chemotherapy, radiotherapy, or surgery.

13. Ethical and Legal Considerations in Medical Physics for Cancer Care

Medical physicists have well-defined knowledge, skills, and professional competencies in the application of physical and engineering principles to cancer care and are collectively recognised as medical physics experts. Ethical aspects of medical physics practice encompass the expectations based on the moral principles concerning the rights, duties, and obligations of medical physicists in their interactions with patients, safety of workers and the public, perceptions, attitudes and personal behaviour, and respect toward disadvantaged populations [23]. Legal aspects refer, on the one hand, to norms enacted by the legal authority that regulate essential and binding aspects of medical physics practice, including the competency standards of professionals, and, on the other hand, to different legal acts pursued by an offended party in case of violation of the provided legal norms. The development of requirements for professional ethics and suggestions for addressing legal and regulatory considerations in the International Atomic Energy Agency documentation, and to raise awareness of medical physicists about the importance of those aspects in order to reduce risks for medical physicists, other health workers, and patients, are presented. The Food and Drug Administration involves medical physics staff in several aspects of radiation oncology including approval of clinical protocol proposals, dose discrepancy metrics, and consultations.

14. Future Directions and Challenges in the Field of Medical Physics in Oncology

Brachytherapy involves the introduction of radioactive sources into or close to a tumour volume. This has been found to be effective in many cancer sites and important medical physics research is ongoing, especially in terms of 3D dose calculation algorithms for brachytherapy. This is very detailed particularly for high dose-rate (HDR) afterloaders, involving the use of miniature radiosensitive detectors, plastic water and Perspex phantoms, an Ir-192 source and linear accelerators, as well as the development of novel geometric modelling techniques. Dosimetry also needs to be verified for different sites and clinical situations, consultant physicist review should involve regular discussion with clinicians, and potential improvement or modifications in treatment delivery highlighted. Dosimetry data may be gathered in situations with unusual geometry and where the tissue has properties different from those used in the treatment planning system; correction factors may then be applied to the treatment planning system, affecting the prescribed dose. When phantoms are used care is needed to ensure they are accurately modelled; experimental and Monte Carlo methods suggest inaccuracies may result, particularly for low energies. Overall, it is important that a strategy is in place for the verification of the calculated dose and the audit of dose delivery [24].

15. Conclusion

Explosive growth in diagnostic and therapeutic medical physics research has generated quite promising technology, enabling in turn new powerful tools in cancer diagnosis and treatment. The result is a breakthrough in diagnostic methods, equipment used in diagnosis, and therapy, especially for radiotherapy. The appearance of radiation therapy apparatus with linear accelerators as source of radiation and the possibility of shaping the dose by means of multileaf collimators were the main steps to create new opportunities in treatment planning for radiotherapy. The paper shows examples of achievements in attempting to utilize these new possibilities. Either the comparison between some algorithms used in the treatment planning systems or the ways of optimizing the source shape by means of attenuators may be of interest. A few examples of approach to improve the results of conventional 2D or 3D treatment planning procedures are presented.

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