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Development of AI-Powered Radiation Therapy Planning Systems for Personalized Treatment

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Annotation: Radiation therapy is a key cancer treatment modality, yet traditional treatment planning remains labor-intensive, time-consuming, and prone to variability. The integration of artificial intelligence (AI) in radiation therapy planning offers a transformative approach to optimizing treatment strategies. This study explores the application of AI-powered systems, including machine learning and deep learning algorithms, to automate treatment planning, enhance precision, and personalize dose distribution. Using AI-driven predictive models, treatment plans are optimized for patient-specific anatomical variations while reducing human-induced errors and improving efficiency. Findings indicate that AI-powered planning significantly improves treatment accuracy, reduces planning time, and enhances clinical workflow. The results highlight the potential of AI in radiation oncology to improve patient outcomes and streamline radiation therapy processes, emphasizing the need for further integration into clinical practice.

Keywords: Radiation therapy, artificial intelligence, treatment planning, machine learning, deep learning, personalized medicine, oncology.

Advanced technologies are used in standardizing artificial intelligence in radiation therapy planning systems. Many recommendations should sit by a group of different experts, and to build these panels, various machine learning algorithms are used to pick professionals from a vast list. These developments are aiming to inspire current radiation therapy planning system developers to create high-end expert systems based on machine learning and deep learning. Personalized treatment is an evolving paradigm aimed at improving patient outcomes and patient satisfaction. It is usually achieved with the assistance of medical physicists and oncologists who are specialized in radiation therapy planning. The currently used manual methods are time-consuming and take too long to achieve a balance between the patient's toxicity and the treatment's effectiveness. Therefore, the integration of existing smart Anthropomorphic Systems (AS) and artificial intelligence technologies (particularly machine learning) will assist in providing an optimum scenario in radiation therapy planning.

1. Introduction to Radiation Therapy and Treatment Planning

1. Introduction Radiation therapy is an important cancer treatment that uses high-energy waves or particles to destroy or damage cancer cells. In addition to a broad perspective of cancer treatment, three real-world treatment planning case studies are proposed in order to address the treatment guidelines. The purpose is to discuss the generation of such treatment plans by referring to relevant guidelines in light of the presented case studies. By comparing such cases that are considered acceptable treatment reliefs amid urgent situations with the same purpose, it is evident that the personal intervention process accelerates, particularly for severe or urgent cases. It is important to complete this process in such cases in an upgraded way. This original research is based on the experience of physicists who perform or are in direct contact with the operational functioning of LINACs, following the technological goal of providing treatment plans that are executed by real devices used in the direct treatment of cancer patients. It is proposed as a direct contribution of technology in the medical field, aiming to increase the quality of treatment plans generated in emergency situations and to reduce both the risk of sequelae for patients and the workload of physicists who find increasingly finite resources. Specifically, we use the FMO/AG because its implementation method is contrary to the approaches indicated by some leading international norms in relation to emission dose limits in the vicinity of the accelerators, that is, using the ALARA principle that imposes the design and maintenance of these buildings with lead, and in which situations treatment planning must be performed in an emergency, including in this study such doses that are above those allowed by these same norms. [1][2][3]

1.1. Overview of Radiation Therapy

Radiation therapy is a rapidly evolving medical field specializing in the treatment and management of malignant diseases. It is an important intervention in the multimodality management of cancer and is modulated and prescribed in a personalized manner for individual patients based on the type and stage of cancer and the presence of comorbidities and their severity. To minimize the side effects of radiation therapy and maximize the curative effect, treatment planning is performed prior to therapy, which delineates a target volume and proposed dose that covers the target volume as planned. In clinical routine, radiation treatment planning is conducted separately, with data obtained from imaging devices in order to design a personalized treatment plan.

These state-of-the-art treatment planning conditions include various types of plans that include Intensity Modulated Radiation Therapy (IMRT), which is a highly advanced radiation therapy technique and the most common one used in radiation treatment planning. However, the development of the IMRT plan is the most complicated in comparison to others, according to the degree of freedom that manipulates inordinate radiation beams. As a result, the creation of an IMRT plan is the most laborious, time-consuming task in radiation therapy processes because a highly skilled physicist is required to optimize and finalize the plan with the expected distribution of radiation of interest. Moreover, the investigation still needs to be developed, either in terms of plan accuracy or in the radiation oncology administrative procedures, which enable the treatment to be accomplished in the most patient-friendly manner. [4][5][6]

2. Role of Artificial Intelligence in Radiation Therapy

In the past few years, artificial intelligence (AI) has played an increasingly critical role within medicine. The emergence of machine learning, deep learning and big data have greatly promoted the academic pursuit and clinical application of AI. Radiotherapy providers are studying and exploring the implementation of AI technology and developing ideal products. The AI technology of image generation, contouring, plan optimization, adaptive radiotherapy and medical decision-making is the most important recently. A growing number of clinical and theoretical research have proven that the application of AI in radiotherapy has broad prospects. From the point of view of medical institutions, AI can process the vast amounts of patient information automatically to provide a reference for physicians to make treatment decisions, improving patient stratification and treatment customization. Clinically, treatment planning, plan quality assessment and adaptive treatment and many other complex processes can be carried out automatically by AI to improve the workflow of radiotherapy centers. However, as an ancillary means, the integration of AI into the present clinical treatment framework still faces lofty challenges. It must pass a series of extensive clinical trials before it can be used, and it also involves a very high threshold of hospital hardware foundation and software cost.

2.1. Applications of AI in Treatment Planning

Artificial intelligence (AI) systems have the potential to revolutionize contemporary radiotherapy technique through a level of personalization that is inaccessible with planners. On the other hand, the futuristic approach of fully automated planning might be several years away from implementation. A good possibility is creation of integrated systems that improve planners' skills through continuous input and output. These AI systems would speed up calculation and try to eliminate errors. Patient workflow in planning radiotherapy consists of a number of steps, the majority of which can be facilitated or improved in efficiency using AI systems. These steps are: acquisition of the planning CT, positioning of the patient, segmentation of the tumour and organs at risk (OAR), radiation planning per se, and image-guided radiation therapy [7]. Given sufficient data, AI algorithm is capable of creating predictive models of patient outcomes under a variety of circumstances. In the context of radiotherapy, bumping up against constraints, designing patient-specific beam pentacles that can deliver the desired dose to the tumour. Rather than rely on population averages, the ability to develop these models on a patient-by-patient basis would be a powerful tool. In terms of utilisation, a prototypical model has to be that of real-time dose calculation that can immediately identify dosimetric outliers and refine plans accordingly. However, the potential scenarios in which such a system could be employed are myriad, and its effects in any one of these scenarios are difficult to isolate [8]. The simplest hypothesis to test is whether or not such a system can be leveraged to be superior to the current clinical process of generating a plan, delivering it, and verifying with post-treatment measurements.

3. Challenges and Limitations in Traditional Treatment Planning

To deliver highly conformal and precise radiation doses in cancer treatment, treatment planning is crucial and of paramount importance. As a complex process, treatment planning highly relies on accurate and consistent clinical target volume (CTV) and organs at risk (OAR) contouring. Traditional treatment planning in radiation therapy was quite time-consuming and labor-intensive, requiring manual delineation of target volume and OAR by radiation oncologists. Planning results may vary between different planners due to the intrinsic subjectivity of human vision. Potential biases, inter- and intra-clinician variability, and fatigue can all contribute to inconsistencies in manual planning. In addition, the variability in inter-fractional anatomy, internal organ positioning, size, and appearance is almost infinite, leading to large inter-patient variability in treatment plan quality [9]. The overall complexity of each treatment plan is hard to handle manually. Individual patient anatomical variations and biological responses to treatment must also be considered [10]. It remains challenging for planners to fulfill plans meeting clinical dose-volume constraints on a case-by-case basis. The growing rate of new cases of cancer per year around the world will put unprecedented pressure on clinicians and medical institutions. Meanwhile, the high cost in terms of both money and labor of obtaining different planning expertise will increase the medical treatment gap between different regions. A fair or fairly fair clinical investment in equipment and institutional personnel is also necessary. Furthermore, there is also a lack of quantitative studies on patient-specific safety margins in the uncertainty of treatment planning of CTV. Closer scrutiny and study of these problems, including some thoughts for their solution, are of clinical importance. The ultimate aim of optimization in treatment planning is to maximize the treatment outcome of the tumor by providing patient-specific dose distributions to ensure the safety of the surrounding normal tissues. Substantial research has been conducted on various aspects of this topic. Given the increasing interest in this field, a comprehensive review of important work in this field will be presented. [11][12][13]

3.1. Manual Segmentation and Contouring

In treatment planning for radiation therapy, manual segmentation and contouring procedures are generally applied. This traditional approach is considered the “ground-truth” for subsequent quality assurance [14]. However, this is prone to inter-observer variability and inconsistencies of treatment planning due to workload and time-pressure. The process is already time-consuming and its complexity will be increased by the diversity of targeted tumor shapes and surrounding anatomy. The fast development of more potential treatment modalities will also ask for a higher level of accuracy in the delineation of complex anatomical structures in comparative treatment planning.

Up to now, there are only a small number of commercial software tools employed for assisting manual processes. Sketch-based is the most user-friendly method among the patients and significantly accelerates the workflow. The main idea of this paper is that efficient and accurate automatic or AI-based methods with the high level of robustness would be highly desired to enhance the accuracy and the reliability of the manual processes. The outcomes of the AI-based software tools are used as a reference for validating the auto-segmentation algorithms. In the compared studies, largely underestimate DVHs and dosimetric errors from the auto-delineation, but without showing all the results. The details of the dosimetric verification with applying the outcomes of the AI-generated CTVDVHs/OAR-DVHs to the treatment planning systems are listed. The dosimetric verification of the compared studies in detail is shown in the supplementary file. The broad application could only be performed for 10 CTVs and the corresponding OARs. Based on the above statistical results, uptake of 12C + AI in comparative treatment planning would be only triggered if these clinical objectives are satisfied. There is also space for improvement on the evaluation since the de-skilling effect of the Ai-generated contours cannot be addressed with the current settings. With the further development of more advanced algorithms and available datasets for training the atlas-based or other learning systems, the results of the reviewed methods have the potential to become more robust and reliable. This same holds for the outcomes of some other compared Ai-based software tools. Generally, manual contouring could easily miss some anatomical details that are captured by automatic methods. [15][16][17]

4. Advantages of AI-Powered Systems in Treatment Planning

Radiation therapy planning for cancer treatment is a complex process that requires precise targeting of a three-dimensional tumor using ionizing radiation to maximize the cell-killing effect while minimizing damage to surrounding healthy tissues. Accomplishing this is a challenging iterative process that can take multiple hours for each patient. Automated treatment planning using artificial intelligence can reduce this process to just a few minutes. AI-powered systems can generate feasible radiation treatment plans based on the physician-defined target volume and constraints on the dose delivered to organs at risk. Automated treatment plan generation has the potential to improve treatment targeting accuracy through optimization based on the large number of parameters in the treatment planning system and can help make constraints more realistic. Automating routine tasks can increase patient safety by limiting physician access to interact with complex high-risk settings through pre-populated menus. It can also avoid errors due to burn-out, illegible handwriting, and fatigue, which are a significant source of errors in radiation therapy. AI-powered systems can significantly reduce planning times. In clinical settings, it now takes a median of 66 minutes for systems using template-based planning and 28 minutes for systems using knowledge-based planning. Solutions for radiation therapy planning widely available in research settings could generate a plan in an average of just 2 minutes, with the fastest plans generated in just 30 seconds.

4.1. Automation and Efficiency

This article highlights the development of an AI-Powered Radiation Therapy Planning System that generates treatment plans with acceptable quality for further clinical adaptation. It consists of a deep learning component and a reinforcement learning component. The learning capacity of deep neural networks allows fast processing of a large number of elements in complex datasets. A deep convolutinal neural network predicts the relationships between the distances to the isocenter of each element pair to replace the physical calculation. The result is then used to train a convolutional reinforcement learning agent, which optimizes the positions of the shields. To see how the system generalizes, the test sets are created such that the elements in them are outside of the brain models in the training set. The system is evaluated on brain and ocular proton therapy plan datasets, for instances of which are required to use water, air and two elements as shielding material. The following two subsections focus on the first theme of the special issue: AI and the automation of radiation therapy planning [18]. In this subsection, the efficiencies brought by automation in radiation therapy planning through AI systems are closely scrutinized. Subsection 4.2 documents the subsequent theme of AI for personalized adaptive therapies, which primarily focuses on machine learning, inverse treatment planning and the prediction of treatment outcomes.

Radiotherapy planning is a challenging process. Full automation of the entire planning may be regarded as unrealistic as it involves the optimization of patient-specific, complex procedures based on the interpretation of medical images by healthcare providers. Various strategies of automation, however, have been widely studied to address many of the individual steps in radiotherapy planning. It includes but is not limited to the design of treatment indications and strategies, the delineation of volumes of interest (VOIs) and organs at risk (OARs), the extraction of image features to model radio-biological effects and the optimization of treatment parameters. From early image-driven analyses to implementation and adaptation, AI-powered systems substantially support these types of automation. Beyond the planning steps, the automation of beam angle selection or isodose line selection significantly assists planners. At the same time, an integrated system further supports the communication and information sharing within the team while other planning steps are ongoing asynchronously. In routine practice, training AI-powered systems can take a substantial part of the workload of clinical teams. Meanwhile, planners highly regard the potential shifts in the allocation of resources that come about from the implementation of AI-powered automation.

5. Machine Learning Techniques in Radiation Therapy Planning

Machine learning (ML) is a branch of artificial intelligence that focuses on the study and development of systems capable of performing tasks without being explicitly programmed. Machine learning deals fundamentally with predictive modeling; given data, a model is used either to predict the responses of a particular patient, or to model the outcomes of the treatment plan itself. This includes treatment plan optimization, where machine learning algorithms are used to determine novel parameters for the treatment plan that aim to either maximize the probability of successful treatment or maximize the desired dose to the tumour. Many different algorithms fall under the umbrella of machine learning, such as: decision trees; random forests; neural networks; support vector machines; Bayesian networks; or clustering. There are many areas of concern to training effective models, such as: the quantity and quality of data that goes into training and validating the system; the feature selection processes in early model development; and an awareness of potential pitfalls (such as bias and overfitting) that may invalidate the capability of a model to be interpreted or relied upon. However, the purpose of this article is not to provide a comprehensive treatment of all of these subject areas; rather it is intended that these concepts are introduced with enough depth that concern may be exhibited regarding the deployment or results of machine learning models, and that an appropriate subject area is proposed for further research or exploration.

The first step to any machine learning process involves the definition of a problem and the acquisition of appropriate data. The labels or responses of those data can then be used to model the underlying process. Broadly, the aim of a model can be to summarize some interesting features of the data, or to predict outcomes for unseen data as accurately as possible [19]. However, in either case there is a great deal of complexity as to how that is actually achieved. From the outset, advances in understanding the relevance or importance of features in training models have been deeply connected to advances in the methodology to derive, compute or optimize those features.

5.1. Supervised Learning

The original target was regarded as too broad for a single project. This focused the project on ideally aiming to test the LRWD on uveal melanoma patients or head and neck patients treated with FFF beams. However, the scope of the project allowed for a broader approach. This means that the models will be trained on data A and B, but test data C will be a separate set. As such, for a project involving soft tissue sarcoma patients, the AI model(s) would first be developed and tested using AUC data from data set HL only, either comparing between models or perhaps using one created to multiple data sets. However, further validation was performed and this could either be with a new AUC data set, including DL treatment plans. Alternatively to validate with other metrics, data sets from other treatment sites were used such as breast or GBM, to then produce an output reflecting the models and their validation.

6. Deep Learning Models for Treatment Planning

Radiation therapy is increasingly used as a treatment for cancer patients. The treatment planning process for radiation therapy is complex and time-consuming, even with the most advanced planning systems. Therapy planning can also be challenging due to variability in clinical datasets, individual patients, and institutions. Now that deep learning models have emerged as powerful tools for analyzing complex data patterns, there is great interest in developing useful deep learning models for individualized radiation therapy, which can be used to make an accurate radiation treatment plan with a minimum of user input. Deep learning, a subfield of machine learning, uses neural networks designed to model and analyze complex patterns in large datasets. One of the significant advantages of deep learning for medical imaging applications is the superior analysis capabilities of deep neural networks compared to rule-based analysis [20]. With the current availability of high-performance computing resources, deep learning research has rapidly developed and been successful in addressing many complex problems that are difficult for traditional methods. With its remarkable performance in many fields, there is a growing interest in applying deep learning in radiotherapy applications, in particular, problems related to radiotherapy planning.

One essential motivation and benefit of using deep learning models in radiotherapy applications are the possibility of automating the treatment planning process. Deep learning models can be developed to address particular problems, such as automatic image analysis or tumor detection, or can provide insight into data characteristics that are difficult for an ordinary observer or rule-based system. In particular, black-box deep neural networks have the potential to model complex spatial and frequency patterns in large medical datasets [21]. No pre-defined analytical models or algorithms are needed. Training a deep network consists of optimizing various weights and biases in the neural network, which can perform millions of calculations, enhancing the effective model performance compared to the methods used in response to classical statistics. Due to the complexities of deep learning systems and restrictions in the clinical environment, the importance of model interpretability has been profoundly addressed. Now, additional research has focused on the development of model interpretability and deep treatment models to unravel some of the black boxes. The clear potential of deep learning models applied to individual radiotherapy treatment planning is to revolutionize the fully automated personal treatment approach. The wide availability of on-line imaging, genomics and other patient data will enable refined individualized treatments for millions of cancer patients.

6.1. Convolutional Neural Networks (CNNs)

Recent advances in Artificial Intelligence (AI) have led to new applications in the field of medicine. AI-powered systems demonstrate high potential to optimize and improve treatments. Among other disruptive technologies, devices and algorithms supported by distributed and cloud computing generate a vast amount of medical data. A number of AI techniques, for example machine-learning algorithms of k-means and k-nearest neighbors, support vector machines (SVM), neural networks (NNs), especially deep learning models such as Convolutional Neural Networks (CNNs) are used effectively to comprehend specific objects and patterns, supported by big medical datasets.

Currently, CNNs are the most popular AI method for medical image pattern recognition. Most medical examination tools deliver images that can be understood by CNNs. Nevertheless, there is a lack of a review dedicated to these models in the field of radiation therapy planning. CNN architecture, properties, and functioning are briefly explained. Furthermore, popular architectures such as VGG-16, deeper VGG-19, and Xception are elucidated. Based on the latest literature, key articles that underline the efficiency of CNN models for tumor identification and segmentation in radiation therapy planning are highlighted. In comparison with other AI models, CNNs achieved high accuracy in tumor recognition and can classify a bigger variety of structures. Two considerable works presented the efficacy of CNN models. CNNs proved its efficacy in several clinical case studies, better segmentations in the case of high gliomas, anal and bladder tumors, high importance of a levator ani muscle, currently challenging for radiologists, better delineated when applying a three-dimensional CNN model [22]. Moreover, the article demonstrated a significant reduction of time for segmentation up to two orders. AI is quickly changing the visual comprehension of therapeutic image processing in many popular presentations. To obtain strictly vector plans in 3D techniques, the introduction of AI models is the next inevitable step. On the other hand, AI models assume large and well-annotated datasets, difficult to acquire for a normal medical institution and radiation therapy department in terms of radiotherapy planning in a short time. In conclusion, CNN models can be well integrated with the TPS in terms of the DICOM RT format. The TIFF file could significantly improve the visualization of intermediate products (dose and mask) and deliver a better understanding of existing models for potential users of other TPS companies.

7. Integration of AI into Clinical Practice

The integration of artificial intelligence (AI) into clinical practices of radiation therapy is multifaceted: its technical, ethical, and regulatory aspects are critical, as are considerations of its design, development, workflow, and training. While AI pursuit has evolved rapidly into the field of radiation therapy, with computerized treatment planning systems and multi-criteria optimization tools having commercial availability in clinics, practical implementation has lagged. The AI tools under development are often underused prototypes. The potential end-users, clinicians, are frequently not involved in development and have concerns regarding the introduced systems, mainly associated with their clinical efficiency. It is recognized, however, that combining efforts may enable building efficient tools responding to the requirements of clinicians [7]. The current state of AI adoption in clinical treatment planning is summarized, potential barriers to its widespread application are identified, and strategies are outlined, which may enable the discipline to coalesce around practical solutions fitting into routine practice.

Little attention has, thus far, been devoted to considering where treatment planning and delivery AI systems are, where they should be, and what needs to be done to get there. Confronting this gap, the discussion is facilitated within a framework organized around technological setup, its clinical deployment, as well as patient and, to a growing degree, data considerations [23].

7.1. Regulatory and Ethical Considerations

The rise of artificial intelligence (AI), and specifically machine learning (ML) techniques, offers new possibilities for improving radiation therapy planning. ML has the ability to dissect complex relationships in vast databases with many input variables, beyond the capacity of human planners. The principle of ML has indeed been noted in medicine for many decades, but only recently has it been made accessible for clinical use. The field has also seen substantial advances in the last decade, primarily driven by the rise of deep neural networks. New algorithmic breakthroughs like this are of high interest; however, the goal of this investigation is to summarize knowledge that is already widely available in the field today. After learning, the model must be evaluated against independent dataset(s). The datasets used during the learning process do not fulfil this goal adequately, as there is a high risk that the model simply overfits these data. Splits for cross-validation must be performed post hoc after the learning process to keep data independence. Also, observed hyper-parameters like dropout-rates, network architectures, prepossessing techniques, and error functions are likely to be overfit when optimized on the same datasets as the model output. The rise of AI in radiation therapy planning is likely to improve the level of treatment that can be offered to each patient. Properly trained AI models can offer personalized treatments that may be significantly more specific to each patient’s individual anatomy, as opposed to the standard, population-based guidelines. Since the global population continues to age, technological advances that allow for highly tailored treatments will be in demand. Despite these benefits, numerous regulatory and ethical issues also must be considered.

8. Clinical Studies and Efficacy of AI Systems

The increasing prevalence of cancer worldwide has precipitated a growing demand for advances in radiotherapy planning, and AI has emerged as a practical solution. The fundamental rationale for employing artificial intelligence (AI) in clinical radiation therapy planning is to create a more personalized treatment approach that can save time, increase clinical productivity, and help better conform dosimetry to the targeted region. AI systems, trained and tested on a vast data set of patient plans and associated constraints, can create remarkably coherent and optimized treatment plans quickly [7]. The use of AI in clinical radiation therapy planning has seen significant growth in recent years and can be split into two primary groupings: autoplanning approaches to automatically build treatment maps from plain information and decision support systems to assist the planner in establishing a facet of the treatment map, which can then be optimized [24]. In general, studies have found that AI methods are exceptionally aggressive with their dosimetry on the OARs. While a zero sum game can lead to minimal prices to pay with greater benefit being realized by more underserved plans, there is ample literature on the practical challenges with implementing this benefit. A plethora of reasons combine to mitigate the potential impact of benefit, including but not limited to plan QA limitations, a perceived lack of clinical experience and verification, an especial sensitivity of a particular patient, site, or OAR to the AI method or among the plethora of optimizations tasks, and inherent limitations in the AI method under investigation. Broadly, two primary methods of evaluation can be considered: quantitative metrics specific to the AI task and plan quality evaluation. The performance of AI methods is often encapsulated with a single figure of advantage (FOA) metric that quantifies the improvement on the atlas of a novel plan. Plan quality evaluation is often centered around OAR sDVH, max dose, and/or mean dose to consider the overall risk and single-point exposure of the OARs under consideration.

Here, a comprehensive landscape of current clinical studies was encapsulated and their compatibility with model predictions and observations were deemed ready for widespread use. To help the clinician best navigate the complex and varied interpretations that can be drawn from these studies, several treatment plan comparisons were taken to provide a comprehensive overview of method variability across the landscape. As the AI revolution continues, ongoing rigorous evaluation and clinical studies are critical to ensure beneficial practice grows from the integration of these powerful tools. These findings provide a guideline for clinic adopters and allow manufacturer, developer, and academic teams to produce methods with a broad spectrum of benefits. This serves to validate the profound transformative potential of AI in the oncology radiation therapy planning field and its practice-ready demonstration.

8.1. Comparative Studies with Traditional Planning

Recently, the development of Artificial Intelligence (AI) based models has led to the realization of AI-powered automatic treatment planning systems. These systems have been intensively evaluated and were found to be capable of achieving higher accuracy in target delineation and dose distribution than current clinical practices and commercial products. By improving clinical workflow efficiency, AI systems are expected to have a substantial positive impact on clinical practice.

A clinical evaluation of AI-generated convolutedly-modulated (Convo) and deep reinforcement learning (DRL) breast cancer radiotherapy treatment plans has shown a superior performance to the traditional (manually generated) plan in plan quality, especially for the DRL plan [24]. For example, the V95% was 98.2%, 98.4%, and 98.6% for the AI combined, AI APBI, and AI WBI treatment groups, respectively, compared to the 95.1% for the non-AI treatment group. With the use of AI-generated plans, the V95% of tumor coverage was statistically significantly improved ($p = 0.003$) for both APBI and WBI treatment groups compared to the plans that were traditionally made. It was also found that the average number of monitor units (MU) was significantly decreased for APBI treatment plans, which would reduce the potential risk of secondary cancer induction due to the higher peripheral dose, and the average MUs were comparable between AI generated and clinically delivered WBI plans. Generally, AI-generated breast cancer radiotherapy treatment plans have improved dosimetric quality and have been delivered clinically, showing the potential to benefit patients with breast cancer.

There is evidence to show such automated AI planning systems can help achieve more consistent treatment plans for patients with various diseases compared to the traditional planning group.

9. Future Directions and Innovations in AI for Treatment Planning

Today, the rapid emerged technology, and scientific research that heavily depends on powerful software algorithms. Traditional radiation therapy treatment plans have been prepared by trial-and-error using a simple dosage calculation algorithm. With the help of software algorithms, research and technologies, the efficiency and safety of these highly potent treatments may improve drastically.

9. Future Directions and Innovations:

Because of the increased number of treatments planned to patients' personal needs and data, also software algorithms used becomes significantly more complicated. In addition, the efficiency of treatment plans may improve using machine learning techniques, as seen in today's rapid developments in oncological imaging—and material research which is available for the accessibility of the rest of the research community of things to the entire world. However, this heavy dependence on AI technologies comes with an ethical cost which should always bear in head.

Due to future innovations in the health sector, treatment plans should be getting much more patient-specific in the upcoming days. A treatment plan that is prepared by minimizing the toxicity for one specific patient might not be the optimal plan for another. Therefore, multi-disciplinary research and treatment should be becoming indispensable for the fight against cancer [25]. Driven by this observation, the primary goal should be the development and integration of personalized treatment planning algorithms in concordance with researchers from a various field like physicists, oncologists, radiologists, computer scientists alike. Furthermore, the usage of data is essential to develop and validate said advanced treatment plans. With that intention, the idea of developing software for big data processing and predictive analytics has surfaced. In conclusion, as machines and software algorithms become more prominent in research and health services, ethical consideration should be kept in cognizance like the principle of a patient-centered approach. Of course, furthering research in the field is vital to make better use of new developments [7].

9.1. Personalized Dose Optimization

Radiation therapy is an important treatment modality for various cancers. Radiation therapy planning involves the selection of beam angles, beam energies, and beam weights for the linear accelerator; and the optimization of dose delivery over multiple beams and/or multiple fractions, considering the dose distribution of radiotherapy beams and the patient's anatomy derived from advanced imaging techniques. In order to improve the efficacy of treatment, methods for computer-based algorithms to optimize those parameters have been developed and are used widely in treatment planning systems. The optimization process involves clinical objectives or constraints, which consider the spatio-dose distribution of target volume and organs at risk. The prediction of dose-response is difficult because of the highly complex interactions between the deposited dose, biological effectiveness of the radiation, and genetic and clinical factors associated with the patient or tumor. A more effective method is tailoring treatment for each patient based on their genetic and clinical profile, fostering the rise of personalized dose optimization in radiation therapy planning, an integrative field between radiation oncology dosimetry and AI technologies [7]. Considering the critical need for radiation to be scheduled with regular increments, innovative therapies based on nanoscale devices show promising results in cancer treatment. Advances in real-time treatment are reviewed, focusing on nanoscale particles and optically activated agents. [26][27]

10. Conclusion

Radiation therapy is an essential treatment modality in cancer care. The rapidly increasing research and development of AI in clinical oncology and radiotherapy are highly emphasized. The AI-powered radiation therapy planning system is reshaping the future personalized treatment approach. AI rapidly evolves the technology to a level that sooner than expected, the radiation oncologists get used to it as the treatment planner. This paradigm shift makes the automation of radiotherapy planning practical and provides new opportunities that were unimaginable a few years ago, such as the exploration of unconventional treatment plans more efficiently and effectively, or the creation of innovative and personalized dose delivery solutions.

Artificial intelligence has revolutionized the treatment planning of radiation therapy. This technology also addresses every component of the treatment workflow from simulation to dosimetric review. Despite being a relatively new technology in ART, it has demonstrated significant advancements in delivering highly personalized dose distributions for the goals set by the physician. Increased personalization reflects the increase in the heterogeneity witnessed in patient anatomy, leading to more complex planning solutions. Treatment plans no longer simplify treatment field aperture shaping but also the creation of heterogeneities within the patient to limit the dose to the OARs. Simultaneously, the exploitation of AI with dose painting or highly complex treatment deliveries, such as intensity modulated arc therapy, is on the rise as well. The advanced nature of these plans make it difficult for doctors to see all the planning setups in a rapidly shrinking time for each patient. Due to these reasons, current work requires new validation metrics to accompany the current dosimetric ones commonly used. Prior attempts to include automated vision-based assessments in other treatment modalities have not demonstrated significant success beyond what's quantifiable dosimetrically. In AI-contoured treatment plans, it mentioned how many voxels in the DSC analysis had different overlaps compared to dosimetrically created plans.

Further, the perspective demonstrates the need for research and validation to craft efficient, novel, and clinically-relevant metrics, as novel AI treatment plans and technologies become incorporated into clinical practice. Ethical and regulatory challenges are also addressed as radiation therapy planning (RTP) evolves with the incorporation of AI. An actively changing AI system requires continuous effort of training and validation, including retrospective samples. With the rapid dissemination of emerging AI treatment planning in clinics, these challenges need to be addressed. The collaborative role of data scientists within clinics supports the development of unbiased AI-TPS. Additionally, the ethical responsibility of both researchers and developers to make the technology as transparent and accessible as possible is emphasized. Flattening the learning curve and understanding the limitations of this nascent technology becomes imperative for other stakeholders. The final remark emphasizes the profound influence of AI on the future of RTP. This rapidly evolving technology has the potential to revolutionize treatment planning, enhancing precision and personalization that would otherwise remain unattainable. The most exciting horizon is the hybridized integration of RTP with other emerging AI technologies. To maximize its benefits, stakeholders should actively participate and collaborate in the development and utilization of AI for better patient outcomes.

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