




**BME 704– Radiation Therapy Devices**

**Design of Radiation Treatment Planning Software**

<b>Semester/Year</b>	F2024
----------------------	-------

<b>Instructor:</b>	Victor Yang
--------------------	-------------

<b>Student Name</b>	<b>Student ID xxxx12345</b>	<b>Signature</b>
Marija Simic	24933	
Sidra Sayed	95234	S.S
Sravya Reddy Yammanuru	91452	Y.S.R
Tahsin Islam	20879	T.I
Jermaine Walters	38764	J.W
Aiden Van Greuning	40587	A.V
Rachna Patel	88917	R.B

By signing above you attest that you have contributed to this written lab report and confirm that all work you have contributed to this lab report is your own work. Any suspicion of copying or plagiarism in this work will result in an investigation of Academic Misconduct and may result in a 0 on the work, an F in the course, or possibly more severe penalties, as well as a Disciplinary Notice on your academic record under the Student Code of Academic Conduct, which can be found online at: [www.ryerson.ca/senate/current/pol60.pdf](http://www.ryerson.ca/senate/current/pol60.pdf)

# Design of Radiation Treatment Planning Software

Marija Simic (xxxx24933), Sidra Sayed (xxxx95234), Sravya Reddy Yammanuru (xxxx91452), Tahsin Islam (xxxx20879), Jermaine Walters (xxxx38764), Aiden Van Greuning (xxxx40587), & Rachna Patel (xxxx88917)

## I. INTRODUCTION

Substantial challenges remain in achieving both optimal and personalized radiation therapy treatment via patient specific customization despite significant advances. There is still a delicate balance that has not been achieved in current treatment planning where there is precise targeting of the tumour while collateral tissue damage is minimized. Thus there is a critical need for innovative solutions that can integrate computational modeling, intelligent algorithmic approaches and advanced imaging techniques seamlessly. This research project aims to address that critical need by developing a comprehensive software solution that combines methodologies from artificial intelligence (AI), machine learning (ML) and medical imaging such that radiation therapy delivery is revolutionized.

## II. BACKGROUND

Radiation therapy is a pivotal tool in oncology, relying on advanced technologies to maximize tumor targeting while minimizing collateral damage to healthy tissues. The integration of AI and ML into treatment planning software has significantly improved the precision and adaptability of radiation delivery. AI-powered segmentation tools now enable the seamless integration of imaging modalities such as computed tomography (CT), magnetic resonance imaging (MRI), and positron emission tomography (PET) to produce highly detailed 3D models of patient anatomy. These models are crucial for identifying tumors and organs at risk (OARs), with dynamic adaptation to anatomical changes like organ motion during respiration, ensuring precise radiation delivery throughout the treatment cycle. [1] Accurate dose distribution modeling is further enhanced by Monte Carlo simulations, which are widely regarded as the gold standard for simulating radiation transport and interactions within tissues. By accounting for

stochastic variations in particle behavior, these simulations allow for precise adjustments in dose calculations, particularly in techniques like intensity-modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT) [2]. VMAT, for instance, provides continuous radiation delivery across multiple angles, improving dose conformity, reducing treatment times, and minimizing exposure to adjacent healthy tissues [3]. In addition to EBRT, other modalities such as brachytherapy, which involves placing radiation sources close to or within tumors, and proton therapy, which uses protons instead of X-rays to achieve precise dose distributions, expand the versatility of radiation treatments [4]. By leveraging AI and ML to analyze historical patient data and refine algorithms, modern treatment planning software not only personalizes treatment but also continues to evolve in accuracy and efficiency, ensuring better outcomes for patients and advancing the field of radiation oncology [5].

## III. PURPOSE

The purpose of this project is to develop a radiation treatment planning program that deals with the current issues of accuracy, flexibility, and radiation therapy patient-specific treatment optimization. To improve treatment accuracy while reducing the negative effects on nearby healthy tissues, this innovative software attempts to combine cutting-edge imaging methods, artificial intelligence, and machine learning algorithms. By incorporating adaptive planning capabilities and simulation models, the software will improve the efficiency and personalization of radiation therapy. By offering a solution that not only meets present clinical requirements but also helps in forming the baseline for future developments in radiation treatment planning, this project aims to advance the field of medical technology.

#### IV. DESIGN CONCEPT

##### *Theory*

The radiation treatment planning software will incorporate and integrate multiple different platforms to ensure that the treatment plan is carefully optimized and verified to ensure safety and efficacy. The software would integrate/connect to imaging softwares such as CT, MRI, or PET scans, and import the patient-specific imaging data. With the imaging data and image segmentation tools, a detailed 3D and 4D representation of the patient's body/organ will be created. The segmentation tools will be AI-powered, and are used to contour the anatomical structure of the tumor and organs at risk (OARs). The software will adapt the contour in response to real-time imaging, which will account for change in the patient anatomical structure, such as organ moving during breathing, during treatment [6].

Past radiation treatment data will be stored on the software and used for machine learning and algorithm development for dose calculation. The past data and cases will be used in order to compare the current patients' data, diagnosis, tumors, and anatomical structure to create dose calculations that would be appropriate for the specific patient. Deep learning algorithms such as the Convolutional neural network (CNN) will be used for image processing of the x-ray images to be able to detect the differences between tumors and normal tissues. X-ray images will be fed to the algorithm and based on the contrasts of the tissues on the images, the algorithm will be trained to be able to identify cancerous/tumour tissue. The dose calculation will display how the radiation will be distributed through the body with the integration of a simulation model, such as the Monte Carlo simulation. The simulation mimics the treatment and will allow the clinicians to adjust parameters such as beam energy, angles, shapes, and intensity including the difference between intensity-modulated radiation therapy (IMRT) or volumetric modulated arc therapy (VMAT) [7]. The software will display a timeline of the effects the radiation will have on the tumor and surrounding tissue. Different treatment plans will be offered for comparison for the clinician to choose which one will be best suited for the patient's specific needs and circumstances. The software will be able to support three types of radiation therapy: External Beam Radiation Therapy (EBRT), Brachytherapy,

and Proton therapy. EBRT is the most common type of therapy where the beams are delivered from outside the body [8]. Brachytherapy involves having the radiation source being placed inside or next to the tumor, and Proton Therapy uses protons instead of x-rays for delivering the radiation [8].

##### *Detailed fabrication*

The software infrastructure will use the programming language of python and C++. Python will be used for handling script, machine learning, and integration tasks, whereas C++ will be used for real-time processing of data. The machine learning frameworks will include the implementation of PyTorch and/or scikit-learn. These frameworks will train and implement deep learning algorithms for segmentation and adaptive planning of the radiation treatment. Integrated within python and C++ will be medical imaging libraries such as the Insight Segmentation and Registration Toolkit (ITK) and the Visualization Toolkit (VTK). The libraries will be used to create the 3D and 4D models of the patient's organs/body. The software will follow the Digital Imaging and Communications in Medicine (DICOM) standard for important medical imaging. Libraries like the DCMTK or the GDCM will consolidate and ensure a seamless transition of the hospital medical images. All data will be stored in a HIPPA approved database, such as PostgreSQL. Previous treatments, patient data, and machine learning parameters will be stored in the database and encrypted to ensure privacy and data security. The dose calculation and simulation will be created by a Monte Carlo simulation framework that is built on Geant4 [9]. Geant4 is an open-source tool kit that stimulates the passage of particles through different tissues and calculates the dose distribution [9]. Beam and parameter adjustments will be modifiable because of a graphical user interface (GUI) built with React. The software will continuously learn and adapt from stored patient data and real-time image and therapy processing to improve efficiency, accuracy, and personalization.

##### *Testing & Validation*

The software will undergo multiple phases of testing before clinical use approval :

- I. Bench Testing/Software Validation
- II. Phantom Studies
- III. Clinical Trials and Validation

#### IV. Safety and Efficacy Testing

**Bench Testing/Software Validation** - Each algorithm will be rigorously tested compared to benchmark dataset. Accuracy and precision of the algorithm will be evaluated to ensure the results meet the clinical requirements.

**Phantom Studies** - The software and simulation will be tested on phantom models, artificial tissue and organs. The dose distribution will be taken from the phantoms and compared to the software values to validate the accuracy of the simulation. The software's ability to process different medical images will also be tested using phantoms as it will verify if the image and contour of the tissue is correct.

**Clinical Trials and Validation** - A small scale trial will first be conducted to compare the outcome of the software to pre-existing softwares. The patient's outcome will be tracked and compared to historical data to see if there is an improvement. Treatment planning time, accuracy of dose of delivery, minimizing damage to healthy tissue, results of the tumor, and clinicians satisfaction are all parameters which will be noted.

**Safety and Efficacy Testing** - The software will be tested to ensure it is in the acceptable parameters of medical device regulations and radiation regulations such as: International Commission on Radiological Protection (ICRP) and International Commission on Radiological Units (ICRU).

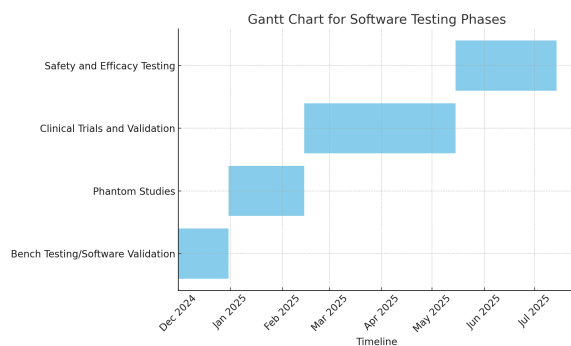


Fig. 1. Gantt Chart for the Software Testing Phases

#### Limitations

External Beam Radiation Therapy (EBRT) is the most commonly used and available modality in

veterinary medicine [10]. EBRT uses a machine to aim either x-ray, gamma ray photons, or electrons at a tumour from a distance; the electrons are used to treat superficial lesions like sarcoids and other cutaneous tumours and scars, whereas the gamma ray photons are used to treat deeper tumours like lacrimal duct tumours, nasal, and oral tumours [10]. EBRT has become increasingly more available and in demand for treating small animals such as dogs, who are usually treated with these beams using manual dose calculations. But there has been an increase in demand for the use of EBRT in treating larger animals such as horses. The difficulty in treating larger animals is due to a multitude of reasons. To effectively use EBRT, further imaging using a radiograph for bone tumors, a CT scan, or an MRI scan is needed to accurately define the volume of a tumour within a deep tissue [10]. After which, the normal tissues are identified to avoid damaging them. These scanned images are uploaded to a planning software to contour the tumour and normal tissues to differentiate between them, and then the oncologist determines the number and orientation of beams and the software then calculates the dose required [10]. One of the difficulties that arise when applying this practice on larger animals such as horses is that a special table would be needed to handle the weight of the animal, and the materials used to make these tables must be compatible with the MRI/CT machines, and because of the limited size available in the MRI bore/CT gantry, only some parts of the large animal can be scanned properly [10]. Another difficulty is that these larger animals are put under general anaesthesia, which makes tumours in the dorsal aspect of the head tough to treat with the restricted gantry angle [10]. These difficulties lead to limited or inaccurate details to be recorded, which makes it difficult to use our planning software effectively to provide accurate dose calculations and makes it harder for oncologists to create an effective treatment plan for these larger animals.

Brachytherapy on the other hand uses the TG-43 formalism, which is based on single-source dose superposition within an infinite water medium without accounting for the true geometry in which conditions for scattered radiation are altered by the presence of air [11]. A limitation that was discovered for brachytherapy is the amount of scattered radiation that occurs, which leads to inaccurate dose calculations to be made by the planning software. To avoid this drawback, the use of a bolus is

recommended so that the radiation can be focused on the selected area and the dose calculations can become more accurate for the targeted tumors without affecting the surrounding tissues [11].

Proton Therapy involves laser-acceleration of proton beams that are pulsed with very short bunch times which causes a high number of protons to be delivered within one laser shot, which cannot be portioned or modulated during irradiation [12]. This simulated beam line and its assumed shape of the proton spectrum makes it impossible to produce clinically acceptable treatment plans that can be delivered in a reasonable amount of time [12]. Through the use of a method or a device in the beam line which can modulate the number of protons from shot to shot, we can optimize these proton beams and make them more suitable for our software to evaluate to produce more accurate dose calculations and treatment plans [12].

### *Safety*

In developing our software, safety is our top priority. We are planning on using advanced AI-driven imaging to precisely target tumors while protecting surrounding healthy tissues. Real-time imaging adjusts radiation doses during treatment, ensuring accuracy and safety. We will strictly be adhering to international safety protocols and standards set by the International Commission on Radiological Protection (ICRP) and the International Commission on Radiological Units (ICRU), ensuring our device meets global safety requirements. Our radiation delivery approach will be using sophisticated dose calculation algorithms that upgrade the accuracy and safety of treatments. Techniques such as Intensity-Modulated Radiation Therapy (IMRT) will enable us to provide radiation in targeted doses that conform closely to the shape of the tumor, decreasing the risk to adjacent healthy tissues. Safety features which will be built into our device includes automatic fail-safes which activate in case of any operational discrepancies, preventing any potential overexposure. We will be conducting regular maintenance and quality assurance tests to make sure that every component functions correctly, handling risks of malfunction. Operator training is rigorous, with comprehensive education on the device's use, safety features and emergency procedures to maintain a high standard of treatment safety. In addition, we are committed to ethical

practices, reassuring that all patients undergo a detailed informed consent process. We shall make sure they are educated about the treatment, its potential risks, and the safety measures in place to protect them. We will also be focusing on patient comfort during treatment to decrease anxiety and ensure a positive experience, integrating ergonomic features into the design of the device.

## V. CONCLUSION

In conclusion, the design and deployment of the radiation treatment planning software uses advancements in radiation oncology and optimizes its precision. The technologies implemented by this software are AI-powered imaging, ML algorithms, and Monte Carlo simulations, which help in increasing the accuracy of dose delivery, while limiting damage to healthy tissues. It also accommodates patient ease and personalizes their care by accommodating real-time anatomical changes and enhances multiple therapy modalities. Moreover, the fortified data protection will adhere to industry standards, making it ideal for clinical application.

This project has successfully addressed crucial issues in radiation therapy, such as ensuring increased accuracy, efficiency, and patient-specific treatment planning. The rigorous testing and validation framework will fortify its clinical reliability for use in clinical applications. All of these factors will create opportunities for clinical adoption of this innovation that not only meets the demands of current practices, but enables the potential for advancing other therapeutic delivery systems in the field of medical technology.

## VI. REFERENCES

- [1] Y. Rong et al., "NRG Oncology Assessment of Artificial Intelligence Deep Learning-Based Auto-segmentation for Radiation Therapy: Current Developments, Clinical Considerations, and Future Directions," *International Journal of Radiation Oncology\*Biophysics*, vol. 119, no. 1, pp. 261–280, Nov. 2023, doi: <https://doi.org/10.1016/j.ijrobp.2023.10.033>.
- [2] James, "Quantum Computing in Medicine," *Medical Sciences*, vol. 12, no. 4, pp. 67–67, Nov. 2024, doi: <https://doi.org/10.3390/medsci12040067>.
- [3] L. de Freitas Nascimento and A. Gasparini, "Review of real time 2D Dosimetry in External Radiotherapy: Advancements and

Techniques," *Radiation Measurements*, p. 107344, Nov. 2024, doi: <https://doi.org/10.1016/j.radmeas.2024.107344>.

[4] P. B. Johnson et al., "First-in-human trial using mixed-reality visualization for patient setup during breast or chest wall radiotherapy," *Radiation Oncology*, vol. 19, no. 1, Nov. 2024, doi: <https://doi.org/10.1186/s13014-024-02552-0>.

[5] Y. Rong et al., "NRG Oncology Assessment of Artificial Intelligence Deep Learning-Based Auto-segmentation for Radiation Therapy: Current Developments, Clinical Considerations, and Future Directions," *International Journal of Radiation Oncology\*Biophysics*, vol. 119, no. 1, pp. 261–280, Nov. 2023, doi: <https://doi.org/10.1016/j.ijrobp.2023.10.033>.

[6] A. Buchner et al., "Deep learning for autosegmentation for radiotherapy treatment planning: A review," *Strahlentherapie und Onkologie*, vol. 200, no. 10, pp. 967-975, 2024.

[7] S. Aggarwal et al., "A Monte Carlo simulation-based decision support system for radiation therapy treatment planning," *Radiation and Environmental Biophysics*, vol. 63, no. 2, pp. 345-356, 2024.

[8] D. Sarrut et al., "Artificial Intelligence for Monte Carlo Simulation in Medical Physics," *Frontiers in Physics*, vol. 9, article 624, 2021.

[9] "Monte Carlo simulations in radiotherapy dosimetry," *Radiation Oncology*, vol. 13, article 121, 2018.

[10] Desai, N. C., & Green, E. M. (2020). Equine external beam radiation therapy: Techniques and challenges. *Equine Veterinary Education*, 32(2), 84–89. <https://doi.org/10.1111/eve.12943>

[11] Granero, D., Perez-Calatayud, J., Vijande, J., Ballester, F., & Rivard, M. J. (2014). Limitations of the TG-43 formalism for skin high-dose-rate brachytherapy dose calculations. *Medical Physics (Lancaster)*, 41(2), 021703-n/a. <https://doi.org/10.1118/1.4860175>

[12] Hofmann, K., Masood, U., Pawelke, J., & Wilkens, J. (2014). SU-D-BRE-05: Feasibility and Limitations of Laser-Driven Proton Therapy: A Treatment Planning Study. *Medical Physics (Lancaster)*, 41(6Part3), 112–112. <https://doi.org/10.1118/1.4887876>