Design of Radiation Treatment Planning Software

Marija Simic, Sidra Sayed, Sravya Reddy Yammanuru, Tahsin Islam, Jermaine Walters, Aiden Van Greuning, Rachna Patel

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TABLE OF CONTENTS

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01

BACKGROUND

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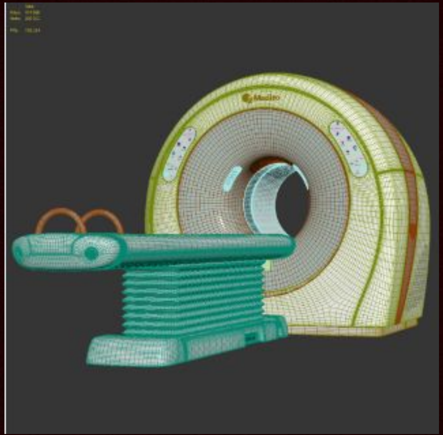
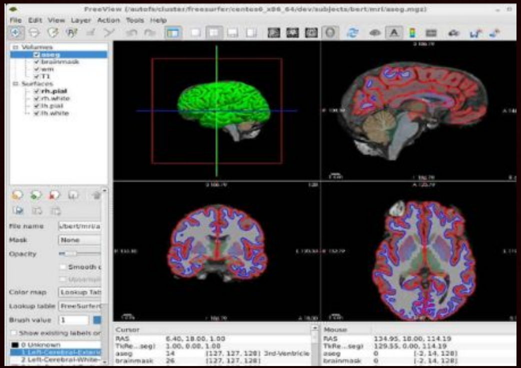
BACKGROUND

- **Enhanced Precision with AI and ML:** Advanced AI-powered segmentation tools integrate imaging modalities (CT, MRI, PET) to create detailed 3D models, enabling precise tumor targeting and organ protection [1].
- **Monte Carlo Simulations:** Widely regarded as the gold standard, these simulations improve dose calculation accuracy by modeling radiation transport and interactions within tissues [2].





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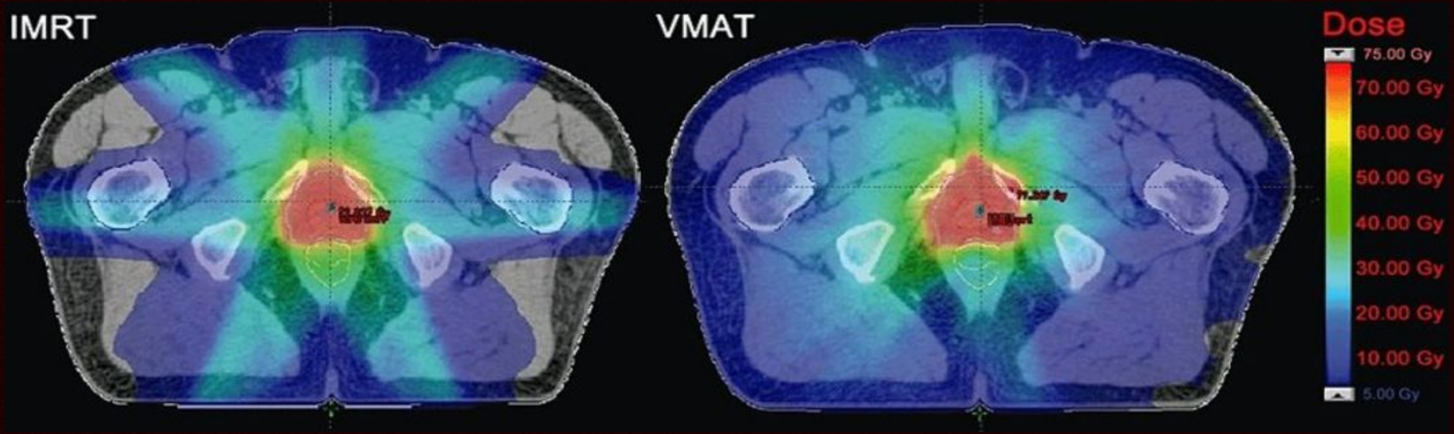
BACKGROUND

- **Versatile Treatment Modalities:**
  Techniques like IMRT, VMAT, brachytherapy, and proton therapy optimize radiation delivery, reducing treatment time and minimizing damage to healthy tissues [3, 4].
- **Continuous Evolution and Personalization:**
  AI and ML analyze historical patent data to refine treatment plans, improving accuracy, efficiency, and patient outcomes in radiation oncology [5].



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INTRODUCTION

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INTRODUCTION

- Achieving optimal and personalized radiation therapy remains challenging, in balancing precise tumor targeting with minimizing collateral tissue damage.
- Current treatment planning lacks the customization to address patient-specific needs effectively.
- Innovative solutions integrating computational modeling, intelligent algorithms, and advanced imaging techniques are critically needed.
- This project seeks to revolutionize radiation therapy by developing software that leverages AI, ML, and medical imaging for enhanced treatment delivery.

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PURPOSE

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PURPOSE

- This project aims to create a radiation treatment planning program that addresses accuracy, flexibility, and patient-specific optimization in radiation therapy.
- The software will implement advanced imaging techniques, AI, and machine learning to improve treatment precision and minimize harm to healthy tissues.
- Adaptive planning and simulation models will enable greater efficiency and personalization in radiation therapy.
- By meeting current clinical needs and laying a foundation for future innovations, this project seeks to advance medical technology in radiation treatment planning.

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THEORY

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THEORY

- The software integrates various platforms to optimize and verify radiation treatment plans, ensuring safety and efficacy [6].
- It connects to imaging software (CT, MRI, PET scans) to import patient-specific imaging data for precise treatment planning.
- AI-powered image segmentation tools create detailed 3D and 4D representations of the patient's anatomy, contouring tumors and organs at risk (OARs) [7].
- Real-time adaptive contouring accounts for anatomical changes, such as organ motion during breathing, ensuring accurate targeting during treatment [8].

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THEORY

- Past radiation treatment data is utilized for machine learning and algorithm development, enabling personalized dose calculations based on patient-specific data and historical comparisons [7].
- Simulation models, like Monte Carlo simulations, display radiation distribution and allow clinicians to adjust beam energy, angles, shapes, and intensity for optimal treatment [9].
- The software provides a timeline of radiation effects on tumors and surrounding tissues, offering multiple treatment plan comparisons to tailor decisions to individual patient needs.
- It supports three types of radiation therapy: External Beam Radiation Therapy (EBRT), Brachytherapy, and Proton Therapy, accommodating a wide range of clinical scenarios [9].

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MATERIALS & TECHNIQUES

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MATERIALS & TECHNIQUES

- The software uses Python for scripting, machine learning, and integration, while C++ handles real-time data processing, ensuring performance and flexibility.
- Machine learning frameworks like PyTorch and scikit-learn enable deep learning for segmentation and adaptive radiation treatment planning, integrated with medical imaging libraries (ITK, VTK) for 3D and 4D modeling.
- It adheres to the DICOM standard for seamless medical imaging integration, using libraries such as DCMTK or GDCM, with all data securely stored in a HIPAA-compliant, encrypted PostgreSQL database.
- Dose calculations rely on a Monte Carlo simulation framework built on Geant4, with a React-based GUI allowing real-time beam and parameter adjustments while continuously learning from patient data for improved treatment outcomes.

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TESTING

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TESTING

- Bench Testing/Software Validation: Algorithms will be rigorously tested against benchmark datasets to evaluate accuracy and precision, ensuring clinical requirements are met.
- Phantom Studies: The software will be validated on artificial tissue and organ models, comparing dose distribution and image contouring accuracy with simulated values.
- Clinical Trials and Validation: Small-scale trials will assess the software's performance against existing tools, tracking outcomes like planning time, dose accuracy, healthy tissue preservation, tumor response, and clinician satisfaction.
- Safety and Efficacy Testing: The software will undergo thorough evaluation to meet medical device and radiation safety regulations, including compliance with ICRP and ICRU standards.

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LIMITATIONS

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LIMITATIONS

- External Beam Radiation Therapy (EBRT): Widely used in veterinary medicine for treating tumors, EBRT relies on x-rays, gamma rays, or electrons. Treating large animals like horses presents challenges due to imaging limitations, specialized equipment needs, and difficulties with anesthesia, complicating dose calculations and treatment planning [10].
- Brachytherapy Challenges: Brachytherapy's TG-43 formalism struggles with scattered radiation inaccuracies, but using a bolus can improve dose focus and accuracy for targeting tumors without affecting surrounding tissues [11].
- Proton Therapy Limitations: Laser-accelerated proton beams lack modulation, making it hard to produce clinically viable treatment plans. Beamline modulation methods could optimize proton therapy for more accurate dose calculations and effective treatment plans [12].

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SAFETY

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SAFETY

- The software prioritizes safety by leveraging AI-driven and real-time imaging to precisely target tumors, adjust radiation doses during treatment, and protect surrounding healthy tissues, while adhering to ICRP and ICRU global safety standards.
- Advanced dose calculation algorithms, including Intensity-Modulated Radiation Therapy (IMRT), enhance treatment accuracy, delivering radiation in targeted doses that conform closely to the tumor's shape to minimize risks to adjacent tissues.
- Built-in safety features, such as automatic fail-safes and rigorous maintenance and quality assurance tests, prevent overexposure and ensure the device operates reliably.
- Comprehensive operator training, patient-focused ethical practices like informed consent, and ergonomic design aim to ensure safe, informed, and comfortable treatment experiences.

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CONCLUSION

CONCLUSION

- The radiation treatment planning software leverages AI-powered imaging, ML algorithms, and Monte Carlo simulations to enhance dose accuracy, minimize tissue damage, and personalize patient care by adapting to real-time anatomical changes.
- The software improves radiation therapy by addressing key challenges like accuracy, efficiency, and personalized treatment, supported by a rigorous testing and validation process for clinical reliability.
- By adhering to data protection standards and accommodating multiple therapy modalities, the software offers significant potential for clinical adoption and future advancements in medical technology.

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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*Biology*Physics, vol. 119, no. 1, pp. 261–280, Nov. 2023, doi: https://doi.org/10.1016/j.ijrobp.2023.10.033.
- [1] 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*Biology*Physics, 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

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