MODELING OF A RADIATION THERAPY SYSTEM FOR BREAST AND LUNG CANCER THERAPY

An Undergraduate Research Scholars Thesis

by

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Chemical Engineering[2]

RESEARCH COMPLIANCE CERTIFICATION

Research activities involving the use of human subjects, vertebrate animals, and/or biohazards must be reviewed and approved by the appropriate Texas A&M University regulatory research committee (i.e., IRB, IACUC, IBC) before the activity can commence. This requirement applies to activities conducted at Texas A&M and to activities conducted at non-Texas A&M facilities or institutions. In both cases, students are responsible for working with the relevant Texas A&M research compliance program to ensure and document that all Texas A&M compliance obligations are met before the study begins.

We, Ayesha Azimuddin[1], Insha Ayaz Shaikh[2], certify that all research compliance requirements related to this Undergraduate Research Scholars thesis have been addressed with my Research Faculty Advisors prior to the collection of any data used in this final thesis submission.

This project did not require approval from the Texas A&M University Research Compliance & Biosafety office.

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ABSTRACT

Modeling Of A Radiation Therapy System For Breast And Lung Cancer Therapy

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The success of a treatment planning system (TPS) for the treatment of cancer is highly dependent on the accuracy of the radiation administered and the dose delivered to the tumor volume. Based on the previous research, clinical beam accelerators are an imperative feature of the TPS which are widely used in radiation therapy facilities. Our project aims to conduct the reconstruction of the clinical beam accelerator, LINAC Varian Clinac 2300 C/D using comprehensive modeling method on a Monte Carlo Simulation software (TOPAS) and extract the radiation dose of the organs from simulations on phantoms to design a radiation therapy treatment plan. Monte-Carlo Simulation techniques are a precise tool to estimate the dose delivery to the target organs with the aid of sophisticated and reliable Geant4 toolkit. This research is vital to the understanding of the dose delivery to the cancerous tissues and the accuracy of a treatment

planning system designed to act as an effective therapeutic weapon that implements a dosimetrically feasible strategy. The expected outcomes of this study are the validation of the LINAC with a previously modelled LINAC using the GATE simulation toolkit, determining the accuracy in the dose calculation of the heart which will contribute to the development of an effective treatment planning system that delivers the proper amount of dose to the cancerous tissues, limiting the exposure and consequent harm to the surrounding healthy tissues. This study will further be applied to the investigation of the correlation between the radiation dose imparted to the heart, the onset of cardiac toxicity and the occurrence of cardiovascular risks associated with the radiation therapy procedure.

DEDICATION

To our friends, families, instructors, and peers who supported us throughout the course of the research.

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The geometric dimensions of the LINAC developed on TOPAS software was obtained from a MONTE CARLO STUDY OF A VARIAN 2300C/D PHOTON ACCELERATOR USING GATE were conducted in part by YASSINE TOUFIQUE AND OTHMANE BOUHALI and was published in 2018.

All other work conducted for the thesis was completed by the students independently.

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1. INTRODUCTION

Radiation therapy (RT) is one of the main modalities of control, cure, and palliation for cancer, with approximately 50% of cancer patients requiring radiation therapy during their disease course. Following a radiation therapy in patients with long-term lung and breast cancer, the toxicity in the cardiac tissues due to exposure to high amounts of radiation dose has been observed and is of clinical relevance [1]. Long-term follow-up of these patients has revealed that some past RT regimens led to an increased risk of death from heart disease, particularly 10 years after RT, presumably because of some unwanted irradiation of the cardiac structures. A 27% increase in relative risk of mortality from diseases of the heart was found from recent studies on radiotherapy for breast cancer [2]. The rise in cardiotoxicity is a cause of concern for both cardiologists and the oncologists. Furthermore, it is unknown which quantitative measures of the heart dose or volume are most relevant to subsequent heart disease risk [3]. Therefore, it is of high relevance that the effect of radiation dose to healthy vital organs such as heart and lungs is studied to perform radiations on target organs with tumors with minimal effect to the healthy tissues.

The employment of treatment planning systems for the purpose of treatment of cancer by delivering therapeutic dose through clinical beam accelerators are of great significance in healthcare facilities. In order to produce accurate results for dose distribution in the tumorous tissues and limit the radiation to healthy tissues surrounding the tumor volume, Monte Carlo (MC) technique is used to model the radiation therapy system on a software. Having a single code allowing the simulation of several specific applications (PET, SPECT, CT, internal/external radiotherapy, hadron therapy) should facilitate the use of MC in medical physics [8]. This is a precise approach to achieve an excellent level of accuracy in calculating the absorbed dose during

a treatment planning process [4]. The accurate prediction of dose distributions guide clinical plan optimization to save time and maintain high quality plans [5]. MC serves as a powerful tool in performing simulations of 3D geometries of the clinical beam accelerator, absorbed dose and dosimetry calculations along with the determination of a complete phase-space characterizing the energy and particle generations within the patient's organ [6]. They differ from the analytical algorithms present in commercial software by their ability to realistically consider both the mechanical and geometrical characteristics of 15 the radiation source, and the tissue heterogeneities in the patient's body [4].

The TOPAS MC simulations can serve as an independent dose calculation over the course of radiotherapy treatment, from the planning to quality assurance (QA) stages. The objective of this work is to reconstruct a clinical beam accelerator on the TOPAS MC simulation software, validate the results of the dose distribution of a water phantom with simulations performed on the GATE software and use the accelerator to produce dose distribution of the organs (Lung and Breast) through the XCAT phantoms provided on TOPAS. This will aid in studying the effect of dose on the heart to facilitate the treatment guidelines for patients along with the assessment of cardiac risk associated with their RT plan in order to reduce the cardiac dose.

2. METHODS

The methodology for the study involves computing the dose estimates using the TOPAS MC software and the related optimization, in addition to the comparison parameters used to validate the study.

2.1 Software Preparation

2.1.1. TOPAS MC software

The simulation is based on TOPAS [7] (Tool for Particle Simulation), a licensed software obtained after a basic virtual training. TOPAS brings the sophisticated and reliable tools available in Geant4 into an experimentally validated and easy-to-use MC tool within reach of every medical physicist. It presents a complete set of validated physical models, description of complex geometries, generation and monitoring of particles and visualization of volumes and particle trajectories.

2.2. Comparison Parameter

To validate the TOPAS-modeled LINAC Varian Clinac 2300C/D, we have compared the estimated dose distribution (Percent depth doses (PDD) and dose profiles (D)) with experimental measurements using a previously modeled LINAC on the GATE software [4].

2.3. Geometry

In this study, a recent LINAC called Varian Clinac 2300C/D was modeled using TOPAS and validated against measurements. Varian Clinac 2300C/D systems are used to generate high photon energies of 6 MV, 10 MV, 15 MV, 18 MV and 20 MV as well as electron beam energies between 4 MeV and 22 MeV. This LINAC is composed of different elements: Target, Primary

collimator, Flattening-Filter and the Air Phase Space. To achieve complete and accurate modeling of the LINAC head, we have used the technical compositions provided by [4].

2.3.1. Target

Inside a LINAC, different X-ray energies were generated by Bremsstrahlung effect from a high energy electron beam (between 6 and 23 MeV) striking a metal target made of high-Z material (Tungsten) coupled with a 75 copper (Cu) layer. Copper is used to dissipate heat from the target and filter low X-ray energies. However, as the energy is increased, the emission of braking radiation becomes more directed towards the front. In this case, the target acts as a transmission target.

2.3.2. Primary Collimator

To guide the X-ray field, a Tungsten collimator is placed after the target. It consists of a cylinder with a conical Air gap. The dimension of the conical gap is selected to cover a circle of 50 cm diameter by considering the target as an X-ray source (maximum field of treatment given by Varian).

2.3.3. Flattening Filter

After the primary collimator there is a flattener beam, positioned on a rotational Aluminum carousel to bring the adequate X-ray flattening filter. The flattening filter is composed of a set of conical metal slices with different depths and aligned with the central axis. The dimension and the material of the flattening filter depend on the required X-ray energy.

2.4. Physics Setting

In this paper we conduct a comprehensive modeling of a Varian Clinac 2300C/D from the electron beam to the target. Starting from the electron beam to the water tank. To validate our numerical model, GI parameter was used to compare the simulation results with the experimental

ones. To better understand the influence of the electromagnetic processes (EM) provided by TOPAS, three models were used: Standard, Livermore and Penelope. The obtained results were compared with the measured ones.

2.5. Variance Reduction Techniques (VRT)

To minimize the computing time of the dose profile, VRT such as Bremsstrahlung splitting and Russian roulette [8] were used.

3. RESULTS

The results for this project are retrieved from the TOPAS MC simulation software. The implementation of this technique for the Livermore and Penelope model will be the topic of future research. The results presented in this research are the predecessor for the dose variation in the water phantom, for which the comparison of the plots has been made with the results obtained for the standard model on GATE software.

This LINAC is assembled using a source code on the simulation space on which a 6 MeV electron beam is used to hit the target that produces a dose distribution on the water phantom through the Bremsstrahlung splitting.

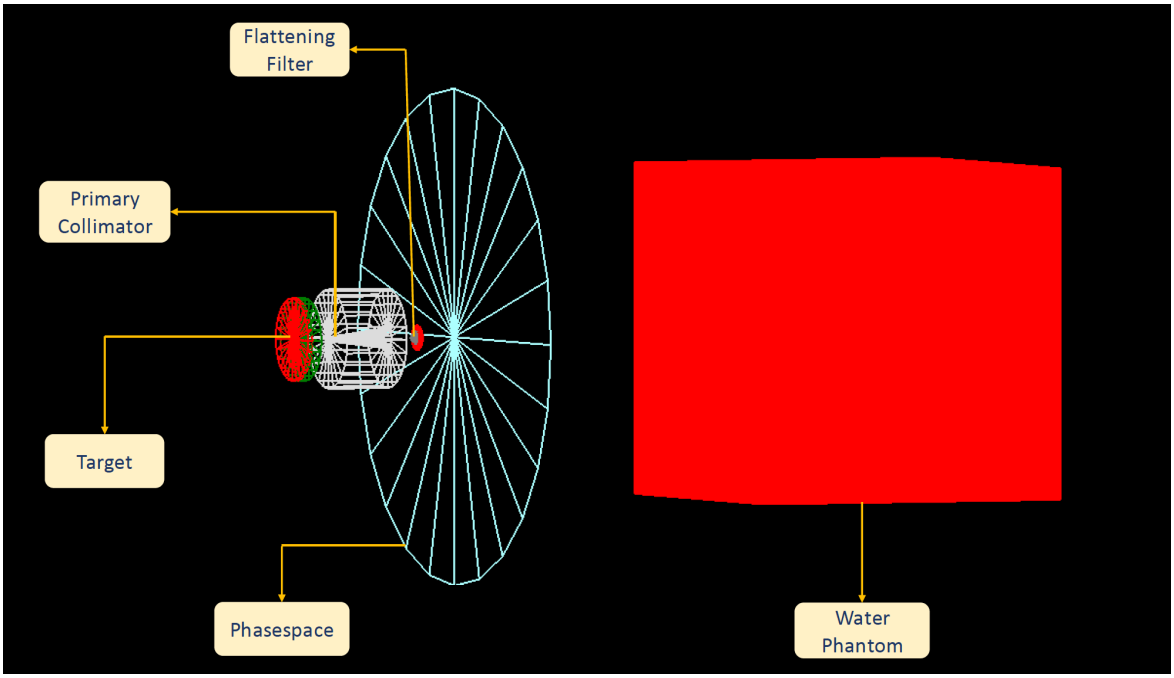

Figure 3.1: LINAC modelled on the simulation space

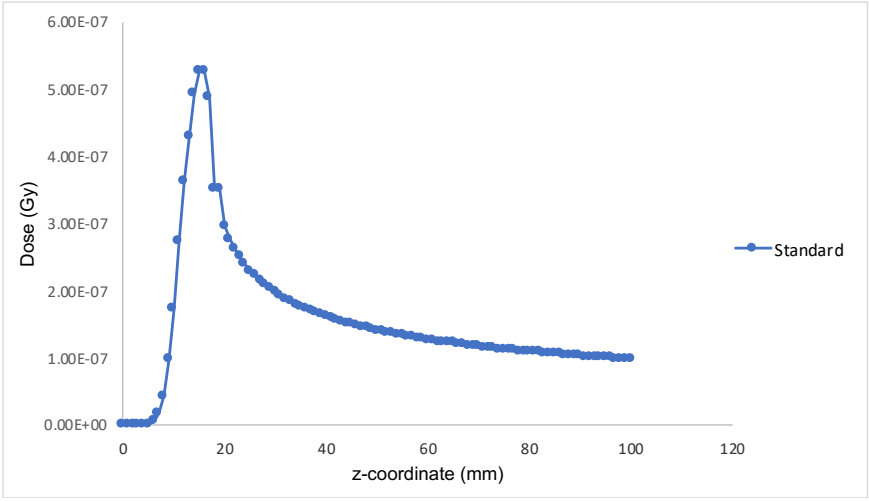

Figure 3.2: Variation of dose with z-coordinate for the Standard Model

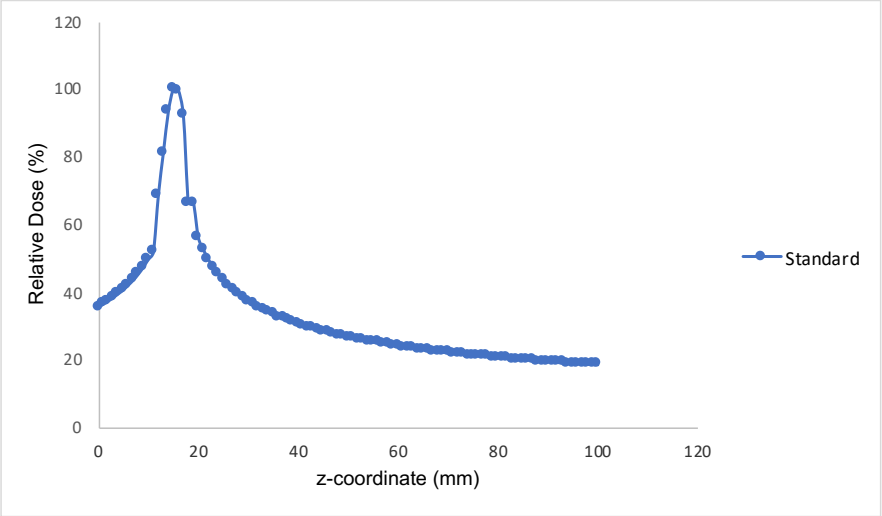

Figure 3.3: Relative depth dose (PDD) for standard model

The initial dose variation along the z-coordinate of the water phantom is presented in Figure 3.2 obtained from a simulation 10^7 primary electron particles. The plot shows a gradual increase in the dose till it reaches 15mm inside the water phantom, which is the point of maximum dose. Figure 3.3 presents the relative depth dose, which is the normalization of the dose values with respect to the maximum dose in the phantom along the z-coordinate of the water phantom.

The simulation of the modeled LINAC including all components and using around 10^7 electrons takes about 20 hours on the software. Each run generates the same number of electrons to bombard the water phantom to record a dose deposition in the water phantom.

The obtained results do have a slight deviation from the expected results as obtained in the simulation using the GATE software, which is the scope of the future work that will evaluate the inconsistencies in the plot at various points by analyzing the source code used for the simulation.

4. CONCLUSION

The goal of this work was to conduct a comprehensive modeling of the Varian Clinac 2300C/D apparatus using TOPAC MS simulation toolkit. Results from Percent Depth Dose and Dose Profile are compared to experimental measurements based on a previously modelled and validated LINAC on the GATE software. The results obtained for the standard model are an initial point for extracting the desired data for the Penelope and Livermore model and its validation by comparison of the data with those of GATE simulation.

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