PERFORMANCE EVALUATION OF RADIOTHERAPY TREATMENT PLANNING SYSTEM USING THE CIRS THORAX PHANTOM

BY

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THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON, IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF MASTER OF PHILOSOPHY (MPHIL) MEDICAL PHYSICS DEGREE

DEPARTMENT OF MEDICAL PHYSICS

SCHOOL OF NUCLEAR AND ALLIED SCIENCES

SEPTEMBER, 2024

DECLARATION

This thesis is the result of research work undertaken by Clement Kwame Akrobotu in the Department of Medical Physics, School of Nuclear and Allied Sciences, University of Ghana, under the supervision of Dr. Samuel Nii Adu Tagoe, Dr. Theresa Bebaaku Dery, Prof. Edem K. Sosu

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To my parents Mr.Simon Akrobtotu, and Mrs.Rosemary Akrobotu, and my siblings, who have given me guidance, love, support, prayers, encouragement, and social, spiritual, and emotional support in addition to my higher education.

ACKNOWLEDGEMENTS

I express my uttermost appreciation and gratitude to my supervisors: Dr. Samuel Nii Adu Tagoe, Dr. Theresa Bebaaku Dery, and Prof. Edem K.Sosu for their unselfish and incalculable advice, recommendations, support, and assistance in carrying out this study and writing this thesis.

I thank the Medical Physics Department, Radiological and Medical Sciences Research Institute (GAEC), and Radiological and Medical Sciences Research Institute (GAEC) for the official documents needed to be presented at various facilities and for the equipment that aided me in conducting this research.

My sincere thanks also go to Mr. Micheal Nyamede and Mr. Philip Nyarko medical physicists who assisted me in data collection.

I am also grateful to my family who assisted me financially and my fellow students at the School of Nuclear and Allied Sciences for their various contributions.

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LIST OF ABBREVIATIONS

3D-CRT	Three-Dimensional Conformal Radiation Therapy
AAA	Anisotropic Analytical Algorithm
CIRS	Computerized Imaging Reference Systems
CT	Computed Tomography
DICOM	Digital Imaging and Communications in Medicine
ED	Electron Density
IAEA	International Atomic Energy Agency
IMRT	Intensity-Modulated Radiation Therapy
Kpol	Voltage Polarity Correction Factor
KQQ	Beam Quality Correction Factor
KS	Ion Recombination Correction Factor
KT1P	Temperature Pressure Correction Factor
LINAC	Linear Accelerator
MC	Monte Carlo
MRI	Magnetic Resonance Imaging
MU	Monitor Units
ND_w	Absorbed Dose-to-Water Calibration Coefficient
OAR	Organs at Risk
QA	Quality Assurance
RTPS	Radiotherapy Treatment Planning Systems
SBRT	Stereotactic Body Radiation Therapy
SCD	Source Chamber Distance

TECDOC	Technical Document
TLD	Thermoluminescent Dosimeter
$TPR_{20,10}$	Tissue Phantom Ratio at 20 cm and 10 cm depth
TPS	Treatment Planning System
TRS	Technical Report Series
VMAT	Volumetric Modulated Arc Therapy

ABSTRACT

Treatment Planning System (TPS) authentication is essential for ensuring accurate dose calculations in radiotherapy. This study verified the Varian Eclipse TPS algorithm using a CIRS Thorax phantom, for a 6MV photon beam in conformal radiotherapy. A CT stimulator was used to scan the phantom, and TPS was used to plan eight distinct irradiation geometries simulating conformal radiotherapy. Dose measurements were taken using ionization chambers, and The differences between the measured and computed dosages were examined. The findings demonstrate the variation between measured doses and calculated doses by the TPS were 1.57% and 3.88% respectively within the acceptance criteria of ±5%. The TPS consistently delivered accurate dose calculations even under complex conditions such as oblique incidences and blocked fields. The CT to electron density conversion assessment all measured values within the acceptance criteria of ±20HU.The study validates the Varian Eclipse TPS algorithms's precision in dose delivery ensuring patient safety. The CIRS Thorax phantom proved competent for the routine TPS verification.

CHAPTER ONE

INTRODUCTION

The introduction, problem statement, the research objective, the scope, and the significance of the study are all provided in this chapter. This chapter also describes how the work is organized.

1.1 Background

Radiotherapy plays an important role in treatment of cancer, and delivering the precise dose accurately is essential for effective radiation therapy to ensure the maximum therapeutic effect while minimizing the risk of complications (Trofimov *et al.,* 2011). Deployment of advanced radiotherapy treatment planning systems (RTPSs) has become standard practice in modern radiotherapy. These systems allow for the precise calculation of radiation dose distribution in the patient's body, considering the complex anatomy and tissue heterogeneities. Discrepancies between planned and delivered radiation doses can arise from various sources, such as setup errors, organ motion, and anatomical deformations, which can significantly impact the intended doses to the target and surrounding normal tissues (Zhang *et al*,, 2023).

An extensive paper by the International Atomic Energy Agency (IAEA) titled The Commissioning and Quality Assurance of Computerized Planning Systems for Radiation Treatment of Cancer, offers a broad framework and outlines numerous tests and processes to be considered by the RTPS users (TECDOC 1583). One of the key components of the commissioning process is the performance evaluation of the RTPS using phantoms that simulate the human body.To address these challenges, researchers have developed various phantoms and measurement techniques to verify the performance of radiotherapy treatment planning systems (Webster *et al.,* 2008) (Burnet,

2004). One such phantom is the CIRS thorax phantom, which has been used to evaluate the accuracy of dose calculations and delivery for different treatment modalities (Followill *et al.*, 2007).

The CIRS thorax phantom is a realistic, water-fillable anthropomorphic phantom that simulates the human torso anatomy, including the lungs, heart, and spine (Followill *et al.*, 2007). The phantom contains various imaging and dosimetry inserts, such as radiochromic film and thermoluminescent dosimetry capsules, which enable the measurement of relative and absolute dose distributions (Followill *et al.*, 2007). The use of such realistic phantoms has been recognized as a valuable tool for the development and implementation of clinical radiotherapy techniquesbecause they make it possible to precisely confirm dosage distributions in areas of therapeutic interest. (Ramos *etal.*,2017).

The study conducted by (Banaee *et al.*, 2024) aimed to evaluate the performance of a radiotherapy treatment planning system using a CIRS thorax phantom. The study demonstrated that variations in the external contour impact the phantom's computed volume and, consequently, the dose. Automated external contouring tools must be used according to the right guidelines and re-checked before treatment planning to produce accurate results.

These findings emphasize the importance of thorough evaluation and quality assurance procedures when implementing radiotherapy treatment planning systems in clinical practice. This is particularly important for treatment planning in the thorax region, where the presence of lung tissue, bone, and soft tissue can cause substantial mistakes in dose calculation if not properly accounted for. Several studies have been conducted to evaluate the performance of different RTPS using the CIRS thorax phantom (Saini *et al.*, 2023).

The radiotherapy treatment planning process involves several steps and precise delivery of radiation to the target tumor. These steps include imaging and contouring of the target volume and critical structures, dose calculation, optimization, and quality assurance. (Stieb *et al.*, 2019).

The process begins with obtaining Computed Tomography (CT) and/or Magnetic Resonance Imaging (MRI) scans of the patient to accurately define the tumor and normal tissue anatomy. After contouring the target volume and critical structures, a dose calculation algorithm is used to estimate the radiation dose distribution. This calculation takes into account various factors such as the beam geometry, tissue heterogeneity correction, and treatment machine-specific parameters.

Optimization techniques are employed to improve the dose distribution while adhering to dose constraints for critical structures. Finally, a comprehensive quality assurance process is done in order to verify how accurate the treatment plan before it is delivered to the patient.
However, there is still a need for further research in this area to address the limitations and gaps in the existing literature. The proposed study aims to contribute to this important area of research by providing a comprehensive evaluation of the performance of a specific RTPS using the CIRS thorax phantom.

The study will evaluate the precision of dosage computation when tissue heterogeneities are present, evaluate the effectiveness of various algorithms for dose calculation, and evaluate the influence of different treatment techniques on the performance of the RTPS using the CIRS thorax phantom. The study's conclusions will offer insightful information about the performance of the RTPS under various clinical scenarios and contribute to the ongoing efforts to guarantee the efficient and safe administration of radiation treatment.

1.2 Problem Statement

Treatment Planning Systems (TPS) are essential in radiotherapy for generating accurate dose distributions that ensure tumor control while sparing healthy tissue. However, their accuracy remains a critical concern, particularly in complex anatomical regions and with advanced techniques such as IMRT and VMAT. Current TPS evaluations primarily focus on algorithmic accuracy under idealized conditions, often neglecting clinical factors such as organ motion, anatomical changes, and tissue heterogeneity, which significantly influence dose delivery (Gaur et al., 2023). Additionally, there is a lack of standardized quality assurance protocols across institutions, leading to inconsistencies in TPS validation and commissioning. Over-reliance on internal dose calculation algorithms without systematic cross-verification using independent methods, such as Monte Carlo simulations or in vivo dosimetry, further increases the risk of discrepancies between planned and delivered doses (Thibodeau, 2023).

Moreover, existing evaluation frameworks rarely incorporate comprehensive end-to-end testing or quantify uncertainties related to contouring, CT calibration, and dose calculation algorithms. These limitations hinder the ability to detect and correct clinically significant errors, potentially compromising patient safety and treatment outcomes. The absence of real-time verification and the failure to link dose discrepancies to clinical endpoints, such as tumor control probability or normal tissue complication probability, further exacerbate this issue. Consequently, there is an urgent need for an integrated, standardized, and adaptive QA framework that addresses these gaps and ensures the accuracy and clinical reliability of TPS in modern radiotherapy.

1.3 Objectives of the Study

The primary goal of the research is to assess the effectiveness of the

Varian Eclipse treatment planning system using CIRS thorax phantom.

The specific objectives to be addressed:

1. To Verify/determine the CT numbers to relative electron density conversion in the RTPS.

2. Determine the dose variation of the Varian Eclipse TPS.

1.4 Significance of the Study

The study's findings have the potential to revolutionize the field of radiation oncology in several key areas. Firstly by to identifying differences between calculated and measured doses inradiotherapy, which can enhance treatment planning algorithms. By ensuring more accurate dose delivery to tumors while protecting healthy tissues, It can lessen adverse effects and enhance therapeutic results, thereby enhancing patients' quality of life.

Additionally, the findings can optimize treatment planning system (TPS) settings and procedures, leading to more efficient workflows and better clinical decision-making in radiotherapy departments. Finally, exploring various dose calculation algorithms can inform the development of improved, personalized algorithms for specific clinical situations, resulting in better patient outcomes.

1.5 Scope and Limitation of the Study

The study evalutes the accuracy of dose calculations in the tissue heterogeneities, comparison of dose calculation algorithms, and the impact of treatment techniques on the system's performance.However, the study limitations include the specific focus on a single treatment planning system, potential bias from CIRS thorax phantom characteristicsn. Furthermore, the study's scope was constrained by factors such as resource availability, time limitations, and the complexity of the algorithms being evaluated.

1.6 Organisation of the Study

The thesis is structured chronologically in five chapters. Chapter One provides the background of the study, offering a comprehensive summary of the most recent findings pertinent to the study. Chapter Two delves into the current body of literature that is relevant to the research problem. Chapter three concentrates on establishing the theoretical and experimental framework for the study. The results of the investigation are presented and discussed in Chapter Four. Lastly, Chapter Five concludes the study, providing recommendations and suggestions for future research.

CHAPTER TWO

LITERATURE REVIEW

The literature is thoroughly reviewed in this chapter relevant to the performance evaluation of radiotherapy treatment planning systems, specifically using the CIRS Thorax Phantom. This review explores existing studies and methodologies employed in the field, focusing on the precision, reliability, and optimization of treatment planning systems (TPS) in delivering precise radiation doses to target tissues while minimizing exposure to surrounding healthy structures.

2.1 Radiotherapy

Ionizing radiation is used in radiotherapy, sometimes referred to as radiation therapy, as a means of killing cancer cells. It is one of the most widely used cancer treatments, with around half of all cancer patients requiring radiation treatment at some stage during their disease. The purpose of radiation therapy is to harm the DNA. of cancer cells, preventing them from dividing and proliferating further. Cancer, a complex and multifaceted disease characterized by uncontrolled cellular growth, poses a significant threat to global health. Fortunately, advancements in medical science have equipped healthcare professionals with a diverse arsenal of tools for combating cancer.

Radiotherapy, harnessing the power of ionizing radiation to eradicate malignant cells, stands as a cornerstone of cancer treatment, offering a potent and targeted approach to combating this disease (Primo, 2023). Ionizing radiation, a form of energy capable of dislodging electrons from atoms and molecules, forms the foundation of radiotherapy (Higley *et al*., 2023). When these high-energy rays interact with biological tissues, they trigger various effects within cells. Primarily, radiation

damages the DNA of cancer cells, disrupting their ability to divide and proliferate. This targeted assault disrupts the cancer's growth cycle, ultimately leading to cell death (Al-Janabi, 2022).

Additionally, radiation can damage the blood vessels supplying tumors, hindering their ability to receive nutrients and oxygen, further contributing to tumor control (Huo *et al*., 2017).

The versatility of radiotherapy allows for its application in various contexts throughout the cancer treatment spectrum. Radiotherapy can be used with curative intent, aiming to eliminate the cancer. This approach is often employed for early-stage or localized cancers, where complete eradication holds the potential for a complete cure. Radiotherapy can also play a crucial role in adjuvant therapy, administered after surgery to eliminate any microscopic cancer cells remaining and reduce the risk of recurrence (Markham *et al*., 2020).

Additionally, radiotherapy finds application in palliative therapy for individuals with severe or incurable cancers. In these scenarios, the focus shifts to symptom management, aiming to alleviate pain, reduce tumor size, and enhance patients' quality of life facing advanced disease stages (Vicini *et al*., 2022). The advantages of radiotherapy extend beyond its effectiveness in cancer cell eradication. Unlike surgery, radiotherapy offers a non-invasive approach, eliminating the need for major incisions or extensive procedures. This minimally invasive nature can be particularly beneficial for patients with underlying medical conditions that may pose risks associated with surgery (Sundaresan *et al*., 2023). Additionally, advancements in radiotherapy technology have yielded increasingly precise and targeted treatment delivery. Modern techniques, such as intensity-modulated radiation therapy (IMRT) and stereotactic body radiotherapy (SBRT), allow for highly focused radiation beams, minimizing damage to surrounding healthy tissues (Salari & Parsai, 2023).

This enhanced precision not just cuts down potential side effects but also expands the potential applications of radiotherapy to treat tumors close to critical organs. Radiotherapy often functions most effectively as part of a multimodal treatment approach when combined with other cancer treatment modalities. Surgery plays a crucial role in removing the primary tumor bulk, while chemotherapy utilizes potent drugs to target cancer cells systemically. Radiotherapy complements these approaches by targeting remaining microscopic diseases or delivering a localized dose to inoperable tumors (Hegi *et al*., 2018).

This strategic combination therapy often enhances overall treatment efficacy, offering patients a better chance of achieving a complete cure and improving long-term survival outcomes. Radiotherapy, harnessing the power of ionizing radiation to combat cancer, serves as a vital tool in the modern oncological armamentarium. Its ability to eradicate cancer cells, offer a minimally invasive approach, and deliver targeted therapy makes it a valuable asset in the fight against this multifaceted disease.

Radiotherapy, alone or in combination with other treatment modalities, provides a beacon of hope for countless patients battling cancer, contributing to improved survival rates, better symptom management, and eventually , a higher quality of life. As research and advancements in technology continue to refine radiotherapy techniques and expand their applications, this powerful ally holds immense promise for further progress in the ongoing battle against cancer.

2.2 Treatment Planning Systems

Treatment Planning Systems (TPS) play a vital role in optimizing radiotherapy, a key component in cancer treatment that uses ionizing radiation to target malignant cells. The effectiveness of radiotherapy largely depends on accurate dose delivery, which TPS facilitates by simulating the

treatment process before actual radiation is administered (Rijken, 2020). These systems utilize patient imaging data to outline tumors and surrounding healthy tissues, employing complex algorithms to calculate optimal radiation paths and dose distributions (Fleury *et al*., 2021). The choice of algorithm is crucial, as it impacts the accuracy of dose delivery and helps minimize discrepancies between planned and delivered doses (Kry *et al*., 2017; Fulkerson *et al*., 2020).

Modern TPS also includes advanced features such as 3D visualization tools and optimization algorithms that enhance treatment planning by allowing clinicians to visualize anatomy and adjust beam parameters effectively (Yan *et al*., 2024). Quality assurance (QA) programs are essential for verifying TPS performance, employing specialized phantoms to ensure accurate dose calculations (Aland, 2022; Aldosary, 2022).

Tumor shape significantly influences treatment planning, with irregular shapes requiring advanced techniques like intensity-modulated radiotherapy (IMRT) to deliver uniform doses while protecting nearby organs at risk (OARs) (Fulkerson et al., 2020). The balance between adequate tumor coverage and adhering to OAR dose constraints is critical for treatment efficacy and patient safety (Kajikawa *et al*., 2019). Advanced modeling tools and imaging techniques further support personalized planning strategies by considering tumor biology and normal tissue tolerance variations (Perez, 2017; Panayides *et al*., 2020).

The Varian Eclipse TPS 13.6 is widely used for its streamlined workflow and automation features that enhance planning efficiency. However, user experience varies, with reports highlighting challenges in navigation and a steep learning curve for new users (Dashnamoorthy *et al*., 2022; Ahmad *et al*., 2018). Future iterations could benefit from improved user interface design and the integration of artificial intelligence to enhance usability while maintaining user control over critical decisions (Dashnamoorthy *et al*., 2022). Overall, continuous advancements in TPS

technology and rigorous evaluation processes are essential for refining dose delivery accuracy and improving patient outcomes in radiotherapy.

2.2.1 Limitations Associated With TPS Technology

Treatment Planning Systems (TPS), the invisible architects of radiotherapy, play a critical role in ensuring accurate and effective dose delivery. Despite their vital function, current TPS technology faces several challenges and limitations that can potentially compromise treatment outcomes. Accurately representing patient anatomy within the TPS remains a significant challenge (Johnson *et al*., 2017). Current TPS primarily rely on static images like CT scans, which struggle to capture patient-specific anatomical variations. These variations, encompassing factors like organ movement due to respiration or organ deformation when receiving treatment, may result in discrepancies between the planned and delivered dose (Rosu & Hugo, 2012). Additionally, accurately modeling complex anatomical structures, particularly near the tumor target, presents a challenge. Inaccuracies in these regions can potentially expose critical organs to unintended radiation doses, increasing the risk of side effects.

Dose calculation algorithms, the workhorses of TPS, utilize complex mathematical models to predict how radiation interacts with tissues (Liney & Van Der Heide, 2019). However, these algorithms have limitations. Different algorithms exhibit varying degrees of accuracy depending on the treatment complexity and tissue composition. Choosing the "optimal" algorithm becomes a balancing act, as factors like accuracy, computational speed, and suitability for specific scenarios must be considered. Additionally, limitations in current algorithms can lead to dose calculation uncertainties, particularly for advanced treatment modalities or complex anatomical geometries. These uncertainties introduce an element of ambiguity into the treatment plan, potentially impacting dose delivery accuracy.

Modern radiotherapy often involves intricate tumor shapes, proximity to critical organs, and complex treatment techniques (e.g., IMRT, VMAT). These factors significantly increase the complexity of treatment planning within the TPS (Das *et al*., 2020). Clinicians face the challenge of balancing tumor control with minimizing dose to healthy tissues, requiring meticulous planning and expertise. Additionally, the time-consuming nature of complex treatment planning within the TPS can pose logistical challenges and impact workflow efficiency.

Optimization algorithms play a crucial role within the TPS by automatically adjusting beam parameters and dose distributions to achieve pre-defined treatment goals (Chandrasekaran, 2012). However, these algorithms are not perfect and may not always identify the absolute optimal dose distribution . Factors like algorithm limitations and user-defined constraints can lead to compromises. While the goal is to maximize tumor dose while minimizing exposure to healthy impacting treatment efficacy or increasing the risk of side effects (VanderWalde, 2022).

The challenges and limitations associated with current TPS technology highlight the need for continuous improvement. Advancements in anatomical modeling that incorporate deformable image registration and 4D imaging hold promise for capturing patient-specific anatomy more accurately. Ongoing research on developing more sophisticated and versatile dose calculation algorithms is crucial for enhancing accuracy across a wider range of treatment scenarios. Additionally, advancements in optimization algorithms that can better navigate the complexities of modern radiotherapy can further refine treatment planning strategies.

2.2.2 Performance Evaluation in Radiotherapy

Performance evaluation is crucial in the field of radiotherapy as it allows for the assessment and improvement of treatment planning systems. By using a CIRS thorax phantom, the accuracy and reliability of the radiotherapy treatment planning system can be examined and validated. This evaluation process helps identify and address any potential errors or discrepancies in the system, ensuring patient safety and optimized treatment outcomes (Aldosary, 2022).

Radiotherapy utilizes ionizing radiation to target and eradicate malignant cells. Its effectiveness hinges on a delicate balance: delivering a potent dose to the tumor while causing the least amount of damage to the nearby healthy tissues. This intricate dance relies heavily on Treatment Planning Systems (TPS)**,** sophisticated software platforms that simulate the entire treatment process before any radiation is delivered to the patient (Hoisak *et al*., 2020). However, the accuracy of these TPS is paramount, and rigorous performance evaluation becomes the unsung hero, ensuring safe and effective radiotherapy for patients.

Even minor discrepancies between planned and delivered dose distributions within a TPS can have significant consequences. Under dosing, the tumor can compromise treatment efficacy, potentially leading to local recurrence of cancer. Conversely, overdosing healthy tissues can increase the risk of severe side effects, impacting a patient's quality of life (Kavak, 2023).These potential repercussions highlight the crucial role of performance evaluation in identifying and rectifying any limitations within a TPS.

Several strategies form the backbone of TPS performance evaluation. Phantom-based studies utilize standardized phantoms like the CIRS thorax phantom, meticulously designed to mimic

human anatomy with tissue-equivalent materials. These phantoms allow for controlled comparisons of dose calculations between different TPS platforms or algorithms (Agency, 2012). Additionally, analysis of clinical data from actual treatment plans can offer valuable insights into the real-world performance of a TPS for various treatment scenarios. However, this approach requires careful consideration of patient-specific anatomical variations and ethical considerations regarding data privacy. Performance evaluation goes beyond assessing dose calculation accuracy. The user interface and planning efficiency of a TPS also play a significant role in therapy delivery. A user-friendly interface with clear instructions minimizes the risk of human error during treatment planning (Nijalingappa *et al*., 2024). Additionally, evaluation should consider the time required for treatment planning within a TPS.

Complex Systems with lengthy planning processes can impact workflow efficiency in busy clinical settings. Performance evaluation of TPS is not a one-time event; it necessitates an ongoing commitment. As new TPS versions emerge and treatment techniques evolve, continuous evaluation ensures that these systems remain reliable and optimized. Additionally, advancements in research on novel evaluation methods, such as Monte Carlo simulations, hold promise for further refining the accuracy and scope of TPS assessments.

Performance evaluation of TPS, though often overshadowed by the technology of radiation machines themselves, is essential to guaranteeing the safety and effectiveness of radiotherapy. By identifying limitations, optimizing treatment planning strategies, and ensuring user-friendliness, performance evaluation acts as the unsung hero in the fight against cancer. Ongoing efforts in refining evaluation methods and adapting to evolving technologies will continue to empower clinicians to utilize TPS more effectively, ultimately benefitting countless patients battling cancer through more precise and optimized radiotherapy treatment.

2.2.3 CIRS Thorax Phantom As a Tool For Evaluation

The CIRS thorax phantom, meticulously designed to mimic human anatomy, provides a standardized platform for TPS evaluation (Aldosary, 2022). This phantom incorporates tissue-equivalent materials with properties closely resembling human organs and soft tissues, allowing for a realistic simulation of radiation interaction within the body.

Additionally, the CIRS thorax phantom often incorporates internal inserts with varying electron densities, enabling the evaluation of dose calculation accuracy and cross-different tissue types encountered in treatment planning. With its elliptical shape (30 cm long by 30 cm wide by 20 cm thick), the CIRS Thorax Phantom (Figure 1) mimics the dimensions, density, and two-dimensional configuration of the typical human torso.

The phantom has bone, lung, and soft tissue sections with holes for rod inserts that can be switched out. Ionization chambers are accommodated by interchangeable tissue equivalent rod inserts, which enable point dose measurements in several phantom planes.

Verification in the most important regions of the chest is made possible by the holes' placement. In order to assist with either radiographic or radiochromic firm, one-half of the phantom is separated into 12 sections, each of which is 1 cm thick. The use of alignment base electron density reference plugs aids in the handling, assembly, and correct orientation of the phantom (Table 2.1).

Table 2.1: Characteristics of calibrated electron density reference plugs

	Density(g/cm^3)	Electron density Per cc × 10^{23}	Electron density relative to water
Lung	0.21	0.69	0.207
Bone	1.60	5.03	1.506
Dense bone	2.17	6.70	2.005
Muscle	1.06	3.48	1.042
Adipose	0.96	3.17	0.949

The measurement are performed by placing the calibrated ionization chambers into each of the phantom's holes.

Figure 2.1: Thorax Phantom (The CIRS Model 002LFC)

The phantom's holes are labeled to indicate the positions of the measurement points, allowing the TPS computations and the measured values to be compared. Figure 2.2 shows the suggested labelled holes and the positioning of the calibrated electron density reference plugs during the CT scan.

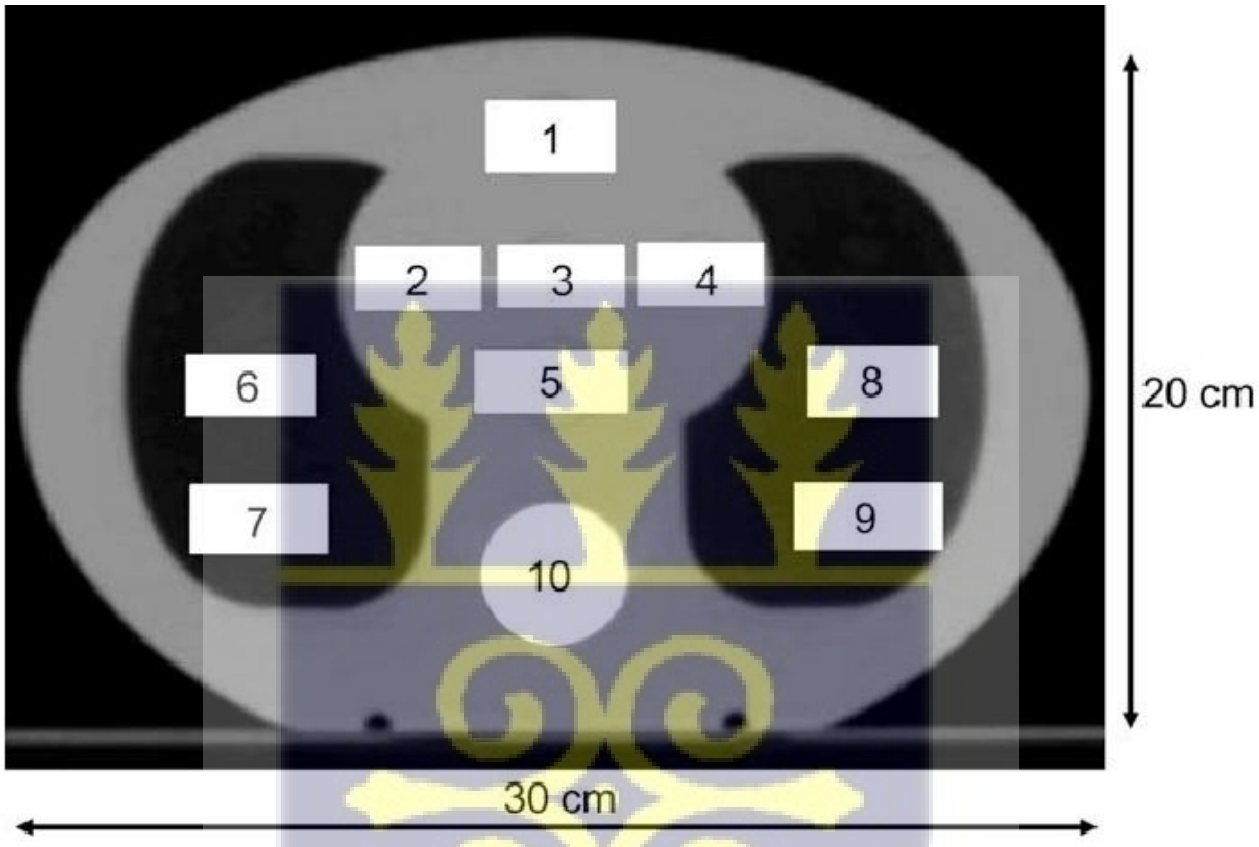

Figure 2.2: The recommended configuration for the CT scan's certified electron density reference plugs. (IAEA TECDOC 1583).

Plug 1-muscle substitute, plug2 - bone substitute, plug 3 – syringe filled with water. Plug 4 – adipose substitute, plug 5 – water equivalent, plug 6 – lung substitute, plug 7- air, plugs 8 & 9 – lung substitute, plug 10 – dense bone substitute.

2.2.3.1 Clinical Tests

The clinical tests cases cover range of typical 3D CRT techniques and are set up so that the dose distributions for individual beams are initially examined, afterwards, conventional multiple field methods are employed, and ultimately, intricate multi field configurations are analyzed. The measurements are performed with either a farmer type ionization chamber or small volume ionization chamber, which is placed into the proper plug and is inserted into selected plugs. The measurements were conducted using both single beam and multi-filed approaches.

The comparism of the measured and calculated dose values uses the criteria described in the TRS 430. The measured and TPS-calculated values are evaluated using equation 2.1.

$$Error\ \% = 100 \times \frac{Dcal - Dmeas}{Dmeas,ref} \qquad (2.1)$$

where the dose value measured at the reference position is denoted by $D_{meas.ref}$. The reference point is a location that is anticipated to receive 2Gy, and designated for each test case. The TPS calculated doses and electrometer readings were acquired and the measured dose was calculated according to the IAEA TRS 398. The deviations were displayed and compared with agreement on the criteria.

2.2.3.2 Phantom-based evaluation in radiotherapy

Radiotherapy, a vital tool in the fight against cancer, relies heavily on precise distribution of doses to eradicate malignant cells meanwhile minimizing harm to the surrounding healthy tissues. This

necessitates meticulous Treatment Planning System (TPS) evaluation to ensure the accuracy and efficacy of dose calculations within the system. Phantom-based studies emerge as a crucial strategy in this evaluation process, utilizing meticulously designed phantoms to simulate human anatomy and provide a standardized platform for assessing TPS performance (Agency, 2017). This thesis delves into the advantages and limitations of using phantoms like the CIRS thorax phantom for TPS evaluation, highlighting the benefits of its standardized anatomy, tissue-equivalent materials, and compatibility with diverse dosimetry methods.

One of the significant advantages of using phantoms like the CIRS thorax phantom lies in its standardized anatomy. Unlike patient-specific anatomy, which exhibits inherent variations, phantoms are meticulously designed to represent a "typical" human thorax with well-defined structures like lungs, heart, esophagus, and bones. This standardized anatomy offers several benefits:

2.2.3.2.1 Reproducibility

Multiple TPS systems can be evaluated using the same phantom, ensuring consistent test conditions and facilitating comparative analysis of their performance, This reproducibility allows researchers to isolate the impact of different TPS algorithms or functionalities on dose calculations.

2.2.3.2.2 Benchmarking

The standardized anatomy serves as a benchmark for evaluating the precision of dose computations within a TPS. By comparing planned dose distributions with measured values within the phantom using various dosimetry methods, researchers can identify potential discrepancies and refine algorithms for improved accuracy.

Another cornerstone of the CIRS thorax phantom, and other phantoms used in TPS evaluation, is the incorporation of tissue-equivalent materials. These materials are meticulously engineered to mimic the density and composition of human tissues like muscle, lung, and bone (Thomadsen, 2005). This material equivalence ensures that the phantom interacts with radiation in a way that closely resembles human tissue, allowing for realistic simulation of dose deposition within the body.

The benefits of these tissue-equivalent materials are numerous. They are;

2.2.3.2.3 Realistic Dose Calculations

By mimicking human tissues, phantoms enable more realistic calculations of dose distribution within the TPS. This allows researchers to evaluate the proficiency of the TPS to accurately estimate how radiation interacts with different tissue types, crucial for complex treatment plans involving heterogeneous anatomy.

2.2.3.2.4 Evaluation of Dose Variations

Tissue-equivalent materials enable the investigation of how dose varies within different tissues encountered during radiotherapy treatment. This can be particularly valuable for evaluating how accurate dose calculations are in regions adjacent to bone-tissue interfaces, where significant dose variations can occur.

The CIRS thorax phantom's compatibility with various dosimetry methods further enhances its utility in TPS evaluation . These methods allow researchers to measure the actual dose distribution delivered within the phantom and analyze it with the planned dose calculated by the TPS. Common dosimetry methods employed with phantoms include:

2.2.3.2.5 Ion Chambers

These provide point measurements of dose within the phantom, offering high accuracy for localized dose verification.

2.2.3.2.6 Film Dosimetry

This method utilizes special films that darken upon exposure to radiation, providing a two-dimensional representation of the dose distribution within the phantom.

2.2.3.2.7 Thermoluminescent Dosimeters (TLDs)

These solid-state dosimeters store the energy deposited by radiation and release it as light when heated, offering point measurements with high sensitivity.

The compatibility with diverse dosimetry methods provides several advantages:

2.2.3.2.8 Comprehensive Evaluation

Utilizing multiple dosimetry methods allows for a more comprehensive evaluation of TPS performance. Ion chambers provide high-precision point measurements, while film dosimetry offers a visual representation of the dose distribution. Combining these methods strengthens the evaluation process.

2.2.3.2.9 Versatility

The compatibility with diverse dosimetry methods allows researchers to tailor the evaluation approach to specific research questions. For instance, film dosimetry may be preferred for visualizing dose conformity within the phantom, while TLDs might be used for high-sensitivity point measurements in critical structures.

Despite its numerous advantages, it is important to acknowledge the limitations associated with phantom-based studies for TPS evaluation. The most significant limitation lies in the fact that it is not human.

2.2.3.3 Clinical Data Analysis

The relentless pursuit of improvement in radiotherapy hinges on the meticulous evaluation of Treatment Planning Systems (TPS)**.** While phantom-based studies offer valuable insights, analysing clinical data from actual treatment plans provides a powerful window into the real-world performance of a TPS (Hoisak *et al*., 2020). However, utilizing patient data presents unique challenges and ethical considerations that must be carefully navigated.

One significant challenge in using clinical data for TPS evaluation lies in the inherent anatomical variations between patients. Unlike the standardized anatomy of phantoms, patient anatomies exhibit significant variations in organ size, shape, and relative positions (Wall, 2020). These variations can impact the precision of dose calculations within the TPS, as the system has to adapt to these unique anatomical structures. To effectively utilize clinical data for evaluation, researchers must account for this heterogeneity by including a diverse patient population with representative anatomical variations.

The complexities of modern radiotherapy treatment pose another challenge in utilizing clinical data for TPS evaluation. Treatment plans encompass a spectrum of techniques, ranging from simple 3D conformal radiotherapy (3D-CRT) to highly complex modalities like intensity-modulated radiotherapy (IMRT) and volumetric modulated arc therapy (Kry *et al*., 2017) . Evaluating TPS performance across this spectrum of complexities requires careful selection of clinical data representing a broad range of treatment scenarios. Additionally, differing treatment

objectives, such as curative vs. palliative intent, further complicate data analysis and necessitate stratification within the patient population.

Clinical data analysis offers invaluable insights into the real-world performance of TPS. However, researchers must acknowledge the challenges associated with anatomical variations, treatment complexities, and paramount privacy concerns. Careful consideration of these challenges is essential to ensure that clinical data is utilized responsibly and ethically for TPS evaluation. By adopting a data-driven approach while upholding ethical principles and protecting patient privacy, researchers can leverage the power of clinical data to improve the precision, efficacy, and safety of radiation therapy treatment for future patients.

2.3 Comprehensive Review on TPS Evaluation

The Varian Eclipse TPS remains a widely used software platform in radiotherapy treatment planning. Ensuring its accuracy and effectiveness necessitates rigorous evaluation. A recurring theme in the literature centers on the dosimetric accuracy of Varian Eclipse TPS for diverse treatment modalities. Studies by Saini *et al.* (2023) and Kavousi *et al.* (2019) employed phantoms to evaluate dose calculations for photon beams in various treatment scenarios.

These studies reported generally strong congruence between the dose distributions that are delivered and those that are planned for 3D conformal radiotherapy (3D-CRT) plans. However, for more complex modalities like intensity-modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT), some studies identified discrepancies, particularly in high-dose regions (Kry *et al.*, 2017). This suggests that while Eclipse TPS 13.6 performs well for simpler photon treatment plans, caution might be warranted for complex IMRT and VMAT plans, potentially requiring rigorous verification procedures before clinical implementation.

Studies have investigated the performance of Eclipse TPS 13.6 for electron beam therapy. Banaee *et al*. (2024) compared different dose calculation algorithms within Eclipse for electron beam therapy. Their findings suggest that the precision of dose calculations can vary depending on the chosen algorithm. Similarly, Kavousi *et al*. (2019) identified differences between planned and delivered dose distributions for electron beam therapy using Eclipse TPS 13.6. These studies highlight the importance of selecting appropriate algorithms and conducting thorough verification for electron beam treatments planned within Eclipse.

The literature also reveals limitations associated with Eclipse TPS 13.6. One recurring theme concerns the computational demands of the system, particularly for complex treatment plans (Kry *et al*., 2017). This can lead to increased planning times, potentially impacting workflow efficiency in busy clinical settings.

2.3.1 Dose Calculations Algorithms

Accurate prediction of dose distribution within a patient's anatomy is essential for successful radiotherapy, as it enables effective tumor targeting while sparing healthy tissues. Treatment Planning Systems (TPS) are critical in this process, using sophisticated dose calculation algorithms to predict how radiation interacts with different tissues. Monte Carlo (MC) simulations are often deemed the gold standard for accuracy because they can simulate the random transportation of millions of radiation particles through a patient's virtual anatomy, accounting for complex interactions like scattering and absorption (Agency, 2017). This high precision makes MC simulations invaluable, especially for cases with heterogeneous anatomy or advanced techniques such as proton therapy (Verhaegen & Seco, 2021). However, the computational intensity of MC simulations results in longer calculation times, limiting their widespread use in routine clinical settings.

Analytical algorithms provide a balance between accuracy and speed by using pre-calculated dose kernels specific to beam configurations and energies (Liney & Van Der Heide, 2019). These algorithms work efficiently in scenarios with simple anatomy and straightforward treatment plans, like 3D-Conformal Radiotherapy (3D-CRT), but can struggle in cases with complex tissue compositions or oblique beam angles. Hybrid algorithms offer a promising compromise, combining the strengths of both MC simulations and analytical methods. They use analytical calculations for most of the anatomy while applying MC techniques in specific regions with complex geometry or tissue composition, thus improving accuracy without substantial increases in computational time.

The choice of dose calculation algorithm depends on factors such as treatment complexity, tissue composition, and the level of accuracy required (Rijken, 2020). Analytical algorithms may be sufficient for routine treatments with homogenous anatomy, while MC simulations are preferred for complex cases or those near critical structures. For highly intricate plans like Intensity-Modulated Radiotherapy (IMRT) or Volumetric Modulated Arc Therapy (VMAT), where scattered radiation and complex geometries need consideration, MC simulations or hybrid approaches are more effective (Dance, 2014; Kavousi *et al*., 2019). Emerging hybrid algorithms (Hatt et al., 2017) aim to balance efficiency with precision, allowing clinicians to achieve optimal dose distributions suited to each patient's unique anatomy.

Selecting the appropriate dose calculation algorithm is key to achieving accurate and efficient radiotherapy planning. Analytical algorithms are ideal for simpler cases, while MC simulations offer unmatched accuracy for complex cases, albeit with higher computational demands. Hybrid

approaches are increasingly valuable for balancing these demands, representing an evolution in TPS that enhances precision in radiotherapy treatment.

2.3.2 Investigation of Different Algorithms

The Varian Eclipse TPS 13.6 is widely utilized in radiotherapy treatment planning, where the accuracy of dose calculation algorithms plays a pivotal role. Analytical algorithms serve as the primary tool for dose calculations in Eclipse TPS 13.6, with studies by Saini *et al*., (2023) and Kavousi *et al*. (2019) demonstrating that these algorithms perform well for 3D-Conformal Radiotherapy (3D-CRT), exhibiting close agreement between planned and measured dose distributions. Their computational efficiency makes them suitable for routine clinical use; however, limitations arise in more complex scenarios. For instance, in Intensity-Modulated Radiotherapy (IMRT), analytical algorithms within Eclipse may not fully account for complex beam geometries and scattered radiation, leading to discrepancies between planned and delivered doses (Saini *et al*., 2023; Kavousi *et al*., 2019). Consequently, alternative approaches, such as Monte Carlo (MC) simulations, are often preferred for cases requiring higher accuracy. MC simulations, by statistically modeling radiation transport, offer superior fidelity for complex treatments but come with computationally intensive requirements that can impede clinical workflow efficiency (Reinhart *et al*., 2016; Haghighat, 2020).

Selecting the appropriate algorithm within Eclipse TPS depends on the treatment context. Analytical algorithms are well-suited for simple 3D-CRT plans, while MC simulations may be necessary for IMRT or other complex treatment plans that demand precise dose calculations. As computational power improves, MC simulations may become more feasible for regular use.

Additionally, hybrid algorithms combining analytical and MC methods offer a promising compromise, potentially balancing accuracy with efficiency.

In the pursuit of optimal dose distributions, Eclipse TPS also integrates advanced optimization algorithms. Traditional inverse planning approaches within Eclipse, which rely on weighted objectives to balance coverage of tumors and preservation of organs-at-risk (OAR), may not achieve optimal outcomes for complex cases (Wang *et al*., 2020). Advanced optimization techniques, such as evolutionary algorithms that mimic natural selection, have shown potential for refining beam configurations and dose distributions in complex scenarios, improving conformity and OAR sparing compared to conventional methods (Wang *et al*., 2020; De Martino *et al*., 2021). These advanced methods, however, present increased computational demands that require consideration for clinical practicality.

Advanced planning techniques like Intensity-Modulated Radiotherapy (IMRT) and Volumetric Modulated Arc Therapy (VMAT) further enhance the precision of dose delivery within Eclipse TPS. IMRT uses multiple beams with variable intensities, allowing precise dose shaping around critical structures, while VMAT employs continuously rotating gantry arcs to deliver intensity-modulated beams. Studies by Khan *et al*. (2019) and Tang *et al*. (2010) underscore the advantages of these methods, particularly VMAT, in achieving superior dose conformity and sparing healthy tissues. However, VMAT requires specialized expertise and is not universally applicable to all treatment cases.

Looking forward, the integration of artificial intelligence (AI) within Eclipse TPS 13.6 holds transformative potential for enhancing treatment planning. AI-driven tools could automate complex planning tasks and optimize dose distributions, potentially increasing both precision and

efficiency in radiotherapy (Sumida, 2022). As these advancements evolve, the Varian Eclipse TPS can continue to refine and improve the precision and efficiency of radiotherapy treatment planning, contributing to safer and more effective cancer treatment.

2.3.3 Anatomical Modeling

The effectiveness of radiation treatment hinges on distributing a precise dose of radiation to target tumors meanwhile minimizing harm to nearby healthy tissues. This delicate balance necessitates accurate modeling of patient anatomy within Treatment Planning Systems (TPS). However, this seemingly straightforward task presents a multitude of challenges due to limitations in current software and inherent anatomical variations.

Limitations in image acquisition and segmentation, the foundation of accurate anatomical modeling lies in high-fidelity image acquisition. Imaging modalities like Computed Tomography (CT) provide detailed anatomical information. However, artifacts introduced during image acquisition, such as metal implants or motion blur, can distort the representation of tissues (Bibb *et al.*, 2014). Furthermore, the process of segmentation**,** where different tissues are defined within the images, remains a challenge. Manual segmentation is time-consuming and prone to human error, while automated segmentation algorithms may struggle with complex anatomies or subtle tissue variations (Yi *et al.*, 2019). These limitations in image acquisition and segmentation can introduce inaccuracies in the patient model used by TPS, potentially affecting dose calculations and treatment planning.

The human body is inherently variable. Anatomical variations in organ shape, size, and position exist between individuals (Panero & Zelnik, 2014). Furthermore, physiological processes like organ filling and respiration can cause dynamic changes in anatomy throughout treatment (Panero & Zelnik, 2014). Current TPS often rely on static anatomical models, failing to account for these

variations and dynamic movements. This can lead to miscalculations of dose distribution, potentially under-dosing tumors or overdosing healthy tissues, compromising treatment efficacy and increasing the risk of side effects.

The consequences of inaccurate anatomical modeling in TPS can be severe. Underdosing tumors reduces the effectiveness of treatment, potentially leading to tumor recurrence. Conversely, overdosing on healthy tissues increases the risk of late toxicities, compromising patient quality of life. For example, inaccuracies in modeling organs at risk like the spinal cord can increase the risk of radiation myelitis, a debilitating neurological complication (Langen *et al.*, 2008). These potential consequences highlight the critical need for improved methods to model patient anatomy within TPS.

The field of anatomical modeling in TPS is constantly evolving. Image registration techniques are being developed to account for organ movement during treatment delivery (Panero & Zelnik, 2014). Machine learning algorithms show promise in automating segmentation processes with improved accuracy (Tripathi *et al.*, 2022). Furthermore, the integration of functional imaging modalities like PET scans can provide additional information on tumor biology and organ function, leading to more sophisticated anatomical models. These advances hold the potential to revolutionize anatomical modeling in TPS, contributing to more precise and effective radiotherapy treatments.

2.3.4. Impact of Anatomical Variations

The dosing of critical organs surrounding the tumor presents a delicate balancing act. Studies by (Nelms *et al.*, 2012) and (Knöös *et al.*, 2006) highlight the impact of anatomical variations on dose calculations for critical organs within Eclipse TPS 13.6. Nelms *et al.* (2012) investigated the

influence of intestinal filling on dose calculations for rectal cancer treatment. Their findings suggest that variations in bowel filling can result in significant inaccuracies in dose distribution to the rectum within Eclipse. Similarly, explored the impact of organ motion on dose calculations for the heart during lung cancer treatment.

Their study revealed that failing to account for cardiac motion within Eclipse can lead to under-dosing of the tumor and potential increased dose to the heart (Rijken, 2020). These studies underscore the sensitivity of dose calculations for critical organs to anatomical variations within Eclipse TPS 13.6.

Complex anatomical geometries, like bone-muscle interfaces or sinus cavities, pose another challenge for accurate dose calculation within Eclipse TPS 13.6. A study by (Kry *et al.*, 2017)

Investigated the impact of complex geometries on dose calculations for electron beam therapy and IMRT (Intensity-Modulated Radiotherapy). Kry *et al.*(2017) compared different dose calculation algorithms within Eclipse for electron beam therapy treating tumors near bone structures. Their findings suggest that variations in bone density can significantly affect dose calculations within Eclipse (McShan *et al.*, 2010). Similarly, Castelli *et al.* (2015) investigated the accuracy of dose calculations for IMRT plans treating head and neck cancers, characterized by complex anatomical structures. Their study revealed that these complexities may results in discrepancies between planned and delivered dose distributions within Eclipse (Castelli *et al.*, 2015). These studies highlight the need for careful consideration of anatomical variations when planning treatments with complex geometries within Eclipse TPS 13.6.

Several strategies can be employed to mitigate the impact of anatomical variations on dose calculation accuracy within Eclipse TPS 13.6. Image registration techniques can account for organ

movement during treatment delivery (Kry *et al.*, 2017).Furthermore, utilizing advanced imaging modalities like PET scans can provide additional information on tissue density and function, leading to more refined anatomical models within Eclipse. Additionally, implementing robust dose calculation algorithms, particularly for complex treatment scenarios, can improve accuracy despite anatomical variations (Castelli *et al.*, 2015).

The quest for accurate dose calculation in the face of anatomical variations remains an ongoing battle. Studies reveal the particular challenges associated with critical organs and complex geometries within Varian Eclipse TPS 13.6. However, advancements in segmentation techniques, functional imaging integration, and potentially hybrid dose calculation algorithms offer hope for improved accuracy in the future. By continuously evaluating the impact of anatomical variations and implementing mitigation strategies, we can strive toward more precise and effective radiotherapy treatments.

2.5 Evaluation of TPS Performance with CIRS Thorax Phantom

The evaluation of Treatment Planning System (TPS) performance remains critical for ensuring accurate dose delivery in radiotherapy. The CIRS thorax phantom stands as a widely adopted benchmark for TPS evaluation (Peet & Chung, 2021). This phantom mimics human anatomy, containing tissue-equivalent inserts representing various thorax structures. Dosimetric parameters, such as dose distribution within targets and organs at risk (OARs), is capable of being measured within the phantom using ion chambers (Smilowitz *et al.*, 2015).

These measured values are then compared with the dose calculated by the TPS under investigation, revealing potential discrepancies in dose calculation accuracy. Several studies have employed the CIRS thorax phantom to evaluate the performance of Varian Eclipse TPS 13.6. Studies by Saini

et al. (2023) and Udoy *et al.* (2023) reported generally excellent agreement between planned and measured dose distributions for photon beam therapy using analytical algorithms within Eclipse for 3D-conformal radiotherapy (3D-CRT) plans ((Saini *et al.*, 2023); (Udoy *et al.*, 2023)). These findings suggest that Eclipse may achieve acceptable accuracy for conventional treatment scenarios.

However, limitations of Eclipse 13.6 are revealed when evaluating complex treatment plans using the CIRS phantom. Studies by Kavousi *et al.* (2019) identified potential discrepancies between planned and measured dose distributions for intensity-modulated radiotherapy (IMRT) plans within Eclipse (Kavousi *et al.*, 2019). These discrepancies likely stem from the limitations of analytical algorithms in accurately accounting for scattered radiation in complex beam geometries present in IMRT plans. While phantom studies provide valuable insights, limitations exist. The CIRS thorax phantom represents an idealized anatomy, not encompassing the inherent variability of human patients. Future research warrants investigating Eclipse performance using more patient-specific phantoms or in-vivo dosimetry techniques for a more comprehensive evaluation.

The Literature review highlights the CIRS thorax phantom as a valuable tool for evaluating Varian Eclipse TPS 13.6 performance. Studies suggest generally good agreement for conventional treatment plans using analytical algorithms. However, limitations arise for complex IMRT plans, underscoring the need for further investigation with more patient-specific approaches. By continuously evaluating TPS performance using evolving techniques, we can strive towards improved accuracy and efficacy in radiotherapy treatment planning.

The Quest for safer and more effective radiotherapy hinges on accurate dose calculation within Treatment Planning Systems (TPS). However, current evaluation methodologies often fall short

of capturing the complexities of human anatomy. The proposed study aims to move beyond the limitations of traditional phantom-based evaluation. We propose utilizing patient-derived anatomical models generated from computed tomography (CT) scans of real patients undergoing radiotherapy. These models will incorporate individual anatomical variations unlike standardized phantoms (Langen *et al.*, 2008).

Furthermore, the study proposes utilizing multi-material phantoms constructed with tissue-equivalent materials that mimic the heterogeneity of different human tissues. This stands in contrast to uniform materials used in traditional phantoms, offering a more realistic representation of dose deposition within the patient (DeSouza *et al.*, 2015).

The proposed study will employ advanced dosimetry techniques beyond traditional ion chambers. We plan to utilize optical phantoms and thermoluminescent dosimeters (TLDs) for more precise and three-dimensional measurements of dose distribution within the patient-derived models (Wu *et al.*, 2015). These techniques can potentially reveal subtle discrepancies in dose calculations missed by conventional methods.

The findings from our proposed study will directly contribute to advancing TPS evaluation methodologies. By identifying discrepancies between planned and measured doses in patient-specific scenarios, we can highlight the limitations of current TPS algorithms and treatment planning strategies. This information can then be fed back into the development of more accurate TPS algorithms and personalized treatment-planning approaches.

CHAPTER THREE

MATERIALS AND METHOD

This chapter gives the details of the experimental framework, equipment, and materials used to achieve the study's objectives.

3.1 Ethical Consideration

Ethical clearance for this study was endorsed by the Ethics Committee of the University of Ghana's College of Basic and Applied Sciences and the facility's institutional review board.

3.2 Materials

The materials employed in this study include a Varian Eclipse TPS version 13.6, CIRS Model 002LFC thorax phantom, electron Density phantom model 062M, PTW 30013 waterproof farmer ionization chamber, Siemens CT scanner, Catphan 700 phantom, Low energy Unique Performance linear accelerator (LINAC), electrometer, manual 1D water phantom, barometer, and thermometer.

3.2.1 Varian Eclipse TPS

The Varian Eclipse Treatment Planning System (TPS) version 13.6, developed by Varian Medical Systems, is a versatile software used in radiotherapy to design and optimize patient-specific treatment plans. This version employs advanced dose calculation algorithms, including the Anisotropic Analytical Algorithm (AAA) for heterogeneous tissues and the Acuros XB algorithm for high-precision modeling in complex cases. Supporting techniques like IMRT, VMAT, and 3D-CRT, Eclipse TPS 13.6 also includes 3D visualization tools, dose-volume histograms, and

automated organ-at-risk segmentation to enhance planning accuracy. Its automated planning features improve workflow efficiency, and built-in quality assurance tools ensure accurate dose delivery, making it a comprehensive and reliable solution for radiation therapy planning. Figure 3.1 shows the interface of the TPS system.

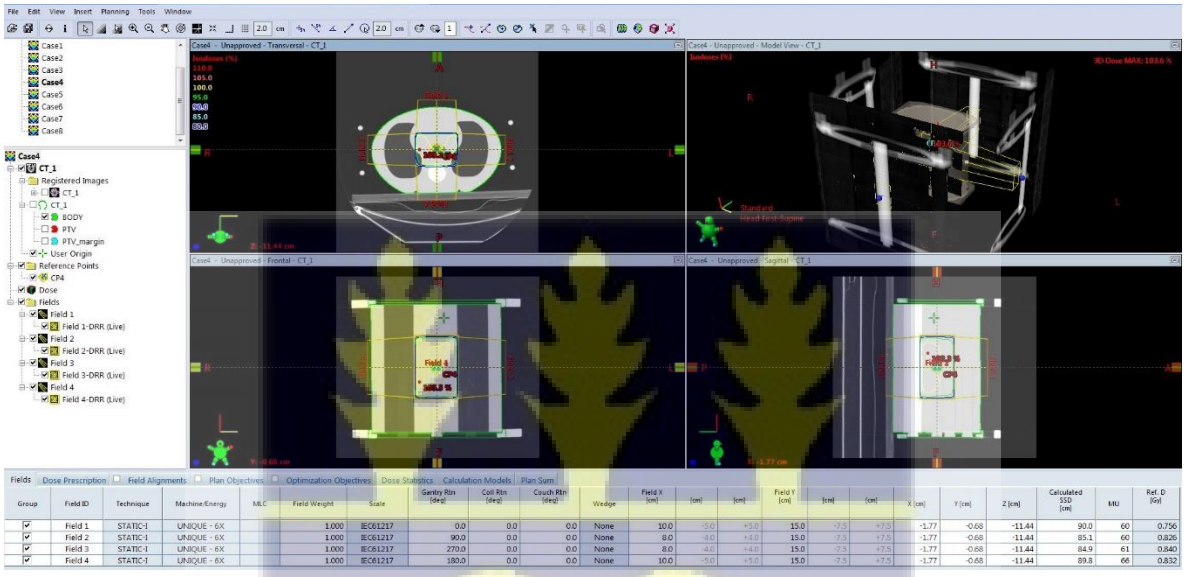

Figure 3.1: Interface of the Varian Eclipse TPS. (Field work, 2024)

3.2.2 The CIRS Thorax Phantom

The elliptical CIRS model 002LFC thorax Phantom accurately depicts the proportions, density, and two-dimensional structure of an average human torso. It is 20 cm thick, 30 cm long, and 30 cm wide. The phantom is made of epoxy materials that are proprietary to tissue. From 50 keV to 15 MeV, the simulated tissues' linear attenuations fall within 1% of the real attenuation for water and bone and 3% for the lung.

Ionization chambers are accommodated by tissue-equivalent interchangeable rod inserts, which enable point dose measurements in several phantom planes. It is feasible to verify the most crucial regions of the chest due to the placement of the holes. The CIRS Thorax Phantom is depicted in Figure 3.2.

Figure 3.2: The CIRS Model 002LFC Thorax Phantom (Field work, 2024)

3.2.3 Electron Density Phantom

The Electron Density Phantom Model 062M is designed for accurate relationship between CT data and different tissues' electron densities. This phantom accounts for tissue heterogeneity, allowing for accurate dosimetry and treatment verification. The Model 062M, which is made of CIRS tissue-equivalent materials, has two disks. that facilitate the assessment of electron density across different tissue types. Its design ensures the effective translation of CT numbers into electron density values, which is crucial for optimizing radiation therapy outcomes. Figure 3.3 shows a picture of the Electron Density Phantom model 062M.

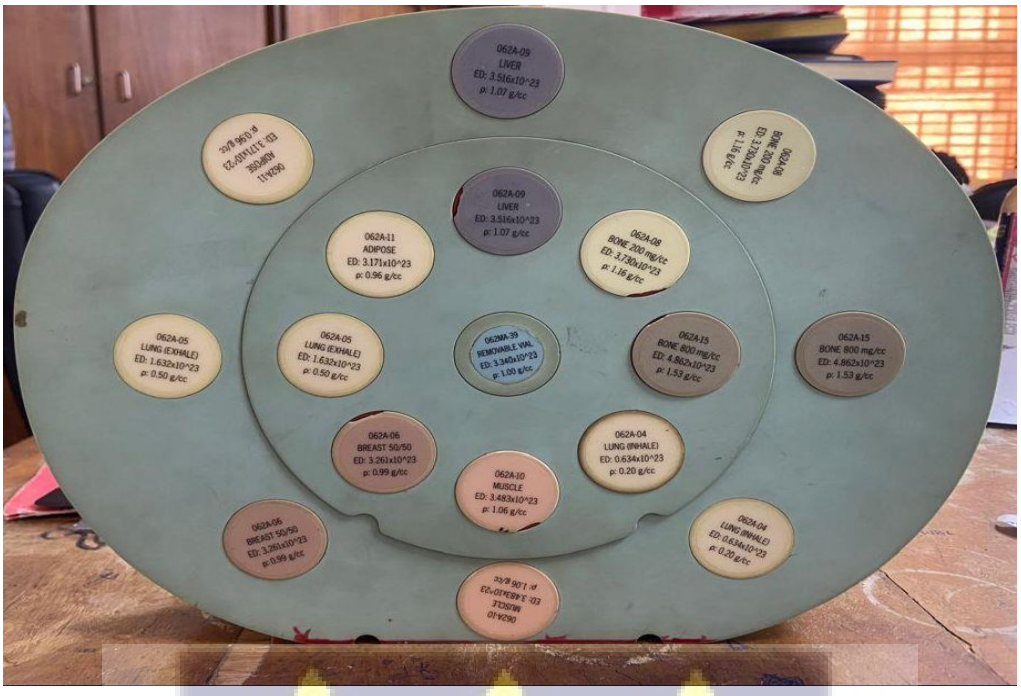

Figure 3.3: Electron Density Phantom model 062M (Field work, 2024)

3.2.4 Ionization Chamber

Figure 3.4 shows the waterproof Farmer-type ionization chamber from PTW Freiburg, model, and serial number SN 009262 utilized for this study. To determine the reference check source measurements and the absorbed-dose-to-water in clinical scenarios, its absorbed dose-to-water calibration coefficient N_(D, W) was combined using methods that are based on absorbed dosage to water (TRS-398). A temperature of 20.0 ^{0}C, a pressure of 101.325 kPa, and a relative humidity of 50.0% were used to calculate the calibration coefficients.

Figure 3.4: PTW 30013 Waterproof Farmer ionization chamber (Field work, 2024)

3.2.5 CT Scanner

The 24-row adaptive detector array of the SOMATOM Scope CT scanner, which gathers 16 data slices at once with sub-millimeter isotropic accuracy, was utilized for this study. The SOMATOM Scope CT Scanner is presented in Figure 3.5.

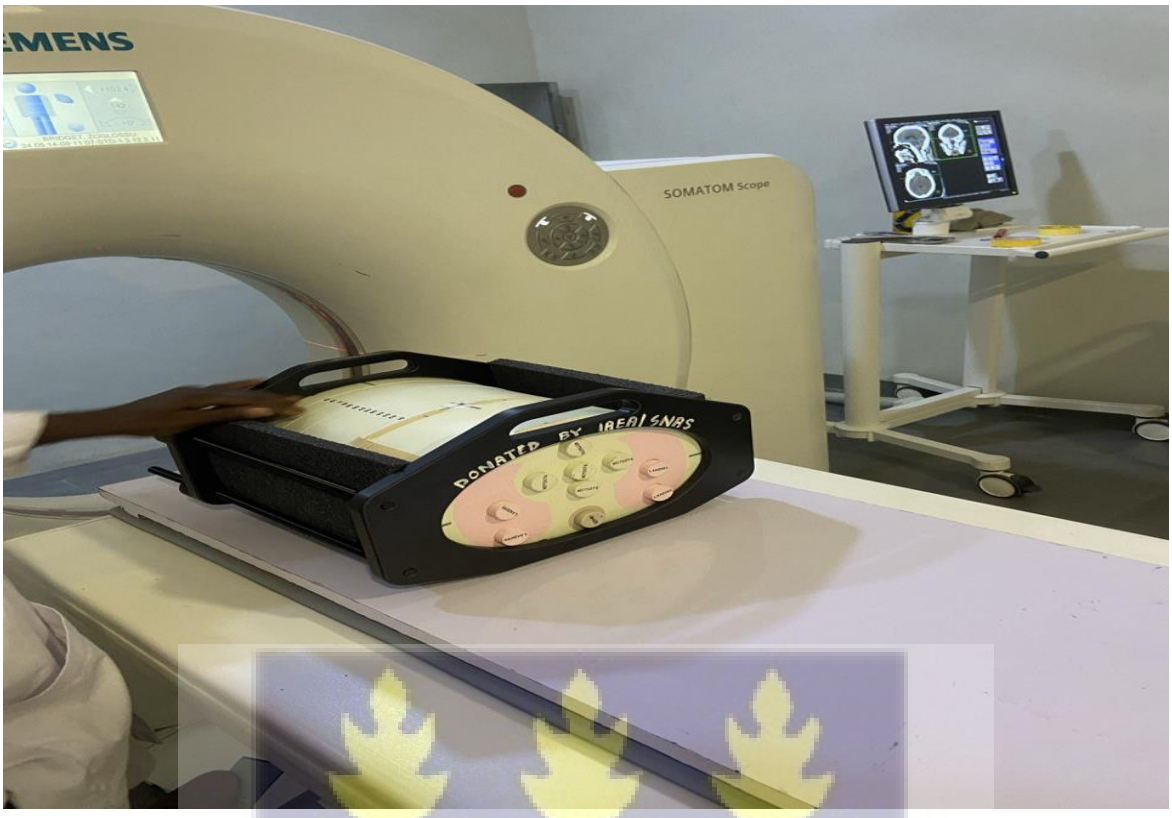

Figure 3.5: Positioning of the phantom for scanning. (Field work, 2024)

3.2.6 Varian Unique Linear Accelerator

The Unique linear accelerator, which operates at a photon energy of 6 MV, was used for the study. It operates in the low energy spectrum, ranging approximately from 50 kV to 300 kV. It Supports variable field sizes ranging from small (e.g., 3 cm x 3 cm) to large (e.g., 20 cm x 20 cm), adjustable to accommodate different treatment areas and target sizes, equipped with an MLC 120 with full leaves overlap, and also a maximum dose rate up to 600 MU. It is accessible for various Treatment delivery modes and techniques such as 2D and 3D CRT, IMRT, and RapidArc treatment with Static therapy field size from (0.5 x 0.5 cm to 40 x 40 cm). Figure 3.6 shows the Varia Uniqe Linear Accelerator.

Figure 3.6: The Varian Unique LINAC during irradiation [Field work, 2024]

3.2.7 Electrometer

The PTW UNIDOS electrometer (PTW, Freiburg, Germany, serial number T10005-50316) was utilized for measurements in this project. The electrometer made by PTW UNIDOS is primarily used for precise measurement and verification of radiation dose and it is designed to offer high accuracy in measuring radiation doses, essential for ensuring patient safety and treatment efficacy. The ionization chamber was connected to the Unidos electrometer for every measurement as shown in Figure 3.7.

Figure 3.7 PTW Unidos Electrometer (Field work, 2024)

3.2.8 Manual water Phantom

The water phantom employed in this study measures 30 x 30 x 30 cm^2 and is composed of transparent, easily see-through Perspex that is 1 cm thick. As seen in Figure 3.8, it has an aluminum component that holds the detector at the different depths.

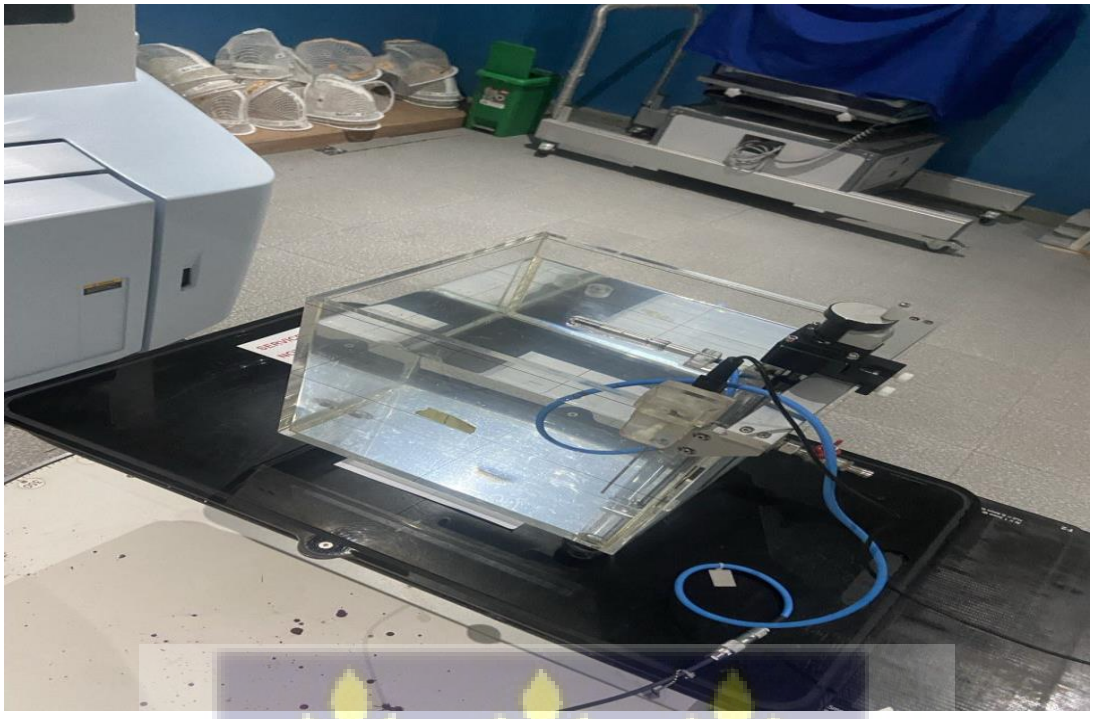

Figure 3.8: In-house water phantom (Field work, 2024)

3.3 Methodology

3.3.1 Quality Control Tests

Quality control tests were performed on the CT scanner used in the study. This was done to ensure that the scanner was functioning properly and to prevent the translation of errors . Some of the tests performed were visual inspection, CT number uniformity, CT image noise and the CT accuracy of other materials. These tests were all performed using the (IAEA) Quality Control Harmonized Diagnostic Radiology protocol(RN:54020377).

3.3.2 Experimental Method

The study was performed at the National Radiotherapy Oncology and Nuclear Medicine Centre, and Diagnostic Centre, all in Accra with approval from the two facilities. In this study, calculations were performed using Varian Eclipse TPS. The Eclipse TPS has been used to execute 46 distinct treatment programs with an anisotropic analytical algorithm (AAA), demonstrating its versatility and reliability in handling diverse patient cases. A central component of this planning process is the Anisotropic Analytical Algorithm (AAA), which serves as the primary dose calculation engine within Eclipse,by employing AAA across 46 distinct treatment programs, the Eclipse TPS demonstrates both its computational robustness and clinical adaptability.

The International Atomic Energy Agency's (IAEA) TECDOC-1583 guidelines, which cover acceptance, commissioning, and QA testing, were followed in order to confirm the Eclipse TPS's quality assurance. A Siemens 16-slice CT scanner with an energy of 110 kVp and a slice thickness of 1 mm parameter were used to scan the Electron Density phantom model 062M, also known as the CT-ED phantom, and the Thorax phantom Model 002LFC, both from the CIRS company

(CIRS Co., USA) .The relative electron density conversion was calculated and fed into the TPS. This is because it allocates the interaction probabilities and attenation Coefficients to each voxel according to its mass density, these data are essential to Eclipse's dose calculation. It used the developed CT-ED curve to translate CT numbers to EDs.

After importing the CIRS thorax phantom CT images in DICOM format into Eclipse TPS, the external contour of the phantom—the line separating the phantom from the treatment couch and air—was identified using the TPS's automated contouring tools. Then, in accordance with the guidelines given by the IAEA-TECDOC-1583, several dosimetric tests were conducted, and the anisotropic analytical algorithm (AAA) was used to calculate the dose while taking the dose-to-water (Dw) conversion into account. Using the Unique linear accelerator (linac), 6MV photon beams were used to deliver the radiation. The Farmer ionization chamber (PTW, Freiburg, Germany) then carried out the dose measurements of the previously computed plans per the guidelines given by the IAEA-TECDOC-1583. Afterward, the TPS and ion chamber results were analyzed, and equation (3.1) was used to report each test's error.

$$\boldsymbol{Error}\ \% = \mathbf{100} \times \frac{\boldsymbol{Dcal - Dmeas}}{\boldsymbol{Dmeas,ref}} \qquad (3.1)$$

Where (D_{meas}), (D_{cal}) and $D_{meas,\ ref}$ are, respectively, the dosage value measured at the reference location, the measured value, and the computed value. Every test case specifies this reference point.

3.3.3 Beam Quality Specification

The tissue–phantom ratio $TPR_{20,\ 10}$ determines the beam quality Q for high-energy photons generated by clinical accelerators. With a constant source-chamber-distance of 100 cm and a field size of 10 cm × 10 cm at the chamber plane, measurements were made with 10 g/cm^2 and 20 g/cm^2 of water over the chamber.

The beam quality Q for high-energy photons produced by clinical accelerators is determined by the tissue–phantom ratio $TPR_{20,\ 10}$. Measurements were performed using 10 g/cm^2 and 20 g/cm^2 of water over the chamber with a constant source-chamber distance of 100 cm and a field size of 10 cm x 10 cm at the chamber plane.

The experimental set-up for measuring $TPR_{20,\ 10}$ is shown in Figure. 3.9

Figure 3.9: Experimental set-up for the determination of the beam quality index Q ($TPR_{20,\ 10}$).

(Field work 2024).

3.3.4 Determination of absorbed dose under reference conditions

Equation 3.2 provides the absorbed dosage to water at the reference depth z_{ref} in water under a photon beam of quality Q and without the chamber:

Absorbed dose;

$$D_{W_1Q} = M_Q \times N_{D_1W} \times K_{T_1P} \times K_S \times K_{pol} \times K_{QQ} \quad \text{(3.2)}$$

Where;

$\mathbf{M_Q}$=Monitor reading

N_{D_1W} =Calibration factor in terms of absorbed dose to water

K_{T_1P}=Temperature Pressure correction factor

K_S=Ion recombination correction factor of an ionization chamber

K_{pol} =Voltage polarity correction factor

K_{QQ}=Beam quality correction factor

3.3.5 Determination of CT to RED conversion

For every chosen inhomogeneity, the air and water CT values were successfully averaged throughout a certain region, with the diameter of the averaged region of interest (ROI) set to approximately 0.5 times the radius of the insert. Care was taken to ensure that the ROI for

averaging CT numbers was positioned away from the edges of the selected areas, avoiding any boundary effects. The averaged CT values were then compared with the CT numbers in the CT-to-relative electron density (RED) conversion curve stored in the radiotherapy treatment planning system (RTPS). The comparison showed agreement within the acceptable threshold of 0.02 for RED values, meaning CT numbers varied by no more than ±20 from the established values. No significant deviations in CT numbers were observed. Consequently, no recalibration of the CT scanner was required, and the existing CT-to-RED data remained valid without any updates to the RTPS.

3.3.6 Dosimetric test cases

Case 1: Testing for reference conditions based on CT data

This test was conducted to verify the basic beam data for a reference field using a 10 cm x 10 cm field with a gantry angle of 0° and a collimator angle of 0°. The results show minimal deviations between the calculated and measured doses across different points (holes 3, 9, and 10), with all deviations being well within the agreement criterion.

Case 2: Oblique incidence, lack of scattering, and tangential fields

For a tangential field, this test concentrates on the effects of oblique incidence and the lack of dispersion. The field employed was 15 cm x 10 cm, with a gantry angle of 90° and a collimator angle that varied according to the wedge orientation.

Case 3: Significant blocking of the field corners

The purpose of this test is to confirm the blocked field computation. Use the MLC or conventional blocks to block a 14 cm x14 cm field with a 45° collimator angle to a 10 cm x 10 cm field. It assesses the accuracy of the dosage estimate when large areas of the field are obstructed, resulting in an irregular field.

Case 4: Four field box

The purpose of this test is to confirm that the dosage from four fields and the dose given with a single beam are calculated correctly. The specifications and measuring sites were established in the center of holes 5, 6, and 10, and all four fields have an identical weight.

Case 5: Automatic expansion and customized blocking

The purpose of this test is to confirm the RTPS's auto-aperture function, tailored blocking, and lung inhomogeneity computations. Using the available expansion tools, an 8 cm diameter by 8 cm length cylinder centered at point #2 was enlarged with a 1 cm margin in all directions. To comply, an MLC was used. The center of hole 7 was used as the measuring point.

Case 6: Oblique incidence with irregular field and blocking the centre of the field

The purpose of this test is to confirm the computations for irregular fields when the field's center is blocked. The center of hole #5 was supposed to represent the isocentre. The field was 20 cm x 10 cm, with a gantry angle of 45° and a collimator angle of 90°. A 6 cm × 12 cm field was blocked off using custom block or MLC to create an L-shaped field. In the center of holes 3, 7, and 10 (the reference point), the parameters and measurement points were established.

Case 7: Three fields, two wedge-paired, asymmetric collimation

The purpose of this test is to confirm the computations using wedge-paired fields and asymmetric collimation (use a half-beam block if asymmetric collimators are not available). The center of hole #3 was supposed to represent the isocentre. Every field has the same weight. The angle of the collimator was adjusted based on the wedge insertions. In the center of hole #5, the parameters and measuring point were established.

Case 8: Non-coplanar beams with couch and collimator rotation

The purpose of this test is to confirm the calculations using collimator and couch rotation. Equal weights were assigned to three fields with varying gantry angles and collimator rotations. The center of hole #5 was supposed to represent the isocentre. The specifications and measuring point were specified in the center of the hole #5.

3.4 Data Analysis

The analysis of the data collected for the study was conducted using Microsoft Excel spreadsheet, a feature of the 2016 version of Microsoft Office. The mean electrometer readings, temperature and pressure correction factors, ion recombination, beam quality index, deviations between calculated and measured doses, and all of the study's plotted graphs used Microsoft Excel for the analysis.

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter outlines the results of the quality control tests and the findings of the clinical test cases, with a comparison between measured and computed values in each case accompanied by specific dose variations. The determination of CT to RED conversion is also discussed as well.

4.1 Quality Control Tests

4.4.1 Visual inspection

The table 4.1 represents the quality assurance test results for visual inspection on a CT scanner machine, focusing on various aspects critical to ensuring optimal performance and accuracy in imaging ,The quality assurance visual inspection of the CT scanner verified the functionality and safety of key components, including the power supply, scanner gantry, control panel, patient table, and restraints. Critical systems such as the laser alignment, emergency stop button, and intercom were also tested to ensure smooth operation, accurate patient positioning, and clear communication during scans. The radiation shielding and scanner exterior were inspected for integrity, confirming that the machine poses no radiation risks and is physically intact. All tests passed without issues, indicating that the CT scanner is in optimal condition for safe and effective use.

Table 4.1: Visual Inspection

QA Test	Component	Expected Condition	Result	Pass/Fail
Power Supply	Cables and connectors	All cables securely connected, no fraying	No issues	Pass
Scanner Gantry	Movements	Smooth gantry rotation, no unusual noises	No issues	Pass
Control Panel	Buttons and display	All buttons functional, display clear	No issues	Pass
Laser Alignment System	Laser lights	Bright, clearly visible, properly aligned	No issues	Pass
Emergency Stop Button	Button function	Immediate cessation of all functions when pressed	No issues	Pass
Intercom System	Sound clarity	Clear communication between control room and gantry	No issues	Pass
Radiation Shielding	Door interlock system	Doors lock automatically during scanning, no radiation leaks	No issues	Pass
CT Scanner Exterior	Physical condition	No visible damage or wear on scanner surface	No issues	Pass

4.1.2 CT uniformity

The data presented in Table 4.2 reveal that the CT number uniformity test passed. This result indicates that a homogeneous material's Hounsfield Unit (HU) values demonstrate consistent and uniform variation across any CT image produced at the facility. By analyzing the differences between the HU values at the central Region of Interest (ROI) and those at peripheral positions (specifically at 12 o'clock, 3 o'clock, 6 o'clock, and 9 o'clock), it was found that all the measured differences were within the acceptable tolerance range, which is defined as 5 HU or less(ACR, 2017). This uniformity test was done using the manufacturer's water phantom.

Table 4.2: CT Number Uniformity Test Results

Test Location	Measured CT Number (HU)	Expected CT Number (HU)	Difference (HU)	Pass/Fail
Center (ROI 1)	-0.28	0	-0.28	Pass
12 O'Clock (ROI 2)	-0.57	0	-0.57	Pass
3 O'Clock (ROI 3)	-1.25	0	-1.25	Pass
6 O'Clock (ROI 4)	-0.87	0	-0.87	Pass
9 O'Clock (ROI 5)	-0.31	0	-0.31	Pass

4.1.3 CT Accuracy of Other Materials

This test was performed to evaluate the accuracy of the CT scanner in differentiating various materials based on their density. The scanner measures the CT numbers (Hounsfield Units) of known materials (inserts) and compares them with their expected values. The acceptance criteria typically depend on how closely the measured CT numbers match the expected ones. The small deviations observed (ranging from 2HU to 5 HU) are within typical acceptable limits for clinical CT scanners. Based on the dataset provided in Table 4.3, the insert test results are acceptable, demonstrating that the CT scanner is functioning correctly and producing reliable able measurements across different materials.

Table 4.3: Insert Test Results

Insert Material	Expected CT Number (HU)	Measured CT Number (HU)	Deviation (HU)
Air	-1000	-998	+2
Water	0	2	+2
Bone Equivalent	+1000	+995	-5

4.1.4 CT Image Noise

Table 4.4 presents the results of the CT image noise levels which was within the 5 HU threshold. This outcome indicates the successful completion of the CT image noise test. The low noise levels demonstrate the CT scanner's optimal performance in minimizing image noise, thereby contributing to the production of high-quality diagnostic images.

Table 4.4: CT Image Noise Results

Noise(Standard Deviation)	Tolerance ($\leq 5HU$)
3.993	**Pass**

4.2 Results of Dosimetric test cases

Case 1: Testing for reference conditions based on CT data

The results show minimal deviations between the calculated and measured doses across different points (holes 3, 9, and 10) of the CIRS Thorax phantom, with all deviations being well within the agreement criterion. For instance, hole 3 showed a deviation of 1.57%, which is within the acceptable limit of 2%. This indicates a high level of accuracy in dose calculation for standard reference conditions, confirming the TPS's reliability for basic beam data.

Table 4.5. Results for reference conditions based on CT data

Case	Location of measuring point	Calculated dose (Gy)	Measured dose (Gy)	Deviation (%)	Agreement criterion (%)
1	3	1.97	2	1.57	2
	9	0.14	0.16	1.01	4
	10	1.21	1.24	1.50	3

Case 2: Oblique incidence, lack of scattering and tangential fields

The measurement point at hole 1 showed a deviation of 2.93%, which is slightly higher than in Case 1 but still within the 3% agreement criterion. The results suggest that the TPS can accurately account for oblique incidence and limited scattering, ensuring that doses remain within acceptable limits even under less conventional conditions: see Table 4.6

Table 4.6: Results of Oblique Incidence, Lack of Scattering And Tangential Fields

Case	Location of measuring point	Calculated dose (Gy)	Measured dose (Gy)	Deviation (%)	Agreement criterion (%)
2	1	1.94	2	2.93	3

Case 3: Significant blocking of the field corners

The measured and calculated doses at the measurement point (hole 3) showed a deviation of 2.21%, within the 3% agreement criterion. The accurate calculation under blocked conditions is crucial for treatments requiring complex field shaping, as it ensures the correct dose is delivered even when large parts of the field are obstructed: as shown in Table 4.7

Table 4.7: Results of Significant Blocking of The Field Corners

Case	Location of measuring point	Calculated dose (Gy)	Measured dose (Gy)	Deviation (%)	Agreement criterion (%)
3	3	1.96	2	2.21	3

Case 4: Four field box

The results for different field angles (0°, 90°, 180°, and 270°) showed deviations ranging from 1.83% to 3.88%, all within the respective agreement criteria. These findings demonstrate the TPS's capability to deliver consistent and accurate doses when using multiple fields, an essential feature for complex treatment plans involving several angles: as shown in Table 4.8

Table 4.8: Results for Four Field Box

Case	Location of measuring point	Calculated dose (Gy)	Measured dose (Gy)	Deviation (%)	Agreement criterion (%)
5	F1: 0°	0.50	0.49	1.83	2
	F2: 90°	0.50	0.49	2.85	3
	F3:270°	0.50	0.49	2.24	3
	F4:180°	0.50	0.51	-2.65	3
6	F1: 0°	0.50	0.49	2.04	3
	F2: 90°	0.50	0.52	-3.06	4
	F3:270°	0.50	0.51	-2.86	3
	F4:180°	0.50	0.52	-3.88	4
10	F1: 0°	0.50	0.48	2.88	3
	F2: 90°	0.50	0.52	-3.29	4
	F3:270°	0.50	0.51	2.06	3
	F4:180°	0.50	0.49	2.67	4

Case 5: Automatic expansion and customized blocking

The results showed deviations of -0.86% and -3.52% at holes 2 and 7, respectively, both within the acceptable criteria. The accuracy in handling inhomogeneities and customized fields suggests that the TPS can reliably adjust for patient-specific geometries and tissue variations: as shown in Table 4.9.

Table 4.9: Results of Automatic expansion and customized blocking

Case	Location of measuring point	Calculated dose (Gy)	Measured dose (Gy)	Deviation (%)	Agreement criterion (%)
5	2	2.02	2	-0.86	3
	7	1.81	1.74	-3.52	4

Case 6: Oblique incidence with irregular field and blocking the centre of the field

The deviations at holes 3, 7, and 10 were all within the specified agreement criteria, ranging from -0.82% to -3.54%. This confirms that the TPS can handle complex geometries and orientations, maintaining dose accuracy even with irregularly shaped fields: as shown in Table 4.10.

Table 4.10: Results of Oblique incidence with irregular field and blocking the centre of the field

Case	Location of measuring point	Calculated dose (Gy)	Measured dose (Gy)	Deviation (%)	Agreement criterion (%)
6	3	2.02	2	-0.82	3
	7	1.04	1.03	-0.38	4
	10	0.18	0.11	-3.54	5

Case 7: Three fields, two wedge-paired, asymmetric collimation

The deviations at the measurement points (hole 5) were within acceptable limits, with the largest deviation being 3.60%. The results support the use of the TPS for plans involving asymmetric collimation and wedge-pair techniques, which are common in radiotherapy: as shown in Table 4.11.

Table 4.11: Results of Three fields, two wedge-paired, asymmetric collimation

Case	Location of measuring point	Calculated dose (Gy)	Measured dose (Gy)	Deviation (%)	Agreement criterion (%)
7	5	0.75	0.76	0.54	2
		0.29	0.32	3.60	4
		0.30	0.32	3.18	4

Case 8: Non-coplanar beams with couch and collimator rotation

The deviations for the measurement points were within 1.21%, well within the 3% agreement criterion. This performance indicates that the TPS is well-suited for non-coplanar beam arrangements, crucial for advanced treatments like stereotactic radiosurgery: as shown inTable 4.12.

Table 4.12: Results of Geometry for Test Case 8

Case	Location of measuring point	Calculated dose (Gy)	Measured dose (Gy)	Deviation (%)	Agreement criterion (%)
8	5	0.66	0.67	1.21	3
		0.66	0.67	1.07	3
		0.66	0.67	0.95	3

4.3 CT to RED conversion

The CT to RED conversion curves on the Varian Eclipse system under review in this audit were either generic or provided by the TPS manufacturer. The CT-ED curve shown in Figure 4.1. is used to assign the electron density to the voxels and determine the dose . This is because it shows The relationship between the CT number and the relative electron density of various tissues. CT numbers were averaged over a predetermined area for each tissue inhomogeneity (such as water or air). The accuracy of the CT scanner was evaluated by comparing the average values with the reference CT numbers that were stored as shown in table 4.13 .The CT values for the phantom materials did not deviate from the reference values by more than ±20 (HU), which is the acceptable limit of ±20 HU.

Table 4.13:Results of Comparism of CT to Electron density Values

Insert	Manufacturer CT Number (HU)	Manufacturer Electron Density	TPS Electron Density (Interpolated)
Lung	-700	0.207	0.2
Adipose	-100	0.949	0.95
Plastic Water	0	1.003	1
Muscle	40	1.042	1.04
Bone	1000	1.506	1.5
Dense Bone	1700	2.005	2

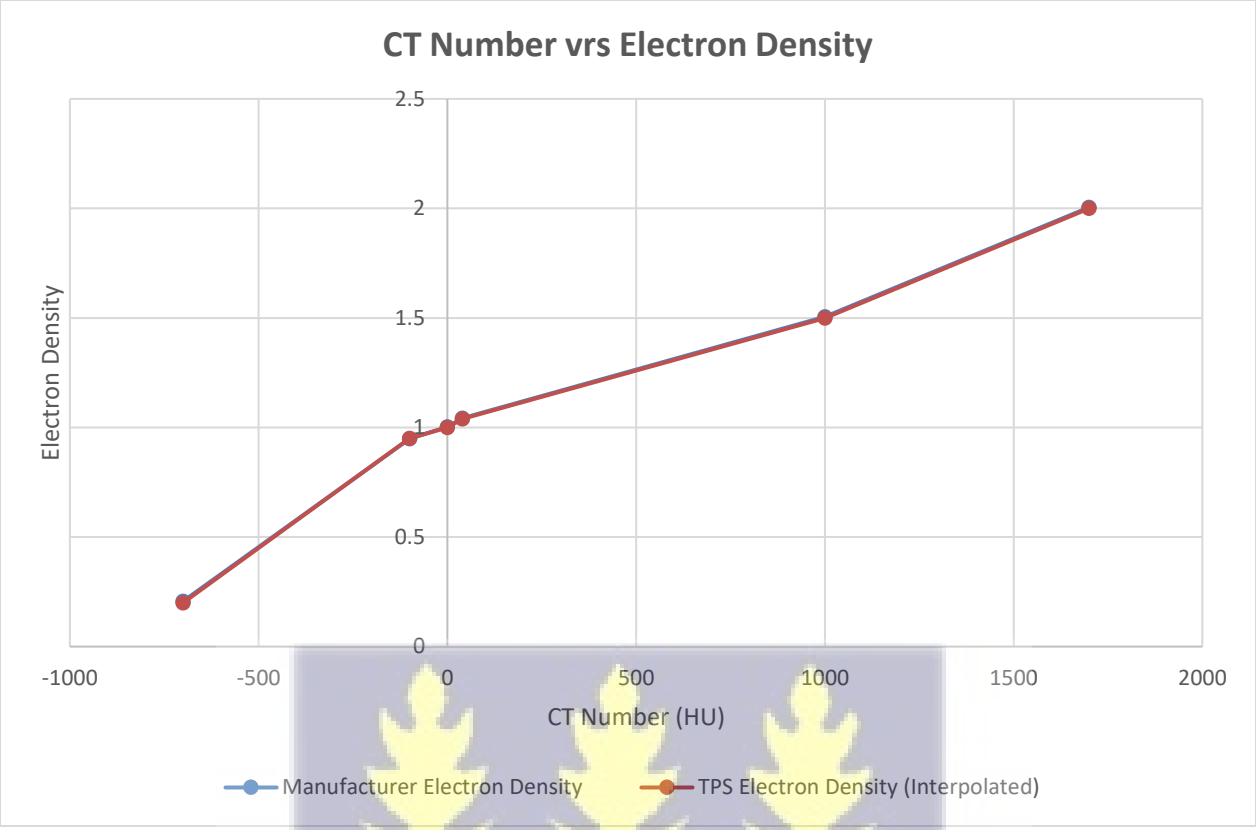

Figure 4.1: CT calibration curve measured with CIRS phantom

4.5 Discussion

The study investigated the accuracy of the Varian Eclipse TPS 13.6 using the CIRS thorax phantom across multiple test cases. The results indicate that the Eclipse TPS, particularly with the Anisotropic Analytical Algorithm (AAA), performed well within the tolerance levels for dose calculation accuracy, meeting the acceptance criteria set by the IAEA TECDOC-1583 guidelines. For instance, in the reference conditions test, deviations between calculated and measured doses were minimal, showing high alignment with standard beam data. This aligns with findings from Saini *et al.* (2023) and Kavousi *et al.* (2019), which reported similar levels of accuracy for 3D-

Conformal Radiotherapy (3D-CRT) when using analytical algorithms within the Varian Eclipse TPS.

However, discrepancies emerged in cases with oblique incidences or significant field blocking, suggesting potential limitations of the AAA in complex scenarios. This trend is consistent with studies by Reinhart *et al.* (2016) and Haghighat (2020), which found that Monte Carlo (MC) simulations, while more computationally intensive, provide higher accuracy for scenarios with complex geometries or heterogeneities due to their statistical modeling of radiation transport. In line with this, the study results suggest that while the AAA is sufficient for simpler cases, MC simulations may be preferable for higher-precision demands, such as intensity-modulated radiotherapy (IMRT).

In terms of anatomical accuracy, the study showed consistent CT-to-RED conversion, ensuring reliable dose calculations. Other studies, like those by Udoy *et al.* (2023), have highlighted the importance of CT-to-RED calibration, as it significantly affects dose prediction in heterogeneous regions. The successful CT uniformity test with results within ±5 HU supports the scanner's ability to provide consistent image quality, in line with the American College of Radiology (ACR) recommendations. Similar uniformity across ROI locations (e.g., central and peripheral ROIs) has been documented as critical for reducing artifacts in complex anatomical structures.Also This detailed correlation and validation provide a robust framework for ensuring accurate electron density assignments, ultimately improving treatment planning accuracy. The visual data plot further highlights these relationships, showing measured electron densities closely aligned with TPS values and manufacturer data, reinforcing model fidelity.

These findings underscore the overall robustness of the Varian Eclipse TPS 13.6 but also highlight its limitations in complex geometries. Continued exploration of hybrid algorithms could balance the computational efficiency of analytical methods with the accuracy of MC simulations for clinical application. In future work, expanding evaluations with patient-specific phantoms could further refine TPS performance under varied clinical scenarios, aligning with emerging trends in personalized radiotherapy.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

This chapter presents the conclusions and recommendations drawn from the study's findings.

5.1 Conclusion

The study offered a thorough assessment of the performance of the Varian Eclipse Treatment Planning System (TPS) using the CIRS thorax phantom, assessing its dose calculation accuracy in heterogeneities tissue and complex treatment geometries. The findings demonstrate that the Varian Eclipse TPS performed well under standard conditions,with minimal dose deviations.The system's ability to model oblique incidence,blocked fields,and muti-field techniques.such as the four-filed bix method ,was affirmed with the results falling within the acceptable criteria.

5.2 Recommendations

1. To the Scientific Community

Enhance Quality Assurance Protocols, The study underscores the importance of using advanced quality assurance (QA) protocols that include phantoms like the CIRS thorax phantom for verifying Treatment Planning System (TPS) accuracy. Regulatory bodies should mandate routine TPS evaluations with anthropomorphic phantoms to ensure that dose calculations meet clinical accuracy standards, thereby enhancing patient safety.

2. To the Treatment Facility

Ensure continued accuracy and patient safety, the treatment facility should maintain routine quality assurance of both the CT scanner and the Varian Eclipse TPS, including regular visual inspections, CT number uniformity checks, and CT-to-RED verification. For advanced techniques such as IMRT and VMAT, additional end-to-end verification methods—such as Monte Carlo simulations, film dosimetry, or in-vivo measurements—should be implemented to minimize uncertainties in complex dose calculations. Periodic updates and recalibration of CT-to-RED data and TPS configurations are essential, particularly following software upgrades or equipment maintenance. Furthermore, ongoing staff training on IAEA TECDOC-1583 protocols and systematic documentation of QA outcomes will enhance workflow consistency, improve planning accuracy, and uphold high standards of radiotherapy delivery within the facility.

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APPENDIX I (Ethical Clearance)

University of Ghana,ECBAS approved and Ethical clearance for this research

UNIVERSITY OF GHANA
ETHICS COMMITTEE FOR BASIC AND APPLIED SCIENCES (ECBAS)
P. O. Box LG 1195, Legon, Accra, Ghana

Ref. No: ECBAS 042/23-24

22nd April, 2024

Clement Kwame Akrobotu
Department of Medical Physics,
School of Nuclear and Allied Sciences
University of Ghana
Legon, Accra

Dear Mr. Akrobotu,

ECBAS 042/23-24: PERFORMANCE EVALUATION OF RADIOTHERAPY TREATMENT PLANNING SYSTEM USING THE CIRS THORAX PHANTOM

This is to inform you that the above referenced study has been presented to the Ethics Committee for Basic and Applied Sciences for a full board review and the following actions taken subject to the conditions and explanation provided below:

Expiry Date:	23/04/2025
On Agenda for:	Initial Submission
Date of Submission:	24/02/2024
ECBAS Action:	Approved
Reporting:	Annually

Please accept my congratulations.

Yours sincerely,

ETHICS COMMITTEE FOR BASIC AND APPLIED SCIENCES APPROVED 22 APR 2024 UNIVERSITY OF GHANA

Professor Dorcas Osei-Safo
ECBAS Chairperson