A STUDY OF RADIATION DOSE FROM COMPUTED TOMOGRAPHY (CT) SIMULATION SCAN IN BRACHYTHERAPY TREATMENT

WAN NURUL AIN BINTI WAN MAHAZELI

SCHOOL OF HEALTH SCIENCE

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by

WAN NURUL AIN BINTI WAN MAHAZELI

Dissertation submitted in partial fulfilment of the requirements for the degree of Bachelor of Medical Radiation (Honours)

July 2025

CERTIFICATE

This is to certify that the dissertation entitled “DISSERTATION TITLE” is the bona fide record of research work done by Ms Wan Nurul Ain Binti Wan Mahazeli during the period from “month” 2024 to May 2025 under my supervision. I have read this dissertation and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation to be submitted in partial fulfilment for the degree of Bachelor of Health Science (Honours) (Medical Radiation).

Main supervisor,

………………………………

Assoc. Prof Dr Mohd Zahri Abdul Aziz

Lecturer

Advanced Medical and Dental Institute

Universiti Sains Malaysia

13200 Kepala Batas

Penang, Malaysia

Date: ………………………….

DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated and duly acknowledged. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at Universiti Sains Malaysia or other institutions. I grant Universiti Sains Malaysia the right to use the dissertation for teaching, research and promotional purposes

WAN NURUL AIN BINTI WAN MAHAZELI

25/6/2025

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LIST OF SYMBOLS

cm	centimeter
kV	kilovoltage
mA	miliampere
mGy	miligray
mGy.cm	miligray centimeter
mm	milimeter
sec	second

LIST OF ABBREVIATIONS

AAPM	American Association of Physicists in Medicine
ALARA	As Low as Reasonable Achievable
CT	Computed Tomography
CTDIvol	volume Computed Tomography Dose Index
CTDIw	weighted Computed Tomography Dose Index
CTV	clinical target volume
DICOM	Digital Imaging and Communications in Medicine
DLP	Dose-length product
DRL	Diagnostic Reference Levels
ERTC	European Radiation Protection Report
FOV	field of view
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IPPT	Institut Pergigian dan Perubatan Termaju
IQR	interquartile range
LDRLs	Local Diagnostic Reference Levels
MPR	multi-planar reconstruction
MRI	magnetic resonance imaging
OAR	organ at risk
PACS	Picture Archiving and Communication System
RN	registration number
TPS	treatment planning system

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ABSTRAK

Brakiterapi merupakan satu bentuk terapi radiasi dalaman yang bergantung pada pengimejan tepat untuk penempatan aplikator dan perancangan rawatan. Kajian ini bertujuan untuk menilai dos radiasi yang disampaikan semasa imbasan simulasi Pengimejan Berkomputer (CT) untuk rawatan brakiterapi melibatkan kanser hati, lidah, dan endometrium. Memastikan keselamatan pesakit sambil mengekalkan kualiti imej adalah penting, kerana dos pengimejan berlebihan menyumbang kepada pendedahan radiasi keseluruhan. Analisis retrospektif dijalankan terhadap parameter imbasan simulasi CT dan metrik dos, termasuk Indeks Dos Tomografi Berkomputer isipadu (CTDIvol) dan Hasil Darab Dos-Panjang (DLP), yang dikumpulkan daripada 46 pesakit merangkumi tiga tapak rawatan. Data yang dikumpul dibandingkan dengan Tahap Rujukan Diagnostik (DRL) antarabangsa pada persentil ke-75 untuk menentukan pematuhan. Nilai CTDIvol bagi kanser hati, lidah, dan endometrium masing-masing ialah 46.42, 32.76, dan 54.20 mGy. Manakala nilai DLP bagi kanser hati, lidah, dan endometrium pula ialah 1496.0 mGy·cm, 1893.1 mGy·cm, dan 1585.5 mGy·cm. Data menunjukkan bahawa majoriti imbasan berada dalam had dos yang dibenarkan; nilai CTDIvol bagi hati, lidah, dan endometrium adalah masing-masing 46.42 mGy, 32.76 mGy, dan 54.20 mGy, manakala nilai DLP pula ialah 1496 mGy·cm, 1893.10 mGy·cm, dan 1585.5 mGy·cm. Namun, kes CTDIvol dan DLP tinggi dikenal pasti, terutamanya dalam kes endometrium disebabkan ketebalan kepingan lebih nipis dan anatomi pelvis kompleks. Kajian ini menekankan keperluan pemantauan berterusan dan pengoptimuman protokol untuk mengurangkan pendedahan radiasi tidak perlu semasa simulasi CT untuk brakiterapi, menyokong prinsip ALARA (As Low As Reasonably Achievable) serta bagi memastikan amalan pengimejan yang selamat.

Kata kunci: brakiterapi, simulasi CT, CTDIvol, DLP, Paras Rujukan Diagnostik**.**

ABSTRACT

Brachytherapy is a form of internal radiation therapy that relies on precise imaging for accurate applicator placement and treatment planning. This study aimed to evaluate the radiation dose delivered during CT simulation scan for brachytherapy treatments involving liver, tongue, and endometrial cancers. Ensuring patient safety while maintaining image quality is essential, as excessive imaging doses contribute to overall radiation exposure. Method: A retrospective analysis was conducted on CT simulation scan parameters and dose metrics, including volume Computed Tomography Dose Index (CTDIvol) and Dose-length product (DLP), collected from 46 patients across the three treatment sites. The collected data were compared against international Diagnostic Reference Levels (DRLs) set at the 75th percentile to determine compliance. The CTDIvols for liver, tongue, and endometrial cancer were 46.42, 32.76, and 54.20 mGy, respectively. Meanwhile, DLP values for liver, tongue, and endometrial cancer were 1496.0 mGy.cm, 1893.1 mGy.cm, and 1585.5 mGy.cm, respectively. The data revealed that the majority of scans were under permissible dosage limits; liver, tongue, and endometrial cancer were 46.42 mGy, 32.76 mGy, and 54.20 mGy, respectively, while DLP values were 1496 mGy.cm, 1893.10 mGy.cm, and 1585.5 mGy.cm. However, instances of elevated CTDIvol and DLP were identified, particularly in endometrial cases due to thinner slice thickness and complex pelvic anatomy. In conclusion, this study highlights the need for continued monitoring and protocol optimisation to minimise unnecessary radiation exposure during CT simulation for brachytherapy, supporting the ALARA principle and promoting safe imaging practices.

Keywords: brachytherapy, CT simulation, CTDIvol, DLP, Diagnostic Reference Levels.

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Brachytherapy is a type of internal radiation therapy where a radioactive source is placed directly or nearly to the tumour to treat various cancers such as cervical, tongue, and liver. In most brachytherapy treatments, a radiation oncologist relies on imaging techniques such as computed tomography (CT) simulation scan during the treatment planning and delivery to accurately placement of encapsulated brachytherapy sources in the patient’s body (Mohd Khairi et al., 2023). The method used depends on the type and location of the cancer. Radioactive sources (or catheters loaded with radioactive sources) must be implanted either inside the tumour (interstitial brachytherapy) or relatively near the tumour (Chargari et al., 2019). In interstitial brachytherapy, the radiation source is inserted directly into the tumour tissue, commonly used for cancers like prostate cancer. In intracavity brachytherapy, the radiation is delivered into a natural body cavity or a space created during surgery, such as the vagina, which is for treating cervical or endometrial cancers. Before treatment begins, the doctor carefully positions the catheter or applicator to ensure accurate radiation delivery.

CT simulation scan in brachytherapy procedures help in accurately localizing the tumour and surrounding tissue to ensure the correct placement of the radioactive source and provide detailed 3D images. A CT-based treatment plan has the advantage of accurate dose evaluation because it is based on the volumes of anatomic structures (Lim & Kim, 2021). It allows doctors to visualize the patient's anatomy in three dimensions, ensuring the precise positioning of catheters or applicators relative to the tumour and nearby organs at risk (OARs) (Lim & Kim, 2021). While other modalities like magnetic resonance imaging (MRI) may offer superior soft tissue contrast, MRI can be time-consuming, more expensive, and less practical for frequent imaging during a treatment course. Unlike MRI, CT efficiently accommodates repeated imaging during multi-fraction brachytherapy, tracking anatomical changes, for example, tumour regression, and organ motion without workflow disruption (Lee, 2014). However, CT simulation scan involves ionizing radiation, which contributes to the patient's overall radiation exposure. The risk of secondary cancer is increased when non-target areas receive excessive radiation exposure. To limit the risk, we should lower exposure doses as much as is practically possible. Adhering to the ALARA (As Low as Reasonably Achievable) principle, it is crucial to optimize CT simulation protocols in brachytherapy to minimize this additional exposure without compromising diagnostic quality (Larson, 2014).

To control patient radiation doses and prevent unnecessary radiation exposure in medical imaging, the International Commission on Radiological Protection (ICRP) advises using medical methods and the best radiological protection (Kito et al., 2024). This involves the use of appropriate imaging protocols, advanced technologies, and patient-specific adjustments to scan parameters such as tube current, voltage, and scan range. To quantify and evaluate the radiation exposure from CT simulation scan, two key metrics are commonly used, which are the volume CT dose index (CTDIvol) and dose-length product (DLP). These parameters provide information about the radiation dose administered during CT imaging, with CTDIvol representing the average dose across the volume of the scanned area, meanwhile DLP indicates overall radiation during the scan length. Understanding these values is important for optimizing CT protocols and minimizing unnecessary radiation exposure.

Diagnostic Reference Levels (DRLs) are dose benchmarks typically derived from the 75th percentile of dose distributions for specific imaging procedures. They are not regulatory limits but serve as reference values to help identify unusually high or low radiation doses in clinical practice. To establish local DRLs, a commonly accepted method involves collecting data from at least 20–30 procedures for well-defined clinical indications and calculating the third quartile values. (Damilakis et al., 2023). Several international studies have reported DRLs for CT simulation scans in radiotherapy and brachytherapy settings, providing a baseline for comparison (Japan DRL Committee, 2020; European Commission, 2014). However, limited local data are available, especially for site-specific CT simulation scans in brachytherapy, highlighting the need for updated, institution-specific DRLs.

This study aims to address that gap by comparing radiation doses from CT simulation scans across different treatment sites. The CTDIvol and DLP values are extracted from Digital Imaging and Communications in Medicine (DICOM) metadata using the Picture Archiving and Communication System (PACS), and then compared with established international DRLs.

Problem Statement

CT simulation scan is widely used in treatment planning for brachytherapy procedures, but they introduce additional radiation exposure to patients. This cumulative radiation dose is a concern because it can increase the risk of radiation-induced side effects and long-term health complications. The radiation dose from CT simulation scan varies depending on the type of brachytherapy procedure, tumour location, scan parameters, and the frequency of scans required for precise treatment planning (Rao et al., 2024). For example, liver brachytherapy may require a larger scanning area and thus deliver higher doses compared to tongue brachytherapy. The dose is also significantly influenced by technical scan parameters such as tube current, voltage, and scan length.

Therefore, optimizing these parameters is essential to minimize unnecessary exposure while maintaining adequate image quality. A study conducted in Morocco assessed radiation doses from thoracic CT scans used in radiotherapy planning and found that the CTDIvol ranged from 4 to 35.2 mGy, with an average of 14.58 mGy, while the DLP ranged from 215 to 1606.8 mGy·cm, with an average 735 mGy·cm. These values were notably higher than those reported for diagnostic CT scans of comparable anatomical regions, underscoring the need for careful dose management in radiotherapy planning CT simulation scan (Semghouli et al., 2024).

Despite this, the radiation dose from CT simulation scan is often underreported or overlooked in clinical dose audits because it is frequently considered negligible relative to the therapeutic dose delivered by brachytherapy itself, or due to practical challenges in routinely recording and integrating these data (Kito et al., 2024). Imaging doses are often stored separately in the PACS or embedded within DICOM metadata, but not automatically integrated into the treatment planning system's cumulative dose calculations. In busy radiotherapy workflows, routine dose audits prioritize treatment beam quality assurance and dose delivery verification rather than diagnostic or planning imaging doses. This oversight can lead to an underestimation of the patient's total radiation burden, potentially affecting long-term risk assessment and hindering comprehensive efforts to optimize patient safety (Yu et al., 2009). By examining actual patient dose data and comparing it with established international DRLs, the contribution of CT simulation scan should be properly accounted for as part of the total radiation dose received by patients undergoing brachytherapy. Several studies and guidelines emphasize that neglecting imaging doses, such as those from CT simulation can lead to underestimation of total patient dose and thus impact risk assessment and safety optimization. For example, research on dose accumulation in combined radiotherapy including brachytherapy underscores the importance of considering all imaging and treatment dose components to accurately evaluate organ dose and overall patient exposure (Zhao et al., 2022).

1.2 Objective of Study

General objective: To investigate the radiation dose delivered to patients during CT simulation scan among liver, tongue, and endometrial cancer.

Specific objectives:

1. To evaluate the volume CT Dose Index (CTDIvol) received by patients from CT simulation in different brachytherapy treatments.
2. To evaluate the Dose-length product (DLP) received by patients from CT simulation in different brachytherapy treatments.
3. To compare with established international diagnostic reference levels (DRLs).

1.3 Significance of Study

The significance of this study lies in enhancing awareness of the often-underappreciated radiation exposure patients receive during CT simulation scan in brachytherapy planning. By quantifying and analyzing this imaging dose, the study aims to highlight its potential impact on cumulative patient radiation burden, an aspect frequently neglected in clinical audits and treatment evaluations. This improved understanding can drive protocol optimization, encourage routine dose monitoring, and ultimately contribute to safer, more informed brachytherapy practices. While Malaysia has guidelines and research on local diagnostic reference levels (DRLs) for common CT examinations and general radiotherapy planning, there is no evidence of published local DRLs specifically for CT simulation scan in brachytherapy. Existing studies and guidelines focus on CT scan for diagnostic purposes or for broader radiotherapy applications, not the niche of brachytherapy treatment.

Furthermore, comparing the collected data against international DRLs can help identify whether current clinical practices align with recommended dose thresholds. This has practical implications for enhancing patient safety, promoting dose optimization strategies, and encouraging the implementation of more standardized CT imaging protocols in radiation oncology departments.

Additionally, the findings may serve as a platform for establishing local DRLs adapted to specific clinical settings, resulting in improved quality assurance and regulatory compliance in medical imaging. The results of this study can also inform medical physicists, radiation oncologists, and radiographers in making evidence-based decisions regarding scan protocol selection and dose management resulting in more effective and safe brachytherapy treatments.

CHAPTER 2

LITERATURE REVIEW

2.1 Computed Tomography (CT) Simulation Scan

A CT simulation scan was performed using a CT simulator, which is specifically designed for radiation treatment planning in brachytherapy. Unlike a standard diagnostic CT scanner used primarily for general diagnostic imaging, a CT simulator acquires detailed anatomical data to assist in accurately localizing tumours and surrounding organs. These images are essential for constructing three-dimensional treatment plans and guiding the precise placement of radioactive sources, ensuring safe and effective dose delivery. Figure 1 showed a CT-based treatment planning image for brachytherapy, most likely for a gynecological cancer, such as cervical or endometrial cancer. This type of image is used during the planning phase of brachytherapy to optimize the radiation dose delivered to the tumor while protecting nearby organs at risk (such as the bladder and rectum). It is a crucial step in modern radiation oncology for ensuring precise, effective, and safe cancer treatment (Skowronek, 2011).

Figure 2.1: Reconstruction of a plastic applicator in a 3D CT study (Skowronek, 2011).

CT simulators differ from standard diagnostic CT scanners in both design and function. One key difference is the larger bore size and flat tabletop, which facilitate consistent patient positioning for both simulation and treatment (Ledley et al., 2017) represented in Figure 2.2. CT simulators are also equipped with external laser positioning systems to ensure precise patient alignment. While diagnostic CT scanners (Figure 2.3), prioritize minimizing radiation dose for diagnostic purposes, CT simulation scan in brachytherapy focus on accurately defining the tumor location and surrounding organs to support effective treatment planning. Although CT has lower soft-tissue contrast compared to MRI and may not clearly define the clinical target volume, it is valuable for identifying nearby organs at risk (OARs) and enabling three-dimensional dose distribution planning (Davidson et al., 2008).

Figure 2.2: Example of CT Simulator in HPUSM.

Figure 2.3: Example of Diagnostic CT Scanner in HPUSM.

In brachytherapy, CT simulation scans typically require a larger scan length to cover the full treatment area, which increases the absorbed dose due to more tissue being exposed to ionizing radiation (Rao et al., 2023). Additionally, large-bore CT simulators often use an extended field-of-view (eFOV) to accommodate larger patients or treatment setups. While eFOVs help capture more anatomical detail, they can introduce image distortion and reduce image quality, potentially affecting contouring accuracy. Nevertheless, the increased scan volume contributes to a higher cumulative radiation dose (Wu et al., 2020).

2.2 Radiation Exposure from CT Simulation in Brachytherapy

A variety of patient and technological factors influence the radiation dose delivered during a CT simulation scan in brachytherapy. Tumour location is a key factor, as regions such as the pelvis, abdomen, or thoracic cavity often require extensive imaging ranges and multiple angles to adequately visualize the target and surrounding organs (Zhu et al., 2024). For example, a CT simulation scan for pelvic brachytherapy, commonly used in cervical cancer treatment, typically extends from the lower abdomen to the upper femur to include critical organs at risk (OARs) such as the bladder, rectum, and small bowel.

Technical parameters like tube current (mA) and tube voltage (kVp) also play a crucial role in determining patient dose. Increasing these settings can improve image quality by reducing noise, which is particularly important for visualizing dense pelvic or abdominal regions and ensuring accurate applicator placement. However, this comes at the cost of higher radiation exposure. Recent studies demonstrate that dose optimization is feasible without compromising clinical effectiveness; for instance, Zhu et al. (2024) showed that a low-dose CT protocol combining optimized tube settings with iterative reconstruction significantly reduces radiation dose while maintaining adequate image quality for applicator reconstruction and target delineation.

Finally, scan length has a direct impact on dose. Longer scan ranges expose more tissue and increase the dose–length product (DLP). In cervical cancer brachytherapy, the scan often needs to cover the pelvis from the iliac crest to below the pubic symphysis. Unnecessary extension of this range, however, can deliver excess dose to non-target tissues. According to Semghouli et al. (2024), CT scans performed for radiotherapy planning frequently deliver higher doses than standard diagnostic scans of the same region, underscoring the importance of carefully tailoring the scan length to the clinical objective.

2.3 Computed Tomography (CT) Dosimetry

The radiation dose from CT simulation scans is quantified using metrics such as the CTDIvol and DLP. Studies have shown that these doses can vary significantly depending on the type of brachytherapy procedure and the specific protocols used (Pintakham et al., 2021). CTDIvol represents the average radiation dose delivered to a standardized phantom over a particular volume during a single CT scan. Clinicians can determine the level of radiation exposure for a specific scan protocol by estimating the dose distribution within the scanned volume. A larger CTDIvol, for example, indicates a higher dose per unit volume, which might be required for imaging dense anatomical regions. DLP, on the other hand, is the radiation emitted by a CT tube is measured in milligrays per centimetre (mGy.cm). DLP considers the radiation source's z-axis length (the patient's long axis) (Malik et al., 2024). CTDIVOL is comparable to the volume CT dose index. However, it only measures the dose using one phantom slice. It is calculated by multiplying the CTDIvol by the scan length as in equation 1.

$$\mathrm{DLP(mGy.cm)} = \mathrm{CTDI_{vol}(mGy)} \times \mathrm{ScanLength(cm)} \qquad 1$$

The unit to measure DLP is mGy.cm. This metric reflects the cumulative radiation exposure from the entire CT examination, providing a more comprehensive assessment of the patient's total dose. For example, a CT simulation scan covering the abdomen and pelvis will have a higher DLP compared to a scan limited to the pelvis alone, even if the CTDIvol remains constant, due to the increased scan length.

However, while CTDIvol and DLP are helpful indicators for scanner output and imaging protocol intensity, they do not account for individual patient anatomy or actual organ doses (Burton & Szczykutowicz, 2017). They do not consider variations in patient size, body composition, or the specific organ sensitivity to radiation. Therefore, they are not direct measures of the actual dose absorbed by the patient. According to the American Association of Physicists in Medicine (AAPM), to bridge the gap, the size-specific dose estimates (SSDE) have been introduced to better approximate patient-specific doses by incorporating body structure and anatomical features into dose calculations (Burton & Szczykutowicz, 2017). In clinical contexts such as brachytherapy planning, where repeated CT simulations may be necessary and involve sensitive OARs, relying only on CTDIvol and DLP may underestimate or misrepresent actual biological risk. Table 2.1 displays a summary of dose metrics used in CT dosimetryto quantify and standardize the radiation dose delivered during a scan.

Table 2.1: Summary of dose metrics used in CT dosimetry.

Metric	Unit of Measure	Details
$CTDI_{100}$	mGy	The average air kerma in a 100 mm ion chamber divided by the x-ray beam width in a single rotation CT x-ray tube
$CTDI_{periphery}$	mGy	The measured dose at periphery of an acrylic phantom
$CTDI_{center}$	mGy	The measured dose at center of acrylic phantom
$CTDI_w$	mGy	Equal to 1/3 ($CTDI_{center}$) + 2/3 ($CTDI_{peripheral}$). is averages from 4 periphery dose
$CTDI_{vol}$	mGy	Equals to $CTDI_w$/pitch

DLP	mGy.cm	The total of $CTDI_{vol}$ for one scan length

2.4 Radiation Exposure from CT Simulation in Brachytherapy Treatment

Radiation exposure from CT simulation scan used in brachytherapy procedures has been widely studied to ensure patient safety while maintaining high image quality for accurate treatment planning. Unlike diagnostic CT scan, CT simulation scan for brachytherapy often requires repeated imaging sessions during treatment, which may cumulatively increase a patient's radiation dose (Pintakham et al., 2021). For example, cervical cancer patients typically undergo several brachytherapy fractions, each necessitating a new CT scan to verify applicator placement and adapt treatment plans, thereby increasing cumulative exposure to radiosensitive organs such as the bladder and rectum.

The doses associated with CT simulation scans vary considerably depending on institutional protocols, scanner specifications, and the required image quality for precise target delineation. Factors such as tube current, voltage, slice thickness, and scan length contribute to this variability. Several studies have reported diagnostic reference levels (DRLs) for radiotherapy planning CT scans, providing benchmarks for acceptable dose levels. For instance, Zalokar et al. (2022) reported mean CTDIvol values of 22.6 mGy and 17.9 mGy with corresponding DLPs of 969.2 mGy·cm and 667.1 mGy·cm for head and neck and pelvic scans, respectively. Since CTDIvol reflects dose intensity per slice and DLP accounts for the total dose over the scan length, DLP is a more comprehensive indicator of patient dose burden during simulation.

Table 2: Mean CTDIvol and DLP from previous study (Zalokar et al. 2022)

Region	Mean CTDIvol (mGy)	Mean DLP (mGy.cm)
Head and neck (n=278)	22.6	969.2
Pelvis	17.9	667.1

Although higher doses are justified in the context of treatment planning, repeated exposure raises concerns about cumulative radiation risk, especially for radiosensitive organs near the treatment site. Consequently, international organizations such as the International Atomic Energy Agency (IAEA) and European Radiation Protection Report (ERTC) emphasize the importance of applying the ALARA principle.

Local studies evaluating CT simulation dose in brachytherapy are still limited, particularly in developing countries. Establishing local DRLs can help institutions identify opportunities for dose reduction and standardize practice across different centers. This study aims to fill this gap by comparing the CTDIvol and DLP values for CT simulation scan performed for brachytherapy at our institution with published DRLs. The outcomes are expected to contribute to better protocol optimization and safer practice while maintaining the precision required for effective brachytherapy treatment.

2.5 Previous Studies on Diagnostic Reference Level

Various radiological procedures constitute different DRL implemented by the International Council of Radiation Protection (ICRP). The ICRP encourages the establishment of a standard DRL to represent a particular medical practice in a specific geographical area. DRLs cannot differentiate between fair and unfair medical practices. The main objective of the suggested DRL is to minimize the radiation dose and improve the image quality for a medical practitioner. Recent research has demonstrated the importance of establishing local diagnostic reference levels (LDRLs) for computed tomography used in radiotherapy planning, which is crucial for optimizing patient safety and image quality. For instance, a study conducted at a regional oncology center in Morocco aimed to determine LDRLs for breast cancer CT imaging used in 3D conformal radiotherapy planning. In this study, data from 106 adult breast cancer patients were collected over five months using a Hitachi Supria 16-slice CT simulator. The investigators calculated the 75th percentile values for the DLP and CTDIvol, which were found to be 330.4 mGy·cm and 6.8 mGy, respectively (Nhila et al., 2024). When compared to similar studies in European countries such as the United Kingdom, Croatia, and Slovenia, the Moroccan values were lower, indicating more optimized dose levels for breast CT in radiotherapy planning (Zalokar et al., 2020). These findings highlight the need for each institution and region to determine their own reference levels tailored to local practices and patient populations. In the context of brachytherapy, similar efforts to establish and monitor local DRLs for CT simulation scans are essential to ensure that high-quality imaging for applicator placement and treatment planning is achieved without unnecessary radiation exposure to patients.

CHAPTER 3

METHODOLOGY

3.1.Research Tools

3.1.1. Computed Tomography (CT) Scan Toshiba LB Aquilion

The CT simulator used in this study was the Toshiba CT Simulator, a 16-slice multi-detector computed tomography (MDCT) system. This CT simulator is specifically configured for radiotherapy simulation, offering high-resolution imaging essential for accurate treatment planning in radiation oncology. The 16-slice configuration allows for rapid image acquisition with enhanced anatomical resolution, making it an ideal tool for precise delineation of the clinical target volume (CTV) and OARs, which is crucial in both external beam radiotherapy (EBRT) and brachytherapy applications.

In addition, Toshiba CT Simulator is to acquire multiple slices in a single rotation, enabling faster scanning times and reducing motion artifacts, which is vital for maintaining the integrity of the images during patient setup, particularly for patients undergoing brachytherapy. Additionally, the system's high-resolution imaging provides detailed cross-sectional images, which are essential for visualizing tumour volumes and adjacent critical structures such as the bladder, rectum, and sigmoid colon. This is particularly important in gynecological brachytherapy where intracavitary applicators, such as tandem and ovoid, are used, and their precise positioning relative to surrounding tissues must be accurately assessed for optimal treatment planning.

The system includes advanced image reconstruction algorithms, which enhance image quality while optimizing radiation dose, ensuring a balance between diagnostic precision and patient safety. This ability to provide clear, high-resolution images with minimal patient exposure is crucial, especially in repetitive imaging scenarios like CT simulation for brachytherapy. The system also integrates seamlessly with various treatment planning systems (TPS), such as Eclipse and Oncentra, through DICOM export, allowing the imaging data to be directly transferred for treatment planning and dose calculation. The use of virtual simulation also allows for precise three-dimensional (3D) visualization of the target volume, facilitating accurate dose optimization and delivery planning.

The CT simulator's integration with advanced treatment planning software allows for effective delineation of structures on the CT images, including both the tumour and critical organs. In the case of brachytherapy, precise dose planning is achieved by imaging the intracavitary applicators (such as tandem and ovoid) and accurately mapping their position to the target volume and surrounding OARs. The ability to visualize these applicators in three dimensions ensures that the prescribed dose can be delivered with high precision, reducing the risk of radiation exposure to healthy tissues.

3.1.2. Picture Archiving and Communication System (PACS)

The Picture Archiving and Communication System (PACS) is a digital imaging infrastructure widely implemented in modern medical institutions for the efficient management, storage, retrieval, and distribution of medical images. In this study, PACS served as a primary research tool for the retrospective collection of patient imaging data, particularly from patients who underwent CT simulation scans as part of their brachytherapy planning process.

PACS at Institut Perubatan Pergigian Termaju (IPPT) is integrated across multiple imaging modalities, including CT, MRI, and radiographic units, and is designed to handle DICOM (Digital Imaging and Communications in Medicine) format files. These DICOM files store both image data and metadata such as scanning parameters, patient demographics, and imaging protocols. For research purposes, PACS enabled secure, organized, and efficient access to a large volume of patient data, which was essential for this study's retrospective analysis, represented in Figure 3.1. The system allows clinicians and researchers to retrieve and view high-resolution images and associated technical information from CT simulation scans conducted during the planning phase of brachytherapy

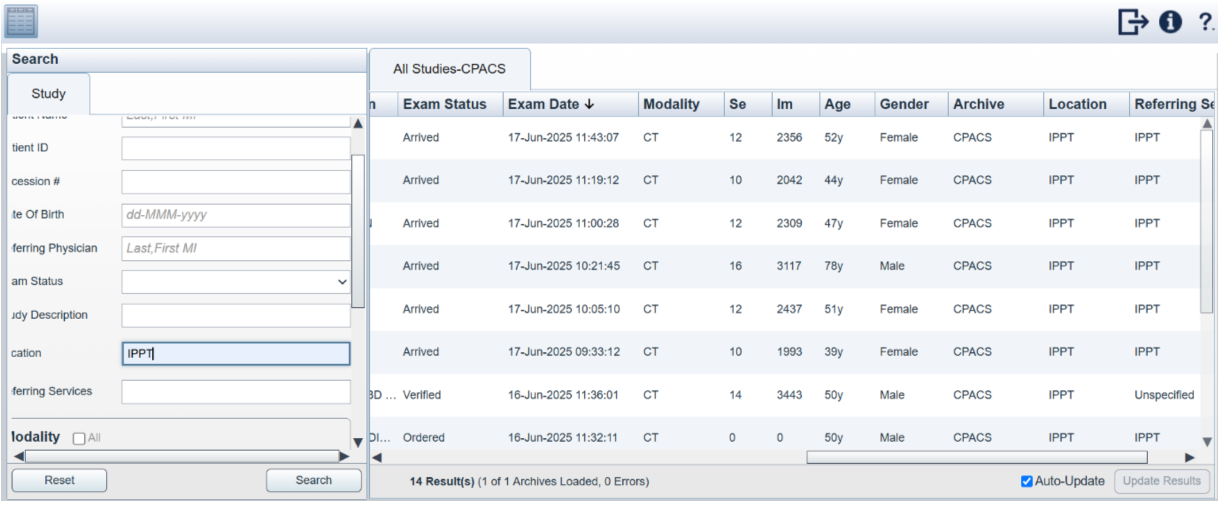
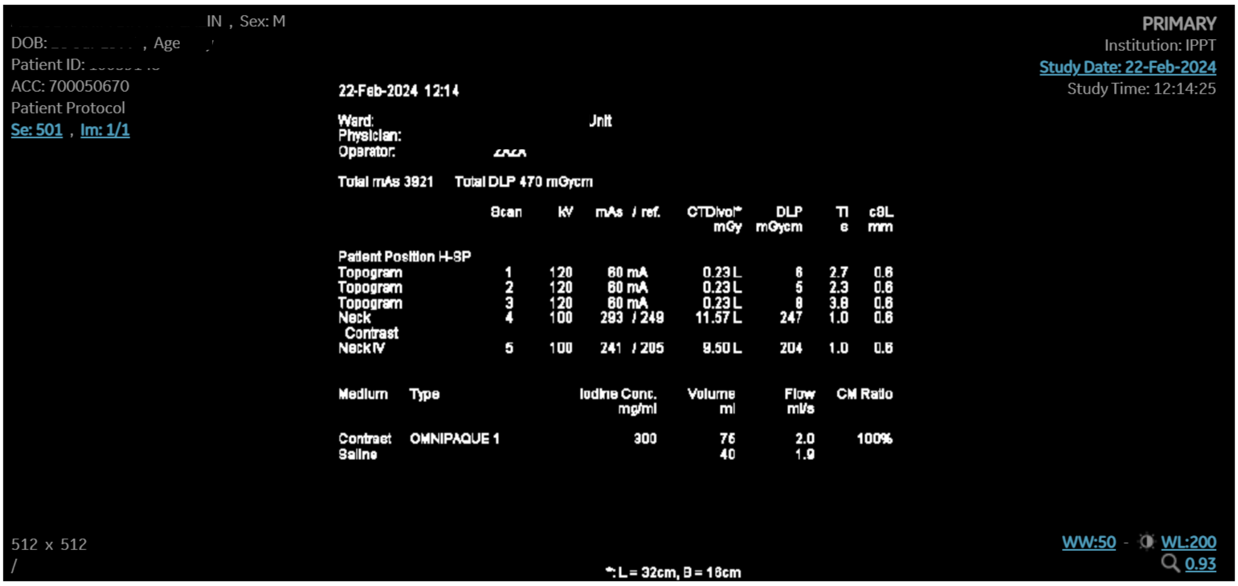


Figure 3.1: PACS interface.

Among the critical information collected from PACS were the patient protocols generated during CT simulation scans. Figure 3.2 shows a patient protocol details in PACS. These protocols included essential radiation dose metrics such as the CTDIvol and the DLP, which were used to assess and analyze the radiation exposure delivered to patients during their planning scans. CTDIvol is a standardized measure that represents the average radiation dose output per slice from a CT scanner, expressed in milligrays (mGy). It accounts for the scan pitch and reflects the intensity of radiation within the scanned volume. In this research, CTDIvol values provided insight into the dose level delivered during CT simulations for various anatomical regions, including the pelvis for gynaecological cancers, the upper abdomen for liver cancer, and the head and neck areas for tongue and buccal mucosa cancers. This parameter is essential for understanding dose consistency across different imaging protocols. DLP, on the other hand, is the product of CTDIvol and the scan length, and it is expressed in milligray-centimeters (mGy·cm). DLP gives an estimation of the total radiation dose delivered over the entire scan range. Unlike CTDIvol, which focuses on dose intensity, DLP reflects the cumulative exposure and is a more comprehensive indicator of patient dose burden. Although this risk from a CT examination is small, it is not zero. DLP was particularly important in this study as it allowed comparisons of total radiation exposure across patients with different cancer types and varying scan lengths. These dose metrics were obtained directly from the protocol or dose report images available within the CT scan series in PACS. Each patient's protocol included scanning parameters such as tube voltage (kVp), tube current (mA), and the automatically calculated CTDIvol and DLP values.


[redacted]IN , Sex: M
DOB: [redacted], Age [redacted]
Patient ID: [redacted]
ACC: 700050670
Patient Protocol
Se: 501 , Im: 1/1

PRIMARY
Institution: IPPT
Study Date: 22-Feb-2024
Study Time: 12:14:25

22-Feb-2024 12:14

Ward: Jnit
Physician:
Operator: [redacted]

Total mAs 3921 Total DLP 470 mGycm

	Scan	kV	mAs / ref.	CTDIvol* mGy	DLP mGycm	TI s	cSL mm
Patient Position H-SP							
Topogram	1	120	60 mA	0.23 L	6	2.7	0.6
Topogram	2	120	60 mA	0.23 L	5	2.3	0.6
Topogram	3	120	60 mA	0.23 L	8	3.8	0.6
Neck	4	100	293 / 249	11.57 L	247	1.0	0.6
Contrast							
NeckIV	5	100	241 / 205	9.50 L	204	1.0	0.6

Medium	Type	Iodine Conc. mg/ml	Volume ml	Flow ml/s	CM Ratio
Contrast	OMNIPAQUE 1	300	76	2.0	100%
Saline			40	1.9	

512 x 512
*: L = 32cm, B = 16cm
WW:50 - WL:200
0.93

Figure 3.2: Patient protocol details for Toshiba CT scanner in the PACS.

PACS also supports various tools, shown in Figure 3.3, including image manipulation, including zoom, window/level adjustments, and multi-planar reconstruction (MPR), which help researchers better visualize anatomical structures and applicator placement in three dimensions. For this study, the use of PACS not only enhanced the efficiency of data collection but also ensured the consistency and reliability of the image datasets used for dose evaluation and treatment assessment.

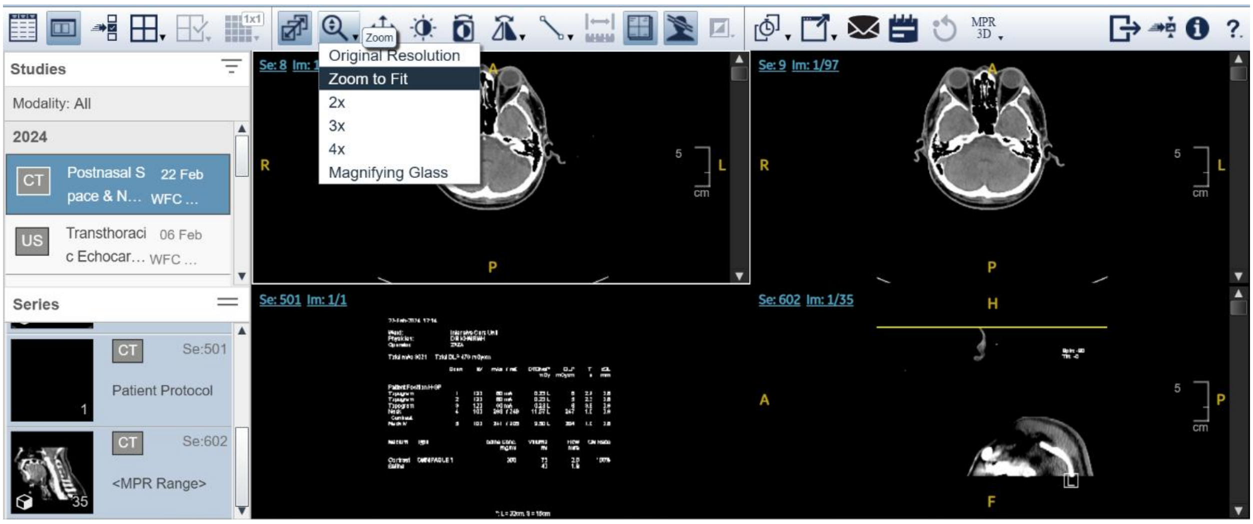
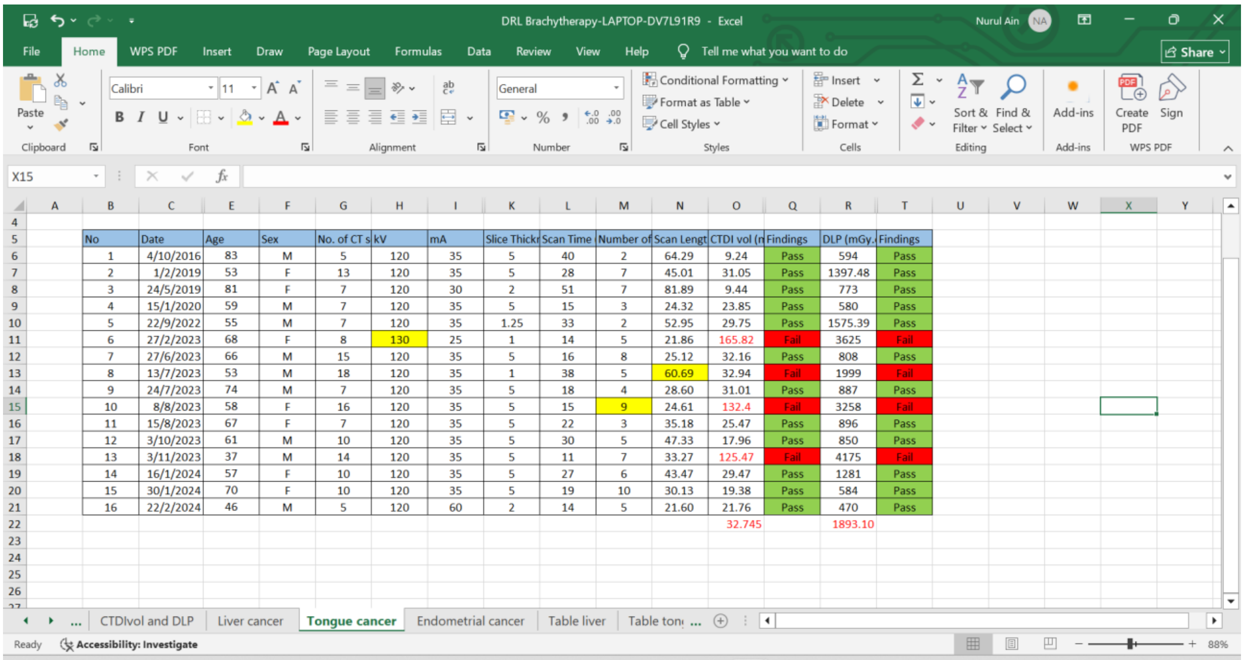


Figure 3.3: Various tools in PACS.

3.1.3. Microsoft Excel

Figure 3.4 shows a screenshot of Microsoft Excel. Microsoft Excel is another valuable research tool used in this study, mainly for organizing and analyzing the data collected from the PACS. In this research, Excel is used to neatly organize all the patient details and scan parameters, such as CTDIvol and DLP, which are needed for the analysis. After arranging the data, Excel's built-in formulas make it easy to calculate important statistical values like the third quartile, which is used to set the DRL for this study. For each patient, a formula is used in Excel to check whether their CTDIvol and DLP values fall within the acceptable range or exceed the DRL by comparing them to the third quartile. Besides calculations, Excel helps me present the results using tables and charts.



No	Date	Age	Sex	No. of CT s	kV	mA	Slice Thickr	Scan Time	Number of	Scan Lengt	CTDI vol (n	Findings	DLP (mGy.	Findings
1	4/10/2016	83	M	5	120	35	5	40	2	64.29	9.24	Pass	594	Pass
2	1/2/2019	53	F	13	120	35	5	28	7	45.01	31.05	Pass	1397.48	Pass
3	24/5/2019	81	F	7	120	30	2	51	7	81.89	9.44	Pass	773	Pass
4	15/1/2020	59	M	7	120	35	5	15	3	24.32	23.85	Pass	580	Pass
5	22/9/2022	55	M	7	120	35	1.25	33	2	52.95	29.75	Pass	1575.39	Pass
6	27/2/2023	68	F	8	130	25	1	14	5	21.86	165.82	Fail	3625	Fail
7	27/6/2023	66	M	15	120	35	5	16	8	25.12	32.16	Pass	808	Pass
8	13/7/2023	53	M	18	120	35	1	38	5	60.69	32.94	Fail	1999	Fail
9	24/7/2023	74	M	7	120	35	5	18	4	28.60	31.01	Pass	887	Pass
10	8/8/2023	58	F	16	120	35	5	15	9	24.61	132.4	Fail	3258	Fail
11	15/8/2023	67	F	7	120	35	5	22	3	35.18	25.47	Pass	896	Pass
12	3/10/2023	61	M	10	120	35	5	30	5	47.33	17.96	Pass	850	Pass
13	3/11/2023	37	M	14	120	35	5	11	7	33.27	125.47	Fail	4175	Fail
14	16/1/2024	57	F	10	120	35	5	27	6	43.47	29.47	Pass	1281	Pass
15	30/1/2024	70	F	10	120	35	5	19	10	30.13	19.38	Pass	584	Pass
16	22/2/2024	46	M	5	120	60	2	14	5	21.60	21.76	Pass	470	Pass
											32.745		1893.10	

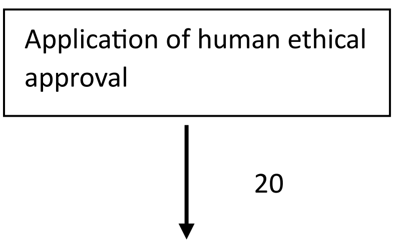
Figure 3.4: An Excel worksheet post data cleaning.

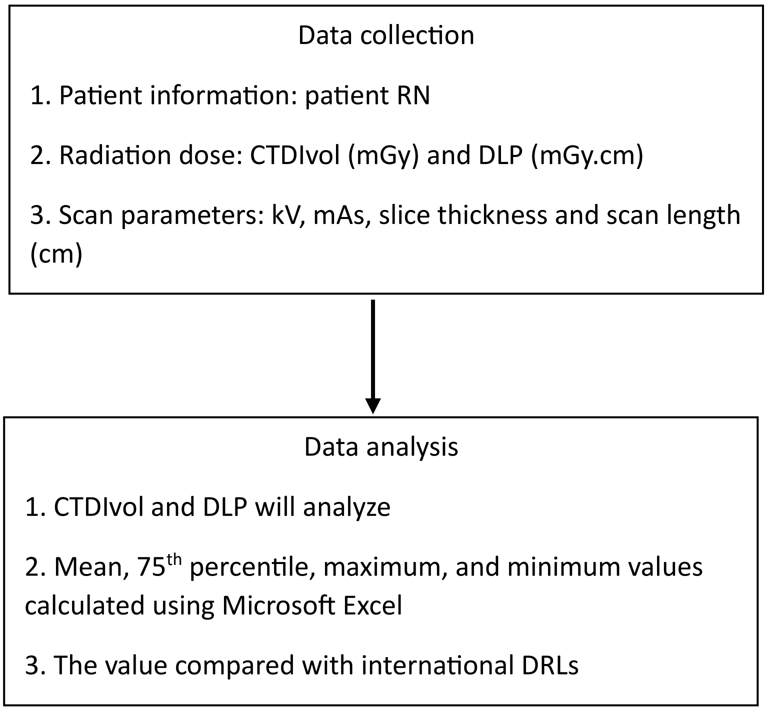
3.2. Research Methodology

3.2.1. Study Design

This study involved a retrospective survey on the CT patients' dose data. The existing data from each brachytherapy treatment CT simulation were retrieved from the PACS at the IPPT. The collected data included patient's demographic information (age, gender); clinical indication; radiation dose indices (displayed CTDIvol (in mGy) and DLP (in mGy.cm)); and other CT scanning parameters (kVp, mAs, scan length (in cm), number of acquisition and slice thickness (in mm)). The data were categorized based on the three clinical indications: liver cancer, tongue cancer, and endometrial cancer.

3.2.2. Study Flowchart





3.2.3. Study Location and Duration

All CT data were collected at Radiotherapy and Oncology, Institut Perubatan dan Pergigian Termaju (IPPT) for 10 years (October 2016 – February 2024). It involved retrospective data collection from patients undergone brachytherapy treatment using the CT simulator Toshiba LB Aquilion.

3.2.4. Study Population and Sample

The target population for this study was patients who received CT simulation prior to brachytherapy treatment at IPPT, Penang.

3.2.5. Selection Criteria

3.2.5 (a)Inclusion Criteria

The inclusion criteria for this study consist of patients of both genders who completed CT simulation and received brachytherapy treatment.

3.2.5 (b) Exclusion Criteria

The exclusion criteria for this study were patients with incomplete data required, such as dose information (CTDI vol in mGy and DLP in mGy.cm), scanning parameters (kV, mA, slice thickness, and scan length). Patients with multiple tumours in different areas were also not included in this study.

3.2.6. Sample Size Estimation

Based on the recommendations of the ICRP (2017), a minimum sample size of 20 patients is required to establish DRL. This study focuses on specific cancer types which are tongue, buccal mucosa, liver and endometrial. The sample size in this study is limited due to the availability of retrospective data from IPPT, as brachytherapy procedures at this institution were only initiated in 2015. As a result, this study includes a reasonable dataset based on available patient records.

3.2.7. Data Analysis

The collected radiation dose data from CT simulation scans used in brachytherapy treatment planning were analysed using Microsoft Excel. Excel was selected due to its wide accessibility and functionality in managing large datasets, performing descriptive statistical analysis, and generating visual data representations.

The dataset was first compiled into structured Excel spreadsheets, containing anonymized patient identifiers (RN), tumour site classifications (liver, tongue, and endometrial), and relevant scan parameters including tube voltage (kV), tube current (mA), scan length (cm), volume CT dose index (CTDIvol, mGy), and dose-length product (DLP, mGy·cm).

For each tumour site group, descriptive statistics were calculated, including minimum, maximum, mean, median, first quartile (Q1), third quartile (Q3), and interquartile range (IQR). These metrics provided a summary of the dose distribution across patients and helped identify trends or inconsistencies within the dataset.

To identify potential outliers, the IQR method was applied. The lower and upper bounds were computed as $Q1 - 1.5 \times IQR$ and $Q3 + 1.5 \times IQR$, respectively. Values falling outside these bounds were flagged as potential outliers. Excel's conditional formatting was employed to highlight such values automatically, ensuring easier detection and review of anomalous data points.

Visual analysis was conducted through the generation of box plots and charts for both CTDIvol and DLP distributions across each tumour site. These visual tools facilitated a clearer understanding of the data spread, central tendency, and variability, as well as highlighting any extreme values that may require further investigation.

To evaluate clinical practices against international benchmarks, the 75th percentile (Q3) values of CTDIvol and DLP were computed for each tumour site to establish local Diagnostic Reference Levels (DRLs). These local DRLs were then compared with published international DRLs using Excel formulas and visual markers. Entries exceeding international DRLs were flagged to assess areas where radiation dose optimisation might be needed.

CHAPTER 4

RESULTS

4.1 CT Simulation Dose Analysis and Compliance for Liver, Tongue, and Endometrial Brachytherapy

Table 4.1 compares the CTDIvol values for liver, tongue, and endometrial brachytherapy treatment sites, highlighting variations in radiation dose during CT simulation. For the liver group (n = 20), the CTDIvol ranges from 15.48 to 60.77 mGy, with a median of 32.32 mGy and a 75th percentile of 46.42 mGy. The mean value of 34.94 mGy is close to the median, indicating a consistent dose distribution with no significant outliers. In contrast, the tongue group (n = 16) shows the widest dose variation, with values ranging from 9.24 to 229.82 mGy. While the median and 75th percentile are 29.61 mGy and 32.75 mGy, respectively, the mean rises to 52.60 mGy due to an extreme high-dose outlier, suggesting potential protocol deviation or patient-specific variation. The endometrial group (n = 10) shows moderate variation, with CTDIvol values between 9.86 and 65.14 mGy. The median is 37.76 mGy, the 75th percentile is 54.20 mGy, and the mean is 35.29 mGy. This indicates a relatively stable dose distribution, similar to the liver group but with a slightly wider range. Overall, the findings suggest that liver and endometrial scans have more controlled dose patterns, whereas tongue scans exhibit significant variability, warranting further review. These results support the establishment of local DRLs and highlight areas for protocol optimization.

Table 4.1: $CTDI_{vol}$, min, median, 75^{th} percentile, max, and mean for different treatments.

Treatments	Min	Median	75^{th} percentile	Max	Mean