TOMOGRAPHIC SENSITIVITY ANALYSIS OF SPECT/CT DETECTORS EQUIPPED WITH LOW ENERGY HIGH RESOLUTION COLLIMATORS AT DIFFERENT TC-99M ACTIVITY LEVELS

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BY

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DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF HEALTH SCIENCE (MEDICAL RADIATION)

YEAR 2025

CERTIFICATE

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TOMOGRAPHIC SENSITIVITY ANALYSIS OF SPECT/CT DETECTORS EQUIPPED WITH LOW ENERGY HIGH RESOLUTION COLLIMATORS AT DIFFERENT TC-99M ACTIVITY LEVELS

is the bona fide record of research work done by Ms

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LIST OF SYMBOLS

A	Activity of Radionuclide
cps	Counts per second
keV	Kiloelectronvolt
mm	Millimetre
mCi	Millicurie
Ci	Curie
MBq	Megabecquerel
cm	Centimetre
S	Sensitivity
RE	Relative error
C	Contrast
AC	Activity Concentration
N	True value total number of counts
V	Volume
t	acquisition time per projection.
n	Total number of counts

LIST OF ABBREVIATIONS

AVG	Average
FWHM	Full Width Half Maximum
TC-99M	Technetium-99m
SNR	Signal-to-Noise Ratio
USM	Universiti Sains Malaysia
SD	Standard Deviation
SPECT	Single Photon Emission Computed Tomography
MO-99	Molybdenum-99
LEHR	Low Energy High Resolution
PMT	Photomultiplier Tube
FOV	Field of View
OSEM	Ordered Subset Expectation Maximisation
VOI	Volume Of Interest
BKG	Background
ASiR,	iterative reconstruction algorithm

ABSTRAK

Single Photon Emission Computed Tomography/Computed Tomography (SPECT/CT) ialah teknik pengimejan hibrid utama dalam perubatan nuklear, menggabungkan data fungsi dan anatomi untuk pengesanan dan pengurusan penyakit yang lebih baik. Walaupun kepekaan satah dikaji dengan baik, kepekaan tomografi pengesan SPECT/CT dengan kolimator Resolusi Tinggi Tenaga Rendah (LEHR) pada tahap aktiviti Tc-99m yang berbeza-beza masih kurang diterokai. Kajian ini mengkaji kesan aktiviti Tc-99m dan ciri kolimator LEHR terhadap kepekaan tomografi, resolusi spatial, kontras imej dan ketepatan kuantiti. Hantu Jaszczak telah diimej menggunakan sistem SPECT/CT dengan kolimator LEHR pada tahap aktiviti Tc-99m 7 mCi, 10 mCi, dan 12 mCi. Protokol pemerolehan dan pembinaan semula standard telah digunakan. Kepekaan tomografi diukur dalam kiraan sesaat per milicurie (cps/mCi), resolusi spatial dinilai melalui visualisasi rod hantu, dan kontras imej dan ralat relatif dikira daripada kawasan yang ditentukan yang diminati. Keputusan menunjukkan peningkatan aktiviti Tc-99m meningkatkan kepekaan tomografi (176.49 cps/mCi pada 7 mCi kepada 209.45 cps/mCi pada 12 mCi), resolusi spatial (rod yang lebih kecil kelihatan pada 12 mCi), dan kontras sfera yang lebih besar menunjukkan lebih banyak kontras negatif (cth., -47% untuk 31.8 mm pada 7 mCi), yang bertambah baik dengan aktiviti yang lebih tinggi. Sfera yang lebih kecil mempamerkan kebolehubahan yang lebih besar dan ralat relatif yang lebih tinggi. Ringkasnya, aktiviti Tc-99m dan reka bentuk kolimator LEHR mempengaruhi kepekaan tomografi, resolusi spatial dan kontras imej dengan ketara dalam pengimejan SPECT/CT. Mengoptimumkan tahap aktiviti dan parameter sistem adalah penting untuk meningkatkan kualiti imej dan mengurangkan dos radiasi, memberikan cerapan kritikal untuk penambahbaikan protokol klinikal dalam perubatan nuklear.

ABSTRACT

Single Photon Emission Computed Tomography/Computed Tomography (SPECT/CT) is a key hybrid imaging technique in nuclear medicine, combining functional and anatomical data for improved disease detection and management. While planar sensitivity is well-studied, the tomographic sensitivity of SPECT/CT detectors with low energy high resolution (LEHR) collimators at varying Tc-99m activity levels remains underexplored. This study examines the effects of Tc-99m activities and LEHR collimator characteristics on tomographic sensitivity, spatial resolution, image contrast, and quantification accuracy. A Jaszczak phantom was scanned using a SPECT/CT system with LEHR collimators at Tc-99m activity levels of 7 mCi, 10 mCi, and 12 mCi. Standard acquisition and reconstruction protocols were used. Tomographic sensitivity was measured in counts per second per millicurie (cps/mCi), spatial resolution was assessed via phantom rod visualisation, and image contrast and relative error were calculated from defined regions of interest. Results show increasing Tc-99m activity enhances tomographic sensitivity which was 176.49 cps/mCi at 7 mCi to 209.45 cps/mCi at 12 mCi, spatial resolution (smaller rods visible at 12 mCi), and contrast the larger spheres showed more negative contrast (e.g., −47% for 31.8 mm at 7 mCi), which improved with higher activity. Smaller spheres exhibited greater variability and higher relative errors. In summary, Tc-99m activity and LEHR collimator design significantly influence tomographic sensitivity, spatial resolution, and image contrast in SPECT/CT imaging. Optimising activity levels and system parameters is vital for enhanced image quality and reducing radiation dose, providing critical insights for clinical protocol improvement in nuclear medicine.

CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION

The SPECT/CT is a non-invasive hybrid imaging technique that integrates morphological and functional information from the CT and SPECT components. The SPECT image provides functional information about organs and tissues, enabling the detection of functional abnormalities before anatomical changes occur, while CT images provide radionuclide localisation and facilitate attenuation correction of SPECT emission images (Bouchareb et al., 2024). This combination is essential in nuclear medicine by providing both functional and anatomical information, which can enhance disease detection, staging, and treatment monitoring (Willowson et al., 2024)

The performance of SPECT/CT systems depends on factors like collimator design, detector properties, and radiotracer activity levels. This study examines how varying technetium-99m (Tc-99m) activity affects count rates, image noise, resolution, and quantification accuracy. Lower activity reduces radiation exposure but may degrade image quality, while higher activity improves sensitivity but increases radiation risks. Sensitivity does not always increase proportionally with activity due to system dead time and count rate limits (Kupitz et al., 2021). Low energy high resolution (LEHR) collimators, specifically designed to optimise spatial resolution for low-energy isotopes like Tc-99m, feature longer septa and smaller hole diameters compared to high-sensitivity as shown in Figure 1.1.1 (Li et al., 2022). This design enhances the resolution of fine details by reducing the number of photons reaching the detector, thereby affecting overall system sensitivity.

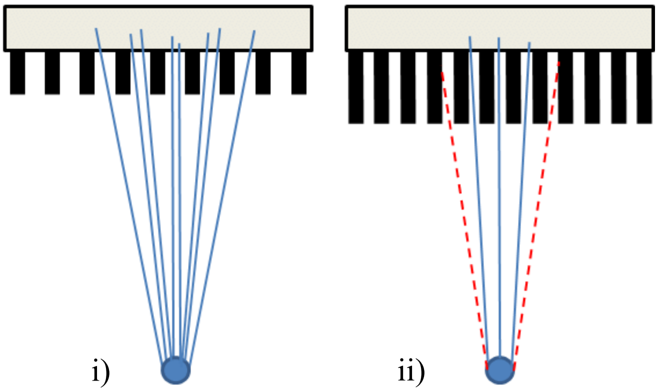

Figure 1.1.1: A comparison of a i) high sensitivity and a ii) high resolution collimator

In SPECT, gamma rays emitted from a radiopharmaceutical within the patient's body are detected externally to form images of functional processes. The detection of these gamma rays commonly employs sodium iodide (NaI) crystals, which act as scintillators converting gamma photons into visible light photons that can be measured by a photomultiplier tube (PMT) (Ritt, 2022). The sensitivity of the (NaI) crystal is a critical parameter in scintigraphic image formation because it directly affects the system's ability to capture true signals while minimising noise, thus determining the signal-to-noise ratio and ultimately the image quality. Moreover, the physical properties of NaI crystals, such as their thickness and packing ratio, influence detection efficiency and sensitivity, making them key factors in optimising SPECT imaging performance (Ritt, 2022).

Tomographic sensitivity analysis provides a systematic approach to evaluate the performance of SPECT/CT detectors, as it considers the 3D imaging process and the system's capability to detect and locate radioactive sources. High tomographic sensitivity improves image contrast and quantitative accuracy, allowing better detection of small lesions and subtle physiological changes. Factors that contribute to sensitivity include detector efficiency, geometric factors, and the attenuation and scatter of photons within the patient's body. Optimising tomographic sensitivity is essential for achieving high-quality images and reliable quantification, especially under varying clinical conditions or activity levels (Halim et al., 2021).

This study aims to evaluate the tomographic sensitivity of SPECT/CT detectors equipped with LEHR collimators at different Tc-99m activity levels, focusing on the correlation between sensitivity, contrast, and resolution. It seeks to quantify how variations in radiotracer activity affect system sensitivity, image quality, and quantitative reliability. By analysing tomographic sensitivity across different activity levels, this study can identify limitations and optimise system parameters for improved diagnostic accuracy. The findings will contribute to the ongoing development of nuclear medicine imaging techniques, ensuring better patient outcomes through enhanced sensitivity and resolution in SPECT/CT applications.

1.2 PROBLEM STATEMENTS

Single-photon emission computed tomography (SPECT) integrated with computed tomography (CT) is critical for clinical diagnostics, relying on optimised detector sensitivity and collimator performance to produce high-quality 3D images. Despite the acknowledged importance of sensitivity in imaging quality, current research predominantly focuses on planar sensitivity tests, which assess the system's response in two dimensions. It is well understood that increasing the radiotracer activity typically boosts sensitivity; nevertheless, this relationship holds true mainly within controlled planar measurements and does not necessarily reflect true three-dimensional (3D) tomographic performance.

The tomographic sensitivity of the SPECT detectors, particularly when equipped with LEHR collimators, can vary depending on the activity levels of Tc-99m and the physical characteristics of the collimator itself. This variation can influence the detection efficiency of the system, leading to fluctuations in image quality. Moreover, the collimator design, including its thickness and material, plays a pivotal role in controlling the trade-off between spatial resolution and sensitivity. Studies using Monte Carlo simulations have demonstrated that fine-tuning LEHR collimator thickness can significantly affect tomographic spatial resolution and sensitivity, thereby influencing the noise-resolution balance in SPECT imaging (Sawant et al., 2025)

Additionally, physical properties of detector crystals critically influence in determining of the detection efficiency and tomography sensitivity of SPECT detectors. Thallium-doped sodium iodide (NaI:Tl) is a widely used scintillator, known for its high light yield (~38,000 photons/MeV), enhancing gamma photon conversion and improving system sensitivity and image quality (Maeng et al., 2022). In addition, the hygroscopic nature of NaI:Tl necessitates hermetic sealing to prevent moisture-induced degradation, which can significantly degrade their optical properties and thus reduce tomography sensitivity in SPECT systems (Lee et al., 2023). Recent advances in SPECT/CT technology, including novel detector configurations, improved reconstruction algorithms and crystal purification, have aimed to optimize sensitivity and resolution without compromising image quality (Ferri et al., 2022).

Nonetheless, a comprehensive analysis of how different Tc-99m activity levels impact tomographic sensitivity in detectors with LEHR collimators remains essential to fully understand and mitigate these effects. This understanding is particularly important for clinical protocols that require precise quantification of radiotracer distribution and for improving the reliability of SPECT/CT as a diagnostic tool. In conclusion, this research addresses the critical issue of how variations in tomographic sensitivity, influenced by Tc-99m activity levels and LEHR collimator characteristics, affect radiation detection and image quality in SPECT/CT systems. By clarifying these relationships, the study aims to advance the performance and clinical applicability of SPECT/CT imaging, ultimately contributing to improved diagnostic precision and patient outcomes in nuclear medicine.

1.3 OBJECTIVES

1.3.1 GENERAL OBJECTIVES

This study aims to compare the sensitivity of the SPECT/CT equipped with LEHR using a different Tc-99m activities

1.3.2 SPECIFIC OBJECTIVES

1. To prepare and set up the Jaszczak Phantom for SPECT/CT imaging with Tc-99m.
2. To measure the tomographic sensitivity of SPECT/CT detectors equipped with LEHR collimator at different Tc-99m activity levels from 7 and 12 mCi.
3. To analyse the result of the tomographic sensitivity, contrast and resolution of SPECT/CT.

1.4 SIGNIFICANCE OF STUDY

This study highlights the importance of optimising nuclear medicine imaging by determining the minimum radiotracer dose needed to maintain diagnostic accuracy in line with the ALARA principle. Its findings can help medical institutions improve patient care and provide researchers with valuable data on sensitivity and resolution trade-offs in SPECT/CT imaging, fostering advancements in medical imaging.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION AND PRINCIPLE OF SPECT/CT

Single-photon emission computed tomography/computed tomography (SPECT/CT) is an advanced hybrid imaging modality that integrates the functional imaging capabilities of SPECT with the high-resolution anatomical detail provided by CT scans. This combination has significantly enhanced sensitivity and specificity across numerous clinical applications (Bouchareb et al., 2024; Ljungberg & Pretorius, 2018; IAEA, 2008). The SPECT component operates using a gamma camera that detects photons emitted by a radiopharmaceutical administered systemically. Most clinical SPECT systems are based on the Anger camera principle, utilizing sodium iodide (NaI(Tl)) scintillation crystals, parallel-hole collimators, and photomultiplier tubes to detect gamma photons and determine their spatial origin (Bouchareb et al., 2024; Ljungberg & Pretorius, 2018).

Technological advancements have revolutionized SPECT/CT systems, including the replacement of bulky photomultiplier tubes with position-sensitive PMTs, avalanche photodiodes, and semiconductor detectors such as cadmium-zinc-telluride (CZT). These innovations have improved spatial resolution and sensitivity, enabling more precise quantification of radiotracer uptake and reduced acquisition times (Bouchareb et al., 2024; Cantoni et al., 2021). Additionally, artificial intelligence (AI) techniques are increasingly being employed for automated segmentation, partial volume correction, and accelerated reconstruction, narrowing the gap between SPECT/CT and PET/CT in terms of image quality and quantitative performance. The evolution of SPECT/CT reflects advancements in detector design, acquisition geometry, reconstruction algorithms, and AI, driving its widespread clinical adoption and expanding its diagnostic and therapeutic capabilities.

2.2 TOMOGRAPHIC SENSITIVITY IN SPECT IMAGING

Tomographic sensitivity is a crucial parameter in SPECT/CT imaging, directly affecting the detection and accurate localisation of pathological changes within the body. With the introduction of hybrid SPECT/CT systems, sensitivity analysis has become a vital aspect of performance evaluation, influencing image quality, lesion detectability, and quantitative accuracy. High sensitivity ensures the identification of small or early-stage lesions, which is essential for timely diagnosis and effective treatment planning (Bouchareb et al., 2024; Ljungberg & Pretorius, 2018).

Research has increasingly focused on quantifying and stabilising the counting sensitivity of SPECT/CT cameras to ensure consistent and reproducible imaging results. Sensitivity analysis plays a pivotal role in guiding system design improvements and optimising clinical protocols to balance diagnostic accuracy with patient radiation doses. For example, SPECT/CT provides approximately 10% better quantification accuracy than planar imaging due to improved sensitivity and attenuation correction, which is critical for individualised radionuclide therapy planning (Prakash & Tafti, 2022). Sensitivity analysis also evaluates the trade-offs between additional CT radiation exposure and diagnostic benefits, enabling radiation protection strategies without compromising image quality (Faridnejad, 2022).

Technological advances, including improved detector materials and reconstruction algorithms, have further refined sensitivity analysis, enabling detection of small lesions and more precise radiation quantification (Bouchareb et al., 2024). Overall, tomography sensitivity in SPECT/CT is pivotal for accurate radiation detection, leading to improved diagnostic accuracy, patient management, and tailored therapeutic interventions across various clinical fields

2.3 DIFFERENCE IN PLANAR AND TOMOGRAPHY SENSITIVITY TEST

The methodological differences between planar sensitivity testing and tomographic sensitivity testing highlight distinct approaches to performance evaluation. Planar sensitivity tests measure detector response to a fixed radionuclide source, in a Petri dish, at a set distance, with counts recorded in CPS/MBq after background subtraction (Kheruka et al., 2025; An et al., 2016; Demirkaya et al., 2014). For instance, Matsumoto et al. used a Petri dish containing I-131 solution placed between two detectors 10 cm apart, measuring both photopeak and scatter counts to determine planar system sensitivity. This method is straightforward and minimises measurement error but requires iterative reconstruction with accurate corrections for attenuation, scatter, and resolution recovery for reliable quantitative calibration (Matsumoto et al., 2017).

In contrast, tomography sensitivity tests utilise cylindrical phantoms filled with a homogeneous radioisotope solution to simulate the volumetric activity distribution found in clinical imaging. These tests assess total system sensitivity by acquiring tomographic data across the entire phantom volume, directly incorporating factors such as attenuation and scatter into the measurement. Tomography sensitivity is calculated based on the known activity concentration and acquisition parameters, providing a thorough evaluation of system performance (Demirkaya et al., 2014). Matsutomo et al. (2017) conducted a study on tomography sensitivity using phantom-based absolute quantification on a SPECT/CT system, employing corrections for attenuation, scatter, and resolution through OSEM reconstruction. Their approach enabled precise sensitivity calculations across varying activity concentrations, achieving deviations of less than 10% from true activity values, thereby improving diagnostic accuracy in clinical imaging (Matsutomo et al., 2017). According to Kurkowska et al. (2021), NEMA NU 1–2018 tomography sensitivity standards are integral for ensuring clinical quantification fidelity.

Comparative studies highlight that while planar sensitivity tests offer practical advantages and demonstrate strong correlation with calculated activities, tomography sensitivity measurements generally provide more accurate absolute quantification. Percent differences between calculated and measured activities are as low as −0.28% for tomography sensitivity tests compared to −4.68% for planar methods when appropriate corrections are applied (An et al., 2016). However, volume tests require a more complex setup and longer acquisition times. Findings consistently indicate that planar sensitivity tests serve as a reliable baseline for system calibration and quality control, even under varying activity levels. Yet, tomographic sensitivity tests deliver superior diagnostic accuracy and a more comprehensive evaluation of imaging performance, particularly in the context of clinical protocols and reconstruction fidelity.

2.4 FACTOR AFFECTING TOMOGRAPHY SENSITIVITY

Tomography sensitivity in SPECT/CT is influenced by multiple interdependent technical factors that directly impact diagnostic accuracy across various clinical applications. Technical parameters include collimator selection, where high-resolution designs improve spatial resolution but reduce count sensitivity, requiring longer acquisition times to maintain image quality. Another factor is the condition of the scintillation crystal, which further affects system sensitivity. For instance, a study stated that the presence and increasing thickness of a dead layer in the NaI(Tl) crystal can lead to a significant reduction in SPECT sensitivity—up to 33.5% for low-energy gamma emissions—alongside minor deteriorations in spatial and energy resolution, ultimately degrading image quality and diagnostic performance (Aynur et al., 2025).

Matrix size presents a fundamental trade-off: larger matrices improve spatial sampling but increase image noise, whereas smaller matrices compromise resolution and exacerbate partial volume effects, particularly for sub-centimetres lesions (Dickson et al., 2023). For instance, Noori-Asl (2020) demonstrated through Monte Carlo simulations that matrix size significantly affects image contrast and signal-to-noise ratio (SNR), both of which are proxies for sensitivity. Reconstruction parameters, such as the number of iterations and the application of filters, also play a critical role. Optimizing reconstruction protocols is essential, as under-convergence results in negative bias (activity underestimation), while inadequate filtering amplifies Poisson noise, leading to positive bias (overestimation) (Dickson et al., 2023).

Lastly, Seevinck et al. (2007) reported that the type of radiopharmaceutical and its distribution within the body also influence sensitivity, particularly in multimodal imaging contexts where SPECT is combined with CT (Seevinck et al., 2007). Collectively, these findings emphasize the importance of optimizing technical parameters, reconstruction algorithms, and hardware maintenance to maximize tomography sensitivity and diagnostic accuracy in SPECT/CT imaging. Operational considerations, such as tailoring radiopharmaceutical doses, acquisition times, and collimator choices to specific clinical scenarios, as well as regular hardware maintenance, are equally vital for minimizing technical variability.

2.5 TOMOGRAPHY SENSITIVITY EFFECT ON SPATIAL RESOLUTION & CONTRAST

In SPECT/CT imaging, tomography sensitivity plays a crucial role in determining image quality, particularly in terms of spatial resolution and contrast detectability. Willowson and Bailey (2024) reported that advancements in detector design, including digital solid-state systems and novel collimator geometries, have significantly enhanced system sensitivity, enabling more accurate assessments of biodistribution and dosimetry in theranostic applications (Willowson & Bailey, 2024). High-sensitivity detectors, such as cadmium-zinc-telluride (CZT), improve both spatial resolution and contrast by enhancing energy resolution and reducing full width at half maximum (FWHM) values (Wang et al., 2022; Ito et al., 2021).

Iterative reconstruction algorithms, such as OSEM with resolution recovery, leverage sensitivity gains by integrating scatter and attenuation corrections, which reduces noise amplification while improving spatial resolution beyond four iterations (Cheng et al., 2025; Noori-Asl, 2020). However, the collimator remains a critical factor limiting sensitivity, as it allows only a small fraction of gamma photons to be detected, directly affecting spatial resolution and contrast. Innovations like the SmartZoom collimator, designed to focus on specific regions such as the heart, can enhance sensitivity by up to fourfold. This improvement significantly boosts image quality by increasing photon detection efficiency without compromising spatial resolution (Willowson & Bailey, 2024).

Emerging deep learning methods further exploit sensitivity data to predict resolution recovery, showing promise in compensating for hardware limitations without costly modifications (Cheng et al., 2025). Overall, synergistic advancements in detector sensitivity, collimator design, and reconstruction software have progressively decoupled the sensitivity-resolution trade-off, enabling sub-centimetres lesion detection critical for early-stage oncology.

2.6 CONCLUSION

Tomographic sensitivity analysis is crucial for optimizing SPECT/CT performance, directly influencing diagnostic accuracy, lesion detectability, and quantitative reliability (Bouchareb et al., 2024; Willowson & Bailey, 2024; Prakash & Tafti, 2022). Advances in detector technology, collimator design, and reconstruction algorithms have enhanced sensitivity, improving imaging precision and patient outcomes. Current research effectively evaluates technical parameters like matrix size, collimator type, and reconstruction protocols, highlighting their impact on sensitivity, spatial resolution, and image contrast (Dickson et al., 2023; Wang et al., 2022). High-sensitivity systems offer clinical benefits, particularly in individualised dosimetry and early lesion detection in oncology and theranostics (Willowson & Bailey, 2024).

However, gaps persist. Many studies focus on overall system performance without a detailed analysis of sensitivity variations across radionuclide activity levels or specific collimator types like LEHR. Limited research addresses real-world applications of planar vs. tomographic sensitivity tests with varying Tc-99m activities (Kheruka et al., 2025; Matsutomo et al., 2017). Methodological issues, such as inconsistent phantom designs and a lack of standardised sensitivity protocols, hinder reproducibility and cross-system comparisons

This research addresses gaps through a tomographic sensitivity analysis of SPECT/CT detectors with LEHR collimators at varying Tc-99m activity levels. Using standardised phantoms and rigorous attenuation/scatter correction protocols, this study will generate reproducible, clinically relevant data that can inform both system calibration and protocol optimisation. Ultimately, this work will contribute to the field by providing actionable insights for improving SPECT/CT performance, supporting evidence-based adjustments to clinical imaging protocols, and enhancing diagnostic confidence in nuclear medicine.

CHAPTER 3: MATERIALS & METHODOLOGY

3.1 MATERIALS

3.1.1 GE DISCOVERY NM/CT 670, USA

All measurements were performed at the Department of Nuclear Medicine and Oncology, Hospital Pakar Universiti Sains Malaysia (HPUSM), on the Discovery NM/CT 670 Pro as shown Figure 3.1.1.1.1, manufactured by GE Healthcare. Discovery NM/CT 670 Pro is a premium hybrid SPECT/CT imaging system. It is an all-purpose, dual-detector, free-geometry integrated nuclear imaging camera that features the advanced all-digital Elite NXT NM detector technology. It is available in 3/8” or 5/8” NaI(Tl) crystal thicknesses, and detectors are mounted on a free-geometry robotic gantry, capable of flexible positioning (90° or 180°) and automatic body contouring (ABC) for optimized spatial resolution and scanning efficiency.

The gantry aperture is a 70 cm wide-bore gantry that combines a slim NM gantry with a CT compact design. The CT module is based on the Optima CT540, featuring a 16-slice HiLight Matrix detector and a Performix Ultra X-ray tube with 6.3 MHU heat capacity and 53.2 kW maximum power. CT image acquisition was supported by automatic exposure control and dose reduction features such as ASiR and OptiDose. OptiDose dynamically adjusts scanning parameters such as tube current based on patient anatomy, enabling automated exposure control across a wide range of protocols. ASiR, an iterative reconstruction algorithm, reduces image noise and enhances image clarity, allowing for lower tube current settings without compromising spatial resolution or anatomical detail. Lastly, the acquisition station is based on the Linux operating system with an icon-based graphical user interface shared with the Xeleris workstation.

Figure 3.1.1.1.1: GE Discovery NM/CT 670 Pro

3.1.2 LOW ENERGY HIGH RESOLUTION (LEHR) COLLIMATORS

This study uses LEHR collimators as shown in Figure 3.1.2.1. The physical characteristics of the collimators include hexagonal holes with a diameter of 1.5 mm, a septal thickness of 0.2 mm, and a hole length of 35 mm. The specifications of the collimators used in this study were taken from the Discovery NM/CT 670 Pro Data Sheet. This combination of hole diameter and length is theoretically the best option for obtaining high resolution with low-energy photon emitters such as Tc-99m, which is 140 keV. To increase the sensitivity of the imaging system, thinner collimators with larger hole diameters are required, which leads to a reduction in the spatial resolution of the imaging system due to the increased photon acceptance angle (Noori-Asl, M. and Jeddi-Dashghapou, S., 2022).

Figure 3.1 2.1: LEHR collimator

3.1.3 DELUXE JASZCZAK PHANTOM, BIODEX

This study was performed using a Deluxe Jaszczak Phantom. The phantom body (a main cylinder) is a flangeless source tank with a 6.4 mm wall thickness, 20.4 cm interior diameter, 18.6 cm interior height and background compartment volume of approximately 6.1 litres (with inserts) and 6.9 litres (without inserts). It consists of six cold spheres representing various lesion sizes with diameters of 9.5, 12.7, 15.9, 19.1, 25.4 and 31.8 mm, and six sets of cold rods with diameters of 4.8, 6.4, 7.9, 9.5, 11.1 and 12.7 mm based on . This phantom enables easy access to spatial resolution, contrast computation for cold lesions, and volumetric sensitivity of the systems (Gonçalves et al., 2022).

The cold spheres consist of multiple solid acrylic spheres of varying diameters. These spheres are non-radioactive and, when the phantom is filled with a radionuclide, they simulate "cold" lesions. They are used to evaluate lesion detectability and image contrast (Demirkaya et al., 2014). The clarity and distinctness of these spheres in the reconstructed image indicate the system's ability to visualise lesions of varying sizes.

The cold rod consists of sets of precisely drilled acrylic rods. These rods are arranged in pie-shaped segments. When the main cylinder is filled with a radioactive solution, these acrylic rods remain non-radioactive "cold", allowing for the assessment of spatial resolution under scatter and attenuation conditions (Demirkaya et al., 2014). The ability to distinguish smaller rods indicates better spatial resolution.

Figure 3.1.3.1: Jaszczak Phantom

The Jaszczak (Deluxe) Phantom serves as an essential tool in the material evaluation section of research, offering a controlled environment to assess the impact of different imaging parameters. Its design allows for the reproducible testing of system resolution, contrast and sensitivity when subjected to varying activity levels, collimators, and reconstruction settings.

3.1.4 TECHNETIUM-99M (Tc-99m)

This study was conducted using three different activity levels of technetium-99m (Tc-99m), which are 7, 10 and 12 mCi, it is a widely used medical radionuclide in SPECT imaging. Technetium-99m (Tc-99m) is a pure gamma emitter with an energy of 140 keV. It is derived from molybdenum-99 (Mo-99), which undergoes isobaric transition and decays via beta (β-) emission to its metastable state ${}^{99m}_{43}Tc$, with the remainder transitioning to the ground state of technetium-99 (${}^{99}_{43}Tc$). The metastable state decays by emitting a gamma ray with an energy of 140 keV, leading to the transition to the ground state. The ground state ${}^{99}_{43}Tc$, through isomeric transition, has a relatively long half-life and eventually decays via beta (β-) emission to form stable ruthenium-99 (${}^{99}_{44}Ru$), the decay scheme was shown in Figure 3.1.4.1(Al-Qinnah and M.Y.H., 2023).

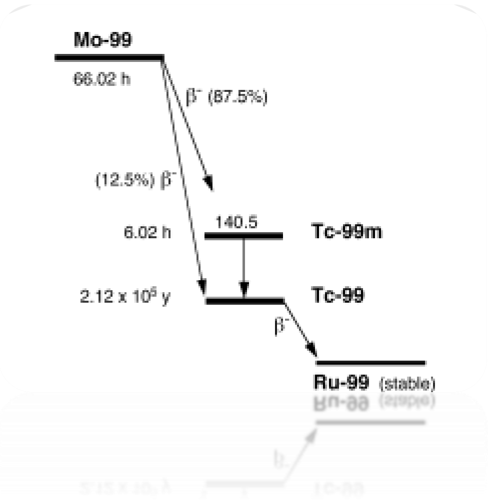

Figure 3.1.4.1: Decay scheme parent Mo-99 to stable Ru-99

The separation of short-lived Tc-99m from the longer-lived Mo-99 is achieved through a chromatographic generator, based on the principle of anion exchange. The ideal characteristics of Tc-99m that contribute to its versatility are the emission of pure gamma photons without primary particle emission, minimising unnecessary radiation exposure to the patient. Its energy level of 140 keV is sufficient to penetrate the patient's body, and a half-life of 6.02 hours, allowing adequate time for preparation, injection, uptake, and imaging, while being short enough to be quickly excreted and eliminated from the body.

3.1.5 XELERIS WORKSTATION

Xeleris offers Volumetrix MI, a hybrid imaging tomography review package to superimpose and display matching pairs of nuclear and CT tomograms. Volumetrix MI is an interactive display allowing users to navigate in 3D throughout the entire tomographic study, including comparative display of corrected and uncorrected images.

The Volumetrix MI hybrid processing allows SPECT and CT attenuation correction. By incorporating energy-based corrections and scatter compensation, it can evaluate how Tc-99m activity fluctuations affect tomographic uniformity and quantitative accuracy.

For Q Metrix, it utilises both SPECT and CT segmentation tools to quantify radiopharmaceutical uptake, incorporating patient demographics information and the same methods currently employed to calculate SUV for PET images. The Metrix workflow integrates SPECT and CT segmentation tools to define organ or lesion-specific volumes of interest (VOIs), utilising patient demographic data to compute parameters such as radiotracer concentration (Bq/ml), percentage of injected dose and total uptake within segmented regions as shown in Figure 3.1.5.1.

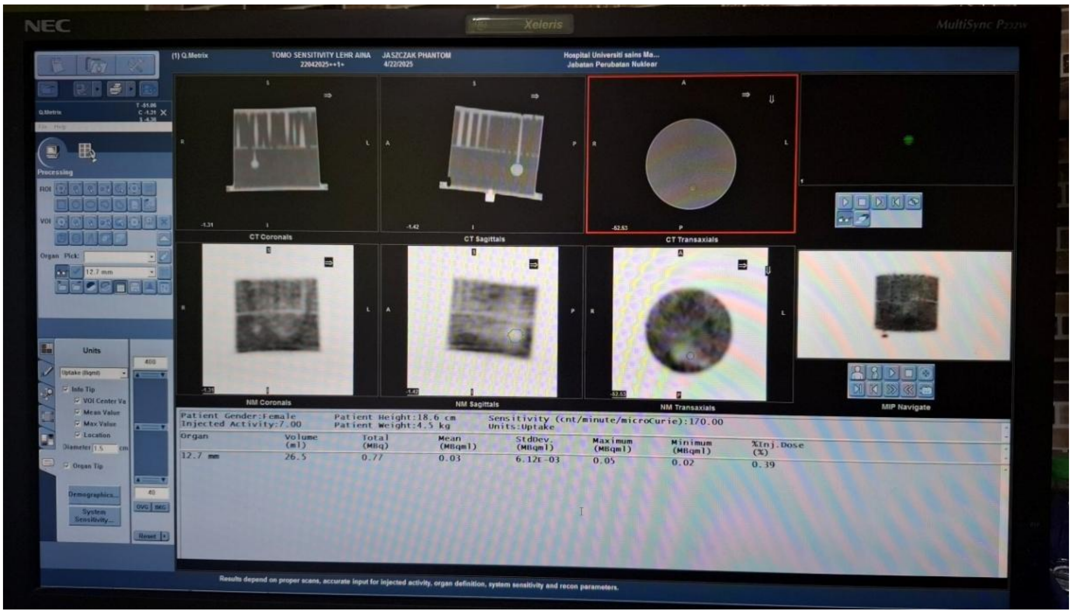

Figure 3.1.5.1: Data analysis at Q Metrix

3.2 METHODOLOGY

3.2.1 PHANTOM PREPARATION

The phantom was filled with distilled water, ensuring that no contaminants interfered with the imaging process. Once the water has been fully inserted, close the covers of the phantom securely. Move the phantom to the scanning room. Using the prepared syringe, take the ^{99m}Tc solution following the measurement needed, follow the activity use and inject it into the phantom filling holes. Once the ^{99m}Tc solution has been inserted, close the covers of the filling holes securely. After mixing the solution, place the phantom upright and reopen the filling holes. Add additional water to remove any remaining air bubbles. Once all bubbles have been removed, close the phantom securely to complete the preparation process. For the tomography sensitivity, the cold sphere and rod were removed from the phantom, as shown in Figure 3.2.1.1. It functions to get uniform cylindrical activity for tomographic scanning.

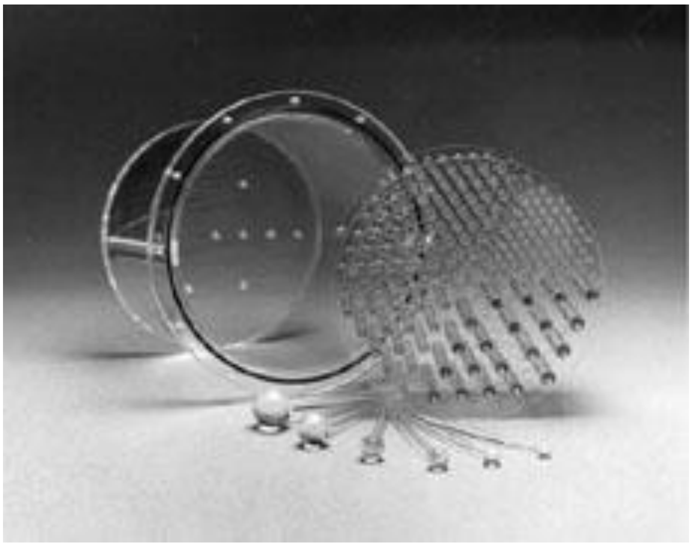

Figure 3.2.1.1: Jaszczak phantom with the insert

3.2.2 SETTING UP THE COLLIMATORS AND PHANTOM POSITIONING

The installed Low energy high resolution (LEHR) collimators were thoroughly examined to verify that they were correctly mounted and securely fastened. After mounting, the phantom must be carefully positioned at the end of the pallet, lying on its side along the primary patient axis. For optimal imaging results, the largest "cold" sphere in the phantom must be placed at the bottom, closest to the pallet, as shown in Figure 3.2.2.1. This orientation enhances visibility in the final image acquisition. The cylinder axis should be positioned near the gantry's axis of rotation, ensuring that the distance between the collimators and phantom remains constant during rotation.

Figure 3.2.2.1: Phantom setup

To verify alignment, the gantry should be set to 90° in the H-mode, allowing detectors to be positioned as close to the phantom as possible, as shown in Figure 3.2.2.2. Ensuring that the entire phantom remains visible within the detector's Field of View (FOV) is crucial for consistent image quality. A careful rotation test should be conducted to prevent collisions between the detectors and the phantom.

Figure 3.2.2.2: Gantry setup

3.2.3 DATA ACQUISITION

To compare the image quality between systems and evaluate the trend of each activity, images of each activity were acquired using the specified acquisition parameters. For each scan, 60 projections were acquired in step & shoot mode, with the angular step of 6°. Total angular range was 360° (180° per detector). Body-contour orbit was used to keep the camera close to the phantom during the entire SPECT acquisition. The acquisition time was set for 30 seconds per projection. The matrix size was 128x128. The SPECT acquisition settings are detailed in Table 3.2.3.1 and Figure 3.2.3.1

Panel	Parameter	Value
Detector setting	Both detector	Both selected
Rotation	Total angular range	360 (180 per detector)
	Angular steps	3
	Direction	CW
Start position		H
Image setting	Matrix	128 × 128
	Zoom value	1.33
Scan mode	Step and shoot	Selected
	Stop on time per projection	25 s

Table 3.2.3.1: Parameter acquisition

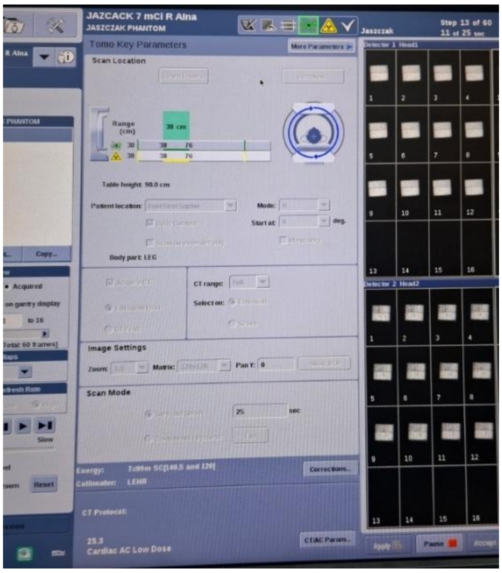

Figure 3.2.3.1: Acquisition parameter

In addition to SPECT, CT acquisitions were performed, providing an anatomical reference of the phantoms to assist the segmentation of the regions of interest (ROI). This was done in the CT component of the GE NM/CT 670 gamma camera. The CT scan was performed in the axial mode with the tube voltage of 120 kV and the current of 20 mA. The slice thickness was 5 mm. The matrix size was 128 × 128, and the parameter was shown in Figure 3.2.3.2. Lastly, the results of each scan were transferred to the Xeleris workstation.

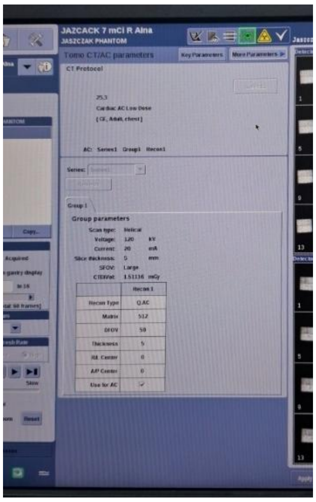

Figure 3.2.3.2.: CT parameter acquisition