IMPACTS OF BUTTERWORTH POST-FILTERING ON ABSOLUTE QUANTIFICATION OF ^{99m}Tc SPECT/CT USING NEMA PHANTOM

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by

LEAH TAN SHIN CHI

Dissertation submitted in partial fulfilment of the requirement for the degree of

Bachelor Health Science (Honours)

(Medical Radiation)

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CERTIFICATE

This is to certify that the dissertation entitled IMPACTS OF BUTTERWORTH POST-FILTERING ON ABSOLUTE QUANTIFICATION OF ^{99m}Tc SPECT/CT USING NEMA PHANTOM is the bona fide record of a research done by Ms. LEAH TAN SHIN CHI using the period from October 2023 to June 2024 under my supervision. I have read this dissertation, and that in my opinion it conforms to acceptable standards of scholarly presentation, and it 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).

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DECLARATION

I hereby declare that this dissertation is the results of my own investigations, except where otherwise stated and duly acknowledged. I also declare that it has not been previously or concurrently submitted 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.

……………………………

LEAH TAN SHIN CHI

Date: August 2024

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LIST OF ABBREVIATIONS

SPECT – Single Photon-Emission Computed Tomography

CT – Computed Tomography

SPECT/CT - Single Photon-Emission Computed Tomography/Computed Tomography

PET – Positron Emission Tomography

RC – Recovery Coefficient

AC – Activity Concentration

NEMA – National Electrical Manufacturers Association

IEC – International Electrotechnical Commission

^{99m}Tc – Technetium-99m Pertechnetate

COF – Cut-off Frequency

SNR – Signal-to-Noise Ratio

ROI – Region of Interest

VOI – Volume of Interest

LEHR – Low Energy High Resolution

OSEM – Ordered-Subset Expectation Maximization

HUSM – Hospital Universiti Sains Malaysia

SUV – Standardised Uptake Value

Bg – Total Background

Bc – Mean Background

Sbg – Standard Deviation Background

TBR – Target Background Ratio

Ave – Average

mCi – Millicurie

kBq – Kilobecquerel

MBq – Megabecquerel

Bq – Becquerels

mL – Milliliter

ABSTRAK

Latar Belakang:

Kuantifikasi mutlak taburan radiotracer menggunakan pengimejan SPECT/CT adalah penting untuk dosimetri dan terapi radionuklid perubatan. Walau bagaimanapun, ketepatan kuantifikasi bergantung kepada pelbagai faktor. Dengan menggunakan ukuran fantom, kajian pelbagai vendor dan pelbagai pusat ini menilai ketepatan kuantitatif dan variabiliti antara sistem SPECT/CT, serta kesan saiz pesakit, perisian pemprosesan dan algoritma pembinaan semula ke atas pekali pemulihan (RC).

Kaedah:

Kajian ini menggunakan ukuran fantom untuk menilai prestasi kuantitatif sistem SPECT/CT GE Discovery NM/CT 670 Pro. Aktiviti Tc-99m disediakan untuk mencapai nisbah sasaran-ke-latar belakang (TBR) 4:1 dan 10:1. Fantom NEMA 2012/IEC 2008 digunakan, dan imej diperolehi, dibina semula, dan dianalisis menggunakan stesen kerja Xeleris dan perisian Q. Metrix. Metrik seperti kontras, nisbah isyarat-ke-hingar (SNR), dan RC dinilai di bawah parameter penapis Butterworth yang berbeza.

Keputusan:

Hasil kajian menunjukkan bahawa pemilihan parameter penapis Butterworth, khususnya frekuensi penapisan (COF) dan kuasa, memberi kesan yang signifikan terhadap kualiti imej dan ketepatan kuantitatif. Untuk senario nisbah sasaran-ke-latar belakang (TBR) 10:1, parameter penapis Butterworth optimum adalah COF 0.8 kitaran/mm dan kuasa 15, yang menghasilkan kontras dan nisbah isyarat-ke-hingar (SNR) tertinggi. Manakala untuk senario TBR 4:1, parameter optimum adalah COF 0.8 kitaran/mm dan kuasa 10.

Kesimpulan:

Penemuan ini menunjukkan kepentingan mengoptimumkan parameter penapis Butterworth dalam pengimejan dan nisbah sasaran-ke-latar belakang yang spesifik SPECT/CT untuk mencapai keseimbangan terbaik antara kualiti imej dan ketepatan kuantitatif. Dengan memilih parameter penapis Butterworth yang sesuai, para klinisi dapat memperoleh imej SPECT/CT dengan kontras, SNR dan ketepatan kuantitatif yang lebih baik menjadikan penemuan ini berkesempatan untuk

membimbing pemilihan tetapan pembinaan semula yang sesuai untuk meningkatkan kuantifikasi mutlak, yang sangat penting untuk aplikasi seperti dosimetri dan terapi radionuklid perubatan yang disesuaikan.

ABSTRACT

Background:

Absolute quantification of radiotracer distribution using SPECT/CT imaging is crucial for dosimetry and personalized radionuclide therapy. However, the accuracy of quantification depends on various factors. Using phantom measurements, this multi-vendor and multi-center study evaluated the quantitative accuracy and inter-system variability of different SPECT/CT systems, as well as the impact of patient size, processing software and reconstruction algorithms on recovery coefficients (RC).

Method:

The study utilized phantom measurements to assess the quantitative performance of the GE Discovery NM/CT 670 Pro SPECT/CT system. Tc-99m activity was prepared to achieve target-to-background ratios (TBR) of 4:1 and 10:1. The NEMA 2012/IEC 2008 phantom was used, and images were acquired, reconstructed, and analysed using the Xeleris workstation and Q. Metrix software. Metrics such as contrast, signal-to-noise ratio (SNR), and RC were evaluated under different Butterworth filter parameters.

Results:

The results showed that the choice of Butterworth filter parameters, specifically the cutoff frequency (COF) and power, had a significant impact on image quality and quantitative accuracy. For the TBR 10:1 scenario, the optimal Butterworth filter parameters were a COF of 0.8 cycle/mm and a power of 15, which produced the highest contrast and SNR. For the TBR 4:1 scenario, the optimal parameters were a COF of 0.8 cycle/mm and a power of 10.

Conclusion:

This study demonstrates the importance of carefully optimizing the Butterworth filter parameters in SPECT/CT imaging to achieve the best balance between image quality and quantitative accuracy. The findings can guide the selection of appropriate reconstruction settings for improved absolute quantification, which is crucial for applications such as dosimetry and personalized radionuclide therapy.

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Nuclear medicine relies heavily on imaging with gamma (γ) rays from radionuclides to detect and stage various disorders like myocardial perfusion, bone malignancy, and thyroid disease. (Ahmad Saib et al., 2022) Single-photon emission computed tomography (SPECT) is a widely used nuclear imaging technique that provides valuable information about the functional and physiological processes within the body. It is a popular imaging technology that uses radiotracers to show the distribution of a γ-emitter within a patient. (Ahmad Saib et al., 2022) Technetium-99m (99mTc) is the most used radionuclide in SPECT imaging due to its favorable physical and chemical properties. (Boschi et al., 2019) The versatility of Technetium-99m chemistry allows for the creation of various radiopharmaceuticals that can target specific biological processes. (Benny & Moore, 2011) However, the supply of the parent isotope Molybdenum-99, which is used to produce Technetium-99m, has experienced several disruptions in recent years, highlighting the need for optimization of SPECT imaging techniques. (Metello, 2015) (Banerjee et al., 2001)

Over the last few decades, rapid advances in image reconstruction for SPECT systems have been achieved through the development of various iterative reconstruction approaches for system response, photon scattering, and attenuation. (Ahmad Saib et al., 2022) Since SPECT imaging detects various diseases, it is necessitated for SPECT quantification. Since the radioactivity was discovered, there was a sudden interest in quantification arising from the need to study it.

One important aspect of SPECT imaging is quantifying radiotracer uptake, which is crucial for accurate diagnosis and treatment monitoring. SPECT quantification is vital in detecting or staging the variety of diseases. Accurate quantification of radiotracer uptake and distribution in SPECT imaging relies on its image quality. There are three factors affecting the SPECT image quality and its quantification. First, SPECT equipment is a crucial note that should be taken. It is because different reconstruction protocols are standardized, and various radionuclides are used with different SPECT equipment. (Zhang et al., 2021) Besides, reconstruction affects the SPECT image quality and its quantification due to the various acquisition and reconstruction parameters impacting the accuracy of SPECT quantification. Small iterations and subsets used in OSEM reconstruction may influence the quantification accuracy. (Zhang et al., 2021) Moreover, one of the most important elements that greatly affect the quality of clinical SPECT images is image filtering. Post-filtering can affect the SPECT image quality and quantification. The Butterworth filter was found the best for trade-off between contrast, SNR, and defect size accuracy. (Salihin Yusoff et al., 2009) (Lyra & Ploussi, 2011)

Image filtering is the term used for any operation that is applied to pixels in an image. It is a mathematical process by which images are suppressed in noise and includes smoothing, edge enhancement and resolution recovery. A low-pass filter enables low frequencies to pass through and remain unchanged while stopping the high frequencies. It soothes the noise and preserves the image resolution. (Lyra & Ploussi, 2011)

There is a tendency to focus more on the application of absolute quantification in radionuclide therapy of SPECT/CT. It impacts the accuracy and reproducibility in diagnostic medicine. (De Schepper et al., 2021) Quantification defines the evaluation of exact amount of radiotracer uptake in specific tissue or organ, (Bq/ml). Absolute quantification is a precise approach to quantify and measure the absolute amount of a target with external standards which allow the expression level to be calculated as an exact number. Absolute quantification of SPECT images can be challenging due to various factors, including scatter, attenuation, and partial volume effects. Post-filtering techniques, such as Butterworth filtering, are common approaches to address these issues and improve quantification accuracy.

Accurate absolute quantification of radiotracer distribution is critical for dosimetry in the context of personalized radionuclide therapy, and it may improve therapeutic response prediction, toxicity prevention, and treatment monitoring for follow-up. Both positron emission tomography (PET) and single-photon emission computed tomography (SPECT) show promise for absolute radioactivity quantification. However, quantification in SPECT is considered less easy since its accuracy is dependent on a few elements, including the use of a collimator, the shifting detector trajectory, and the necessity for more complex scatter and attenuation correction than in PET. (Peters et al., 2019)

Furthermore, quantification is affected by both the reconstruction algorithm and the settings. Recent advances in corrections for photon attenuation and scatter, collimator modelling, and 3D reconstruction, such as resolution recovery and noise management, have enhanced reconstruction approaches, allowing for absolute SPECT quantification. The incorporation of an integrated computed tomography (CT) system not only gives an anatomical reference, but also allows for accurate attenuation and scatter correction, which improves quantification. Nowadays, integrated SPECT/CT systems are routine clinical practice. (Peters et al., 2019)

The purpose of this study is to investigate the impact of Butterworth post-filtering on the absolute quantification of 99mTc SPECT/CT images using a NEMA (National Electrical Manufacturers Association) phantom. The NEMA phantom is a standardized imaging phantom used to evaluate the performance of SPECT/CT systems.

1.2 PROBLEM STATEMENT

Filtering is a usual technique used in Nuclear Medicine. It is abundantly used on nuclear medicine images to lower the statistical noise, upgrade the edges for edge detection and help in the tomographic image reconstruction (Galt et al., n.d.). The application of smoothing filters which are low-pass filters can help in noise removal and resolution recovery in SPECT images. The image quality can be improved meanwhile the accuracy quantification can be enhanced. The low-pass filters enable the low frequencies to pass through and remain unchanged while stopping the high frequencies. (Lyra & Ploussi, 2011)

Much research discussed regarding the absolute quantification or filtering but there are less research studies about the complementation of the post-filtering with absolute quantification. Some studies have suggested that absolute SPECT quantification is affected with different SPECT equipment when reconstruction protocols are standardized and various radionuclides. (Zhang et al., 2021) Some studies have suggested that the small number of iterations and subsets used in OSEM reconstruction influences the quantification accuracy. (Zhang et al., 2021)

Despite these validations and clinical practices, post-filtering may also affect the accuracy of SPECT absolute quantification. Thus, the impacts of Butterworth post-filtering on absolute quantification of SPECT/CT might need to be studied. A low-pass filter may smooth images to a high degree that does not permit discerning small lesions, leading to contrast loss. (Lyra & Ploussi, 2011) The application of a post-reconstruction smoothing filter may inevitably degrade the spatial resolution and exaggerate partial volume effects. (Dickson et al., 2023)

Previously, application of a low-pass filters resulted in inconsistencies findings:

1. The application of a 10 mm Gaussian post-filter (a low-pass filter) can substantially improve the consistency of measurements of activity concentration. (Dickson et al., 2023)
2. Butterworth post-filtering reduced the accuracy of the RC compared to the unfiltered data. (van de Burgt et al., 2021)
3. Butterworth post-filtering compromises the SNR and image detail while preserving the size accuracy of the lesions. (Steer, n.d.)

This study aimed to assess the impacts of Butterworth post-reconstruction filter on the accuracy of absolute quantification of ^{99m}Tc pertechnetate SPECT/CT in low and high contrast acquisition.

1.3 AIM OF STUDY

The general objective of the study is to assess the impacts of Butterworth post-reconstruction filter on the absolute quantification of ^{99m}Tc pertechnetate SPECT/CT.

Specific Objectives: -

1 To evaluate the impact of the Butterworth post-reconstruction filter on ^{99m}Tc SPECT/CT image quality.
2 To investigate the correlation between the absolute quantification (recovery coefficient, RC) with the Butterworth post-reconstruction filter.
3 To define an optimal Butterworth filter for ^{99m}Tc SPECT/CT quantification

1.4 SIGNIFICANCE OF STUDY

The study aims to determine the SPECT/CT image quality and the absolute quantification of image by using the Butterworth filtering (To evaluate the impact of the Butterworth post-reconstruction filter on ^{99m}Tc SPECT/CT image quality). In the context of using the specific parameters, the highest image quality with the best acquisition is analysed and selected from all the images. Next, it is used for quantification analysis to investigate the correlation between the absolute quantification (recovery coefficient, RC) with the Butterworth post-reconstruction filter and evaluate the optimal Butterworth filter for ^{99m}Tc SPECT/CT quantification which with the best image quality with its acquisition protocols and parameters. This study aimed to assess the impacts of Butterworth post-reconstruction filter on the accuracy of absolute quantification of ^{99m}Tc pertechnetate SPECT/CT in low and high contrast acquisition to find out the best definition of the optimal Butterworth filter for ^{99m}Tc SPEC/CT quantification.