THE USE OF ALUMINIUM FILTER TO IMPROVE THE IMAGE QUALITY IN TC-99M BRAIN SPECT IMAGING: A PHANTOM STUDY

BY

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ABSTRACT

Scattered gamma photons are the result of Compton scattering interaction of radiation within the matter. They have low energy as compared to unscattered photons and their contribution is adverse in terms of degradation of spatial resolution and image quality in single photon emission imaging. The objective to apply a physical filter is to reduce the amount of scattered gamma photons before reaching the scintillation detection system. The physical filter material aluminium, Al sheet (0.10mm and 0.20mm thickness) was chosen to perform this study. The type and thickness of physical filter was selected on the basis of percentage attenuation calculations of different gamma ray energies by various thicknesses and materials. The parameters that were investigated in this study are spectra of Tc-99m, spatial resolution, uniformity and system volume sensitivity. For the specific organ study, the image acquisitions from the Hoffman 3-D brain phantom and the RSD Striatal brain phantom were investigated. Data were acquired using Infinia® GE Healthcare dual-head gamma camera without and with physical filter with LEHR collimator installed. Spatial resolution study was done by scanning a Tc-99m line source (0.8mm inner diameter) at various source-to-collimator distances in air and in scattering medium. For spectra, uniformity and sensitivity, a cylindrical source tank filled with water added with Tc-99m was scanned. Both Hoffman 3-D and RSD Striatal brain phantoms with water with added Tc-99m were scanned. The Hoffman 3-D brain phantom was prepared with two conditions; normal brain and cold defect brain. Both brain phantoms images were analysed qualitative (visual analysis) and quantitatively (grey-to-white ratio, thalamus size and contrast ratio). All SPECT images were reconstructed with filtered-back projection (FBP) method by applying Butterworth filter of order 5 with different cut-off frequencies 0.30, 0.40 and 0.50 cycles/cm. The images were corrected by Chang's attenuation correction method using linear attenuation coefficient, LAC $0.11cm^{-1}$ and $0.12cm^{-1}$ for without physical filter and $0.12cm^{-1}$, $0.13cm^{-1}$ and $0.14cm^{-1}$ for with physical filter. The spatial resolution with the physical filter improved as the source-to-collimator distance increases. There was a significant reduction in count rate from Compton and photopeak regions of Tc-99m spectra with physical filter compared to without physical filter. There was a substantial reduction in the counts from the photopeak region where the decrease in the scatter radiation is probably higher. System volume sensitivity was reduced. Despite reduction in system volume sensitivity, the system uniformity improved with physical filter. Enhancement in image quality of Hoffman 3-D brain phantom and the RSD Striatal brain phantom by applying 0.10 mm Al physical filter was achieved. Therefore, this technique is considered suitable for further investigation for clinical trials to validate the applicability of physical filter technique in clinical SPECT imaging.

خلاصة البحث

فوتونات غاما المتشتتة هي نتيجة لتداخل تشتت كومبتون للإشعاع داخل المادة، وتعتبر طاقة هذه الفوتونات منخفضة مقارنة بالفوتونات الغير مشتتة وتعتبر آثارها سيئة حيث تقلل من دقة تفاصيل الصورة ومن جودة الصورة في تصوير انبعاث الفوتونات. الهدف من وضع مصفاة مادية هو لتقليل كمية فوتونات غاما المتشتتة قبل الوصول إلى نظام الكشف عن الوميض. تم اختيار الألومنيوم كمادة للمصفاة المادية على شكل ورقة من الألمنيوم (بسُمك 0.10 مم و 0.20 مم) لأداء هذه الدراسة. تم اختيار نوع وسُمك المصفاة المادية بناء على حسابات التوهين النسبية للمستويات المختلفة من طاقات أشعة غاما الناتجة عن مختلف السماكات والمواد. المعايير التي تم التحقيق فيها في هذه الدراسة هي أطياف Tc-99m، ودقة تفاصيل الصورة، والتماثل، وحساسية النظام تجاه الحجم. بالنسبة للدراسة التحديدية للعضو، تم التحقيق في الصور المأخوذة بواسطة نموذج دماغ هوفمان D-3 ونموذج RSD للجسم الخطط للدماغ. تم الحصول على البيانات باستخدام جهاز التصوير النووي Infinia® GE Healthcare بكاميرا أشعة غاما ثنائية الرأس مع وبدون المصفاة المادية مع مسدد LEHR مركّب. تم إجراء دراسة دقة تفاصيل الصورة عن طريق مسح مصدر خط Tc-99m (القطر الداخلي 0.8 مم) في مسافات مختلفة من المصدر إلى المسدد في الهواء وفي محيط التشتت. بالنسبة للأطياف والتماثل والحساسية، فقد تم مسح خزان مصدر أسطواني مليء بالماء مضاف إلى مادة Tc-99m. تم مسح كل من النماذج الدماغية لهوفمان D-3 ومخطط دماغ RSD مع الماء و الـ Tc–99m المضاف. تم إعداد نموذج دماغ هوفمان D-3 على حالتين، وهما الدماغ العادي والدماغ المختل بالبرد. تم تحليل كل من نماذج الأدمغة نوعيا (التحليل البصري) وكميا (نسبة اللون الرمادي إلى الأبيض، وحجم مهاد الدماغ، ونسبة التباين). أعيد بناء جميع صور SPECT بطريقة الإسقاط المعاد التصفية (FBP) من خلال تطبيق مصفاة بتروورث من الرتبة 5 مع ترددات قطع مختلفة وهي 0.30، و 0.40 ، و 0.50 دورة/سم. تم تصحيح الصور بواسطة طريقة تصحيح التوهين لتشانغ باستخدام معامل التوهين الخطي، LAC 0.11 سم$^{-1}$ و 0.12 سم$^{-1}$ بدون مصفاة مادية، و 0.12 سم$^{-1}$، 0.13 سم$^{-1}$ و 10.14 سم$^{-1}$ بمصفاة مادية. تحسنت دقة تفاصيل الصورة مع المصفاة المادية مع زيادة المسافة من المصدر إلى المسدد. كان هناك انخفاض كبير في معدل العد من كومبتون ومناطق الذروة الصورية من أطياف Tc-99m مع المصفاة المادية مقارنة في حال عدم وجودها. لوحظ أيضا انخفاض كبير في العد في منطقة الذروة الصورية حيث كان الانخفاض في الإشعاع المتشتت عال محتملا. على الرغم من الانخفاض في حساسية حجم النظام فقد تحسن تماثل النظام مع المصفاة المادية. تم أيضا تعزيز جودة الصور من نموذج دماغ هوفمان D-3 ونموذج دماغ المخطط الدماغي RSD من خلال وضع 0.10 مم من المصفاة المادية الألومونيومية. ختاما، تعتبر هذه التقنية مناسبة لمزيد من التحقيق لأجل التجارب السريرية للتثبُّت من صحة قابلية استعمال طريقة المصفاة المادية في تصوير SPECT السريري.

APPROVAL PAGE

The thesis of Norhanna Binti Sohaimi has been approved by the following:

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DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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Norhanna Sohaimi

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LIST OF ABBREVIATIONS

2-D	Two dimension
3-D	Three dimension
Al	Aluminium
cFOV	Centre field of view
$C_{nonscattered}$	Count of non-scattered gamma photons in the photopeak region
$C_{scattered}$	Count of scattered gamma photons in the photopeak region
C_{total}	Total count in the photopeak region
Cu	Copper
DCF	Decay correction factor
DF_{eff}	Effective decay factor
DSC	Data Spectrum Corporation
FBP	Filtered back projection
FDG	Fluorodeoxyglucose
FOV	Field of view
FWHM	Full-width-half-maximum
FWTM	Full-width-tenth-maximum
HVL	Half value layer
IAEA	International Atomic Energy Agency
IIUM	International Islamic University Malaysia
IIUMBC	IIUM Breast Centre
LAC	linear attenuation coefficient
LEAP	low energy all purposes
LEGP	low energy general purposes
LEHR	low energy high resolution
LSF	Line spread function
Mo-99	Molybdenum 99
MRI	Magnetic resonance imaging
MTF	Modulation transfer mode
NaI(Tl)	Sodium iodide added with thallium
Pb	Lead
PET	Positron emission tomography
PHA	Pulse height analyser
PMMA	Polymethyl methacrylate
QC	Quality control
RNI	Radionuclide imaging
ROI	Region of interest
SCD	source-to-collimator distance
SD	Standard deviation
Sn	Tin
SNR	Signal-to-noise ratio
SPECT	Single photon emission computed tomography
SPET	Single photon emission tomography
SVS	system volume sensitivity
Tc-99m	Technetium 99m
TBV	Total blood volume
UFOV	Useful field of view
Zn	Zinc

LIST OF SYMBOLS

Bq	Bacquerel
cm	centimetre
cpm	count per minute
keV	kilo electron volt
kcps	kilo count per second
%	Percentage
MBq	Mega Bacquerel
mCi	mili Curie
mm	millimetre
μCi	micro Curie

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

In general, radionuclide imaging (RNI) also known as nuclear medicine imaging can be described as the application of radionuclide techniques that has the ability to diagnose diseases especially cancer in early stages hence it can be treated properly. RNI uses radiation sources as a tracer that emits only gamma rays. In the RNI, radioactive source is used in order to provide internal physiological information on the human organs or body. These radioactive materials do not work alone but tagged with certain pharmaceuticals that act as carrier agent to take the radioactive material to the target organs or tissues. The carrier agent is specific to each target organ and will not interfere in the non-target organ. The combination of radioactive materials and pharmaceuticals is known as radiopharmaceuticals.

The gamma rays of the injected radionuclide from each part of a patient are emitted in all directions. The gamma rays from organ of interest emit more as compared to the other parts of the body. Single Photon Emission Computed Tomography (SPECT) has a main problem of scatter and attenuation of gamma photons in the object or patient to be scanned, which compromise its utility e.g., poor quality images and non-linearity in the quantification of radioactivity uptake (Gustafson et al., 2000 and Guido Germano, 2001).

In SPECT system, scintillation detectors are used in order to detect the emitted gamma photons from the patient's body. The phenomenon of interactions between gamma photons with an atom of a scintillation detector will emit photoelectron or Compton electron. However, not all gamma photons which hit a scintillation detector will result in a single emitted photoelectron. Some of the gamma photons will pass through without any interaction and some of them will scatter to any other directions. Compton scattered photons also occur within the patient's body. The presence of scattered gamma photons in the image data degrades the spatial resolution of the image, decreases the image contrast, and reduces the signal to noise ratio of the image and lead to an overall degradation in the perceived quality of the image. These cause errors in the quantification of radioactivity distribution.

The problem of Compton scattered photons has been handled by using energy discrimination window by narrowing down the energy window. But this method has limitations and not able to eliminate all scattered gamma photons from projection data. Thus, the collected data comprises of primary (unscattered) and scattered gamma photons. Therefore, a method for the reduction of the influence of low energy (scattered) gamma photons on SPECT projection data by means of physical filter are applied. Such physical filter decreases the relative concentration of low energy (scattered) gamma photons by preferentially removing them before they can reach the surface of the detector of gamma camera.

1.2 PROBLEM STATEMENT

One of the major goals of diagnostic imaging especially in radionuclide imaging field is to produce a high quality image without losing any important diagnostic information. In SPECT imaging, there are many factors that influence the quality of images. Gamma photons that are emitted from radionuclide in the patient's body not only contain useful gamma photons also known as primary or unscattered radiation, but also some fraction of gamma photons that are low energy and are known as scattered radiation. Even though the technology of SPECT system is very rapidly growing and developing, however, it has some problems which compromise its utility. The major problem in SPECT is poor quality images due to the scatter and attenuation of gamma photons in the patient to be scanned.

Nowadays, sodium iodide added with thallium NaI(Tl) material is commonly employed in gamma camera systems as scintillator. The scintillator has relatively poor energy resolution as compared to solid state detectors but a significant fraction of scattered gamma photons is still detected in the image data. The presence of scattered photons degrades the spatial resolution of the image, decreases the image contrast and reduces the signal-to-noise ratio (SNR) in the image. All the factors can lead to overall degradation in the perceived quality of the image. Thus, it leads to errors in the quantification of radioactivity distribution.

A number of techniques have been developed to reduce the scatter of gamma photon effects in radionuclide imaging. They are post-processing methods and reconstruction algorithm. Very little studies have been done using physical filter but have been applied only in planar and positron emission tomography (PET) imaging and not specific to brain SPECT imaging. It is expects that this study will contribute in providing better image quality in Tc-99m SPECT.

1.3 RESEARCH OBJECTIVES

The study expected to achieve the following objectives:

1.3.1 General objective

To reduce the scattered radiation component from projection data by using additional physical filter in order to enhance image quality and achieve accuracy in the quantification of the radioactivity distribution in brain Tc-99m SPECT images.

1.3.2 Specific objectives

1. To investigate and determine the suitable materials and thickness for the design of physical filter(s)-theoretical approached
2. To analyse the Tc-99m spectra without and with physical filter(s)
3. To study the effects on spatial resolution, system sensitivity and uniformity of the imaging system without and with physical filter(s)
4. To enhance the brain structures using Hoffman 3-D phantom (e.g. thalamus) and striatal detectability (size, shape and count density), cold defect detectability, quality and the accuracy in the quantification of radioactivity concentration in Tc-99m brain SPECT images