REDUCING THE EFFECTS OF SCATTERED GAMMA PHOTONS IN Tc-99m MYOCARDIAL SPECT IMAGING

BY

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ABSTRACT

Myocardial SPECT is one of the techniques that provide high diagnostic accuracy for the assessment of coronary artery disease. However, in general, the presence of Compton scattered photons in the resulting image data will reduce the diagnostic accuracy. This undesirable effect is even more significant in heart thorax-linked analysis compared to other regions with a more homogenous volume. In this study, the use of physical filter was proposed to reduce the undesirable scattered gamma photons. In this context, the scattered gamma photons were absorbed by the filter before they reach the gamma camera detector. Initially, a selection of the types and thickness of the filter materials based on a theoretical calculation was done. They were then incorporated into the basic procedures of Planar and SPECT imaging, and finally to Myocardial SPECT imaging, where a Tc-99m radionuclide was used. In Myocardial SPECT imaging procedure, an anthropomorphic torso (heart/thorax) phantom was used. The image reconstruction procedure was based on filtered back projection. Chang's attenuation correction method was used. The image quality was analyzed qualitatively and quantitatively. In Tc-99m spectra test, a decrease in the ratio of scattered to non-scattered photon for the whole spectra was observed for all types of the physical filters examined. However, the reduction in photopeak region was only recorded by Zn 0.2 mm filters. The physical filters were also found to improve system's spatial resolution, but the uniformity of the tomographic image was unchanged, and the system volume sensitivity was reduced to 16% for Cu and 4% for Zn filter. It was found that Zn 0.2 mm reduced the scatter in Myocardial SPECT imaging, where a clear separation between the liver and heart was observed. A significant improvement in contrast (10.98%) and signal-to-noise ratio of myocardial wall to defect areas (12.68%) was achieved with the use of Zn 0.2 mm material filter. Thus, it is concluded that the use of Zn 0.2 mm material filter has the potential to enhance the image quality in clinical SPECT imaging. However, clinical trials of this technique are required prior to its use in patient studies.

خلاصة البحث

إن عضلة القلب سبيكت (SPECT) هي إحدي التقنيات التي توفر تقييم مرض الشريان التاجي بدقة عالية. ولكن، إن وجود كومبتون متناثرة الفوتونات في بيانات الصورة بشكل عام يقلل دقة التشخيص. ويوجد هذا التأثير غير المرغوب فيه أكثر في التحليل المرتبط بالقلب الصدر بالمقارنة مع المناطق الأخرى التي لديها حجم أكثر تجانساً.فلذا في هذه الدراسة، اقترحنا استخدام فلتر الفيزيائي للحد من فوتونات غاما متناثرة غير مرغوب فيها. في هذا السياق، تم امتصاص الفوتونات غاما المتناثرة من قبل الفتر قبل أن تصل إلى كاشف كاميرا غاما. ففي البداية، تم اختيار أنواع وسمك مواد الفتر على أساس حساب نظري. ثم تم دمجها في الإجراءات الأساسية للتصوير مستو و سبيكت، وأخيرا إلى تصوير سبيكت عضلة القلب، حيث تم استخدام النويدات المشعة TC-99m. فأيضاً في إجراء التصوير سبيكت عضلة القلب، تم استخدام الجذع مجسم (القلب / الصدر) الوهمية. وقد استند إجراء إعادة إعمار الصورة إلى الإسقاط الخلفي المصفى. وذلك باستخدام طريقة تصحيح تشانغ. ومن هنا تم تحليل جودة الصورة نوعيا وكميا. وفي اختبار الطيف TC-99m ، لوحظ انخفاض في نسبة فوتون متناثرة إلى غير متناثرة للأطياف بأكملها لجميع أنواع الفلاتر الفيزيائية التي تم فحصها. ومع ذلك، فإن الانخفاض في منطقة فوتوبيك سجلت فقط من قبل فتر الزنك 0.2 مم. ووجدت الفلاتر الفيزيائية تحسن القرار المكاني للنظام، ولكن لم يتم تغيير التوحيد للصورة المقطعية، وانخفضت حساسية حجم النظام إلى 16٪ لنحاس و 4٪ لفتر الزنك. وقد وجد أن زنك 0.2 مم خفضت الانتشار في تصوير سبيكت عضلة القلب، حيث لوحظ فصل واضح بين الكبد والقلب. فقد تحقق تحسن معنوي (10.98٪) في التباين ,ونسبة الإشارة إلى الضوضاء لجدار عضلة القلب (12.68٪) إلى مناطق الخلل باستخدام فلتر الزنك 0.2 مم. وهكذا، استنتجنا أن استخدام فلتر الزنك 0.2 مم لديه القدرة على تحسين جودة الصورة في التصوير سبيكت السريرية. بينما التجارب السريرية لهذه التقنية مطلوبة قبل استخدامها في دراسات المرضى.

APPROVAL PAGE

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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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LIST OF ABBREVIATIONS

Al	Aluminum
CAD	Coronary Artery Disease
CF	Calibration Factor
COR	Center-of-Rotation
Cu	Copper
CVD	Cardiovascular Disease
DEW	Dual Energy Window
DF_{eff}	Effective Decay Factor
EDX	Energy Dispersive X-ray
FBP	Filtered back Projection
Fe	Ferum
FWHM	Full Width at Half Maximum
GIF	Graphics Interchange Format
HLA	Horizontal Long Axis
IAEA	International Atomic Energy Agency
ICRU	International Commission on Radiation Units and Measurement
JPEG	Joint Photographic Experts Group
keV	Kilo Electron Volt
LEHR	Low Energy High Resolution
LSF	Line Spread Function
LV	Left Ventricle
MatLab	Matrix Laboratory
mCi	Milli Curie
Mo-99	Molybdenum 99
MPI	Myocardial Perfusion Imaging
MW	Myocardial Wall
NaI(Tl)	Sodium Iodide doped with Thallium
Ni	Nickel
PHA	Pulse Height Analyzer
PMT	Photomultiplier Tube
RBSC	Reconstruction Based Scatter Compensation Method
RMS	Root Means Square
ROI	Region of Interest
SA	Short Axis
SC	Scatter Correction
SCD	Source to Collimator Distance
SEM	Scanning Electron Microscopy
SNR	Signal to-Noise Ratio
SPECT	Single Photon Emission Computed Tomography
Tc-99m	Technetium 99 Metastable
TEW	Triple Energy Window
VLA	Ventricle Long Axis
WHO	World Health Organization
Zn	Zinc

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

The presence of scattered gamma photons in planar and single photon emission computed tomographic (SPECT) imaging procedures hamper accuracy of interpretation and quantification of image (Niu & Yang, 2011). There are two types of scattered photons: Compton and coherent. However, in the range of nuclear medicine energy, Compton scattering is more dominant compared to coherent scattering (Cherry, Sorenson & Phelps, 2012). Generally, Compton scattering forms when incoming photons interact with an individual electron and the electron absorbs only part of the energy from the photon. The rest of the energy from the photon that was not absorbed by the electron remains in a secondary photon, which is considered to be the Compton scattered. Its energy is reduced and the direction of movement changes. However, if the scattered photon still has enough energy, the process may be repeated. During imaging, distortion of the image may be possible as photons seem in a different location in the body (Nguyen, Truong, Morvidone & Zaidi, 2012).

The probability of this process to occur depends very strongly on the atomic number and density of the medium. In Myocardial SPECT imaging it is further complicated by the anatomical structure and properties of non-uniform attenuation in the chest area. Anatomically, the chest area is composed of various layers and structures. The heart is primarily enclosed by soft tissues, then is surrounded by the lungs. The lungs, in turn, are surrounded by the sternum, spine, and ribs, and another layer of soft tissue and skin. According to Tsui, Zhao, Frey and McCartney (1994), photons with energy of 140 keV originating from inside the body can be attenuated by as much as 25% before being detected by the gamma camera. In addition, the International Atomic Energy Agency (IAEA) Human Health Series No 6 (2009), reported that due to the limited resolution of the system, about 40% scatter of the total counts in a cardiac study is still being recorded in a primary photopeak energy window.

Moreover, in cardiac SPECT imaging, the production of scattered photons degrade the qualitative and quantitative aspects of the image, which eventually reduce the diagnostic sensitivity for coronary artery disease (CAD). High quality of the tomographic image is considered to be a requirement for an accurate clinical diagnosis (Lyra, Ploussi, Rouchota & Synefia, 2014). Consequently, many manufacturers and researchers provide software technology in an attempt to develop scatter correction methods that could increase image quality. These attempts can be generally divided into two categories: a subtraction-based scatter compensation method and a reconstruction-based scatter compensation method. However, these two scatter correction methods have many drawbacks and not feasible to be implemented in clinical practice.

In this study, the scattered correction method was applied using a physical filter. It was developed from a suitable material to reduce the number of scattered photons passing through the collimator and detected by scintillation detector. At this juncture, it is presumed that the scattered photons would be absorbed by the physical filter before they interact with scintillation crystal. The performance of the material filters was evaluated qualitatively and quantitatively. Planar and SPECT procedures on a number of parameters, such as spatial resolution, sensitivity, and uniformity, were also tested. The selected physical filter was also implemented for SPECT Myocardial Imaging using Heart/Thorax Phantom.

1.2 STATEMENT OF THE PROBLEM

Ideally gamma photons emitting from the object should be detected from the originating source by a scintillation detector. However, in reality, the occurrence of gamma photon attenuation by absorption and the scattered photons within a patient's body cannot be denied. The heart thorax has various attenuating properties. Therefore, some of gamma photons may not be detected by the gamma camera detector. The problem worsens when the scattered photons deviate from the place of origin of the radioactive source and interacts with the scintillation crystal detector. In addition, the inability of gamma camera to efficiently discriminate between the scattered gamma photons and primary photons make the problem more complicated and contributes to the reduction of image quality (Cherry et al., 2012).

To overcome this limitation, many scatter correction (SC) techniques have been developed and various degrees of success of this scatter correction application have been reported. However, most of the SC techniques have not received widespread acceptance in routine clinical practice due to the computational cost and patient specificity (Hutton, Buvat & Beekman, 2011). For these reasons, a new and simple technique of scatter correction which efficiently reduces the scattering effect is needed to improve image quality.

1.3 PURPOSE OF THE STUDY

The improvement of image quality by implementation of various existing scatter correction methods for planar and SPECT imaging cannot be denied. Several studies based on phantom experiments demonstrated that scatter correction improved lesion detectability in planar images (Buvat et al., 1998) and also increased contrast-to-noise ratios in SPECT images (Xiao et al., 2006). In gated cardiac SPECT imaging studies, Niu and Yang (2011) showed the correction for degrading factors such as spatial resolution, attenuation, scatter, and patient motion which can lead to improved image quality. Therefore, in terms of impact on clinical investigations, it decreased the number of false-positive diagnoses of viable myocardium (Harel et al., 2001). The advantages of scatter correction also benefit in brain studies where the contrast improvement can be significant mainly based on relatively simple approaches (Iida et al., 1998, Kado et al., 2001, Shidahara et al., 2002).

To retain improvement in health of people and enabling better outcomes, researcher continues to bring solutions into the field of nuclear medicine for the enhancement of image quality. One of the solutions is to form a good quality image in the collection of more gamma photons in image data from emitted radiation. It can be achieved by a choice of radionuclide that delivers a much higher radiation dose. Restrictions on the amount of radio-pharmaceutical that can be administered to a patient add more noise signals in the projections and the limit of spatial resolution of the gamma-camera which results in blurring of the image. In case of myocardial SPECT imaging, Tl-201 delivers a much higher radiation dose per study than for a Tc-99m. However, the choice of radionuclide shoud be justified because it may affect patient radiation dose.

This research sought to improve image quality by reducing scattered photons using a physical filter. Materials used for construction of physical filters were selected based on theoretical calculations using a linear attenuation coefficient. In the study, a physical filter was mounted on the outer surface of collimator of a gamma camera.

Therefore, generally, scattered photons emitted from the patient’s body were preferentially removed before reaching the surface of the detector of the gamma camera. In this study, the terms of scattered photons refer to Compton scattered photons that were produced by the interaction of gamma photons of injected Tc-99m activity in the thorax phantom.

Several parameters of image quality in planar and SPECT imaging were tested using physical filters. One of the selected physical filters was used for myocardial SPECT imaging. Furthermore, the study focused on improvement of image quality in Tc-99m Myocardial SPECT Imaging. Generally, cardiac images were analyzed qualitatively and quantitavely in terms of contrast, SNR and the boundaries between the myocardial wall and heart. As stated by Kojima, Matsumoto and Mutsumasa (1991), scattered photons may have several negative effects on image quality, such as reducing the contrast in the image, decreasing the image resolution, as well as increasing the noise.

If physical filters prove their effectiveness in improving image quality, this would be a great discovery and provide a significant contribution in planar and SPECT imaging specific to myocardial perfusion SPECT imaging. Indeed, this finding of SC also has an added value compared to the existing SC in terms of cost and practicality for clinical application. This discovery can provide a solution to problems related to degradation in image quality.

1.4 RESEARCH OBJECTIVES

1.4.1 General Objective

The objective of this study is to use a physical filter as a new scatter reduction method to improve image contrast, by reducing the negative effects of scattered gamma photons on an image.

1.4.2 Specific Objectives

1. To find suitable or potential materials for construction of physical filters for Tc-99m SPECT myocardial study.
2. To study the effects of physical filters on spatial resolution, uniformity and sensitivity of the gamma camera on planar and SPECT imaging.
3. To determine the boundaries of liver in a Heart/Thorax Phantom study with Tc-99m radionuclide with and without physical filter.
4. To measure the signal to-noise-ratio (SNR) and contrast of myocardial to defect areas.

1.5 SIGNIFICANCE OF THE STUDY

In nuclear medicine, it is important to achieve the highest quality of images in planar and SPECT. For clinical practices, planar imaging is more critical with the presence of other organs that reduce the contrast by the overlapping images. Therefore, the high quality tomographic imaging is considered to be a requirement and is essential for accurate clinical diagnosis (Bahnamir, 2015; Lyra et al., 2014; Khalil, Brown & Heller, 2004).

Reduction in image quality contributes to the false diagnosis that results from the misinterpretation of the image, and consequentially, false diagnosis could cause further mistakes in treating the patient and management error could result in death (Wu, Mainprize, Boone & Yaffe, 2009; Yao & Leszczynski, 2008; Singh, Bateman, Case & Heller, 2007; Burrell & MacDonald, 2006). As stated by Graber (2013), annually, approximately 10% to 15% (40,000 to 80,000) cases of deaths in United State hospitals are related to incorrect diagnose. Therefore, accurate diagnoses using high quality images can help physicians to provide effective treatment and to prevent common mistakes in cardiac imaging either false positive or false negative (Jaarsma, Leiner, Bekkers, Crijns, Wildberger, Nagel, Nelemans, & Schalla 2013; Li, Li, Shi & Zhang, 2012; Singh et al., 2007). A false negative is a test result that indicates a person does not have a disease or condition when the person actually has it. A false-positive test result indicates that a person has a specific disease or condition when the person actually does not have it. As stated by many American Heart Association studies, false-positives may lead to additional diagnostic tests that are not required.

Enhancing the image quality not only decreases false diagnosis, but can also reduce the burden of Cardiovascular Disease (CVD). The meaning of burden here is not limited to expenditure, but also to the exposure of radiation to patients and workers through repetition of diagnostic procedures (Jennifer, 2011). Einstein, Weiner, Bernheim, Kulon, Bokhari, Johnson, Moses, and Balter (2010) stated that it is not uncommon that patients have to undergo multiple rounds of Myocardial Perfusion Imaging (MPI) testing or other procedures. Another study by Eisten (2012) showed that when typical effective doses are used, SPECT imaging shows the highest effective dose compared to all the cardiac imaging procedures. The primary concern about ionizing radiation from MPI relates to the contribution of stochastic effects and potential risk of the development of cancer. Thus, the improvement of image quality can also be considered to be part of the effort to reduce dosages, improve and optimise procedures, and to potentially reduce the exposure to radiation (Maiello, 2010).

Besides the high exposure of radiation to the patient, reduction of image quality also has relevance to the burden of health care expenditures. As mentiond by Jennifer (2011) DePuey (1994) DePuey and Garcia (1989), the expenditure in CVD involves direct (e.g. drugs and medication, physician visits, hospitalisations, and rehabilitation services) and indirect costs (e.g.short and long term disability). For all of the above justifications, planar and SPECT imaging nuclear medicine should find a solution to improve image quality, and it can indirectly compete with other alternative imaging methods. Thus, it will survive and continue to provide highly valuable clinical and investigational data to the entire medical community.

1.6 CHAPTER SUMMARY

This thesis consists of seven chapters. Chapter 1 has five parts. The first part presents the background of the study to this thesis, the second part is a statement of the problem, third is the purpose of the study followed by research objectives and significance of the thesis and the last part explains how the thesis is organised.

Chapter 2 provides the literature review about CVD and the development process of CAD. In this chapter, a brief overview of the gamma camera, the SPECT camera regarding its performance characteristics, as well as the acquisition parameters and reconstruction algorithms needed for emission and transmission imaging are presented. Limitations in SPECT imaging are generally discussed in this chapter, including the limitations to be solved in this study. All the parameters for the image quality for the basic planar imaging and myocardial perfusion imaging were also described in Chapter 2.