The Effect of Collimator Geometrical Characteristics on Image Quality in GAMMA CAMERA

ISMAEL MOHAMMED MOHAMMED SAEED

A dissertation submitted in partial fulfillment of the
requirements for the award of the degree of
Master of Science (PHYSICS)

Faculty of Science
Universiti Teknologi Malaysia

May 2012

To my beloved Mother and Father, to my great family; my wife Sharmin and my darling daughter Asmaa.

ACKNOWLEDGEMENTS

First of all, a great praise and a huge thanks to my Great Lord, Allah S.W.T who guide me through this work and give me enough support to continue and succeed...

A great thanks to my beloved and ultra-gentle supervisor, prof. Ahmad Termizi Bin Ramli for his support and expensive advises, and his patience during my preparing this work. To all members of Nuclear Medicine Department of Sultanah Aminah Hospital, thank you for your support and co-operation during my work there. Especially to the head of Department Dr. Ng Chen Siew, to Mr. Azamnie bin Ab.Kader, thank you for everything.

To everyone who support me and advice, because without others help we can not do any valuable work.

ABSTRACT

Collimator is one of the main parts in the structure of most of the diagnostic or therapeutic devices in nuclear medicine. It is used to reduce the amount of the radiation dose deposited in the body of the patient, for example in CT scan devices, to redirecting the radiation arrays coming from the radionuclide source in gamma camera, and to absorb some of the high energy photons since a part of the camera head consists of sensitive crystal material like NaI (Sodium Iodide). Collimator also determines the spatial resolution and the sensitivity of the system, which are most important factors in determining the efficiency and accuracy of the image in gamma camera in nuclear imaging. The physical and geometrical properties of collimators used in gamma camera are determined by the purpose of the imaging. The pharmaceutical energy limit and the size or the position of the organs is also important to decide the type of collimator to be used in the imaging. The common type of collimator used with gamma camera is low energy general purpose (LEGP) due to its acceptable values of both resolution and sensitivity. The focus in the current study is to compare the performance of various design demonstrated and tested in gamma camera. Parallel multi-hole collimator is found to be the best type to be used in medical nuclear imaging provided it fulfills the radiation protection requirements, and is valid for most of the low level energy radio-nuclides. The LEGP is the most common collimator type used in most of diagnosis cases, but if a more accurate information from the image is needed the most suitable design of collimator need to be used.

ABSTRAK

Kolimator merupakan satu bahagian utama dalam kebanyakan struktur alat diagnostik atau terapeutik dalam perubatan nuklear. Ia digunakan untuk mengurangkan jumlah dos radiasi yang terenap dalam badan pesakit, contohnya di dalam alat imbasan CT, untuk memperbetulkan arah sinaran radiasi yang datang dari sumber radionuklid dalam kamera gamma, dan untuk menyerap sesetengah tenaga foton yang tinggi kerana sebahagian kepala kamera terdiri daripada bahan kristal sensitif seperti NaI(Natrium Iodida). Kolimator juga menentukan resolusi ruang dan kesensitifan sesuatu sistem, yang mana faktor paling penting dalam menentukan keefisian dan ketepatan imej pada kamera gamma dalam pengimejan nuklear. Ciri-ciri fizikal dan geometrikal kolimator yang digunakan dalam kamera gamma dapat ditentukan dengan tujuan pengimejan. Had tenaga farmaseutikal dan saiz atau kedudukan organ juga penting untuk menentukan jenis kolimator yang akan digunakan bagi pengimejan. Jenis kebanyakan kolimator yang digunakan oleh kamera gamma ialah tenaga rendah serbaguna (LEGP) berdasarkan nilai yang boleh diterima bagi resolusi dan sensitiviti. Fokus kajian ini ialah untuk membandingkan prestasi pelbagai bentuk yang didemonstrasi dan diuji dalam kamera gamma. Kolimator selari pelbagai lubang telah ditemui sebagai jenis yang paling baik untuk digunakan dalam pengimejan nuklear perubatan kerana memenuhi syarat perlindungan radiasi, dan sah untuk kebanyakan tenaga rendah radionuklid. LEGP ialah jenis kolimator yang kebanyakannya digunakan dalam kes diagnosis, tetapi jika informasi yang tepat dari imej diperlukan, maka reka bentuk sesuai diperlukan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

UTM	-	Universiti Teknologi Malaysia
LEGP	-	Low Energy General Purpose
FOV	-	Field of View
LEHR	-	Low Energy Hiegh Resolution
MEGP	-	Medium Energy General Purpose
^{99m}Tc	-	Meta-Stable State of ^{99}Tc
KeV	-	Kelo Electron Volt
PMT	-	Photomultiplier Tubes
PHA	-	Pulse-Height Analyzer
CRT	-	Cathode Ray Tube
NaI	-	Sodium Iodide Crystal
PAS	-	Picture Archiving Systems
Tl	-	Thallium
CT	-	Computed Tomography
Cs	-	Cesium

LIST OF SYMBOLS

R_o	-	Spatial rResolution
R_i	-	Intrinsic resolution
R_g	-	Geometrical (collimator) resolution
R_s	-	Scatter resolution
d	-	Diametr of the collimator
c	-	The distance between the back face of the collimator and the mid-plane of the detector
l	-	The length of the hole
t	-	Septal thickness
t_e	-	Effective length of the holes
z	-	the distance between the front of the collimator and the gamma source
MBq	-	Mega Becquerel
mCi	-	Milli Curie
μ	-	Linear attenuation coefficient

CHAPTER 1

INTRODUCTION

1.1 Introduction

Imaging is important in modern medicine, either in diagnostic or in supporting planning or directing the clinical procedures. Nuclear medicine as a branch of radiology is used to obtain biological information from patient's body by giving compounds or chemical solutions containing radioactive isotopes to patients by injection or inhalation. From outside the patient's body, a radiation detector system detects radiation emitting from the patient's body after the radioactive compound distributed totally inside the patient body. The output of the process will produce an image that gives the information about the patient's body.

Images produced by nuclear medicine are emission type image, which is in the opposite of transmission type images, since the radiation emissions come from inside the patient's body (Schiepers, 2006) .

Gamma camera is one of the most widely used device in nuclear medicine. It is also called scintillation, or Anger camera, in respect of Hal O. Anger, the first designer of the gamma camera in 1950. Gamma camera can detect radiation from a certain field of view (FOV) synchronically and therefore is able to record both dynamic and static images of any area of interest in the body of the patient(Cherry et al, 2003).

Many types of camera with a wide variety in design have been proposed and made available to be used in nuclear medicine, but in the last few years, many good improvements in quality and design modify the structure of gamma cameras, but the same basic principles for the system operation have remained. The most widely used one is the Anger camera with single crystal detector (Cherry et al, 2003).

Gamma camera, in contrast to the other types of medical imaging instruments; X-ray, ultrasound and magnetic resonance, does not create anatomical map of the body, but instead, image of the local distribution of the radionuclides (radiopharmaceuticals) injected in the body. The supplementary role of nuclear medicine in diagnoses is due to the fact that any changes in the chemistry and the biochemistry of a tissue will influence the probability of appearance of any deficiencies in the organ functions or change in the physical properties of the tissue, such us; cell swelling, formation of edema, meta-static and enlargement of tumors, morphologic changes in tissue and more other biological changes, which may be lead to disease in the future. The importance of nuclear medicine imaging clearly is in early detection of the disease signals before these changes become distributed inside the body (Webb-A, 2003).

The imaging of the distribution and uptake of the radionuclide (radio-pharmaceutical) inside the body, the early indicators of many diseases can be detected. However, the amount of the radionuclide given is very small, in nanogram (Webb-A, 2003).

The radiopharmaceutical or sometimes called radiotracer is a composition of a chemical substrate added with a radioactive element, its structure decide the size of the bio-distribution of the compound inside the body. There is an intrinsic value of the size and type of distribution of the radiopharmaceutical inside a healthy tissues. Any deviation from the normal size of distribution and absorption of radiation in any tissue is an indicator of existence of a disease. Gamma camera can give informative biological details about the bio-molecular and cells by imaging the radiation coming out from the body (Webb-A, 2003).

Figure 1.1: Gamma camera

Many factors characterise the performance of the imaging process in a gamma cameras, and determine the quality and the accuracy of the image. Starting from the level of the energy of the radiopharmaceuticals which should be limited by the biological usage and the capacity of human body. Currently diagnostic processes in nuclear medicine mostly use ^{99m}Tc. ^{99m}Tc emit gamma ray with the energy of 140 keV with life time of 6.01 hours. The range of energy is most suitable for human usage but most of the energy is lost inside the body by absorption or scattering. This degrades the quality of the image in gamma camera. The degradation is proportional to the energy coming from the tracer. Use of sensitive detectors can provide good solution to this problem. Use of collimators for redirecting the beam of photons coming from the radiotracer absorb most of the output radiation. Thus very little amount of the photons arrive at the surface of the detector in the gamma camera (Pedroso De Lima, 2003).

1.2 Gamma camera

Gamma camera generally converts photons which are emitted by the radioactive pharmaceutical which is administrated to the patient into a light pulse by opto-electronic processes and then converted to electric signal. To image the distribution of the radionuclides inside the patient body, these electric signals must be processed by some electrical circuits (Mettler & Guiberteau, 2006).

The main components of a gamma camera are as shown in Figure:1.2 :

- A computer.
- The control console.
- Cathode ray tube (CRT).
- Digitsal correction circuitry.
- Pulse-hight analyzer (PHA).
- Preamplifiers.

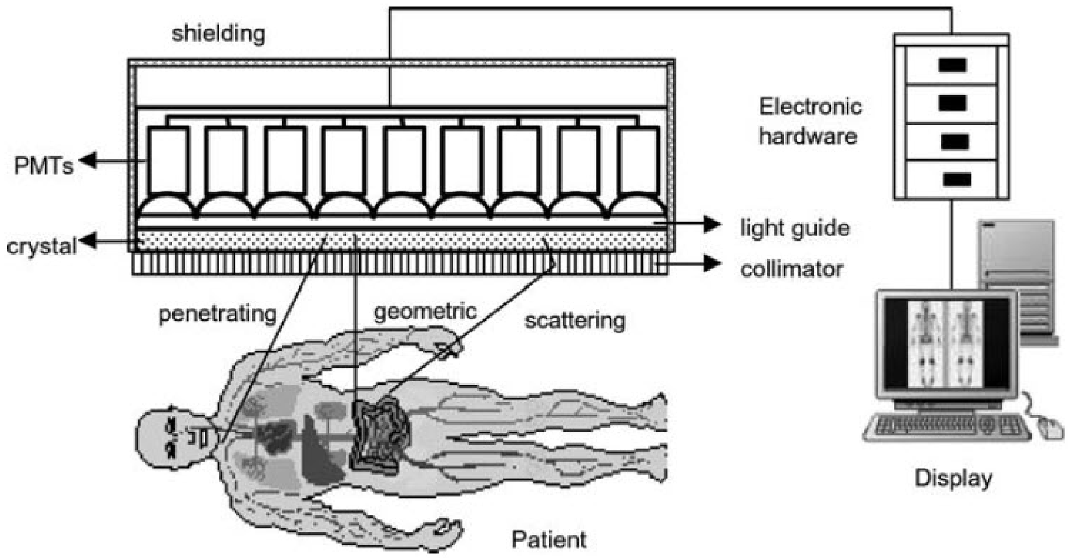

Figure 1.2: Schematic description of the principles and basic components of an Anger (gamma) scintillation camera , (Zaidi, 2006)

- Photomultiplier tubes (PMT).
- the scintillation crystal.
- Collimator.

But the basic parts of a gamma camera is:

1.2.1 Photomultiplier tubes (PMT).

A Photomultiplier Tube consists in one ends of a photosensitive (visible or ultra violate) photocathode, in the middle a number of metallic electrodes which are known as dynodes, and on the other end an anode exist, all parts are enclosed inside a vacuum glass tube. It usually referred to by its abbreviation(PM) (Le Saha, 2006).

Traditionally the photocathode is made of an alloy of cesium (Cs) and antimony (An). It releases electrons when it absorbed the energy of light photons coming from

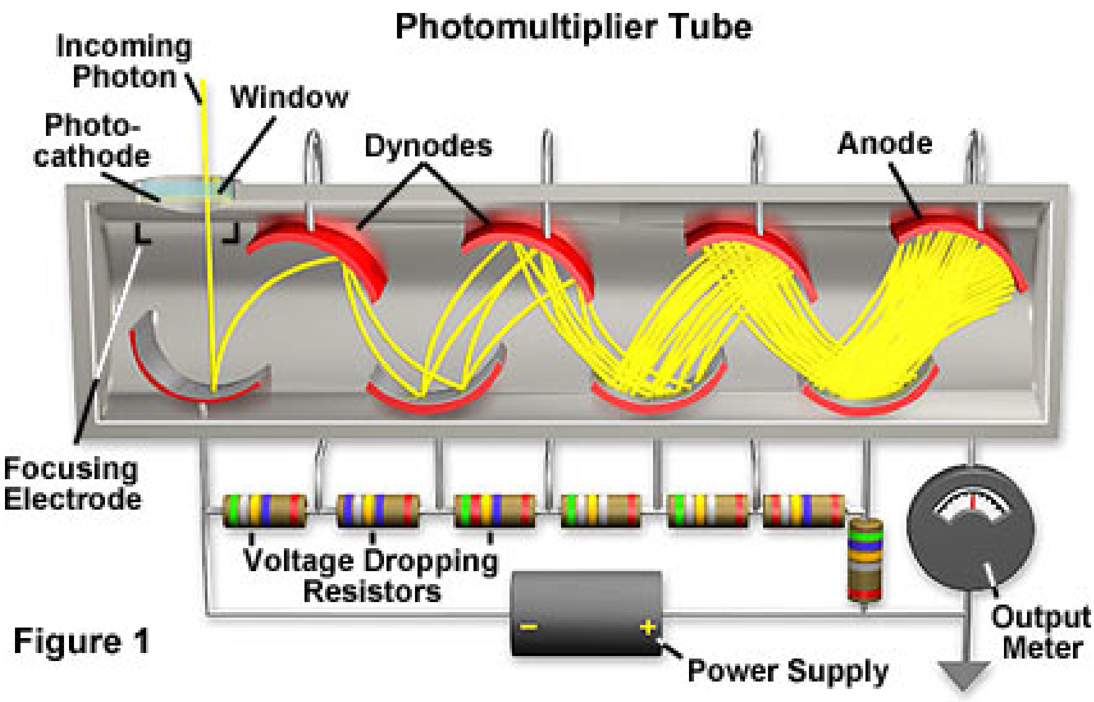

Figure 1.3: Photomultiplier,[http://learn.hamamatsu.com/articles/images/photomultiplier.jpg]

the scintillator camera. To ensure that the most of the light produced by the camera is received by the photomultiplier tubes, the photomultiplier tube is fixed to the crystal head NaI(Tl) in such a way that the photocathode facing the camera head (the crystal) is optically coupled, using a special optical grease or light pipe to reduce the effect of external light sources.

1.2.2 Scintillation camera

Gamma camera detectors are a piece of scintillation crystal. The most common is a thin and large circular crystal made of sodium iodide (NaI), activated with a trace of thallium (Tl) that act as a scintillatior. Usually it has a diameter of (30-50 cm). The thickness of the crystal is a trade-off between intrinsic resolution (the spatial resolution of the system without collimator) and the detection efficiency of the incident photons. Most of the gamma Camera designed to use the isotope ^{99m}Tc-labeled pharmaceuticals (emit 140 keV gamma photons) (Webb-S, 1988).

For the best result the thickness of the crystal should be around (9-12 cm), this will give the best trade-off between the resolution and the efficiency (Webb-S, 1988).

1.2.3 Collimator

A collimator is a hole or patterns of holes separated by certain thickness named septa, designed with a specific geometric pattern on a slab of a material with high atomic number, such as tungsten, lead and platinum. Use of lead as a collimator is preferred due to its good stopping power quality and economic availability (Schiepers, 2006).

The geometric design of the holes and septa determines the function and type of the collimator. Unfortunately, most of the gamma radiation emitted from a radionuclide source cannot be detected by the gamma camera while another big part of them travels in different paths and directions not associated to the direction of collimator holes. This generally returns to the very small solid angle of field of view FOV, which is determined by the collimator area and by the septal thickness (Mettler & Guiberteau, 2006).

Collimator is important part used in structure of most of the diagnostic and therapy instruments in nuclear medicine, for various purposes, including: redirection, restricting the amount of photon (radiation) falls on the sensitive detectors which used in the imaging device and for limiting the amount of the energy passing throw the collimator to inside the patient body (Mettler & Guiberteau, 2006)(Khalil, 2011).

In gamma camera, a collimator is used to regulate direction of the rays coming from the radiation source to fall on the surface of the detector, so that each point of detecting photons on the detector matches to a certain position in the source. Because the gamma radiation emitted from the radiation source is distributed symmetrically

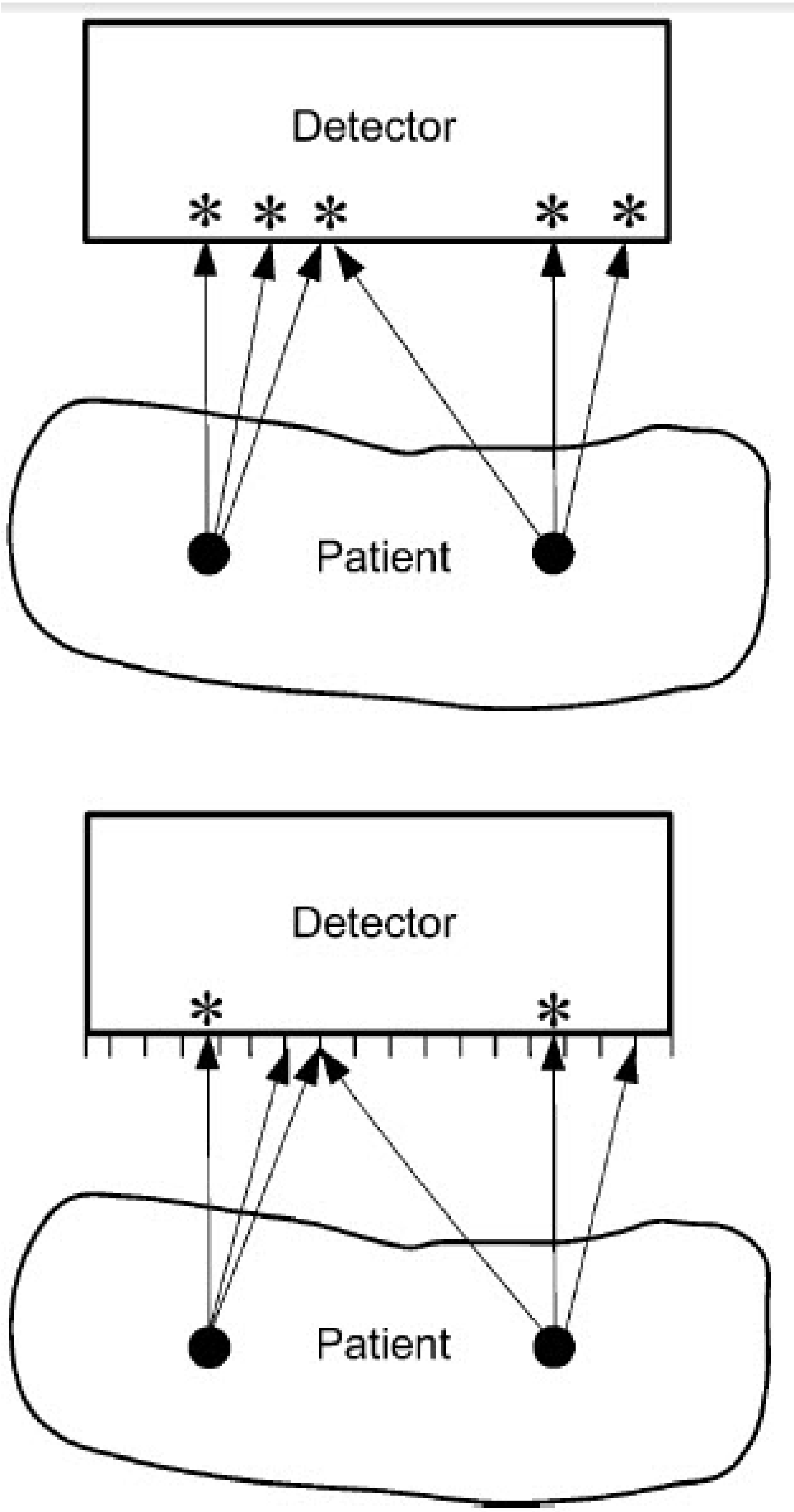

Figure 1.4: The effect of collimator on spatial resolution, (Sharp et al,2005)

along a spherical geometry, not like a light source, can be focused by lens. Many types of collimator used for this purpose, according the case of the imaging (Mettler & Guiberteau, 2006).

Collimators are classified by the type of focusing, the septal thickness and the number of holes. Based on the types of focusing the most widely used types of collimator as shown in Figure 1.5. They are:-

- Pin-hole collimator.
- Parallel multi-hole collimator.
- Diverging multi-hole collimator.
- Converging multi-hole collimator.

Based on the septal thickness, there are three types of collimator; high energy collimator, medium energy collimator and low energy collimator. For energy of the isotope around 150 keV, the low energy collimator is preferred. For energy around 400 keV medium energy collimator is preferred (Le Saha, 2006).

1.3 Parallel multi-hole collimator

Parallel multi-hole collimator is the most widely used in nuclear medicine. Usually, it consists of many parallel holes with a long axis vertical on the surface of the scintillation crystal of the detector. Made from lead or tungsten, it is expected to absorb the most of the gamma rays that are emitted out of the desired direction as defined by hole axis (Le Saha, 2006).

The distance between holes and the length of its axis are fabricated based on the energy level of the radiopharmaceutical. For higher gamma energy it is preferred to use thicker septa collimator (Bushberg et al, 1994).

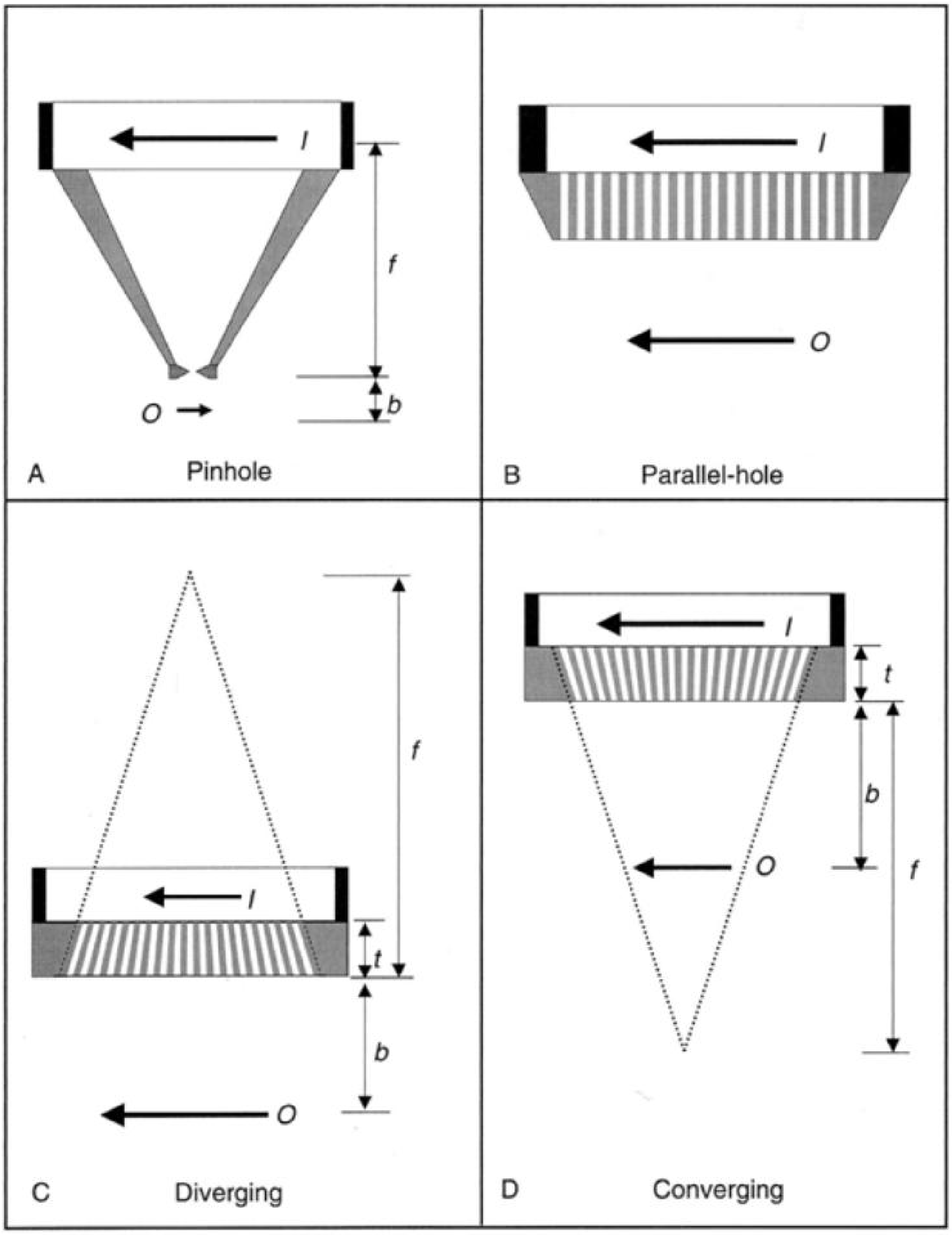

Figure 1.5: Main types of collimator (Cherry et al,2003)

Generally, these parameters, septal length, thickness between the holes, septal radius, and the distance between the source and the collimator decide the specific characteristics of the collimator. Apart from the geometric parameters of the collimator, the material used for producing the collimator will also influence it's characteristics (Le Saha, 2006).

Each type of collimators is used in certain cases. Pinhole collimator enlarge the image of the object, so it is used for imaging small size organs like thyroid and parathyroid, while the diverging collimator reduces the size of the image compared to the object, so it is used for imaging larger size structure, that is larger than the size of the detectors (Webb-A, 2003).

1.4 Statement of the problem

The purpose of the gamma camera imaging in nuclear medicine is to get more information on the physiological state of the human tissue, which cannot be obtained by another methods of medicine imaging. A gamma camera image depends on the detection of the radiation beam (photons) coming out from the human body after it has travelled through a distance inside the body facing absorption and scattering processes. The radiations that survived arrive at the head of the detector carry very valuable information about the structure and the biological statement concern to these biomolecules. Radiations absorbed by the thickness of the collimator are not detected by the camera and will not contribute in the formation of the image.

Collimator is the first part of the gamma camera that receives the radiation coming from the source. It determines the amount and the direction of the radiation that arrive at the surface of the scintillation detector. The quality and accuracy of the image by a gamma camera is determined by the type of collimator used.

Research on improving the collimator design are on going to fulfils both the medical purposes and the radiation protection requirements. The aim is to reduce the defects in the image resolution and accuracy that is caused by the effect of the collimator design.

Using different collimator for every case of imaging may be cost more and might be impossible economically, but still collimator is the easiest part in the gamma camera to modified in order to get a more informative and accurate images.

1.5 Objectives of the study

The objectives of this study are:-

- Show the effect of collimator in gamma camera image processing.
- Explain the effect of the geometrical properties of collimator on the resolution and sensitivity of gamma camera.
- using the collimator in such a way that no need to use high energy radiopharmaceuticals in the image process to preserve the radiation protection concepts.
- Measuring both of resolution and sensitivity of the most used types of collimators in Sultana Amina Hospital, to explain the best type of collimators to be used in any case.

1.6 Scope and limitation of the study

This work is within the field of nuclear medicine. It is an important application of nuclear physics. It is also related to medical engineering, since the designing and instrumentation involved fill with the field of engineering.

This work show the effects of the geometrical properties of the collimator in a gamma camera. It helps in determining the best values of these factors in designing various types of collimators to be used for various imaging cases.

REFERENCES

Baert, A. L.and Sartor, K. (2006). *Diagnostic Nuclear Medicine*. Heidelberg: Springer.

Bushberg, J. T.,Seibert, J. A.,Leidholdt, J.E.and Boone, J. M. (1994). *The Essential Physics of Medical Imaging*. Philadelphia: Williams & Wilkins.

Cherry, S., Sorensen, J. and Phelps, M. (2003). *Physics in Nuclear Medicine*. New Jersey: Willey.

Giokarisa, N., Loudosa, G., Maintasa,D., Karabarbounisa, A., Spanoudakia, V., Stiliarisa,E., Boukisa, S., Gektinc, A., Boyarintsevc, A., Pedashc, V. and Gayshan, V. (2004). Development of multi-pinhole Collimator for Large Imaging area with High Spatial Resolution. *Nuclear Instruments and methods in physics research A.*. 605(1): 77.

Grant, P. (2009). *Tomography*. London: Wiley.

Habib Zaidi (2006). *Quantitative Analysis in Nuclear Medicine Imaging*. Singapore: Springer.

Hayashida, H., Segawa, M., Yasuda, R., Likura, H., Sakai, T. and Matsubayashi, M. (2009). Crystal and collimator optimization studies of a high-resolution gamma camera based on a position sensitive photomultiplier. *Nuclear Instruments and methods in physics research A.*. 527: 134.

Khalil, M. M. (2006). *Basic Science of Nuclear Medicine*. Heidlberg: Springer.

Le Saha, G. B. (2006). *Physics and Radio-biology of Nuclear Medicine*. New York: Springer.

Lowe, D., Truman, A., Kwok, H. and Soluri, A. (2010). A new Variable Parallel Holes Collimator for Scintigraphic Device with Validation Method Based on Monte Carlo Simulation. *Nuclear Instruments and methods in physics research A.*. 621(1): 406.

Mettler, F. A. and Guiberteau,M. J. (2006). *Essentials of Nuclear medicine Imaging*. Pensselvanya: Saunders Elsevier.

Pedroso De Lima, J. J. (2003). *Nuclear Medicine Physics*. Boca Raton: CRC Press.

Schiepers, C. (2006). *Diagnostic nuclear medicine*. Heidelberg: Springe.

Sharp, P. F., Gemmel, H. G.and Murray, A. D. (2005). *Practical Nuclear Medicine*. Singapore: Springer.

Trinci, G. , Masari, R. , Scandellari, M. , Costantini, S. , De Serio, R. , Basso, A. , Sala,R. , Scopinaro, F. and Bergman, A. (2002). Optimization of the design of round-hole parallel collimators for ultra-compact nuclear medicine imaging. *Nuclear Instruments and methods in physics research A.*. 448(1): 429.

Webb, A. (2003). *Introduction to medical imaging*. Philadelphia, Pennsylvania: Saunders.

Webb, S. (1988). *The Physics of Medical Imaging*. New York: Taylor and Francis.

Wrobel, M. C., Chor-yi Ng, Clinthorne, H. C., Webster, T. A., Yong Zhang and Rogers, W. L. (1996). Design, construction and performance of one-dimensional lead foil parallel plate and fan-beam collimators for gamma ray imaging. *Nuclear Instruments and methods in physics research A.*. 376: 477.