Quantitative Assessment of the Influence of Crystal Material and Size on the Inter Crystal Scattering and Penetration Effect in Pixilated Dual Head Small Animal PET Scanner

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Abstract— **One of the most discriminator parameters for all PET scanners systems, is spatial resolution. The dimension and pitch of crystal elements, in scintillator based systems, impose some deteriorative limitation on spatial resolution. Whereas, the detraction in the scintillator size, provide increment on the fraction of gamma rays perpendicularly incident on the surface of the crystal arrangement, causing inter-crystal scattering and parallax error.**

In this study, we took advantages of Monte Carlo Simulation in order to investigate and evaluate ICS and penetration effects on pixilated dual head PET scanner as a function of crystal material and size.

The Geant4 application for Tomographic Emission (GATE) simulation package was used in this study. After validation code It was concluded that by increasing crystal dimension percentage of ICS and penetration decreased for all crystal material but around the pixel size 2 mm there will be a good trade of between true coincidences and mispositioned event. LORs have less mispostioning for BGO crystals. Following the current results, our future work consists of incorporating the simulated effects of ICS and penetration on image quality of dual head animal PET scanners.

Keywords— **Inter crystal scattering, parallax, GATE, Animal PET.**

I. Introduction

Small animal imaging is a significant tool at the disposition of biological researchers to use in non-invasive study of preclinical animal models[1]. In the last two decades, commercialization of these technologies has significantly increased due to the utility and flexibility of these original prototype systems in providing non-invasive, repeatable and nondestructive studies for academic and industrial purpose and its compatibility to detect nano-molar to pico-molar concentration of radiolabel in vivo imaging[2]. On the other hand, any improvement and proceeding on the design of this kind of prototype systems are more likely to translate into the clinical scanner, by considering the point that there are miniaturized of clinical PET systems[3]. However, several groups try to develop pixilated dual head systems, which are cost benefits and can satisfy requirement of basic PET studies. Designing such a systems posse many challenges for improving spatial resolution and reduction of ICS and penetration photons[4]. Nowadays many investigators, researchers and manufactures make an effort to improvement spatial resolution of such a systems by decreasing the mentioned deteriorative parameters[2].

Penetration effects happen whenever an incident photon without any interaction passes through the crystal which is hit to it and then detected in the other position in the wrong place of detector (in pixilated scintillator). It could cause an error which is famous as a parallax error. Parallax events most probably happened for the photons which entering to the detector with non-perpendicular angle. It significantly influenced by the crystal materials of the detectors and photon incident energies. Whereas, the basic operation in PET systems is according to detecting photons with energy of 511keV, this error will be significantly substantial for this kind system.

On the other part, Inter crystal scattering phenomena happens for both, non-perpendicular and perpendicular photons that abandoned the interacted crystal after one or more Compton scattering interaction and detected in other crystals. These two phenomena could cause mispositiong in the detection of right place of LORs, because some photons detected in the crystals not correspond to the original position of photons emission[5]. These mispositioning diminished spatial resolution, due to the probability of ICS and parallax intensify, especially for the crystals to design with small pixel size to achieve high spatial resolution which is the aim of most manufactures.

To the best of our knowledge, in all published studies for assessing limitation of ICS and penetration in detection of the right position of LORs, photons assumed as a single

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photon with 511-keV energies instead of coincidence events [5-7]. It should be noted that considering a single-photon study instead of coincidences not provide adequate system matrix for accurate image reconstruction[8]. The aim of this study is quantification of ICS and Parralax error in coincidence mode which can be used for generation of an accurate system matrix.

Whereas, statistical image reconstruction methods is based on system matrix and this matrix formed according to LORs, therefore considering a single-photon study instead of coincidences not provide adequate and correct details, So exploiting photons as coincidences for organizing LORs in system matrix has key role in image reconstruction [9].

II. MATERIALS AND METHODS

A. GATE Model of the System

In this study simulate pixilated dual head animal PET scanner using GATE Monte Carlo Package.

Monte Carlo simulation is an essential tool for assisting of emission tomography in the design of new medical imaging ans optimization performance property of them and the development or assessment of image reconstruction algorithms and correction techniques[10].

The basic design of the proposed tomography system, consist of two detector blocks. Each detector is formed by a pixelized scintillator crystal array. It is well known that the highest spatial resolution significantly depend to different parameters such as crystal material, crystal size and inter material crystal dimension. So, it is essential to specify the smallest crystal size with sufficient space as an inter material size that compatible with the scintillation light output for particular crystal material[11-12]. In order to assess the influence of crystal dimension on ICS and penetration, numerous pixel size, ranging between 0.5×0.5 to 3×3 mm by increment of 0.5 mm (0.5:0.5:3) with 0.2 millimeter Epoxy as an inter material space was considered. The crystal materials simulated in this study were Bismuth Germanate Orthosilicate (BGO), Cerium-doped Lutetium Orthosilicate (LSO), gadolinium Orthosilicate (GSO).

Mispositioning and incorrect estimation of LORs depends on many factors. Positron range and noncolinearity of photons and Compton scattering and random coincidence are number of them but among all of these restricting factors, ICS and penetration have considerable effects on mispositioning of the events.

To evaluate the fraction of photons which ICS and penetration, we exploited an ideal 511 keV point source at the center of FOV. The energy window with lower and upper threshold respectively 300 keV and 650 keV was set in simulation. A 6 ns coincidence window was used in all. Table 1 summarizes the specification of system under study.

Table 1 Characteristics and geometrical dimension of simulation systems

Characteristics	
Detector ring diameter (mm)	100
Number of module detectors	2
Crystal material	BGO/LSO/GSO
Crystal pixel size (mm)	From 0.5×0.5 to 3×3(step 0.5)
Crystal length (mm)	10
Total effective area of scintillator (mm^2)	50±0.7
Inter crystal material	Epoxy
Inter crystal space (mm)	0.2

B. Classification of ICS and Penetration

For classification of the data which are stored in the ASCII output of the GATE, We exploited an in-house software was supplemented for classification of detected events. For primary grading events, all random coincidences and scattered photons, before reaching to the detector, eliminated from the output data of simulation. Other post processing conduct on the events which were not random and scatter and called True coincidences. So the result of post processing confined to mispositioned events only caused by ICS or ICS-penetration. For each simulation true coincidence events evaluated according to the position of LORs registration proportion to the volume defined by using two detection elements (pixels). Each two pixels of the detector define a tube of response (TOR) which connects two pixels to each other instead of a line as a LOR. So by using the soft-ware the position of the point source examined if it was in the TOR the event be a purely True Coincidence; if not it would be a mispositioned coincidence. The possibility of registration Compton events is available in the GATE, So misposioned events classified and assembled into three associated groups that related to condition happen for each single photon in a coincidence event, if two singles or one of them just undergo penetration it considered as a Group-1. In fact Group-1 including mispositioned events which suffer penetration and free from ICS. If one of the two singles affected by ICS or penetration and the other one not undergo ICS and suffer penetration or not any mispositioning it considered as a Group-2. If both single undergo ICS (or also penetration) they categorized in Group-3. Figure 1. Illustrates the categorization of coincidence events. In order to categorize and distinguish LORs which correctly registered (Purely True Coincidences) and mispositioned LORs from True Coincidence ones.