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Simulations of the Effect of Collimation on Count Rates of an LSO PET System

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Abstract

We present a simulation study of the effect of different degrees of collimation on countrate performance of a hypothetical PET scanner with LSO crystals. The simulated scanner is loosely based on the geometry of the Siemens Biograph Hi-Rez scanner.

System behavior is studied with a photon tracking simulation package (SimSET).

We investigate the NEMA NU2-2001 count rate and scatter fraction behavior for systems with different amounts of collimation, which is achieved by adding septa to the fully-3D system as in clinical use. We study systems with 2, 5, 11, and 40 septa. The effect of collimation is studied for three patient thicknesses.

The resulting count rate curves for true, scattered, and random coincidences as well as noise equivalent count rates are compared for the different collimation cases. Improved countrate performance with partial collimation is seen. However, except for the largest diameter phantom, the NEC rate increase is seen at higher activities than those used clinically.

The NEC countrate versus activity curves for the LSO systems are also compared to those from a BGO system where partial collimation increases NEC countrate over a clinically relevant activity range.

I. Introduction

In the debate over advantages of 2D versus fully-3D acquisition mode for whole-body PET imaging, the noise equivalent counts (NEC) metric [1] has been used to compare the statistical quality of 2D and fully-3D mode raw sinogram data [2] – [4].

Previously, we have presented simulation studies on the effect of partial collimation in clinical BGO PET systems using the NEC metric [5], [6]. There we found partial collimation with one-half or one-third of the number of 2D septa favorable over conventional 2D or fully-3D setups in clinically important activity ranges.

With the higher timing resolution of Lutetium Orthosilicate (LSO), much better reduction of random coincidences is achieved in comparison to BGO-based systems. Therefore 2D collimation has never been considered useful for LSO systems. The situation may be different for a partially collimated system, but to our knowledge there are no studies of partial collimation for LSO.

This work extends our investigation of the effect and potential gain of partial collimation to a hypothetical scanner with LSO crystals. In this study we concentrate on partial collimation for wholebody imaging, investigating 3 different patient thicknesses.

We also compare the new results with LSO to the previous outcome for BGO as scintillator.

II. Methods

The photon tracking Monte Carlo package SimSET [7] is used to generate system characteristic count rates of true, scattered, and random coincidences as well as the flux of single photons for various collimation scenarios and 3 different phantom thicknesses of the NEMA NU2-2001 countrate phantom as shown in Fig. 1. This allows us to investigate the influence of collimation for different patient thicknesses. We then compare the resulting noise equivalent count (NEC) rates as a metric for statistical data quality of the simulated PET systems.

A generic LSO system was modeled. The tomograph geometry was loosely based on the Siemens Biograph Hi-Rez scanner [8] and the simulation's livetime model (necessary as SimSET does not model the system electronics response) was extrapolated from the Hi-Rez count rate performance. The LSO scintillator was chosen with a depth of 20 mm at a radius of 83 cm. SimSET does not model the block or crystal substructure of the detector, but rather simulates a solid detector annulus. However, two axial air gaps are introduced of 3mm width (almost the width of one HiRez crystal) to account roughly for the axial block structure of the Hi-Rez scanner. The packing fraction is determined as the scanner crystal volume over the modeled LSO volume. The resulting axial field-of-view (FOV) is 16.2 cm long, and the transaxial FOV is 58.5 cm wide. Our system is modeled to have a 4.5 ns timing resolution and 15% overall energy resolution. The energy acceptance window is set to 425 – 650 keV.

Different amounts of collimation are added to the system in the form an increasing number of symmetrically arranged septa. In addition to the conventional septa-less 3D case, we study a minimally collimated system with only 2 septa located in between axial blocks, a sparsely collimated system with 5 symmetrically placed septa, a more collimated setup with 11 septa and the fully-collimated 2D case with 40 septa inserted between every crystal (and the axial gaps). Septa placement is illustrated in Fig. 2. In all cases the septa are 1 mm thick and made of Tungsten. They have a length of 5.65 cm, filling the entire radial space between the patient port cover and the detector covers.

Coincidence and single photon livetimes are derived separately from published NEMA countrate curves of the Hi-Rez scanner [8] in the following way: we extrapolate a straight line from the lowest activity part of the countrate curves, first for the sum of true and scattered coincidences (coincidences) and then for the square root of random coincidences (single photons). The ratio of the measured rate to the straight-line fit yields the livetime as a function of activity. This livetime describes the situation for the clinical fully-3D system. To derive a collimation-independent model, the livetime is related to the flux of single photons out of the collimator and onto the detector – instead of the activity. This photon flux is made up of trigger singles, photons with just enough energy to trigger a count in the electronics. They are modeled in SimSET as single photons with energy above 100 keV. The

relationship of measured livetime versus simulated trigger singles is fitted with a single exponential.

The trigger photon rate for each system contains the collimator effects, allowing us to extrapolate the livetime model to other collimator configurations.

III. Results

We derive separate coincidence and single photon livetimes as a function of simulated trigger singles rates. The process and resulting livetime curves are shown in Fig. 3. The exponential fit is a good extrapolation to the data.

For the most representative phantom (27 cm diameter), we compare the simulated NEMA countrates of true, scattered, and random coincidences as well as the resulting NEC curves for all 5 collimation scenarios in the middle column of Fig. 4. The most promising systems are the ones with no, 2, or 5 septa. For the 20 cm and 35 cm phantoms (first and last column of Fig. 4), for clarity, we omit the more collimated choices.

We find that adding a small amount of collimation to this LSO system suppresses scattered and random coincidences significantly with only a slight reduction in trues yielding an increased NEC rate. However, the activity range where partial collimation surpasses the fully-3D case starts at rather high activities in the phantom: about 5–10 mCi. The crossing points between the curves move to lower activities for larger phantom diameters.

The corresponding simulated NEMA scatter fractions are given in Table 1. They confirm the stronger effect partial collimation has on scattered than on true coincidences, especially for larger diameters.

We have also studied partial collimation for the BGO-based GE Discovery STE (DSTE) scanner [3], so we can compare a modern BGO and LSO system with similar axial extent under influence from partial collimation. Only the shape and relative change of the curves are compared in Fig. 5, because SimSET is overestimating absolute countrates.

On the DSTE system, partial collimation yields a much more favorable outcome, because with a large timing window and somewhat worse energy resolution there are many more random and scattered coincidences that get absorbed by the collimation. Therefore the BGO curves peak at lower activities in the clinically useful regions, with partial collimation yielding a large increase in statistical data quality over 2D or fully-3D.

However, the general trends of partial collimation are seen with both scintillators: with increasing collimation, the NEC peaks shift to higher activities and rise more slowly to the peak.

IV. Conclusions

Our SimSET simulations of an LSO system with partial collimation are overestimating the absolute count rates for the Hi-Rez scanner by a factor of about 2. No attempt was made to correctly model this system. Instead we are looking for generic trends of adding partial collimation to an LSO scanner.

Full 2D collimation is clearly not desirable for this LSO system. Even minimal partial collimation does not lead to significant gains in this particular system. Only for the largest phantom diameter do we see an increase in NEC rates in the clinically important activity

region. This is different from BGO scanners, where partial collimation can significantly increase system performance.

However, it is possible that with system modifications (for example longer LSO crystals) partial collimation might yield improvements also for LSO scanners because more true coincidences would be captured. This is work in progress, based particularly around the livetime characteristics of such systems.

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Fig. 1.

A scale drawing of the NEMA NU-2 count rate phantom (20 cm diameter) with the additional optional sleeves (extending diameter to 27 cm and 35 cm). The average person in North America has an effective diameter of approximately 27 cm.

Fig. 2. Axial septa placement in the five collimation cases with increasing number of septa. From top to bottom: no septa, 2, 5, 11, and 40 septa.

Fig. 3.
Derivation of coincidence (top) and singles (bottom) livetime from the countrate curves in [4], shown as related to simulated trigger singles rates.

Fig. 4. Simulated count rate curves for true, random and scattered events and derived noise-equivalent count rates (top to bottom) for all collimation settings and for three phantom diameters: 20, 27, and 35 cm (left to right).

Fig. 5.
Comparison of effect of partial collimation on an LSO system (top) and a BGO system (bottom).

Table 1

NEMA scatter fractions with partial collimation, numbers in %

Diam./ Mode	0 septa	2 septa	5 septa	11 septa	40 septa
20 cm	34.2	32.2	29.5	—	—
27 cm	44.3	41.8	39.0	32.1	12.6
35 cm	53.5	51.4	47.4	—	—