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Investigation of the possibility of improving spatial resolution in SPECT with the combination of $LaBr_3$:Ce-based detector and 3D-OSEM reconstruction algorithms

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ABSTRACT

This study investigates the potential of improving spatial resolution in SPECT imaging using a combination of $LaBr_3$:Ce detectors and 3D-OSEM image reconstruction algorithms. Potential spatial resolution improvement was assessed intrinsically and extrinsically using GATE Monte Carlo simulation. Significantly improved MTF of $LaBr_3$:Ce detectors suggests better resolution performance at all spatial frequencies. In comparison to conventional NaI(Tl) scintillators, a combination of the $LaBr_3$:Ce crystal and 3D-OSEM incorporating resolution recovery could significantly improve the extrinsic spatial resolution of SPECT images.

1. Introduction

Radiation detectors play a major role in non-invasive clinical investigations such as nuclear medicine, particularly as gamma cameras and Positron Emission Tomography (PET) Scanners. Over the last 40 years, NaI(Tl) has been used exclusively for gamma-camera SPECT systems [1]. Recently, interest in the use of the cerium-doped lanthanum crystals has grown significantly, in particular $LaBr_3$:Ce, due to their high scintillation yield that is well matched to present photocathodes, which makes them ideal for gamma-camera systems.

In parallel with the detector module development, there are continual advances in image reconstruction algorithms. This led to increasing recognition that iterative reconstruction plays a key role in improving the quality of reconstructed images and may improve the accuracy of SPECT image quantification, particularly where attenuation is non-homogeneous or where a more exact model of the emission and detection processes is required [2,3]. Iterative reconstruction algorithms, such as 3D-OSEM have become a clinically practical alternative to Filtered Back-Projection (FBP) due to advances in hardware and software developments [4].

The main aim of this study is to investigate the possibility of developing a SPECT system that combines the potential use of the $LaBr_3$:Ce detectors with the excellent performance of 3D iterative reconstruction algorithms.

2. Mont Carlo simulations

GEANT4 application for tomographic emission (GATE; version 3.1.2) as used in this study is a relatively new Monte Carlo simulation package based on GEANT4 dedicated to nuclear imaging applications. The GATE Monte Carlo simulation code has been extensively described and validated elsewhere [5–7].

For this study, a dual-head camera was modelled as a combination of (Fig. 1):

- Low-Energy-High-Resolution (LEHR) collimator made of lead (hole diameter: 1.4 mm, collimator thickness: 32 mm and septal thickness: 0.156 mm);
- $(560 \times 560 \times 9.5)$ mm scintillator crystal (LaBr3:Ce or NaI(Tl));
- shielding made of lead, 35 mm thick around the camera head and 30 mm thick on the rear.

GATE allows the modelling of a so-called back-compartment to account for the photomultiplier tubes and electronics located behind the crystal. Assié et al. [6] have demonstrated the vital role of back-compartment modelling in GATE, without which, large differences between simulated and experimental data were observed. Hence, a back-compartment was modelled as a 50 mm Perspex layer (density 2.5 g/cm^3). For a more realistic

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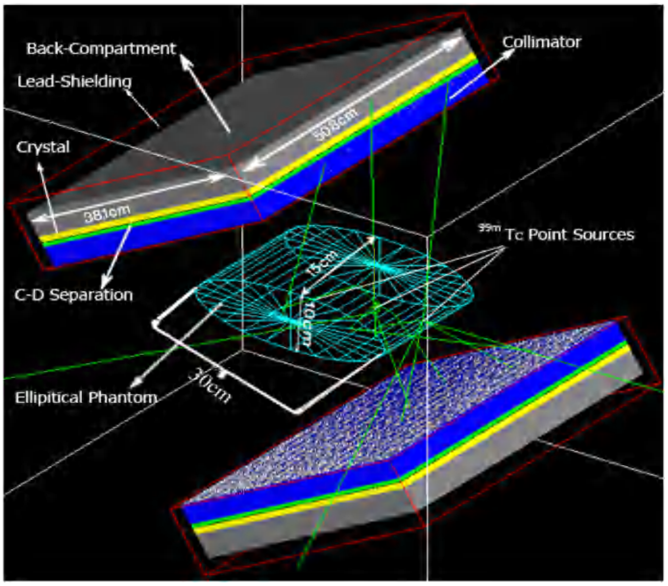

Fig. 1. A dual-head gamma camera and an elliptical Phantom as modelled by GATE.

representation, an aluminum cover of 0.1 mm thickness and a 6 mm thick air compartment to represent the distance between the collimator and the detector face were simulated for each detector.

The system's point spread function (PSF) was calculated by simulating a highly collimated beam of 140 keV photons emanating from a $^{99}Tc^{m}$ point source located on face of the collimator. The Modulation Transfer Functions (MTF) of the system were then calculated by taking the fast Fourier transform (FFT) of the normalised PSFs. To assess spatial resolution performance, an elliptical phantom filled with water and $^{99}Tc^{m}$ solution was modelled to test a more realistic SPECT imaging setup with three $^{99}Tc^{m}$ point sources located at three different radial positions (as SPECT resolution is depth-dependent). Acquisition parameters such as angular step and radius of rotation were simulated in accordance with the National Electrical Manufacturers Association (NEMA) [8] test standards. Simulated images with the $LaBr_3$:Ce and NaI crystal-based cameras were reconstructed with 3D-OSEM using HERMES software (Nuclear Diagnostics Ltd.) with a variety of reconstruction parameters and resolution recovery (RR) option.

3. Results and discussions

Fig. 2 shows the PSF of a $^{99}Tc^{m}$ point source, located on the surface of the LEHR collimator, for the two different scintillators. The FWHM of the PSF obtained for $LaBr_3$:Ce and NaI(Tl) are 3.2 and 4.1 mm, respectively.

However, the FWHM of the PSF is a relatively crude expression of resolution and is also an insensitive measure of the effect of scattered radiation on resolution. Therefore, a more comprehensive expression of the ability of the gamma camera to reproduce spatial information is given by the MTF, which shows directly the extent to which the information carried by each spatial frequency has been attenuated by the imaging system. Fig. 3 shows the calculated MTFs for both detector scintillators. This demonstrates a much improved MTF performance for the $LaBr_3$:Ce detector at all frequencies, suggesting that $LaBr_3$:Ce crystals are better in visualising large and small low-contrast structures. This is primarily due to the fact that $LaBr_3$:Ce has 60% higher light output than NaI(Tl).

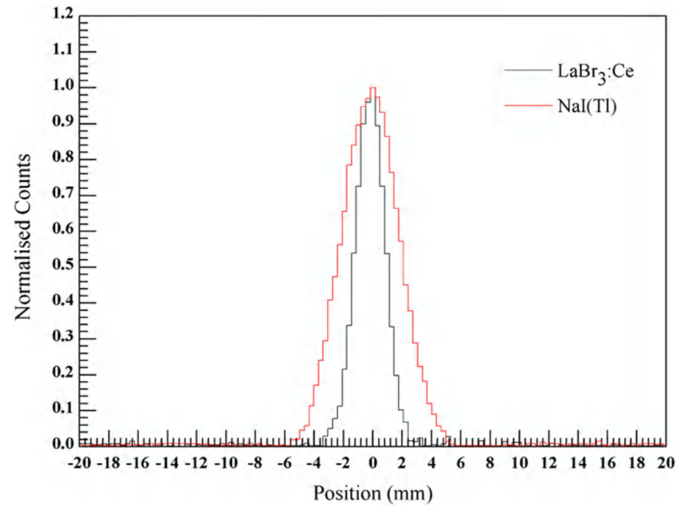

Fig. 2. Simulated PSF of a $^{99}Tc^{m}$ point source for the $LaBr_3$:Ce, and NaI(Tl) scintillators.

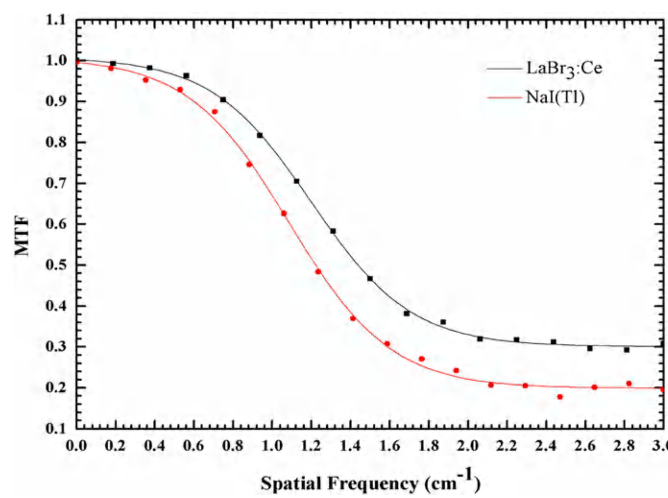

Fig. 3. Simulated MTF for the $LaBr_3$:Ce, and NaI(Tl) crystal-based systems.

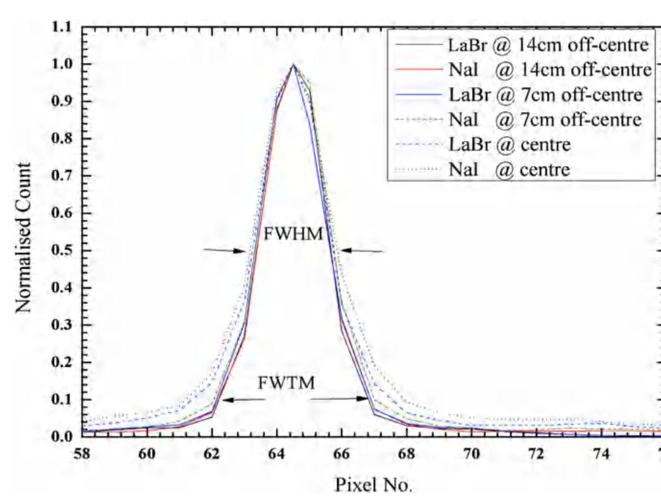

Fig. 4. Simulated horizontal profiles of $^{99}Tc^{m}$ point sources for the $LaBr_3$:Ce and NaI(Tl) scintillators.

Table 1
Spatial resolution results.

The position of point source	FWHM (mm)		FWTM (mm)	
	LaBr3:Ce	NaI(Tl)	LaBr3:Ce	NaI(Tl)
Centre	10.8	11.4	22.3	24.5
7 cm Off-centre	10.3	11.1	21.5	22.8
14 cm Off-centre	9.75	10.2	19.4	20.3

Horizontal profiles of a point source SPECT images obtained from the $LaBr_3$:Ce and NaI(Tl) crystal-based systems and reconstructed with 3D-OSEM (iteration no. = 12/subset no. = 16) are illustrated in Fig. 4 and the average system spatial resolution results are summarised in Table 1. The better spatial resolution of the $LaBr_3$:Ce, particularly FWTM, is mainly due to enhanced light yield and improved energy resolution of the $LaBr_3$:Ce crystal-based systems. Note that further improvement in resolution, particularly at the centre, could be achieved with the increasing number of iterations [9]. However, caution should be exercised with the increasing number of iteration as it increases noise in SPECT images [9].

In summary, these preliminary results are very encouraging and demonstrate the potential for improving spatial resolution in SPECT imaging using a combination of $LaBr_3$:Ce detectors and 3D-OSEM image reconstruction algorithms. However, further experimental and simulation investigations are required, including System Quantum Detective Efficiency, Signal to Noise and Image Contrast performance.

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