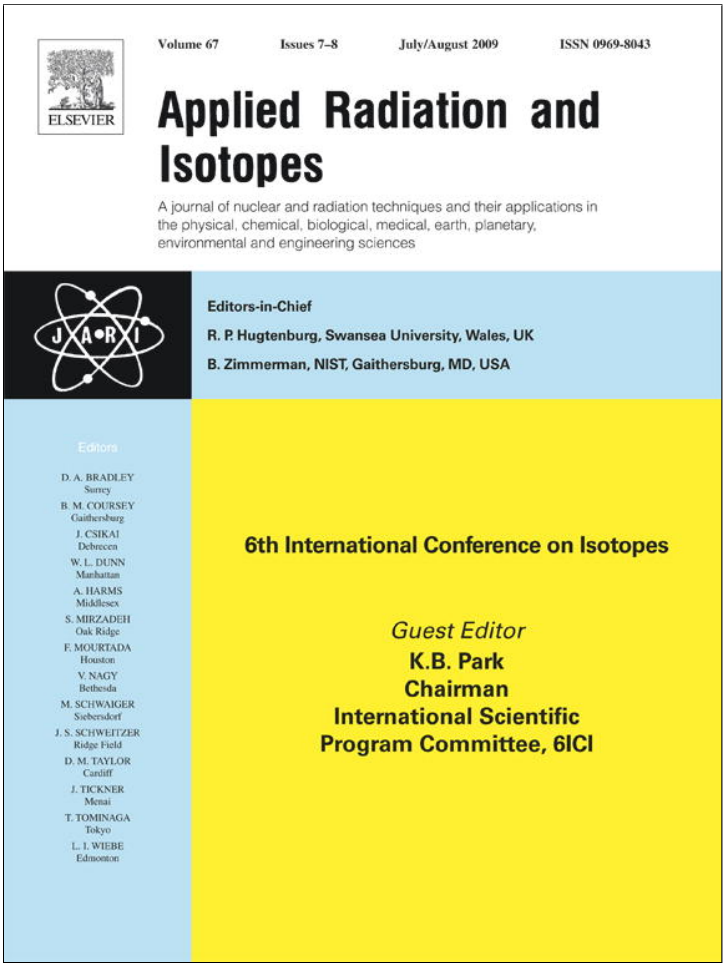

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Feasibility study on hybrid medical imaging device based on Compton imaging and magnetic resonance imaging

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ABSTRACT

In this paper, we propose a combined Compton camera/magnetic resonance imaging (MRI) scanner. For this, the table-top Compton camera currently under development in our laboratory is suitable, considering that it is not very large (i.e., a table-top size) and that it uses semiconductor detectors (for both the scatterer and absorber detectors), which in principle are not very sensitive to a magnetic field. The Compton camera takes three-dimensional images from a fixed position and, therefore, does not require a large ring-type structure, making it possible to fit it into an existing MRI system, without requiring major modifications to the system. In the present study, the potential of combining the table-top Compton camera and an MRI scanner for real simultaneous imaging was demonstrated by fusing a Compton camera image of an instance of multi-tracing, generated by using Geant4 Monte Carlo simulations, with an MR image.

1. Introduction

The positron emission tomography (PET) scanner is an attractive molecular imaging device that provides functional and metabolic information on the human body; however, it does not provide any anatomical information. This limitation has been overcome by combining the PET scanner with a computed tomography (CT) scanner, which combination has proved very successful in tumor diagnosis and staging (Beyer et al., 2000; Townsend et al., 2004). Nonetheless, the combination of a PET scanner with a magnetic resonance imaging (MRI) scanner would provide even better performance, considering that the MRI scanner produces a much higher soft-tissue contrast than a CT scanner, and that MRI scanning, unlike CT scanning, does not expose the patient to any radiation. The combined PET/MRI system, however, has a technical limitation in that the detectors in the PET scanner respond to the magnetic field of the MRI scanner (Mackewn et al., 2005; Pichler et al., 2006; Shao et al., 1997). Many researchers are currently working on this issue.

In the present study, we substituted the Compton camera (Todd et al., 1974) for the PET scanner, combining an example of the former, instead of the latter, to an MRI scanner. For this application, the table-top Compton camera currently under development in our laboratory (Lee et al., 2005) is suitable, considering that it is not very large (i.e., a table-top size) and that it uses semiconductor detectors (for both the scatterer and absorber detectors), which in principle are not very sensitive to a magnetic field. The table-top Compton camera takes three-dimensional images from a fixed position and, therefore, does not require a large ring-type structure, making it possible to fit it into an existing MRI system, without requiring major modifications to the system. In addition, the multi-tracing capability of the Compton camera allows for the use of several different radio-isotopes/pharmaceuticals at the same time. In the present study, the potential of combining the table-top Compton camera and an MRI scanner was demonstrated by fusing a Compton camera image of an instance of multi-tracing, generated by using Geant4 Monte Carlo simulations, with an MR image.

2. Methods

Given the several advantages accruing from the novel collimation method, the so-called electronic collimation, the Compton imaging is considered to be a very promising imaging technique in nuclear medicine and molecular imaging applications (LeBlanc et al., 1999; Singh, 1983; Yang et al., 2001; Zhang et al., 2004). A Compton camera is generally composed of two position-sensitive detectors, that is, a scatterer detector and an absorber detector. The emission of a photon from a radioisotope source, its

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subjection to Compton scattering in the scatterer detector and subsequently its full absorption in the absorber detector, are defined as an effective event. The track of the scattered photon, from the scatterer detector to the absorber detector, is directly determined from the interaction positions in the scatterer and absorber detectors. The scattering angle (at the scatterer detector) is calculated from the deposited energies in the detectors. Then, we can determine the conical surface on which the photon source is located (Fig. 1). Using three or more effective events (or conical surfaces), we can three-dimensionally determine the location (or distribution) of the photon source.

In the present study, the Compton camera was assumed to be composed of four independent Compton camera modules, each module consisting of four double-sided silicon strip detectors (DSSDs) as the scatterer detectors and four pixellated CdZnTe (CZT) detectors as the absorber detectors. The DSSDs are $5 \times 5 \times 0.15\,\text{cm}^3$ in size and have 16 orthogonal strips on each side. Four DSSDs were stacked to increase the sensitivity of the Compton camera. The CZT detectors, each of which is composed of 256 pixels, are of the dimensions $2.5 \times 2.5 \times 0.5\,\text{cm}^3$. To cover a wide solid angle, the CZT detectors were arranged in the planar direction. The Compton camera modules were placed at 30° intervals in order to form a curvature. The imaging process of the Compton camera was simulated with the Geant4 detector simulation toolkit (Agostinelli et al., 2003). All of the major detector parameters affecting the imaging resolution and sensitivity of the Compton camera (An et al., 2007) were considered in the simulation.

This study employed a head phantom (see Fig. 2) taken from a Korean voxel model (Kim et al., 2008). The head phantom was composed of ~1,800,000 voxels and the size of each voxel was $2 \times 2 \times 2\,\text{mm}^3$. Two point sources of different gamma energies, 364 and 511 keV, were placed 6 cm apart inside the brain of the phantom. The Compton image was reconstructed using the list-mode expectation maximization (LM-EM) algorithm (Wilderman et al., 1998), and then fused with the corresponding MRI image. Fig. 3 shows the simulated geometry, including the head phantom and the Compton camera modules.

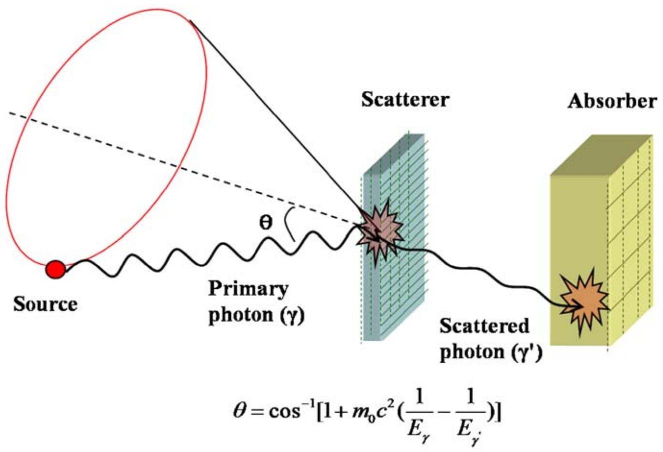

Fig. 1. Principle of Compton camera. The source is located on the conical surface.

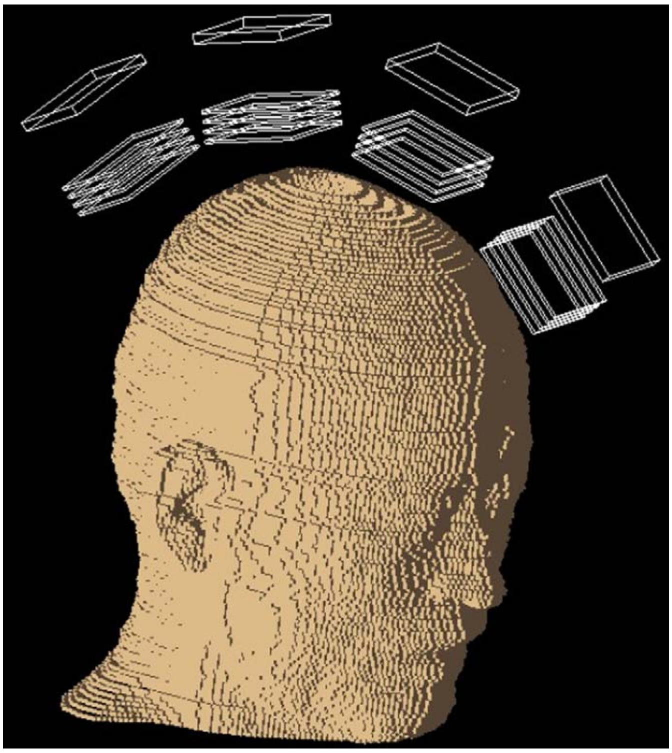

Fig. 3. Imaging geometry, including head phantom and Compton camera modules.

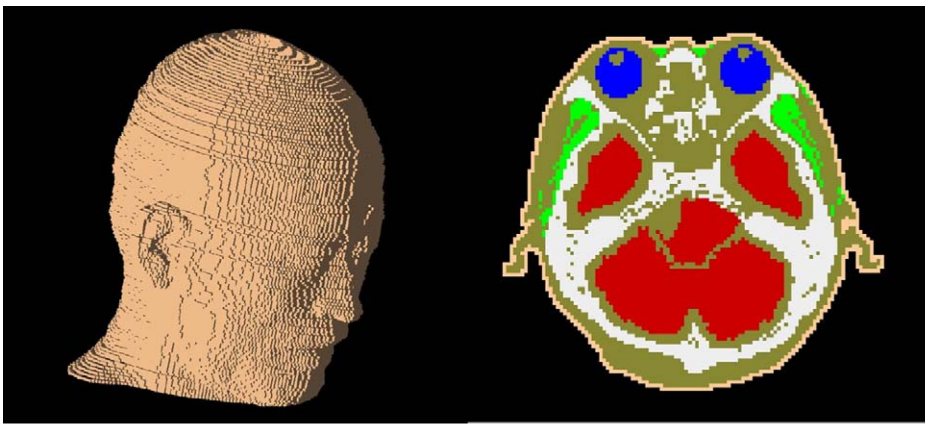

Fig. 2. Head phantom used in the present study.

3. Results and discussion

A total of 11,161 effective events, 7670 events for the 364 keV source and 3491 events for the 511 keV source, were recorded from 1×10^8 primary photons (for each source). The imaging sensitivity of the proposed system, for the 364 and 511 keV sources, respectively, was 7.7×10^{-5} and 3.5×10^{-5}. The table-top Compton camera showed higher imaging sensitivity for the lower-energy (364 keV) photon source for two reasons: (1) the probability of Compton scattering is slightly higher for lower-energy photons, and (2) lower-energy photons tend to be more easily absorbed in the absorber detector. Fig. 4 shows the energy spectra of the photons as measured in the component detectors and considering only the effective events. The scattering angles were mostly within the 20–60° range.

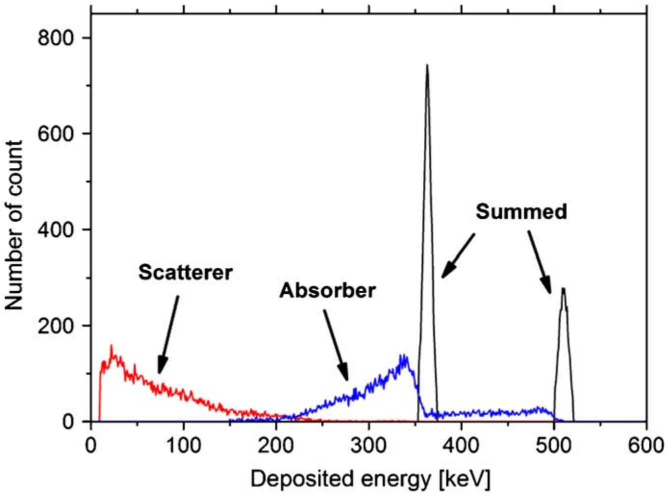

Fig. 4. Energy spectra in component detectors, considering only effective events.

Fig. 5 shows the reconstructed Compton images and corresponding energy spectra. The imaging resolution for the higher-energy gamma source (511 keV) was higher than that for the lower-energy gamma source (364 keV), mainly due to the fact that the degree of Doppler energy broadening in Compton scattering is lower for higher-energy gammas (Zoglauer and Kanbach, 2003). Fig. 5 highlights the multi-tracing capability of the table-top Compton camera, that is, the simultaneous imaging of multiple gamma sources. Various gamma-emitting radionuclides, therefore, can be used at the same time, resulting in a wider range of options for radiopharmaceuticals in diagnosing diseases. Fig. 6 shows the MR image, the Compton image and the Compton-MR fusion image, taken for the case considered in this study.

4. Conclusions

The concept of dual imaging modality for real simultaneous imaging achieved by combining a Compton camera and an MRI scanner is proposed in this paper. The feasibility of the proposed system was demonstrated based on Monte Carlo simulation studies using Geant4. The combination of functional/metabolic imaging and anatomical imaging modalities, most pertinently, will provide better clinical care for patients.

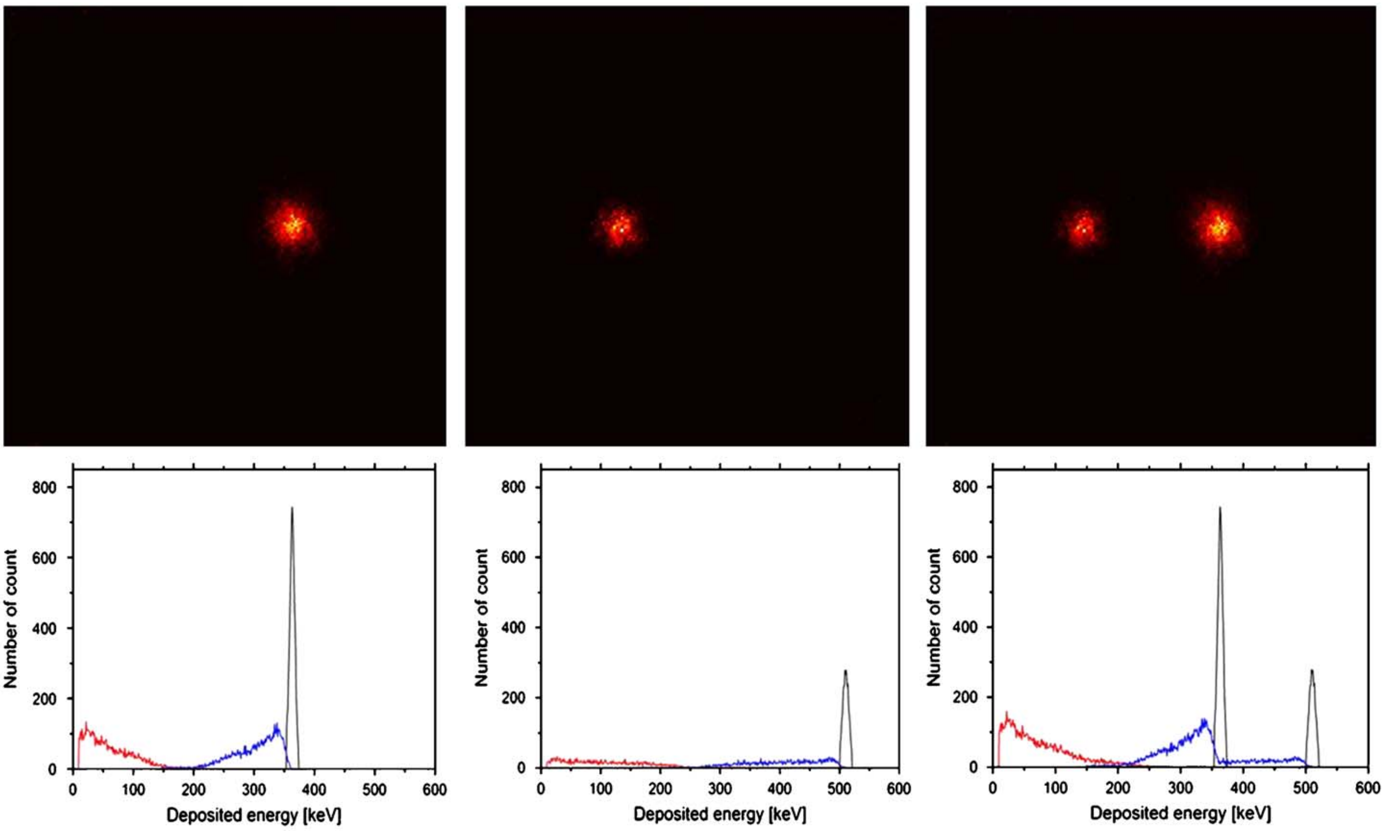

Fig. 5. Reconstructed Compton images and energy spectra for 364 keV source (left), 511 keV source (middle) and both (right).

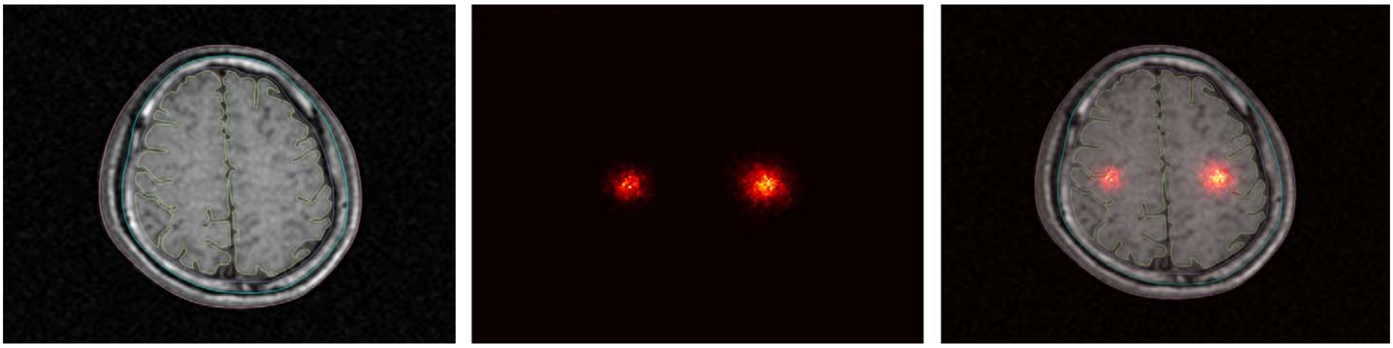

Fig. 6. MR image (left), Compton image (middle) and Compton-MR fusion image (right).

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