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Gamma camera with a two-layer diverging-slat collimator for radioisotope monitoring

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ABSTRACT

The purpose of this study was to develop and evaluate a gamma camera with a newly designed diverging collimator for monitoring radiation fields in nuclear medicine. Simulations using the Geant4 Application for Tomographic Emission (GATE) were performed to model the gamma camera system designed to monitor Tc-99m radioactive isotopes usually used in nuclear medicine. A gamma camera consists of a diverging collimator, a CsI(Na) scintillation crystal with dimensions of 50.0 mm $\times$ 50.0 mm $\times$ 6.0 mm and Hamamatsu H8500 PSPMT. The diverging collimator is composed of two layers of diverging slats stacked directly above each other, and the front layer is rotated by 90° with respect to the back layer. The point source at different positions was simulated, and the optimal slat thickness and slat height were determined by evaluating the spatial resolution and sensitivity. The slat thickness is 1.0 mm, the slat height is 40.0 mm and the angle of slats ranges from 0 to 22.5°. The front and back layers are composed of 40 and 18 slats, respectively, to achieve equal spatial resolution in the *x* and *y* directions. The diverging collimator improves the uniformity of the spatial resolution and sensitivity across the field of view and the count rate better than the pinhole collimator. Experimental measurements were performed, and the results agreed well with simulations in terms of spatial resolution and sensitivity. The results demonstrated that the two-layer diverging-slat collimator is suitable for large area monitoring of the radiation fields.

1. Introduction

A compact hand-held gamma camera was studied for use in nuclear survey imaging systems. Gamma images may potentially be used to help localize the radiation source position and minimize the radiation exposure in nuclear facilities, and it is possible to visually identify contaminations. The quality of the gamma images depends on the performance of both the detector and the collimator. In particular, the collimator is the limiting component in the sensitivity and resolution of the gamma camera because it is the first process layer of the camera to encounter photons from the source [1,2]. The use of a gamma camera with a pinhole collimator is the most expedient means for radiation monitoring due to its large-area imaging capability [1]. However, a shortcoming of the pinhole collimator is that it loses efficiency rapidly with distance, and has non-uniform spatial resolution and sensitivity across the field of view (FOV).

To cope with these drawbacks, we proposed a new diverging collimator for monitoring the contamination of Tc-99m (140 keV) radioactive isotopes most commonly used in nuclear medicine. This new diverging collimator is easier to make than existing diverging collimators, and takes advantage of uniform sensitivity and resolution over the entire FOV, which make it useful for large-area monitoring [3,4].

The purpose of this study was to develop and evaluate a newly designed diverging collimator. For this purpose, we optimized a diverging collimator using a Monte Carlo simulation and evaluated its performance experimentally.

2. Materials and methods

2.1. Design parameters

Simulations using GATE were performed to model the gamma camera system as shown in Fig. 1. A gamma camera consists of a diverging collimator and a CsI(Na) scintillation crystal with

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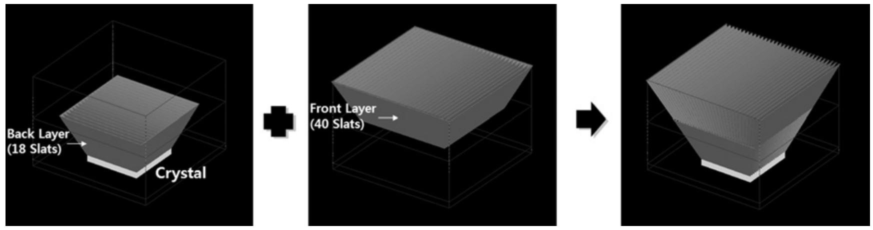

Fig. 1. Simulated geometry of a gamma camera with a diverging collimator consisting of dual-layer diverging slats.

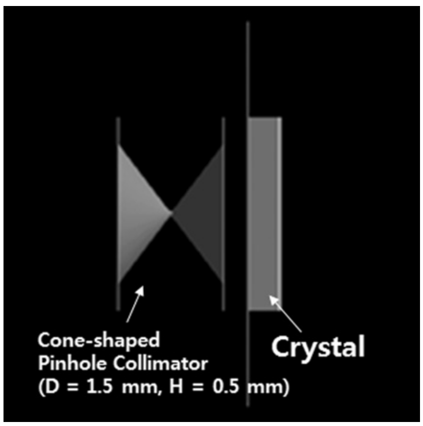

Fig. 2. Simulated geometry of a gamma camera with a pinhole collimator.

dimensions of 50.0 mm $\times$ 50.0 mm $\times$ 6.0 mm. The diverging collimator is composed of two layers of diverging slats stacked directly above each other, and the front layer is rotated by 90° with respect to the back layer. The front and back layers are composed of different numbers of slats to achieve equal spatial resolution in the x and y directions. The angles of the slats range from 0.0 to 22.5°, and the useful field of view is designed to monitor $4.2 \times 4.2\ \mathrm{m}^2$ at 5.0 m distance. The desired resolution is less than 40 cm full width at half maximum (FWHM) at 5 m distance. To evaluate the system performance, the slat thickness was varied from 0.5 mm to 2.0 mm and slat height was set to 40.0 mm by considering gamma-ray penetration [5]. Optimal slat thickness was determined by evaluating the spatial resolution and sensitivity.

To compare the performance of the proposed system, a gamma camera with a pinhole collimator was also simulated. Fig. 2 shows the simulated geometry of a gamma camera consisting of a cone-shaped pinhole collimator and a CsI(Na) crystal with dimensions of 50.0 mm $\times$ 50.0 mm $\times$ 6.0 mm. The pinhole diameter and channel height were 1.5 mm and 0.5 mm, respectively, and the focal length was 14.5 mm.

2.2. Comparison of pinhole and diverging collimator

The system sensitivity (defined as the number of detected events divided by the number of emitted events) and spatial resolution (defined as the FWHM of the point source profile) were calculated by GATE simulation for the diverging and pinhole gamma cameras. A Tc-99m (140 keV) point source was moved in 20 mm steps from the center to the edge of the FOV to also evaluate the spatial resolution uniformity and angle-dependent sensitivity throughout the FOV.

The distance between the collimator surface and the detector was set to 25.0 cm and 7.25 cm for diverging and pinhole cameras, respectively, considering a minification factor of 5. Additionally, the disk source was imaged and the measured total counts were decomposed into net, penetrated, and scattered counts for net sensitivity estimation. Events were detected in the photopeak window (126–154 keV) to reduce the noise effects [6].

2.3. Experimental measurements

The gamma camera system consists of a diverging collimator, a CsI(Na) crystal and Hamamatsu H8500 PSPMT. To improve the spatial resolution, a 24×24 array CsI(Na) pixelated scintillation crystal with a pixel size of 2 mm $\times$ 2 mm $\times$ 6 mm was used. Fig. 3 demonstrates the developed diverging collimator composed of two layers of diverging slats. The front and back layers are composed of 40 and 18 slats, where the slat thickness and slat height are 1.0 mm and 40.0 mm, respectively.

The H8500 PSPMT is mounted to the SIB064-1018 sensor interface board (Vertilon Corporation) and optically coupled to the crystal. The 64 anode signals of PSPMT are routed to an on-board resistive Anger logic circuit that generates four anger signal outputs [7]. These outputs are connected to the PhotoniQ IQSP418 multichannel data acquisition system (Vertilon Corporation) using four coaxial cables. The data acquisition system is triggered by a constant fraction discriminator signal from the SIB064-1018 board, and then four positioning signals are digitized and recorded. Digitized output data from the PhotoniQ IQSP418 are sent to a PC for display, logging, or real time processing via a USB output port.

Fig. 4 shows the prototype gamma camera and the multi-channel data acquisition system. Image acquisitions were carried out using point source of 15 μCi Co-57 positioned 30 cm from the collimator surface. The simulation with the same geometry was also performed to validate the system.

After validating the system performances, a Co-57 point source positioned 5 m from the camera was simulated to evaluate the spatial resolution and sensitivity for the targeted geometry.

3. Results

3.1. Optimization of the diverging collimator

Fig. 5 shows the sensitivity and spatial resolution of the diverging camera as a function of slat thickness. Sensitivity and spatial resolution are shown as solid and dotted lines, respectively. The sensitivity decreases and spatial resolution improves gradually as slat thickness increases.

To achieve a 40.0 cm FWHM at 5.0 m distance, the desirable detector resolution should be less than 4.8 mm FWHM as indicated in Fig. 5. Based on the simulation results, the optimal thickness was determined to be 1.0 mm.

3.2. Comparison of pinhole and diverging collimator

Fig. 6 shows the simulated point source profiles at different locations for pinhole and diverging collimators, illustrating the angle-dependent sensitivity and resolution uniformity. Spatial resolution