Monte-Carlo simulation of pinhole collimator of a small field of view gamma camera for small animal imaging

ZHU Jie[1,*] MA Wenyan[1] ZHU Yufeng[4] MA Hongguang[1] WU Yuelei[2] HU Huasi[2] ZHANG Boping[2] HUO Yonggang[1] LIU Silu[1] JIAN Bin[1] WANG Zhaomin[3]

[1] *The Second Artillery Engineering College, Xi'an 710025, China*

[2] *Nuclear Engineering Department, School of Energy & Engineering, Xi'an Jiaotong University, Xi'an 710049, China*

[3] *Department of Modern Physics, University of Science and Technology of China, Hefei 230026, China*

[4] *Department of Electric Information Engineering, Wuhan Polytechnic University, Wuhan 430023, China*

Abstract Needs in scintimammography applications, especially for small animal cardiac imaging, lead to develop a small field of view, high spatial resolution gamma camera with a pinhole collimator. However the ideal pinhole collimator must keep a compromise between spatial resolution and sensitivity. In order to design a pinhole collimator with an optimized sensitivity and spatial resolution, the spatial resolution and the geometric sensitivity response as a function of the source to collimator distance has been obtained by means of Monte-Carlo simulation for a small field of view gamma camera with a pinhole collimator of various-hole diameters. The results show that the camera with pinhole of 1 mm, 1.5 mm and 2 mm diameter has respectively spatial resolution of 1.5 mm, 2.25 mm and 3 mm and geometric sensitivity of 0.016%, 0.022% and 0.036%, while the source to collimator distance is 3 cm. We chose the pinhole collimator with hole diameter size of 1.2 mm for our the gamma camera designed based on the trade-off between sensitivity and resolution.

Key words Monte-Carlo simulation, Pinhole collimator, Gamma camera, Small field of view, High spatial resolution

1 Introduction

In recent years great efforts have been made in developing small field of view (FOV), high spatial resolution gamma camera[1-5] for small animal imaging, one of the most useful approaches for drug research, pharmaceutical design, and tracer development, to provide molecular level information of physiological phenomena and pathological processes. This dedicated γ-ray camera consists of a collimator, a position sensitive γ-ray detector based position sensitive photo multiplier tube (PSPMT), image reconstruction software and a display unit. For the camera lens, the collimator plays an important role in the image formation process. It defines the FOV and affects strongly the spatial resolution, the sensitivity and the image distortion.

At close distances, a camera with a pinhole collimator, instead of a parallel-hole collimator, improves the spatial resolution and sensitivity but reduces the FOV. The spatial resolution may be further improved with reduced pinhole diameter, at the expense of sensitivity, though. Imaging a small object like an organ of a small animal, however, require no large FOV, but the animal can be placed closer to the pinhole to increase the magnification and sensitivity. In addition, its organs fit within the available FOV of the pinhole collimator, even at a large magnification. Therefore, a pinhole-collimator camera is good for high resolution and sensitivity.

Aimed at developing an optimized pinhole collimator for small FOV gamma camera, we conducted a study to determine the good trade-off between sensitivity and resolution. A Monte-Carlo (MC) simulation model for the dedicated gamma camera of a pinhole collimator was performed using the GEANT4 codes[6]. Based on the simulation results of the optimized pinhole, a small FOV high resolution

Supported by National Foundation of Nature Science of China (No.10275063)
* Corresponding author. *E-mail address:* zhujie_801@sina.com.cn
Received date: 2008-09-11

gamma camera was developed. It consists of an array of pixelized Nal(Tl) scintillators coupled to a position sensitive photo multiplier tube (PSPMT)[7,8], achieving a good compromise between the spatial resolution and geometric sensitivity.

2 Image system design and the simulation

2.1 Image system design

Fig.1 is a schematic diagram of the gamma camera with a NaI(Tl) pixel array scintillators, and a Hamamatsu R2486 PSPMT (Φ50 mm active area), with which distribution of the scintillating photons is calculated by the center-of-gravity method to determine the exact position of incident photons in the *X*-*Y* plane. A pinhole collimator, made of a cylindrical lead block with two coaxial cone cavities, is placed in front of the NaI(Tl) array. The d is the source-to-collimator distance (SCD), f is the focal length, Φ_0 is the pinhole diameter, and α is the half acceptance angle of the pinhole collimator. The pinhole acts like a lens, and the magnification factor is equal to the ratio of the detector-to-pinhole distance (the focal length f) to the object-to-pinhole distance (the SCD d). For different f and d, the camera will have different amplification power. This zoom function makes the camera have either increased FOV/deceased spatial resolution or deceased FOV/increased spatial resolution in the object plane. To make the image field of view equal to the active area of the PSPMT, to achieve better spatial resolution, we chose α=22.5° and f=60 mm.

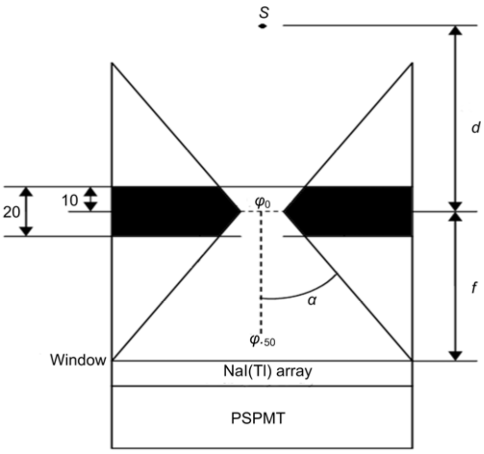

Fig.1 Schematic diagram of the small FOV γ-camera with a pinhole collimator (mm). S, the point γ-ray source; α, the half acceptance angle; Φ_0, diameter of the pinhole; Φ_{50}, diameter of the Na(Tl) and PSPMT.

2.2 Description of the simulation

The simulation is based on the GEANT4 code developed at CERN. The geometric description of the pinhole collimator is shown in Fig.1. The γ-ray point source (*S*) is located at $(X,Y)^0$ with a distance of d to the object plane. The simulation begins with the generation of a γ-ray that propagates isotropically at random. Tracks of the γ-ray are traced. If it does not pass the hole, the counter SUM is added by 1, and another γ-ray is generated for a new round of tracing. A γ-ray passes the hole is traced until it goes through the crystal, and the counter SUM is added by 1. If a photoelectric absorption event occurs in the crystal, the interaction position (X,Y) is recorded, and the point spread function (PSF) is called at (X,Y). Sampling according to probability distribution PSF(X,Y) makes the final image point $(X,Y)^1$ recorded, and both the SENS and SUM counters are added by 1. When the SUM counter gets to 10^6, the sampling is ended, and the point source is moved to the next position along the central axis of the pinhole collimator. The geometric sensitivity, i.e. the number in the SENS divided by the number in the SUM, is defined as the fraction of the detected γ-rays. The simulation program permits modification of two parameters, such as source-to-collimator distance d and the pinhole diameter Φ_0. Fig.2 shows the flow chart of the Monte-Carlo simulation.

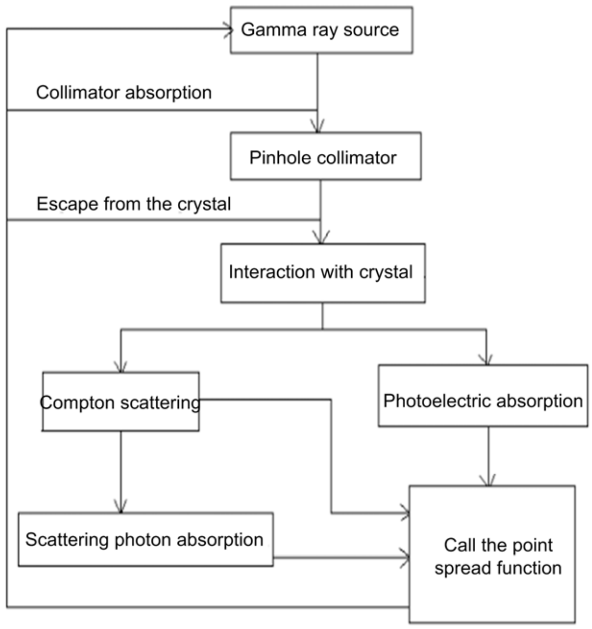

Fig.2 Flow chart of the Monte-Carlo simulation.

3 Results and discussion

3.1 Point spread function

In the simulation, with Φ_0 being 1, 1.5 and 2 mm, different source-to-collimator distances, were used for investigating the spatial resolution and the geometric sensitivity for the gamma camera. **In** data acquisition, the point γ-ray source was moved in 2 mm steps along the central axis of the pinhole collimator. The PSF is defined as the spread in centroid of the distribution of the scintillation photons induced by the γ-ray in the crystal. Fig.3 shows a typical PSF with Φ_0 =1 mm and d=3 cm. By fitting a Gaussian2D curve to the PSF. A spatial resolution of 1.8 mm (FWHM) is obtained for both the x and y directions.

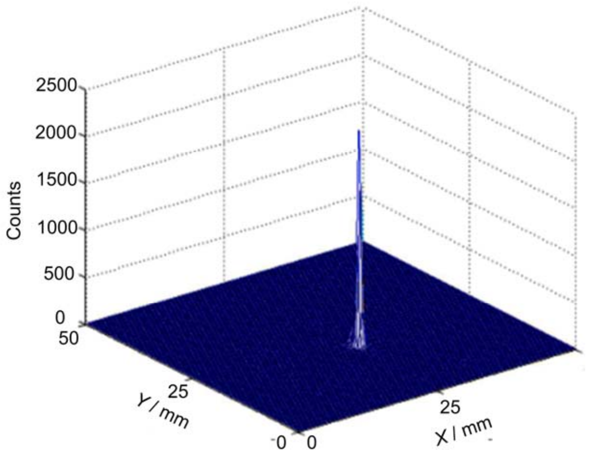

Fig.3 Typical point spread function (PSF) with a Φ1 mm pinhole and source-to-collimator distance of 3 cm.

3.2 Spatial resolution and geometric sensitivity

Fig.4 shows the spatial resolution and geometric sensitivity at different source-to-collimator distances with a Φ1 mm pinhole collimator. The average spatial resolution and geometric sensitivity are 2.56 mm and 0.00278%, respectively. With a Φ1.5 mm (Fig.5) and Φ2 mm pinhole collimator (Fig.6), the spatial resolution and geometric sensitivity are respectively 3.44 mm and 0.0064%, and 4.6 mm and 0.0137%.

It can be seen that the spatial resolution increases and geometric sensitivity decreases with increasing source- to-collimator distance. However, the geometric sensitivity decreases rapidly. The spatial resolution can be optimized by using pinhole of small diameters and bringing the source as close a possible to the collimator. But as the diameter decreases, less numbers of the γ-rays pass the collimator, hence the deterioration of geometric sensitivity and prolonged data acquisition time. So the choice of hole diameter should be balanced between sensitivity and spatial resolution.

The relatively small size of the objects under study in small animal imaging (small organs or cardiac regions of rabbits) requests a dedicated gamma camera of high spatial resolution. Thus, the choice of hole diameter of the collimator should be a major consideration, with compromised sensitivity to a certain extent. For imaging small animals, it is usually acceptable to work with a spatial resolution better than 2-mm (FWHM)[9]. Because of this, it was determined that a pinhole collimator of Φ0 1.2 mm would be acceptable. The 2 mm spatial resolution and 0.0136% geometric sensitivity, at d=3 cm, is a good trade-off that would optimize the sensitivity and spatial resolution, obtaining images of improved quality in reasonable measurement time and possibly allowing a reduction of radioactive dosage administered to the object.

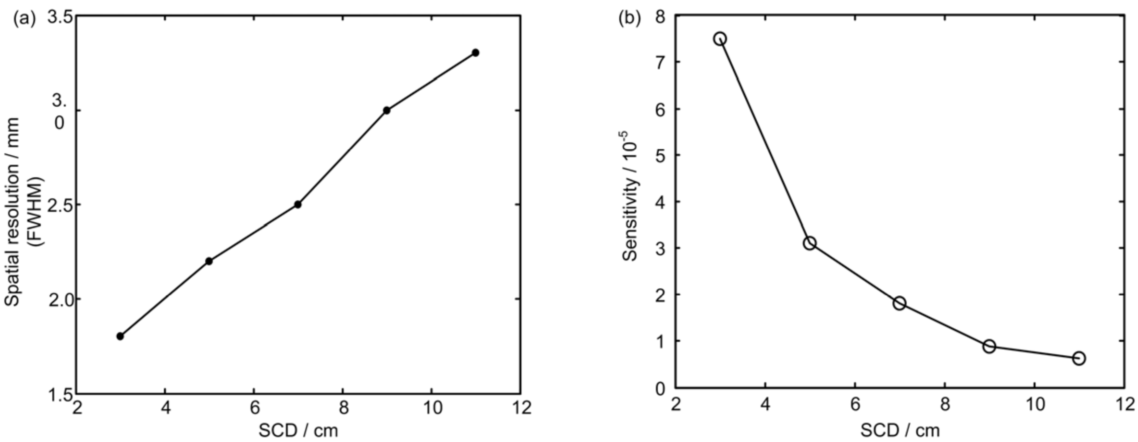

Fig.4 Spatial resolution (a) and geometric sensitivity (b) at diffferent source-to-collimator distance (SCD) for a Φ1 mm pinhole collimator.

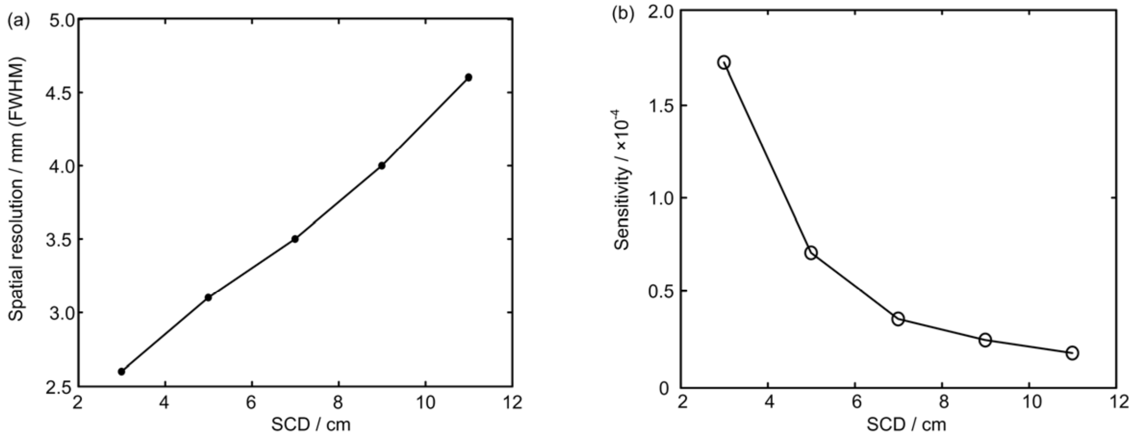

Fig.5 (a) Spatial resolution as a function of source to collimator distance (SCD) for a pinhole collimator with hole diameter size of 1.5 mm. (b) Geometric sensitivity as a function of source to collimator distance (SCD) for the pinhole collimator.

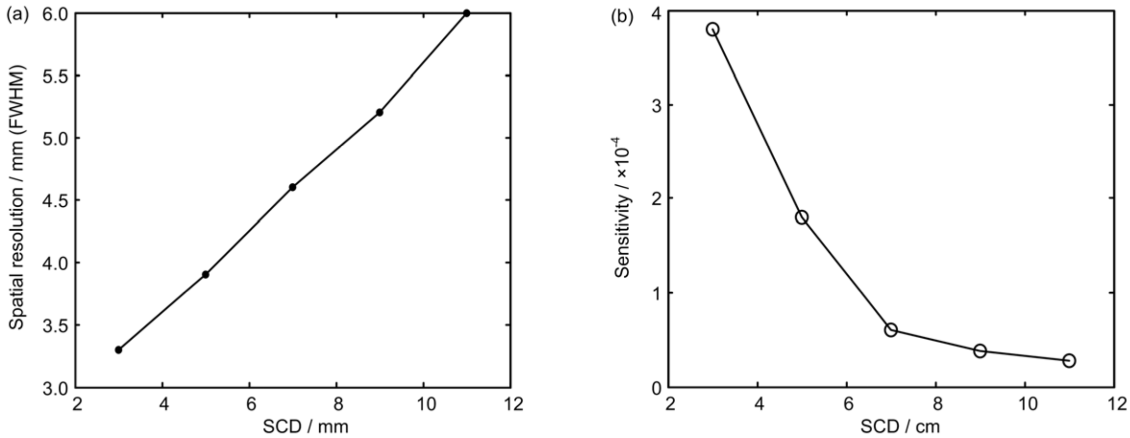

Fig.6 (a) Spatial resolution as a function of source to collimator distance (SCD) for a pinhole collimator with hole diameter size of 2 mm. (b) Geometric sensitivity as a function of source to collimator distance (SCD) for the pinhole collimator.

4 Conclusion

The spatial resolution and geometric sensitivity of a dedicated gamma camera with a pinhole collimator has been studied via Monte-Carlo simulations. The aim of this work was to search a pinhole collimator that has an optimal compromise between spatial resolution and sensitivity. We obtained the spatial resolution and the geometric sensitivity response as a function of the source to collimator distance for the dedicated gamma camera with a pinhole collimator of various-hole diameters. The results show that the camera with pinhole of 1 mm, 1.5 mm and 2 mm diameter has respectively spatial resolution of 1.8 mm, 2.6 mm and 3.3 mm and geometric sensitivity of 0.0075%, 0.0172% and 0.038%, while the source to collimator distance is 3 cm. Based on the trade-off between sensitivity and resolution, we chose the pinhole collimator with hole diameter size of 1.2 mm for our the gamma camera designed. In the future work, we will test the imaging performances of this small FOV gamma camera with the chose pinhole collimator.

References

1 Bird A J, Ramsden D. Nucl Instrum Methods Phys A, 1990, **299:** 480–483.

2 Majewski S, Farzanpay F, Goode A, *et al*. Nucl Instrum Methods Phys A, 1998, **409:** 520–523.

3 Garibaldi F, Cisbani E, Cusanno F, *et al*. Nucl Instrum Methods Phys A, 2001, **471:** 222-228.

4 Craig S L. Nucl Instrum Methods Phys A, 2003, **497:** 60–74.

5 Pani R, Pellegrini R, Cinti M N, *et al*. Nucl Instrum Methods Phys A, 2004, **527:** 54–57.

6 GEANT, Detector Description and Simulation Tool, Application Software Group. < http: // wwwasdoc. web. cern.ch / wwwasdoc / geantole / GEANTMAIN. html>.
7 Pani R, Scafe R, Pellegrini R, *et al.* Nucl Instrum Methods Phys A, 2002, **477:** 72–76.
8 Position sensitive photomultiplier tube with crossed wire anodes R2486 series, Specifications manual (in Japanese). Hamamatsu: K.K. Electron Tube Center, 1993: 1-53. http: // www. Hamamatsu.com.
9 Guerra D, Belcari N. Nucl Instrum Methods Phys A, 2007, **583:** 119–124.