Characteristics of parallel-hole and pinhole collimators for nuclear medicine imaging

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Abstract In this paper, the spatial resolution and geometry sensitivity of parallel- and pin-hole collimators in compact gamma camera are presented, and quantitatively compared by GEANT4 code in Monte-Carlo library. The results show that the geometry sensitivity for pinhole collimator rapidly drops with increasing the gamma source-to-collimator distance (SCD); and for parallel-hole collimator, mildly. Meanwhile, the spatial resolution for pin-hole collimator mildly deteriorates; and for parallel-hole collimator, severely. The pin-hole collimator for close imaging objects has higher geometry sensitivity than parallel-hole collimator. Our findings are helpful for setting compact gamma camera collimators in nuclear medicine imaging.

Key words Spatial resolution, Geometric sensitivity, Collimator, Nuclear medicine

1 Introduction

Compact gamma camera is widely used in nuclear medical imaging, especially breast scintigraphy[1–3] and small animal radiography[4–6]. It can be used to efficiently detect and locate gamma rays produced in lesion tissue, and screen the body's scattered radiation due to its excellent geometry, thus assisting X-ray mammography as adjunct tools. The compact camera is also used in small animal radiography. For example, rabbits and mice are used as specimen in molecular biology, toxicology, drug experimentation, and pharmaceutical manufacturing.

Usually, compact gamma camera is composed of a collimator, a position sensitive gamma-ray detector which is coupled to a position sensitive photo multiplier tube (PSPMT), an image reconstruction software, and displayer. Like the lens of optical camera, the collimator plays an important role in image quality of compact gamma camera, including field of view (FOV), spatial resolution, sensitivity, and image distortion.

At present, the parallel and pin-hole collimators are used for compact gamma cameras[7,8], and their performances are evaluated by spatial resolution. The spatial resolution of gamma camera mainly depends on its collimator. Also, geometry sensitivity of collimator is the ratio of the detected gamma ray to the total gamma ray from the radiation source after going through the collimator, and affects gamma camera performance.

The compact gamma camera is used for close-proximity imaging because its detector head can contact the object, such as human breast. The parallel-hole collimator can reach the same size image as target, and provide high sensitivity and high signal-to-noise ratio under the constant resolution. As comparison, the pin-hole collimator can produce the magnified image, and improve the spatial resolution and sensitivity except the low FOV. In addition, both of spatial resolutions can be improved by reducing their apertures. To find suitable parallel- or pin-hole collimators, their spatial resolution and geometry sensitivity need to be quantitatively optimized. In this paper, both parallel- and pin-hole collimators are made of lead, and simulated by the GEANT4 codes[9].

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2 The image system design and simulation

2.1 The image system design

The compact gamma camera is composed of a Hamamatsu R2486 PSPMT [10] with a photocathode of 50mm, and lead-made parallel- or pin-hole collimators in front of NaI(TI) crystal pixel array[11], as shown in Fig.1. The scintillation is triggered by the gamma ray going through the collimator, and read by the PSPMT. The scintillating photon positions in the *X*-*Y* plane can be determined and computed by their gravity center.

The parallel-hole collimator is made of a cylindrical lead slab of thin septa and parallel round-hole arrays. Its parallel FOV corresponds to the active area of the PSPMT. The source-to-collimator distance (SCD) is from the point gamma ray source to its outer surface (L), t is the lead septa thickness, d is the aperture diameter, and A is the aperture length. Based on the collimation for breast imaging simulated by Monte Carlo[12], we chose the collimator of 0.2-mm septa and 30-mm aperture.

The pin-hole collimator is composed of two interpenetrative cones in a cylindrical lead block. So, the gamma-ray emits from the object passes through its aperture and reaches the image plane of NaI(TI) crystal pixel array without any attenuation. Also, its SCD and the aperture diameter are the same L and d as the parallel-hole collimator, to compare both collimator performances. f is its focal length, and α is its half acceptance angle. The pin-hole collimator can be operated in two models: the large FOV/low spatial resolution and small FOV/high spatial resolution. So, the former FOV enhances with object distance, and the latter spatial resolution increases with decreasing object distance. Here, to fully match effective sensitive area of PSPMT with crystal projection diameter, we choose α =22.5°, f=60 mm, and A =20 mm.

2.2 The simulation

The GEANT4 program library (European Organization for Nuclear Research) was used to simulate a 4π oriented random gamma ray source with 140 keV, and track the passage of the gamma-ray photon. The trace simulation includes four phases:

(1) Track whether the i^{th} gamma photon passes the parallel-and pin-hole collimator.

(2) Verify whether the i^{th} photon hits the scintillating crystal.

(3) Mark the point coordinates of having photoelectric effect in the scintillating crystal. The isotropic scintillation photons are generated by secondary electrons, and traced by Fresnel relationship till the new secondary photons are deposited on the photocathode of PSPMT and trigger photoelectrons. The weight center of every gamma photon, which corresponds to the PSPMT's output in theory, is calculated by Eqs.(1) and (2).

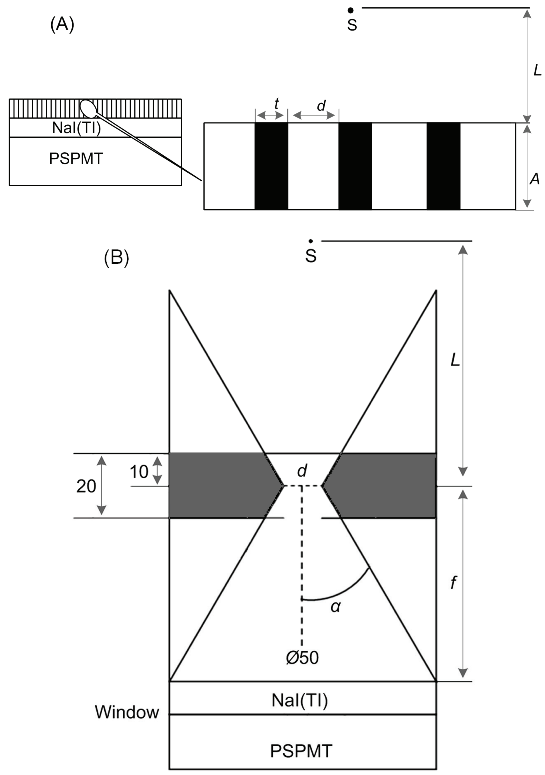

Fig.1 Schematic diagram of the dedicated gamma camera: A parallel- (A) and pin- (B) hole collimator (mm), S: the point gamma-ray source.

$$X_i = \sum_{j=1}^{m_i} (x_{ij} / m_i) \tag{1}$$

$$Y_i = \sum_{j=1}^{m_i} (y_{ij} / m_i) \tag{2}$$

where, (X_i,Y_i) is the coordinates of the i^{th} gamma-ray, (x_{ij},y_{ij}) is the coordinates of the j^{th} photoelectron of the i^{th} gamma-ray, and m_i is the total count of the photoelectrons detected in the i^{th} gamma-ray.

It is assumed that the weight centre of photoelectrons are fitted by a 2D Gaussian distribution, its mean values are taken as the target points of (X_i,Y_i), and the full width of 2.354σ at half maximum (FWHM) is taken as the spatial resolution at the points. When the gamma ray triggers scintillation up to 10^6 on the counter SENS, simulation experiment is stopped, and the gamma-ray source is moved to another point along the collimator axis.

(4) The geometry sensitivity is the ratio of gamma ray photons going through the collimator to the total gamma-ray photons emitting from the gamma ray source. The different combinations of L with d are fed to observe the spatial resolution and geometry sensitivity.

3 Results and Discussion

3.1 Spatial resolution

To simulate the L variation, the gamma ray source was set by 2-cm step at 6 position points along the axis of the collimator. For the parallel-hole collimators, we used d =1, 2, 3, and 4 mm; and for pinhole collimators, d =1, 1.5, 2, and 3 mm, so as to demonstrate its effect on the spatial resolution and geometry sensitivity.

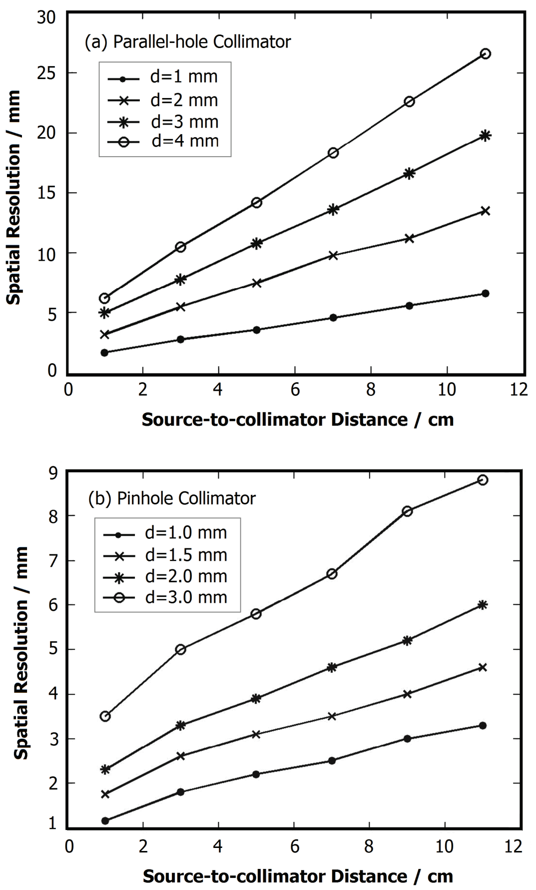

Fig.2 Spatial resolution response to L and d for parallel-hole collimator and pinhole collimator .

For the compact gamma ray camera, the lower spatial resolution is, the better its performance is. Fig.2 shows that the spatial resolutions of parallel- and pin-hole collimators vary with L and d, the spatial resolutions deteriorate with increasing with d. When lengthening gradually the L, the spatial resolution mildly deteriorates for pin-hole collimator; and sharply for parallel-hole collimator because it is majorly decided by L.

3.2 Geometric sensitivity

Geometry sensitivity of the gamma camera is shown in Fig.3. The geometry sensitivities of parallel- and pin-hole collimators vary with L at the same d values, indicating that their geometry sensitivities drop with increasing L, especially for a pin-hole collimator, and increase with d. The L should be as short as possible to achieve better geometry sensitivity, and geometry sensitivity of parallel-hole collimator is better than that of pin-hole collimator at this time.

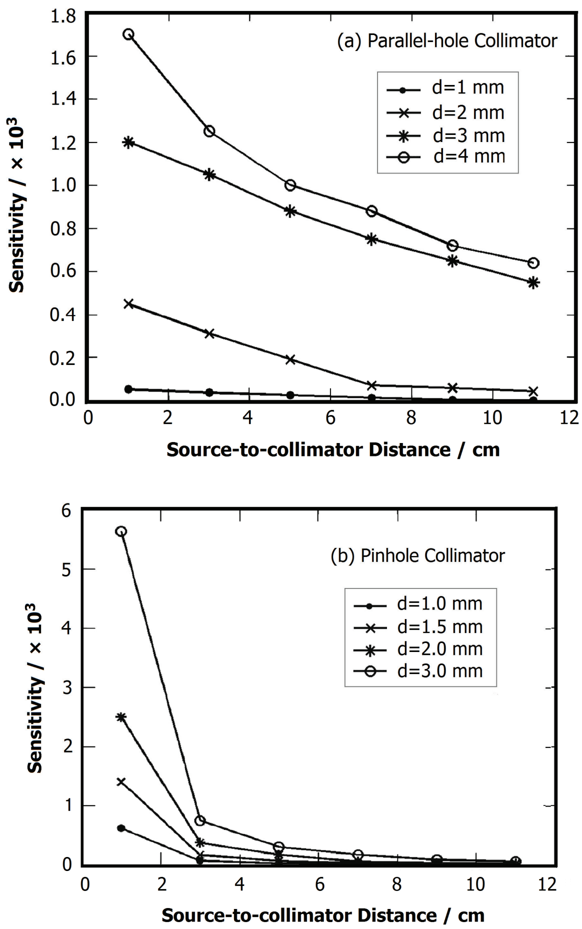

Fig.3 Geometry sensitivities varying with L and d for the pin-hole and parallel-hole collimators.

4 Conclusions

We simulated the performances of the parallel- and pin-hole collimators in gamma cameras. At the identical L, the spatial resolution drops with increasing d, especially parallel-hole collimator. The geometry sensitivity drops with increasing L, and dramatically decreases for pin-hole collimator. These characteristics are suitable for fine imaging of breast cancer in the future.

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