Angular distribution of scattering and penetration components in a multi-lofthole collimator for SPECT: a Monte Carlo study

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Abstract:

In SPECT, scattering and penetration of photons in the collimator result in considerable image degradation. A new version of pinhole collimation is proposed to address the problem. The aim of this study is, therefore, to quantify such effects for the lofthole collimator. In this study, the GATE Monte Carlo simulation was performed to calculate edge penetration and scattering in a breast SPECT scanner equipped with a multi-lofthole collimator. Simulations were carried out for a point source of Tc-99m in the different positions and the scattering and penetration factors are then calculated as a function of incidence angle. A comparison with a pinhole collimator was also conducted. The results illustrate a reduction in the sensitivity by increasing the photon incidence angle. Both scattering and penetration fractions exhibit a decreasing trend across the angle of incidence. In conclusion, the lofthole offers superior performance compared to the traditional pinhole collimators.

Keywords: SPECT; Penetration; Scattering; Collimator; Multi-lofthole; GATE

Introduction

Pinhole collimators are widely used for small-animal and small-organ imaging including the breast [1]. Pinhole collimation suffers from scattering and penetration. For pinhole collimation, penetration typically occurs at the edge of the pinholes, where the collimator material is thin that widen the tails of point spread function, and thereby degrades the resolution of planar and SPECT image. The degree of penetration is often very high but can be compensated during the reconstruction process. Other solutions for limiting edge penetration include the use of asymmetric pinholes, pinholes with channels [2], loftholes [3], clustered pinholes [4], and very high-density materials, such as gold or iridium. Deprez et.al, in 2013, introduced a new pinhole geometry, the lofthole, that has a circular aperture but whose entrance and/or exit opening is shaped by the desired irradiated detector area. Loftholes also have better penetration and penumbra characteristics than pinholes [3]. The scattering and penetration of lofthole collimators are not well-understood. Therefore, this research aims to quantitatively assess the angular distribution of the scattering and penetration components in multi-lofthole collimation.

Materials and methods

The GATE Monte Carlo (MC) toolkit was used for the simulation of a breast-dedicated SPECT scanner equipped with NaI(Tl) detection modules and a cylindrical multi-lofthole collimator. Modeled physics processes include photoelectric, Compton and Rayleigh scattering for gamma rays, as well as ionization, Bremsstrahlung, and multiple-scattering for electrons.

The collimator radius is 47 mm and the detector has a radius of 95 mm. The opening angle of loftholes is about 75° and the number of loftholes without the projections overlapping is 8. Lofthole diameter in the designed scanner is 3.05 mm and the angle between loftholes is 45°. The thickness of the tungsten collimator is 5 mm. The modular detector with 10 mm in thickness consists of 8 modules of monolithic NaI(Tl) crystal (Figure 1). The scanner provides a cylindrical field-of-view (FOV) of 72 mm in height and 72 mm in diameter enabling imaging of a medium-sized breast.

The ratio of scattered counts to detected ones was defined as scatter fraction. Similarly, penetration fraction was defined as the percentage of those that passed through the lofthole edges without any interaction with the edges. The simulation was performed with a 25 MBq Tc-99m point source. The symmetrical 20% energy window centered on 140 keV was also set. A data acquisition period of 300 s was considered. The point source was placed at 6 different positions across line S to cover the axial FOV of the scanner (Figure 2).

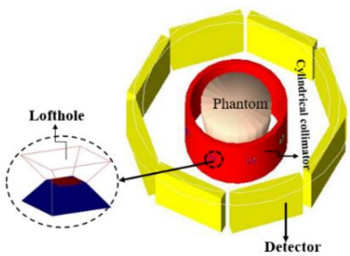

Figure 1. Schematics of the SPECT scanner modeled in the GATE simulator.

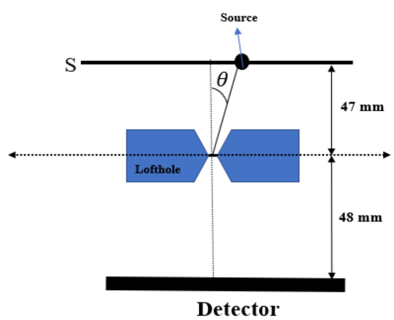

Figure 2. Geometry of simulation and position of the point source at line S.

Results and discussion

Scattering and edge penetration in multi-lofthole collimator as a function of angle of photon incidence (θ), are shown in Figures 3 and 4, respectively. It is evident from these two figures, as the incidence angle increases, fewer photons reach the detector, leading to a reduction in the sensitivity. Furthermore, by increasing the incidence angle, both scattering and penetration fractions decrease. Our trends are in good agreement with those of the analytically predicted by Metzler et al [1] for pinhole collimation.

Scattering and penetration fractions in the lofthole collimator are significantly lower than those of the pinhole collimation. Quantitatively, at θ equal to 0, the scattering and penetration fractions in pinhole are about 0.04 and 0.5, respectively [3]. Whereas, they are 0.002 and 0.005, respectively, in lofthole. Lower scattering and penetration in lofthole collimator offer a higher quality SPECT image, compared to pinhole. The statistical uncertainties of the MC simulations were less than 1%.

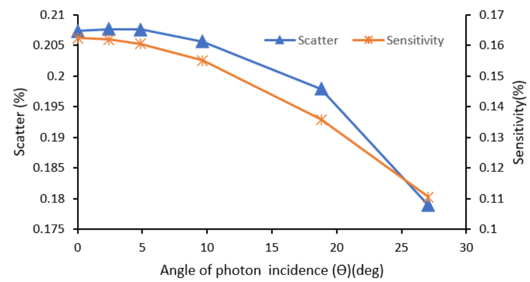

Figure 3. Scatter fraction and sensitivity as a function of angle of photon incidence (θ) in the collimator.

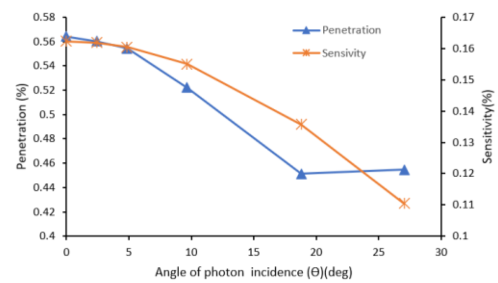

Figure 4. Penetration and sensitivity as a function of angle of photon incidence (θ) in the collimator.

Conclusions

While both pinhole and lofthole collimators exhibit a decreasing trend in scattering and penetration as a function of incidence angle, the lofthole collimator provides superior performance and can be the collimator of choice for high-quality SPECT imaging.

References

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