Characterization of scattering and penetration in lofthole and pinhole collimators: comparison of Tc-99m and I-123 SPECT

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Abstract

Image quality and quantitative accuracy in SPECT are mainly affected by collimator penetration and scattering, particularly for high-energy imaging. Lofthole has been proposed to address the problem. In this research, the GATE Monte Carlo simulator was performed to calculate edge penetration and scattering in pinhole and lofthole collimators using a point source of Tc-99m and I-123. The scattering and penetration factors are then compared. The results show that penetration and scattering are a function of the photon energy. The scattering and penetration in the pinhole aperture are 4.7% and 1.3% higher than those of lofthole aperture, respectively, for I-23 SPECT. Similar trends are also obtained for the Tc-99m SPECT. Furthermore, the lofthole collimator presents a higher sensitivity than the pinhole collimator (0.019 versus 0.015 for the I-123 SPECT). In conclusion, the lofthole collimator offers superior performance and therefore can be the collimator of choice for high-quality SPECT imaging.

Keywords: Penetration; Scattering; Comparison; lofthole; Pinhole; GATE.

Introduction

In SPECT, collimator scattering and penetration play a key role. Image quality is then influenced by scattering and edge penetration. The scattering and penetration are more pronounced in high-energy imaging [1-2]. New collimator geometries are then proposed to overcome the existing problems. The lofthole is an extension of the pinhole collimator resulting in superior performance [3]. In contrast to pinholes where the exit window is circular, loftholes have a circular aperture (similar to pinholes) but a rectangular exit window leading to a rectangular projection on the detector for optimal coverage. The literature about the performance of lofthole for non-Tc-99m tracers is sparse. To this end, pinhole and lofthole are comprehensively compared for Tc-99m and I-123 SPECT.

Materials and methods

Edge penetration and scattering were calculated using a set of GATE simulations. GATE is a dedicated Monte Carlo software package for emission tomography. In this research, all the relevant physics including photoelectric absorption, Compton and Rayleigh scattering for gamma rays, as well as ionization, Bremsstrahlung, and multiple-scattering for electrons were modeled. In addition, the intrinsic energy and spatial resolutions of the detector were taken into consideration.

Both tungsten collimators were 5 mm in thickness. The geometric parameters of aperture, including diameter (d), acceptance angle (α), aperture-to-source distance (f), and detector-to-source distance (D) were considered to be the same. Figure 1 shows schematics of pinhole and lofthole modeled in the GATE simulator. The diameter of the aperture was considered to be 3.06 mm, acceptance angle was about 75-degree, detector-to-source and aperture-to-source distances were 95 mm and 47 mm, respectively (Figure 2). These geometrical settings provide a cylindrical field-of-view (FOV) of 72 mm in height and 72 mm in diameter enabling imaging of a medium-sized breast. The monolithic NaI(Tl) crystal, with an intrinsic resolution of 3.2 mm, was considered as a scintillation detector which was a square with dimensions of 80 × 80 mm^2 and 10 mm in thickness. The magnification factor of the scanner was 1.02.

Penetrated photons were assumed to be those passed through the collimator edge lofthole without interaction. Similarly, photons that interacted with the collimator and also were still detected were defined as scattered photons. The simulation was performed for 10 MBq Tc-99m and I-123 point sources located at the center of the FOV in a water phantom. All simulated data were acquired considering a 20% energy window (126-154 keV for Tc-99m and 143.1-174.9 keV for I-123). A data acquisition period of 300 s was considered for each collimator geometry.

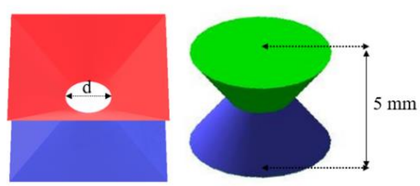

Figure 1: Schematics of lofthole (back-to-back pyramid) (left) and pinhole (back-to-back cone) (right) apertures in GATE simulation.

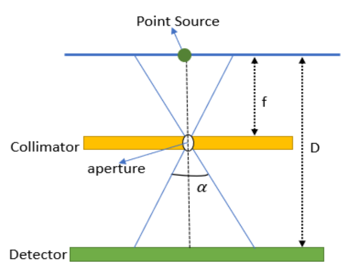

Figure 2: Geometric parameters of aperture.

Results and discussion

Quantitative results of scattering and edge penetration in lofthole and pinhole apertures, for two radiotracers of I-123 and Tc-99m, are listed in Tables 1 and 2.

Table 1: Comparison lofthole and pinhole collimators for I-123 SPECT.

I-123	Lofthole	Pinhole
Scattering (%)	0.2	0.21
Penetration (%)	7.7	7.8
Sensitivity (%)	0.019	0.015

Table 2: Comparison lofthole and pinhole collimators for Tc-99m SPECT.

Tc-99m	Lofthole	Pinhole
Scattering (%)	0.111	0.113
Penetration (%)	2.8	2.87
Sensitivity (%)	0.02	0.016

The statistical uncertainties of the MC simulations (the data listed in Tables 1 and 2) were less than 1%. According to Tables 1 and 2, the scattering and penetration of the lofthole are lower than those of the pinhole. This is mainly due to the shape of the lofthole exit. Compared to the Tc-99m, I-123 SPECT suffers from higher scattering and penetration fraction of approximately 80% and 3-fold, respectively, for lofthole aperture. This is because of the higher energy of I-123 compared to Tc-99m.

For both of the scanners, the sensitivity of the scanner is higher when utilizing the lofthole collimator (0.019 versus 0.015 for the I-123 scanner). This is in good agreement with the published studies [3]. Thanks to optimal coverage of the detector by providing rectangular (instead of circular projections in pinholes) using lofthole, the sensitivity increases. The sensitivity remains constant for both tracers (0.019 vs. 0.02, for the lofthole). The reason is that the reduction in sensitivity due to higher photon energies (i.e., lower detection efficiency) is compensated by higher scattering and penetration from the collimator.

Conclusions

Lofthole exhibits superior performance not only in terms of system sensitivity but also in terms of scattering and penetration in the collimator. Higher energy SPECT imaging automatically leads to inferior performance for both collimators but a lower extent for the lofthole.

References

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