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Design and performance evaluation of a focused multi-pinhole collimator for myocardial perfusion imaging with SPECT

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Abstract

This study aims to design and evaluate the performance of a multi-pinhole collimator offering high sensitivity and high resolution for myocardial perfusion SPECT imaging. Monte Carlo simulation using GATE was performed to assess various configurations. The multi-pinhole collimator comprises 8 apertures focused towards the heart. The spatial resolution was compared for different diameters of lead, tungsten, and gold apertures for 99mTc point-source imaging. The findings demonstrated that the gold outperforms the conventional lead and tungsten as collimator material. The multi-pinhole collimator shows an inferior performance compared to the pinhole in terms of spatial resolution. It is concluded that for high-quality cardiac SPECT imaging with multi-pinhole collimator gold can be the material of choice.

Keywords: SPECT; Multi-pinhole; GATE; Myocardial perfusion imaging

Introduction

Single-photon emission computed tomography (SPECT), by detecting gamma rays emitted from radioisotopes in the human body, is a diagnostic imaging modality [1]. Among the many components constituting a SPECT camera, the collimator plays a pivotal role and mainly affects the image quality [2]. While parallel-hole collimation is routinely used for cardiac SPECT imaging, there is no clinically-demanded resolution-sensitivity balance for simultaneously high-resolution and high-sensitivity imaging. Pinhole collimation has been, therefore, proposed to address the problem. A multi-pinhole collimator has several pinhole apertures in which increasing the number of pinholes increases the system's sensitivity [3,4]. This work aims at designing a multi-pinhole collimator for cardiac SPECT imaging and then investigating the influence of collimator material on its performance. Furthermore, a comparison with single pinhole collimation was also conducted to study the effect of projection overlapping on the designed multi-pinhole collimator.

Materials and methods

GATE version 8.2, for the various single pinhole and multi-pinhole configurations, was used to evaluate and compare their performance. The statistical uncertainties of the Monte Carlo simulations were below 1.0%.

A spherical water phantom containing a 10 mCi Tc-99m point-source at its center was simulated. The spatial resolution of the projection image was calculated in terms of full-width at half-maximum (FWHM). Three conventional collimator materials (gold, lead, and tungsten) with varying diameters were compared and the GATE simulation was repeated. Table 1 lists the technical specifications of both collimators. The detector is also 10 mm-thick NaI(Tl). The multi-pinhole was then compared with the single one.

Table 1. Geometric characteristics of single pinhole and multi-pinhole collimators.

Specification	**Single pinhole**	**Multi-pinhole**
Detector area (mm^2)	200 × 140	200 × 140
No. pinholes	1	8
Hole diameter (mm)	0.5-4.0	0.5-4.0
Opening angle (degree)	60	53
Material	Pb, W, Au	Pb, W, Au

Figure 1 shows multi-pinhole and single-pinhole collimators in different views. All holes are focused toward the center of FOV (i.e., heart). Both collimators cover the whole FOV of the scanner. To avoid large projection overlapping in multi-pinhole collimation, the distance between the collimator and detector was reduced. To perform a fair comparison, the spatial

resolution of the single pinhole collimator was corrected for the distance between the collimator and detector.

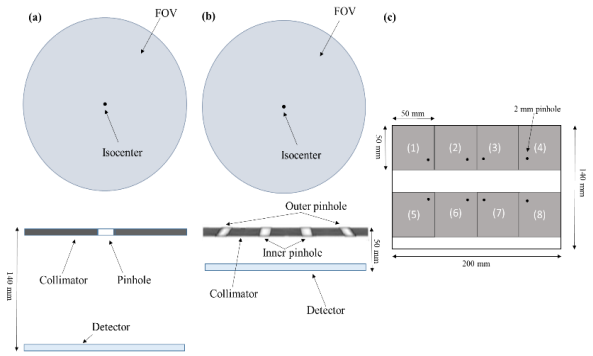

Figure 1. Side view single pinhole (a) multi-pinhole collimators (b), and top view of the multi-pinhole comprising 8 apertures (c).

Results and discussion

Figure 2 illustrates the influence of the collimator material on the system's spatial resolution. The collimator material contributes to edge penetration and scattering and hence leading to degradation of the resolution. The gold offers a promising performance by exhibiting lower FWHM across all hole diameters. It is obvious from Figure 2 that increasing the hole diameter results in deterioration of the spatial resolution. Despite the higher cost, gold outperforms traditional materials used in SPECT scanners. This is because of the higher linear attenuation coefficient of gold compared to the lead and tungsten. The gold is being also used in various small-animal SPECT scanners around the world [1].

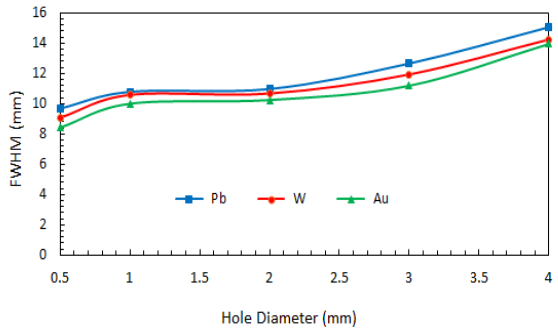

Figure 2. Spatial resolution as a function of hole diameter for three conventional collimator materials.

Figure 3 compares single pinhole and multi-pinhole collimators in terms of spatial resolution. The advantage of a multi-pinhole over a single one is much higher system sensitivity. However, owing to projection overlapping in the multi-pinhole collimator, an inferior resolution would be expected in comparison to the pinhole collimation. Projection overlapping is also known as multiplexing of the projections over the detector face. Referring to Figure 3, the problem is more challenging for higher hole diameters where the extent of projection overlapping is greater.

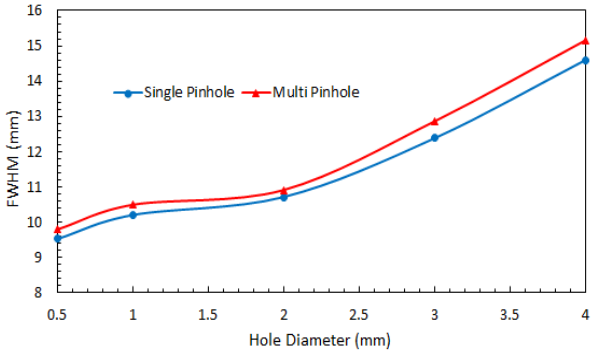

Figure 3: Spatial resolution of multi-pinhole and single pinhole collimators as a function of hole diameter.

Conclusions

A novel multi-pinhole collimated SPECT scanner is proposed for cardiac imaging. We investigated a multi-pinhole collimator for various geometries and configurations. The collimator is an alternative to conventional parallel-hole collimations. Gold provides superior performance compared to lead and tungsten in terms of spatial resolution. While multi-pinhole collimators offer much more sensitivity, they slightly suffer from a lower spatial resolution in comparison to the single pinhole collimator.

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