Original Article

Characterization of low, medium and high energy collimators for common isotopes in nuclear medicine: A Monte Carlo study

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ABSTRACT

Introduction: In an ideal parallel-hole collimator, thickness of septal material should be sufficient to stop more than 95% of incident photons. However, some photons pass the septa without interaction or experience scattering before they reach the detector. In this study, we determined different contribution of collimator responses consist of geometrical response, septal penetration (SP) and scattering (SC) for low, medium and high energy collimators.

Methods: A point source of activity with common energies in diagnostic nuclear medicine and three different collimators were simulated using SIMIND Monte Carlo code.

Results: For Low Energy High Resolution (LEHR) collimator, SP was increased from 7% in 140 keV to 30% in 167keV and more than 75% in energies higher than 296keV. SC also was increased from 4% in 98keV to more than 15% in energies higher than 167keV and reached to its maximum (26%) in 296keV. For Medium Energy All Purpose (MEAP) collimator, SP was suddenly increased from 6% in 186keV to 28% for 296keV and more than 50% for higher energies. SC was also increased from 4% in energies below 186keV to 15% in 296keV and about 30% for higher energies. For High Energy (HE) collimator, SP was about 20% for 364keV photons. SC was 15% for 364keV photons and only 65% of photons were geometrically collimated.

Conclusion: Our results showed that even by using nominally suitable collimators, there are considerable SC and SP that influence the quantitative accuracy of planar and SPECT images. The magnitude of geometrical response, SC and SP depend on collimator geometric structure and photons energy.

Key words: Collimator responses; Monte Carlo; Geometric response; Septal penetration; Scatter

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INTRODUCTION

With the advent of high speed computers, Monte Carlo (MC) techniques have become powerful and popular tools in different areas of nuclear medicine. Monte Carlo techniques are extensively used to evaluate the performance of new collimators and scanners in SPECT [1, 2] and PET [3-5], to find optimum imaging conditions and parameters [6] and to investigate the strengths and limits of attenuation, scatter and partial volume correction algorithms [7, 8].

A collimator restricts the emitted rays from the source so that each point in the source has a unique corresponding point in the image. For an ideal parallel-hole collimator only photons that are parallel to the holes of the collimator can pass the holes and reach to the detector [9]. Therefore an ideal collimator should be a prefect absorber or thick enough to eliminate all other photons. It also needs very small holes diameter to geometrically stop the photons that are not exactly parallel to the holes. This issue significantly decreases the imaging system sensitivity. To increase sensitivity, usually thinner collimators with considerable holes diameter are used. Therefore some other photons that are not completely parallel to the collimator holes can pass the holes. There are also photons that pass the collimator septa without interaction and reach the collimator. Moreover, some photons experience scattering in collimator reach the detector. Therefore collimator response of a gamma camera system has three components: geometric, septal penetration and septal scatter [10]. The geometric response is the portion of the total collimator response that represents the photons that travel through the collimator holes without interacting with or passing through the collimator septa. These components changes by photon energy, collimator shape and source to collimator distance [11].

In this study we determined different contribution of collimator responses consisting of geometrical response, septal penetration (SP) and scatter (SC) for low, medium and high energy collimators for a variety of common isotopes in nuclear medicine.

METHODS

The SIMIND Monte Carlo simulator [12] was used to trace photons through the collimators from their point of emission to their point of detection. A dual-head camera, Symbia T2 gamma camera (Siemens Medical Solution USA, Inc.) was simulated. Geometrical parameters of three different collimators of this company, consist of LEHR, MEAP and HE, were modeled. Table 1 describes geometrical dimensions of these collimators.

A point source of activity with common energies in nuclear medicine imaging (Tl-201: 77keV and 167keV, Ga-67: 98keV, 188keV and 296keV, Tc-99m: 140keV, I-131: 364keV and PET isotopes: 511keV) was simulated in 12cm from the face of the collimator. For each of energies, an individual simulation was done by tracing 100 million photons. All images were acquired in a 256×256 matrix with 1.7 mm pixel size. The width of energy window was 20% of the peak energy. In addition to images, the Monte Carlo was asked to list different contributions of collimator response as a percent of the total response.

Table 1: Geometrical dimensions of different collimators in this study.

Collimator type	Height (mm)	Hole diameter (mm)	Septal thickness (mm)
LEHR	24.05	1.11	0.16
MEAP	40.64	2.94	1.14
HE	59.70	4.00	2.00

RESULTS

LEHR collimator

Figure 1 shows the LEHR collimator responses for different energies. A star-like tail due to septal penetration is obvious for energies higher than 184keV. There is also considerable background, mainly due to scattered photons. This effect is more noticeable when photon energy increases.

Figure 1 also represents the percent of different components of LEHR collimator response for different photon energies. By increasing photon energy from 140keV to 511keV, septal penetration increases from 7% to 85%. Moreover, for energies higher than 296keV, less than 1% of detected photons are collimated geometrically. As a general rule, by increasing photon energy, geometric response decreases and septal penetration increases. There is however one expectation when energy increases from 77keV to 98keV. This discontinuity is because the lead K edge appears at 88keV. Below this energy the gamma ray does not have sufficient energy to dislodge a K electron. The scatter fraction, however, has an irregular variation by energy. Its maximum value is appeared in 296keV.

It is clear that the geometric component has decreased with increase in energy, sharp transition in LEHR (Figure 1) while comparatively smooth transition in MEAP (Figure 2) and HE (Figure 3) collimators.

MEAP collimator

Figure 2 shows the MEAP collimator responses for different energies. A star-like tail due to septal penetration can be seen for energies higher than 296keV. This effect is more noticeable when photon energy increases.

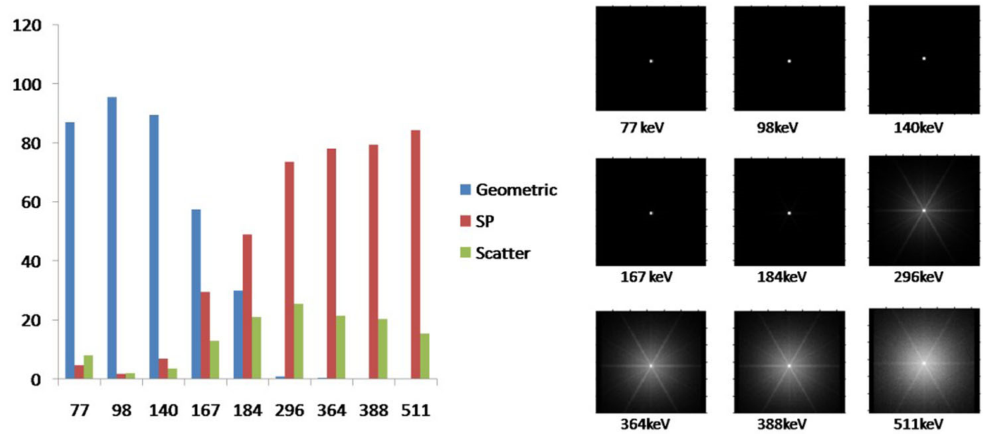

Fig 1. Variation of geometric, septal penetration and scatter response of LEHR collimator for different photon energies (left) and the total collimator response of the collimator for different photon energies (right).

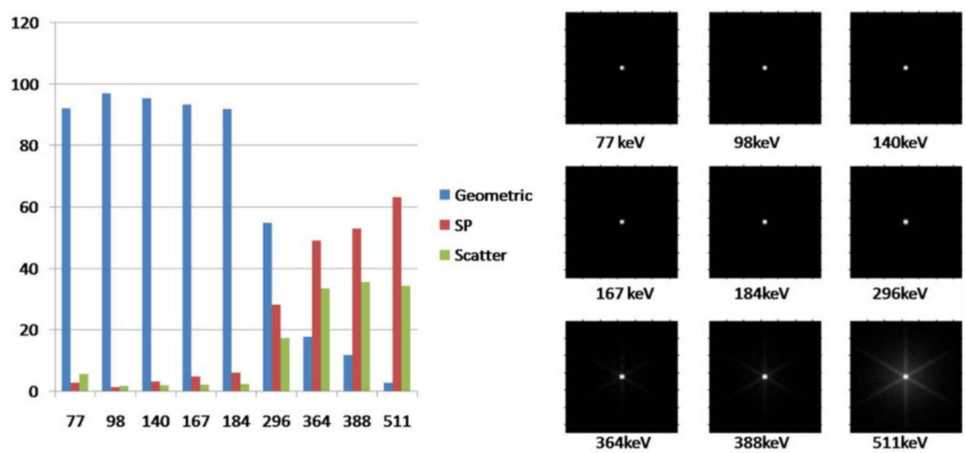

Fig 2. Variation of geometric, septal penetration and scatter response of MEAP collimator for different photon energies (left) and the total collimator response of the collimator for different photon energies (right).

This figure also represents the fraction of different components of MEAP collimator response for different photon energies. More than 90% of photons with energies less than 184keV were collimated geometrically. This value decreases to 20% for I-131 that emits 364keV photons. Compared to LEHR collimator, there are more scatter components in higher energies.

HE collimator

Figure 3 represents the percent of different components of HE collimator response for different photon energies. More than 35% of I-131 (364keV) photons contribution are septal penetrated or scatter. For energies below 296keV, septal penetration is less than 10%. This amount reaches to 50% for PET isotopes (511keV). It also shows the HE collimator responses for different energies. It is not easy to see the septal penetration effect because it has less contribution compared to geometric response. Therefore we showed the images in logarithmic scale (Figure 4).

The septal penetration star and scatter backgrounds can be seen in Figure 4 for energies higher than 296keV. Scatter contribution increases for HE collimator when the photon energy increases.

DISCUSSION

When we talk about collimator response we usually refer to its geometric response [13].

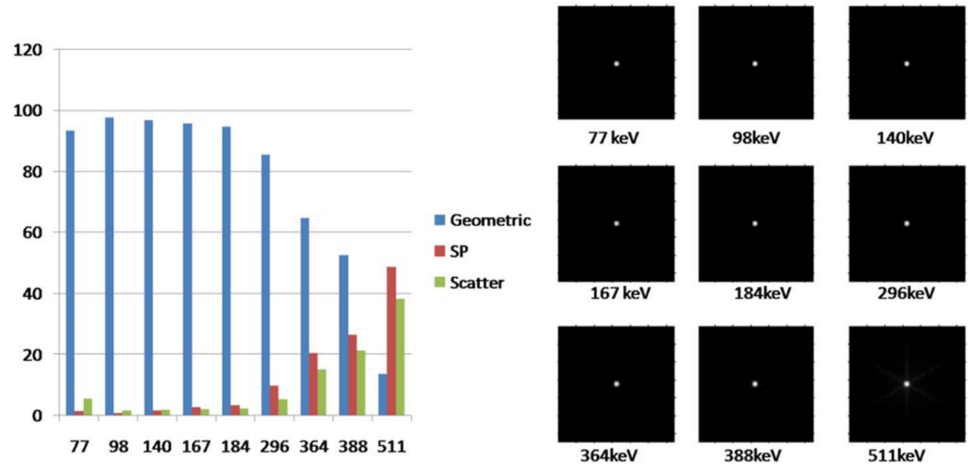

Fig 3. Variation of geometric, septal penetration and scatter response of HE collimator for different photon energies (left) and the total collimator response of the collimator for different photon energies (right).

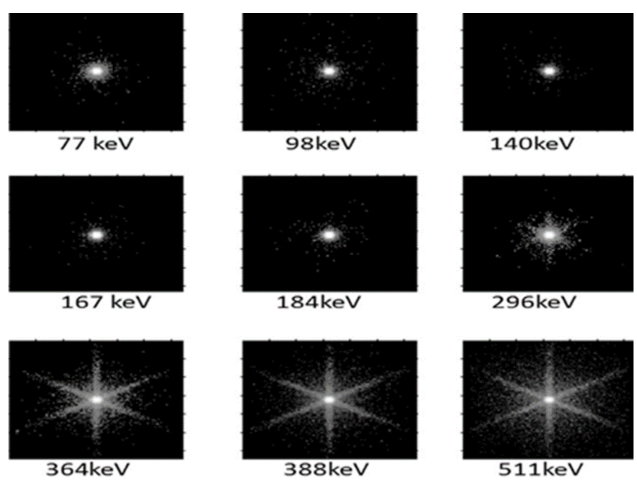

Fig 4. Total response functions of HE collimator for different photon energies. The images are individually normalized and shown on a logarithmic scale to emphasize the features in the tails of the response functions.

However for high energy photons, there are considerable amount of photons that can't be collimated geometrically. We should note that even without septal penetration and scattering, there are a number of errors associated by distance dependent geometric response of collimators. Partial volume effect in small and complex structures such as small tumors or brain generally happens due to poor resolution of gamma camera that results in significant quantitative errors in SPECT studies [14]. This problem become more serious when scattering in collimator and septal penetration is added to collimator response [15]. We determined geometric, septal penetration and scatter response of LEHR, MEAP and HE collimators for currently used isotopes in diagnostic nuclear medicine. We used Monte Carlo simulation as the only tool capable to distinguish different parts of collimator response [16]. For an I-131 point source in air, when HE collimator is employed, simulations show that about %40 of events in the photopeak window had either scattered in or penetrated the collimator, indicating the significance of collimator interactions.

CONCLUSION

The effect of geometric, septal penetration and scattered components have been studied quantitatively for LEHR, MEHR and HE collimators and currently used isotopes in diagnostic nuclear medicine imaging. Our results showed that even by using nominally suitable collimators, there are considerable SC and SP that influence the quantitative accuracy of planar and SPECT images. For Ga-67 there are considerable amounts of septal penetration and scatter for 296keV and 388keV photons when MEAP collimator is used. There is same issue for I-131 when HE collimator is employed. The HE collimator may by better choice for Ga-67 imaging. It is important to compensate for septal penetration and scattering for quantitative I-131 imaging, even when a HE collimator is used. The magnitude of geometrical response, septal penetration and scattering depend on collimator geometric structure and photons energy. The results of our current study can be used for design and development of new correction algorithm for evaluation and design of algorithms for image quantification.

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