Original Article

Evaluation of Acceptance Angle in Iodine-131 Single Photon Emission Computed Tomography Imaging with Monte Carlo Simulation

Abstract

Introduction: In iodine-131 (I-131) imaging, the image quality is degraded by scatter and penetration in a collimator. In this work, we assessed the penetrated and the scattered photon fractions in the photopeak energy window using Monte Carlo Simulation code. **Materials and Methods:** The Siemens Medical System equipped with high-energy collimator was simulated. We evaluated the acceptance angle values on geometric, penetration, and scatter components in a separate file. Binary images in a data file are obtained and each one of them was imported in software ImageJ. Full-width at half-maximum (FWHM) and sensitivity were calculated and compared. **Results:** The simulation data show that for the acceptance angle value equal to 4.845°, the geometric, scatter, and penetration components were 93.20%, 4.13%, and 2.67%, respectively. Moreover, the resolution is improved (FWHM = 7.21 mm, full width at tenth maximum = 12.36 mm) for a point source at 12 cm from the detector. **Conclusion:** The small acceptance angle has a major impact on the image quality in I-131 single photon emission computed tomography.

Keywords: *Acceptance angle, geometrical, I-131, penetration, scatter, simulation Monte Carlo imaging nuclear detector*

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Introduction

The accurate quantification of iodine-131 (I-131) activity, which is estimated from scintigraphic images, has great importance because of the recent success of using it in thyroid cancer therapy, as well as in liver cancer therapy.[1] However, quantitative imaging is limited mainly by the phenomena of scattering and penetration into the septa of a collimator which leads to an error in the determination of activity. The highest intensity emissions of I-131 are 284 (6.1%), 364 (82%), 637 (7.2%), and 723 keV (1.8%).[2] The photons of 637 and 723 keV undergo only a slight attenuation in the phantom, and they have a higher probability of penetrating the collimators. They are counted in the window of the photopeak 364 keV.[3-5] The I-131 imaging was evaluated using its 364-keV photons.[6] Several methods have been proposed to correct scattering and septal penetration in I-131 imaging.[7-9] However, no method has yet been universally successful. The solution is to use a Monte Carlo simulation code such as simulation Monte Carlo imaging nuclear detector (SIMIND),[10] for scatter and penetration evaluation to develop a method for correcting these events. The aim of this work was to evaluate the imaging parameters of I-131, especially the collimator acceptance angle to obtain the optimum conditions allowing as much as possible the precise quantification of the activity.

Materials and Methods

We simulated the Siemens Medical Systems equipped with high-energy collimator using Monte Carlo simulation SIMIND code version 5.0. We used the following imaging parameters: 0.95 cm NaI (Tl) crystal thickness, intrinsic spatial resolution of 1.2 cm, and energy resolution of 9.80% at 140 keV. The dimension of the crystal was 50 cm × 40 cm. The energy window setting was 20% at 364 keV. The collimator data used during the simulation are given in Table 1.

A cylindrical water phantom of dimension 22 cm × 30 cm × 22 cm was placed at 20 cm from the detector surface. We used the SIMIND Monte Carlo simulation to acquire the data from I-131 point source

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of 0.005-cm diameter located at the center of the cylinder phantom.

The images have 0.3 cm pixel size and 128 × 128 matrix size. We imported binary images created by SIMIND in ImageJ software, National Institutes of Health and the Laboratory for Optical and Computational Instrumentation (LOCI, University of Wisconsin.[11]

In this study, we used the acceptance angles to evaluate the image quality.

Photons are isotropically emitted from a point source O, but the photons which are only propagating within the angle α can be detected [Figure 1]. The angle α can be defined as the collimator acceptance angle, and it is determined by the ratio of the hole size and length of the collimator.[12]

$$\alpha = \tan^{-1}\left(\frac{\text{Hole diameter}}{\text{Hole length}}\right)$$

Practically, the acceptance angle α is small to eliminate most of the tilted rays.

Results and Discussion

The contribution of geometric, penetration, and scatter photons was calculated for a point source at 20 cm from the detector surface as shown in Table 2. When the acceptance angle is 45°, the geometric component is very weak and does not carry even half of the detected photons. The scattering and penetration components are increased by the contribution of the 637-keV and 723-keV photons in the photopeak energy window, and thus, the geometric photons are decreased.[3,4] When 4.845° is used, we notice that the geometrical component goes up to (82% at 20 cm) that explains why the contribution of the photons of the upper peaks becomes weak. This is due to small acceptance angle.

Figure 2 diagram shows that blue and green spectra are obtained when the acceptance angles are 45° and 4.845°, respectively. The counts of blue spectrum are more than the one in the green spectrum. That can be explained by the existence of other peaks of high energies such as 637 keV and 723 keV which can be detected by the detector after the scattering in the collimator. Hence, the photopeak energy window in the case of 45° contains an important part of the scattered photons in comparison to the case of 4.845°.

A star like appears in the image of Figure 3a resulted from septal penetration, while this star is not as clear as the image for Figure 3b.

According to Table 3, the best resolution is obtained when the distance between the source and the detector is 12 cm full-width at half-maximum (FWHM = 7.21 mm, full-width at tenth maximum [FWTM] =12.36 mm), but the sensitivity slightly decreases at the same distance.

Figure 4 shows that the sensitivity becomes large when using the 3-cm thickness value.

Conclusion

In this study, we have evaluated the imaging parameters for I-131 using Monte Carlo simulation. The obtained results show that the image quality

Table 1: Design parameters of high energy collimator

Characteristics	
Hole diameter (cm)	0.506
Hole length (cm)	5.970
Septal thickness (cm)	0.2
Hole shape	Hexagonal
Type of collimation	PA

PA: Parallel holes

Table 2: Contribution of geometric, septal penetration, and scattered photons

Acceptance angle (°)	Geometric (%)	Penetration (%)	Scatter (%)
45	46.42	27.80	25.79
4.845	81.98	14.49	3.53

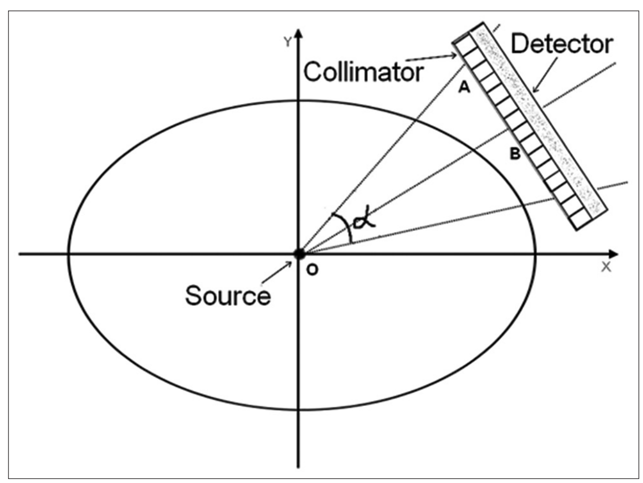

Figure 1: Schematic of acceptance angle

Table 3: The results of the simulations at three different distances from the detector

Distance (cm)	Geometric (%)	Penetration (%)	Scatter (%)	Sensitivity (Cps/MBq)	FWHM (mm)	FWTM (mm)
20	81.98	14.49	3.53	54.24	9.45	16.15
15	79.28	16.83	3.89	55.07	7.9798	14.1678
12	84.75	11.99	3.26	52.36	7.21	12.36

FWHM: Full-width at half-maximum, FWTM: Full-width at tenth maximum

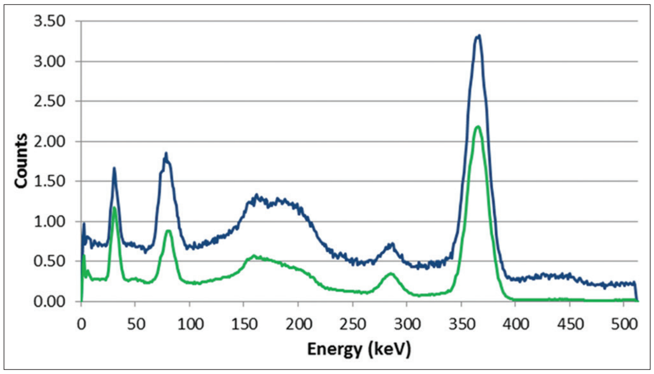

Figure 2: Energy spectra for iodine-131 source for two acceptance angles values: Blue spectrum (45°), green spectrum (4.845°)

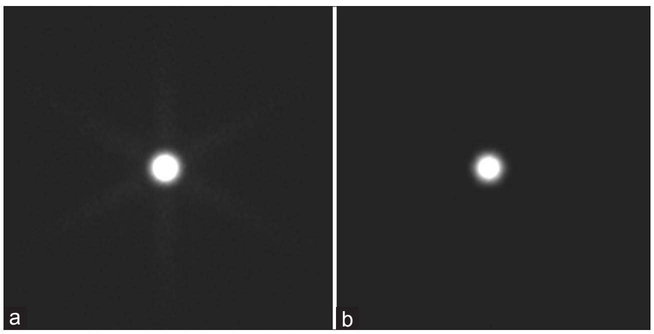

Figure 3: Images of iodine-131 point source obtained with two acceptances angles: (a) 45° and (b) 4.845°

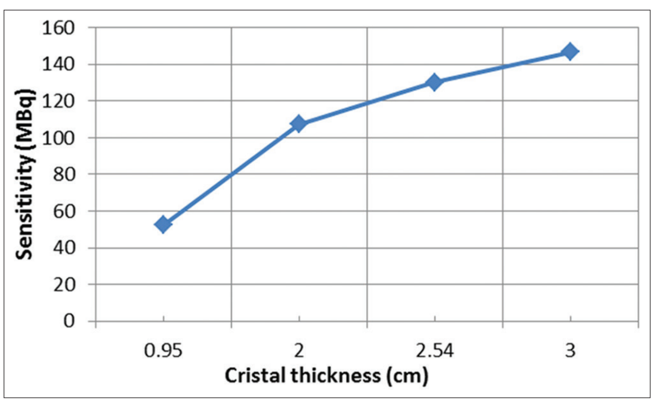

Figure 4: Variation of sensitivity with NaI (Tl) crystal thickness

very depends on the acceptance angle. When its value equal to 4.85°, the good results were obtained for the geometric component (81.98%) and the resolution (FWHM = 7.21 mm, FWTM = 12.36 mm).

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Conflicts of interest

There are no conflicts of interest.

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