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Validation of a model of the Symbia Intevo Bold SPECT scanner for Monte Carlo simulations

M.H.H. Bui, A. Robert, J.-N. Badel, M. Kvasshheim, C. Stokke, S. Rit, A. Etxebeste

Abstract—In nuclear medicine, Monte Carlo (MC) simulation is a powerful technique to model the stochastic nature of radiation, e.g. radiation detection in single photon emission computed tomography (SPECT). The aim of this study was to validate a MC model of the Symbia Intevo Bold SPECT scanner. To this end, we conducted two experiments with Tc-99m: 1) planar imaging with a point-like source to evaluate the detector response in terms of intrinsic energy resolution, spatial resolution and detector efficiency and 2) tomographic imaging with a NEMA IEC body phantom to evaluate the image quality in terms of activity recovery coefficient. The experimental results were then compared with the MC simulations performed in the same configuration and with the reference values provided by the manufacturer. The spatial resolution showed good agreement among all three values at 10 cm but had slight deviations (below 1.2 mm) at further distances. Detector efficiency measured from simulation and experiment was slightly higher than the manufacturer value with a relative difference below 7.1%. The activity recovery coefficients were comparable between the simulation and the experiment and reached a maximum value of 0.9 when both attenuation and scatter were corrected. The studied MC model has shown its potential to simulate the Symbia Intevo Bold SPECT scanner.

Index Terms—Monte Carlo simulation, SPECT

I. INTRODUCTION

MONTE Carlo (MC) modeling techniques have been widely used in nuclear medicine over the last 50 years [1]. Single photon emission computed tomography (SPECT) is a key tomographic imaging device that enables 3D reconstruction of the activity distribution from several planar projections acquired by one or several rotating gamma cameras.

Our work is based on a MC model of the Siemens Symbia Intevo Bold SPECT/CT scanner originally introduced in [2]. The goal of this study was to validate this model. To this end, we simulated planar and SPECT images and compared the results to experimental data and to reference values provided by the manufacturer.

II. MATERIALS AND METHOD

The Symbia Intevo Bold SPECT/CT scanner has two detector heads with NaI crystals equipped with low energy high resolution (LEHR) collimators for ^{99m}Tc . Projection images have 256×256 pixels with 2.3976 mm isotropic spacing.

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Data were acquired within a primary energy window of 15%¹ centered around the main photopeak of 140.5 keV and a lower scatter window of 17.5% centered around 120 keV —mainly used to classify the scatter and then correct it from acquired projections prior to tomographic reconstruction.

For planar imaging, a drop of 1.63 MBq ^{99m}Tc solution was placed at the top of a plastic support in air at several distances from the collimator entrance: 5, 10.6, 16.2, 20, 25 and 30 cm. The system spatial resolution was obtained as the full width at half maximum (FWHM) of a Gaussian fit on the projection profiles. The detector efficiency was computed as the ratio of the number of detected photons after subtraction of the background over the number of emitted photons by the source according to the known 1.63 MBq radioactivity. Energy spectra of the source at 30 cm were also recorded separately by the two detectors, without collimators, to measure the intrinsic energy resolution at 140.5 keV.

For tomographic imaging, we used a NEMA IEC body phantom with 6 spheres of inner diameters 10, 13, 17, 22, 28, and 37 mm. The spheres and the background were filled with a homogeneous solution of ^{99m}Tc . Based on [3], we used a concentration ratio of 10:1 with approximately 100 kBq/ml and 10 kBq/ml in the spheres and in the background, respectively. A set of 120 projection images were acquired in “step and shoot” mode, each one during 20 s. The detector trajectory was set to body contour.

Reconstruction was performed with the ordered subset expectation maximization (OSEM) implemented in RTK [4] using 5 iterations and 8 subsets on two possible configurations: correction for attenuation only, and correction for both attenuation and scatter. A calibration factor (CF) to convert the voxel values of the reconstructed image into activity was estimated by taking the ratio of the total activity in the phantom (calculated using the knowledge of the activity concentration and the geometry of the phantom) over the summation of the reconstructed values. We then determined the activity recovery coefficient (ARC) as the ratio of measured activity concentration over the true activity concentration in each sphere. Volumes of interest (VOIs) were segmented manually with 3D Slicer on the CT images of the phantom.

Monte Carlo simulations were performed with GATE version 9.2 built on GEANT4 version 11.1.1. The digitizer chain applied in the simulation, which aims at modeling the detector response, contains an adder, a spatial blurring, and an energy blurring with an energy dependence following the inverse square law. The adder generates a single signal per event where

¹Range of energy windows are defined by the scanner accordingly to the acquisition protocol.

the energy corresponds to the total deposited energy and the position corresponds to the energy-weighted position of all the interactions. The intrinsic spatial blurring was set to 3.9 mm FWHM to model the intrinsic spatial resolution at 140.5 keV of a 9.5 mm thick NaI(Tl) detector [5].

Reference values (measured in accordance with [6]) from the Symbia Intevo datasheet for the studied characteristics are summarized in Table I.

TABLE I
MAIN CHARACTERISTICS OF SYMBIA INTEVO PROVIDED BY THE MANUFACTURER

Parameter	Reference
Intrinsic energy resolution at 140 keV	9.9 %
System resolution at 10 cm and 140 keV	7.5 mm
Detector efficiency at 10 cm	0.0091 %

III. RESULTS

The measured intrinsic energy resolution was 9.45 % at 140.5 keV. This value is close to the manufacturer reference with 4.5 % relative deviation. The measured value was used in the energy-blurring digitizer for all the simulations.

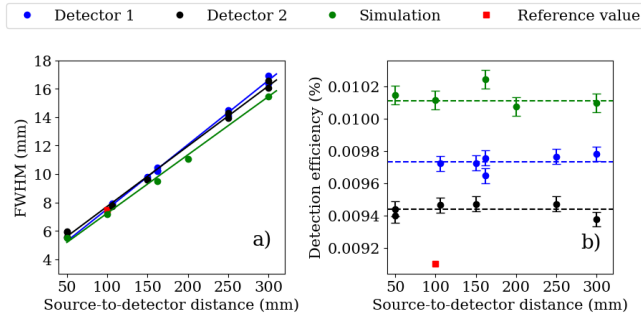


Fig. 1. Spatial resolution (a) and detector efficiency (b) as a function of the source-to-detector distance. Vertical error bars indicate one standard deviation assuming Poisson noise.

System spatial resolution (FWHM) was calculated and plotted as a function of source-to-detector distance in Fig. 1a. A least-squares linear fit was carried out to obtain the relation between those two quantities. The fits showed good agreement at close distances between simulated, experimental and manufacturer values. The deviation increased with the source-to-detector distance but were below 1.2 mm within the studied range of distances.

The detection efficiency was quite independent of the source-to-detector distance (Fig. 1b). The relative differences between the detector sensitivity (averaged over all measurements) estimated from the simulation and each detector head were 3.9 % and 7.1 %. Both experimental and simulated values are larger than and within 12% of the manufacturer value.

The CF was calculated similarly for simulated and experimental projections and the two values were comparable. For instance, with attenuation correction only, 1.06 and 0.94 kBq per voxel value were obtained for experimental and simulated data respectively. Fig. 2a shows one axial slice of the reconstructed image obtained from the experimental data taken with the NEMA IEC body phantom while Fig. 2b shows

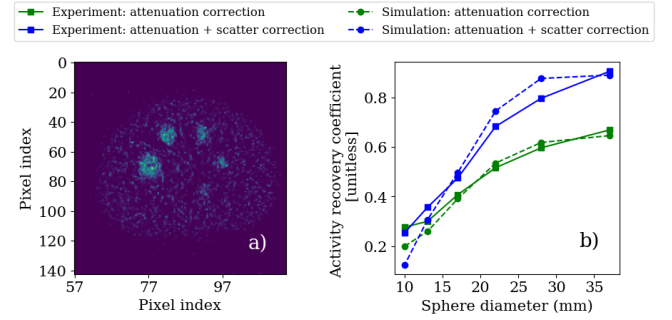


Fig. 2. Axial slice of the reconstructed image of the NEMA IEC body phantom from experimental projections (a); activity recovery coefficient as a function of sphere diameters (b)

the ARC as a function of the diameter of the sphere for the two applied approaches of reconstruction on both simulated and experimental data. The ARC increases as the diameter of the sphere increases and when both attenuation and scatter corrections were applied, the resulting ARC increases and reaches 0.9 for the largest sphere.

IV. DISCUSSION AND CONCLUSIONS

We have evaluated the performance of the Monte Carlo model of the Symbia Intevo Bold SPECT scanner in terms of detection efficiency, spatial resolution and ARC values. A good agreement was obtained between both simulated and experimental data despite some discrepancies, e.g. the ARCs with scatter correction, that still need to be further investigated.

We plan to extend the study to evaluate the level of agreement of the exponential data consistency conditions [7] between simulated and experimental data and their ability to detect motion which was demonstrated on simulations only [8].

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