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Original Article

Simulation of a Quality Control Jaszczak Phantom with SIMIND Monte Carlo and Adding the Phantom as an Accessory to the Program

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Abstract

Introduction
Quality control is an important phenomenon in nuclear medicine imaging. A Jaszczak SPECT Phantom provides consistent performance information for any SPECT or PET system. This article describes the simulation of a Jaszczak phantom and creating an executable phantom file for comparing assessment of SPECT cameras using SIMIND Monte Carlo simulation program which is well-established for SPECT.
Materials and Methods
The simulation was based on a Deluxe model of Jaszczak Phantom with defined geometry. Quality control tests were provided together with initial imaging example and suggested use for the assessment of parameters such as spatial resolution, limits of lesion detection, and contrast comparing with a Siemens E.Cam SPECT system.
Results
The phantom simulation was verified by matching tomographic spatial resolution, image contrast, and also uniformity compared with the experiment SPECT of the phantom from filtered backprojection reconstructed images of the spheres and rods. The calculated contrasts of the rods were 0.774, 0.627, 0.575, 0.372, 0.191, and 0.132 for an experiment with the rods diameters of 31.8, 25.4, 19.1, 15.9, 12.7, and 9.5 mm, respectively. The calculated contrasts of simulated rods were 0.661, 0.527, 0.487, 0.400, 0.23, and 0.2 for cold rods and also 0.92, 0.91, 0.88, 0.81, 0.76, and 0.56 for hot rods. Reconstructed spatial tomographic resolution of both experiment and simulated SPECTs of the phantom obtained about 9.5 mm. An executable phantom file and an input phantom file were created for the SIMIND Monte Carlo program.
Conclusion
This phantom may be used for simulated SPECT systems and would be ideal for verification of the simulated systems with real ones by comparing the results of quality control and image evaluation. It is also envisaged that this phantom could be used with a range of radionuclide doses in simulation situations such as cold, hot, and background uptakes for the assessment of detection characteristics when a new similar clinical SPECT procedure is being simulated.
Keywords: Jaszczak Phantom, Quality Control, SIMIND Monte Carlo, SPECT

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1. Introduction

Monte Carlo simulations are nowadays employed as an essential tool in nuclear medicine imaging, both in single-photon emission computed tomography (SPECT) and in positron emission tomography (PET) [1-3].

One of the aims of a medical physicist involved in nuclear medical imaging research is to optimize the design of imaging systems and to improve qualitative and quantitative accuracy of reconstructed images.

The quality assurance of nuclear medicine imaging equipment has been an important issue and recommended by a number of highly regarded institutions and organizations [4-8]. One important area of measurement is the assessment of the quality of SPECT images. The design of SPECT and PET systems using the Monte Carlo method has received considerable attention and a large number of applications were the result of such investigations [9, 10]. We used the SIMIND Monte Carlo simulation program [11, 12] which is well established for SPECT with low-energy photons for photonic physics and other applications. The program is freely downloadable from the related site: www.radfys.lu.se/simind. This program was originally designed for the calibration of whole-body counters, but soon evolved to simulate scintillation cameras [1, 12]. It is now available in Fortran-90 and can be run on major computer platforms including PCs. The SIMIND program actually consists of two programs, CHANGE, which defines the parameters, and SIMIND, which performs the actual simulation. The program can simulate non-uniform attenuation from voxel-based phantoms and includes several types of variance reduction techniques.

Assessment of the quality control parameters in simulated systems is important for verification. There is therefore a need for a simulated phantom that can be easily used on a routine basis if the quality control of a simulated SPECT system is to be verified. This paper describes the simulation and initial use of such a phantom and adding the phantom as an input file to the program.

2. Materials and Methods

In this work, we used the SIMIND Monte Carlo code, which is well established for SPECT with low-energy photons and simulate a dual-head SPECT camera (E.Cam TM, Siemens Medical Systems) [13].

The phantom design was based on the Deluxe model of a SPECT Jaszczak phantom [14, 15] (Figure 1). The Deluxe Phantom is used for high resolution cameras whereas the standard phantom is used for lower resolution cameras, with discrete cavities of either hot or cold regions that could be used to assess image quality. The phantom was constructed of a clear Acrylic Plexiglass material and consists of six spheres with different diameters (9.5, 12.7, 19.1, 15.9, 25.4, and 31.8 mm) and 148 rods (4.8, 6.4, 7.9, 9.5, 11.1, and 12.7 mm). Technical drawings are provided in Figure 1. Specification of the phantom is shown in table 1. The Phantom is used for [14]: (a) system performance evaluation of collimator, artifacts, calibration, and parameters reconstruction, (b) acceptance testing, (c) routine quality, assurance, and control, (d) evaluation of center-of-rotation error, (e) evaluation of non-uniformity artifact, (f) evaluation of changes of radius-of-rotation on spatial resolution, (g) evaluation of reconstruction filters on spatial resolution, (h) evaluation of attenuation and scatter compensation, (i) single slice volume sensitivity, (j) total system volume sensitivity, and (k) lesion detectability

Table 1. Specification of a Deluxe Jaszczak phantom used for simulation

Cylinder Interior Dimensions: Diameter: 21.6 cm and heigh: 18.6 cm
Cylinder Wall Thickness: 3.2 mm
Volume: 6.75 L
Volume with Inserts: 6.1 L
Cold Rod Insert Height: 8.8 cm
Height of Spheres from Base Plate: 12.7 cm

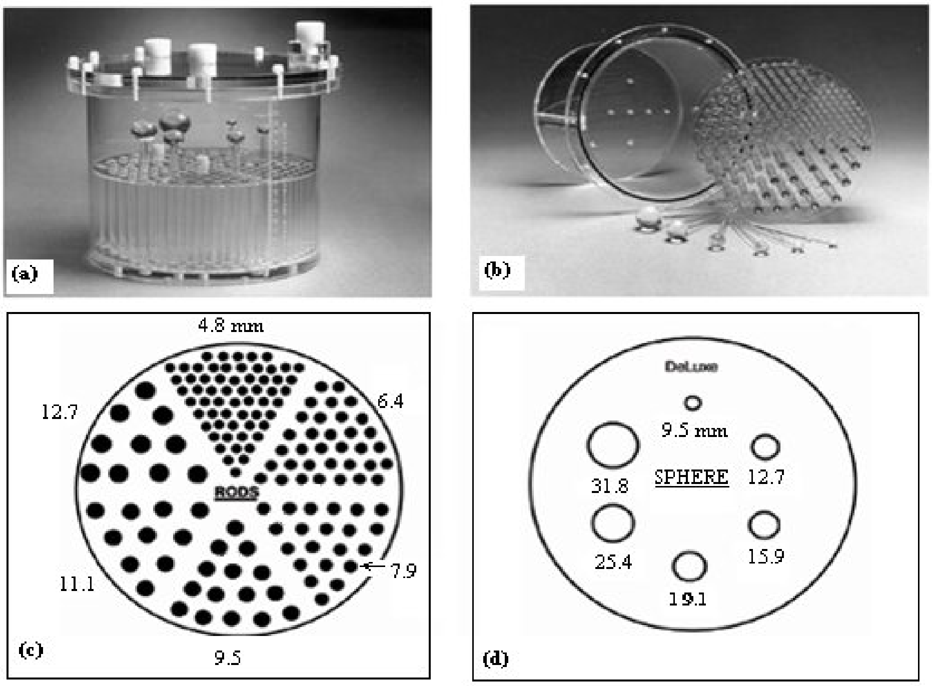

Figure 1. A Deluxe Jaszczak phantom Model ECT/FL-DLX/P. (a) components (b) a cross-sectional schematic drawing of a Deluxe Jaszczak phantom showing the position and diameter of 148 rods in 6 sectors, (c) and 6 spheres, and (d) the diameters for the objects are expressed in mm.

The Phantom and related structures' sizes and also its structural material were defined to the SIMIND as an input file.

The acquired and the SIMIND simulated SPECT of the phantom were generated using the phantom filled with 370MBq ^{99m}Tc. The acquisition parameters were 128×128 matrix, 128 views, 1.23 zoom factor, 3.9 mm pixel size, and images were reconstructed by filtered reconstruction using a Butterworth filter with a cut-off frequency of 0.5. The qualities of the produced images were compared in terms of image contrast and spatial resolution [16]. Image contrast was calculated according to the method described by Bahreyni Toossi et al. [13]. Briefly, Image contrasts for the six spheres were calculated by Equations (1) and (2):

$$\text{ContrastH} = N_{sp} / N_{b} \quad (1)$$

$$\text{ContrastC} = 1 - (M_{sp} / M_{cy}) \quad (2)$$

Where N_{sp} and N_b are the mean pixel values for the hot spheres and background, respectively. M_{sp} and M_{cy} correspond to the minimum pixel value in cold spheres and the maximum pixel value in the phantom cylinder, respectively. Spatial tomographic resolution (in mm) was obtained by the smallest visible and recognizable rods.

3. Results

Figure 2 shows the acquired and the SIMIND simulated SPECT reconstructed images of the Deluxe model of a SPECT Jaszczak phantom. The hot phantom was also simulated and an SPECT acquisition is shown in Figure 3.

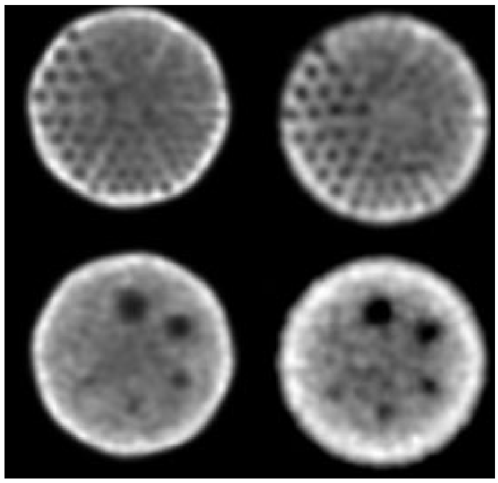

Figure 2. Images of experimental (right) and simulated (left) SPECT Jaszczak Deluxe phantom acquisition, consisting of six cold spheres and 148 rods, filled with 370MBq ^{99m}Tc. Recorded events were 128 Mcounts for simulations.

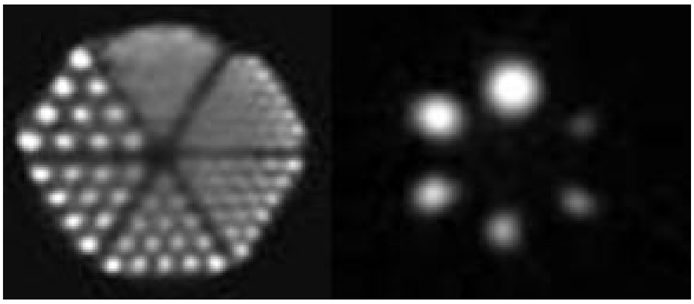

Figure 3. Images of simulated SPECT Jaszczak Deluxe phantom acquisition, consisting of 148 rods and six hot spheres with different diameters (9.5, 12.7, 15.9, 19.1, 25.4, and 31.8 mm) filled with 10 mCi ^{99m}Tc. The acquisition and reconstruction parameters were similar to Figure 2.

Table 2. Calculated contrast of Jaszczak phantom spheres from reconstructed SPECT acquisitions.

Condition	Spheres diameter (mm)					
	31.8	25.4	19.1	15.9	12.7	9.5
Cold Experiment	0.774	0.627	0.575	0.372	0.191	0.132
Cold Simulated	0.661	0.527	0.487	0.400	0.230	0.200
Hot Simulated	0.920	0.910	0.880	0.810	0.760	0.56

Results for calculated contrast of the simulated and experiment Jaszczak phantom spheres from reconstructed SPECT were shown in Table 2. From Figure 2 it is evident that reconstructed spatial resolution of both SPECTs is nearly equal to 9.5 mm.

In order to add flexibility of the phantom for selecting the objects by user, an executable phantom file was also created and produced to the code. Using the file, user may select the number, sizes, and also shapes of the phantom objects.

4. Discussion

Quality control is now a mandatory practice for any diagnostic imaging department and may be the subject of review and audit procedures to ensure the appropriate standard of service [17, 18]. Such procedures would also be a requirement for any department wishing to achieve a level of formal accreditation. We have described the design, construction, and simulation of a Jaszczak Deluxe phantom produced by SIMIND Monte Carlo program.

Implementing such a phantom should provide a proper comparison of the assessment of SPECT image performance more extensively practicable by experiment and simulated systems. In Figure 2, cold rod pie slices allow spatial resolution to be assessed, whereas, the cold spheres allow both resolution and image contrast to be evaluated. Notice a slight ring artifact in the spheres image, midway between the center and edge of the phantom; this is likely due to the high count acquisition (i.e., the ring would likely not be visible in the count statistics of common clinical study). The spatial resolution and also image contrast appear better for hot objects in Figure 3. From Table 2 it can be seen that contrast decreased with decreasing sphere diameter, as would be expected. The calculated contrasts for cold and hot simulated spheres with the diameters larger than 15.9 mm have a remarkable value compared with the diameter of 9.5 mm. Similar results were also seen for the experiment with an apparent similarity for sphere sizes above the diameter of 15.9 mm. However, there was no significant change in contrast for the 12.7- and 9.5-mm spheres. Therefore, the obtained contrast similarity for cold spheres, as an imaging parameter, is another evident for verification of the simulation.

5. Conclusion

Implementation of the SIMIND Monte Carlo program with the executable Jaszczak phantom file and also the related input file may be considered as a benefit, from the point of view of time saving and providing flexibility, for those who intend to plan a SPECT simulation study with the phantom. We would also suggest that the same phantom should be used for the simple assessment of X-ray CT images and the assessment of image offset for SPECT/CT and PET/CT systems.

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References

1. Ljungberg M, Strand SE. A Monte Carlo program for the simulation of scintillation camera characteristics. Comp Meth Progr Biomed. 1989;29(4):257-72.
2. Ljungberg M. Simulation Techniques and Phantoms. Emission Tomography: The Fundamentals of PET and SPECT. In: Wernick M, Aarsvold J, editors. New York, USA: Academic Press Inc.; 2000.
3. Zaidi H. Relevance of accurate Monte Carlo modeling in nuclear medical imaging. Med Phys. 1999;26(4):574-608.
4. Siegel JA, Group AAoPiMST. Rotating Scintillation Camera SPECT Acceptance Testing and Quality Control: Report of AAPM SPECT Task Group: American Inst. of Physics; 1987.
5. Hines H, Kayayan R, Colsher J, Hashimoto D, Schubert R, Fernando J, et al. National Electrical Manufacturers Association 2000 Recommendations for Implementing SPECT Instrumentation Quality Control. J Nucl Med. 2000;41(2):383-9.
6. National Electrical Manufacturers Association (NEMA). Performance Measurements of Scintillation Cameras. NEMA . Washington; 2001.p.1-45.
7. Agency IAE. Quality Control of Nuclear Medicine Instruments 1991: International Atomic Energy Agency; 1991.
8. IPEM 86: Quality Control of Gamma Camera Systems. Institute of Physics and Engineering in Medicine, York; 2003.
9. Bradshaw J, Burnham C, Correia J, Rogers WL, Clinthorne NH. Application of Monte Carlo methods to the design of SPECT detector systems. IEEE Trans Nucl Sci. 1985;32(1):753-7.
10. Lupton LR, Keller NA. Performance study of single-slice positron emission tomography scanners by Monte Carlo techniques. IEEE Trans Med Imaging 1983;2(4):154- 68.
11. Dewaraja YK, Ljungberg M, Koral KF. Characterization of Scatter and Penetration Using Monte Carlo Simulation in 131I Imaging. J Nucl Med. 2000;41(1):123-30.
12. Ljungberg M. The SIMIND Monte Carlo program. In: Ljungberg M, Strand SE, King MA, editors. Monte Carlo calculation in nuclear medicine: Applications in diagnostic imaging. Bristol: IOP Publishing; 1998. p. 145-63.
13. Bahreyni Toossi MT, Pirayesh Islamian J, Momennezhad M, Ljungberg M, Naseri Sh. SIMIND Monte Carlo simulation of a single photon emission CT. J Med Phys. 2010; 35(1): 42-7.
14. Groch MW, Erwin WD. Single-photon emission computed tomography in the year 2001: Instrumentation and quality control. J Nucl Med Technol. 2001;29(1):9-15.
15. Flanged Jaszczak ECT Phantoms. Available from: http://www.spect.com/pub/Flanged_Jaszczak_Phantoms.pdf . Accessed. Aug 10, 2012.

16. Holstensson M, Hindrof C, Ljungberg M, Partridge M, Flux GD. Optimization of energy-window setting for scatter correction in quantitative 111in imaging: Comparison of measurements and Monte Carlo simulations. Cancer Biother Radiopharm. 2007;22(1):136-42.
17. Padhy AK, Agency IAE, Solanki KK. Nuclear medicine resources manual: International Atomic Energy Agency; 2006.
18. Jarritt PH, Perkins AC, Woods SD. Audit of Nuclear Medicine Scientific and Technical Standards. Nucl Med Commun. 2004; 25(8):771-5.