GATE simulations for small animal SPECT/PET using voxelized phantoms and rotating-head detectors

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***Abstract*– GATE (Geant4 Application for Tomographic Emission) simulation toolkit has become a well validated toolkit for the simulation of SPECT and PET systems. A very important feature of GATE is that it allows modelling of time-dependent phenomena. In addition, complex voxelized object such as realistic anthropomorphic or small animal phantoms can be used as emission sources. In this work two small field of view scanners have been evaluated experimentally, modelled in GATE and mice studies have been simulated using MOBY mouse phantom. Two scanners have been simulated: The first one is a mouse sized gamma camera (field of view is 5x10cm) that is based on two Hamamatsu H8500 PSPMTs, a NaI pixelized scintillator and a tungsten collimator with hexagonal parallel holes. The system has been modelled in GATE and good agreement has been found between simulation and experimental results. MOBY mouse has been introduced as a voxelized source and planar and tomography simulations were carried out. The second small animal PET scanner has four heads which are equipped with a H8500 PSPMTs and a pixelated LYSO scintillator. System's geometry has been modelled in GATE. The results of both systems simulation and comparison between simulation and experimental data are presented. In addition, mouse bone scans were simulated both for SPECT and PET and tomographic image are derived. The presented methodology is aimed to provide all necessary tools in order to perform optimized simulations of small animal emission tomography scans..**

I. Introduction

MONTE Carlo simulations are widely used in Nuclear Medicine especially in the development of new imaging instrumentation, image acquisition strategies and processing and reconstruction methods. GATE (Geant4 Application for Tomographic Emission) finds high acceptance among Monte Carlo users and is considered as the standard simulation code in emission tomography [1]. A large variety of clinical and prototype systems have been simulated using GATE. Additionally many tools are consistently being developed by the members of the openGATE collaboration as well as many GATE users; thus it is possible to perform more complicated simulations. Among the attractive features of GATE (including large variety of geometries, moving sources, time management), its ability to manipulate voxelized phantoms allows the simulation of realistic-like experiments.

Two are the main categories of voxelized phantoms: the first are clinically obtained data such as Computerized Tomography (CT) images or Emission Tomography (ET) examinations; the second are voxelized phantoms which are usually based on detailed MRI data. In literature NCAT torso phantom [2], Zubal brain phantom [3] and MOBY mouse phantom [4] are used in a number of simulation studies. Since the geometry of these phantoms is accurately described and since the emission and attenuation properties are controlled by the user, they are perfect tools for the study of a number of parameters of interest in realistic-like scans. In addition organs movement (cardiac cycle, respiration etc) can be simulated and gated studies can be performed as well as object movement e.g. respiration correction algorithms can be evaluated.

In this work two dedicated small field of view scanners have been simulated in GATE and MOBY mouse phantom has been used, as the emission source. Dedicated scanners both for SPECT and PET have been developed by a number of groups and are now commercially available. On the one hand, they are a tool for biologists in order to study novel radiopharmaceuticals and animal models. On the other hand, they provide the means for continuous research in detector design, study of new materials and image reconstruction and processing procedures. In the latter case, simulation is a standard tool for detectors' optimisation and the use of small animal voxelized phantoms provides additional accurate tools for this. Section II briefly describes the two cameras that have been simulated and the software tools that have been used. In section III the simulation procedures and the simulated experiments are descried and results are presented in section. Finally discussion and final conclusions are drawn in sections V and VI respectively.

II. Materials

A. Description of the mouse sized gamma camera

The mouse sized gamma camera consists of two flat panel PMT's attached to a pixelated NaI(Tl) crystal array and a high resolution parallel hole collimator optimized for Tc99m compounds. The H8500 flat panel PMT is square with

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external dimensions 52mm x 52mm and 34mm thick and has an active area of 49mm x 49mm. The NaI(Tl) crystal has an active area of 98mm x 48mm approximately to match the active region of the flat panel phototubes and crystal pixels are 1mm x 1mm x 5mm with 0.2mm septa. The array is viewed through a 3 mm glass window and encapsulation is completed by an aluminum cover 50μm thick. The crystal array is surrounded by a protective outer perimeter of 2mm crystal pixels to maintain the integrity of the scintillator. A high resolution parallel hole collimator with 25mm thickness and an active area of 52mm x 105mm is used. The flat-to-flat distance of the hexagonal holes is 1.2mm and the septal distance is 0.2mm and 0.4mm thick (septum walls are either single or double owing to manufacturing reasons). A tungsten 8mm thick box with external dimensions 140mm x 82mm x 107mm is used to host the detector. An aluminium entrance window, 0.5mm thick, is placed in front of the collimator.

B. Description of the mini PET

The small animal PET system consists of 4 detector heads with a distance of 80mm between the opposite detector heads. Each detector head includes a block LSO crystal with 30 crystals in the transaxial and 35 crystals in the axial direction and total dimensions of 48mm x 56mm and 12mm thick. The crystal dimensions are 1.5mm x 1.5mm x 12mm . The block detector is attached to a H8500 flat panel position sensitive PMT. The coincidence time window is 12ns and the energy resolution is 6.63% .

C. GATE and computer resources

GATE is a Monte Carlo simulation package optimized for simulations in emission tomography. GATE has been well validated and is currently used by a large number of groups worldwide. It is an open source software is an open-source extension of the GEANT4 Monte Carlo toolkit and the ROOT object oriented data analysis framework. In this work Gate version 3.0.0 was used. Simulations were carried out on cluster of 54 CPUs (27 dual CPUs) with 2GBytes of RAM each.

D. Description of MOBY phantom

MOBY phantom is a realistic and flexible 4D digital mouse, based on high-resolution 3D magnetic resonance microscopy (MRM) data. The phantom models organ shapes realistically while maintaining the flexibility to model anatomical variations and involuntary motions such as the cardiac and respiratory motions. More information about MOBY's construction and use can be found elsewhere [4].

III. Methods

A. Simulation of the mouse sized camera and the small PET

The geometry of the mouse sized gamma camera was accurately described in GATE. Two basic parameters were measured experimentally and compared with simulation data; spatial resolution and sensitivity. In order to experimentally measure spatial resolution a thin capillary (1.1mm inner diameter and 8cm long) was filled with a Tc99m solution. Total activity was 14,837kBq (401 μCi). The capillary was placed with a slight rotation (~3 crystal pixels wide) and three profiles were averaged. Measurements were taken at distances 4, 7, 10 and 13cm from the detector's surface. In order to experimentally measure sensitivity the results from the same experiment were used.

The geometry of the mini PET camera was accurately described in GATE. Since the system is currently being finalized no experimental data were collected in order to validate its simulation.

In GATE photon histories were generated in 4π sr. The physical processes (photoelectric effect, Compton scatter and Rayleigh scattering) were modelled using the low-energy electromagnetic package of GEANT4, while gamma-conversion was disabled. A ±10% energy cut was applied both in simulated and experimental acquisition.

B. Use of MOBY phantom in GATE

The original MOBY consists of 110 slices with size 256x256 pixels. Two separate files are necessary; the attenuation map and the emission map. The data format of the MOBY raw binary 3-dimensional maps have first to be converted into an Interfile format required by the Interfile reader of GATE before they can be used either as a voxelized phantom or source.

In the current study and in order to speed up simulation the MOBY's size was reduced to 110x32x32. In this case each voxel corresponds to 1.5mm, which is comparable with the resolution of the system. Thus this approximation can be used for proof of concept.

C. Simulated bone scan with the mouse sized camera

Initially, a planar bone scan was simulated; Activity was supposed in MOBY bones (20Bq/voxel) and acquisition time was 40sec. A dual head SPECT system was simulated, in order to reduce the acquisition time of the simulated experiment. The results were compared with a real bone scan. Following, a SPECT bone scan was simulated assuming two mouse-sized detector heads; Activity of 100Bq/voxel was used and 36 projections were obtained from 0o to 360o with a 10o step. The distance between the two heads was 80mm. Slices were reconstructed using av ML-EM and 30 iterations. The system matrix was calculated using the geometric approach and object to collimator distance was taken into account. Both planar and SPECT bone scans were performed twice; without and with an attenuation map.

D. Simulated bone scan with the small PET camera

A bone PET scan was simulated; Continuous rotation with speed 0.5deg/sec has been assumed. Total acquisition time is 180sec. A rotation step of 2.5deg and 36 steps resulted to 144 projection angles. Slices were reconstructed using OSMAPOSL in STIR [5] and 6 iterations. Again this experiment was performed without and with an attenuation map.

IV. Results

In Figure 1 the simulation configuration in GATE of the (a) SPECT bone scan and (b) PET bone scan are shown.

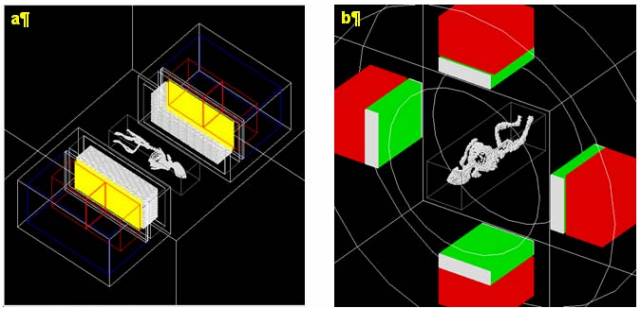

Fig. 1: Simulation configuration in GATE of the (a) SPECT bone scan and (b) PET bone scan.

A. Validation of the mouse sized camera

In Fig. 2 the experimental and simulation results for spatial resolution and sensitivity are presented in (a) and (b) respectively. Very good agreement between simulation and experimental data is observed.

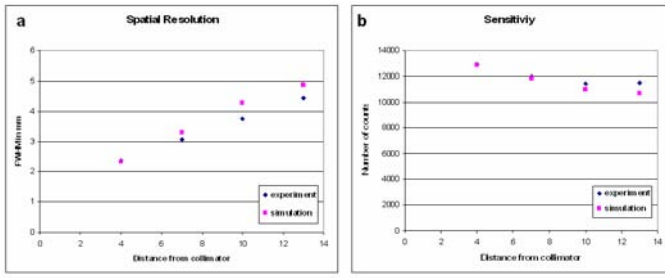

Fig. 2: Comparison between experimental and simulation data for the mouse sized camera. (a) Spatial resolution and (b) sensitivity. Results show very good agreement.

B. Images of MOBY with the mouse sized camera

In Fig. 3 the results from MOBY simulations with the mouse sized camera are presented. Images using only emission map (b, c, d) and both emission and attenuation map (e, f, g) are presented. The planar images are compared with a real mouse scan using Tc^{99m}-MDP. Simulation provided comparable results.

However, it must be emphasized that the real scan has approximately 190,000 counts, while the simulated scan has ~30,000 counts. In addition, the real scan was performed a few minutes after injection, thus kidneys and bladder are visible. Finally the position of MOBY is different compared to the real mouse. The most important difference is that both up legs are below the lungs, thus they contribute to the total activity. On the other hand, the legs of the real mouse are free. Two sets of four successive slices are presented as well. In planar image, as well as in reconstructed slices, the use of an attenuation map increases image blurring as it is expected.

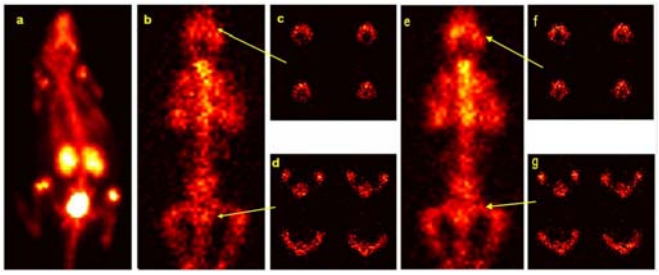

Fig. 3: Studies with the mouse sized camera. (a) Bone scan in an alive mouse injected with Tc99m-MDP. (b) Simulated planar scan, (c) and (d) two sets of coronal slices, without attenuation map. (e), (f) and (g) Similar images with the use of an attenuation map.

C. Images of MOBY with the small PET camera

The results from the similar studies using the small PET camera are presented in Fig. 4. Both emission and attenuation map were used in this case.

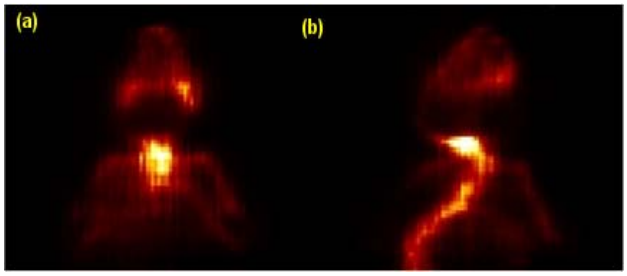

Fig. 4: Simulated studies with the small PET camera. (a) Saggital slice. (b) Transverse slice. Slices were reconstructed using OSMAPOSL in STIR and 6 iterations.

Although the comparison with real data is not performed yet, images show good agreement with already published data.

V. Discussion

The presented results are a "proof of concept" for the successful simulation of mouse studies. The main limiting factor of this study is sensitivity versus simulation time and will be further investigated as well as factors like: i) MOBY's resolution, ii) use of variable voxel size technique, iii) use of a cluster, iv) use of fewer MOBY slices.

The presenting authors aim in developing all necessary methods to facilitate the use of MOBY in GATE environment, in order to provide a valuable tool for the evaluation of animal prototypes in realistic-like imaging conditions. Beside the tools that allow easy manipulation of MOBY into GATE, additional scripts for tomographic reconstruction from ROOT files have been built using a custom made ML-EM algorithm and STIR. These scripts will possibly added in a future GATE version. Since MOBY is a 4D phantom, this work could be further extended and allow the study of organs movement, respiration and simulation of radiopharmaceuticals kinetics.

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