Realistic Pathological Simulations of the NCAT and Zubal Anthropomorphic Models, Based on Clinical PET/CT Data

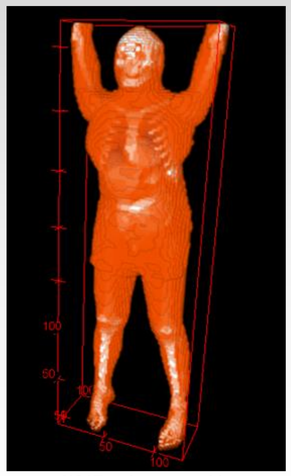
P. Papadimitroulas[1], G. Loudos[2], A. Le Maitre[3], N. Efthimiou[1], D. Visvikis[3], G. Nikiforidis[1], G.C. Kagadis[1]

[1]Department of Medical Physics, University of Patras, Greece
[2]Department of Medical Instruments Technology, Technological Educational Institute of Athens, Greece
[3]Image Processing Laboratory (LaTIM), National Institute of Health and Medical Research, Brest, France

Overview / Conclusion

Realistic clinical PET simulations were performed in the present study. Patient anatomical and functional characteristics were imported in the used computational models.

- Two different oncology clinical pathologies were simulated with the **GATE** Monte Carlo simulation toolkit
- The STIR software was used for data reconstruction (MLEM)
- 3 different methods for tumor simulation were tested :
  i. Homogeneous tumor activity distribution
  ii. Heterogeneous tumor activity distribution
  iii. Partial Volume Corrected (PVC) heterogeneous tumor activity distribution
- Quantitative analysis was performed in central ROIs within different organs for each case
- Profiles within the simulated and the clinical tumors are also presented for patient1
- Brain profiles are also presented in comparison with the clinical image
- High accuracy was performed in the simulated tumors with heterogeneity activity distribution and PVC method, with differences < 10 % compared to the clinical data



NCAT anthropomorphic computational model

Introduction

Over the past years the introduction of computer science in the field of medical physics is rapidly evolving. Monte Carlo simulations are more and more widely used in Nuclear Medicine as a tool that could be used in the clinical practice. GATE Monte Carlo toolkit provides high accuracy in physics modeling.

Positron Emission Tomography (PET) imaging is still considered as the state of the art for oncology diagnosis. ^{18}F-FDG is the most widely used radiotracer in such applications. Optimization of the quantitative use of PET in clinical practice data and imaging processing methods is also a field of intense interest and research.

GATE is a Monte Carlo simulation toolkit based on the precise modeling of the physical processes of the Geant4 code. It is dedicated for Nuclear Imaging applications (SPECT and PET) with large flexibility in using voxelized phantoms and complex geometries with movement incorporation. GATE is extensively validated, although realistic simulations are highly demanding in computational resources.

Using MC simulated datasets in PET is the most reliable approach to validate and assess the performance of image processing algorithms such as:
Partial volume effects correction, denoising, segmentation, reconstruction and automated detection.

Objectives

The **major aim** of the current study, is to standardize a method for **realistic patient-specific oncology simulations**. A dataset of realistic PET simulations for different type of tumors is presented, taking into account the heterogeneity activity distribution of the clinical data. Therefore:

- Patient-specific characteristics were inserted in simulations
- Simulated tumors variability was tested
- Partial Volume Correction method was applied in the simulations
- Quantitative comparison between simulated and clinical PET/CT data was made
- Validation / Evaluation of the procedure was performed
- Finally, a PET simulated database with different clinical oncology pathologies (using computational anthropomorphic models) was created

Materials / Methods

Clinical PET/CT data of oncology patients were used as the basis of the simulated variability, inserting patient-specific characteristics in the **NCAT** and **Zubal** anthropomorphic phantoms.

i. GATE Monte Carlo toolkit was used (version 6.1)
ii. The Siemens **Biograph-6 PET** clinical scanner was simulated
iii. The standard computational anthropomorphic models NCAT & Zubal were used for the 2 pathological cases
iv. The models were adapted to the CT data (organ shapes/sizes), using the **NURBS** algorithm
v. The activity distribution was derived from the PET images
vi. The tumors of both patients were segmented and inserted in the phantom, using:
  - Homogeneous activity distribution
  - Heterogeneous activity distribution in voxel-by-voxel level
  - Heterogeneous activity distribution in voxel-by-voxel level with contrast enhancement for PVC.
vii. The STIR open-source software was used for the reconstruction of the simulated data, with the MLEM iterative algorithm

Technical Features

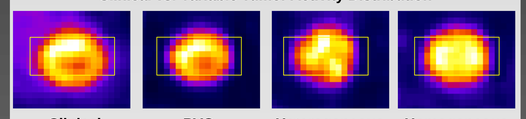
- The simulations were carried out in the GateLab GRID
- 500 CPUs were used in parallel mode for each simulation
- An average of ~5,000 CPU hours are needed for 1 simulation with realistic characteristics
- The “Standard Model” of the Geant4 physics was selected
- No cuts - No Variance Reduction Techniques (VRTs) were applied in the physical processes
- 1 iteration was performed in the MLEM reconstruction algorithm in the STIR software
- The clinical data were taken by a Philips GEMINI system and the RAMLA software was used for the reconstruction
- Gaussian filter was used in the clinical images

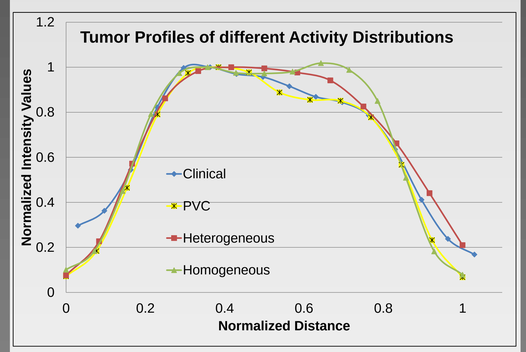
Results I

Patient 1: Lung tumor

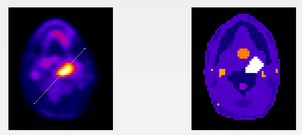

Clinical Image **NCAT Phantom** **Simulated Image**

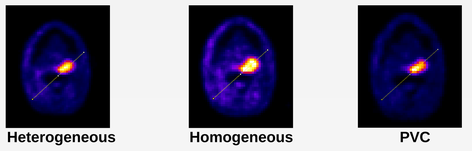
Clinical vs. Variable Tumor Activity Distribution

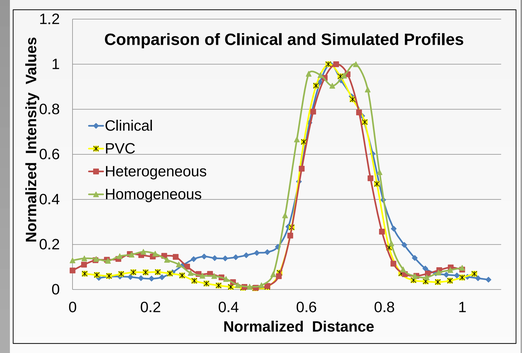

Clinical **PVC** **Heterogeneous** **Homogeneous**



Patient 2: Brain tumor


Clinical Image **Zubal Phantom**


Heterogeneous **Homogeneous** **PVC**



- Post filtering was applied to the reconstructed images for the comparison of the profiles within the tumor (patient1) and of the profiles within the brain phantom (patient2). Gaussian blur filter (ImageJ) was set equal to 0.7.
- Mean values of ROIs for the organs of interest are presented in Table I. The difference between the simulated output and the clinical organs mean values are also calculated. In the homogeneous activity distribution central ROIs of the organs were chosen.

Results II

Mean Organ Values	Simulated	Clinical	Difference
Patient 1 (NCAT) Tumor / Lung			
Homogeneous Tumor (central ROIs)	15.1576	15.0281	0.85 %
Heterogeneous Tumor	13.847	15.0281	7.85 %
PVC Tumor	15.977	15.0281	5.94 %
Patient 2 (Zubal) Tumor / Muscle			
Homogeneous Tumor (Central ROIs)	10.113	10.879	7.04 %
Heterogeneous Tumor	10.133	10.879	6.85 %
PVC Tumor	10.958	10.879	0.75 %

Discussion

- Realistic Monte Carlo simulations play a crucial role in the evaluation of new image processing algorithms. Monte Carlo data are reproducible and the overall process can be accurately modeled. The results of the simulations show very good agreement with the clinical data, where the mean organ values show differences < 10 %. PVC with contrast enhancement improve the accuracy of the tumor activity variability modeling.
- Different PET systems were used, as well as different reconstruction algorithms were applied in the clinical and the simulated data.
- Next steps of this study are the creation of a realistic database with the optimum parameters for the most accurate realistic patient-specific Monte Carlo simulations.

References

i. S. Jan *et al.*, "**GATE V6: a major enhancement of the GATE simulation platform enabling modeling of CT and radiotherapy**," Phys Med Biol 56, 881-901, 2011
ii. A.Le Maitre *et al.*, “**Incorporating patient specific variability in the simulation of realistic whole body ^{18}F-FDG distributions for oncology applications**” Proceedings of the IEEE, 2009
iii. N. Karakatsanis *et al.*, "**A Comparative Evaluation of two commercial PET Scanners using GATE**", Nuclear Instruments and Methods in Physics Research Section A 569, 368-372, 2006
iv. K. Thielemans *et al.*, “**STIR: Software for Tomographic Image Reconstruction Release 2**” Phys Med Biol 57, 867-883, 2012

Acknowledgments

This research has been co-financed by the European Union (European Regional Development Fund—ERDF) and Greek national funds through the Joint Research and Technology Program between Greece and France (2009–2011).

Contact Info

George C. Kagadis, PhD
e-mail: gkagad@gmail.com
Tel: +30 2610 969146
Web: www.kagadis.gr