Preliminary Investigation of Axial and Angular Sampling in Multi-Pinhole AdaptiSPECT-C with XCAT Phantoms

Navid Zeraatkar, Kesava S. Kalluri, Arda Könik, Joyeeta M. Mukherjee, Joyoni Dey, Justin C. Goding, Yulun He, Timothy J. Fromme, Benjamin Auer, Soumyanil Banerjee, Greta Mok, George I. Zubal, Lars R. Furenlid, and Michael A. King

Abstract– **Most brain SPECT imaging procedures are currently being performed using general-purpose systems which are unable to fully take advantage of the use of clinically available agents. We are designing a novel multi-detector, multi-pinhole modular dedicated brain SPECT imaging system called AdaptiSPECT-C to improve sensitivity and resolution, and address the static and dynamic imaging needs. The aim of this study was to evaluate the axial and angular sampling sufficiency of a preliminary design of the system using simulation of the XCAT and a customized Defrise phantom. The simulator as well as image reconstruction projector is based on analytical modeling. The results provided an insight into the axial and angular sampling of the region-of-interest of the AdaptiSPECT-C system and possible approaches to enhance the image quality in this regard showing that the application of approaches for increasing axial and angular samples including multipinhole shattering concept can enhance the quality of the reconstructed images.**

I. Introduction

NEUROLOGICAL disease diagnosis may be improved by exploiting the use of both new and existing clinical imaging agents with systems that are capable of performing both static and dynamic imaging [1-4]. Most brain SPECT imaging procedures are currently being performed using non-dedicated systems that are somewhat limited in their capability and are unable to fully take advantage of the use of clinically available agents.

University of Massachusetts Medical School (UMMS) and the University of Arizona (UA) are designing a novel multi-detector, multi-pinhole modular dedicated brain SPECT imaging system called AdaptiSPECT-C. Goals of the AdaptiSPECT-C are to achieve an improvement in sensitivity and resolution, and address the static and dynamic imaging needs in comparison to the clinically available imaging systems. AdaptiSPECT-C will be capable of automatically adapting its imaging characteristics (aperture size and number of pinholes open for imaging) in response to the imaging tasks and individual patients.

The primary focus of this study was to evaluate the axial and angular sampling sufficiency [5-7] of a preliminary design of AdaptiSPECT-C using simulation of the XCAT [8] and a customized Defrise phantom [9].

II. Methods

A. Preliminary Design of AdaptiSPECT-C

The preliminary design of the system consists of three detector rings: caudal ring and middle ring each having 9 heads while the quasi-vertex ring possesses 5 heads (see Fig. 1). Each detector is combined with a direct double knife-edge aperture, 4 mm in diameter. The volume of interest for imaging was a 21 cm-diameter spherical volume.

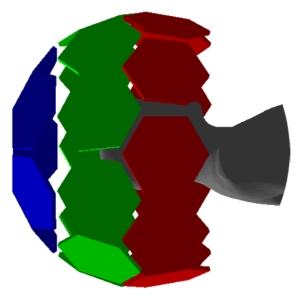

Fig. 1. Lateral view of the preliminary design of AdaptiSPECT-C together with a cropped XCAT phantom positioned inside it. This design consists of three detector rings: caudal ring with 9 detectors (shown in red), middle ring with 9 detectors (shown in green), and quasi-vertex ring with 5 detectors (shown in blue).

B. Analytical Simulator and Image Reconstruction

We developed an algorithm for simulation of AdaptiSPECT system based on analytical modeling [10]. A projector software was developed for generation of projection images for any voxelized phantom. Various physical characteristics of the system including the general geometry, aperture size, acceptance angle, detector size, etc. are modeled in the simulator.

Based on the projector code algorithm, a fully 3D image reconstruction code was also developed based on maximum-likelihood expectation-maximization (MLEM) algorithm [11, 12].

N. Zeraatkar, K. S. Kalluri, A. Könik, J. M. Mukherjee, J. Dey, J. C. Goding, Y. He, B. Auer, S. Banerjee, G. Mok, and M. A. King are with the Department of Radiology, University of Massachusetts Medical School, Worcester, MA, USA (e-mail: Michael.King@umassmed.edu).

T. J. Fromme is with Worcester Polytechnic Institute, Worcester, MA, USA.

G. I. Zubal is with Z-Concepts LLC, East Haven, CT, USA.

L. R. Furenlid is with the Department of Radiology, University of Arizona, Tucson, AZ, USA.

978-1-5386-2282-7/17/$31.00 ©2017 IEEE

C. Phantoms

The XCAT-based brain phantom was customized based on radio-activity in different regions of the brain [13] to simulate perfusion. Also, a voxelized quasi-spherical Defrise phantom was developed in a way to challenge the sampling sufficiency of the system through the whole field-of-view (FOV). The Defrise phantom was made up of 13 parallel disks which were limited to a virtual sphere of radius 10.4 cm. The maximum radius of disks was 9.2 cm and the disk-to-disk pitch size was 0.8 cm.

D. Simulations and Analyses

The Defrise phantom was positioned at the focal point and the scan was simulated using the projector code. The resultant projection images are shown in Fig. 2. In addition, another scan using two more excessive phantom axial translations (i.e.a total of three bed positions) with axial shifts of 3.2 cm and 6.4 cm relative to the initial position was simulated. This simulation shows the effect of more axial sampling on the reconstructed images. For all the reconstructed images, the voxel size was set to 4 mm.

Moreover, the voxelized brain phantom was simulated in two approaches for the scan setup. First, the original setup of the system was used. But for the second simulation, to increase the number of angular samples, in addition to data acquisition at the original setup, projection data were aquired after rotating the scanner around its axis (equivalent to the long body axis). For each of the two simulations, image reconstruction was performed using all acquired projection data with the pixel size of 2 mm. To compare the reconstructed image quality quantitively, normalized mean square error (NMSE) was caclcuated for each dataset.

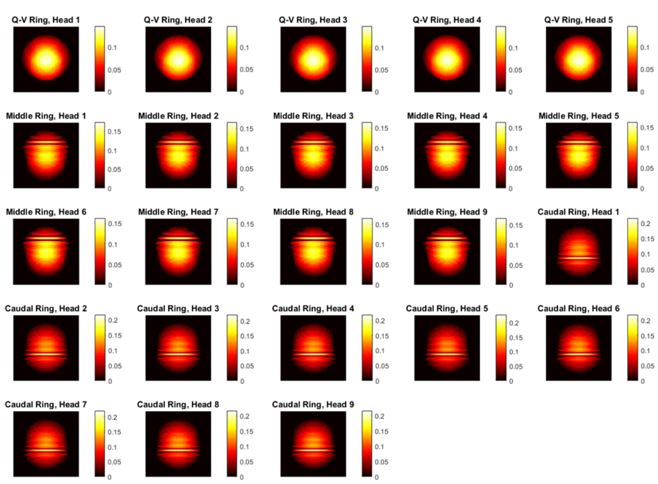

Fig. 2. Projection images of the customized Defrise phantom generated using the analytical simulator.

III. Results

The reconstructed images of the Defrise phantom showed that using more axial samples (three axial translations in this study) can result in resolving all the Defrise disks along axial direction. Shuttering of additional apertures separated axially from the current central ones will be investigated as an alternative to axial translation.

Also, Fig. 3.b and 3.c demonstrate a transverse slice of the reconstructed images of the brain phantom for the scanner setup without rotation and the scan with one additional rotation, respectively. The corresponding slice of the reference phantom is shown in Fig. 3.a. The calculated NMSE values for the brain phantom reconstructed images using the preliminary design of the scanner (i.e. without rotation) and the scan simulated with one additional rotation was respectively 0.130 and 0.119.

As observed in the reconstructed images, the images simulated with higher angular sampling resulted in images with reduced NMSE. Shuttering of apertures displaced laterally from the central one will be investigated as an alternative to rotation of the system.

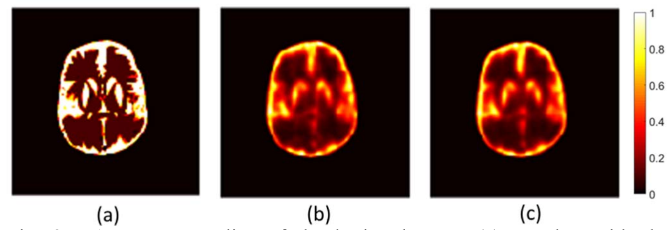

Fig. 3. A transverse slice of the brain phantom (a) together with the corresponding transverse slice of the reconstructed images for the original setup (b) and the scan with one additional rotation (c).

IV. Conclusion

Results from this preliminary study provided an insight into the axial and angular sampling of the FOV of the AdaptiSPECT-C system and possible approaches to enhance the image quality, and help us detect and address imaging artifacts that may occur to further improve its design. It should be noted that with variation of aperture size, the target reconstructed resolution for the system is 2 mm hence a voxel size of 1 mm will be employed. In the current version of the analytical simulator developed, no scatter, attenuation, or noise modeling was performed.

Acknowledgment

Research reported in this publication was supported by the National Institute of Biomedical Imaging and Bioengineering of the National Institutes of Health under Award Number R01 EB022521. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

References

[1] M. J. R. Janssen, "Dopamine Transporter SPECT Imaging," *SNM Brain Imaging Council Newsletter,* Summer 2010 (updated November 2011).

[2] D. S. Djang *et al.*, "SNM practice guideline for dopamine transporter imaging with 123I-ioflupane SPECT 1.0," *J Nucl Med,* vol. 53, no. 1, pp. 154-63, Jan 2012.

[3] J. E. Juni *et al.*, "Procedure guideline for brain perfusion SPECT using (99m)Tc radiopharmaceuticals 3.0," (in eng), *J Nucl Med Technol,* vol. 37, no. 3, pp. 191-5, Sep 2009.

[4] J. Darcourt *et al.*, "EANM procedure guidelines for brain neurotransmission SPECT using (123)I-labelled dopamine transporter ligands, version 2," (in eng), *Eur J Nucl Med Mol Imaging,* vol. 37, no. 2, pp. 443-50, Feb 2010.

[5] K. Van Audenhaege, R. Van Holen, S. Vandenberghe, C. Vanhove, S. D. Metzler, and S. C. Moore, "Review of SPECT collimator selection, optimization, and fabrication for clinical and preclinical imaging," *Med Phys,* vol. 42, no. 8, pp. 4796-813, Aug 2015.

[6] H. K. Tuy, "An Inversion Formula for Cone-Beam Reconstruction," *SIAM Journal on Applied Mathematics,* vol. 43, no. 3, pp. 546-552, 1983.

[7] S. D. Metzler, J. E. Bowsher, and R. J. Jaszczak, "Geometrical similarities of the Orlov and Tuy sampling criteria and a numerical algorithm for assessing sampling completeness," *IEEE Transactions on Nuclear Science,* vol. 50, no. 5, pp. 1550-1555, 2003.

[8] W. P. Segars, G. Sturgeon, S. Mendonca, J. Grimes, and B. M. Tsui, "4D XCAT phantom for multimodality imaging research," *Med Phys,* vol. 37, no. 9, pp. 4902-15, Sep 2010.

[9] G. L. Zeng and G. T. Gullberg, "A study of reconstruction artifacts in cone beam tomography using filtered backprojection and iterative EM algorithms," *IEEE Transactions on Nuclear Science,* vol. 37, no. 2, pp. 759-767, 1990.

[10] N. Zeraatkar, M. H. Farahani, A. Rahmim, S. Sarkar, and M. R. Ay, "Design and assessment of a novel SPECT system for desktop open-gantry imaging of small animals: A simulation study," *Med Phys,* vol. 43, no. 5, p. 2581, May 2016.

[11] L. A. Shepp and Y. Vardi, "Maximum likelihood reconstruction for emission tomography," (in eng), *IEEE Trans Med Imaging,* vol. 1, no. 2, pp. 113-22, 1982.

[12] K. Lange and J. A. Fessler, "Globally convergent algorithms for maximum a posteriori transmission tomography," *IEEE Transactions on Image Processing,* vol. 4, no. 10, pp. 1430-1438, 1995.

[13] H. Ito *et al.*, "Brain and whole body distribution of N-isopropyl-4-iodoamphetamine (I-123) in humans: comparison of radiopharmaceuticals marketed by different companies in Japan," *Ann Nucl Med,* vol. 20, no. 7, pp. 493-8, Aug 2006.