# Reconstruction using Depth of Interaction Information of Curved and Flat Detector Designs for Quantitative Multi-Pinhole Brain SPECT


Benjamin Auer[1], Kesava Kalluri[1], Jan De Beenhouwer[3], Kimberly J. Widrick[2], , Navid Zeraatkar[1], Phillip H. Kuo[2], Lars R. Furenlid[2], and Michael A. King[1]

1. Department of Radiology, University of Massachusetts Medical School, Worcester, MA, USA
2. Department of Radiology & College of Optical Sciences, University of Arizona, Tucson, AZ, USA
3. University of Antwerp, imec-VisionLab, Antwerp, Belgium.



**Objectives:** Brain SPECT has many clinical applications, especially for cerebral blood flow and dopamine transporter imaging [1,2]. In this context, we are designing *AdaptiSPECT-C,* which is a dedicated brain imaging, multi-pinhole system. Recent studies in cardiac and small animal imaging have demonstrated that the use of curved detector could improve image quality, by reducing parallax errors due to depth of interaction (DOI) effect [3,4]. In this simulation study, we proposed to investigate the potential advantage in imaging performance of curved over flat detector for $^{123}$I (IMP) brain imaging using the *AdaptiSPECT-C* system.

**Methods:** The *AdaptiSPECT-C* design used in this work consists of 26 detector modules, 158 by 158 mm$^2$ in size, hemi-spherically arranged in 3 rows along the patient's head. The simulated detector modules were composed of a 8 mm thick NaI(Tl) crystal coupled to a 5 cm thick back-scattering compartment, representing components behind the crystal, to model $^{123}$I down-scatter interactions. Each detector module is associated with a 1.2 mm radius direct knife-edge pinhole aperture collimator. Two different system designs were considered, one based on curved detectors, and one composed of flat detectors. The curved detectors were designed so that the radius of curvature corresponds to the distance between detector surface and system center (*e.g. 30.5 cm*). The surface center of the flat detectors was the same. Gate simulation was employed to compute the system matrix [5-7] for the curved and the flat detector designs. Individual DOIs per image voxel/projection pixel (*e.g. no average DOI was used*), were incorporated into the system matrix (SM) and therefore corrected for during reconstruction [5,6]. An XCAT brain phantom [8] with source distribution for the perfusion imaging agent $^{123}$I IMP was simulated to assess the quality of the images reconstructed using the two designs. Data were simulated following three scenarios: noise free case (**S1**), equal number of counts comparison (**S2**) (*5.5M detected counts* [9]), and equal imaging time comparison for which the typical scan time (e.g. 30 min [10]) was considered (**S3**). For S3, the total number of counts for the curved and flat detector designs, were respectively 9.24M and 9.17M. Projections were reconstructed with a customized 3D-MLEM software into images of $120^3$ voxels of (2 mm)$^3$. The reconstructed images, using the two different designs were then compared to the ground truth image. The normalized root mean squared error (NRMSE) as well as % activity recovery (%AR) for meaningful brain regions were used to evaluate the image quality.

**Results:** Only a small gain in volumetric sensitivity (~*0.8%*) is obtained with the curved detector design. Qualitatively, the reconstructions for the curved and flat detector designs appear similar for all the 3 noise scenarios. Differences are shown mostly for the peripheral regions of the head (*e.g.* outside of the brain) where the differences in the obliquity of the gamma-rays passing through the apertures would be the greatest. Due to lower activity, those regions are also more impacted by noise. Quantitatively, slight NRMSE improvement using curved detector is seen. The curved detector design leads on average to the best ARs, especially for the striatum and putamen. Regions at the edges of the brain *(e.g.* cortex and cerebellum*),* more impacted by DOI effect, are similarly recovered by the two designs.

**Conclusion:** We demonstrated that using curved instead of flat detector for *AdaptiSPECT-C* containing solely a centered pinhole leads to small improvement in sensitivity and image quality based on visual inspection, NRMSE, and activity recovery analysis. Flat detector associated with a sophisticated DOI correction was found to lead to similar results than those obtained with the curved detector. Further investigation will be performed using additional pinholes positioned outward from the center towards the corners of the detectors which will increase the obliquity of the rays striking the detectors. We expect to see larger improvement for such oblique pinholes.



**Research Support**: National Institute of Biomedical Imaging and Bioengineering (NIBIB), National Institutes of Health, Grant No R01 EB022521.

## References


[1] Catafau, A. M. (2001). Brain SPECT in clinical practice. Part I: perfusion. *Journal of Nuclear Medicine*, *42*(2), 259-271.

[2] Camargo, E. E. (2001). Brain SPECT in neurology and psychiatry. *Journal of Nuclear Medicine*, *42*(4), 611-623.

[3] Dey, J. (2012). Improvement of performance of cardiac SPECT camera using curved detectors with pinholes. *IEEE Transactions on Nuclear Science*, *59*(2), 334-347.

[4] Funk, T., Després, P., Barber, W. C., *et al*. (2006). A multipinhole small animal SPECT system with submillimeter spatial resolution. *Medical physics*, *33*(5), 1259-1268.

[5] Auer, B., Zeraatkar, N., Banerjee, S., *et al.* (2018, November). Preliminary investigation of a Monte Carlo-based system matrix approach for quantitative clinical brain 123 I SPECT imaging. In *2018 IEEE Nuclear Science Symposium and Medical Imaging Conference Proceedings (NSS/MIC)* (pp. 1-2). IEEE.

[6] Auer, B., Zeraatkar, N., De Beenhouwer, J., *et al.*. (2019, May). Investigation of a Monte Carlo simulation and an analytic-based approach for modeling the system response for clinical I-123 brain SPECT imaging. In *15th International Meeting on Fully Three-Dimensional Image Reconstruction in Radiology and Nuclear Medicine* (Vol. 11072, p. 1107214). International Society for Optics and Photonics.

[7] Jan, S., Santin, G., Strul, D., *et al.* (2004). GATE: a simulation toolkit for PET and SPECT. *Physics in Medicine & Biology*, *49*(19), 4543.

[8] Segars, W. P., Sturgeon, G., Mendonca, S., *et al.* (2010). 4D XCAT phantom for multimodality imaging research. *Medical physics*, *37*(9), 4902-4915.

[9] Juni, J. E., Waxman, A. D., Devous, M. D., *et al.* (2009). Procedure guideline for brain perfusion SPECT using 99mTc radiopharmaceuticals 3.0. *Journal of nuclear medicine technology*, *37*(3), 191-195.

[10] Thomsen, G., De Nijs, R., Hogh-Rasmussen, E., *et al.* (2008). Required time delay from 99m Tc-HMPAO injection to SPECT data acquisition: healthy subjects and patients with rCBF pattern. *European journal of nuclear medicine and molecular imaging*, *35*(12), 2212.