Keel-edge height selection for improved multi-pinhole ^{123}I brain SPECT imaging

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Objectives: Given its excellent resolution versus sensitivity trade-off, multi-pinhole SPECT has become a powerful tool for clinical imaging of small human structures such as the brain [1]. Our research team is designing and constructing a next-generation multi-pinhole system, *AdaptiSPECT-C,* for quantitative brain imaging. In this context, keel-edge pinhole has proven to increase significantly attenuation of gamma rays through the edges of the pinhole aperture compared to the most clinically used knife-edge profile [2,3,4]. In this work, we investigate the potential improvement in imaging performance of multiple keel-edge pinhole profiles as a function of keel height compared to a knife-edge collimation for ^{123}I IMP brain perfusion using the *AdaptiSPECT-C* system.

Methods: The prototype *AdaptiSPECT-C* system used herein is composed of 23 hexagonal detector modules hemi-spherically arranged along 3 rings. For modeling in GATE simulation [5], each of these modules is composed of 1.5 mm radius pinhole and a 1 cm thick NaI(Tl) crystal with a 5 cm thick back-scattering compartment, which was considered to simulate ^{123}I down-scatter interactions. Multiple keel-edge heights, corresponding to 0.0 (knife edge), 0.375, 0.75, 1.0, 1.125, 1.5, 1.875, and 2.25 mm were studied. We evaluated the volumetric sensitivity and relative amount of collimator penetration for a 15% energy window centered at 159 keV in simulated projections of a 21 cm diameter sphere source (e.g. *corresponding to the system's volume of interest*) centered at the focal point of the pinholes. For reconstruction, an approach developed in our group was employed for modeling the system matrix (SM) using GS [6,7] for the knife and the keel-edge designs. Collimator penetration was incorporated into the SM, and thus corrected for during reconstruction [6,7]. An XCAT [8] brain phantom with source distribution for the perfusion imaging agent ^{123}I-IMP was simulated using the pinhole designs. Data were acquired following two scenarios, noise free case for which projection were obtained directly from the SM (S1), and equal imaging time comparison for the typical scan time (e.g. *30 min* [9,10]) (S2). Projections were reconstructed with a customized 3D-MLEM reconstruction software into images of 120^3 voxels of $(2\text{ mm})^3$. The reconstructed images were then compared to the ground truth image in terms of the normalized root mean squared error (NRMSE) and activity recovery (%AR) for meaningful three-dimensional brain regions.

Table 1. Volumetric sensitivity values (e.g. *21 cm diameter sphere activity*) and amount of penetration (%) using a 15% energy window centered at 159 keV for the keel and knife-edge designs considered in this study as well as for a typical system used in clinic. On the middle column, total number of detected acquired counts for the S2 scenario computed for a realistic imaging time (e.g. *30 min*) [8,9]. On the right column lowest NRMSE values obtained for the S2 scenario.

Systems	Volumetric Sensitivity ($\times 10^{-4}$) and Amount of Penetration in parenthesis (%)	Total Number of Detected Counts for S2 scenario ($\times 10^6$)	Lowest NRMSE values for S2 scenario
Dual headed Parallel-hole (LEHR/Phillips Forte)	1.29	5.5	
Knife-edge	3.67 **(15.7)**	15.61	0.333
Keel-edge (*h=0.375 mm)*	2.72 **(9.9)**	13.69	0.332
Keel-edge (*h=0.75 mm*)	2.94 **(8.3)**	12.52	0.332
Keel-edge (*h=1 mm*)	2.35 **(8.1)**	11.92	0.333
Keel-edge (*h=1.125 mm*)	2.54 **(8.1)**	11.56	0.333
Keel-edge (*h=1.5 mm*)	2.18 **(8.2)**	10.8	0.336
Keel-edge (*h=1.875 mm*)	2.8 **(8.7)**	10.02	0.338
Keel-edge (*h=2.25 mm*)	3.21 **(9.1)**	9.26	0.340

Results: A keel-edge height of 0.375-0.75 mm represents the best choice leading to a significant reduction of the amount of penetration (*up to 50%*) at the expense of sensitivity (*-20%*) compared to a knife-edge profile. Visually, for all scenarios, the use of such a keel-edge profile leads to better separation of the brain structures (*especially the caudate and the putamen*). When sensitivity is not taken into account (e.g. noise free scenario), increasing the keel height improves NRMSE results. For an equal imaging time comparison, lowest NRMSE values are achieved for a

0.375-0.75 mm keel height. A 0.75 mm keel height leads on average to the best %ARs (e.g. *closest value to 100%*), especially for the striatum and putamen. For grey-matter regions at the edges of the brain, %ARs are comparable with those obtained for a knife-edge design.

Conclusion: In this work, we demonstrated that the use of a 0.75 mm height keel-edge profile for *AdaptiSPECT-C* leads to superior imaging performance compared to knife-edge collimation in case of clinical ^{123}I brain perfusion imaging. A range of aperture radii from 0.5 to 3.5 mm for each design as well as multiple noise realizations simulation have been investigated and will be shown at the time of the conference. We are currently working on performing a numerical-observer task-performance study of defect-detection in perfusion.

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