Optimization of Pinhole Aperture Size of a Combined MPH/Fanbeam SPECT System for I-123 DAT Imaging

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***Abstract*– We proposed an inexpensive method to improve the performance of the conventional dual-camera SPECT systems for I-123 dopamine transporter (DAT) imaging for Parkinson Disease. In this method, one of the collimators is replaced with a specifically designed multi-pinhole (MPH) collimator, thus performing combined MPH/Fanbeam acquisition. The MPH consists of 9 pinholes focusing to the central brain and covering a cylindrical field of view (diameter: 12cm and height: 8cm), which includes the striatum. We present here our Monte Carlo simulation work investigating the optimal aperture size for the striatal binding ratio (SBR) and caudate/putamen ratio (C/P). Projections of the XCAT brain phantom were obtained for a range of aperture sizes (radius:1–5 mm, with increments of 1mm). Multiple noise realizations were simulated for each aperture size at realistic count levels. Reconstructions from MPH, Fanbeam and combined MPH/Fanbeam systems were obtained for various numbers of iterations. For SBR and C/P calculations activities within the striatum were estimated for a range of region of interests. Normalized root mean square errors (NRMSE) of the SBR and C/P measurements were obtained for the Fanbeam and combined MPH/Fanbeam reconstructions at different iterations and VOIs, using custom made and clinically employed quantitative analysis software. Our preliminary results suggest that an aperture radius of 2-3 mm for the MPH component yields both visually and quantitatively better estimations for the MPH/Fanbeam reconstructions.**

I. Introduction

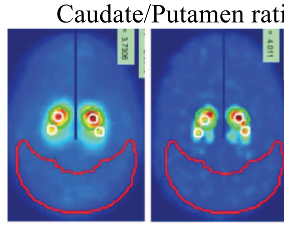
We have proposed a relatively inexpensive method to improve the performance of the conventional dual-camera SPECT systems for I-123 dopamine transporter (DAT) imaging by replacing one of the collimators with a specifically designed multi-pinhole (MPH) collimator[1-3]. The MPH focuses on the interior portion of the brain covering the striatum region at a high resolution and Fanbeam provides lower resolution, but complete sampling of the brain. The MPH collimator plate consists of 9 pinholes (8 oblique and 1 direct).

In this work, we investigate the optimal pinhole aperture size for the striatal binding ratio (SBR calculations, a measure of striatal specific binding, relative to the non-specific binding in the occipital cortex. SBR= (STR – OCC)/OCC, where STR and OCC are the activity concentrations estimated in the striatum and occipital regions in the reconstruction. We also calculate, Caudate-to-putamen ratio (CPR), which is another potentially useful measurement since parkinsonian syndromes tend to affect the caudate nucleus and putamen with different severity.

II. Methods

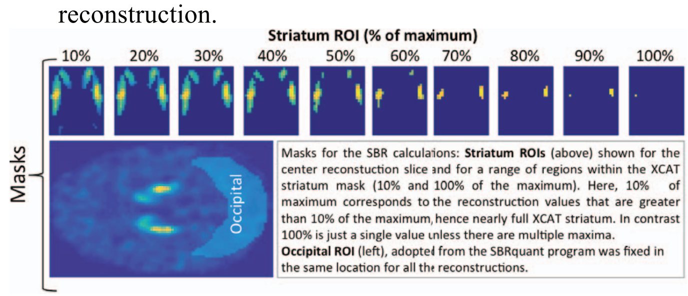
Using the GATE simulation package[4], high-count (noise-free) MPH projections of the XCAT brain phantom[5] were obtained for a range of aperture sizes (radius:1-5 mm). For each case, 10 noise realizations were simulated at realistic count levels. Fanbeam (60 projections views) and combined MPH/Fanbeam (30 projections for MPH and 30 projections for Fanbeam) reconstructions were obtained at different OSEM iterations (5-30). Sample images for the projections and reconstructions are presented in Figure 5. In the combined reconstruction method, the MPH-only reconstruction (equivalent of 69 ML) was used as the prior for the Fanbeam reconstruction[6]. Reconstructions were analyzed using the following two approaches:

1. Using the clinical software package, SBRquant[7], SBR and Caudate/Putamen ratios (C/P) were calculated



Screenshots from the clinical software package SBRquant. Sample images from Fanbeam **(Left)** and Combined MPH/fanbeam with 2mm pinhole aperture radius **(Right)** reconstructions. The SBRquant program automatically identifies the stritum and the occipital lope and perform quantitative measurements within these regions. Here, the white circular regions are placed within the small structures (caudate and putamen) of the striatum and the red region is on the occipital lobe.

2. Using a custom made analysis code, reconstruction values within the striatum were obtained for a range of regions (10-100% of maximum intensity) within the 13 center slices of the XCAT striatum mask. These regions are shown below. For the OCC measurements, the mask in Figure 3 was adopted from the SBRquant program and placed at a fixed location at the center slice of the reconstruction.



Masks for the SBR calculations: **Striatum ROIs** (above) shown for the center reconstuction slice and for a range of regions within the XCAT striatum mask (10% and 100% of the maximum). Here, 10% of maximum corresponds to the reconstruction values that are greater than 10% of the maximum, hence nearly full XCAT striatum. In contrast 100% is just a single value unless there are multiple maxima. **Occipital ROI** (left), adopted from the SBRquant program was fixed in the same location for all the reconstructions.

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III. Results

Results using SBRquant: Normalized-Root-Mean-Square-Errors (NRMSE) of the SBR and Caudate/Putamen (C/P) ratios are presented in Figure 4. With this quantification approach, the error in SBR estimations with the conventional Fanbeam (Dual FAN) was only slightly lower than that of the Combined MPH/FAN. On the other hand, the error in C/P was lower for the Combined MPH/FAN for all aperture sizes and iterations.

Results using a custom code: NRMSE of SBR are calculated for different iterations and striatum ROIs. The lowest NRMSE was obtained from the combined MPH/Fanbeam reconstructions (at iteration 5 and 40% maximum within the striatum) with MPH using 2-mm apertures.

In Table I, resolution and relative sensitivity of different collimators are presented.

TABLE I. **RESOLUTION AND SENSITIVITY**

Collimator	FWHM (mm) at VOI center	Relative Sensitivity at VOI center
MPH(radius:1 mm)	**4.4**	**1**
MPH (radius:2 mm)	**7.6**	**4**
MPH (radius:3 mm)	**11.1**	**9**
MPH (radius:4 mm)	**14.7**	**16**
MPH (radius:5 mm)	**18.3**	**25**
LEHR-Fan	**8.9**	**2.5**
LEUHR-Fan	7.4	1.5
LEHR-Parallel	9.2	1.8
LEUHR-Parallel	7.6	1.1

The collimators shown in bold font are used in this paper.

IV. Discussion and Conclusion

Combined reconstructions provide better differentiation of the caudate and putamen, especially for the aperture radii of 2-3 mm. For the 1 mm radius, the images are too noisy because of the poor count level and for radius ≥ 4mm, the caudate and putamen are less differentiable because of poorer resolution. Quantitative results seem to confirm these visual assessments. In summary, Combined MPH/Fanbeam with 2-3 mm radii apertures, visually and quantitatively (preliminary) perform comparable or better than conventional Fanbeam. Further improvements in the system design and the combined reconstruction approach are being investigated.

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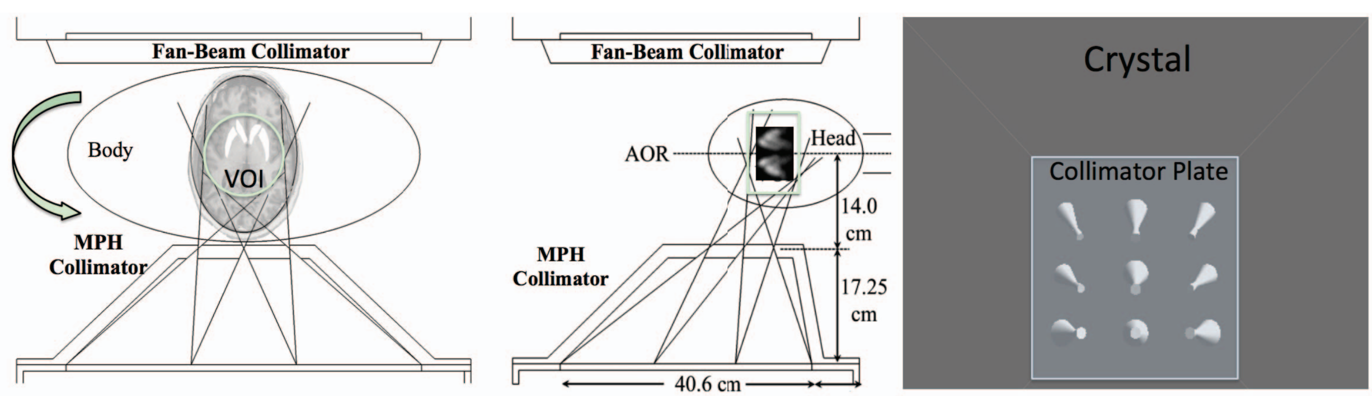

Two views of the combined system design and GATE implementation of the MPH (front view) with circular apertures of 3 mm radius. White back-to-back conical shapes are the pinholes in the MPH collimator plate.