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A Feasibility Study of a Novel Variable-Aperture Full-Ring SPECT using Large-Area Pixelated CZT Modules: Simulation Results

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A Feasibility Study of a Novel Variable-Aperture Full-Ring SPECT using Large-Area Pixelated CZT Modules: Simulation Results

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Introduction

Emerging single photon emission computed tomography (SPECT) scanner using cadmium zinc telluride (CZT) offers improved quantitative imaging capability over conventional NaI(Tl)-based SPECT scanner.

In this study, on top of the previously-developed **energy-optimized parallel collimator** design [1], we further evaluated a **full-ring SPECT system** design with **eight large-area CZT detectors**. In order to evaluate the imaging performance of our proposed CZT-SPECT system, we employed **analytical phantom** and **brain phantom**, using a conventional NaI(Tl)-SPECT system as a reference.

Materials and Methods

Image Acquisition Design & Specifications

- Using large-area CZT detectors with energy-optimized tungsten-alloy collimators
- **Type 1** and **Type 2** image acquisition types we simulated for our proposed system

Specifications of Proposed and Conventional SPECT

Parameter	Proposed	Conventional
Detector head	8	2
Detector type	CZT	NaI(Tl)-PMT
Detector size (mm³)	153.6 × 153.6 × 5.0	563.2 × 563.2 × 9.5
Hole Shape	Rectangular	Hexagonal
Material	Tungsten-Alloy	Lead
Hole length (mm)	23	35
Septal thickness (mm)	0.32	0.2
Hole diameter (mm)	1.28	1.5

Angle Information for Image Acquisition

Parameter	Type 1	Type 2	Conventional
Rotation Angle	-42° ~ 42°	-42.5° ~ 42.5°	-
# of Total Angles	120	72	120
Step Angle	3°	5°	3°
Rotation Step	60 steps	29 steps	18 steps

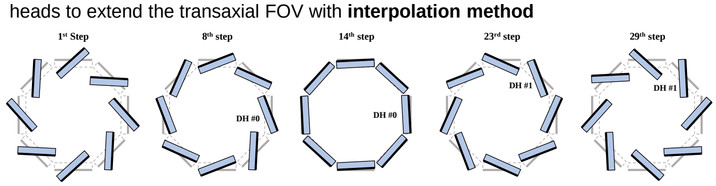
Image Acquisition Time (sec.)

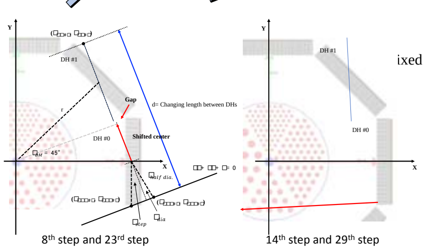
Study	Type 1		Type 2		Conventional	
	per step	total	per step	total	per step	total
Hot-rods	10	290	10	180	10	600
Brain Perfusion	10	290	10	180		-
Brain DaT	15	435	25	450		-

48% ↓ 30% ↓

Virtual Projection Data Generation

- Generated virtual projection by combining two projection data of adjacent detector heads to extend the transaxial FOV with **interpolation method**





$$Gap = |\text{ixed width of two DHs} - \text{Changing length between DHs}| = |153.6 \times 2 - d|$$

$$\text{Shifted center} = r \cdot \sin\theta_{step}$$

Fig. 1. Type 1 scanning geometry examples related to the gap and edge corrections (upper) and diagrams for gap and shifted center calculation (left) and a truncation example in the edge part (right, red arrow).

MC simulation and Image Reconstruction

- Using Geant4 Application for Tomographic Emission (**GATE**, ver. 8.2) [2] in parallel
- Using Software for Tomographic Image Reconstruction (**STIR**, ver. 3.0) [3] package with Collimator and Detector Response (**CDR**) and Attenuation correction
- Projection and Reconstructed Images
  - Proposed : 192 × 96 and 193 × 193 × 191 with 1.6 mm pixel size
  - Conventional : 128 × 128 and 129 × 129 × 255 with 4.4 mm pixel size

Performance Estimate with Phantoms

- Standard Performance : **Spatial resolution** and **Sensitivity** with 37 MBq of Tc-99m
- Derenzo hot-rod phantom with 300 kBq/mm³
- Zubal Phantom with 10% of recommend dosage
  - Brain Perfusion w/ Tc-99m (White : Grey : Soft = 100 : 25 : 4)
  - Brain DaT w/ I-123 (Striatal : Background = 3 : 1 to 10 : 1)
- **Profile, CNR** and **Contrast-Recovery Ratio (CRR)**

$$CNR = \frac{|M_{ROI} - M_{BG}|}{\sqrt{\sigma_{ROI}^2 + \sigma_{BG}^2}}$$

$$CRR = \frac{M_{STRLATAL}/M_{BG}}{R_{STRIATAL}/R_{BG}}$$

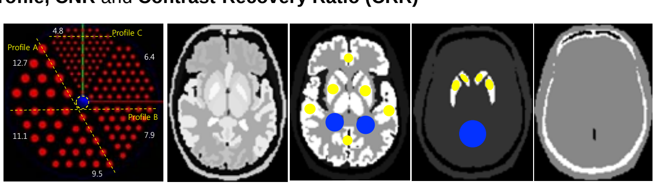


Fig. 2. Derenzo hot-rod phantom and Zubal phantom for brain perfusion imaging with Tc-99m and and dopamine transporter (DaT) imaging with I-123

Results

Spatial Resolution and Sensitivity

- Sensitivity : **2.94 or 2.8 times higher** than tomographic sensitivity of conventional

Performance		Type 1	Type 2	Conventional
Spatial resolution	Planar @10 cm (mm FWHM)	6.91**		7.4*
	Tomographic @ 0 cm from center of FOV (mm FWHM)	12.72	13.36	9.75 (≤9.9*)
	Tomographic @ 10 cm from center of FOV (mm FWHM)	7.00	7.59	8.97
Sensitivity	Planar @10 cm (cpm/uCi)	261**		202*
	Tomographic (s^{-1} MBq^{-1})	544.5	518.5	185.4

* referenced by Conventional SPECT brochure and ** referenced by our previous research

Virtual Projection Data Correction

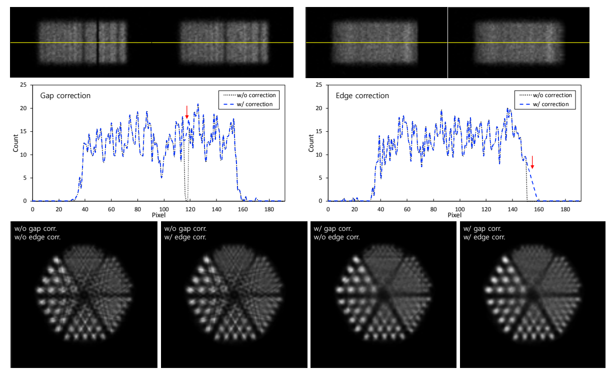


Fig. 3. Example projection data with gap and edge correction (upper) and reconstructed images with and without corrections (bottom)

Analytical Phantom Study

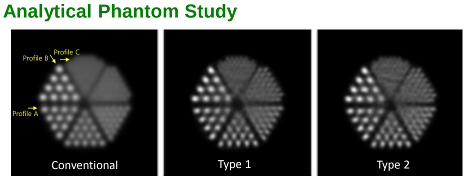
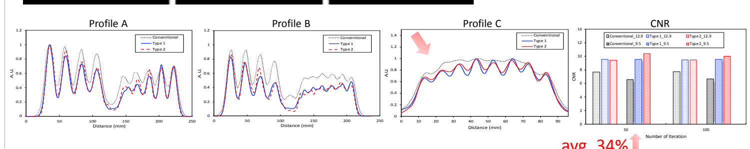


Fig. 4. Summed axially reconstructed images of Derenzo phantom with post-processed with 3D Gaussian Filtering with sigma 1 (left) and profiles and CNRs (bottom)



Brain Phantom Studies

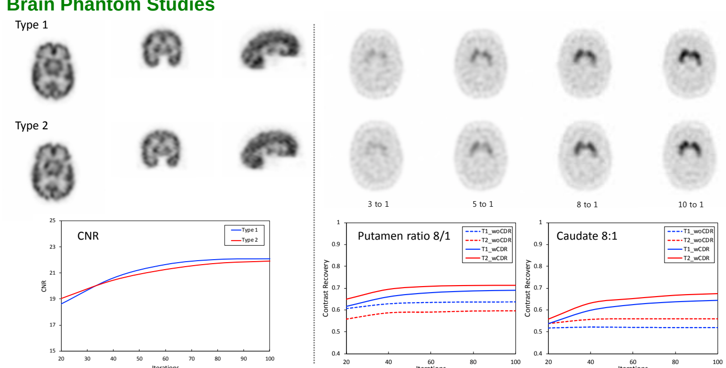


Fig. 5. Reconstructed images using CDR and attenuation correction with 3D Gaussian filtering with sigma 1, CNR and CRR of Brain Perfusion study (left) and Brain DaT study (right)

Conclusion

Our simulation studies showed that the proposed CZT SPECT system design could result in **improved system sensitivity and contrast-to-noise ratio and reduced acquisition time** while maintaining other important imaging parameters such as tomographic spatial resolution. This encouraging result warrants **further studies to realize the full potential of our new system design for general-purpose studies such as fully 3D bone SPECT** with an acquisition strategy that optimizes of radial positions.

References

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