Image Quality Evaluation Study of an RF-Penetrable Brain PET Insert: A Phantom Assessment Toward Clinical Translation

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Identifying the Value of a Dedicated Radiofrequency (RF) Penetrable Brain PET insert: What can this Brain PET insert offer patients and clinics?

First Generation Radiofrequency Penetrable Brain PET Insert for MRI: How is our system designed and how do we acquire data?

Comparative PET Spatial Resolution Performance: Contextualizing our Brain PET Insert Spatial Resolution against current clinical systems

Hoffman Phantom Scans: Can we anticipate the performance of our PET system when applying the system to patients?

Initial Hoffman Phantom Images: Initial Hoffman phantom images contextualized for clinical translation

Comparative Hoffman Images: Dedicated Brain PET Insert versus GE Signa

Future Work: Improving image quality and experimental sequencing
Combined PET/MRI – Benefits/Limits and Costs

Individual Modalities

- **PET as a modality:** PET provides (a) biodistribution information, (b) excellent depth of penetration, (b) high intrinsic sensitivity (picomolar order)

- **MRI as a modality:** MRI provides (a) anatomical information, and (b) excellent soft tissue

**Individual Modality Strength**

- **PET/MRI versus PET/CT:** Anatomically slow, excellent contrast, no anatomical radiation emerging attenuation correction (AC) for PET versus anatomically fast, poor contrast, additional dose, and PET AC capable

- **PET/MRI Specific Benefits in Brain:** PET function can be easily localized to sub-brain anatomical features using MRI

- **Economics of PET Insert versus Full PET/MRI Setup:** Easily incorporated in to pre-existing MRI versus full infrastructure development

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Detector Module Design and RF Shielding

- **Detector Module Design**: 3.2 x 3.2 x 20 mm³ LYSO crystal elements 1-1 coupled to arrays of silicon photomultipliers (SiPM) with a total of 128 crystals.

Compressed Sensing Readout

- **Compressed Sensing**: Front end electronics reduce 128 pixels to 16 rather than using 1:1 pixel to channel ratio.
- **Event Information**: 16 channel yield energy, timing, and spatial position of each event.

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PET System Assembly and System DAQ

- **BrainPET System General Geometry:** 16 modules form a 32-cm I.D. and 40-cm O.D. which can be inserted into a 3T MR system

- **Active Field of View:** 128 crystals from a 3 cm axial FOV for this prototype system

**RF Compatibility and Sensing**

- **RF Penetrability:** System is electrically floating and detector modules are separated by 1 mm

- **Receiver Coil:** Attenuation is limited to one direction as a body coil/phased array coil combination is employed
PET Data Processing

Data Acquisition Method and Processing – Parallel

- **Brain PET Header Information**
  - Source port – (DAQ System) – FPGA Firmware Coded: “192.168.1.1”
  - Destination Port – (PC) – BrainPET Hardcoded: “192.168.1.2”

- **Modified Brain PET Header Information for Parallel Processing**
  - Source port – (DAQ System) – FPGA Firmware Coded: “192.168.1.1”
  - Destination Port – (PC) – BrainPET *User Defined*: “X.X.X.X”
Resolution Phantom Layout and Design

- **Custom Resolution Phantom**: 3D-printed phantom for spatial resolution [3]
- **Hot Rod Dimensions**: 5.2 mm, 4.2 mm, 3.2 mm, and 2.8 mm
- **Cold Rod Dimensions**: 4.2 mm

Resolution Phantom Experimental Parameters

- **BrainPET Acquisition Parameters**: 300 μCi and scanned for 45 minutes. Reconstruction was performed with our OSEM with voxel sizes of 1 x 1 x 1 mm³
- **GE Signa Acquisition Parameters**: 500 μCi and scanned for 30 minutes. Reconstruction was performed with the native OSEM algorithm provided by the system with voxel sizes of 1.17 x 1.17 x 2.78 mm³

System Spatial Resolution – BrainPET versus GE Signa

Comparative Resolution Phantom Results – BrainPET Versus GE

Prototype brain-sized PET insert

GE Signa whole-body PET/MR

Figure 7: (A1) Reconstructed spatial resolution phantom. (A2) 2.8 mm rod cross-section profile. (B1) GE Signa reconstructed resolution phantom. (B2) 2.8 mm rod cross-section profile
**Hoffman Phantom**

**Hoffman Brain Phantom Reference Images**

![Image of Hoffman brain phantom]

**Figure 8:** Digital Hoffman brain phantom. Targeted features of first [4]

- **Hoffman Phantom:** Designed to simulated blood flow and metabolism with 4:1 uptake between grey and white matter.

- **High Resolution System:** Anticipation of improved axial midbrain (highlighted RED box) resolution provided by PET insert (2.8 mm vs. >4 mm)

Hoffman Phantom System Orientation

(A)

(B)

Hoffman Phantom Acquisition from Saturation – Coincidence Events Per Second

(C)

Figure 9: (A,B) Hoffman phantom setup. (C) Initial Hoffman saturation curve intended to describe absolute system limitations.
Hoffman Experiment Parameters

- **BrainPET Acquisition Parameters**: 10 mCi initial activity, 9 hrs imaging (1 hr coincidence/10 minute randoms), 2 mm x 2 mm x 2 mm voxels

- **GE Signa Phantom Data**: Provided by GE with 3.125 mm x 3.125 mm x 2.78 mm voxels

*Figure 10: (A,B) Hoffman phantom setup. (C) BrainPET fully time integrated image. (D) GE Provided brain phantom.*
- **Hoffman Phantom Acquisition**: Manual acquisition of 10 minute intervals of coincidence data in sequences of 6 followed by single random coincidence acquisition.

- **Normalization Data**: Manual acquisition of 10 minute intervals of coincidence data in sequences of 6 followed by single random coincidence acquisition.

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**Figure 10**: (A) Hoffman Brain Phantom Coincidence measurement versus activity with coincidence events and random coincidence data (B) Normalization measurement versus activity with coincidence events and random coincidence data.
Hoffman Phantom Images by Hour of Acquisition

Reference

Hoffman Brain Phantom Images (3 – 5)

Hoffman Images Removed

GE Signa

Hoffman Brain Phantom Images (6 – 8)

Hoffman Images Removed
Post-Processing Image Improvements

- **Clinic Application Potential**: Without image corrections, 1 Hr (or slightly longer) studies for clinical translation are reasonably the lower limit of acquisition time.

- **GE Signa versus BrainPET**: Our system lacks proper AC, randoms correction, and Monte-Carlo based scatter correction contributing to the discrepancy in image quality.

Future Work

- **Normalization**: Switching between normalization cylinder and a normalization ring.

- **Randoms Correction**: Normalization and Hoffman phantom random data available but needs to be applied.

- **GRAY Monte Carlo based scatter correction**: Using in-house simulation software to remove scatter in 410 keV to 610 keV range.

- **Quantification**: Use image quality metrics to precisely describe performance (e.g. CNR).
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