Evaluation of High-Sensitivity Organ-Specific Positron Emission Tomography (PET) System

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Introduction

Continued developments of medical imaging systems have vastly improved our ability to visualize body tissues and processes, enabling more accurate detection of medical conditions. However, recent trends for personalized or precision medicine, i.e., delivering "the right treatment to the right patient at the right time", impose new requirements for imaging modalities in terms of the required diagnostic and predictive capabilities and are changing the emphasis from a nonspecific to an organ-specific imaging approach- a significant paradigm shift in medicine.

Precision medicine often cannot be achieved with existing general purpose or whole-body imaging devices. Predictive and preventative precision medicine calls for new approaches where organ-specific imaging tools are customized for particular organs or diseases to provide the highest efficacy and diagnostic capability. Based on the demands of the health system we have developed, integrated, and tested high-resolution, high-sensitivity PET technology for organ specific imaging. The first application of this technology is in the breast – dedicated imaging, i.e., in Positron Emission Mammography. Our technological advances provide the ability to look beyond the limitations of existing and commercially available breast imaging technologies (including x-ray mammography and breast tomosynthesis and MRI) and represent opportunities of tremendous potential for improvements in patient care. Clinical testing is underway in the University Health Network-Princess Margaret Cancer Center (UHN-PMCC), Toronto, Canada.

Clinical Prototype

The PEM clinical system (Figure 1) developed in collaboration with Radialis Medical employs patent-pending technology [1] with sensor modules based on solid state photodetectors – Silicon Photomultipliers (Si-PMs).

[1] Tileable block detectors for seamless block detector arrays in Positron Emission Mammography, US Patent application US20190064367A1

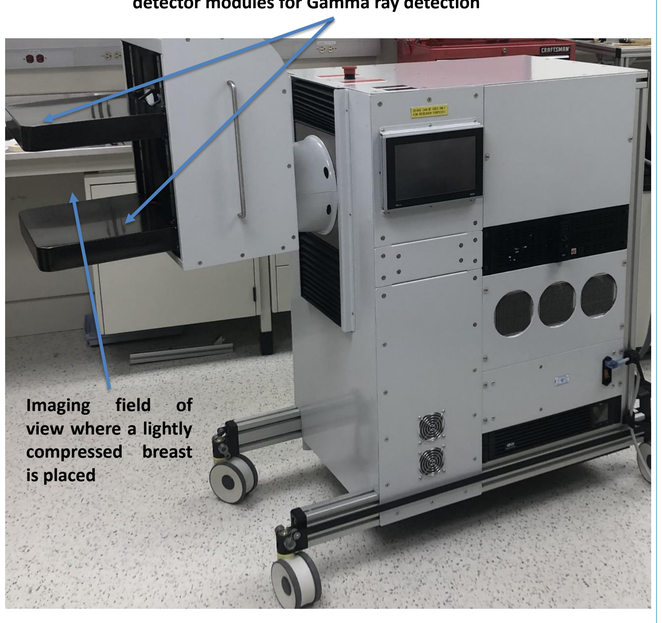

Figure 1. The Radialis research system used for image acquisitions

Detector Technology

Our PET detector head is a 2D array of individual sensor modules. The size of a module is 58×58 mm^2. Each module is four-side tileable, which allows to connect individual modules seamlessly, without gaps or dead zones, into arrays of virtually any size and to obtain the required field-of-view (FOV). For breast imaging, 12 modules per detector head are positioned to form a rectangular 4×3 array (Figure 2). This results in a sensor area of ~ 23×17 cm^2 to match the imaging plate of a standard mammographic unit and to cover the entire breast during PEM image acquisition. To minimize the distance between the detector heads and the patient's chest, a thin, durable housing material is used. Thus, the imaging area is only 4 mm from the patient chest, which is best in-class and provides a tremendous improvement in the visualization of lesions near the chest wall.

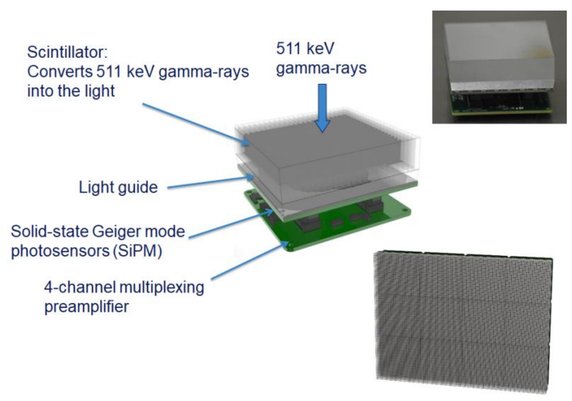

Figure 2. Schematic representation of detector block used in PEM clinical system prototype.

Property/Prototype	*Clinical organ-specific PET prototype*
Detector configuration	3×4 to 3×4
Scintillation crystal	LYSO:Ce
Crystal size, mm^3	2.32 × 2.32 × 13
Crystal pitch, mm	2.4
Crystal size array	24 × 24
Photosensor array	Si-PM, Sensl, C-series (ArrayC), 60035 8x8
# of detector modules	24
Total # of crystals	13,824
# of readout channels	96
Number of ADCs	6
FOV, mm	172 × 232
Axial FOV, mm	45 – 250

Table 1. Selected specifications of small-scale PEM prototype.

In the current design, clinical PEM system employs two detector heads to be positioned on either side of slightly compressed breast (Figure 1). The schematic of the axes arrangement is shown in Figure 3.

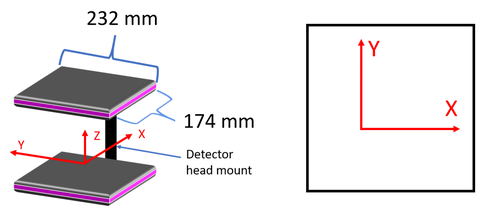

Figure 3. Schematic of two detector heads used. Left: arrangement of axes between two detector heads in a small-scale PEM imaging prototype where the axial plane is aligned with Z axis direction. Right: Arrangement of axes on the image slice produced by a reconstruction software.

Methods

- NEMA provides a standardized set of measurements and experiments in order to compare and classify the performance of PET systems and detectors. Measurements of these values were performed in accordance to the procedures outlined in the most recent NEMA NU-4 standards.
- Phantom studies were performed with a supply of (F-18) FDG from the cyclotron facility and several different radiation distributions. These images were reconstructed with parameters which are used in typical clinical applications of the system. The hope of these acquisitions is to validate the initial imaging capabilities of the system and compare the controlled imaging conditions of the lab to clinical imaging.
- Clinical images were produced with scans which took place in Princess Margaret Cancer Center (PMCC). Each patient which was scanned had both breasts scanned in two different views (MLO and CC) at two different times after radiotracer injection (AM and PM). FDG was administered to each patient in the morning after they fasted and imaging began approximately 2 hours after injection. This procedure is common practice for modern PET imaging.

Acknowledgement:

The authors are indebted to Sergey Reznik and Giovanni DeCrescenzo for technical support. Financial support from the Ontario Research Fund – Research Excellence program, Natural Sciences and Engineering Research Council of Canada, Canadian Breast Cancer Foundation, Northern Ontario Heritage Fund Corporation and Radialis Medical is gratefully acknowledged.

Results

NEMA Measurements

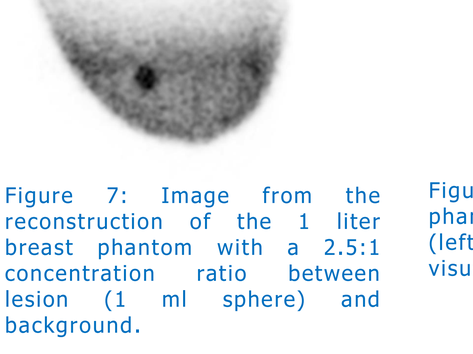

Figure 4: Count Rate Plots for the system showing the Total, True, Scattered, and Noise Equivalent Count Rates. Scatter phantom source activity started at ~5.5 MBq.

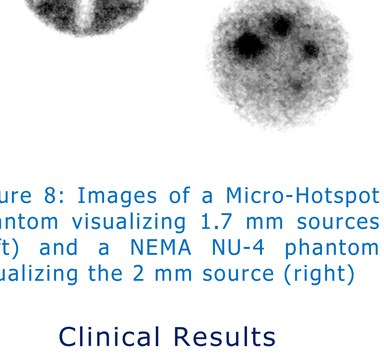

Figure 5: System Sensitivity Plotted as a function of point source position within the FOV. 1.6% Sensitivity compares to current clinical systems who reported 0.2% [2]

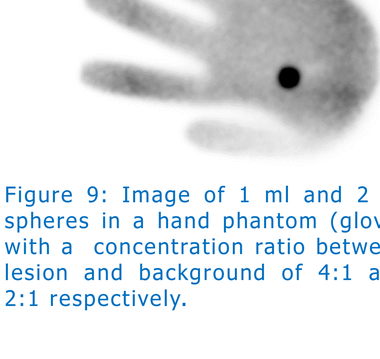

Figure 6: X Spatial Resolution plotted as a function of point source location within the FOV.

[2] - W. Luo, E. Anashkin, and C. G. Matthews, "Performance evaluation of a PEM scanner using the NEMA NU 4-2008 small animal PET standards," *IEEE Trans. Nucl. Sci.*, vol. 57, no. 1 PART 1, pp. 94–103, 2010.

Phantom Studies

Figure 7: Image from the reconstruction of the 1 liter breast phantom with a 2.5:1 concentration ratio between lesion (1 ml sphere) and background.

Figure 8: Images of a Micro-Hotspot phantom visualizing 1.7 mm sources (left) and a NEMA NU-4 phantom visualizing the 2 mm source (right)

Figure 9: Image of 1 ml and 2 ml spheres in a hand phantom (glove) with a concentration ratio between lesion and background of 4:1 and 2:1 respectively.

Clinical Results

Within the past 6 months this prototype system has been involved in clinical trials at Princess Margaret Cancer Centre in Toronto, ON, which has resulted in a successful batch of initial clinical images of breast cancer. The images in Fig. 10 display several patients with confirmed breast cancer, and show the varied capabilities of the prototype system including: localization of malignant masses, visualization of tumors close to the patients chest wall, and visualizing smaller secondary malignant masses around primary cancers. The results shown here prove the initial applicability of the system to visualizing breast cancer and will undoubtedly improve as changes to the system and image reconstruction are implemented. As of now a second system is being constructed here in Thunder Bay and will involve such possible improvements as: modified preamplifiers for the detectors, detector efficiency corrections within the image reconstruction, possible truncated center of gravity data acquisition, improvements to detector light guides, and a finalized exterior housing of the device.

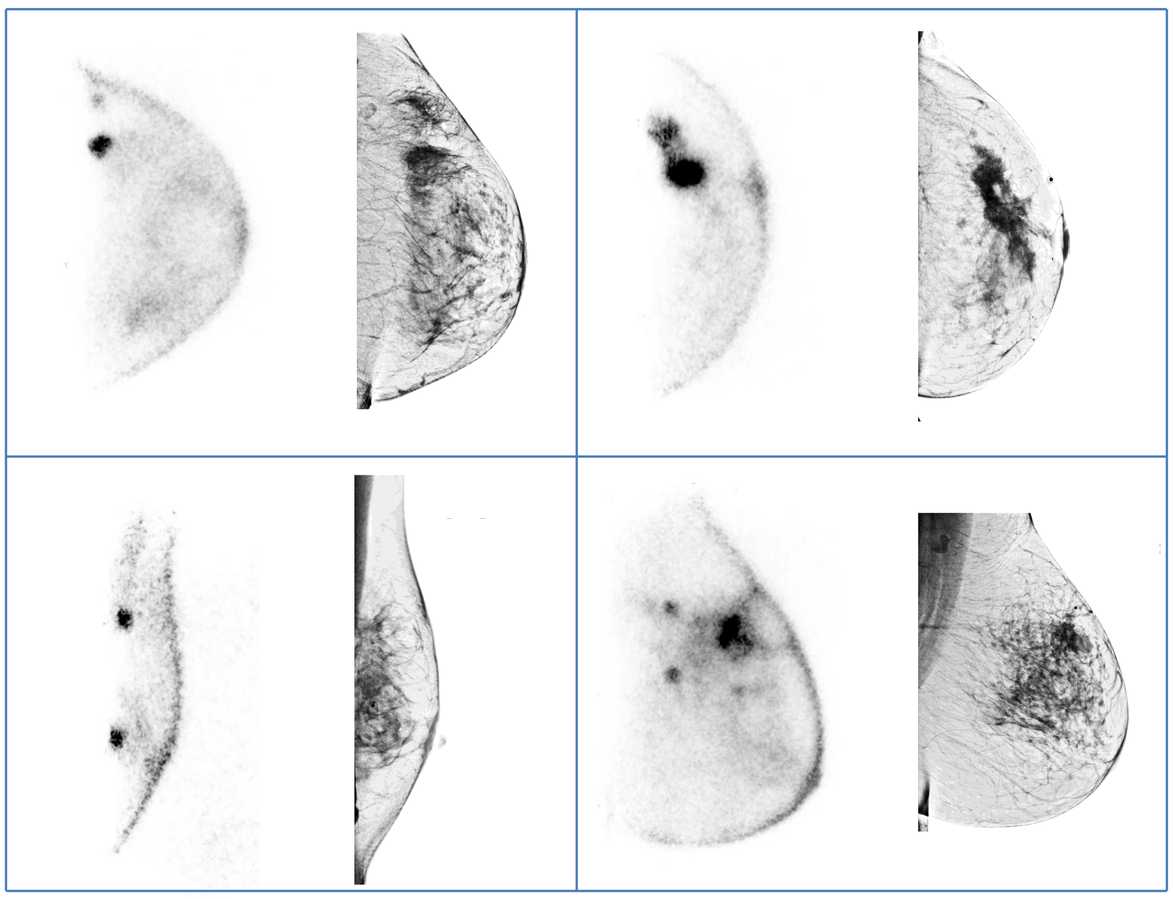

Figure 10: Four images of confirmed breast cancer patients scanned at PMCC displaying the reconstructed images from the Radialis PEM prototype system (left) and the corresponding mammographic image of each patient (right)

Summary

- The Clinical PEM prototype demonstrates best in class in-plane spatial resolution and a vastly improved sensitivity of 1.6% compared to currently available PEM systems with 0.2%. This will facilitate the implementation of predictive and preventive precision breast cancer medicine.
- Clinical adaptation of the developed PEM technology will move the field of breast cancer diagnosis forward by addressing existing limitations related to poor diagnostic imaging in dense breasts and poor prognostic information for pre-invasive cancers.
- The high sensitivity of the proposed PEM system should allow the administered dose of radiopharmaceuticals to be reduced, increasing the population of patients for whom it would be considered an appropriate screening tool given clinical concerns with exposure of undiagnosed patients to radiotracers. High sensitivity has a potential to reduce exam time and to improve patient throughput.
- The next step will include widespread multi-year, multi-center prospective clinical testing to quantify the contribution of PEM technology to improved clinical outcomes when added to existing imaging techniques.