IV. 4. Study on Spatial Resolution of PET Camera Using Semiconductor Detector

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Introduction

PET is a technique that acquires functional image of tissues by injecting positron labeled medicine into objects. Usually, PET cameras contain radiation detectors arranged circularly (gantry). Two back-to-back photons, which derive from annihilation of positron-electron pair, are measured coincidently by detectors, and image is reconstructed by the measured data.

Mainly, PET is used in clinic. Moreover, PET is applied in fields of biology and pharmacology. Objects in these fields are small experimental animals like mice, rats and so on. Because high spatial resolution PET camera is needed in these animal applications, PET cameras for animal, whose gantry diameter is smaller, has been developed and commercialized. Resolution of these PET cameras is about 2mm, but higher resolution camera is demanded.

Physical limitation of resolution is determined by two factors, positron range and fluctuation of emission angle between two back-to-back photons[1)]. The limitation is below 1mm in case that positron range of label nuclide, for example ^{18}F, is short. Resolution of PET camera also depends on detector size, adding to two factors abovementioned. If detector size is smaller than another two factors, influence of detector size can be neglected. Thin detector is useful to reduce influence of detector, but in conventional PET camera using scintillation detector this way cannot be adopted because fluorescence intensity decreases before reach to photo-detector and output signal become small.

We propose use of semiconductor detector for PET instead of scintillation detector. Output signal from semiconductor detector is independent of detector size. From our previous research, it was determined that CdTe (cadmium telluride) semiconductor detector, whose atomic number was high (Cd: 42, Te 52), was suitable for application of PET and high resolution could be achieved by using small semiconductor detectors[2)].

We are planning to develop prototype of semiconductor PET camera. In this study, we made dual head gantry system containing a pair of movable detector units, and we investigated resolution and sensitivity of the gantry for design of the prototype.

Materials and Methods

a) Dual head gantry system

It is necessary that influence of detector alignment on resolution is investigated for developing high resolution PET camera. First, dual head gantry was made by placing a pair of movable detector units oppositely.

32-ch CdTe detector array shown in Fig. 1 is adopted as detector for the gantry. This detector array is obtained by dividing the surface electrode of a semiconductor crystal and detectors are packed densely (size per channel 1.2 mm (1.4 mm pitch) x 1.1 5 mm x 4.5 mm). Energy resolution of these detectors is 3% (FWHM) for 511 keV and time resolution is about 5 nsec (FWHM).

A detector unit is made by placing the array in aluminum case. A pair of the detector units is installed in movable stage. With movable stage, detector units can be rotated and moved to both radial direction and transaxial direction, so that gantry diameter and FOV are changeable.

Signals from detector unit are amplified, pulse-shaped and time-picked off by NIM modules. Next, signal is converted to digital data and stored by PC based CAMAC data acquisition system. Because the data acquisition system also controls movement of gantry, information about position of detectors is involved to the acquired event data. After measurement, reconstructed image is obtained by the data.

b) Radioactive source and Phantom

With the dual head gantry system, ^{22}Na point source and ^{18}F phantom were measured. Size of the ^{22}Na point source, embedded in acrylic disk, is 0.6 mm diameter and its activity is 1.6 MBq. ^{18}F phantom is acrylic cylinder penetrated by tube whose inside diameter is 0.5 mm. Radioactivity distribution shown in Fig. 4 is formed by filling tube with ^{18}F solution in section of the phantom. Resolution can be estimated by identifying each spots in reconstructed image.

Experimental Setup

With rotating the detector pair, angular data samples (0, 45, 90, 135 degree) were acquired. ^{22}Na point source was measured gantry at 50mm and 150mm distance between detector units of the gantry in order to assume small gantry diameter like commercial animal PET camera. In the measurement, eight detectors of each the detector array were used.

In measurement of ^{18}F, twenty-four detectors of the each the detector array were used at 100 mm distance between detector units. FOV of 33.4 mm could be covered by moving detector units to transaxial direction during the measurement. Measurement period at initial position of the detector units was 5 min, and at following each position, period was extended to keep statistical uniformity at each position. Concentration of ^{18}F solution was 7.2 mCi/ml.

Reconstructed images

Reconstructed image of point source at 150 mm distance between detector units and profiles at 50 mm and 150 mm distance are shown in Figs. 5 and 6. Generally, influence of angular fluctuation is proportional to gantry diameter, but there is no difference in FWHM of profile between 50 mm distance and 150 mm distance. FWHM is about 1.0 mm. It is supposed that high resolution below 1 mm can be achieved with PET camera whose gantry diameter is by 150 mm, however resolution cannot be concluded from point source images because width of profile may be affected by image reconstruction. About 150 mm diameter gantry is available for application to larger animals than mice, for example rats.

Image of ^{18}F is shown in Fig. 7. Spots in the image are blurred somewhat, but each spot is identified in profile (Fig. 8). The profile of the phantom image indicates that resolution below 1 mm can be achieved clearly. Because it has been confirmed that resolution is uniform at 50 mm to 150 mm gantry diameter from the point source study, image to be equivalent can be obtained at 150 mm gantry diameter in phantom study.

Blurring of the image may be caused by statistical problem or fine shift of detector array alignment.

Estimation about sensitivity of prototype

Sensitivity is important parameter. Sensitivity of the prototype semiconductor PET camera was simulated. GATE (GEANT4 Application for Tomographic Emission), simulation tool for Nuclear Medicine, was used. Assumed prototype PET camera is composed of detector units aligned circularly and detector units are made by detector arrays stacked.

a) Validity of Simulation

First, simulation to be equivalent to the ^{18}F phantom measurement was compared with the measurement in order to investigate validity of simulation. When LLD was 250 keV and ULD was 650 keV, total counts in the measurement were 86 % of the simulation counts.

b) Simulation condition

Assumed detector size was 1.2 mm x 1.15.mm x D (mm) (D = 5, 10, 15, 20, 25, 30 mm) and detector array included twenty-eight detectors with 1.4 mm pitch. Detector units were composed of the detector arrays stacked with 1.4 mm pitch to axial direction (layer number: L = 8, 16, 24). The detector units were aligned octagonally and point source was located at CFOV (Center of FOV).

c) Results

Result of simulation (Fig. 9) indicates relation of the detector depth (D mm) and layer number of the array (L) to absolute sensitivity. Sensitivity of commercial animal PET camera is several percents, for example in Micro PET R4 (Concorde Inc.) about 3 %[3]. When the R4 is referred and difference between the phantom study to simulation is considered, calculated sensitivity of the prototype is not inferior to commercial camera's sensitivity at L = 24 and D = 20 mm, however the axial FOV is narrow. Generally, depth of animal PET camera's detectors is about 10 mm and shorter than whole body PET. This is in order to avoid decrease of resolution in edge of gantry, caused by DOI effect. In case of semiconductor PET, several detectors can be aligned to radial direction, so that there is possibility to avoid the effect without additional techniques like use of phoswich detectors[4].

Conclusion

Detector alignment and sensitivity were investigated for design of prototype of high resolution semiconductor PET camera. It was supposed that spatial resolution below 1 mm was achieved at 150 mm diameter gantry that can be applied in study to rats. Sensitivity may be obtained commercial animal PET camera by thickening total depth of detector. We guess that high resolution and sensitive prototype camera can be developed.

References

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3) Knoess C., Siegel S., Smith A., Newport D., Richerzhagen N., Winkeler A., Jacobs A., Goble R., Graf R., Wienhard K., and Heiss W., Eur. J. Nucl. Med. **30** (2003) 737.
4) Liu H., Omura T., Watanabe M., and Yamashita T., Nucl. Instrum. Methods B **459** (2001) 182.

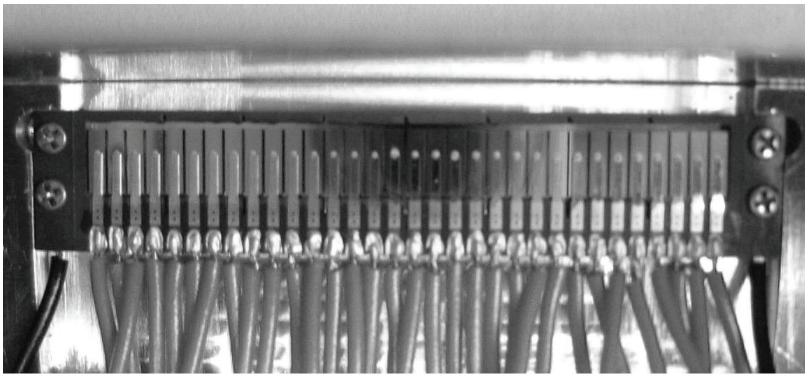

Figure 1. The picture of 32 ch CdTe detector array. The 32 ch detector array is composed of eight CdTe crystals and each crystal is divided into four sections.

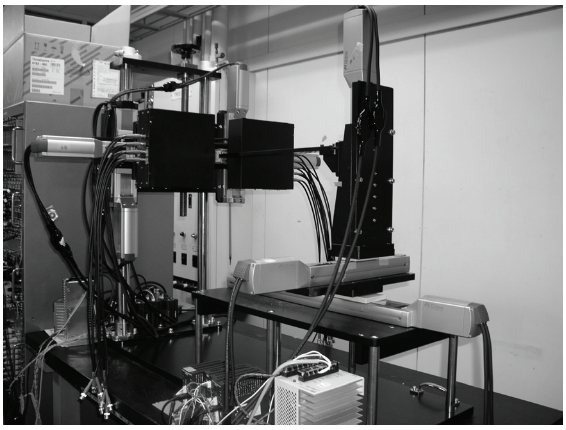

Figure 2. The dual head gantry system.

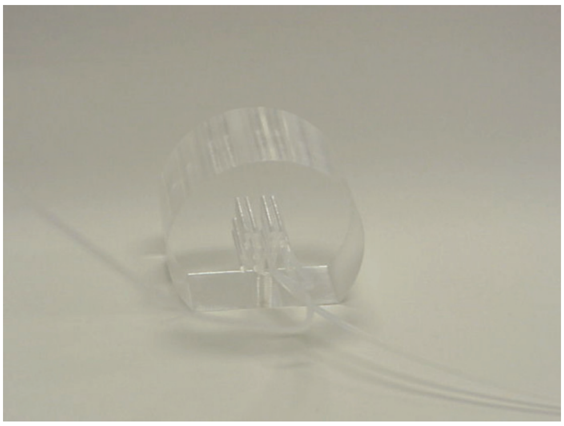

Figure 3. The picture of ^{18}F phantom.

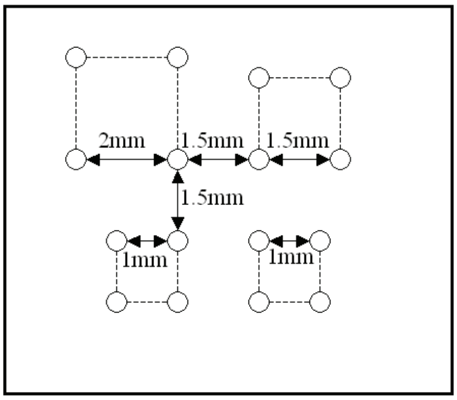

Figure 4. Schematic arrangement of hot spots in ^{18}F phantom.

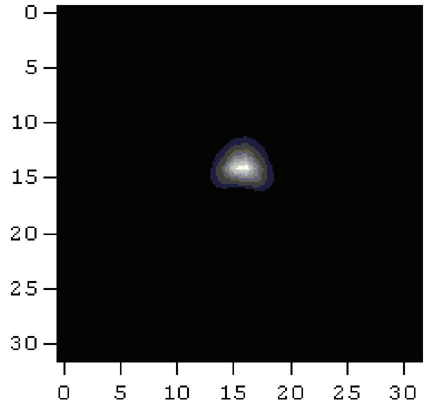

Figure 5. Reconstructed image of ^{22}Na point source.

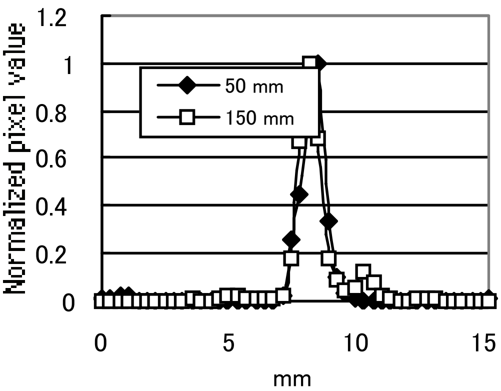

Figure 6. Profile of point source image.

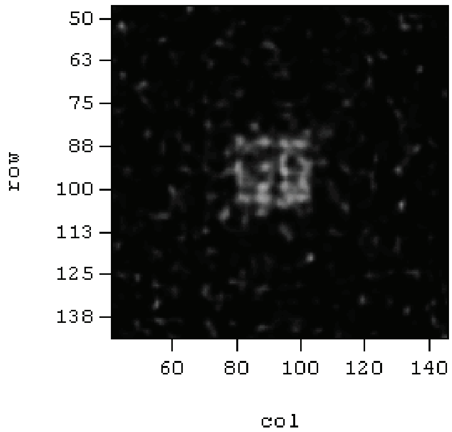

Figure 7. Reconstructed image of ^{18}F phantom.

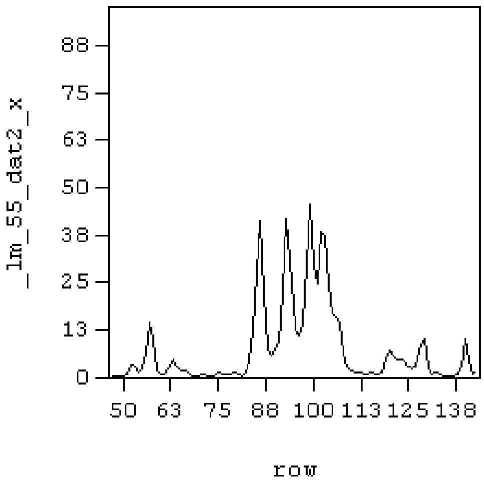

Figure 8. Profile of phantom image along axis in Fig. 7.

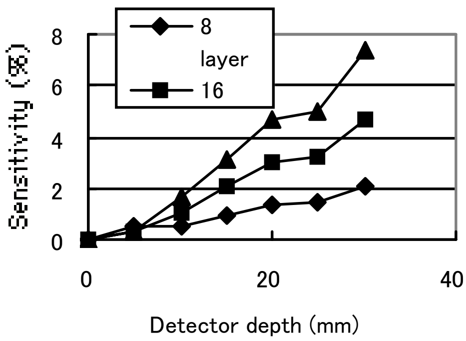

Figure 9. Simulated sensitivity of the prototype of semiconductor PET.