Characterization of the Ferrara animal PET scanner

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Abstract

A dedicated small animal PET scanner, YAPPET, was designed and built at Ferrara University. Each detector consists of a 20×20 matrix of 2×2×30 mm³ YAP:Ce finger-like crystals glued together and directly coupled to a Hamamatsu position sensitive photomultiplier. The scanner is made from four detectors positioned on a rotating gantry at a distance of 7.5 cm from the center and the field of view (FOV) is 4 cm both in the transaxial direction and in the axial direction. The system operates in 3D acquisition mode. The performance parameters of YAPPET scanner such as spatial, energy and time resolution, as well as its sensitivity and counting rate have been determined. The average spatial resolution over the whole FOV is 1.8 mm at FWHM and 4.2 mm at FWTM. The sensitivity at the center is 640 cps/μCi. © 2002 Elsevier Science B.V. All rights reserved.

PACS: 87.59.Wb; 87.59.Qx

Keywords: PET; Small animal

1. Introduction

PET has become a useful tool to measure regional in vivo distributions of various compounds, to study the blood flow, metabolism and receptors binding in humans. Before these tracers can be used in man, kinetic models of the tracers uptake in animals have to be derived, using data obtained by ex vivo procedures. This requires the use of a large number of experimental animals, thus also introducing errors due to inter-animal variation. The use of a dedicated animal PET scanner [1–4] could overcome these problems.

Animal PET scanners require a very high spatial resolution and sensitivity for studies on rats and especially on mice. At the University of Ferrara we have developed a PET scanner suitable for rats and mice studies. In this paper, we present its main performance and characterization.

2. Material and methods

Each block detector is a YAP:Ce matrix [5] consisting of 400 finger-like crystals (2×2×30 mm³ each) closely packed together and optically isolated by a 5 μm thick reflective layer. The multocrystal is directly coupled to a Hamamatsu position sensitive photomultiplier (model...
R2486-06) with high intrinsic resolution (≈0.5 mm, FWHM) which allows a good identification of small crystals [6]. Four of these detectors have been assembled on a rotating gantry. The opposite detectors are in coincidence and can be positioned at a distance ranging from 10 to 25 cm. The readout and data acquisition are handled by standard NIM and CAMAC electronics and controlled by “in house” developed software. The data were acquired in list-mode; at the end of acquisition they were corrected for dead-time losses, source decay and differences in field of view (FOV) sensitivity due to the planar rotating detectors [7]. The data were reconstructed by using a simple 3D backprojection filtered algorithm [8] with a Hamming window \( (a + (1 - a) \cos(\pi v/v_{\text{max}})) \) so as to reduce the noise effect in the final image. Every measurement has been performed by using a lower energy threshold of 50 keV.

### 3. Results

#### 3.1. Spatial resolution

The spatial resolution was measured using a (3.6 µCi) \(^{22}\text{Na}\) point-like source 0.8 mm in diameter. The source was suspended in air in various positions within the FOV and for each position the detectors were rotated by 90° in 32 steps. The data were reconstructed using a 3D backprojection filtered algorithm with a Colsher filter [8] and no window. The axial, radial and tangential FWHM and FWTM values are shown for radial (Fig. 1) and for axial (Fig. 2) source positions. These resolution values include the source dimension: to obtain the intrinsic FWHM\(_{\text{intr}}\) the source dimension (\(\phi\)) must be unfolded. We used the conservative formula

\[
\text{FWHM} = \sqrt{\text{FWHM}_{\text{intr}}^2 + \phi^2}
\]

The radial, tangential and axial intrinsic FWHMs are better than 1.6, 2.0 and 1.8 mm, respectively. Fig. 3 shows the reconstructed images of a small Derenzo phantom. The diameters of rods for each of the four segments are 3.0, 2.5, 2.0 and 1.5 mm, respectively, and the center to center spacing is two times the rod diameter.

#### 3.1.1. Sensitivity

The sensitivity measurement was performed by moving the \(^{22}\text{Na}\) point-like source in air by 1 mm increments in the axial direction. The results are shown in Fig. 4. The axial response is triangular, as expected. The background due to the coincidences generated by the 1.275 MeV photon emitted by the \(^{22}\text{Na}\) source with one of the two annihilation photons has been subtracted. By fitting the data with a triangular response plus a
second degree polynomial (to model the background) we estimate the sensitivity at the center to be 640 cps/µCi.

3.1.2. Scatter fraction

The fraction of scattered events was measured with a solid Lucite phantom measuring 4 cm in diameter and 4 cm in length, with a 2 mm hole drilled along its axial direction at its center. The hole was filled with a 18F–FDG line source and 10 million events were acquired. A second acquisition was performed with the 18F–FDG line source alone. Both sources were placed at the center of the FOV. The list-mode data were put into a sinogram that was single slice rebinned [9,10]. The unscattered events were assumed to lie within a 4 FWHM wide strip centered on the image in each sinogram of the line source. The scatter fraction value for the Lucite phantom was SCF₁ = 33% and for the line source was SCF₂ = 26%. The scatter contribution due to the Lucite phantom was estimated by Monte Carlo simulation: the value obtained was SCFₘₐₖ = 7.3% that is in good agreement with the difference between SCF₁ and SCF₂. The scatter fraction SCF₂ is due to the scanner and to multiple interactions within the crystal. The contribution due to the scanner can be reduced by better shielding.

3.2. Count rate

We have separately measured the count rate performance of our acquisition system based on CAMAC standard and the count rate performance of detection system. In both cases we have used a cylinder phantom filled with ≈500 µCi of ¹¹C
solution. Fig. 5 shows the acquisition versus the coincidence count rate. The fitting curve was $R_{\text{acq}} = \tau \cdot (1 - \exp(-R_{\text{coinc}} \cdot \tau))$ and the analytical curve was used for data dead-time correction. The count rate performance of the detection system is determined by the total count rate $R_{\text{tot}}$ and the random count rate $R_{\text{rand}}$. The true count rate is $R_{\text{true}} = R_{\text{tot}} - R_{\text{rand}}$ and the noise equivalent count $\text{NEC} = R_{\text{true}}^2/(R_{\text{tot}} + R_{\text{rand}})$ [10]. The count rate behavior observed is shown in Fig. 6. The curves show that random coincidences have little influence on YAPPET count rate performance (if the source is inside the FOV).

4. Conclusion

YAPPET is a dedicated animal PET with a volumetric resolution of $\approx 4.1 \text{ mm}^3$ and a sensitivity of 640 cps/µCi. Its performances allow the successful application of the scanner in studies of small animals such as mice and rats [11,12].

References