Development of Skin Surface Radiation Detector System to Monitor Positron Emission Tomography

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Watabe H., Narita Y., Hayashi Y., Nakamura T. and Itoh M.

Cyclotron and Radioisotope Center, Tohoku University

Introduction

Positron Emission Tomography (PET) is an unique device to determine quantitatively and localize precisely physiological functions in human. The measurement of regional cerebral blood flow (rCBF) is one of the most commonly used clinical PET studies. To obtain reliable result of rCBF it is necessary to know the time course of activity concentration (TCC) in the arterial blood during the PET scanning. Two conventional methods are commonly used to measure TCC in the arterial blood:

1. Samples of arterial blood are taken out with syringe several times at certain interval. Their activities are measured with the well-counter which has been cross-calibrated with the PET device. TCC is given by plotting activity data of each sample as a function of time.

2. Using a pump and a tube, arterial blood is taken out continuously during PET scanning. One end of the tube is a catheter putting into the artery of a subject, and other end is connected to the pump. On the way of the tube a radiation detector is fixed to measure positron-annihilation photons or positron in arterial blood. Blood is drawn continuously by the pump during PET scanning. TCC is obtained from the measured data of the detector, when the sample activity is calibrated with PET.

The former method does not require any detection system and any space for it in the PET room, but the TCC data is much less precise than that with the latter method due to a small number of measured data points. This produces large errors in numerical analysis of PET image. Another disadvantage of the former method is to make the examiner busy for blood sample measurement during PET study. On the other hand, the latter method gives us the smooth TCC data of blood curve because of continuous measurement, which enables us more precise analysis of the PET data than that with the former method. The latter method, however, brings problems about time delay and dispersion of a blood curve because of the tube between the subject and the pump. We must correct the measured data against time delay and dispersion [1]. Using this method, a considerable amount of arterial blood is taken out inevitably, then we must consider a burden to the subject.

We have developed a new type of detector system in order to measure the time course of activity concentration in the arterial blood of a subject in PET study, without taking the arterial blood. The system measures radioactivity in arterial blood through the subject's skin. The similar detector system was reported by J. E. Litton et al. [2]. They put the detector on the skin over the internal carotid artery. We placed a detector on the skin over the wrist. The detector consists of a thin plastic scintillator (1 mm thick), which can detect mainly positrons rather than γ rays. In order to subtract the background from tissue outside artery, we put the same type of detector on the skin outside the artery near the first detector.

Material & Methods

DETECTOR SYSTEM

Figure 1 shows the block diagram of the detector system. We tried to measure the ^{15}O activity (half life of 122 sec). The nucleus emits positrons of maximum energy 1.73 MeV, which has about 9 mm range in tissue, and is possible to penetrate through a skin from an artery. We used a 1 mm thick plastic scintillator (NE102A) of 8 mm × 20 mm which has much higher sensitivity for electron and positron than for photon. The photomultiplier (HAMAMATSU, R1548) has a small size of 24 mm × 24 mm × 70 mm, for easy handing above the patient. Signals from two detectors were fed to the pre-amplifier (ORTEC, 113) and were amplified by the linear amplifier (ORTEC, 571). Output signals were stored in the memory of MCA (NAIG, NLAB system) in every one second through the single channel analyzer (ORTEC 551). The stored data were analyzed with the personal computer (NEC, PC9801).

PHANTOM EXPERIMENT

In order to examine the performance of the detector system, we carried out the phantom experiment. Figure 2 shows a phantom of 200 mm × 200 mm × 360 mm which simulated a wrist and an artery. The phantom was made of acrylic resin containing saline. Saline mixed with ^{32}P (half life of 14.3 days) of 1 mCi was filled in an acrylic pipe (internal diameter of 7 mm and external diameter of 10 mm) simulating the artery. The pipe was designed to move in the phantom. ^{32}P emits only β rays of 1.71 MeV maximum energy which is very close to ^{15}O positron energy of 1.73 MeV. The detector was attached on the wall of the phantom.

Figure 3 illustrates an experimental set up showing movement of the detector and acril tube. The pipe was first moved to the direction of (a) in Fig. 3, then the detector was moved to the direction of (b) in Fig. 3. In these experiments we examined the maximum depth of artery which can be detected with the detector.

In the next step, we added ^{32}P radioactivity (200 μCi) also in the phantom, which simulated the radioactivity in the tissue outside artery. This experiment evaluated the

capability of the detector to detect radioactivity only in artery with the existence of tissue background.

CLINICAL EXPERIMENT

We tested our detector system on clinical PET studies. The study was the measurement of rCBF by using ^{15}O labeled water and ECAT 931 (CTI). This tomography has a spatial resolution of 8 mm (transaxial) and 7 mm(axial) full width at half maximum (FWHM) in the center of the field of view. The transmission scans were performed by using a ^{67}Ge-^{68}Ga external ring source for correction of tissue attenuation. ^{15}O labeled water was injected into the subject's vein of the left hand by a computer controlled injector. One detector was put on the subject's skin of the writst of the right hand under which an artery most closely contacted as a result of the medical doctor's palpation. Another detector was put on the skin near the first detector. The measurements started simultaneously when PET started to scan.

Results and Discussion

PHANTOM EXPERIMENT

Figure 4 shows the results of the experiment in which the pipe was moved along line (a) in Fig 3. These energy spectra consist of two components of bremsstrahlung in lower energy region and β rays in higher energy region. As shown in the figure, if the pipe is near the wall of the phantom (the depth ≤ 4 mm), β rays from ^{32}P can be measured through wall, whereas, only bremsstrahlung is measured when the pipe is beyond that depth.

From these results we concluded that the detector can detect β rays from the artery of less than 7 mm depth (considering the thicknesses of the pipe and the phantom wall).

Figure 5 shows the results of the experiment in which the detector was moved along line (b) in Fig. 3. In this experiment, we examined that two detectors should be separated each other. Figure 5 indicates that two detectors are better to be separated with the distance of more than 10 mm.

Figure 6 shows the result of the third experiment, in which, there was a background radioactivity in the phantom and the detector was moved along line (b) in Fig. 3. The spectra in Fig. 6 were obtained by subtracting the background spectra from the measured data. This figure shows that we could distinguish the signals of the pipe from the background counts, especially in lower energy region.

CLINICAL EXPERIMENT

Figure 7 shows one example of the clinical experimental result. As shown in this figure, counts obtained with the detector fixed on artery increase especially in lower energy region more rapidly after injection than those with another detector, and gradually these two

curves become close together, which suggests radioactivite concentrations reach equilibrium between artery and tissue. The subtraction of these two curves clearly gives the TCC in artery blood.

We could find the potentiality to measure true arterial blood activity curve by our new detector system. Since this detector system measures positrons, it has a limitation that the positron energy must be high enough to reach the skin surface from the artery and the artery must locate thin enough to penetrate the positron to the skin surface vice versa. The better method to fix the detector system on the patient's skin must be developed.

References

1) Iida H. et al., J. Cereb. Blood Flow Metab. **6** (1986) 536.
2) Litton Jan E. and Eriksson L., IEEE Trans. Nucl. Sci. NS **37** (1990) 627.

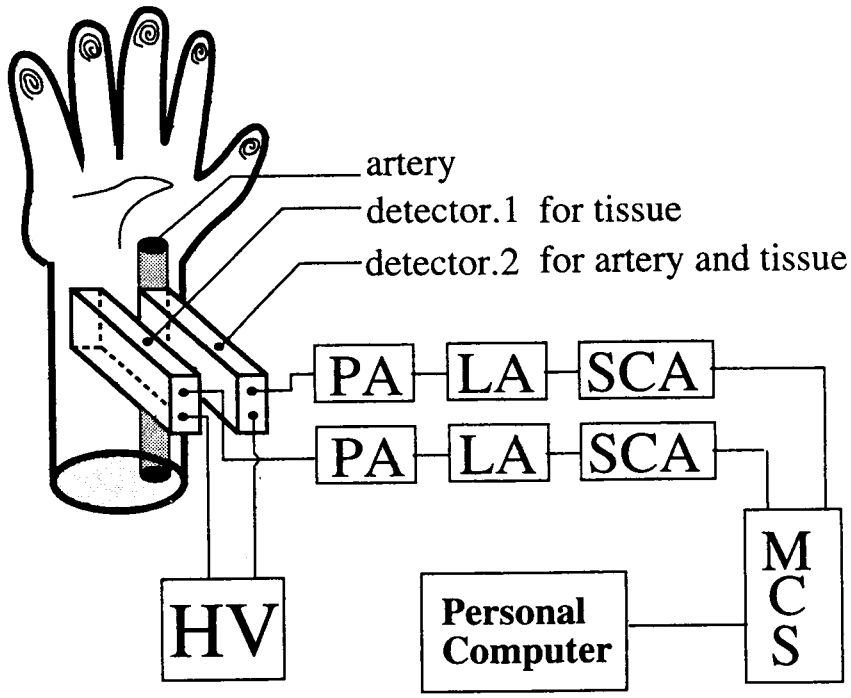

Fig. 1. The block diagram of the detector system.

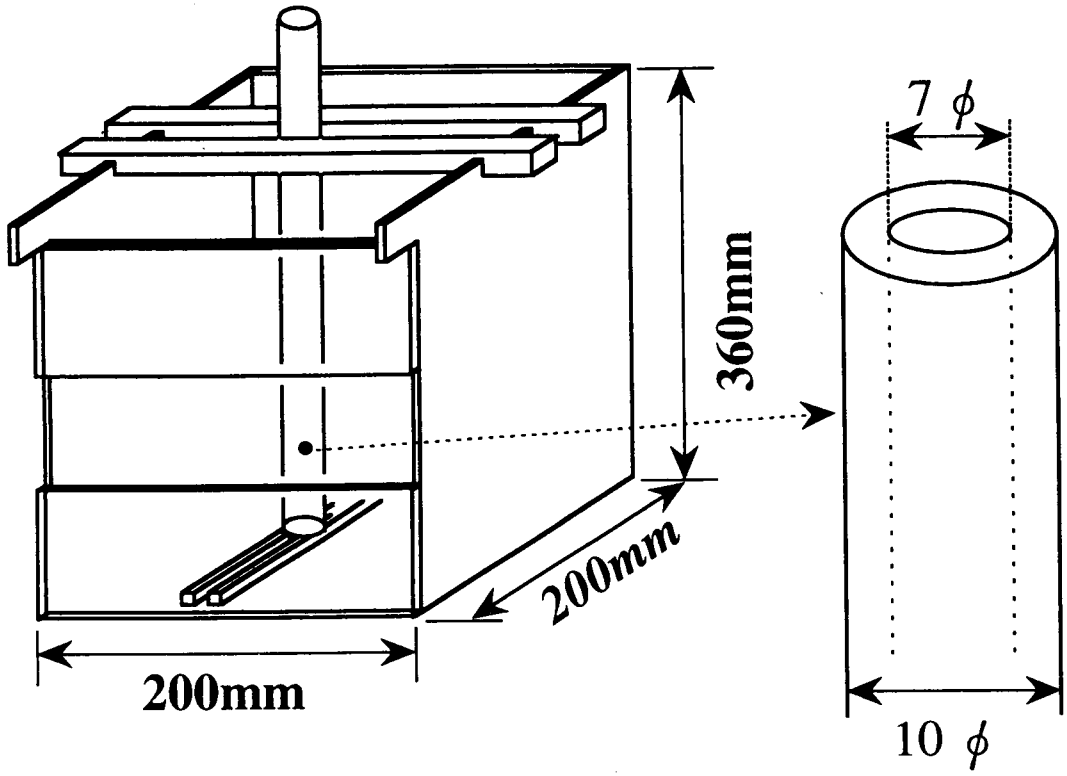

Fig. 2. Schematic illustration of the phantom which simulated a wrist and an artery.

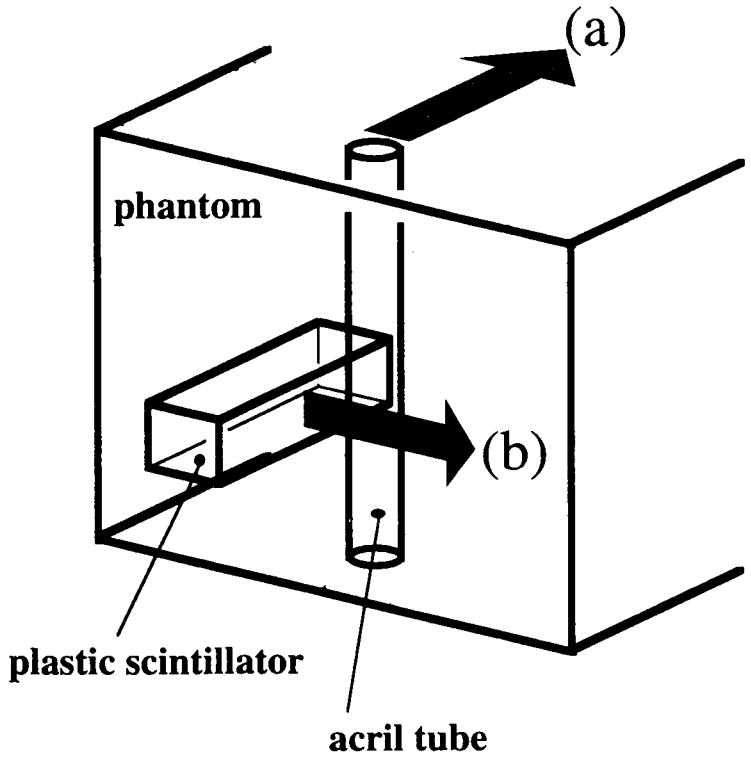

Fig. 3. The movement of detector and acril tube

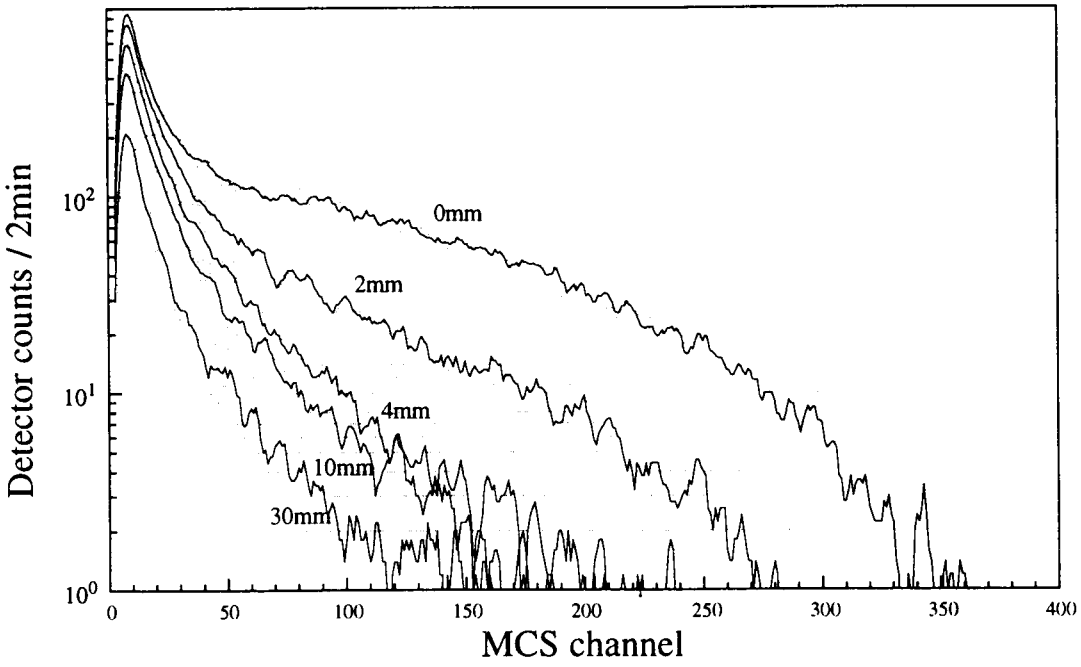

Fig. 4. The spectrum of the experiment in which the pipe was moved along line (a) in Fig. 3

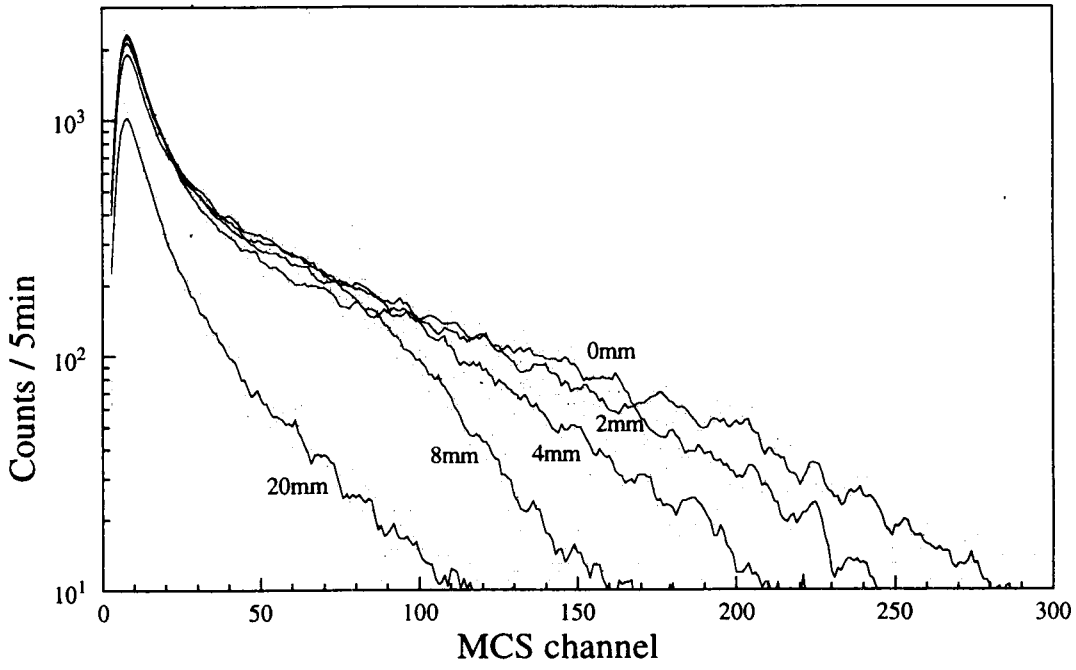

Fig. 5. The spectrum of the experiment in which the detector was moved along line (b) in Fig. 3.

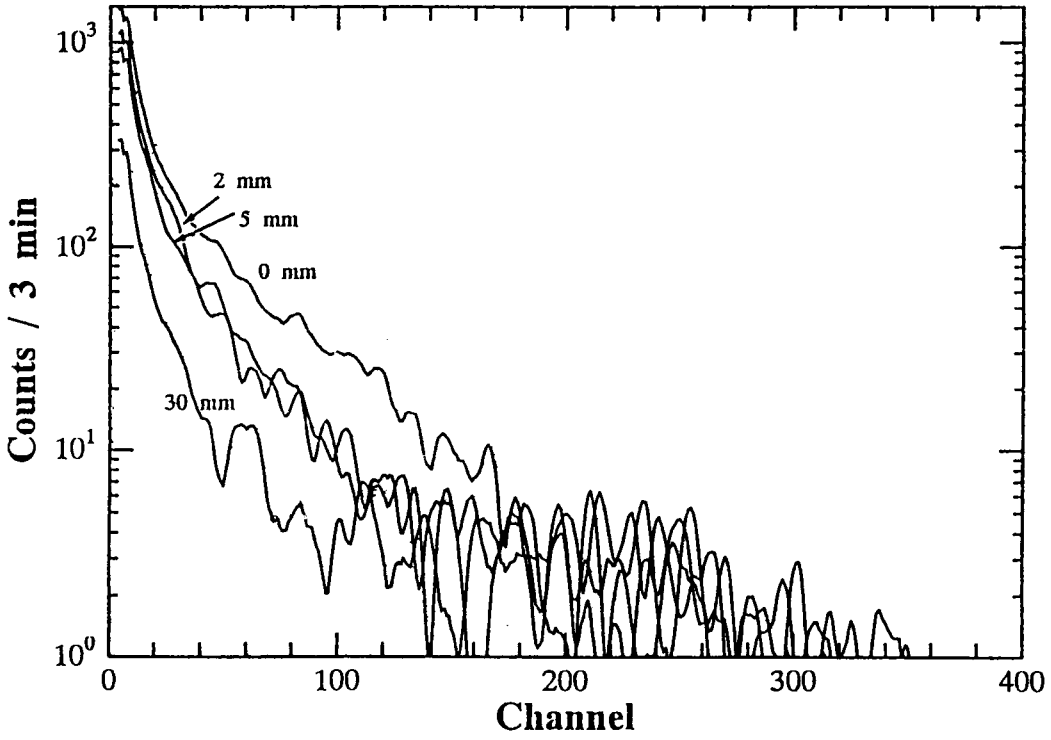

Fig. 6. Yields obtained by subtracting the background spectra from the measured data.

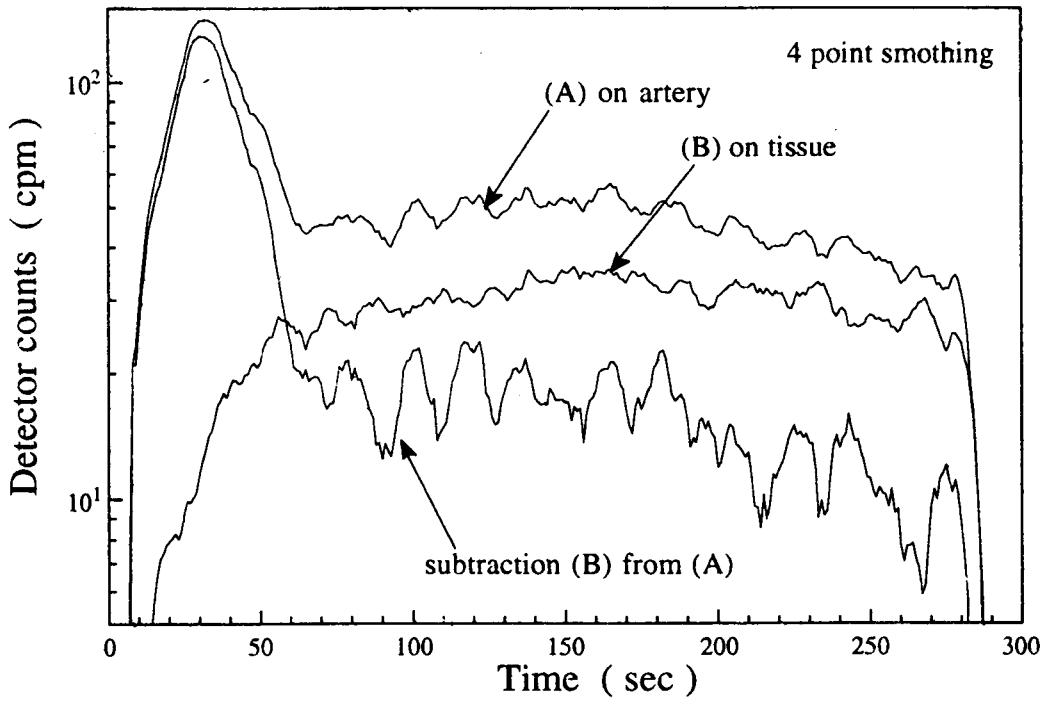

Fig. 7. The time-related curve between arterial and tissue counts.