Fluorescent scanning x-ray tomography with synchrotron radiation

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Fluorescent scanning (FS) x-ray tomography was developed to detect nonradioactive tracer materials (iodine and gadolinium) in a living object. FS x-ray tomography consists of a silicon (111) channel cut monochromator, an x-ray shutter, an x-ray slit system and a collimator for detection, a scanning table for the target organ, and an x-ray detector with pure germanium. The minimal detectable dose of iodine in this experiment was 100 ng in a volume of 2 mm^3 and a linear relationship was shown between the photon counts of a fluorescent x ray and the concentration of iodine contrast material. A FS x-ray tomographic image was clearly obtained with a phantom. © *1995 American Institute of Physics.*

I. INTRODUCTION

From the analysis of a fluorescent x ray, we can determine several characteristics of the materials and biological specimen. However, these specimens must be thin sliced sections and scanned surfaces of the object.[1] Some fluorescent tomographic studies were performed using an x-ray tube,[2] and a microtomographic study with synchrotron radiation was also done to detect iron of Bee.[3] In this study, a new fluorescent scanning (FS) x-ray tomography was developed to detect nonradioactive tracer materials (iodine and gadolinium) in living object-like radionuclide examinations with single photon emission computed tomography (SPECT) or positron emission computed tomography (PET). In the preliminary experiment with phantom, about 200 ng iodine was detected.[4] Here, the concept of the system, detailed results of this FS x-ray tomographic experiment with a phantom and the FS x-ray tomographic image are reported.

II. MATERIAL FOR TRACER STUDY

In studies with single photon emission CT, a radionuclide agent "I-123 *N*-isopropyl-*p*-iodoamphetamine (IMP)" is used for the analysis of cerebral blood flow. About 16.5 ng/g iodine accumulates in the gray matter of the brain after intravenous administration of this drug. This value was calculated from the known uptake percentage of IMP which is 8.5% of the total injection dose. When we administer an arterial injection, about 178.6 ng/g iodine accumulates in the gray matter because the first pass extraction of the drug is 92%. Abnormal drug reaction has not been reported in animal studies even at 1000 times the dose used for clinical SPECT study. So if we use 10 times the clinical dose or 50 times the dose, approximately 1786 or 8930 ng/g iodine will accumulate in gray matter. Then the excitation volume is adjusted to almost the same size as that in positron CT (i.e., $5\times5\times5$ mm^3), so 223 ng or 1115 ng iodine will be excited by the monochromatic x ray. These doses seem to be detectable using the fluorescent imaging system.

III. METHOD

FS x-ray tomography consists of a silicon (111) channel cut monochromator, an x-ray shutter, an x-ray slit system, a scanning table for the target organ and an x-ray detector with pure germanium that detects a fluorescent x-ray excited by a monochromatic x-ray tuned from synchrotron radiation (SR) (Fig. 1). The experiment was carried out at the bending magnet beam line of BLNE-5A of the Tristan accumulation ring (6.5 GeV, 10–30 mA) in Tsukuba, Japan. The energy of the monochromatic x-ray beam was adjusted to 33.17+0.2 keV. The photon flux is approximately 7×10^7 photons/mm^2/s in front of the object at a beam current of 30 mA. The mono-

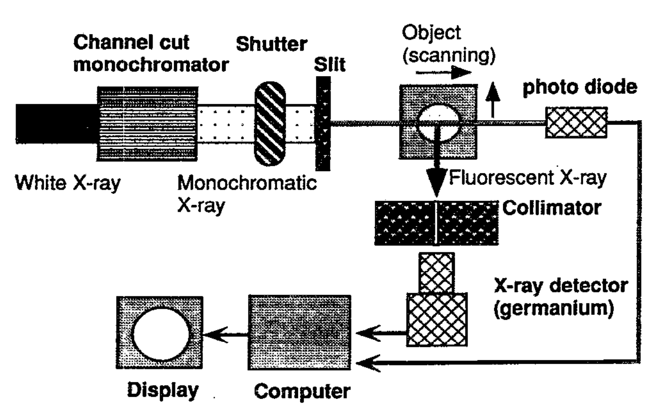

FIG. 1. Schematic diagram of the fluorescent scanning x-ray tomography.

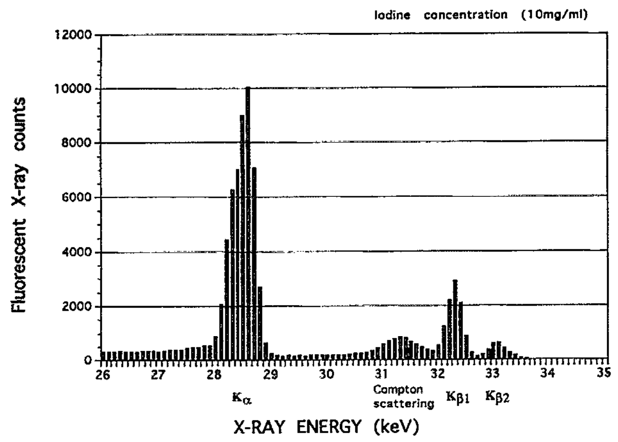

FIG. 2. The histogram of fluorescent x ray excited by monochromatic x ray. Fluorescent x-ray and Compton scattering are observed at a monochromatic x-ray energy of 33.37 keV.

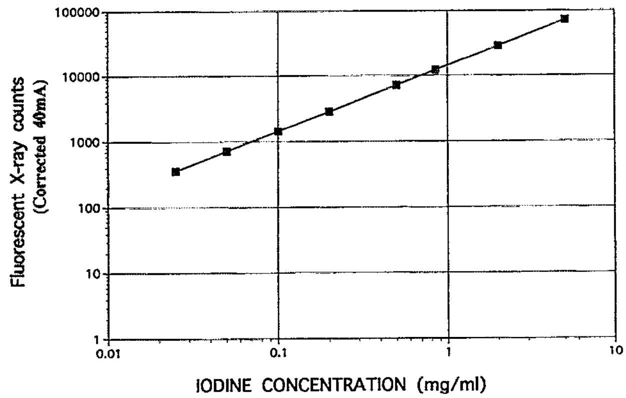

FIG. 3. The relationship between the fluorescent x ray and the concentration of iodine.

chromatic x-ray beam was collimated into 1×2 mm^2 (horizontal and vertical) using an x-ray slit system. In the detecting portion, the excited fluorescent x ray was also collimated to 1×2 mm^2 and the length of this collimator was 105 mm. Then the spatial resolution of this experiment is 1×1 mm^2 with a 2 mm slice thickness. Distance between the sensor and the object was 220 mm. Scanning step size was set to 1 mm in both the $X-Y$ axes, and data acquisition time was 60 s at each scanning point. A FS x-ray CT image was obtained by point scanning with a K_α count correction for object absorption.

A phantom filled with various concentration of an iodine contrast material was scanned. The phantom size is 20×20 mm^2 with a cross ditch filled by iodine contrast material (4 and 3 mm).

A. Correction of x-ray absorption by the object

The fluorescent x-ray count was measured as the area of K_α. The correction for x-ray absorption of an excited monochromatic x ray and K_α fluorescent x ray must be done for quantitative analysis. The attenuation coefficients of the acrylic phantom and iodine by a monochromatic x ray (above K edge: 33.37 keV) and K_α (28.61 keV) are 0.291 and 0.378 cm^2/g and 36.35 and 10.55 cm^2/g, respectively. The scanning position of the object can be determined by the stage position. To correct object position on the stage, production of Compton scatter was measured because Compton

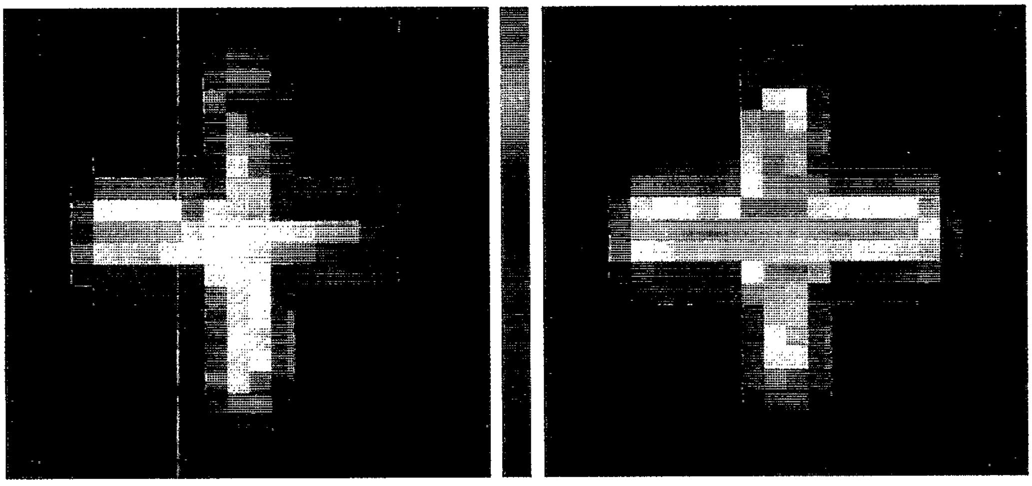

FIG. 4. The image obtained by fluorescent scanning x-ray tomography using a phantom.

scatter is generated by the object. So attenuation correction of the object can be performed by the stage position of the object corresponding to the object position. In future experiments, the tomographic image is thought to use the correction of absorption of the object.[5]

IV. RESULTS AND DISCUSSION

The spectrum of the fluorescent x ray excited by monochromatic x ray is shown in Fig. 2. The K_α, $K_{\beta 1}$, and $K_{\beta 2}$ of the fluorescent x ray and the Compton scattering for the exciting monochromatic x ray were observed separately. The energy of the monochromatic x ray was set at 33.37 keV and K_α x ray was used to analyze the excitation of fluorescent x ray. Compton and Thompson scattering are observed at a monochromatic x-ray energy of 32.98 keV.

The minimal detectable dose was determined by changing the iodine concentration from 25 μg/ml to 5 mg/ml (Fig. 3). A linear relationship was observed between the fluorescent x-ray counts and the concentration of iodine contrast material. The minimal detectable dose of iodine in this experiment was 50 μg/ml, i.e., the excitation dose of iodine is 100 ng (50 μg/ml$\times 2\times 10^{-3}$ ml). A dose of 25 μg/ml iodine was also detected when the observation time was increased to 100 s.

The image of the box-shaped phantom filled with 2 mg/ml iodine is shown in Fig. 4. The cross ditch filled with iodine was imaged clearly. The image with correction for the x-ray absorption by the object shows homogeneous distribution of iodine contrast material, whereas the image without correction of x-ray absorption showed inhomogeneous distribution. It was concluded that the correction for x-ray absorption by the object is indispensable when using FS x-ray tomography. In this experiment, the detection of Compton scattering was used to determine the object connection area. However, for more precise correction for x-ray absorption by the object, the use of the CT image will be considered for the next experiment. To decrease the image acquisition time, a multi-channel detector system with pure Ge is now being constructed.

TABLE I. Various target materials for fluorescent x-ray CT.

Excitation energy		Fluorescent x ray $K_{\alpha 1}$	$K_{\alpha 2}$	$K_{\beta 1}$	$K_{\beta 2}$
1. Iodine (53):	>33.170	28.61	28.32	32.3	33.0 keV
2. Gadolinium (64):	>50.239	43.00	42.31	48.7	50.0 keV
3. Ytterbium (70):	>61.332	52.39	51.35	59.3	61.0 keV

In this experiment, imaging of iodine was performed, and the absorption by the object was severe. Therefore, for human study, other nonradioactive tracer materials such as gadolinium and ytterbium may be suitable, because object absorption can be decreased significantly (Table I).

V. CONCLUSION

FS x-ray tomography might be available to detect a low concentration of contrast material and to reveal its distribution clearly.

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