Comparison of Parallel and Fan-Beam Monochromatic X-Ray CT Using Synchrotron Radiation

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ABSTRACT

Monochromatic x-ray CT has several advantages over conventional CT, which utilizes bremsstrahlung white x-rays from an x-ray tube. There are several methods to produce such monochromatic x-rays. The most popular one is crystal diffraction monochromatization, which has been commonly used because of the fact that the energy spread is very narrow and the energy can be changed continuously. The alternative method is the use of fluorescent x-ray, which has several advantages such as large beam size and fast energy change. We have developed a parallel-beam and a fan-beam monochromatic x-ray CT, and compared some characteristics such as accuracy of CT numbers between those systems.

The fan beam monochromatic x-rays were generated by irradiating target materials by incident white x-rays from a bending magnet beam line NE5 in 6.5 GeV Accumulation Ring at Tukuba. The parallel beam monochromatic x-rays were generated by using a silicon double crystal monochromator at the bending magnet beam line BL-20BM in Spring-8. A Cadmium telluride (CdTe) 256 channel array detector with 512mm sensitive width capable of operating at room temperature was used in the photon counting mode.

A cylindrical phantom containing eight concentrations of gadolinium was used used for the fan beam monochromatic x-ray CT system, while a phantom containing acetone, ethanol, acrylic and water was used for the parallel monochromatic x-ray CT system.

The linear attenuation coefficients obtained from CT numbers of those monochromatic x-ray CT images were compared with theoretical values. They showed a good agreement within 3%.

It was found that the quantitative measurement can be possible by using the fan beam monochromatic x-ray CT system as well as a parallel beam monochromatic X-ray CT system.

Keywords: Synchrotron radiation, crystal monochromator, fluorescent x-ray, monochromatic x-ray CT

1. INTRODUCTION

Monochromatic x-ray CT has several advantages over conventional CT, which utilizes bremsstrahlung white x-rays from an x-ray tube. A CT Image obtained from a monochromatic x-ray CT shows the distribution of linear attenuation coefficients. By using several different photon energies, we can obtain electron densities, which are quite important for radiotherapy treatment planning.

We have developed a dual-energy monochromatic x-ray CT system aiming at quantitative imaging of large objects. The 256-channel CdTe array detector was used in the photon counting mode. The size of the detector element was 1.98mm(h) x 1.98mm(w) x 0.5mm(t) and the length of total sensitive area was 512mm. Each element has two discriminators (upper discriminator and lower discriminator) and two 16-bit counters (upper counter and lower counter). By changing the discriminator levels with a fixed difference of dV continuously, an incident x-ray spectrum can be obtained.

There are two different ways to produce monochromatic x-rays. One is the parallel beam method[1-3] using crystal diffraction, the other is the cone/fan beam method[4-6] using fluorescent x-rays. We made some experiments using these two types of monochromatic x-ray CT systems, and compared some characteristics such as accuracy of CT numbers.

2. MATEIALS AND METRHODS

2.1. Fan-Beam Monochromatic X-Ray CT

The system consists of a fluorescent x-ray source, a rotating table, a CdTe array detector (Matsushita Industrial Equipment Co., Japan) and a computer system as shown in Fig. 1,2. Measurements were taken at bending magnet beam line NE5 (AR (6.5GeV), KEK, Tsukuba, Japan. The fluorescent x-ray generated by irradiating the target material offered a large cone beam due to its divergent characteristic. In this study, we used a fan beam fluorescent x-ray by using a slit collimator. Several phantoms which contain iodine contrast media of different concentrations were measured.

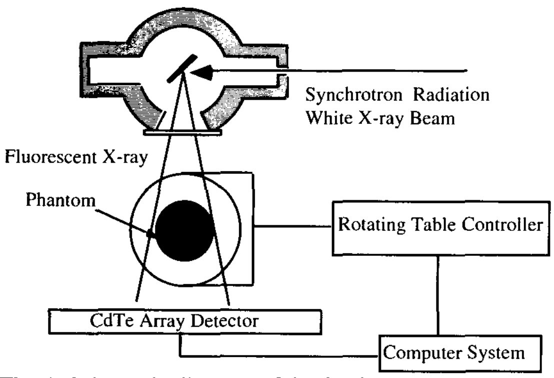

Fig. 1. Schematic diagram of the fan-beam

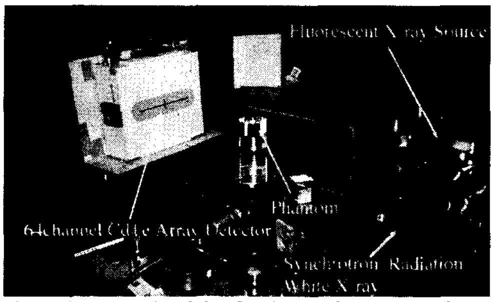

Fig. 2. Photograph of the fan-beam CT system CT system

2.2. Parallel-Beam Monochromatic X-Ray CT

Several monochromatic x-ray energy spectra were measured using the bending magnet beam line (BL20B2) at the Biomedical Imaging Center in Spring-8. From the measured spectra, the upper and lower energy limits were obtained for photon energy discrimination. Cylindrical phantoms of water, alcohol, acetone, paraffin and Lucite were measured at photon energies ranging from 40 to 70 keV.

A phantom on a rotating table was projected by a slit beam of 300mm in width onto a CdTe array detector angled to the incident beam at 45 degrees. A total of 360 projections covering 360 degrees were acquired, and CT images were reconstructed.

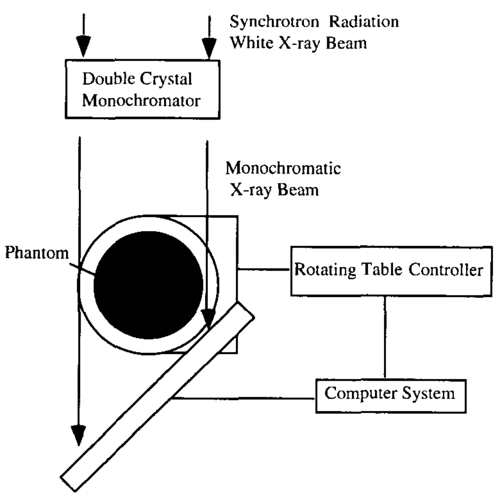

Fig. 3. Schematic diagram of the parallel-beam CT system

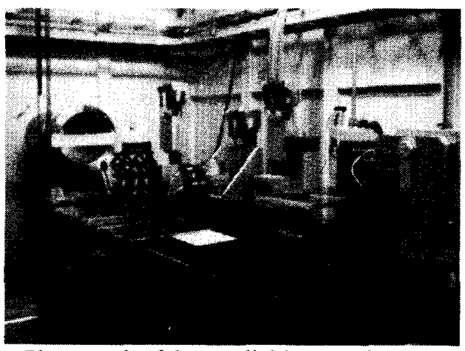

Fig. 4. Photograph of the parallel-beam CT system

3. RESULTS

3.1 Accuracy of Attenuation Coefficient

The linear attenuation coefficients obtained from the cylindrical Lucite phantom were compared with theoretical linear attenuation coefficients calculated from photon cross sections and Gd concentration. They showed a good agreement within 3% over a wide range of Gd concentrations. Fig 5. shows the relationship between experimental values and theoretical value. CT. Similar results were also obtained for parallel-beam CT.

3.2 K-Edge Subtraction

Monochromatic x-ray CT images of a cylindrical phantom containing Gd contrast material with different concentrations were measured by using the energies above (52.4keV) and below (47.5keV) the Gd K absorption edge of 50.2keV. From the subtraction image, the smallest possible detectable quantity was about 1% gadolinium concentration. Fig. 6 shows an example of monochromatic x-ray CT image of a human head phantom. CT images of large size objects such as a human head and body can be taken by using this system.

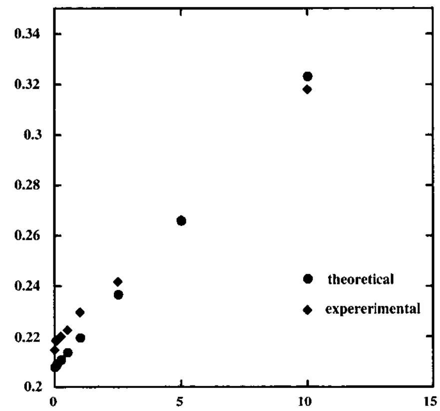

Fig. 5. A relationship between experimental value and theoretical value

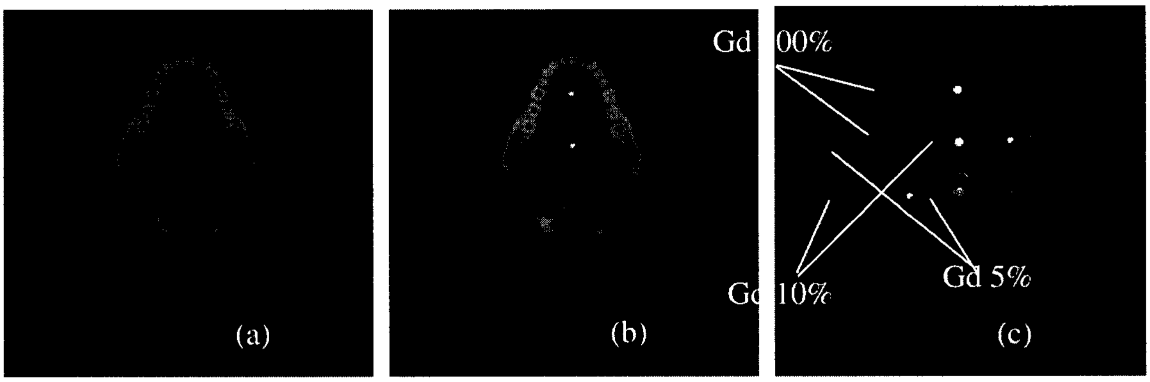

Fig. 6. CT images of a head phantom obtained by fan-beam monochromatic x-ray CT. Image of a head phantom at 47.5keV, (b) Image of a head phantom at 52.4keV, (c) Subtraction image ((b)-(a))

4. DISCUSSION

From the subtraction CT image, the smallest possible detectable quantity was about 1% gadolinium concentration. This shows good agreement with theoretical value. In the low concentration region of Gd contrast media, the linear attenuation coefficient of the water becomes dominant, and the difference of the linear attenuation coefficients of water between the energies above and below the K absorption edge can not be negligible. The smallest detectable concentration will be improved with 0.5%, when the energy of 49.1keV (Tm) and 50.7keV (Er) will be used. In case of parallel-beam CT, the energy can be changed continuously. Therefore, the detectable concentration will be better than fan-beam fluorescent x-ray CT because of the continuous tenability of the photon energy.

However, there are several advantages of the fan/cone beam monochromatic x-ray CT using fluorescent x-rays such as wide beam size, rapid energy switching, wide energy range and so forth. These two method will be complementary to each other in various applications.

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