Medical Application of Synchrotron Radiation in Japan

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ABSTRACT

Over the past two decades there has been a tremendous growth in the number of synchrotron radiation facilities in the world and also in Japan. The high flux and brightness radiation which derive from the third generation low emittance rings provide an ideal source for many applications in the medical sciences. The application of synchrotron radiation to medical imaging started in the early 80's in U.S.A, followed by European countries such as Germany and Russia. In Japan, researchs on intravenous coronary angiography started in 1884 at the Institute for High Energy Phisics(KEK) in Tsukuba. At present, it is the only application of syncrotron radiation which is at the stage of human study. In '90s, newer techniques such as phase and refraction contrast imaging appeared which are at the in vitro or animal study stage. Various types of x-ray CT have also been developed for three-dimensional imaging of the subjects. The present status of medical applications of synchrotron radiation in Japan is reviewed.

Key words: synchrotron radiation, absorption contrast, phase cnntrast, refraction, diffraction

INTRODUCTION

When charged particle moves along the curved orbit, high intensity photons are emitted tangential to the orbit. This is called the synchrotron radiation. The intensity is, typically, more than a million times higher than the x-rays from a conventional x-ray tube and the energy spectrum is continuous. By making use of several monochromatizing techniques, monochromatic x-ray beams are obtained at virtually any energy. The energy tenability allows enhancement of images and dose reduction by selection of most suitable energy for a given procedure.

The other property of synchrotron radiation comes from the wave nature of x-rays. When x-rays travel through an object, both the amplitude and phase of the x-ray wave are modified by the object. Also, x-ray wave causes diffraction, refraction and scattering when traversing the object through the interaction of x-rays with the matter. A source with sufficient spatial coherence makes it possible to detect them. Newer imaging methods such as the phase, diffraction and refraction contrast imaging, which utilize the wave nature of x-rays, have been developed in the last decades.

APPLICATIONS OF SYNCHROTRON RADIATION

2.1. Coronary Angiography

The application of synchrotron radiation to medical imaging started in early 80's.. A few years later, European countries such as Germany and Russia began the research projects. In Japan, the research project started in 1884 at the Institute for High Energy Physics (KEK) in Tsukuba.[1] In the United States and in Europe, non-invasive coronary angiography of the line-scan method using the dual line-detector system was used. In this system, the line images at photon energies just above and below iodine K-edge were acquired simultaneously. By performing K-edge subtraction, static iodine enhanced images were obtained with high image quality. In Japan, a two-dimensional image acquisition system has been investigated for real-time cine-mode imaging using a single photon energy above the K-edge.

Until now over 300 patients were investigated in the United States and in Europe after 1986 when the first human images were obtained in the United States. In Japan, more than 30 patients have been so far investigated after 1996 when the first three patients were investigated using a 6.5 GeV AR ring at KEK in Tsukuba.[2-5]

Michro-angiography which aims at imaging of vessels of other organs rather than coronary artery are also pursued.[6]

2.2. Phase, Diffraction and Refraction Contrast Imaging

In conventional x-ray transmission imaging, contrast is generated by the change of the amplitude of the x-ray wave. In this case, the amplitude contrast (absorption contrast) is not sufficient for imaging of soft tissue structures. On the other hand, phase contrast is suitable for soft tissue imaging, because the phase shift cross section is much larger than the absorption cross section for light elements. [7-10] X-ray phase information is missing in a usual transmission imaging, therefore special device such as interferometer is necessary to generate phase contrast. Phase contrast CT images of human tissues were successfully obtained which showed possibility of distinguishing cancer from benign tumors.

Diffraction and refraction contrast imaging makes use of the wave nature of the x-rays. When x-ray transmit the object, absorption, refraction and scattering occurs. By increasing the distance between detector and the object, it becomes possible to convert a small scattering angle to a detectable length. High contrast images of various specimens including human tissues have been obtained by many studies. [11-15]

2.3. Monochromatic X-Ray CT

There are two types of monochromatic x-ray CT. One is the conventional transmission CT, and the other is the emission CT which measures the fluorescent x-rays generate by the incident monochromatic x-rays emitted from inside the object.

Transmission 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. 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.[16-18] The alternative method is the use of fluorescent x-ray, which has several advantages such as large beam size and fast energy change.[19-21] Quantitative CT images and K-edge subtraction image were obtained using these method.

A fluorescent x-ray emission CT has been also developed using a HPGe detectors which is located at an angle of 90 degrees for Compton scattering measurement. Images of human thyroid specimen were obtained with the spatial resolution of 0.05 mm with slice thickness of 0.05 mm.[22, 23]

DISCUSSION

The research areas reviewed in this paper are for the most part in the stage of phantom or animal studies except for coronary angiography which is at the human study phase. There is a lot of competition from advances of recent imaging technologies such as fast functional MRI, 4D cone-beam CT, high resolution PET, ultrasound imaging and so fourth. The synchrotron radiation imaging will have to provide significant advantages over these conventional modalities in order to be accepted in the medical fields. Furthermore, the development of compact and synchrotron radiation sources will be required for clinical use in the future.

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