Interferometric phase-contrast X-ray CT imaging of VX2 rabbit cancer at 35keV X-ray energy

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Abstract. Imaging of large objects at 17 7-keV low x-ray energy causes huge x-ray exposure to the objects even using interferometric phase-contrast x-ray CT (PCCT) Thus, we tried to obtain PCCT images at high x-ray energy of 35keV and examined the image quality using a formalin-fixed VX2 rabbit cancer specimen with 15-mm in diameter The PCCT system consisted of an asymmetrically cut silicon (220) crystal, a monolithic x-ray interferometer, a phase-shifter, an object cell and an x-ray CCD camera The PCCT at 35 keV clearly visualized various inner structures of VX2 rabbit cancer such as necrosis, cancer, the surrounding tumor vessels, and normal liver tissue Besides, image-contrast was not degraded significantly These results suggest that the PCCT at 35 KeV is sufficient to clearly depict the histopathological morphology of VX2 rabbit cancer specimen

1. INTRODUCTION

Phase-contrast x-ray imaging with an x-ray interferometer [1], has a great potential to reveal the structures inside soft tissues without using a contrast agent because this technique has more than 1000-fold higher sensitivity than that of the conventional absorption-contrast method [2,3] Phase-contrast x-ray CT (PCCT) [4] at 17 7keV x-ray energy clearly demonstrates rabbit cancer lesions [5,6] and human cancer lesions [7-11], however the size of these samples is limited to less than 10-mm in diameter To observe larger biomedical objects, phase-contrast x-ray imaging systems with a large monolithic x-ray interferometer [12] and two-crystal x-ray interferometer [13,14], have been developed A field view of 25 mm x 25 mm can be obtained at 17 7 keV and clear projection images can be depicted [12-15] However, for imaging large objects, low x-ray energy causes huge x-ray exposure to the objects In addition, the drift of interference fringe was generated by long data acquisition on PCCT because the projection number must be increased to obtain adequate spatial resolution and the longer data acquisition per projection is required to obtain a sufficient signal-to-noise ratio of image (2 4-fold in 17 7 keV) (Table 1) Thus, we performed the PCCT at high x-ray energy of 35 keV to attest the obtainability of CT images with a good contrast

TABLE 1. Parameters of PCCT data acquisition

X-ray energy (keV)	Thickness object	cell (mm)	X-ray absorption by object cell	Projection number	Data acquisition time (s/projection)	total image time (hr)
17 7 keV (1 1)	10	17	1/6 5	250	50	6 5
	15	25	1/15 6	400	120	
35 keV (0 308)	15	25	1/2 2	400	50	10 5

Energy (mass absorption coefficient of water cm^2/g)
Data acquisition time (s/projection) means x-ray exposure time per projection
Total data acquisition time included the time required for the mechanical movement of object and data transfer time from CCD camera to computer

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2. METHODS AND MATERIAL

The phase-contrast x-ray imaging system consisted of an asymmetrically cut silicon (220) crystal, a monolithic x-ray interferometer, a phase-shifter, an object cell and an x-ray CCD camera (Fig 1) The study was performed at a 3-pole 5-T superconducting vertical wiggler beam line of the Photon Factory in Tsukuba, Japan The x-ray energy was set at 35 keV The beam exposure time was 50 sec/projection for 400 projections over 180 degrees Details of the image reconstruction methods have been previously described [4]

The object was a formalin-fixed VX2 rabbit cancer specimen with 15-mm in diameter It was placed in a 25-mm-thick sample cell in the beam path between mirror and analyzer of the interferometer

The regional $d\delta$ of sample, which had been normalized by water [9], was measured on typical necrosis, cancer and normal liver of the phase-contrast CT image Image-contrast ratios for these pathological lesions were calculated as pathological lesion $d\delta$ value / normal liver $d\delta$ value Data were expressed as means ± standard deviation Differences between the groups were analyzed using Student's unpaired t test A p value of <0.05 was considered statistically significant

The present study was approved by the Medical Committee for the Use of Animals in Research of the University of Tsukuba, and it was done in conformity to the guidelines of the American Physiological Society

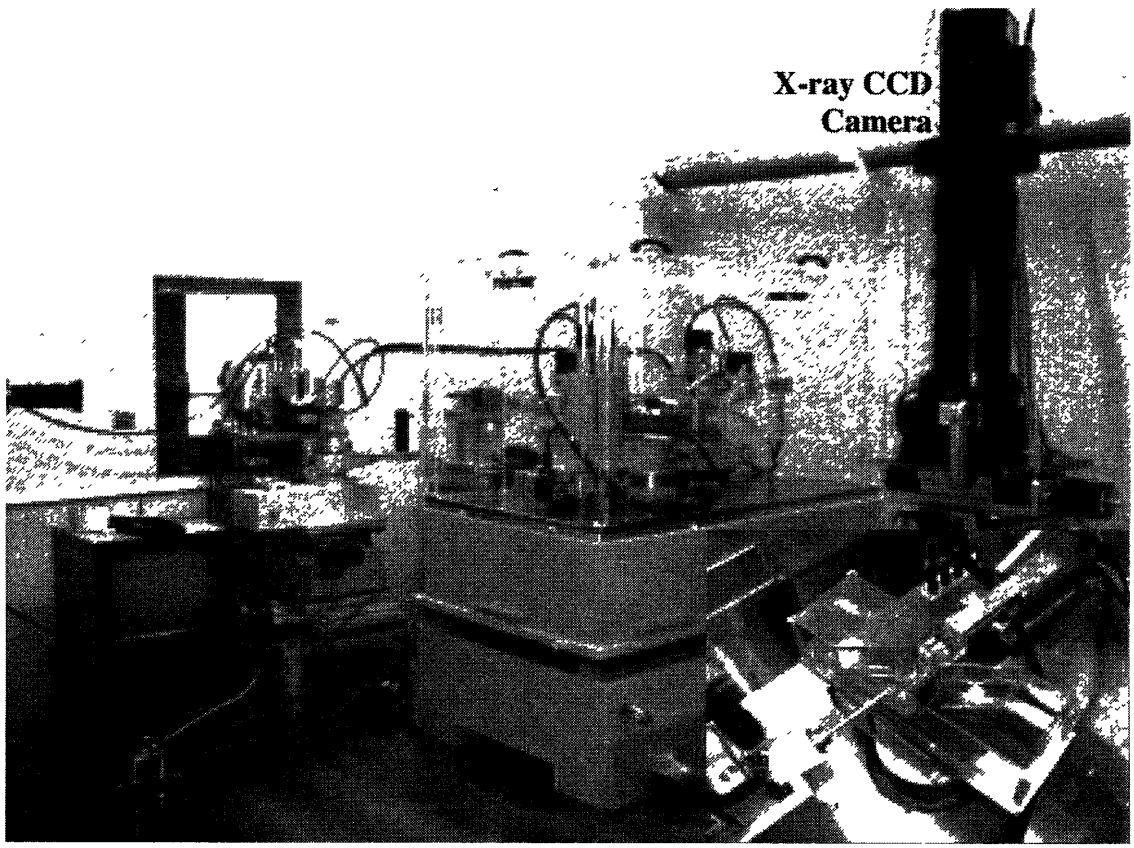

FIGURE.1 A picture of phase-contrast X-ray imaging system with a monolithic x-ray interferometer Inset Set up of CT object

3. RESULTS AND DISCUSSIONS

Interferometric PCCT image obtained at 35keV x-ray energy clearly demonstrated various structures of VX2 rabbit cancer such as necrosis, cancer, the surrounding tumor vessels, and normal liver tissue (Fig 2) Necrosis was seen as a high refractive index and cancer was seen as a relatively low refractive index as reported in a previous study [5-10], and the reconstructed 3-dimensional image well visualized the localization of cancer Quantitative analysis showed that the image-contrast ratio against normal liver was 0 79 ± 0 07 in cancer and 1 31 ± 0 16 in necrosis (Fig.3), and these values were approximately similar to the value obtained at 17 7 keV in a previous study [9]

The use of high X-ray energy, when compared with 18 keV, reduced the sensitivity slightly, however, the sensitivity obtainable at 35 keV was still more than 1000-fold higher than that in the absorption-contrast method (Fig 4) Image quality at 35 keV x-ray energy was not affected significantly by visual inspection and quantitative analysis in this study However, further studies on image contrast at high x-ray energy should be conducted to validate the clinical significance

FIGURE.2 Phase-contrast CT image and Three dimensional image of a VX2 rabbit cancer with 15-mm in diameter

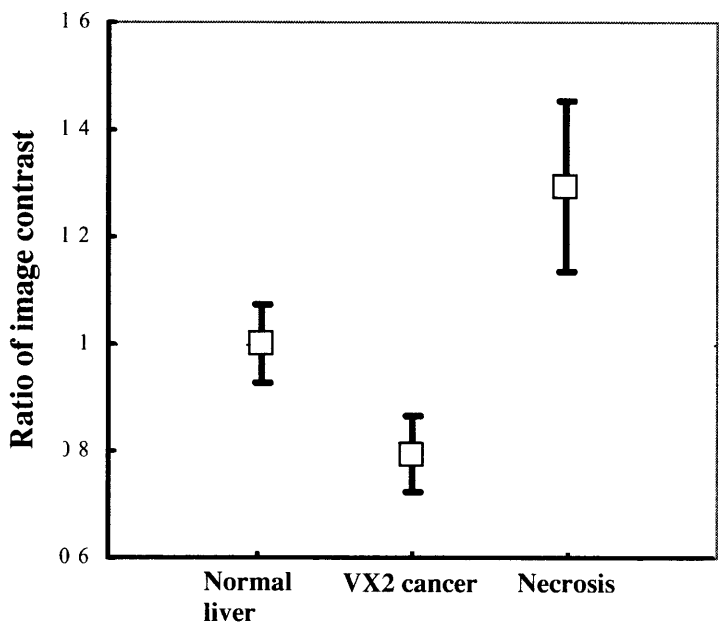

FIGURE.3 A graph of the relative image contrast ratio of pathological lesions against normal liver portion

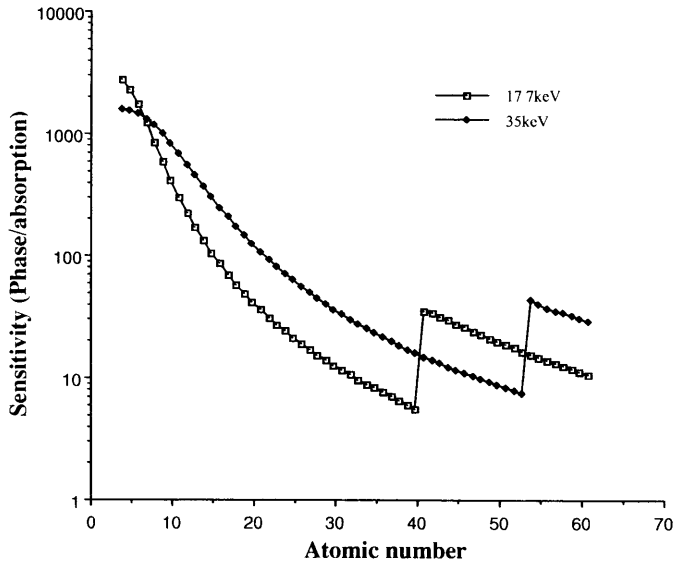

FIGURE.4 A graph showing sensitivities at 17 7 KeV and 35 keV x-ray energy

The observable blurriness on CT images is determined by the instability of interference fringes The acquisition of image data at 35 keV was fairly difficult because the stability time of interference fringe became shorter than that at 17 7 keV, and this causes image blurred To improve this problem, x-ray CCD camera with high-speed data acquisition system must be used in place of the present x-ray detector [16]

In conclusion, without the aid of any contrast agent, the PCCT imaging at 35 keV clearly depicted histopathological morphology of VX2 hepatic cancer with the clarify comparable to images at 17 7 keV

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