Refraction-Contrast Tomosynthesis for a Breast Specimen

Refraction-contrast images based on the difference in X-ray refraction have been proved to be good at depicting objects that consist of matter with weak X-ray absorption (phase objects). However, the projection images show complicated image contrast due to overlapping of many details, which often makes image interpretation difficult. To solve this problem without greatly increasing the exposure dose for clinical use of the future prospects, we developed a novel tomographic system combining a Laue silicon crystal analyzer imaging system based on refraction-contrast and tomosynthesis utilizing reconstruction algorithms of shift-and-add and filtered back projection. This approach provided slice images of a phase object such as a breast specimen of juvenile papillomatosis, which is depicted obscurely by the difference of X-ray absorption.

Some breast cancers are missed in conventional mammography because of superimposition by normal mammary glands, often preventing the detection of tumors or minute calcifications. One possible solution might be to introduce the tomographic technique for breast imaging. With the advent of flat-panel detectors capable of high-speed data communication, conventional geometric tomography is once again attracting attention in the form of digital tomosynthesis [1]. The technique allows an arbitrary number of in-focus planes to be generated retrospectively from a set of low-dose projection radiographs that are acquired during a single scan with a limited tomographic angle. This approach solves the issue of overlapping breast tissues. However, the image contrast in this technique is still based on the difference in X-ray absorption (absorption contrast) in the same way as projection mammography, so the contrast between anatomies with similar X-ray attenuation coefficients remains obscure. In this study, aiming to acquire slice images of an object with weak X-ray absorption (phase object), we conducted a trial of refraction-contrast tomosynthesis for a breast specimen by combining the imaging system by a Laue silicon crystal analyzer (A[L]) based on refraction-contrast [2, 3] and tomosynthesis utilizing reconstruction algorithms of shift-and-add (SAA) and filtered back projection (FBP). We constructed the refraction-contrast imaging system by A[L] at BL-14B using synchrotron X-rays from the vertical wiggler of the Photon Factory. The X-ray energy was tuned to 20.0 keV. The X-ray beam was reflected and expanded horizontally by a monochromator-collimator (MC) made of a single silicon crystal. An A[L], whose role was to discriminate refracted X-rays while penetrating the object from all of the X-rays transmitting the object, was set downstream of the X-ray beam from the MC. The object (a breast specimen excised during a mastectomy from a 17-year-old female with juvenile papillomatosis) was placed between the MC and the A[L] when the imaging was performed. An X-ray CCD camera was used as a detector. The imaging apparatus is shown in Fig. 1. Two angular positions of the A[L] (bottom of the rocking curve [B] and slope of its lower angular side [S]) were used to acquire projections for tomosynthesis. It should be noted that the rocking curve corresponds to the intensity profile for the forward diffracted X-rays without any object. The tomographic angle was ±25°, and with the reconstruction algorithms of tomosynthesis, we applied SAA and FBP dedicated to a parallel X-ray beam. A *Shepp & Logan* filter was used in the FBP algorithm. In addition, absorption-contrast projection imaging of the object was also performed at the same X-ray energy for comparison.

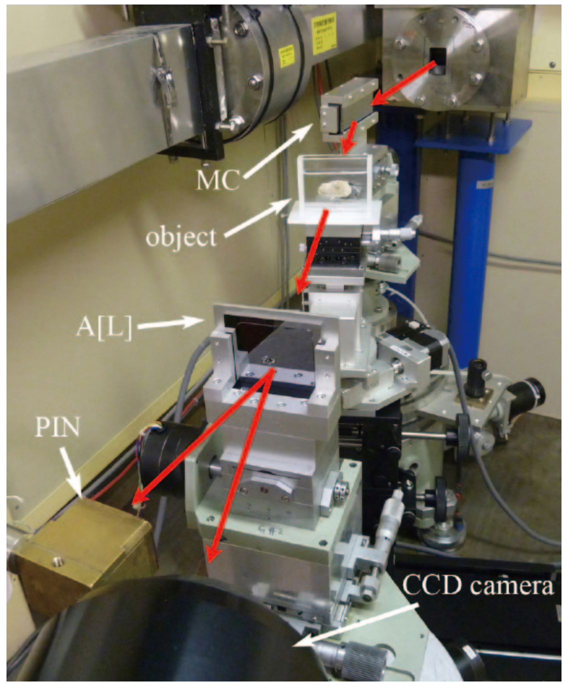

Figure 1
The apparatus for refraction-contrast tomosynthesis constructed at BL-14B. Red arrows indicate the X-ray beam path.

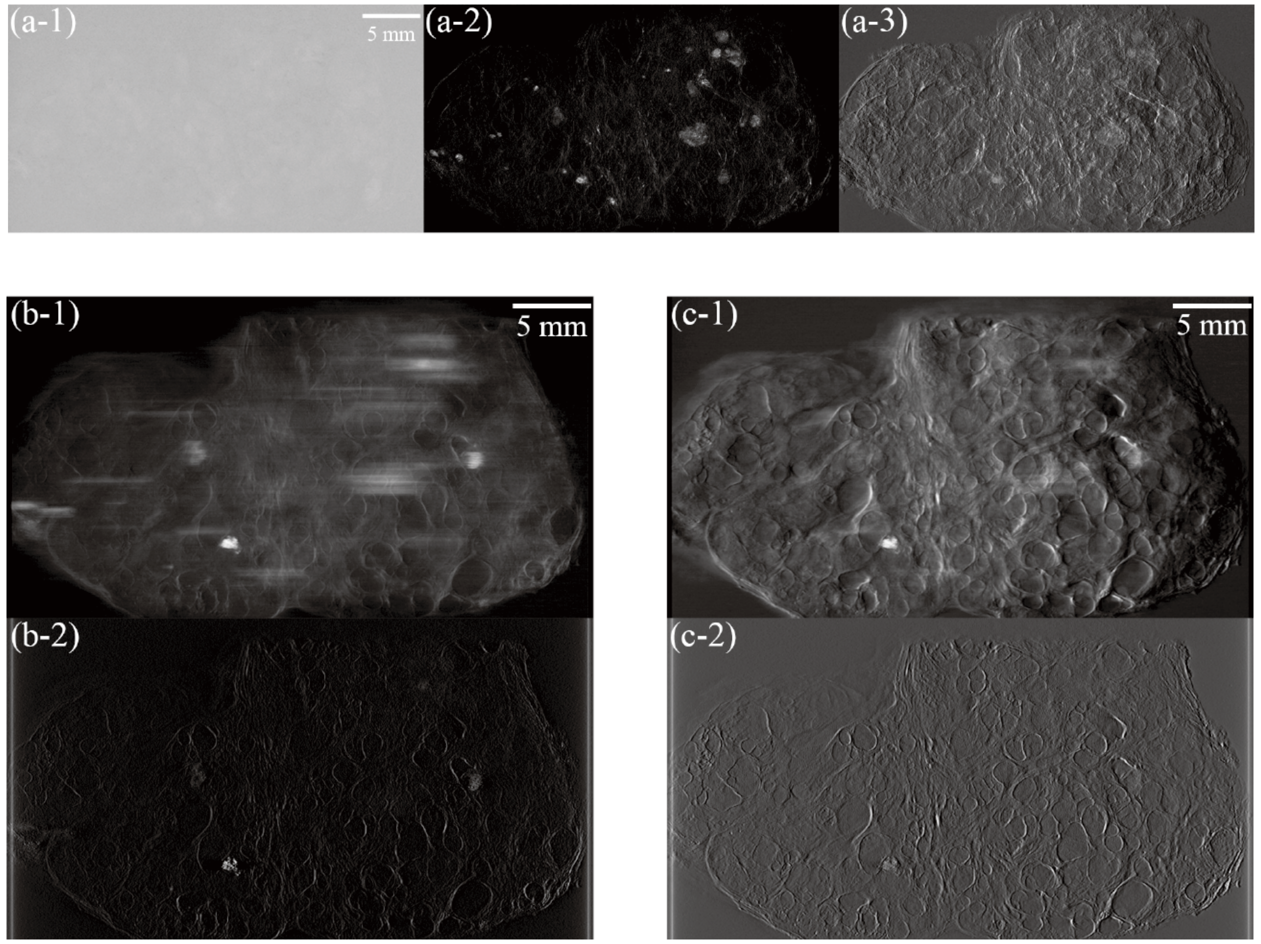

Figure 2
Projection images: absorption contrast (a-1), refraction-contrast images taken at the bottom [B] (a-2) and at the slope of the lower angular side [S] (a-3) of the rocking curve. Tomosynthesis images at the same depth: [B] by SAA (b-1), [B] by FBP (b-2), [S] by SAA (c-1), and [S] by FBP (c-2).

The results are summarized in Fig. 2. There is almost no contrast on the absorption contrast image except for the quite obscure contrast of many small cysts in (a-1), while many secretions containing calcium and cysts are depicted in (a-2) and (a-3), respectively. It is, however, difficult to distinguish individual features due to superimposition. Representative slice images by tomosynthesis using SAA and FBP algorithms for conditions [B] and [S] are shown in Fig. 2 (b-1), (b-2), (c-1), and (c-2), respectively. All the slices were reconstructed at the same slice position. It is well depicted images of secretions containing calcium existing in this plane with reduced streak-like artifacts by FBP (b-2) and cysts in the plane composed of contrast not by contours but by substances by SAA (c-1). This study confirmed that slice images of a phase object could be acquired by our proposed approach. Moreover, it was indicated that refraction-contrast images taken at [B] which contain sharp contrast should be processed by FBP, and other refraction-contrast images with moderate contrast taken at [S] should be processed by SAA. These results suggest that refraction-contrast tomosynthesis is worthy of further investigation for improving the detection of lesions in breast specimens.

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14B

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