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2D and 3D refraction-based visualization of breast cancer for early clinical check

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Abstract Ductal carcinoma in-situ (DCIS) has been visualized by 2D XDFI (X-ray dark-field imaging) and further by a 3D X-ray CT, and the data was acquired by the X-ray optics DEI (diffraction-enhanced imaging). A newly made algorithm was used for CT. Data of 900 projections with interval of 0.2 degrees were used. Ductus lactiferi, microcalcification in a 3D form have been clearly visible. The spatial resolution available was approximately 30 μm.

Key words X-ray dark-field imaging (XDFI), Ductal carcinoma in-situ (DCIS), Diffraction-enhanced imaging (DEI), Microcalcification, 3D CT, Synchrotron radiation, Vertical wiggler, X-ray refraction, Monochrocollimator

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1 Introduction

Breast cancer is a leading cause of cancer death worldwide. In Japan, almost 4% of the females are at a risk of suffering from breast cancer. Using epidemiological analysis on the correlation between mammography and mammotome biopsy H. Hashimoto [1] at Chiba Foundation for Health Promotion and Disease Prevention classified breast cancer with calcification into five groups: In group # 5, cancer has been detected with a probability of 18 out of 19 patients, corresponding to 94.7% ratio, with highly suggestive malignancy. In group # 4, cancer has been detected with a probability of 53 out of 89 patients, corresponding to 59.6% ratio, with suspicious malignancy cancer. In group # 3, cancer has been detected with a probability of 40 out of 366 patients, corresponding to 10.9% ratio, with benign cancer, but with malignancy that cannot be ruled out. Among the breast cancer confirmed by biopsy, 18 patients come from group # 5 corresponding to 15.7% of all the patients, 53 from group # 4, corresponding to 46.1% of all the patients, and 40 from # 3, corresponding to 38.2% of all the patients, respectively.

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Summarizing this data one can say that only 15.7% of the patients with breast cancer, having calcification, can be clearly diagnosed as having breast cancer, by detection of fine linear calcification or pleomorphic calcification in the linear and/or segmental area. Breast cancer death comprises approximately 15% - 20% of all cancer deaths. As early detection of breast cancer usually gives a good prognostic outcome, it is a key to prevent death on account of breast cancer. Mammography together with ultrasonography, as an early check, is one of the powerful screening modalities. Since the discovery of X-ray by Roentgen in 1895, all X-ray medical imaging, including mammography, in hospitals around the world, have been purely based on absorption contrast. Nevertheless, limitation in their spatial and contrast resolutions exists in early detection. As breast cancer is not necessarily visible with absorption contrast, one needs alternative methodology for visualizing breast cancer, with higher contrast and higher spatial resolution.

Following a pioneering study on imaging of breast cancer by Burattini's group [2] a trial to visualize breast cancer tissue has been performed by PCI, [3, 4] DEI, [5 - 7] PIC (phase-interference contrast), [8] the super magnification imaging (SMI), [9, 10] DFI, [11, 12] and XRF (X-ray fluorescence) [13].

2 Observation by X-ray dark field imaging (XDFI)

Here a 2D projected XDFI [11, 12] is proposed that will be used for clinical diagnosis. The X-ray optics XDFI [11, 12] is characterized as shown in Fig.1. This is a double crystal arrangement with a Laue type angular analyzer with a specified thickness, to allow only refracted components to pass through to an imaging detector. In this article, XDFI [11, 12] has been used for an overall survey of a DCIS specimen.

A specimen of a breast DCIS has been chosen from 'c' as shown in Fig.2. This indicates a variety of tissues such as distorted linear structure, healthy, and malignant tissue. Object **s(w)** has been angularly analyzed by **k(w)**, which has a specified thickness of 2.124 mm for 35 keV, hence only ***r(w)*** will be able to pass through **k(w)** in the forward direction. This picture clearly delineates distorted linear structure and ductus lactiferi. A specimen with the diameter of 3.5 mm and depth of 4.7 mm was punched out at the place shown with the label 'c' in Fig. 2. This has been used to show 3D CT.

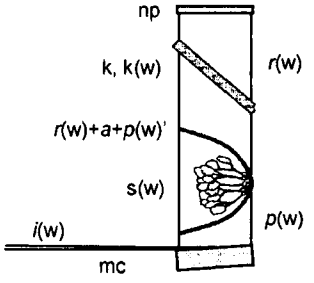

Fig.1 X-ray optics of DFI. A specimen **s(*w*)** DCIS was illuminated by plane wave ***p(w)*** that was made by the monochro-collimator **mc**. **k** is a Laue case analyzer with special thickness of 2.124 mm for 35 keV. The diffracting planes of mc and **k** are 220 in a parallel arrangement. The beam carrying both information ***r(w)*** because of refraction, and ***a*** because of absorption of the sample, and the partial illuminating light ***p(w)***, has been analyzed by **k** with a function of **k(w)**. Only the refracted component ***r(w)*** can pass through **k(w)** as the DF image that is stored in **np** nuclear plate.

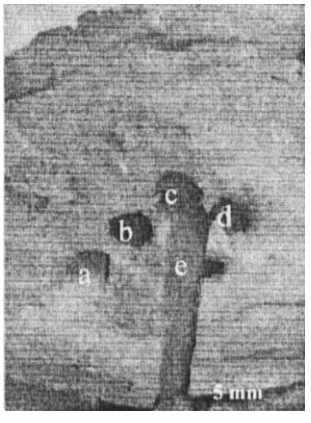

Fig.2 A DCIS (ductus carcinoma in situ) specimen with thickness of 4.7 mm. The field has a dimension of 24.5 mm x 31 mm showing skin tissue in blue-green color, fatty tissue in yellow color, normal mammary tissue in white color and cancer in gray color. The gray area is hard to touch. A rod shaped specimen with size of 3.5 mm in diameter and 4.7 mm in length was punched out from the mark 'c'. 'a', 'b', 'd' and 'e' are other marks from where other specimens were taken out. The whole area shown in this figure corresponds to DCIS.

In Fig. 3 an XDF image is shown, where a – d shows holes corresponding to those in Fig. 2. A lineage image and holes a-e corresponding to those in Fig. 2 are shown. A lineage structure probably ductus lactiferi marked with 'dl' is also seen. The XDF image should involve a great deal of information on the internal structure of the DCIS, whereas the photo in Fig. 2 only shows the surface.