First Attempt at 3D X-Ray Visualization of DCIS (Ductal Carcinoma in Situ) Due to Refraction Contrast – In Good Relation to Pathological View

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Abstract. First 3D X-ray internal observation of DCIS (ductal carcinoma in-situ) is reported. Its rod shaped specimen with 3.6 mm in diameter and 4.7 mm in height was punched out to have successfully observed by using a newly made algorithm due to refraction for x-ray CT. Its data was acquired by the x-ray optics DEI (diffraction-enhanced imaging). Data of 900 projections with interval of 0.2 degrees was used at Photon Factory, KEK in Tsukuba. A reconstructed CT image may include clearly revealed ductus lactiferi, microcalcification and other structure. The voxel resolution is approximately 50 μm by the present instrumental condition. This modality could open up an x-ray pathological diagnosis.

Keywords: X-ray refraction, X-ray dark-field imaging (XDFI), DEI, breast cancer, DCIS, pathological diagnosis, clinical diagnosis, ductus lactiferi.

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1 Introduction

Mammography for early check is one of powerful screening modalities together with ultrasonography. Since the discovery of x-rays by Roentgen in 1895 all x-ray medical imaging at hospital including mammography in the world has been purely based on absorption contrast. Nevertheless limitation in their spatial resolution and contrast resolution exists in early detection. Since breast cancer is not necessarily visible with absorption contrast one may need alternative methodology of being able to visualize breast cancer with higher contrast and with higher spatial resolution.

So far a variety of imaging schemes for a phase object have been proposed [1], [2], [3], [4] (diffraction-enhanced imaging (DEI)), [5], [6], [7] and [8] (phase-interference (PIC)). Further x-ray dark-field imaging (XDFI) [9] was proposed. In order to see breast cancner following a pioneering work on imaging of breast cancer by Burattini's group [10] a trial to visualize breast cancer tissue has been performed by PCI [11], [12], DEI (diffraction-enhanced imaging) [13], [14], [15], PIC (phase-interference contrast) [16], the super magnification imaging (SMI)) [17], x-ray dark-field imaging (XDFI) [18] and XRF (x-ray fluorescence) [19].

Here we would like to propose a world first X-ray CT image that could be used for pathological diagnosis. Trial of 3D reconstruction has begun [20], [21], [22]. Maksimenko et al. have recently proposed a novel tomographic imaging protocol based on a physico-mathematically defined reconstruction algorithm [23], [24] with a paraxial-ray approximation in the domain of a geometrical optics. A satisfactory experimental result has been obtained. This has been applied to successfully visualize DCIS (ductal carcinoma in situ) with high contrast and high resolution [25].

2 Method

2.1 Mathematics

The refractive index can be described as $n = 1 - \tilde{n} + i\kappa$. κ of low atomic-number elements in soft tissue of biomedicine comprising hydrogen, carbon, nitrogen, and oxygen can not produce sufficient contrast because $\kappa \approx 0$. In case of visualizing such object with hard x-rays, for instance in clinical application, it is much more advantageous to detect variations of the propagation direction of incident x-rays using an analyzer with high angular sensitivity over conventional absorption contrast.

We start outlining the principle with the ray equation as follows:

$$d/ds\; n(r)t(r) = \nabla n(r) \tag{1}$$

where r is a spatial coordinate, $n(r)$ is a refractive index distribution, $t(r)$ is a unit tangential vector of ray propagation, and s is an arc length parameter. Executing the differentiation of LHS (light hand side),

$$n\frac{d\alpha}{ds}\boldsymbol{v} + \frac{dn}{ds}\boldsymbol{t} = \nabla n \tag{2}$$