X-Ray Endoscopic Viewing inside the Human Milk Duct – Toward the Establishment of a Novel X-Ray Pathology

Ductal carcinoma in situ (DCIS) has been visualized using a tissue excised from a human body for the first time in the world by means of computer aid. An algorithm suitable for visualizing soft tissue based on X-ray refraction was created by us, as a result of which a three-dimensional (3D) DCIS image was reconstructed. The image clearly shows 5 ductus lactiferi (milk ducts) running along the cylindrical axis of the specimen. Each pair of ductus lactiferi merges into one at each step, and finally the 5 ductus merge into a single one. In one of them, was a high-grade DCIS located within one of the ductus lactiferi. As a result, this modality could be a powerful tool for nondestructive pathological surveys.

Since the discovery of X-rays by Prof. Roentgen in 1895, almost all medical X-ray images have been taken in the framework of X-ray absorption contrast, by which one can clinically visualize bones, blood vessels and digestion vessels filled with a contrast agent. In other words, almost all other organs have been difficult to visualize using X-rays, so that alternative visual modality such as magnetic resonance imaging (MRI) and ultrasonography has been developed. In this paper, the authors propose a novel 3D computer-aided visual technology that would be of some help in precision diagnosis.

The equipment needing for this research is DEI (diffraction-enhanced imaging) [1] X-ray optics, a DCIS specimen mounted on a rotational goniometry, an X-ray sensitive CCD camera, and software [2-4] used to reconstruct a 3D image as a result of refraction contrast. A monochromatic almost plane wave with a divergence of 7/100 arc sec was generated by the adoption of asymmetric diffraction [5], so that the beam is the right size to cover the specimen in a single shot. Two data sets corresponding to an X-ray refraction-based image taken at the flank of both sides of a rocking curve of a Bragg type angle analyzer in the DEI geometry were acquired for every 0.1 degree of specimen rotation by that means, resulting in a total of 1800 images. The images were recorded by a commercially available X-ray CCD camera supplied by Photonics Science that can yield an image voxel size of approximately 30-50 microns. This can nondestructively provide a 3D internal information with a very high contrast, in the order of 1000 times higher than the absorption contrast, and with 5 times higher spatial resolution compared to that at a hospital.

The tissue for the experiment was punched out from a human breast that was excised from a female patient with DCIS. It has a cylindrical dimension of 3.6 mm in diameter and 4.7 mm in height. As a result of 3D reconstruction [6] we learned that it contains 5 ductus lactiferi running almost along the cylindrical axis was lucky. In order to examine the CT, the entire cylindrical tissue was sectioned into 283 slices and stained with hematoxylin and eosion so that we could observe the correlation between the histology and CT. Each view of the histological section was surprisingly identical to the CT scan view (Fig. 1).

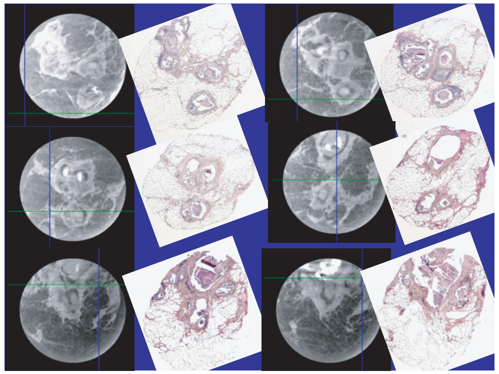

Figure 1
Slices from a 3D reconstruction of DCIS images generated by computer, on the left; and histological section images by hematoxylin and eosion staining using a specimen sliced after reconstructing X-ray images of DCIS specimens, on the right. Round structure such as grey colour in X-ray pictures (left) and purple colour in pathological pictures (right) show cross sections of ductus lactiferi and calcification corresponding to necrosis that looks like a rope like structure in Fig. 2. One can follow the number of ductus lactiferi may reduce from top left (5 ductus lactiferi) to top right (4), again from left (3) to right (3) in the middle line and finally again from left (2) to right (1).

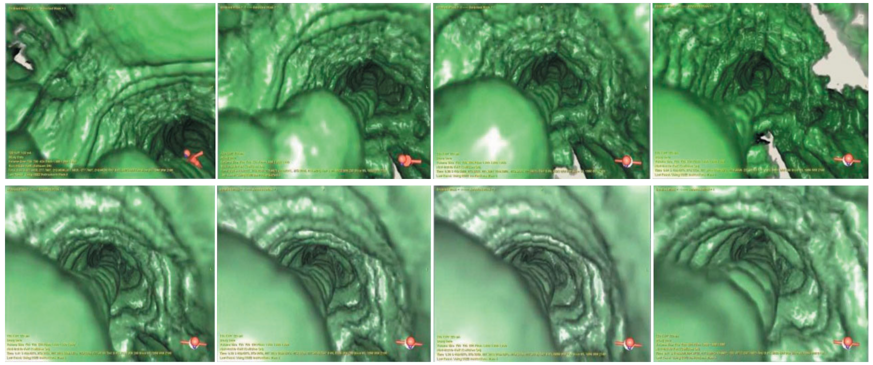

Figure 2
A series of virtual endoscopy images of a human DCIS made by the endoscopy software using figures in Fig. 1. The center structure that appears as a continuous ropelike structure corresponds to a comedotype necrosis within the milk duct. From left to right at the top that continues to the left at the bottom and again from left to right one virtually approaches into depth. The inner diameter of the duct is around 0.6 mm, too small to allow optical-fiber examination. This may have a potential to be able to diagnose inside ducts in a future.

The interior of all of the ducts are imaged by means of virtual ductoscopy software [7], a chainlike linear and branching calcification, together with a necrotic structure at the ends of the ducts were very clearly revealed (Fig. 2) [8]. This particular specimen showed a high-grade DCIS. Each sheet of a pathological-stained slice may lose information at its center, its coordinates and its original shape. For pathologists, 3D reconstruction in a nondestructive way had been a dream; a 3D view can be obtained by stacking slices layer-by-layer to build up a 3D model (see the work by Ohtake [9]), but this is not popular due to the laborious work involved. By introducing this novel system one can very easily obtain 3D information on ductus lactiferi, calcification, glands, fibrous and fatty tissue and stroma without staining.

In conclusion, correlation with radiologic and pathologic findings is essential for a proper evaluation of biopsies performed for mammographic abnormalities. Because the epithelial proliferation in a breast occurs in the 3D mammary duct lobular systems, a 3D approach would aid an understanding of such correlations. This study demonstrated that refraction-based CT can provide a high-quality slice data for a 3D reconstruction of mammary DCIS. It has the potential to become a powerful tool for radiologic-pathologic correlation studies of mammographically detected breast lesions. Hopefully this system will open a new field such as X-ray pathology, which can be a powerful candidate to identify which type of breast cancer a patient has.

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