# Basic Study on the Development of a High-Resolution Breast CT

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**Abstract.** X-ray breast computed tomography (breast CT) was developed by some research groups to overcome the limitations of mammography. Breast CT is expected to be an effective diagnostic tool because it can generate three-dimensional images of a breast. However, the spatial resolution of the existing system is not satisfactory for identifying microcalcifications within the breast. The purpose of this study was to develop a prototype of high-resolution breast CT system, and to evaluate the imaging properties of the developed system. Our experimental system consists of a microfocus X-ray tube and a flat panel detector with a C-arm frame, a bed, and their controllers. Images were reconstructed by using cone-beam X-ray projections and the Feldkamp-Davis-Kress algorithm. We used phantoms to experimentally evaluate three imaging properties and exposure dose. Consequently, the modulation transfer function value was 0.1 at the frequency of 6.0 LP/mm, which is higher than that of clinical CT and breast CT. Breast phantom microcalcifications were observed clearly. Furthermore, entrance surface dose in the experimental system was similar to that of mammography. These results indicate that our experimental system overcomes the limitations of both the mammogram and existing breast CT systems.

**Keywords:** Breast, computed tomography, microfocus X-ray.

## 1 Introduction

Breast cancer is the most prevailing cancer among women in the world; more than 10% of women are likely to develop invasive breast cancer during their lifetime. Mammography is widely used for the detection of breast cancer. However, overlapping breast tissue creates false shadow in many cases. Furthermore, mammography examination causes pain because of the application of pressure. X-ray breast computed tomography (breast CT) was developed to overcome these mammography limitations [1,2]. Breast CT can acquire a 3-dimensional image without incurring any pain by pressure. Breast CT systems have been installed in some research institutes and are currently under clinical evaluation. However, the spatial resolution of the existing

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breast CT systems is lower than that of magnified mammogram; it is not sufficient for identifying microcalcifications within the breast [2]. In this study, we developed an experimental high-resolution breast CT system that aims to improve the spatial resolution. The specific goal of this study was to obtain the sub-50 µm spatial resolution for clear observations of microcalcification. Furthermore, by using the developed system we evaluated its imaging properties and the exposure dose.

# 2 Materials and Methods

## 2.1 High-Resolution Breast CT System

Figure 1 shows the scan part of our prototype system. It consists of a microfocus X-ray tube (L7901, Hamamatsu Photonics, focus size: 5 µm, maximum tube voltage: 100 kV, maximum tube current: 0.1 mA) and a flat panel detector (C7942CA, Hamamatsu Photonics, indirect conversion type, pixel pitch: 50 µm, matrix size: 2366 × 2368, bit depth: 12 bits) with C-arm frame, and computer for control. A woman lies face down on a table with one breast suspended through an opening. X-ray tube and flat panel detector rotate around the breast to collect the projection data. The proposed system obtains high-resolution image data by using geometric magnification. It can be adjusted by changing the position of rotational center. The maximum magnification is 2.5; the spatial resolution reaches 20 µm.

The projection images are reconstructed into a 3-dimensional (3D) image by using the Feldkamp-Davis-Kress (FDK) algorithm [3]. We employed ramp filter as the reconstruction function, and matrix size of the 3D image was 2048x2048x2048. Image reconstruction is performed by original software that was developed and optimized by using Intel C++, and calculation is conducted using personal computer (CPU: Intel Xeon 3.06 GHz, 12 cores, Memory: 32 GB).

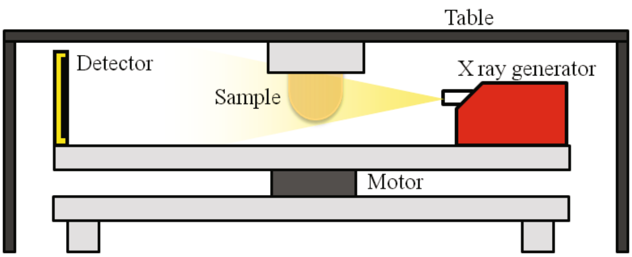



**Fig. 1.** The structure of the proposed system

## 2.2 Performance Evaluation

To evaluate the basic imaging characteristics of our system, the following evaluations were conducted. Phantoms, shown in Fig. 2 and Fig. 3, were employed for these evaluations.

*(1) Uniformity of CT values*

Image uniformity was evaluated by using the uniformity phantom [Fig. 2(a)]. The mean CT values of 5 regions of interest (ROIs) were calculated by using the axial image of the phantom. Then, the standard deviation of mean CT values at 5 locations was determined [4].

*(2) Noise level*

Noise level was evaluated by using the uniformity evaluation phantom and the noise evaluation phantom [Figs. 2(a) and 2(b)] [4]. Noise level was calculated as follows:

$$\text{Noise level} = \frac{\sigma_{AV} \cdot CS \cdot 100}{\mu_w} \ [\%]. \tag{1}$$

$$CS = \frac{\mu_w - \mu_{air}}{CT_w - CT_{air}} \ [\text{cm}^{-1} / \text{CT value}]. \tag{2}$$

CS: Linearity index of CT value.
$\sigma_{AV}$: Standard deviation of mean CT values of water in axial image
$\mu_w$: Absorption coefficient of water (=0.195 $cm^{-1}$).
$\mu_{air}$: Absorption coefficient of air (=0).
$CT_w$: Mean CT value of water in axial image inside the uniformity phantom.
$CT_{air}$: Mean CT value of air part in axial image.

*(3) Modulation transfer function*

The modulation transfer function (MTF) of our breast CT was evaluated by using the MTF evaluation phantom, as shown in Fig. 2(c). The MTF phantom was scanned under the minimal resolution of 5 μm; cross-sectional image of Cu sheet was obtained. Pre-sampled MTF was calculated by using this image [5-7].

*(4) Visibility of mass and microcalcifications*

To evaluate the visibility of mass lesion and microcalcifications, we scanned the breast phantom (model013, CIRS) as shown in Fig. 3. This phantom was developed for the training of needle biopsy examinations, and was made from a gel with a physical consistency similar to the human tissue, including simulated mass lesions and microcalcifications.

*(5) Entrance surface dose*

Entrance surface dose of breast was evaluated by using thermoluminescent dosimeter (MSO-S, Kyokko). It was measured by using total filtration of 3.5 mm Al, tube voltage of 80 kV, tube current of 0.1 mA, and scanning time of 90 seconds.

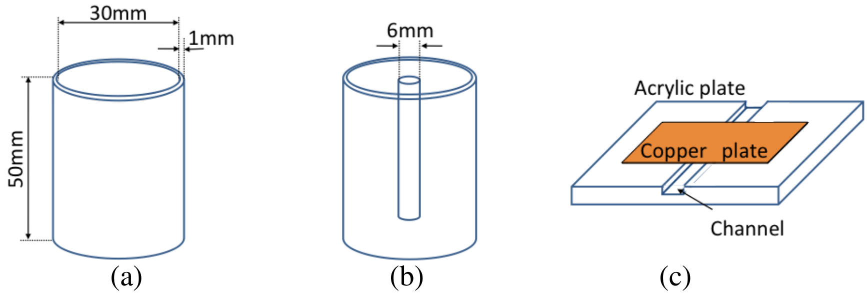



**Fig. 2.** Phantoms for the performance evaluation of the proposed system. (a) The uniformity evaluation phantom: a water-filled cylindrical vessel. (b) The noise evaluation phantom: an air-filled cylindrical acrylic vessel in (a). (c) The MTF evaluation phantom: a 10 μm thick copper overlaid on an acrylic plate.

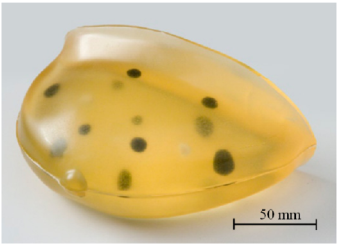



**Fig. 3.** Breast phantom (model013, CIRS)

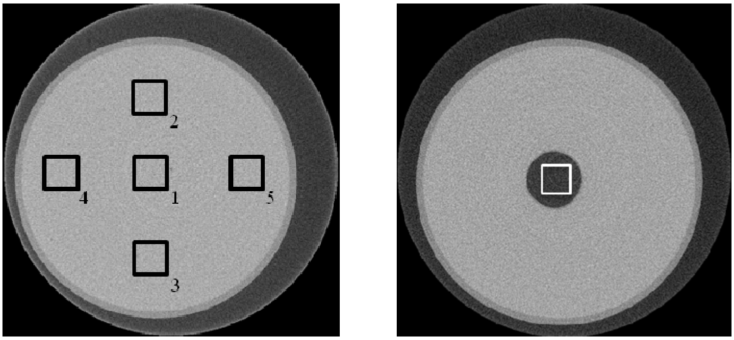
# 3 Results

## 3.1 Uniformity and Noise

Slice images of uniformity evaluation phantom and noise evaluation phantom are shown in Fig. 4. Uniformity and noise level of our system were 2.35 and 14.95%, respectively. The noise level of the proposed system was about 10-fold higher than that of a typical clinical CT system.

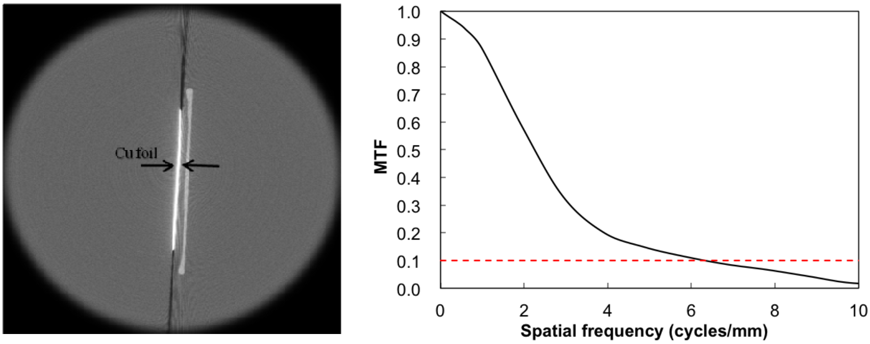
## 3.2 MTF

The slice image and the MTF evaluation results are shown in Fig. 5. The MTF value of the proposed system became 0.1 at the spatial frequency of 6.0 cycles/mm. As for the clinical CT system, the MTF value became 0.1 at the spatial frequency of around 1.0 cycles/mm. The MTF value of the existing breast CT system was 0.1 at the spatial frequency of 0.7 – 1.5 cycles/mm. Therefore, the spatial resolution of our experimental system was better than that of either a conventional clinical CT or an existing breast CT.




(a) (b)

**Fig. 4.** Slice images of uniformity evaluation phantom (a) and noise evaluation phantom (b). Square boxes on these images indicate the regions used for the evaluation.




(a) (b)

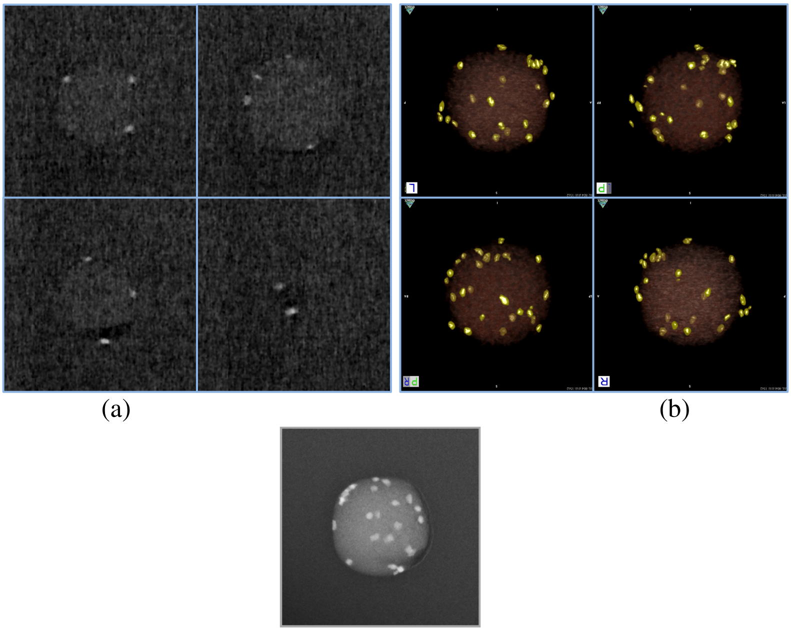
**Fig. 5.** Slice image of the MTF phantom (a) and the MTFs of the proposed system and a clinical CT system (b)

### 3.3 Evaluation Using Breast Phantom

Figures 6(a) and 6(b) show a cross-sectional image and a 3D-rendered image of the breast phantom, respectively. The 3D structure of the mass region and microcalcifications were clearly identified in the obtained images. By comparing these images with the mammogram results [Fig. 6(c)], we found that the proposed system generated a 3D image structure of the breast with the resolution equivalent to that of the mammogram.

### 3.4 Exposure Dose

The entrance surface dose of the proposed system was 14.11 mGy. A typical entrance surface dose in mammography is 10-20 mGy per breast [8]; the exposure dose of our system was similar to that of mammography.



(a) (b)

(c)

**Fig. 6.** Images obtained by using the proposed system (a) Axial CT images obtained by using the proposed system. (b) 3D rendered images. Brown regions and yellow dots represent mass lesions and microcalcifications, respectively. (c) Mammographic magnification image (Mammomat Novation, Siemens).

## 4 Conclusions

We have developed a prototype of high-resolution breast CT system with a microfocus X-ray tube. In addition, we evaluated the imaging properties and the exposure dose of the proposed system. Furthermore, we evaluated the image quality by using breast phantom that included microcalcifications. The MTF of the proposed system was better than that of either a clinical CT or an existing breast CT, and microcalcifications in the breast phantom were observed clearly. These results indicate that our breast CT system overcomes the limitations of both the mammogram and the existing breast CT systems.

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