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# The utility of breast cone-beam computed tomography, ultrasound, and digital mammography for detecting malignant breast tumors: A prospective study with 212 patients

Ni He[a,1], Yao-Pan Wu[a,*,1], Yanan Kong[b,2], Ning Lv[a,3], Zhi-Mei Huang[a,3], Sheng Li[a,3], Yue Wang[a,3], Zhi-jun Geng[a,3], Pei-Hong Wu[a,*], Wei-Dong Wei[b,*]

[a] Department of Medical Imaging and Image-guided Therapy, Sun Yat-Sen University Cancer Center, State Key Laboratory of Oncology in South China, Collaborative Innovation Center for Cancer Medicine, Guangzhou 510060, China
[b] Department of Breast Oncology, Sun Yat-Sen University Cancer Center, State Key Laboratory of Oncology in South China, Collaborative Innovation Center for Cancer Medicine, Guangzhou 510060, China

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ABSTRACT

*Purpose:* Breast cone-beam computed tomography (BCBCT) is a flat-panel detector (FPD)-based X-ray imaging system that provides high-quality images of the breast. The purpose of this study was to investigate the ability to detect breast abnormalities using non-contrast BCBCT and contrast-enhanced BCBCT (BCBCT and CE-BCBCT) compared to ultrasound (US) and digital mammography (MG).
*Materials and methods:* A prospective study was performed from May 2012 to August 2014. Ninety-two patients (172 lesions) underwent BCBCT alone, and 120 patients (270 lesions) underwent BCBCT and CE-BCBCT, all the patients underwent US and MG.
*Results:* Cancer diagnosis was confirmed pathologically in 102 patients (110 lesions). BCBCT identified 97 of 110 malignant lesions, whereas 93 malignant lesions were identified using MG and US. The areas under the receiver operating curves (AUCs) for breast cancer diagnosis were 0.861 (BCBCT), 0.856 (US), and 0.829 (MG). CE-BCBCT improved cancer diagnostic sensitivity by 20.3% (78.4–98.7%). The AUC values were 0.869 (CE-BCBCT), 0.846 (BCBCT), 0.834 (US), and 0.782 (MG).
*Conclusion:* In this preliminary study, BCBCT was found to accurately identify malignant breast lesions in a diagnostic setting. CE-BCBCT provided additional information and improved cancer diagnosis in *style c* or *d* breasts compared to the use of BCBCT, US, or MG alone.


## 1. Introduction

Early detection of breast cancer has been demonstrated to decrease breast cancer mortality during last 30 years [1–4]. The limits of mammography are still well documented, which result from poor contrast between the breast and breast lesions and the variety of pathologic presentations [5,6]. Furthermore, breast density and tissue distribution differ among women, adding to the complexity of interpretation.

Breast cone-beam computed tomography (BCBCT) is a flat-panel detector (FPD)-based system that is used to improve the sensitivity and specificity of breast cancer detection and characterization [7–9]. This rapidly evolving breast-specific imaging modality exhibits unique advantages for diagnostic breast imaging (Fig. 1). BCBCT provides high-quality images and real-time 3D visualization of the breast. Preliminary research shows that breast coverage and radiation dose using BCBCT is comparable to that required for conventional diagnostic MG, and this technique has the potential to further characterize high-risk breast lesions that have been identified in screening by MG or US [7,10,11].

This study was performed to evaluate the ability of BCBCT or/and CE-BCBCT to detect malignant breast lesions and to compare these techniques to conventional diagnostic MG and US, especially for women with dense breasts.

* Corresponding authors. Fax: +86 20 87343272.
*E-mail addresses:* heni@sysucc.org.cn (N. He), 61684754@qq.com (Y.-P. Wu), kongyn@sysucc.org.cn (Y. Kong), lvning@sysucc.org.cn (N. Lv), zhimeih_2015@163.com (Z.-M. Huang), shengl_2015@163.com (S. Li), yuew_2015@163.com (Y. Wang), Zhi-jung_2015@163.com (Z.-j. Geng), 409109980@qq.com (P.-H. Wu), weiweid@mail.sysu.edu.cn (W.-D. Wei).
[1] These authors contributed equally to this study.
[2] Fax: +86 20 87343806.
[3] Fax: +86 20 87343272.

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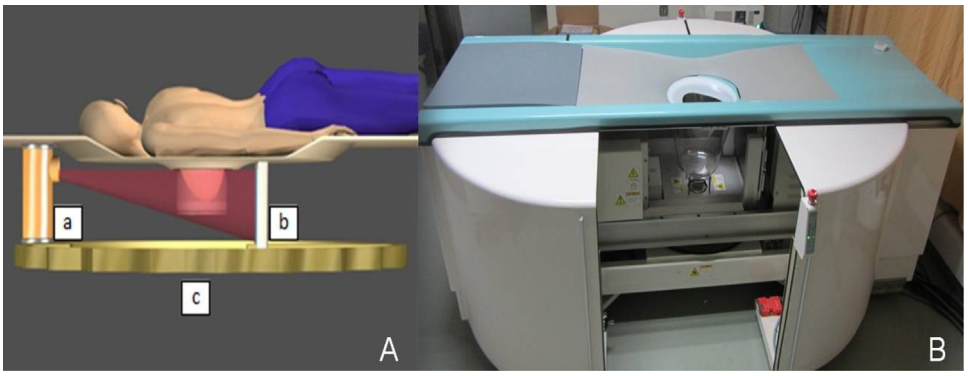


**Fig. 1.** Breast cone-beam CT.
(A) A patient lying prone with one breast suspended through the tabletop opening into the imaging field (a. X-ray tube; b. detector; c. rotating gantry).
(B) Breast cone-beam CT scanner (BCBCT 1000, Koning Corporation, USA).

## 2. Materials and methods

### 2.1. Patients

This prospective study was approved by the Ethics Committee for the Protection and Privacy of Persons Involved in Clinical Trials. Written informed consent was obtained from all patients.

Each patient underwent clinical examination of each breast, including digital MG, US, BCBCT or CE-BCBCT, and biopsies of suspicious lesions detected by US or MG. If lesions seen on Cone Beam CT only, MRI should be suggest to the patient and MRI-guided biopsy would be perform if necessary. The patient demographic information was recorded.

Subjects were selected based on the following inclusion/exclusion criteria:

#### 2.1.1. Inclusion

- Female, at least 35 years of age.
- Diagnostic report read as BI-RADS® (Breast Imaging Reporting and Data System) 1–5.
- Underwent BCBCT or CE-BCBCT no later than 1 week from the date of MG and US.
- Able to provide informed consent.
- Promised to complete all follow-up work.

#### 2.1.2. Exclusion criteria

- Unable to tolerate study constraints, e.g., unable to rest prone on the examination table due to physical limitations.
- Chest radiation history prior to BCBCT.
- Acute or chronic renal dysfunction.
- Previous nonionic contrast reaction.
- Diabetes mellitus treated with metformin.
- Multiple myeloma.
- Dehydration.
- Hyperthyroidism.
- Pheochromocytoma.

### 2.2. US and MG protocol

MG (Senographe DS, General Electric Medical Systems, USA) and US (G4 xMATRIX iU22 of Phillips, Royal Phillips Electronics, USA) were performed for all patients.

Mammograms, including the standard craniocaudal view and mediolateral oblique view, were obtained using a full-field digital MG system. Additional views or spot compression were obtained when necessary.

US was performed using a Phillips iU-22 digital imaging system equipped with a linear-array transducer at a center frequency of 8–13 Megahertz (MHz). Four-quadrant views of each breast and horizontal and vertical images of breast lesions were obtained.

### 2.3. BCBCT protocol

All patients were subjected to a standard BCBCT (BCBCT 1000, Koning Corporation, USA) protocol [10] one week after MG and US. BCBCT was performed according to the manufacturer's instructions. The breast density was estimated visually based on MG and BCBCT.Patients with *style d* (extreme fibroglandular tissue) breasts or for whom inconsistent conclusions were drawn from physical examination and MG or US results subsequently received CE-BCBCT.

CE-BCBCT of both breasts was performed approximately 50–80 s after BCBCT scans, followed by an intravenous bolus injection of 0.1 mmol/kg Omnipaque (iohexol) Injection® (General Electric Medical Systems, USA) at 2 ml/s using a power injector, followed by a 30 ml bolus injection of saline solution.

The subjects were placed prone on the imaging table in a left or right anterior oblique position, such that the targeted breast was suspended into the image acquisition field with no external compression.

For a single continuous acquisition scan, the real-time FPD-based prototype acquired 300 2D projection images ($1024 \times 768 \times 14$ bits/projection) by rotating the X-ray tube and the FPD 360° around the breast, which was located at the center of rotation, in 10 s. The X-ray pulses were of 8 milliseconds duration at a frequency of 30 Hz. BCBCT transverse and sagittal views correspond to the MG craniocaudal (CC) and mediolateral-oblique (MLO) views, respectively. We compared the views carefully to make sure what we found on BCBCT/CE-BCBCT was the same lesion on MG.

Post-acquisition image processing and reconstruction were performed to achieve isotropic reconstructed volumes using a soft tissue filter and a voxel size of 0.273 $mm^3$ (standard mode). Regions with calcifications were reconstructed using the volume-of-interest higher resolution mode with a sharp ramp filter at 0.155 $mm^3$ as a standard post-processing protocol.

Approximately 300–600 image slices were generated in each of the three planes (axial, sagittal, and coronal) for one breast on BCBCT, depending on breast size and the plane viewed. The average time required to scroll through the images was approximately 5 min. The workstation used for the BCBCT (Visage, Koning Corporation, USA) enabled the reader to target a finding of interest in one