A Case for Wide-Angle Breast Tomosynthesis

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Rationales and Objectives: Conventional mammography is largely limited by superimposed anatomy. Digital breast tomosynthesis (DBT) and computed tomography (CT) alleviate this limitation but with added out-of-plane artifacts or limited chest wall coverage. This article presents a wide-angle breast tomosynthesis (WBT), aimed to provide a practical solution to these limitations, and offers an initial study of its utility in comparison with DBT and CT using a singular evaluation platform.

Materials and Methods: Using an anthropomorphic virtual breast phantom, a Monte Carlo code modeled a breast imaging system for three modalities of DBT, WBT, and breast CT (44°, 99°, and 198° total angle range, respectively) at four breast compression levels, all at a constant mean glandular dose level of 1.5 mGy. Reconstructed volumes were generated using iterative reconstruction methods. Lesion detectability was estimated using contrast-to-noise ratio and a channelized Hotelling observer model in terms of the area under the receiver operating characteristic (AUC).

Results: Results showed improved detection with increased angular span and compression. The estimated AUCs for WBT were similar to that of CT. Comparative performance averaged over all thicknesses between CT and WBT was 4.3 ± 3.0%, whereas that between WBT and DBT was 5.6 ± 1.0%. At compression levels reflective of the modality (7-, 5-, and 4-cm thickness for CT, WBT, and DBT, respectively), WBT yielded an AUC comparable to CT (performance difference of 1.2%) but superior to DBT (performance difference of 5.5%).

Conclusions: The proposed imaging modality showed significant advantages over conventional DBT. WBT exhibited superior imaging performance over DBT at lower compression levels, highlighting further potential for reduced breast compression.

Key Words: Anthropomorphic breast phantom; Monte Carlo simulation; iterative reconstruction; wide-angle breast tomosynthesis; Hotelling observer model.

Breast cancer is the leading cause of cancer death in women. It is a global problem and affects countries of all economic levels (1). Earlier detection and treatment could decrease mortality rate by as much as one-third. At present, the main screening program used to identify early breast cancer is mammography (2). Standard two-dimensional mammograms have been effective in reducing breast cancer mortality (1), but drawbacks of overlapping structure and limited three-dimensional (3D) information from only cranio-caudal and mediolateral oblique views cause a number of malignant cases to be missed. Clinical studies have shown digital breast tomosynthesis (DBT) to provide significant advantages over mammography by offering better visual information and increased depth perception (3–5). However, the limited acquisition angle range (∼50°) makes the 3D data subject to out-of-plane artifacts (6). Breast computed tomography (CT) can provide better depth discrimination, leading to improved tumor detection while eliminating the need for breast compression (7). However, in its current implementation, because of patient positioning in the prone position and geometrical clearance needed for 360° image acquisition, breast CT may suffer from reduced chest wall coverage, especially when imaging women with smaller breasts (7).

In this article, we propose a wide-angle breast tomosynthesis (WBT) technique: the technique can alliteratively be recognized as limited angle CT. Compared to conventional breast tomosynthesis systems, WBT increases the acquisition angle range from typical 10°–50° to approximately 100° or more, aiming to reduce out-of-plane artifacts compared to DBT. The projection images are acquired within the maximum angular range possible without obstruction by the patient head and the contralateral breast, anatomic limitations that would reduce the chest wall coverage if the x-ray tube and the detector were to be rotating all around the breast. Figure 1a provides a schematic concept depiction of the hardware. Figure 1b illustrates a superoinferior–oblique geometrical orientation. The acquisition may also be done in the mediolateral–oblique orientation. The exact geometrical set up of the acquisition and the angular range depend on the specific orientation of the breast, the head, the contralateral breast, and how the patient can be positioned by the technologist considering the enhanced angular range. These

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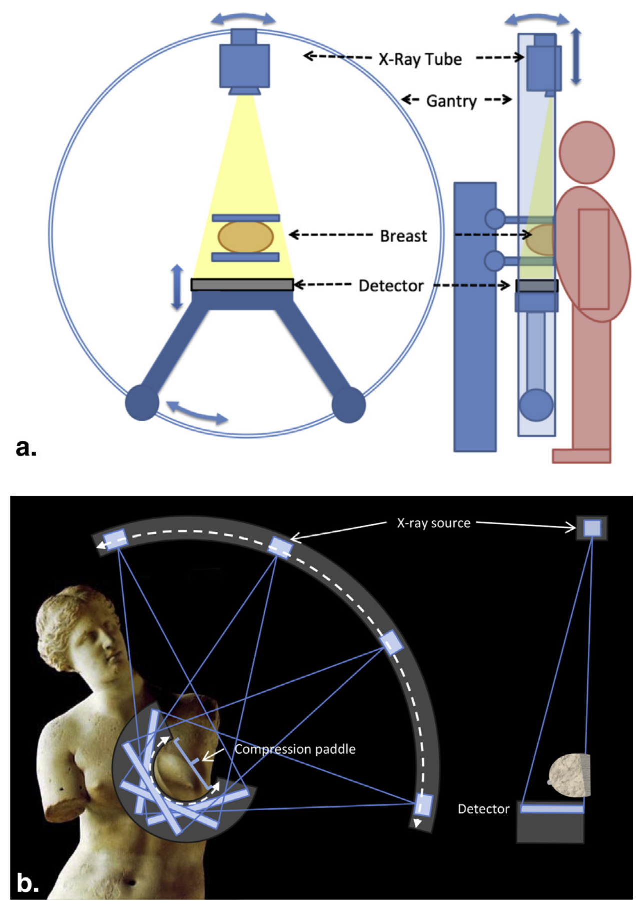

Figure 1. Schematic, illustrating front and side view of the prototype wide-angle breast tomosynthesis **(a)** and one implementation rendition **(b)**. The breast is modestly compressed. The x-ray source rotates along an arc of ~100° angular range consecutively with the detector in either superoinferior–oblique or mediolateral–oblique orientation. This proposed geometry should obtain coverage of the breast and the muscle along the chest wall with minimal discomfort to the patient.

issues, although important in the final design of the method, are not the primary objective of this study. Rather, this study aims to investigate the quantitative impact of enhanced angular range on image quality using a consistent simulation platform.

In this study, a simulation program was used to create realistic breast phantoms in a vowelized format. A custom Monte Carlo (MC) code based on the Penelope package was developed to model a virtual flat-panel breast tomosynthesis system. DBT, WBT, and CT (44°, 99°, and 198° total angle range, respectively) projections were simulated at four breast compression levels (4, 5, 6, and 7 cm). The glandular dose to the breast was kept at a constant dose level of 1.56 mGy, independent of the breast thickness and acquisition geometry. Iterative reconstruction methods were used to reconstruct the volume. Lesion detectability was estimated from contrast-to-noise ratio (CNR) and Hotelling observer model calculation to examine comparative performance across breast thickness and imaging modalities to assess the potential of WBT.

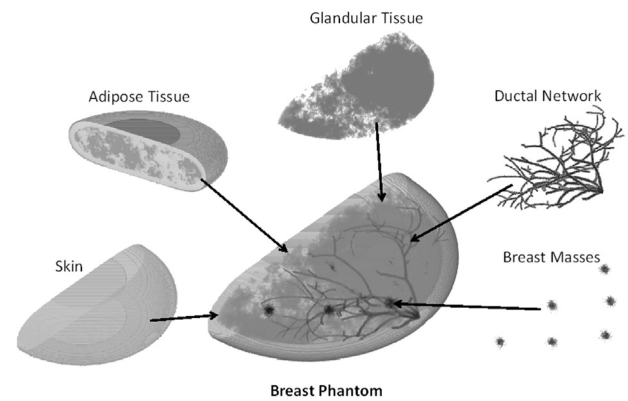

Figure 2. The breast phantom and its various components.

METHODS

Breast Phantom

To evaluate the performance of the imaging systems, the study used an anthropomorphic breast phantom designed based on a mathematical model of the breast anatomy. In this phantom (8), the numerical value of each voxel corresponded to an anatomic structure making it compatible with MC–based simulation software. As shown in Figure 2, the phantom model included realistic anatomic details such as skin, ductal network, glandular and adipose tissues, and breast masses and calcifications. A brief description of the breast phantom is provided in this work; a more detailed description can be found in the report by Chen et al. (8).

The outer envelope of the breast (ie, skin) was defined as a 0.5-mm layer defined by an elliptical equation whose parameters could be modified to model various level of breast compression. Breast compression was modeled by decreasing the breast thickness while increasing the width, keeping the total volume constant, thus assuming that the breast has incompressible characteristics. A 4.5-mm layer of subcutaneous fat was incorporated underneath the skin layer. The volume beneath the subcutaneous fat contained a combination of adipose and glandular tissues. The percentage of glandular tissue in the breast could be varied to imitate varying densities and the arrangement of the tissue randomized to simulate different "patients."

The ductal network was modeled by a series of branching (dividing) cylinders. The nipple was chosen as the origin for 16 main ducts, possessing certain radii and length, which extended toward the chest wall in different directions. At the end of each cylinder, branching takes place by any of three processes: 1) either the duct continues with a smaller branch, 2) the duct continues with a slight shift in direction but no branching, or 3) the duct gives rise to smaller branches. The radii and lengths of the "children" ducts were scaled by a factor with respect to the "parent" ducts resulting in ducts which are shorter and thinner than the "parent" ducts. The angles of the "children" ducts with respect to the "parent" ducts were calculated from the old direction and increments in polar and the azimuth angles. The dividing process terminated when the