Digital Breast Tomosynthesis: A Technological Review

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Abstract - According to American Cancer Society's most recent studies, breast cancer is the most common cancer among women today and a serious threat worldwide. Mammography, whether screen-film or digital, remains the best method to detect early breast cancer. Mammography imaging relies on the projection of a three-dimensional object onto a two-dimensional image in which lesions can be easily obscured and undetected. Digital breast tomosynthesis is a new technology which reconstructs a three-dimensional volume from a series of two-dimensional projection-view images taken over a limited arc angle. Although the technology has not yet been approved by the U.S. Food and Drug Administration, digital breast tomosynthesis has great potential. With digital breast tomosynthesis, physicians can get better insight of the breast structure without the superimposition of the other tissues, reduce number of biopsies, reduce recalls, reduce dose etc. The paper presents an overview of this promising technology.

Keywords - Digital Breast Tomosynthesis, Digital Mammography, Breast Imaging

I. Introduction

Breast cancer is one of the main causes of mortality among women in industrialized countries. A mammography exam, called a mammogram, plays a key role in early breast cancer detection and diagnosis, and helps increase a woman's chances of survival. The detection of breast cancer using mammography, the current standard in breast cancer screening, suffers from the obscuring effect of overlapping breast tissue due to the projection of a three-dimensional (3-D) object onto a two-dimensional (2-D) image [1]. A breast cancer can be masked or camouflaged by surrounding overlapping tissue and not show up on the mammogram, especially in woman with radiographic dense breasts.

Digital breast tomosynthesis (DBT) is a 3-D imaging technology that involves acquiring low-dose images of a stationary compressed breast at multiple angles during a short scan. These individual images are then reconstructed into a series of high-resolution slices parallel to the detector plane that can be displayed individually [2]. The problems caused by dense breast tissue and overlapping structures, and thus structure noise in single slice 2-D mammography imaging are significantly reduced in reconstructed tomosynthesis slices. The results indicate that the architectural distortion, bilateral asymmetry and mass visibility on DBT are superior to digital mammography (DM) leading to higher sensitivity for breast cancer detection. Calcification clusters visibility is poor due to their dispersion in the breast tissue. DBT also offers new opportunities including improved diagnostic and screening accuracy, fewer recalls, greater radiologist confidence, and 3-D lesion localization [2].

II. Technical Aspects of Tomosynthesis

Although the general principles of tomographic imaging were established in the 1930s, introduction of flat panel detectors into breast imaging systems launched the development of DM and allowed derivative technologies to be developed including tomosynthesis.

In comparison with conventional tomography where X-ray source/detector rotates 360° around the subject, digital tomosynthesis uses small tomography angle with a limited number of projection-views. In DBT, the X-ray source is rotated over a limited arc angle while the breast is compressed in a standard way. A series of low dose exposures are acquired, creating a series of digital images. Images are projections through the breast at different angles and these projection-view (PV) images are reconstructed into thin slices [2]. Slices may be thin as 0.5 mm, but are usually 1 mm. The reconstructed DBT slices provide pseudo 3-D structural information and may reduce the camouflaging effects of fibroglandular tissues [3].

Several manufacturers have applied different methods to develop and perform tomosynthesis. Manufacturers vary the arc of movement (typically 11°-60°), the number of individual exposures (typically 9-25), use of continuous or pulsed exposure, stability or movement of the detector, exposure parameters, total dose, effective size of pixels, X-ray source/filter source, single or binned pixels, and patient position [4]. Later studies with prototype systems indicate that the image quality is highly dependent on system geometry and the selection of optimal image acquisition, reconstruction and display parameters. There are likely advantages and disadvantages of each system, but there is still no universally accepted technology. However, these differences may produce different clinical results making clinical comparisons between manufacturers difficult.

A. Motion geometry

The first item to consider is the motion geometry of the DBT system which varies between manufacturers. There are three basic motion geometries: stationary (the multi-beam X-ray source array enables collection of all PV mammograms without mechanical motion), partial isocentric motion (the detector remains stationary while the X-ray source moves in an arc) and full isocentric motion (the X-ray source and detector are fixed with respect to each other and rotate about the same axis). Partial isocentric motion is the most common configuration. An example of DBT system with partial isocentric motion geometry is shown in Fig. 1.

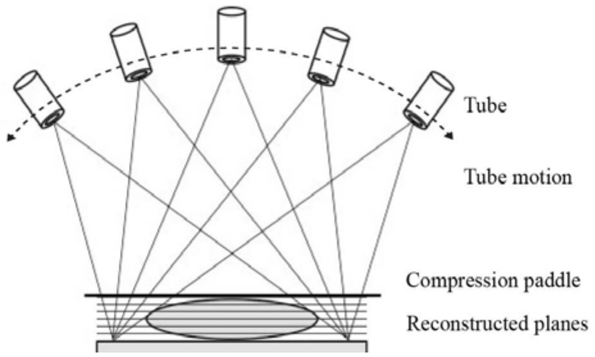

Figure 1. Example of DBT system with partial isocentric motion geometry

B. System geometry

In the world coordinate frame (x, y, z), we can describe the geometry of a tomosynthesis system by using two sets of geometric parameters. The first set describes the X-ray source location with respect to the detector and has the following descriptors: source-to-detector-distance, detector distance from table-top to the X-ray absorber layer, focal spot location, projection of the central ray onto the detector and tomography angle. Because of its utmost importance, tomography angle is described in a separate paragraph. The second set of parameters is related to detector misalignment with respect to the normal ray from the X-ray tube through the pivot axis to the centre of the chest wall edge of the image receptor [5].

C. Tomography angle

The range of angles through which the X-ray source moves while the images are being acquired is called the tomography angle. In general, wide angular range provides better depth resolution and gives increased reconstructed slice separation, while a narrow one enhances in-plane resolution.

Chawla et al. [6] investigated the effects of dose, number of angular projections and the total tomography angle, on the overall diagnostic image quality in both the projection and reconstruction space. Results for both modes offered similar trends: increase in the total acquisition dose level and the tomography angle improved measured performance.

Hu et al. [7] investigated the dependence of out-of-plane image artifacts on image acquisition and reconstruction parameters. Different analytical reconstruction algorithms were used and compared. The results showed that an increase in tomography angle of DBT could reduce the intensity of out-of-plane artifacts.

Hu et al. [8] investigated artifacts in DBT using a linear system approximation. The results showed that decreasing the angular range of acquisition degrades the resolution in the z-direction, resulting in a more pronounced smearing of the in-plane feature along the depth of the reconstructed volume.

D. Number of projections

The number of PV mammograms for a given angular range must be high enough to ensure sufficient angular sampling and to avoid artifacts.

Chawla et al. [6] investigated the effects of acquisition parameters on the overall diagnostic image quality in both the projection and reconstruction space. Both modes, however, offered similar trends: by using a constant dose level and angular span, the performance rolled off beyond a certain number of projections, indicating that simply increasing the number of projections in tomosynthesis may not necessarily improve its performance.

Zhang et al. [9] investigated the effect of different distributions of projection-view images that included different angular range and angular spacing on the reconstruction image quality. Six subsets, each containing 11 projection-views, were selected from the original 21 projection-views. No subset was superior to the others in all performance measures, indicating inevitable trade-off between in-plane resolution and depth resolution. The full set demonstrated a clear advantage.

E. Dose

Radiation dose and image quality are directly related. The U.S. Food and Drug Administration (FDA) limit is 300 mrad per projection-view, while the standard dose per projection-view in conventional mammography is 150 to 250 mrad. However, achieving reduced doses is optimal.

In DBT, a sequence of low-dose PV mammograms is acquired at a small number of projection angles over a limited angular range. The total radiation dose of a DBT mammogram is set to be comparable to that used in a conventional mammogram and can be distributed to individual projection-views evenly or unevenly, resulting in much lower dose for each projection [10]. Therefore, the main requirements for a suitable detector are high detective quantum efficiency (DQE), low noise and rapid readout.

F. Reconstruction algorithms

In comparison with conventional tomography where X-ray source/detector rotates 360° around the subject, digital tomosynthesis uses small tomography angle with a limited number of projection-views. Incompleteness of the object information can be partially overridden by using digital image processing to yield images similar to conventional tomography. Nonetheless, because the information acquired is incomplete, reconstruction algorithms for digital tomosynthesis are different from those of conventional tomography. Although details of specific manufacturer algorithms are not always available in the public domain, the following reconstruction algorithms have studies in DBT:

- Shift-and-Add (SAA);
- Back Projection (BP);
- Filtered Back Projection (FBP);
- Tuned Aperture Computed Tomography (TACT);
- Iterative Matrix Inversion Tomosynthesis (MITS);

- Maximum-Likelihood Algorithm (ML);
- Algebraic Reconstruction Technique (ART);
- Gaussian Frequency Blending (GFB).

Each of the listed reconstruction algorithms has a number of adaptations developed to remove image artifacts and improve image quality. The principles of tomosynthesis and image reconstruction are shown in Fig. 2 and Fig. 3. An example of reconstructed image is given ih Fig. 4.

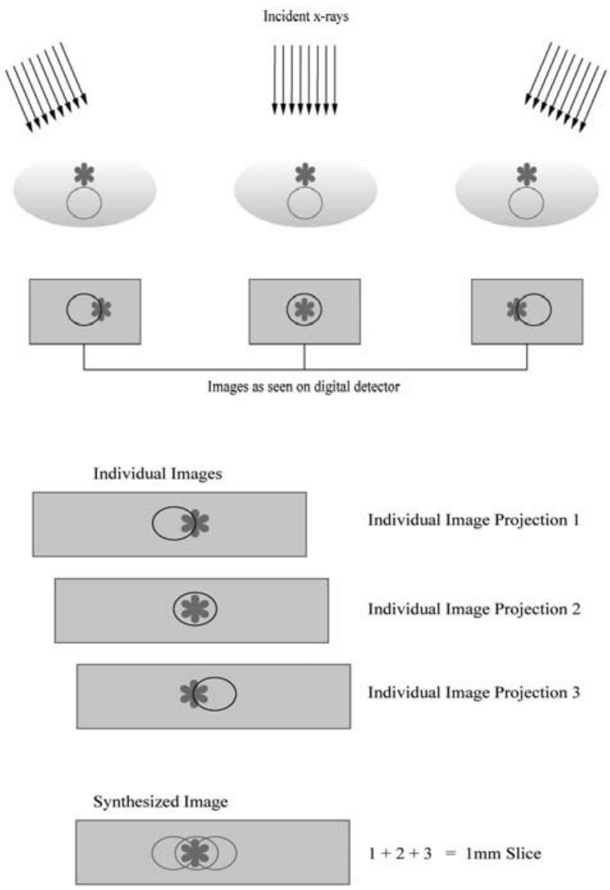

Figure 2. The principles of tomosynthesis [2]

The technical complexity of the comparison of reconstruction algorithms puts it outside the scope of this paper (details can be found in [11] and [12]).

G. *Artifacts*

Due to the finite size of the detector, limited angular range and number of projections, all reconstructions exhibit strong artifacts. Some of these artifacts will obscure the breast tissue details near the boundary of the PV images and may lead to a wrong diagnosis. Others may interfere with radiologist visual evaluation and computer-aided detection (CAD) of subtle mammographic features. Because development of artifact reduction methods is an active research area, some of these DBT specific artifacts are mentioned.

In some or all of the PV images a part of the imaged volume is not exposed because of a finite-size detector. During reconstruction, the imaged volume is updated by processing each individual PV image. Voxel values within the PV image boundary will be updated while the voxel values outside will maintain unchanged. This discontinuity in voxel values will result in detector boundary truncation artifacts, which appear as bright staircase-like lines [13].

Breast tissue outside the imaged volume, e.g. pectoral muscle, will cause estimation error in the X-ray attenuation. In the reconstruction process, overestimation of the attenuation will result in bright voxels and will be referred to as glaring artifact [13].

In DBT, out-of-plane objects above and below the target slice create artifacts in all reconstructions. We refer to these artifacts, which are also known as ghosting artifacts or smearing, as structure noise [14].

III. COMMERCIAL IMPLEMENTATION

Tomosynthesis imaging is in a period of a high rate of change, with an increasing number of investigators and manufacturers nearing completion of projects involving both the physics and clinical aspects of technique [15]. Several companies have developed DBT prototypes in the last few years based on DM systems, although at the time of writing only one system gained U.S. FDA approval and is available in the U.S. market. Some companies market DBT systems in Europe and have several installations.

Selenia Dimensions prototype DBT system has a a-Se/a-Si active matrix flat panel digital detector with a pixels size 0.07 mm × 0.07 mm and the raw image size 23 MB (24 cm × 29 cm). For tomosynthesis imaging, the X-ray tube is automatically rotated in 1° increments to acquire projection images over a 15° angular range in less than 4 seconds. Minimum reconstruction slice thickness is 1 mm. Projection exposure mode is pulsed acquisition in continuous sweep. The digital detector is stationary during image acquisition. The DBT system uses an W-anode/Al-filter X-ray source and anti-scatter grid [16].

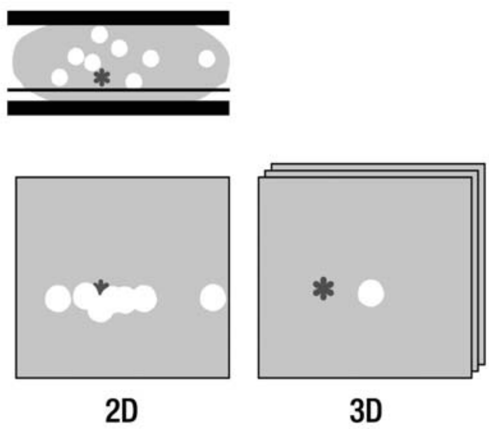

Figure 3. Tissues that overlap and hide pathologies in conventional mammography (left) are less likely to be obscured using tomosynthesis (right) [2]

Mammomat Inspiration prototype DBT system has a a-Se solid-state flat panel digital detector with a pixel size 0.085 mm

× 0.085 mm and the raw image size 20 MB (24 cm × 30 cm). For tomosynthesis imaging the X-ray tube is automatically rotated in 2° increments to acquire projection images over a 50° angular range in less than 25 seconds. Minimum reconstruction slice thickness is 1 mm. Projection exposure mode is continuous. The digital detector is stationary during image acquisition. The DBT system uses a W-anode/Rh-filter X-ray source [16].

IV. Reader Preference Studies And Clinical Trials of DBT

Without an FDA approved DBT system, a great deal of published sensitivity and specificity data, enough clinical trials to determine its best use and some competing technologies, this modality remains at what Dobbins III [15] refers to as a "translational crossroads" between experimental and clinical stages [17].

Poplack et al. [18] evaluated 99 screening recall abnormalities in 99 breasts (43 left breasts, 56 right breasts) in 98 women. The results of screening mammography were compared with the results of tomosynthesis and the need for recall when tomosynthesis was added to digital screening mammography was estimated. Readers determined that the image quality of the DBT was equal (51%) or superior (37%) for 89% of cases. 11% of cases were considered inferior. The recall rate reduction was approximately 40%.

Good et al. [19] investigated ergonomic and diagnostic performance issues of digital breast tomosynthesis in a pilot study. Thirty selected cases were evaluated by nine radiologists. Three reading modes included digital mammography alone, 11 projection-view tomosynthesis images and reconstructed tomosynthesis images. Only 1.9% of DBT images were somewhat worse than conventional mammography images. Measured mean time spent in reviewing, interpreting, and rating the examinations for different readers and modes was longer for DBT than conventional mammography reading.

Gur et al. [20] compared the diagnostic performance of digital mammography with DBT alone and digital mammography and DBT combined. Images from 125 selected examinations, among them 35 with verified findings of cancer and 90 with no findings of cancer, were reviewed by eight radiologists. Use of the combination of DBT and digital mammography versus digital mammography alone was associated with 30% reduction in recall rate for cancer-free examinations. Use of DBT alone versus digital mammography alone reduced recall rate for benign findings for 10%. Finally, results showed that use of DBT may result in a significant decrease in recall rate, but without substantial improvement in sensitivity.

Rafferty et al. [21] compared digital mammography plus breast tomosynthesis to the digital mammography alone as a function of breast density. The images were read in three modes: digital mammography alone, digital mammography plus MLO DBT and digital mammography plus DBT (both CC and MLO). Fifteen radiologists evaluated 310 cases. The results showed that digital mammography plus DBT was significantly better than digital mammography alone in both fatty and dense breasts. Therefore the addition of DBT may increase the detection of breast cancer for women with dense breasts.

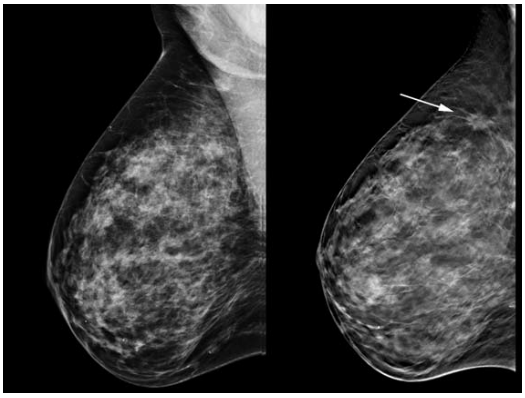

Figure 4. Mammographically occult cancer (left image) is visible with tomosynthesis (right image) [2]

Other trials reporting a benefit in the use of tomosynthesis in breast imaging were performed by Anderson et al., Kopans et al., Michell et al. and Niklason et al., and are described in [22].

Some trials yielded negative results. Teertstra et al. [23] compared the sensitivity of DBT alone with digital mammography alone using a population of 513 women with an abnormal screening mammogram or with clinical symptoms. The results showed no improvement for diagnostic DBT: sensitivity of both techniques was similar (92.9%), while digital mammography's specificity was slightly higher at 86% compared to tomosynthesis alone at 84%. This study suggests that DBT can be used as an additional technique to mammography.

V. Conclusion

Digital breast tomosynthesis offers superior performance to conventional mammography and its use is expected to result in reduced recalls, fewer biopsies, improved lesion localization and cancer detection, reduced dose etc. Although preliminary studies have given promising results, a number of questions remain to be resolved and further clinical research is needed. First, the sensitivity and specificity of DBT should be quantified. Second, it must be determined whether DBT should be used for screening or diagnostic imaging or both. Third, performance standards should be developed. Based on these standards, comparison of commercial systems and optimal configuration could be determined. At present, with new breast imaging technologies like dedicated breast CT and contrast-enhanced X-ray imaging on the horizon, the long term future is difficult to predict with certainty.

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