Digital Breast Tomosynthesis

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Full-field digital mammography offers many advantages over screen/film mammography. However, due to the two-dimensional nature of projection imaging, mammography is limited by overlapping tissue structure. Digital breast tomosynthesis is expected to overcome this limitation by providing slice images of the breast.

By Jay Baker, MD; Joseph Lo, PhD; Axel Hebecker, PhD; Thomas Mertelmeier, PhD; and Jasmina Orman

Although most commercial full-field digital mammography (FFDM) systems have shown superior physical image quality over their analog counterparts – as measured by detective quantum efficiency (DQE) – the ACRIN-DMIST study [1] has shown that, averaged over the entire population of the study, FFDM proved only equivalent to screen/film mammography. However, the ACRIN-DMIST results also show that FFDM provides statistically significant diagnostic advantages over screen/film mammography for certain populations, such as women under age 50 (no matter what level of breast tissue density), women of any age with heterogeneously dense or extremely dense breasts, and pre- or perimenopausal women.

The main limitation of both screen/film mammography and FFDM is not quantum or detector noise but the fact that the 3D anatomical information is projected into a 2D image plane. Therefore, anatomical structures that overlap a tumor limit the radiologist’s ability to detect certain cancers. Initial research of digital tomosynthesis* for mammography has shown promise [2, 3, 4, 5] to overcome this limitation of projection mammography by acquiring several views of the breast from different viewing angles and reconstructing slice images in a 3D volume set.

Principle of Digital Breast Tomosynthesis

Breast tomosynthesis is a 3D imaging technology that acquires 2D projection images of a compressed breast at multiple angles during a sweep of the X-ray tube. Objects at different heights in the breast are projected differently at different angles. During the subsequent reconstruction, for example by the method of filtered back-projection [6], the objects of a given height are enhanced by appropriate filtering, shifting and summation. The reconstruction finally leads to a series of slices of the different depth layers parallel to the detector surface. The in-slice resolution is predominantly determined by the detector resolution and usually much higher than the resolution between slices (‘depth resolution’), due to the incomplete 3D information of the object. The scan angle is usually much smaller than what would be required for completely sampling the object to fully enable 3D reconstruction.

* Caution: Investigational Device. Limited by U.S. Federal law to investigational use. RSNA 2006: The information about Digital Breast Tomosynthesis is preliminary. This product is under development and not commercially available in the U.S., and its future availability cannot be ensured.
[1] Tomosynthesis prototype based on a Siemens MAMMOMAT Novation™ system.
During the acquisition process, the total dose is split among the single views. The summation process in the reconstruction takes care that one voxel is probed by approximately the same number of X-ray quanta as in projection mammography. Therefore, a tomosynthesis scan needs approximately the same dose as a 2D projection mammography examination – under the assumption that the image detector does not excessively contribute to noise. Thus, it is crucial to employ detectors with high Detective Quantum Efficiency (DQE) at very low exposures. When designing a breast tomosynthesis system, several key parameters and their mutual interdependence should be optimized.

■ Angular range: The angle span determines the depth resolution. The wider the span, the higher the resolution in the direction perpendicular to the slices will be. Slices can be thinner, and the intensity of out-of-plane artifacts generally decreases.

■ Number of projections: Streak artifacts caused by the limited number of views will be smaller the larger the number of views is. On the other hand, increasing the number of projections will lead to a lower exposure for each view (at constant total dose), and thus may lead to increased electronic noise in the projections, which may be detrimental to image quality. Also, a large number of measured projections increases the scan time – at a given detector readout cycle – and therefore also the time the breast has to be under compression.

■ X-ray spectrum: For optimizing the dose applied to the breast as well as the image quality, the adequate radiographic technique has to be investigated. In this respect, the tungsten/rhodium (W/Rh) anode/filter combination appears to be beneficial [7].

■ Reconstruction algorithm: Currently, several reconstruction algorithms are under investigation. Besides iterative algorithms [5], analytical reconstruction methods such as filtered backprojection (FBP) are of special interest as they require much less computing power. Therefore, a dedicated FBP algorithm for breast tomosynthesis has been developed [8, 9].

Potential Clinical Benefits

Digital breast tomosynthesis has the potential to improve sensitivity in the detection of breast cancer due to reduced overlap of breast tissue, particularly in dense breasts. This may result in earlier breast cancer detection. Digital breast tomosynthesis may also lead to significant improvements in specificity: with the 3D data available, a 3D analysis of the distribution of microcalcifications, or a 3D analysis concerning shape, margins and size of lesions, might be easier. As a result, this could lead to a reduction of the recall rate of patients and fewer biopsies.

Finally, digital breast tomosynthesis may eliminate the need for multiple exposures of the same breast.

The Siemens Prototype

The objective of the Siemens tomosynthesis prototype device [10] is to gain experience – together with clinical partners – on how to provide a comprehensive solution for 3D mammography. The specific goals are to find the best acquisition mode for a tomosynthesis scan and study reconstruction algorithms to optimize image quality. Another objective is to explore the clinical performance and workflow of tomosynthesis. The prototype is based on a Siemens MAMMOMAT® Novation™ system modified for an X-ray tube motion over an
Interview with Jay Baker, MD: “Ready to Go”

**MEDICAL SOLUTIONS:** What experiences have you had with the prototype of the Siemens tomosynthesis-device so far?

**BAKER:** It has been fascinating. The system worked every bit as well as we had hoped. I think we are with tomosynthesis where we were with MRI, say, 15 years ago. The system is ready to go – it is not as good as it is going to be, but it would be a shame if we didn’t put it into clinical practice soon to improve patient care.

**MEDICAL SOLUTIONS:** Where do you see the main potential of digital tomosynthesis in comparison to the 2D acquisition method?

**BAKER:** I see two primary uses for tomosynthesis. In a first step, it is going to be used for problem solving in patients with a vague density on their 2D mammography screening images. In a second step, it could even replace 2D mammography as the standard screening method. If you look at it in a long-term perspective, it would also be possible to adopt tomosynthesis for image-guided biopsies, as it appears more robust compared to today’s stereotactic technique.

**MEDICAL SOLUTIONS:** Where do you see the main challenges of tomosynthesis? In screening or diagnostics?

**BAKER:** I see two, or rather three, challenges. The first is, are we going to see all of the tissue? To limit the dose, we are hoping we can see all tissue on a mediolateral oblique (MLO) tomosynthesis scan and do not need a second, cranio-caudal setup. Second, we see too much. Especially in dense breasts, we see more benign lumps, cysts, and fibroadenomas. If they are discovered during a conventional mammography, the patient would go to ultrasound, and, if the mass is solid, undergo biopsy to determine if it is benign or malignant. If tomosynthesis replaced conventional mammography, there would simply be too many patients who would have to undergo biopsy. Fibroadenomas show up as an oval, homogeneous, well-defined structure on tomosynthesis images. Once more patients are done, say in the thousands or hundreds of thousands, it may be safe to conclude that if you see such an oval, homogeneous, well-defined structure, it is a fibroadenoma, and you don’t need to work up those findings. Papillary carcinoma may mimic these benign masses, but it is very uncommon. It may be an acceptable trade-off to delay the diagnosis of these often less aggressive papillary cancers for the likely benefit of substantially higher sensitivity for the more common and aggressive types of breast cancer. The third challenge is cost – screening is not a money-maker because of low reimbursement. This has already been an issue when mammography went digital, and many centers only went digital with their mammography unit because the whole radiology department was going digital anyway, and it meant getting rid of the last film unit.

**MEDICAL SOLUTIONS:** Is computer-assisted detection (CAD) a must for tomosynthesis?

**BAKER:** It will be very helpful, but one can’t just rely on CAD yet. With tomosynthesis, we need to look at 20,000 slices to detect one cancer. CAD can be helpful to focus on potential abnormalities, but you can’t yet simply turn it on and have it show you the potentially abnormal slices only.

arc of up to ± 25° relative to the pivoting point, which is six centimeters above the detector surface. Although the system provides W/Rh and molybdenum/molybdenum (Mo/Mo) as anode/filter combinations, all image data are acquired with the W/Rh X-ray spectrum. W/Rh seems to be particularly beneficial for tomosynthesis as the dose of one complete scan can be kept as low as one or two conventional 2D mammograms. In order to get rid of mechanical instabilities as much as possible, a mode with continuous tube motion is selected instead of a ‘step and shoot’ mode, which might induce vibrations. The integrated tomosynthesis mode is shown in Figure 1. The detector used in this prototype tomosynthesis system is a fast, direct-converting amorphous selenium flat detector. The array dimensions are 2816 x 3584, with a pixel pitch of 85 micrometers, which translates into an active area of 23.9 x 30.5 centimeters. No anti-scatter grid is used. The detector has a high DQE at low dose: In all acquisition
modes, the low-frequency DQE exceeds 0.5. The system is quantum-noise limited even for the lowest detector exposures. Various image acquisition modes are designed into the system to facilitate evaluation of the best parameter settings for clinical use. Readout is possible in binning and non-binning mode, and several acquisition strategies are available to study the influence of residual images (lag) and their correction. For example, to almost completely eliminate focal spot blur, a very slow scan time of 40 seconds can be used to acquire 49 different views spanning the entire ± 25°. Other acquisition modes that have been defined include 25 views in full resolution mode with a scan time of 20 seconds, and 25 views in binning mode with a scan time of 12.5 seconds. Table 1 summarizes the different acquisition modes implemented in the current prototype system.

Clinical Image Results

At Duke Medical Center, human subjects are being recruited from a screening population or from among cases already scheduled to undergo biopsy. Informed consent is acquired in accordance with Institutional Review Board (IRB) approved protocols.

One example is shown in Figure 2. The patient with compressed breast thickness of six centimeter underwent tomosynthesis scans on each breast in mediolateral oblique (MLO) position. The anode/filter combination was W/Rh with 28 kilovolt peak (kVp). According to the experimental exposure tables for the FFDM system with the same tube, 133.4 milliampere seconds (mAs) were applied in total for 49 projections. Figure 2A displays a slice through the middle section of the compressed breast, where the ducts and other fine structure are clearly visible. Most prominent is a new invasive ductal carcinoma with some lobular component in this patient, who had a biopsy 25 years ago. This carcinoma could easily be overlooked in the conventional mammogram shown in Figure 2B, a fact that indicates the high potential of early breast cancer detection by tomosynthesis. In Figure 2C, a slice close to the upper surface of the breast is shown, depicting the blood vessels and skin pores.

A second example is shown in Figure 3. The dense breast contains pleomorphic microcalcifications of the branching and casting type. The tomosynthesis scan, consisting of 25 views with the breast in MLO position, nicely demonstrates the detailed microcalcifications associated with a ductal carcinoma in situ (DCIS).

Conclusion and Outlook

Currently, digital breast tomosynthesis is in initial research status. Prototypes exist, and first clinical experience is being gathered. One could say that the fundamental physical problems of data acquisition and image reconstruction have been solved, although many details need further investigation. A tomosynthesis solution for routine clinical use will need to address the following general challenges:

- The projection data must be acquired over the appropriate angular range with the sufficient number of views.
- The detector should be tailored to low noise and fast read-out.
- The reconstruction algorithm has to be fast to provide an efficient workflow.
- The large data set requires rapid transmission, preview, and storage, facing the fact that one scan delivers approximately one gigabyte of data (projections and slices).
- It can be envisioned that some sort of computer-assisted detection (CAD) method might be needed, particularly in a screening environment.
- Specific 3D quality control tools (tests, phantoms) need to be designed.
- One of the biggest challenges might be to find an efficient way of displaying, reading and archiving the huge amount of image data.

Digital breast tomosynthesis has the potential to revolutionize mammography by significantly reducing the tissue overlap problem inherent in conventional 2D mammography. This may lead to improved sensitivity and specificity, fewer recalls,
and fewer biopsies at approximately the same or even lower dose as compared to a standard four-view mammography. It can be expected that digital breast tomosynthesis will be used as a diagnostic tool in the beginning phase. However, after a learning curve, and after the diagnostic benefit has been proven, digital breast tomosynthesis may also be applied in the screening setting.

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References
