

# Full Field Breast Tomosynthesis

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## Introduction

Breast tomosynthesis is a 3-dimensional imaging technology that involves acquiring images of a stationary compressed breast at multiple angles during a short scan. The individual images are then reconstructed into a series of thin high-resolution slices that can be displayed individually or in a dynamic ciné mode. Figure 1 displays an example tomosynthesis slice showing a spiculated lesion.

Reconstructed tomosynthesis slices reduce or eliminate the problems caused by tissue overlap and structure noise in single slice 2-D mammography imaging.

Digital breast tomosynthesis offers a number of exciting opportunities including the possibility of reduced breast compression, improved diagnostic and screening accuracy, 3-D lesion localization, and contrast-enhanced 3-D imaging.

Hologic has performed some preliminary studies to investigate the suitability of a selenium image receptor in a tomosynthesis machine. This paper looks at the key variables in optimizing a breast tomosynthesis system and summarizes the initial results from a scientific investigation of breast tomosynthesis using a selenium full-field digital mammography system.



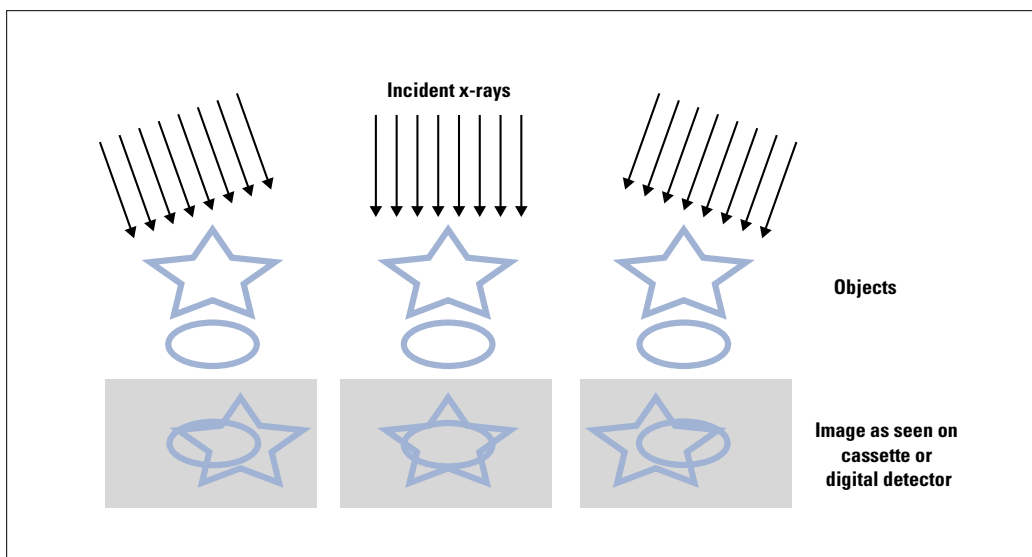
**Figure 1:** This cross-sectional tomosynthesis slice from the center of a breast shows a spiculated lesion

## Theory of Tomosynthesis

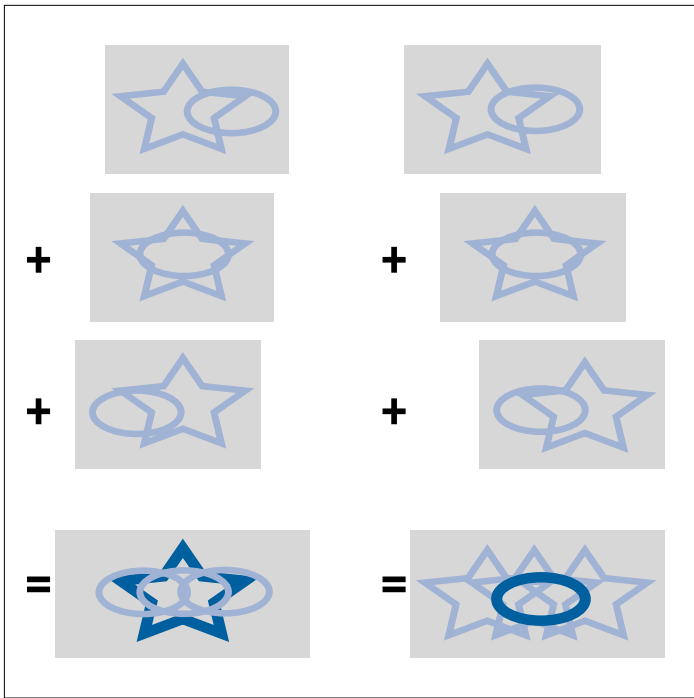
Conventional x-ray mammography is a two-dimensional imaging modality. In conventional mammography, pathologies of interest are sometimes difficult to visualize because of the clutter of signals from objects above and below. This is because the signal detected at a location on the film cassette or digital detector is dependent upon the total attenuation of all the tissues above the location.

Tomosynthesis is a 3-D method of imaging that can reduce or eliminate the tissue overlap effect. While holding the breast stationary, images are acquired at a number of different x-ray source angles. Objects at different heights in the breast project differently in the different projections. In Figure 2, the two objects (a star and an ellipse) superimpose when the x-rays are at 0°, but the  $\pm 15^\circ$  acquisitions shift the objects' shadows relative to one another in the images.

The final step in the tomosynthesis procedure is reconstructing the data to generate images that enhance objects from a given height by appropriate shifting of the projections relative to one another. In Figure 3 the images in the left column are summed, shifting one relative to another in a specific way that reinforces the starred object and reduces the contrast of the ellipsoidal object by blurring it out. Similarly,



**Figure 2:** With tomosynthesis imaging, images acquired from different angles separate structures at differing heights. Conventional mammography would acquire only the central image



**Figure 3:** By shifting and adding the acquired projections, 3-D imaging increases the visibility of objects by blurring out objects from other heights

in the example on the right, the images are reconstructed differently, using different shifts of the projection data, to reinforce the ellipse object and blur the star.

Note that additional acquisitions are not required to achieve this—one set of acquired data can be reprocessed to generate the entire 3-D volume set.

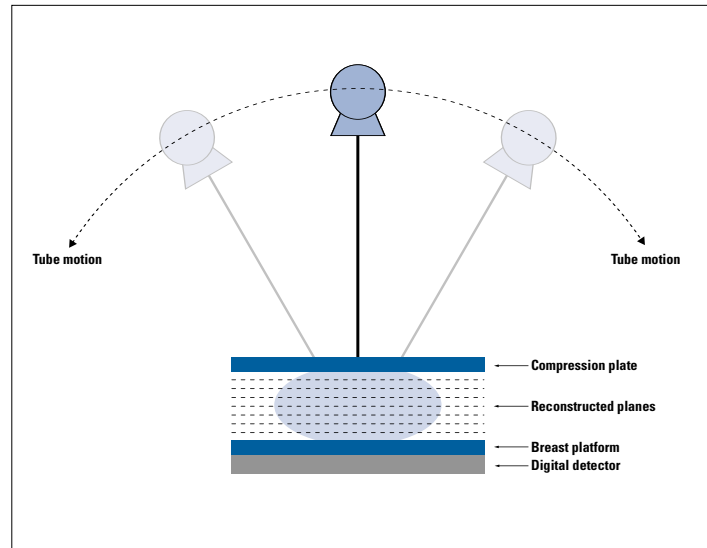
### Performing the Acquisition

The geometry of tomosynthesis is shown in Figure 4. The breast is compressed in a standard way. While holding the breast stationary, the x-ray tube is rotated over a limited angular range. A series of low dose exposures are made every few degrees, creating a series of digital images. Typically, the tube is rotated about  $\pm 15^\circ$ , and 11 exposures are made every  $3^\circ$  during a total scan of 10 seconds. The individual images are projections through the breast at different angles and these are what are reconstructed into slices.

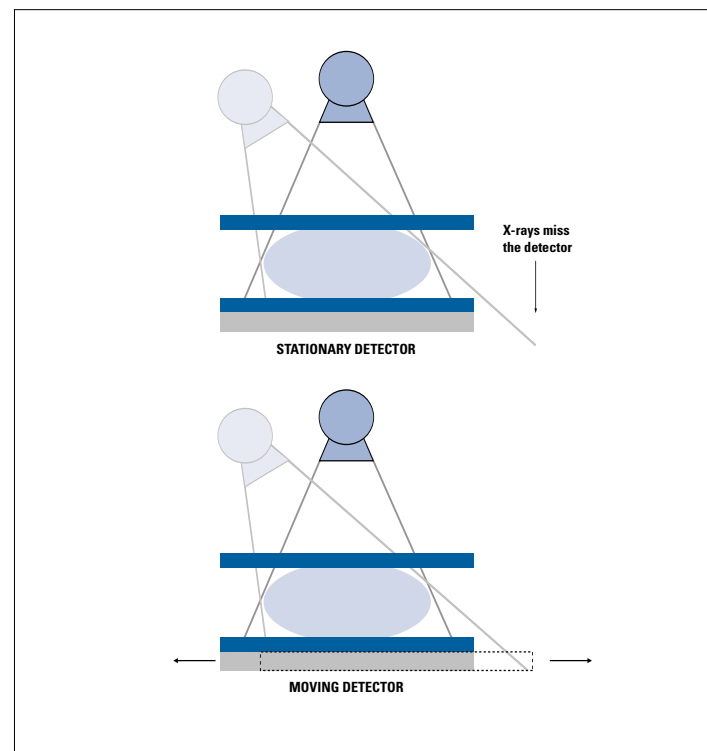
Normally the breast would be placed in the MLO or the CC view, although the tomosynthesis system should support the ability to acquire images in any desired orientation.

There are two basic tomosynthesis system designs, which differ in the motion of the detector during acquisition. One method moves the detector in concert with the x-ray tube, so as to maintain the shadow of the breast on the detector. An alternate method is to keep the detector stationary relative to the breast platform. These two methods are illustrated in Figure 5.

Systems that utilize stationary detectors will have a smaller field of view than systems that move the detector, because only a moving detector manages to keep the entire



**Figure 4:** Tomosynthesis acquisition geometry showing the direction of motion of the x-ray source, and the orientation of the reconstructed planes



**Figure 5:** Tomosynthesis imaging can involve two acquisition geometries: stationary and moving detectors. Stationary detectors have smaller fields of view

breast tissue imaged at all angles.

Another consideration in the design of tomosynthesis systems is the motion of the x-ray source during acquisition. The x-ray tube can move in a continuous or step-and-shoot motion. If the tube rotates continuously, short x-ray pulses are used to avoid blurring the image. If step-and-shoot motion is employed, the gantry must come to a complete stop at each angular location before turning on the x-rays, otherwise vibration will blur the image. With continuous

motion, scan speed must be slow enough, or each x-ray exposure short enough, to avoid image blurring due to focal spot motion.

The angular range and number of exposures acquired during the scan are additional variables that need to be optimized. In general, more exposures will allow reconstructions with fewer artifacts. This must be balanced against the fact that for a given total examination dose, more exposures will mean smaller signals for each of the individual shots. For sufficiently small exposures, imager receptor noise will dominate the image and degrade reconstructed image quality. In regards to angular range, a larger angular range gives superior reconstructed slice separation, where smaller angular ranges keep more structures in focus in a given slice. Increased separation might be desired for resolving two closely lying structures, but could impair the appreciation of a cluster of microcalcifications by having individual calcifications appear in different slices.

### Tomosynthesis System Requirements

#### *Detector Efficiency and Dose*

Tomosynthesis imaging consists of a series of low dose exposures, with every acquisition about 10% of a normal single-view mammogram. Because each exposure is low dose, it is essential that the image receptor have a high quantum efficiency and low noise. Because images are being acquired at a rate of about one per second, rapid imaging is another requirement. Selenium-based image receptors, with their high Detective Quantum Efficiency (DQE), greater than 95% x-ray absorption at mammographic energies, and rapid readout capabilities, are an ideal detector for tomosynthesis systems.

#### *Field of View*

Field of view is another important requirement. If the breast does not fit completely on the detector it will not be possible to acquire a full field tomosynthesis image.

The Hologic amorphous selenium detector used in the initial investigation is ideal because it has the largest field of view of any commercial detector. Additionally, as was seen in Figure 5, the system must ensure that the x-ray shadow of the breast strikes the detector at all angles of acquisition, to avoid further reducing the field of view.

#### *Equipment Geometry*

Many conventional digital mammography gantries have a rotation axis near the breast. For these, a tomosynthesis system can be designed with minimal change to the existing digital mammography gantry, and could even be designed as an add-on unit. If the mechanical changes are minimal, existing hardware, such as paddles, might be useable as they are currently.

### Image Reconstruction

The tomosynthesis reconstruction process consists of computing high-resolution images whose planes are parallel to the breast support plates. Typically, these images are reconstructed with slice separation of 1 mm, thus a 5 cm compressed breast tomosynthesis study will have 50 reconstructed slices. Rapid reconstruction time is essential, especially when tomosynthesis is being considered as part of an interventional study, and for this reason it is important to keep the entire post-acquisition processing to 30 seconds or less.

### Display Methodology

The reconstructed tomosynthesis slices can be displayed similarly to CT reconstructed slices. The operator can view the images one at a time or display them in a ciné loop. The original projections are identical to conventional projection mammograms, albeit at an equivalent or lower total dose, and these can be viewed as well, if desired. The system should also be able to take a normal mammogram under the same compression, and in this case the tomosynthesis slices and the mammogram are completely co-registered allowing correlation between objects in the two differing image sets.

### Potential Clinical Benefits

#### *Reduced Recalls*

#### *Fewer Biopsies*

#### *Improved Cancer Detection*

Tomosynthesis should resolve many of the tissue overlap reading problems that are a major source of the need for recalls and additional imaging in 2-D mammography exams. The biopsy rate should also decrease through improved visualization of suspect objects. Some pathologies that are mammographically occult will be discernable through the elimination of structure noise. Noise and tomosynthesis may allow improved detection of cancers in women with heterogeneously dense breasts.

#### *Reduced Dose*

Tomosynthesis may eliminate the need for multiple exposures of the same breast, because the images do not have tissue overlap. Because of this, a single tomosynthesis acquisition, such as in the MLO orientation, may be all that is required. In addition, less additional imaging is required because of the reduced recall rate. Thus it is entirely reasonable to assume that patient dose will end up less with tomosynthesis than with conventional mammography.

#### *Tissue Localization*

Because the location of a lesion in a tomosynthesis slice completely determines its true 3-D coordinate within the breast, biopsy tissue sampling methods can easily be done using the tomosynthesis generated coordinates.

### *Faster Review Time*

Because the images are presented with reduced tissue overlap and structure noise, objects are expected to be visualized with improved clarity. This will likely lead to faster case review and more confident readings.

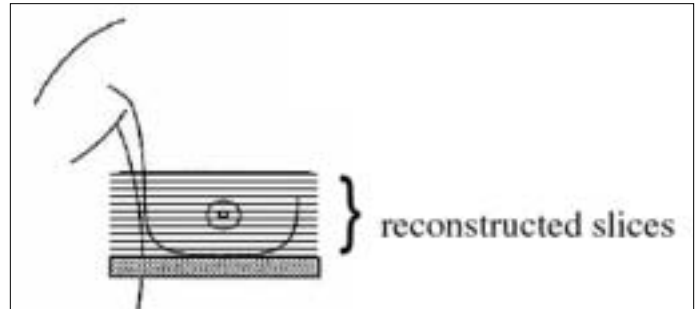
### *Reduced Compression Pressure*

In conventional mammography, breasts are highly compressed so as to reduce tissue overlap. High compression pressure is not needed for tomosynthesis imaging. Just enough breast compression to pull tissues out of the chest wall and keep motion at a minimum is adequate. Therefore, there is the possibility of less painful compression using tomosynthesis.

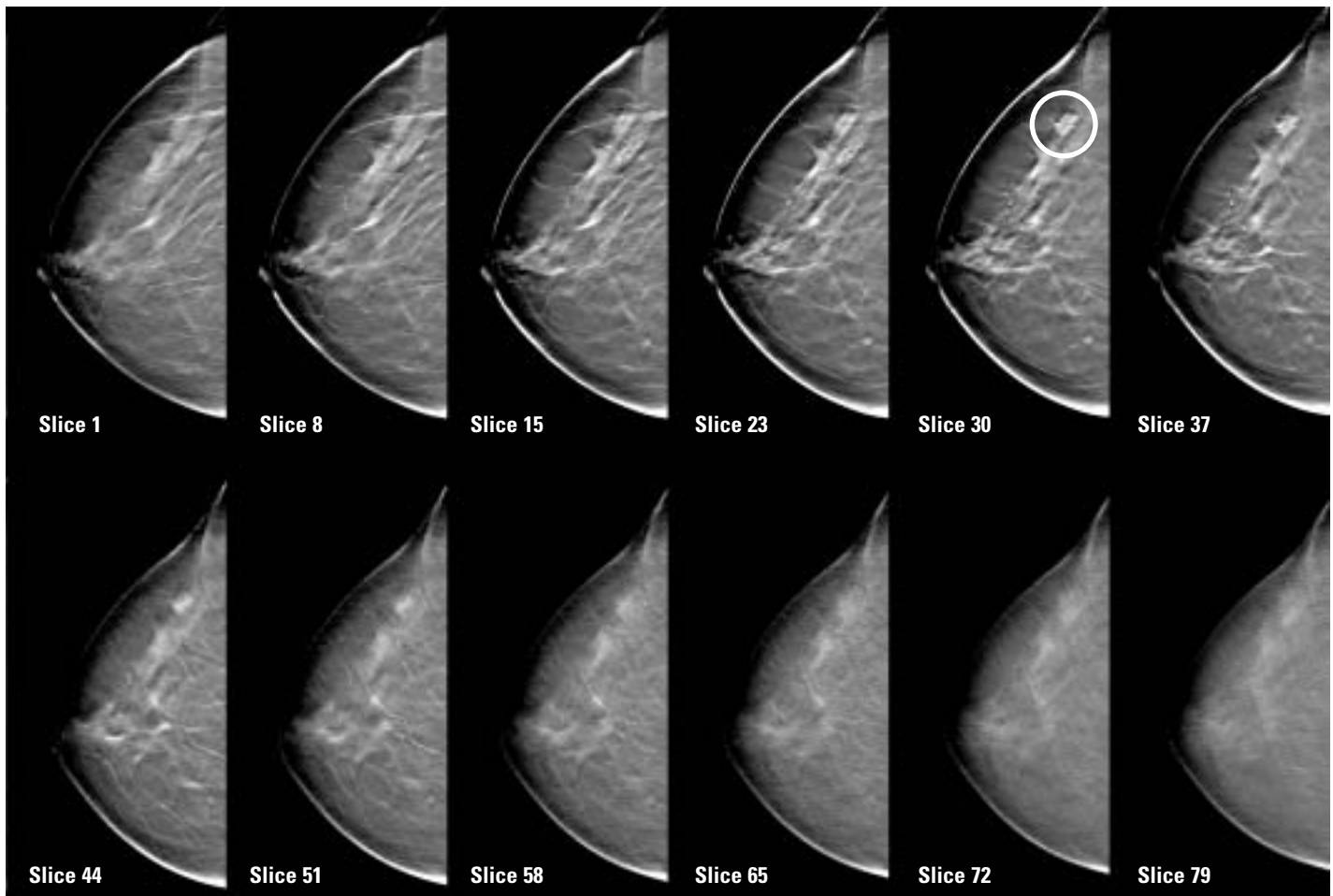
If reduced breast compression is used, the x-ray energies may need to be raised so as to more efficiently penetrate the thicker breasts. In this case, it is important that the image receptor maintain its high quantum efficiency at the higher energies. Cesium iodide, with poor absorption at higher kV, may not be the optimal detector material. A selenium-based detector does not have this limitation as its k-edge is below the mammographic energy range.

### *Contrast Enhanced Imaging*

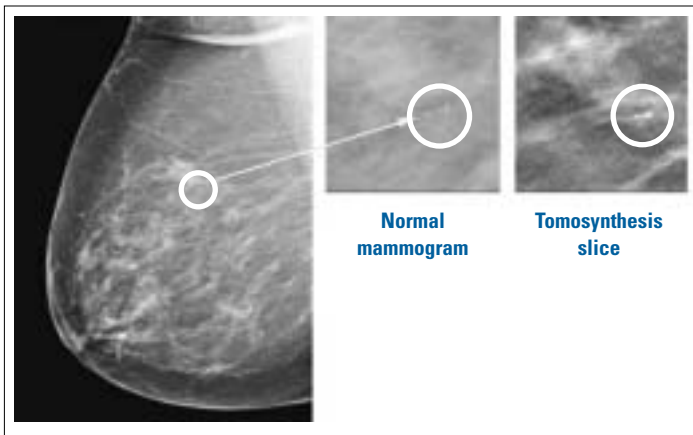
Researchers have studied mammography using IV-administered iodinated contrast agents. Using either dual energy or pre- and post-contrast imaging, they have observed enhancement of otherwise occult cancers and differentiation of benign from malignant tumors. While this research is still in its infancy, contrast enhanced tomosynthesis images might offer even greater malignant tumor to background uptake than observed with the 2-D contrast imaging, and could conceivably supplant MRI gadolinium breast imaging.



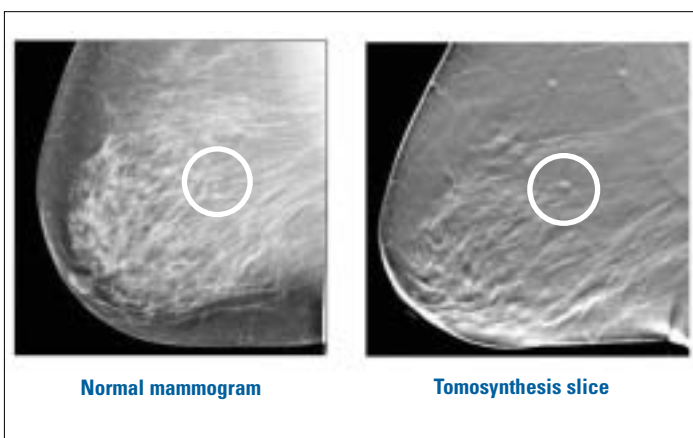
**Figure 6a:** Tomosynthesis slices are reconstructed parallel to the plane of the digital image receptor.



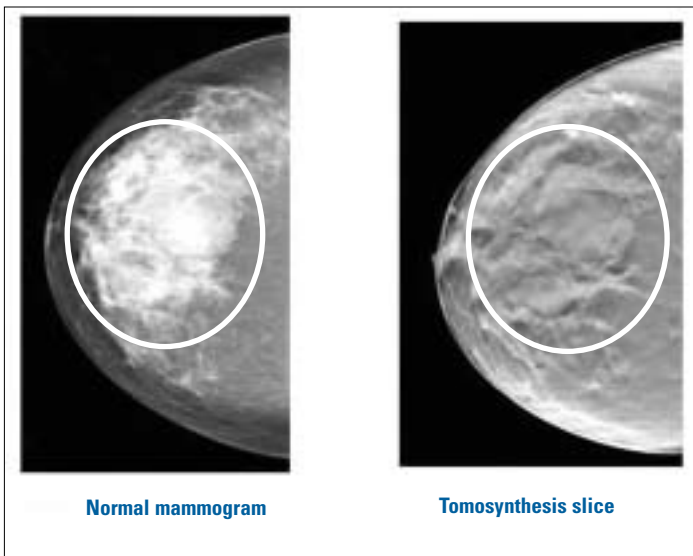
**Figure 6b:** Reconstructed tomosynthesis slices. An invasive lobular carcinoma can be clearly seen in slice 30.



**Figure 7:** This image illustrates the improved contrast for visibility of microcalcifications



**Figure 8:** Seeing through tissue clutter



**Figure 9:** Tomosynthesis may improve the visibility of margins

### Clinical Tomosynthesis Examples

Figure 6 illustrates the display geometry and shows a set of reconstructed tomosynthesis slices, displayed every 7 mm, in planes parallel to the image receptor. An invasive lobular carcinoma can be clearly seen in slice 30.

Figure 7 illustrates an example whereby the contrast of a set of microcalcifications was improved using tomosynthesis.

Figure 8 shows that tomosynthesis imaging improves the visibility of structures that might be otherwise missed. In this example, a spiculated mass is visible in the appropriate tomosynthesis slice but not visible in the mammogram.

Figure 9 illustrates how tomosynthesis can reduce tissue overlap and image confusion due to superimposed parenchyma. In this example, the patient was called back for diagnostic mammography because of asymmetry. The structures were persistent enough to warrant biopsy with a final benign. The tomosynthesis slices do not show anything suspicious enough to warrant biopsy.

### Desired Tomosynthesis System Specifications

These specifications represent a design goal for a tomosynthesis system.

- 10 second scan over  $\pm 15^\circ$  range
- Detector and acquisition geometry to maximize field of view
- Rapid reconstruction of thin slices separated by 1 mm
- Total radiation dose similar to or less than conventional mammography imaging
- High DQE detector to minimize noise
- Large field-of-view detector to accommodate all sizes of breasts
- Breast compression no greater than conventional mammography

### Conclusions

Tomosynthesis offers the possibility of revolutionizing mammography. In particular, tomosynthesis may offer the following potential benefits:

- Elimination of overlapping tissues
- Better cancer detection
- Fewer recalls
- Fewer biopsies
- Less dose
- Less painful compressions
- Faster review

## References

- Dobbins JT III and Godfrey DJ. "Digital x-ray tomosynthesis: current state of the art and clinical potential," *Phys. Med. Biol.* 2003 Oct 7; 48(19):R65-106.
- Jong RA, Yaffe MJ, Skarpathiotakis M, et al. "Contrast-enhanced digital mammography: initial clinical experience." *Radiology.* 2003 Sep; 228(3): 842-50.
- Newman L, "Developing technologies for early detection of breast cancer: a public workshop summary." Washington, D.C.: Institute of Medicine and Commission on Life Sciences National Research Council, 2000.
- Niklason LT, Christian BT, Niklason LE, Kopans DB, et al. "Digital tomosynthesis in breast imaging." *Radiology.* 1997 Nov; 205(2): 399-406.
- Smith A, Hall PA, Marcello DM. "Emerging technologies in breast cancer detection." *Radiology Management.* July-August 2004; 16-27.

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