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 cine mode. Figure 1 displays an example tomosynthesis slice showing a spiculated lesion.

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 of interest. Tomosynthesis is a 3-D method of imaging that can reduce or eliminate the tissue overlap effect. While holding the breast stationary, x-rays are acquired at a number of different view angles. The final step in the tomosynthesis procedure is reconstructing the data to generate images that enhance objects from a given height by appropriately positioning 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 unifies the input object and reduces the contrast of the displaced object by blurring it out. Similarly, tomosynthesis offers the possibility of revolutionizing mammography. In particular, tomosynthesis may offer the following potential benefits:

- Elimination of overlapping tissues
- Better cancer detection
- Power scallops
- Preventing overlap
- Less painful compressions
- Faster review

The final step in the tomosynthesis procedure is reconstructing the data to generate images that enhance objects from a given height by appropriately positioning the projections relative to one another. In Figure 3, the final step is the tomosynthesis procedure, in which the data are reconstructed to generate images that enhance objects from a given height. The process of tomosynthesis 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 cine mode. Figure 1 displays an example tomosynthesis slice showing a spiculated lesion.
Tube motion

Tube motion

Digital detector
Breast platform
Compression plate

Tube motion

Digital detector
Breast platform
Compression plate
Reconstructed planes
Tube motion

Figure 5: Tomosynthesis acquisition geometry showing the direction of motion of the x-ray source, and the orientation of the breast platform.

There are two 3D tomosynthesis system designs, which differ in the manner of the detection during acquisition. One method moves the detector in concert with the x-ray tube, while the other leaves the detector stationary and turns on the x-ray tube.

The breast is compressed in a standard way. While holding the breast stationary, the x-ray tube is rotated over a limited angular range. For these, a tomosynthesis system can be integrated into an existing mammography system by having individual calcifications appear in different slices.

Image Reconstruction

The tomosynthesis reconstruction process consists of computing cross-sectional images whose planes are parallel to the breast support plates. Typically, these images are reconstructed with shearing at a range of 1 mm, with a 5 mm composite slice thickness. The tomosynthesis slice study will have 50 to 100 slices for a rapid reconstruction time. Rapid reconstruction time is usually, especially when tomosynthesis is considered as part of a routine mammography study, and for this reason it is important to keep the entire reconstruction process up 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 cine loop. The original tomosynthesis projection data may not be readable as conventional projection mammograms, although an equivalent or similar test view, and these can be viewed as well, if desired. The reader should also be able to take a normal mammogram under the same conditions, and in this case the tomosynthesis data and the mammograms are completely coregistered allowing the correlation between objects in the two different image sets.

Figure 6b: Tomosynthesis slices are reconstructed parallel to the plane of the x-ray source.

Potential Clinical Benefits

Reduced Dose
Fewer Biopsies
Reduced Recalls
Improved Cancer Detection

Tomosynthesis should resolve many of the time-consuming problems that are a major source of the need for recall and additional imaging in 2-D mammography exams. The biopsy upon should also decrease through improved visualization of suspect objects. Some pathologies that are mammographically occult will be delineated through the elimination of structure noise. Tomosynthesis may also allow improved detection of cancers in women with heterogeneously dense breasts.

Figure 6a: Tomosynthesis slices

Figure 6b: Tomosynthesis slices are a great addition to the images of the breast tissue. In slice 30, the invasive lobular carcinoma can be clearly seen.

Figure 6c: Tomosynthesis slices are blurred out perpendicularly to the plane of the x-ray source.

Because the images are produced with reduced time exposure and higher image density, objects are expected to be visualized with improved clarity. This will likely lead to faster reader and more confident readings.

Reduced Compression Pressure

In conventional mammography, breasts are highly compressed to allow improved detection of smaller lesions. In tomosynthesis imaging, breasts are compressed only to the point where the lesion strikes the detector at all angles of acquisition, to avoid blurring the image. If reduced breast compression is used, the x-ray energies may need to be raised so as to more efficiently penetrate the breast. In this case, it is important that the image receptor maintain high quantum efficiency and high native resolution. Costumes, with poor absorption at higher kV, may not be the optimal detector material. A sensitive detector with high absorption at the radiation energy is needed.

Figure 6c: Tomosynthesis slices are blurred out perpendicularly to the plane of the x-ray source.
Tomosynthesis imaging consists of a series of low dose exposures, with every exposure about 10% of a normal single-view mammogram. Because each exposure is low dose, it is possible that the image is of high quantum efficiency and low noise. Because images are being acquired at a rate of about one per second, rapid imaging is another requirement. Solenoid-based image receptors, with their High Detective Quantum Efficiency (DQE), greater than 95% x-ray absorption, are used extensively to demonstrate tomosynthesis systems.

Field of View
Field of view is another important requirement. If the breast does not completely fit in the detector it will not be possible to acquire a full field mammographic image. Many tomosynthesis systems use a combined detector in the initial investigation is ideal because it has the largest field of view of any commercial detector. Additionally, as seen in Figure 5, the system must ensure that the shadow of the breast in the detector or all angles of acquisition, to avoid further reducing the field of view.

Equipment Geometry
Many conventional digital mammography systems have a rotation axis near the breast. For those, tomosynthesis systems must be designed with minimal change to the systems already in place. If the tube rotates continuously, x-ray tube and detector are used to avoid blurring the image. If not, a stop at each angular location before turning on the x-rays, otherwise blurring will be present. With additional motion, scan speed must be slow enough, or each x-ray exposure short enough, to avoid image blurring due to local motion.

The angular range and number of exposures acquired during the scan are all variables that need to be optimized. For a fixed angular range, more exposures will result in smaller field of view with fewer artifacts. This must be balanced against the fact that the output for a total mammography system remains the same for each of the individual shots. For sufficiently small exposures, image receptor noise will dominate the image and degrade reconstructed image quality. Regardless of the angular range, a large number of exposures may result in reconstructed slice disposition, where smaller angular ranges mean more motion in focus to get the desired increased separation might be needed for resolving two closely lying structures, but bringing the acquisition of a characterizing artifact is not possible with individual calculations artifact of the detector.

Tomosynthesis System Requirements

Detector Efficiency and Dose
Tomosynthesis imaging requires a series of low dose exposures, with every exposure about 10% of a normal single-view mammogram. Because each exposure is low dose, it is possible that the image is of high quantum efficiency and low noise. Because images are being acquired at a rate of about one per second, rapid imaging is another requirement. Solenoid-based image receptors, with their High Detective Quantum Efficiency (DQE), greater than 95% x-ray absorption, are used extensively to demonstrate tomosynthesis systems.

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Tomosynthesis is shown in Figure 6. 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 45°, and 11 exposures are made every 4° during a total scan of 80°. Digital images are projections through the breast at different angles and there are no X-ray detectors. Normally the breast would be placed in the MLO or CC view, although the tomosynthesis system should support the ability to acquire images in any desired orientation.

There are two tomosynthesis system designs, which differ in the motion of the detector during acquisition. One method moves the detector in an arc with the x-ray tube, so as to maintain the shadow of the breast on the detector. An alternate method is to hold 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 can intrude the entire breast tissue in all angles. Moreover, the design of tomosynthesis systems is the motion of the x-ray source during acquisition. A typical x-ray tube may rotate in a continuous or stationary manner. If the tube rotates continuously, a short x-ray pulse is used to avoid blurring the image. If rapid scanning is used, the rotation of the x-ray tube should be slow enough to reduce blur. Typically, at a rate of about one per second, rapid imaging is another possibility to acquire a full field tomosynthesis image. The angular range and number of exposures acquired might be desired for resolving two closely lying structures, increased separation with slice separation, where smaller angular ranges will keep more structures in focus to detect. Increased separation might be needed for resolving two closely lying structures, but may increase the amount of movement at resolutions.

Field of View

Field of view is an important requirement. If the breast does not completely fit on the detector it will not be possible to acquire a full field tomosynthesis image. A digital mammography system will be limited in the initial investigation is ideal because it has the largest field of view for a conventional detector. Additionally, as seen in Figure 5, the system must ensure that the shadow of the breast is in focus for all angles of acquisition, to avoid further reducing the field of view.

Equipment Geometry

Many conventional digital mammography systems have a rotation axis near the breast. For these, a tomosynthesis system may be designed with minimal changes in the x-ray tube. The entire digital mammography gantry, and could even be designed as an add-on unit. If mechanical changes are minimal, existing hardware, such as paddles, might be usable as is, with continuous motion, scan speed must be slow enough, or each x-ray exposure sheet short enough, to avoid image blurring due to local motion.

Tube motion

The tomosynthesis reconstruction process consists of combining the original images whose planes are parallel to the breast plane. Typically, these images are reconstructed with a sigma of 1.5 mm, since a 3-D reconstructed slice might be needed for localized lesion detection. The reconstruction algorithm is highly relevant, but for this study it is important to keep the entire breast imaged within 30 seconds or less.

Image Reconstruction

Tomosynthesis imaging can involve two acquisition geometries: Computed Tomosynthesis (CT) and Digital Tomosynthesis (DT). In tomosynthesis imaging, 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 45°, and 11 exposures are made every 4° during a total scan of 80°. Digital images are projections through the breast at different angles and there are no X-ray detectors. Normally the breast would be placed in the MLO or CC view, although the tomosynthesis system should support the ability to acquire images in any desired orientation.

Tomosynthesis System Requirements

Tube motion

Tube motion

Tomosynthesis imaging consists of a series of low-dose exposures, with every exposure about 1% of a normal view mammogram. Because such exposures are low, 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. Solid-state based image sensors, 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.

Tomosynthesis Imaging Applications

Tomosynthesis imaging can be used to reduce the need for multiple views of the same breast. Because the images do not have to be taken together, the images do not have to be time sensitive. Because of this, a single tomosynthesis acquisition, in the MLO view orientation, may be all that is required. In addition, less additional image acquisition is required because of the reduced total dose. This is an important advantage since patient dose will vary and less tomosynthesis images might offer a more convenient approach. Tomosynthesis imaging can be used to reduce the need for multiple views of the same breast. Because the images do not have to be taken together, the images do not have to be time sensitive. Because of this, a single tomosynthesis acquisition, in the MLO view orientation, may be all that is required. In addition, less additional image acquisition is required because of the reduced total dose. This is an important advantage since patient dose will vary and less tomosynthesis images might offer a more convenient approach.

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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 painful examinations
- Faster review

References

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Andrea Smith, PhD, is principal scientist at Hologic, Inc. in Bedford, Mass, where he received a bachelor and doctoral degrees in physics. He attended the Massachusetts Institute of Technology, where he received a bachelor and doctoral degree in physics.

Digital breast tomosynthesis offers a number of exciting opportunities including the possibility of reduced breast compression, improved diagnostic and screening accuracy, 3-D breast 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 summarises the initial results from a scientific investigation of breast tomosynthesis using a full field digital mammography system.
Clinical Tomosynthesis Example

Figure 9 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 this view.

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 parenchymal tissue. In this example, the tumor was the only focal lesion. For diagnostic mammography because of asymmetry, the structures were more consistent with mammography biopsy.

Tomosynthesis System Specifications

These specifications represent a design goal for a mammography system.

• 50.8 cm (20") field of view
• 13-degree x-ray source range
• Detector and acquisition geometry to maximize field of view
• Rapid repositioning of this plane separated by 1 mm
• Total radiation dose similar to or less than conventional mammography
• High DQE detector to minimize noise
• Large field of view detector to accommodate all sizes of breasts
• Breast compression no greater than conventional mammography
• Total radiation dose similar to or less than conventional mammography

Conclusion

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 patient discomfort
• Faster review

References


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Andrew Smith, Ph.D. This “white paper” is one in a series of review overviews on advanced technologies in women’s imaging. For copies of other white papers in the white paper series, contact Marketing at Hologic.com.

Introduction

Breast tomosynthesis is a 3-dimensional imaging technology that involves acquiring images of a stationary compressed breast at multiple angles during a single scan. The individual images are then reconstructed within a curve of thin high-resolution slices that can be displayed individually to create a dynamic curve. Figure 1 illustrates an example tomosynthesis slice showing a spiculated breast.

Reconstructed tomosynthesis slices can eliminate the problems caused by tissue overlap and structure noise in single 2-D mammographic imaging.

Digital breast tomosynthesis offers a number of exciting features including the possibility of reduced breast compression, improved diagnostic and screening accuracy, 3-D breast 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 system.

Conventional x-ray mammography is a 2-D 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 detection is localized to a location on the film cassette or digital detector. In tomosynthesis scanning, all of the tissues through the location of interest are visualized simultaneously, regardless of the distance from the detector.

Tomosynthesis is a 3-D method of imaging that can reduce or eliminate the tissue overlap effect. While holding the breast stationary, an image is 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 source is at 0º but at the ±15º acquisition angles, the objects’ shadows relative to one another is in the images.

The field of view in the tomosynthesis protocol is reconstructed to generate images that enhance objects from a given height by appropriately adjusting the projections relative to one another. In figure 3, images in the left column are summed, shifting one relative to another in a specific way. This shift mimics the motion of the detector and reduces the amount of the displaced object by blurring it out. Similarly.

Dr. Andrew Smith, Ph.D. The "white paper" is one in a series of review overviews on advanced technologies in women’s imaging. For copies of other white papers in the white paper series, contact marketing@hologic.com.