Digital Breast Tomosynthesis: Observer Performance of Clustered Microcalcification Detection on Breast Phantom Images Acquired with an Experimental System Using Variable Scan Angles, Angular Increments, and Number of Projection Views¹

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Purpose:

To investigate the dependence of microcalcification cluster detectability on tomographic scan angle, angular increment, and number of projection views acquired at digital breast tomosynthesis (DBT).

Materials and Methods:

A prototype DBT system operated in step-and-shoot mode was used to image breast phantoms. Four 5-cm-thick phantoms embedded with 81 simulated microcalcification clusters of three speck sizes (subtle, medium, and obvious) were imaged by using a rhodium target and rhodium filter with 29 kV, 50 mAs, and seven acquisition protocols. Fixed angular increments were used in four protocols (denoted as scan angle, angular increment, and number of projection views, respectively: 16°, 1°, and 17; 24°, 3°, and nine; 30°, 3°, and 11; and 60°, 3°, and 21), and variable increments were used in three (40°, variable, and 13; 40°, variable, and 15; and 60°, variable, and 21). The reconstructed DBT images were interpreted by six radiologists who located the microcalcification clusters and rated their conspicuity.

Results:

The mean sensitivity for detection of subtle clusters ranged from 80% (22.5 of 28) to 96% (26.8 of 28) for the seven DBT protocols; the highest sensitivity was achieved with the 16°, 1°, and 17 protocol (96%), but the difference was significant only for the 60°, 3°, and 21 protocol (80%, $P < .002$) and did not reach significance for the other five protocols ($P = .01-.15$). The mean sensitivity for detection of medium and obvious clusters ranged from 97% (28.2 of 29) to 100% (24 of 24), but the differences fell short of significance ($P = .08$ to $>.99$). The conspicuity of subtle and medium clusters with the 16°, 1°, and 17 protocol was rated higher than those with other protocols; the differences were significant for subtle clusters with the 24°, 3°, and nine protocol and for medium clusters with 24°, 3°, and nine; 30°, 3°, and 11; 60°, 3°, and 21; and 60°, variable, and 21 protocols ($P < .002$).

Conclusion:

With imaging that did not include x-ray source motion or patient motion during acquisition of the projection views, narrow-angle DBT provided higher sensitivity and conspicuity than wide-angle DBT for subtle microcalcification clusters.

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The sensitivity of mammography is limited by the presence of overlapping fibroglandular tissue that may obscure the lesions in the breast. Digital breast tomosynthesis (DBT) is a limited-angle tomography technique in which high-resolution image sections can be reconstructed parallel to the detector plane but with limited resolution along the depth direction (1). It has been shown that DBT increases the detectability of subtle soft-tissue lesions and reduces recall rates by reducing the overlapping breast tissues in a number of retrospective observer studies (2–4) and prospective clinical trials in screening (5–7) or diagnostic (8) settings when DBT is used in combination

with full-field digital mammography (FFDM). Other investigators have studied whether one- or two-view DBT can replace two-view FFDM rather than be used as an adjunct (9–12). However, it is still unknown whether the detectability of microcalcifications in DBT can be as high as that with FFDM, with studies yielding conflicting results (2,13–15). Various methods have been studied to improve the detection of microcalcifications in DBT, including the use of FFDM in combination with one- or two-view DBT, the synthesis of an FFDM-like image to replace the directly acquired FFDM (16), the development of computer-aided detection methods for DBT (17–24), and the enhancement of the visibility of microcalcifications by improving reconstruction and image-processing methods (25–29).

It is known that the visibility of lesions in DBT depends strongly on the image acquisition parameters, including the tomographic scan angle, the angular increment, and the number of projection views, in addition to other factors that affect the image quality of x-ray imaging systems. The visibility of breast lesions also depends on the physical properties of the lesions. Soft-tissue masses and architectural distortion occur over a relatively large area and detection is limited by image contrast, whereas microcalcifications are relatively small and detection is limited by resolution. Structured noise and random noise also play an important role in both detection tasks. The best combination of the DBT scan parameters for each type of lesion is still being investigated. Studies involving simulation and modeling (30–34) or experimental measurement and observation (35–38) were performed to evaluate the effect of these parameters on image quality.

The purpose of this study was to investigate the dependence of

microcalcification cluster detectability on tomographic scan angle, angular increment, and number of projection views acquired with DBT (39).

Materials and Methods

S.Z. and A.S. are employees of GE Global Research, but their efforts in this project were supported by subcontracts from the University of Michigan National Institutes of Health grants RO1 CA151443 and RO1 CA091713. H.P.C. had control of the data and information submitted for publication.

DBT System

A prototype DBT system (GEN2; GE Global Research, Niskayuna, NY) was used to perform DBT scans (Fig 1). The system has a rhodium target and rhodium filter x-ray source and a stationary cesium iodide phosphor and amorphous silicon active matrix flat-panel digital detector with a matrix size of 1920×2304 pixels and a pixel pitch of 0.1×0.1 mm. The system uses a step-and-shoot design to minimize potential motion blurring of the focal spot during x-ray exposure.

An advanced mode was installed in the prototype DBT system. The advanced mode allows the user to select

Advances in Knowledge

- With imaging that did not include x-ray source motion or patient motion during acquisition of the projection views, narrow-angle digital breast tomosynthesis (DBT) provided higher detection sensitivity and conspicuity than wide-angle DBT for subtle microcalcification clusters; the sensitivity of detecting subtle microcalcification clusters with narrow-angle DBT was significantly higher than that with wide-angle DBT (96% [26.8 of 28] vs 80% [22.5 of 28], $P < .002$).
- Interplane artifacts of structured background in DBT acquired with a narrow tomographic angle do not have a strong effect on the detectability of microcalcification clusters in breast phantoms.
- A DBT system that allows imaging of the same set of simulated microcalcification clusters with variable tomographic angles, angular increments, and number of projections is useful for direct comparison of image quality and detectability without other confounding factors, such as differences in the case sets and the mechanical design and image detector of the DBT systems.

Implication for Patient Care

- The understanding of the effect of acquisition parameters on detection of microcalcifications will help optimize the design and the performance of DBT systems.

Published online before print

10.1148/radiol.14132722 Content code: BR

Radiology 2014; 273:675–685

Abbreviations:

DBT = digital breast tomosynthesis

FFDM = full-field digital mammography

Author contributions:

Guarantor of integrity of entire study, H.P.C.; study concepts/study design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important intellectual content, all authors; approval of final version of submitted manuscript, all authors; literature research, H.P.C., J.W.; experimental studies, M.A.H., C.P., C.H.N., H.P.C., M.M.G., S.Z., A.S., M.A.R., A.V.N., P.C.; statistical analysis, H.P.C., A.S., J.W.; and manuscript editing, H.P.C., M.M.G., M.A.H., A.S., M.N., C.P., M.A.R., A.V.N., C.H.N., P.C., Y.L., L.H., J.W.

Funding:

This research was supported by the National Institutes of Health (grants RO1 CA151443 and RO1 CA091713).

Conflicts of interest are listed at the end of this article.

input parameters, including the tomographic scan angle, constant or variable angular increments between the projection views, and the number of projection views for a given scan. The kilovoltage and total tube current–time product for the scan can also be chosen over a wide range. The total tube current–time product is divided evenly among the projection views.

Breast Phantoms

Six slabs of 1-cm-thick heterogeneous breast-tissue–mimicking material (CIRS, Norfolk, Va) were used (Fig 2) to construct breast phantoms. By using five of the six slabs and arranging them in different orders and orientations, we constructed four different 5-cm-thick phantoms. Simulated calcifications (CIRS) consisting of calcium carbonate particles of three nominal speck size ranges were used to form clusters with three visibility levels (subtle, 0.15–0.18 mm; medium, 0.18–0.25 mm; and obvious, 0.25–0.30 mm). The four phantoms contained a total of 81 clusters, of which 28 were subtle, 29 were medium, and 24 were obvious, and they were randomly sandwiched between the slabs in each phantom.

DBT Acquisition Parameters

DBT scans of the breast phantoms were performed with different combinations of acquisition parameters, which included the scan angle and the number of projection views acquired with constant or variable angular increments. For simplicity, we refer to each combination as a DBT protocol.

To keep the interpretation time reasonable, the number of protocols to be compared in the observer experiment had to be limited. Two medical physicists (H.P.C. and M.M.G.), each with more than 25 years of experience in mammography, selected a few protocols from the many possible combinations by visually comparing phantom images obtained with a number of protocols. We observed that imaging with too many projection views with the chosen exposure technique would result in very noisy images, while

large angular increments and too few projection views could result in streaking or ripple artifacts on the reconstructed sections. For variable angular

increments, we compared two major groups: one with small increments at small projection angles and larger increments at large projection angles, the

Figure 1

Figure 1: Photograph shows the prototype DBT system used in this study. The phantom is shown under the compression paddle.

Figure 2

Figure 2: Photograph shows six slabs of 1-cm-thick breast-shape heterogeneous breast-tissue–mimicking material (CIRS) used to construct breast phantoms. Four different 5-cm-thick phantoms were formed by using five of the six slabs arranged in different orders and orientations.

Table 1

Seven Protocols for Breast Tomosynthesis Acquisition Selected for This Study

Protocol	Total Tomographic Scan Angle (degrees)	Angular Increment or Projection Angles Used (degrees)	No. of Projection Views Acquired
Fixed angular increments			
16°, 1°, 17	16	1*	17
24°, 3°, nine	24	3*	9
30°, 3°, 11	30	3*	11
60°, 3°, 21	60	3*	21
Variable angular increments			
40°, variable, 13	40	0, ±1, ±3, ±6, ±10, ±15, ±20†	13
40°, variable, 15	40	0, ±2, ±4, ±6, ±8, ±10, ±15, ±20†	15
60°, variable, 21	60	0, ±2, ±4, ±6, ±8, ±10, ±14, ±18, ±22, ±26, ±30†	21

* Numbers are angular increments.

† Numbers are projection angles.

other with large increments at small projection angles and smaller increments at large projection angles. We observed that, for similar scan angle and number of projection views, the visual quality of microcalcifications, such as sharpness and contrast in the latter group, was generally inferior to that in the former group. We therefore only selected protocols from the former group for this study. After the preliminary comparison, we selected seven protocols, including four protocols with fixed angular increments and three protocols with variable angular increments (Table 1). For the protocols with fixed increments, the scan angle was varied from a range of 16° to 60°, which approximately covered the scan angles of the prototype DBT systems being developed and the commercial DBT system in clinical use.

By using the same compression, each phantom was imaged for all seven protocols with the advanced mode. The phantom configuration, thickness, and positioning were therefore identical among the seven acquisitions. All scans were performed with the same exposure technique, rhodium target and rhodium filter, 29 kV, and 50 mAs, which was estimated to produce a mean glandular dose (approximately 1.1 mGy) similar to a single-view FFDM for a 5-cm-thick 50% glandular and 50% adipose-tissue breast by

using the standard dose mode with our clinical FFDM systems (GE Essential; GE). For a given protocol, all four phantoms were imaged with the same exposure conditions. All DBT images were reconstructed by using a simultaneous algebraic reconstruction technique with two iterations and a relaxation parameter of 0.5 in the first iteration and 0.3 in the second iteration (40). The reconstructed sections were parallel to the detector plane, and the section spacing was fixed at 1 mm. The pixel dimensions on the reconstructed sections were kept the same as the pixel pitch at 0.1 × 0.1 mm.

A contact x-ray image of one of the 1-cm-thick slabs was acquired as a reference to which the corresponding reconstructed DBT sections from the different DBT protocols were compared. Figure 3a–3d shows a 12 × 12-cm region of interest from the DBT section of the same 5-cm-thick phantom scanned with the four protocols (denoted as tomographic scan angle, angular increment, and number of projection views acquired): 16°, 1°, and 17; 24°, 3°, and nine; 40°, variable, and 13; and 60°, 3°, and 21, respectively. Figure 3e shows the same region of interest from the contact x-ray image of the slab containing the sections in Figure 3a–3d. The influence of the DBT acquisition

parameters on the appearance of the background structures can be observed by comparing the images.

Observer Study

The reconstructed DBT volumes were displayed with an in-house-developed interface on a 21-inch 5-megapixel (2048 × 2560) liquid-crystal display monitor (model EIZO SMD 21500 D; contrast ratio, 800:1; maximum luminance, 750 cd/mm²). The monitor was calibrated with the Digital Imaging and Communications in Medicine gray-scale standard display function. The display monitor was similar to those used with clinical FFDM workstations. Six breast radiologists (M.A.H., M.N., C.P., M.A.R., A.V.N., C.H.N.) participated as observers. Their experience in mammography ranged from 5 to 25 years. Five of the six radiologists had previous experience in interpreting DBT images obtained in human subjects with our prototype system, acquired with a fixed protocol (60° scan angle, 3° increment, and 21 projection views acquired). Before the observer experiment, each radiologist was shown five training DBT scans of phantoms embedded with simulated microcalcification clusters that were not a part of the test set. The radiologists were given instructions for marking and rating the clusters by using the user interface of the display workstation. The radiologists were informed that there were multiple clusters with a range of visibility at multiple sections in each phantom, but they were not told the total number of clusters. They were asked to use the cursor to mark every location where they considered a cluster to be present and provide a conspicuity rating of the cluster on a scale of 1 to 10 (10 being most conspicuous).

The order of the 28 DBT volumes (four phantoms × seven acquisition protocols) interpreted by each radiologist was randomized with two constraints: (a) DBT volumes from the same phantom but different scan protocols were separated as far as possible and (b) no two DBT volumes scanned with the same protocol were adjacent

Figure 3

Figure 3: (a–d) DBT sections from a 5-cm-thick breast phantom imaged with four of the DBT scan protocols: 16°, 1°, and 17; 24°, 3°, and nine; 40°, variable, and 13; and 60°, 3°, and 21, respectively. (e) A two-dimensional projection x-ray image is shown of the 1-cm-thick slab that intersected the sections in a–d. If there is no interplane blurring, the dense tissue distribution in a–d should be similar to or even slightly cleaner than that in e, which is a superimposition of all overlapping structures inside the 10-mm-thick slab. Images a–d show that the larger the scan angle, the more similar the dense tissue distribution on the DBT sections is to that on the two-dimensional image. The additional dense tissue structures seen on the DBT sections resulted from interplane blurring from the other slabs sandwiching this slab.

to each other. The reading order of DBT volumes was different for each radiologist and was counterbalanced so that certain DBT volumes would not always be interpreted in the same order (eg, first or last) by all radiologists. The reading time was unlimited.

The significance of the difference in the sensitivity and conspicuity ratings was estimated by using Student two-tailed paired *t* tests (Microsoft Office Professional Plus 2010; Microsoft, Redmond, Wash) between pairs of the DBT protocols. *P* values less than .0024 (.05/21 with Bonferroni adjustment) were considered to indicate a significant difference.

The differences in the appearances of the microcalcifications relative to the background structures due to DBT

acquisition parameters were evaluated by means of visual comparison of the clusters on the reconstructed DBT sections from the different protocols.

Results

The mean and standard deviation of the sensitivity for detecting each group of clusters estimated from the readings of the six radiologists with the seven protocols are tabulated in Table 2. The rows are arranged from the highest to the lowest mean sensitivity for the group of subtle clusters. The last column shows the overall sensitivity of detecting the clusters in all three size groups. The mean sensitivities for detecting the subtle clusters and for all clusters are plotted in

Figure 4. The total number of false-positive marks indicated by the six radiologists ranged from nine to 22 for the seven conditions.

For the detection of subtle clusters by using the seven DBT protocols, the sensitivities varied over a relatively wide range, with the standard deviations ranging from about 7% to 14% (Table 2, Fig 4). The DBTs acquired with a narrow angle and small increment (16°, 1°, and 17) provided the highest sensitivity (96% [26.8 of 28]), while the DBTs acquired with a wide angle and larger increment (60°, 3°, and 21) had the lowest sensitivity (80% [22.5 of 28]). The sensitivities of the 16°, 1°, and 17; 40°, variable, and 15; and 24°, 3°, and nine protocols were significantly higher than that of the

Table 2

Sensitivity for Detection of Simulated Microcalcification Clusters with Three Levels of Subtlety, Averaged over Six Radiologists

DBT protocol	Subtle (<i>n</i> = 28) (%)	Medium (<i>n</i> = 29) (%)	Obvious (<i>n</i> = 24) (%)	All (<i>n</i> = 81) (%)
16°, 1°, 17	95.7 ± 6.6 (26.8/28) [85.7–100]	100.0 ± 0.0 (29.0/29) [100–100]	99.2 ± 1.7 (23.8/24) [95.8–100]	98.4 ± 2.6 (79.7/81) [95.1–100]
40° variable, 15	92.1 ± 6.9 (25.8/28) [82.1–100]	99.3 ± 1.4 (28.8/29) [96.6–100]	100.0 ± 0.0 (24.0/24) [100–100]	97.2 ± 2.7 (78.7/81) [93.8–100]
24°, 3°, nine	91.1 ± 7.7 (25.5/28) [78.6–100]	100.0 ± 0.0 (29.0/29) [100–100]	98.8 ± 2.2 (23.7/24) [95.8–100]	96.5 ± 2.4 (78.2/81) [92.6–98.8]
60° variable, 21	87.5 ± 12.1 (24.5/28) [67.9–100]	97.6 ± 2.8 (28.3/29) [93.1–100]	98.8 ± 3.4 (23.7/24) [91.7–100]	94.4 ± 4.5 (76.5/81) [88.9–100]
40° variable, 13	83.9 ± 14.4 (23.5/28) [64.3–96.4]	98.3 ± 1.9 (28.5/29) [96.6–100]	97.1 ± 5.0 (23.3/24) [87.5–100]	93.0 ± 5.4 (75.3/81) [86.4–98.8]
30°, 3°, 11	81.1 ± 11.7 (22.7/28) [60.7–92.9]	97.2 ± 3.4 (28.2/29) [93.1–100]	99.2 ± 1.7 (23.8/24) [95.8–100]	92.2 ± 4.9 (74.7/81) [84.0–97.5]
60°, 3°, 21	80.4 ± 6.7 (22.5/28) [67.9–85.7]	99.0 ± 1.8 (28.7/29) [96.6–100]	99.2 ± 1.7 (23.8/24) [95.8–100]	92.6 ± 2.7 (75.0/81) [87.7–95.1]

Note.—Data are means ± standard deviations. Numbers in parentheses are raw data. Numbers in brackets are ranges.

Figure 4

Figure 4: Graph shows mean sensitivities for detection of the subtle clusters and for all clusters, averaged over the six radiologists, for the seven DBT protocols. The labels of the abscissa indicate the parameters of the DBT protocols denoted in the following order: tomographic angle, angular increment, and number of projections.

60°, 3°, and 21 protocol ($P < .002$). The sensitivity of the 16°, 1°, and 17 protocol was higher than those of the other five protocols, but the differences did not reach significance ($P = .01$ – $.15$). For the detection of medium and obvious clusters, the sensitivities were relatively stable, ranging from 97% (28.2 of 29) to 100% (24 of 24), with a standard deviation of 0%–5%; the differences in the sensitivities did not achieve significance ($P = .08$ to $>.99$).

The trend of the conspicuity ratings of the subtle clusters generally followed that of the sensitivities; higher conspicuity led to higher sensitivity, except for the protocol 30°, 3°, and 11 (Table 3). For all clusters, the conspicuity ratings for the protocol with narrow angle and small increment (16°, 1°, and 17) were higher than those for the other six protocols (Fig 5), although most of the differences did not achieve significance at the level of $P < .0024$ with Bonferroni correction. For subtle microcalcification clusters, the conspicuity for the 16°, 1°, and 17 protocol was significantly higher than that for the 24°, 3°, and nine protocol ($P < .002$). For medium microcalcification clusters, the conspicuity for the 16°, 1°, and 17 protocol was rated

significantly higher than that for four of the protocols (24°, 3°, and nine; 60°, variable, and 21; 30°, 3°, and 11; and 60°, 3°, and 21 [$P < .002$]), but the differences fell short of significance for the 40°, variable, and 13 protocol and the 40°, variable, and 15 protocol ($P < .01$). The mean conspicuity of the clusters depended on their speck size as expected; the larger the specks, the higher the conspicuity. The range of mean conspicuity ratings of the same group of clusters among the seven DBT protocols was small, with the mean and the standard deviation of 3.01 ± 0.40 , 5.61 ± 0.48 , and 9.11 ± 0.09 , respectively, for the subtle, medium, and obvious groups.

Examples illustrating the conspicuity and the influence of the DBT acquisition parameters on the appearance of microcalcification clusters are shown in Figure 6. The images from the 16°, 1°, and 17 protocol have more obvious background structures, but the specks appear to be the sharpest and have the highest contrast, whereas the images from the 60°, 3°, and 21 protocol have the smoothest structured background, but they are noisier and the specks are less sharp and have lower contrast. The

Table 3

Conspicuity Ratings for Simulated Microcalcification Clusters with Three Levels of Subtlety, Averaged over Six Radiologists

DBT Protocol	Subtle	Medium	Obvious	All
16°, 1°, 17	3.83 ± 0.96 (2.54–5.21)	6.57 ± 1.03 (5.48–7.93)	9.27 ± 0.39 (8.71–9.75)	6.56 ± 0.76 (5.77–7.59)
40°, variable, 15	3.05 ± 1.22 (1.52–5.15)	5.85 ± 1.12 (4.69–7.76)	9.08 ± 0.40 (8.67–9.67)	5.99 ± 0.87 (5.08–7.52)
24°, 3°, nine	3.05 ± 0.97 (1.82–4.46)	5.44 ± 1.17 (4.00–7.00)	9.07 ± 0.53 (8.17–9.54)	5.86 ± 0.79 (4.81–6.99)
60°, variable, 21	2.84 ± 0.55 (2.25–3.48)	5.39 ± 0.94 (3.86–6.55)	9.18 ± 0.53 (8.33–9.67)	5.80 ± 0.57 (4.82–6.51)
40°, variable, 13	2.73 ± 0.68 (1.88–3.32)	5.56 ± 1.00 (3.93–6.50)	9.00 ± 0.48 (8.29–9.63)	5.76 ± 0.59 (4.70–6.29)
30°, 3°, 11	3.01 ± 1.33 (1.29–5.05)	5.14 ± 1.25 (3.26–6.93)	9.03 ± 0.49 (8.29–9.65)	5.73 ± 0.95 (4.56–7.21)
60°, 3°, 21	2.57 ± 0.66 (1.84–3.38)	5.28 ± 1.12 (3.79–6.64)	9.13 ± 0.63 (8.13–9.75)	5.66 ± 0.67 (4.60–6.51)

Note.—Data are means ± standard deviations. Numbers in parentheses are ranges. Conspicuity ratings ranged from 1 to 10, with 10 being most conspicuous.

dense structures in the background of the images obtained with the 24°, 3°, and nine protocol appear to be more prominent but less noisy than those in the other images. Compared with the images obtained with the 16°, 1°, and 17 protocol, the projection views at large angles in the other three protocols reduced the interplane artifacts (see also Fig 3). However, the visibility of the microcalcification clusters, measured as the conspicuity ratings in the observer study, is dominated by the contrast and sharpness of the objects rather than the complexity of the background structures within the protocols studied.

Discussion

For DBT, the sharpness of small targets, such as microcalcifications, is affected by many factors, in addition to the tomographic angle, angular increment, and number of projection views. The reconstruction from multiple projection views will have blurring due to the oblique incidence angle of the x-rays onto the detector (41,42) and the oblique angle at which an x-ray intersects a DBT section of substantial thickness. For DBT systems in which the x-ray source is designed to move continuously during the exposure, there is blurring caused by focal spot motion in addition to the geometric unsharpness due to the inherent focal spot size (43). The inaccuracies in the geometric parameters of the DBT system and/or the ray-tracing algorithm will also

introduce blurring on the reconstructed images (44,45). The long imaging duration required for multiple-projection image acquisition will increase the chance of patient motion. Finally, all factors that affect the image quality of the projection view mammograms and the reconstruction technique will also affect the reconstructed DBT images, of which the pixel pitch could have a major effect on small objects such as microcalcifications (38).

In our study, the DBT scans were performed with a prototype DBT system that operates in a step-and-shoot mode

and records projection views with a stationary detector. The breast phantom was also stationary. Therefore, all projection views were acquired without blurring due to these factors. The same geometric parameters and ray-tracing algorithm were used for all DBT reconstructions. The major differences in blurring among different DBT protocols were those caused by oblique incidence angle onto the detector and the reconstruction of 1-mm-thick DBT sections from oblique-angle projection views. The blurring from both factors increased with increasing scan angle.

Figure 5

Figure 5: Graph shows mean conspicuity ratings for the subtle clusters and for all clusters, averaged over the six radiologists, for the seven DBT protocols. The labels of the abscissa indicate the parameters of the DBT protocols denoted in the following order: tomographic angle, angular increment, and number of projections.

Figure 6

Figure 6: A–L, Images demonstrate examples of the clusters of the three speck size ranges, imaged with four different DBT protocols. Top row: subtle cluster (speck size range, 0.15–0.18 mm); middle row: medium cluster (speck size range, 0.18–0.25 mm); and bottom row: obvious cluster (speck size range, 0.25–0.30 mm). Protocols were as follows: left column, 16°, 1°, and 17; second column, 24°, 3°, and nine; third column, 40°, variable, and 13; and fourth column, 60°, 3°, and 21. Each cluster is shown in a region of interest with an area of 2×2 cm on the reconstructed DBT section where the cluster is in best focus.

Therefore, it can be expected that the DBT protocol involving the smallest scan angle (16°, 1°, and 17) provided the best visibility and detectability for subtle microcalcification clusters with our experimental conditions. To date, observations in clinical studies vary (2,13–15), probably because of the differences in the factors discussed earlier, as well as the small sample sizes used. Differences in the patient cohorts may also contribute to the differences observed in the different studies, but it will be difficult, if not impossible, to directly compare different DBT systems

in the same patient cases because of concerns about radiation exposure risk. By using the same phantoms and the same x-ray imaging system in our study, we were able to avoid many of these confounding factors and give a more definitive comparison of the effect of DBT acquisition parameters on the detectability of microcalcification clusters. Timberg et al (46), who used a prototype DBT system with a large scan angle (about 40°), also found that the detectability of digitally simulated calcifications in DBT was inferior to that in FFDM when imaged at the same

dose in a four-alternative forced-choice observer experiment, but they did not compare large-angle acquisition with small-angle acquisition.

It is known that the scan angle affects the blurring on the DBT section and the depth direction in opposite ways (30,33,37). A larger scan angle provides better depth resolution but lowers resolution on the DBT sections. This trade-off is consistent with our results; small-angle DBT is superior for imaging small objects that require high in-plane resolution, such as microcalcifications, while large-angle DBT is superior for reducing

the interplane artifact from overlapping fibroglandular tissue.

We have previously studied the effects of projection view distribution on spatial blurring and contrast-to-noise ratio of simulated microcalcifications in a phantom. In our previous study, the number of projection views was fixed, while the scan angle was varied (37). We observed the trend that the contrast-to-noise ratio of simulated microcalcifications was higher for small scan angles than for large scan angles, while the blurring along the x-ray source motion direction increased with increasing scan angle. The simulation study by Sechopoulos et al (33) showed that a protocol with a large scan angle (60°, 5°, and 13) had a much higher quality factor than the protocol with the small scan angle (16°, 1°, and 17), probably because their chosen quality measure emphasized the contrast-to-noise ratio and artifact spread function without considering the effect of blurring on the conspicuity and detectability of small objects. The simulation study by Reiser and Nishikawa (34) showed that detectability increased with increasing scan angle for objects larger than 0.5 mm in diameter, which is somewhat larger than the size range of microcalcifications of clinical interest. Their model did not include the effects of physical factors, such as detector blur and detector noise that may have a strong effect on small objects. Tucker et al (38) found that the in-plane resolution and contrast-to-noise ratio were insensitive to total scan angle and number of projection views for their stationary DBT system. Other investigators compared the detectability of masslike objects and found that large DBT scan angles were superior (31,32). Our recent observer study involving contrast-detail phantoms imaged with 12 protocols from the advanced-mode DBT system showed that observers had stronger preferences for DBT images acquired with larger scan angles for masslike objects (47).

This study had several limitations. First, to use the radiologists' time efficiently, many clusters were included in each phantom. With this design,

the readers might have been highly vigilant in searching for clusters, thereby potentially yielding higher sensitivities than if clusters occurred sparsely. However, this potential bias would affect all conditions similarly so that the effect on the relative sensitivity should be much less. Second, "normal" images were not included in the image set. The number of false-positive marks by the six radiologists was small for any of the conditions. The false-positive detections were too few to compare the relative specificity. Third, only seven protocols were included, while many other combinations of system parameters may be of interest. Fourth, this study did not include masslike objects. Fifth, although the interplane artifacts from the heterogeneous structured background of the breast phantoms in DBT acquired with narrow tomographic angle do not affect the conspicuity of the microcalcifications substantially, it is still unknown whether the same is true for real breast tissue texture. Sixth, the combined effects of the DBT acquisition parameters with other factors that affect image quality were not evaluated in this study, so that the relative importance of these factors remains a topic of future investigation.

In summary, with imaging conditions that did not include x-ray source motion or patient motion during acquisition of the projection views, narrow-angle DBT provided higher detection sensitivity and conspicuity of subtle microcalcification clusters. For optimization of DBT system design, the trade-offs between the detection of microcalcification clusters and other subtle lesions (masses, architectural distortion, and asymmetry), as well as other factors that affect image quality, need to be taken into consideration.

Acknowledgments: The DBT system was developed by the GE Global Research Center, with input and some revisions from the University of Michigan investigators, through the Biomedical Research Partnership (USPHS grant CA091713; primary investigator, Paul Carson, PhD) collaboration. The content of this article does not necessarily reflect the position of the funding agencies, and no official endorsement of any equipment and product of any companies mentioned should be inferred.

Disclosures of Conflicts of Interest: H.P.C. disclosed no relevant relationships. M.M.G. disclosed no relevant relationships. M.A.H. disclosed no relevant relationships. S.Z. disclosed no relevant relationships. A.S. disclosed no relevant relationships. M.N. disclosed no relevant relationships. C.P. disclosed no relevant relationships. M.A.R. Financial activities related to the present article: disclosed no relevant relationships. Financial activities not related to the present article: author received payment from Delphinus. Other relationships: disclosed no relevant relationships. A.V.N. Financial activities related to the present article: disclosed no relevant relationships. Financial activities not related to the present article: author received payment for a consultancy with GE. Other relationships: disclosed no relevant relationships. C.H.N. disclosed no relevant relationships. P.C. Financial activities related to the present article: disclosed no relevant relationships. Financial activities not related to the present article: GE Global Research was a subcontractor for a grant the author received for related work. Other relationships: disclosed no relevant relationships. Y.L. disclosed no relevant relationships. L.H. disclosed no relevant relationships. J.W. disclosed no relevant relationships.

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