

# Quality Control of Breast Tomosynthesis for a Screening Trial: Preliminary Experience

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**Abstract.** The Tomosynthesis Mammography Imaging Screening Trial (TMIST) Lead-In Study is a randomized screening trial that aims to compare the performance of standard two-dimensional full-field digital mammography (FFDM) and tomosynthesis at five sites in Canada, with multiple vendors' platforms and a target enrollment of 6300 women. To characterize and monitor the image quality of the tomosynthesis systems in the trial, a quality control (QC) program has been developed, including semi-annual physics tests, and daily tests performed on a phantom imaged by the radiographer.

Here we describe the test regimen and phantoms and present initial results. The physics tests include measurement of image quality parameters in the reconstructed tomographic slices and evaluation of the AEC performance by measuring signal difference to noise ratio (SDNR) of a low contrast simulated lesion. The physics tests have been performed on a GE Senoclaire, two Hologic Selenia Dimensions and two Siemens Mammomat Inspiration units. In addition to the physics tests, we have remotely collected 15 months of daily QC data on the GE unit and 2 and 3 months on the Hologic units.

**Keywords:** Breast tomosynthesis · Image quality · Quality control · Modulation transfer function · Artefact spread function · Radiation dose

## 1 Introduction

The efficacy of tomosynthesis mammography as a screening modality has yet to be determined with a large, multi-vendor, multi-center randomized screening trial in North America. The TMIST Lead-In Study is a randomized screening trial to compare the performance of FFDM and tomosynthesis at five sites in Canada, with a protocol designed to roll into the full TMIST trial (148,054 women at approximately 70 sites in the United States and Canada). To characterize and monitor the image quality of the tomosynthesis systems in a harmonized manner, a QC program has been developed that includes semi-annual tests and performance measures and daily tests to monitor system stability.

## 2 Method

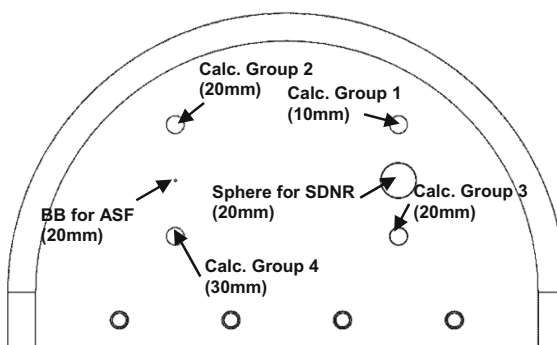
### 2.1 Philosophy

A comprehensive quality control program, including specially designed phantoms and automated analysis software was developed to monitor different aspects of image quality on the different manufacturer's tomosynthesis systems. Wherever possible, image quality is assessed in views most relevant to the radiologists (*i.e.* the reconstructed tomographic slices). The radiographer's tests were set up to be automated as much as possible using a client-server methodology, automatic image analysis and report generation. The tests were designed to be as universal as possible, such that they could be implemented on any system, and ideally, could be compared across systems. Because this was a developmental program, extra tests were performed to determine which tests are most effective.

### 2.2 Phantoms

Four phantoms were developed for QC tests: the *Wire Phantom*, the *Daily QC Phantom*, the *Uniform Phantom*, and the *Modular Phantom*. The latter three are semi-circular in shape.

The 40 mm thick daily QC Phantom incorporates a 12.7 mm (0.5 in.) polyethylene sphere for measurement of signal difference to noise ratio (SDNR), calcification clusters ( $\sim 0.57$  mm diameter calcifications arranged in a 6.3 mm diameter circle) at heights of 10, 20 and 30 mm for assessment of geometric localization (reconstruction accuracy) and a 0.79 mm (1/32 in.) aluminum BB for the assessment of the artefact spread function (ASF) and slice sensitivity profile (SSP) (Fig. 1). A "chest wall" backing plate facilitates placement on the table.



**Fig. 1.** Schematic of the daily QC phantom with test objects indicated. Heights are given in parentheses.

The modulation transfer function (MTF) is evaluated with the Wire Phantom, a slanted 35  $\mu$ m diameter taut tungsten wire embedded in a 4 cm thick uniform resin

block. The wire is slanted 1:10 with respect to the x and z directions to allow pre-sampling estimation of the point-spread function (PSF) [2].

The Modular Phantom (MP) is used for assessment of geometric reconstruction accuracy and the performance of the automatic exposure control. The phantom consists of semicircular slabs, 1 cm thick. The top and bottom slabs have rounded edges to minimize image processing artefacts by avoiding non-breast-like transitions in x-ray beam transmission. The phantom thickness can be adjusted between 2 and 8 cm in 1 cm increments. A thin plastic sheet supporting a grid of 0.79 mm aluminum BBs, spaced 4 cm apart in the x direction and 2 cm apart in the y direction can be positioned at different heights in the phantom. A 2 cm thick insert containing a polyethylene sphere can be added to measure how the SDNR varies with phantom thickness. Blank slabs are used to create uniform regions for evaluation of the noise power spectrum (NPS).

### 2.3 Tests

The QC program includes tests to be performed daily (QC phantom) and monthly (monitor lag) by the radiographer, and semi-annually by the medical physicist (Table 1). Initial tolerances on the test results are given for the daily QC tests (Table 2). Because of limited experience with the wide variety of different technologies available, the tolerances are given with respect to the reference operating levels (ROL) established after acceptance testing of the unit. Note here the “x” direction refers to the direction parallel to the chest-wall edge of the breast-support. The “z” direction is perpendicular to the plane of the breast support plate.

**Table 1.** Performance metrics evaluated during semi-annual physics testing. MP = Modular Phantom, FS = Foam Spacers

Test	Phantom	Parameters evaluated
Resolution (MTF)	Wire Phantom	MTF in x and z directions
Noise power spectrum (NPS)	Uniform Phantom	NPS in x and y directions
Artefact spread function (ASF), Slice sensitivity profile (SSP)	MP + BB-grid insert	FWHM of ASFs (x and y) and SSPs (z)
Reconstruction fidelity	MP + BB-grid insert	Spacing between BBs (x-y) average height of BBs (z)
Mean glandular dose	MP + SDNR insert + FS	Dose at equivalent 21, 45, 75 and 103 mm thick breasts
Collimation	NA	Collimator blades not visible in projection images.
Automatic exposure control (AEC) evaluation	MP + SDNR insert + FS	SDNR
Ghosting evaluation	MP + SDNR insert	Visual assessment in projections and volumes

**Table 2.** Parameters measured on the Daily QC phantom, and preliminary tolerances

Test	Preliminary tolerance
SDNR	Within 10 % of ROL
Geometric localization	Within 1 slice of ROL
ASF and SSP	FWHM in x, y and z' directions within 10 % of ROL
Normalized NPS (NNPS)	Radial NNPS within 10 % of ROL at 1, 2 and 4 mm <sup>-1</sup>

The semi-annual physics tests include an assessment of the MTF and the NPS, which can be combined to assess the noise equivalent quanta (NEQ).

## 2.4 Analysis

**SDNR.** The SDNR is measured in a polyethylene sphere embedded in PMMA. It is calculated as  $SDNR = (I_{\text{bkd}} - I_{\text{sphere}}) / \sigma_{\text{bkd}}$ , where  $I_{\text{bkd}}$  is the mean voxel value in a region of interest (ROI) adjacent to the sphere,  $I_{\text{sphere}}$  is the mean voxel value in an ROI within the sphere and  $\sigma_{\text{bkd}}$  is the standard deviation among the voxels in the background ROI. For the Daily QC Phantom, the slice where the BB (which is in the same plane as the centre of the sphere) has its peak intensity voxel was selected for SDNR measurement. This method ensures a robust yet fully automatic method of segmenting the appropriate ROIs.

**MTF.** The MTF is assessed in the x-z plane. First the pre-sampled PSF is obtained from x-z plane cross-sections of the reconstructed volume. Because the wire is so fine (35 microns), the slight oval-shape of the cross sections through the wire and the size of the wire can be neglected. The Fourier transform of the PSF yields the 2D MTF. The non-linear nature of most manufacturers' reconstruction algorithms gives peaks at frequencies other than zero. On the system for which we have the most data (GE) we found the MTF at low frequencies to be unstable over time. We suspect this is due to non-linearity in the artefact suppression algorithm. To mitigate this, the MTFs are set to 1.0 at  $f_x = 1$  cycle/mm.

**NNPS.** The NNPS is measured in projections and different x-y planes in the reconstructed volume using the multi-taper method described by Wu et al. [3]. The NNPS is calculated at 3 different heights within the modular phantom – 1, 2 and 3 cm above the breast support plate and radially averaged for comparison over time.

**ASF and SSP.** The artefact spread function (ASF in x and y) and slice-sensitivity profile (SSP, in z) are assessed for 0.79 mm (1/32 in.) aluminum BBs. As per Bouwman *et al.* [4] the SSP is calculated as shown in Eq. (1). A Gaussian is fit to the ASF or SSP used to estimate full-width half maximum (FWHM) value.

$$SSP = \frac{P_{\text{obj}}(z) - P_{\text{bkd}}(z)}{P_{\text{obj}}(z_0) - P_{\text{bkd}}(z_0)} \quad (1)$$

$P_{\text{obj}}$  and  $P_{\text{bkd}}$  are the voxel values at slice  $z$  in the object and the background and  $z_0$  is the slice with the peak voxel value.

Most systems report DICOM volumes in a Cartesian coordinate system (CCS) and the out-of-plane artefacts are naturally angled towards the focal spot of the central projection, causing the slice sensitivity profile (SSP) to be dependent on the position of the object with respect to the central ray on the detector. To reduce the effect of object position on SSP, the volumes in CCS can be transformed to a “cone-beam coordinate system” (CBCS) in which the  $(x, y, z)$  positions correspond to points on a cone, effectively creating an alternative coordinate system in which the focal spot is moved to infinity thus making the SSPs parallel [1].

**Reconstruction Fidelity.** The relative locations of the BBs are assessed for constancy of spacing in  $x$  and  $y$ . Because the grid of BBs is imaged at different heights within the modular phantom, the  $z$  locations of the BBs are compared between the different configurations to determine the dimensional accuracy of the  $z$  direction.

**Mean Glandular Dose.** The mean glandular dose is estimated for typical breasts of 2, 4.5, 7.5 and 10.3 cm. Measurements of Half-Value Layer and entrance exposure made in 2D (FFDM) mode for the different technique factors selected by the unit when imaging the SDNR phantom for AEC performance are used. The dose is calculated as per Dance et al. [5], using a “t-factor” to adjust for the difference between tomosynthesis geometry and the conventional FFDM measurement conditions. These calculated doses are then compared with the estimate of dose in the DICOM header.

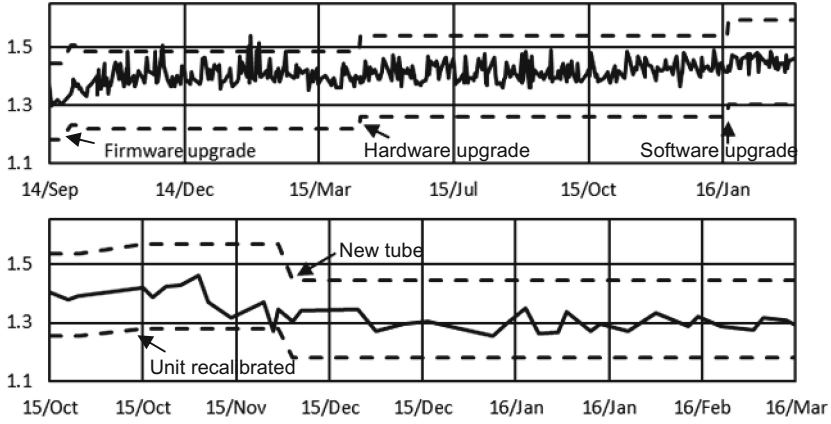
**AEC Performance.** The performance of the AEC was assessed by imaging the modular phantom with the SDNR insert in the configurations given in Table 4, with foam spacers added to achieve compression paddle heights such that the attenuation of the PMMA matches the attenuation of breasts of different compressed thickness, as per the work by Dance et al. [6]. The SDNR between a region inside the sphere and adjacent background regions was calculated for the slices passing through the middle of the sphere.

### 3 Results

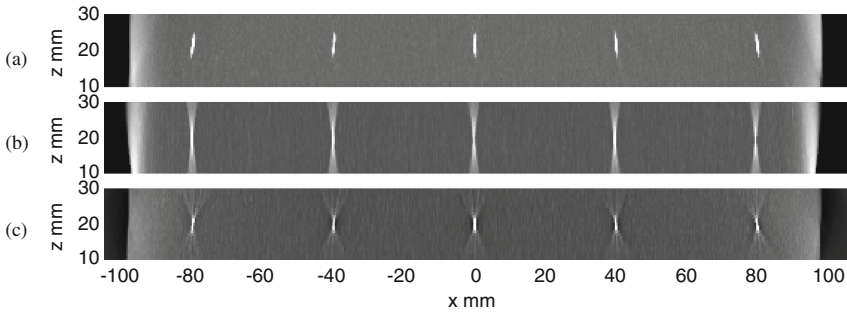
Routine QC data was gathered on a GE Essential Senoclaire for 15 months, and on two Hologic Selenia Dimensions systems for 2 and 3 months. The semi-annual physics data was also collected on all three units, as well as on two Siemens Inspiration units.

Plots of SDNR over time for the GE system and the Hologic system are shown in Fig. 2. The control limits of  $\pm 10\%$  are shown. New baselines were calculated when the units had gain calibrations and hardware upgrades.

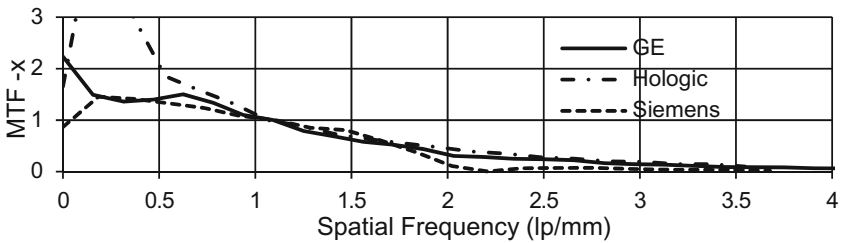
As shown in Fig. 3, GE and Siemens use CCS geometry whereas Hologic employs CBCS. All volumes were transformed to CBCS to evaluate MTF, ASF and SSP. Typical MTFs in the  $x$ -direction for the three system types are plotted in Fig. 4. The  $z$ -direction response is not shown, as the nature of the tomosynthesis reconstruction results essentially in a delta-function dictated by slice thickness. Typical 2D MTFs in the  $x$ - $z$  plane obtained from the Wire Phantom are shown in Fig. 5 (top).



**Fig. 2.** Daily SDNR measurements over time on the GE Essential (top) and Hologic Dimensions (bottom)

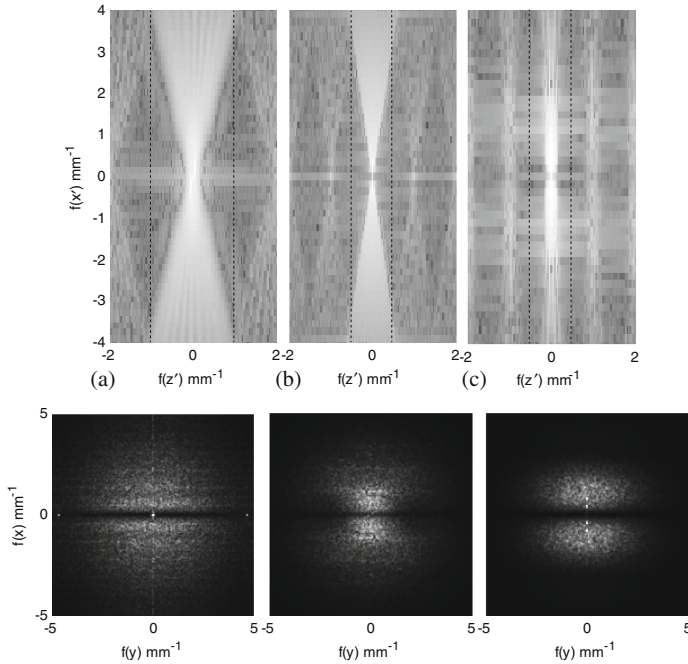


**Fig. 3.** Cross plane (x-z) slices through the reconstructed volumes of the modular phantom with a grid of BBs inserted at 2 cm above the breast support for (a) GE, (b) Hologic, (c) Siemens.



**Fig. 4.** Typical MTF measured from the wire phantom in the x-direction. These curves have been adjusted to 1.0 at 1 cycle/mm.

Figure 5 (bottom) illustrates typical 2D normalized NPS for the x-y plane in the middle of the reconstructed volume for the different systems.



**Fig. 5.** Typical x-z plane pre-sampled MTFs (top, log-scaled) and NNPS (bottom) for (a) GE, (b) Hologic and (c) Siemens. Dashed lines indicate the Nyquist frequency in the z-direction. Each NNPS is scaled to show best detail for display.

Table 3 gives the typical FWHM values measured for the artefact spread functions in x and y and the slice-sensitivity profiles for all 3 systems.

**Table 3.** Typical average FWHMs in mm for the ASF and SSP of the BBs when the BB insert is 2 cm above the breast support plate. The standard deviation is given in brackets.

Unit	ASF x	ASF y	SSP z
GE	0.77 (0.04)	0.75 (0.03)	5.65 (0.2)
Hologic	0.65 (0.03)	0.77 (0.05)	8.72 (0.4)
Siemens	0.59 (0.02)	0.63 (0.02)	2.93 (0.03)

Mean glandular doses for the different phantom thicknesses imaged to characterize AEC and dose are given in Table 4.

**Table 4.** Typical mean glandular dose values as calculated from physicist’s measurements (C) and reported in the DICOM header (D).

PMMA/Equiv. breast (cm)	2/2		4/4.5		6/7.5		8/10.3	
Composition (% Fibroglandular)	97		41		9		3	
Dose (mGy)	C	D	C	D	C	D	C	D
GE	1.2	0.8	1.3	1.2	1.9	2.0	4.4	5.3
Hologic	1.3	1.1	1.8	1.5	3.7	3.3	4.5	4.6
Siemens	1.0	1.0	1.7	1.4	2.7	2.3	5.0	4.2

## 4 Discussion

The measured SDNR values are reasonably stable over time. Upgrades to the equipment resulted in marked shifts in the operating levels. The MTF measurements are very sensitive to background correction and normalization making serial monitoring difficult. The MTFs are very different between systems.

The differences in the angular range used for acquisition of the tomosynthesis images are clearly seen in the differences in the SSP FWHM values. The Siemens system, which has the greatest angular range, has the smallest z FWHM values (best z direction resolution), while the Hologic system, which has the smallest angular range of the three, has the largest z FWHM values.

Examining the reconstructions of the modular phantom with the grid of BBs in the x-z plane is informative. The directionality of the artefacts, angled towards the focal spot, and varying with the position in the phantom relative to the perpendicular beam, are clearly visible in the GE and Siemens images. No evidence of this is seen in the Hologic images. This suggests their reconstruction algorithm assumes a parallel beam geometry (such as the basic shift and add technique).

Some discrepancies between the manufacturer’s calculated doses (reported in the DICOM header) and the physicist’s calculated doses were noted. These may be due to different assumptions regarding the composition of the breast being imaged. It is possible that the homogeneous nature of the PMMA phantom used to simulate a patient breast confused the AEC software. Future work to explore this further by calculating the doses to actual patients is planned.

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