An adaptive toolkit for image quality evaluation in system performance test of digital breast tomosynthesis

Conference Paper · March 2017

DOI: 10.1117/12.2253871

Nicholas Marshall
Universitair Ziekenhuis Leuven

Hilde Bosmans
University of Leuven

An adaptive toolkit for image quality evaluation in system performance test of digital breast tomosynthesis

Guozhi Zhang*, Dimitar Petrov, Nicholas Marshall, Hilde Bosmans
University Hospitals Leuven, Leuven 3000, Belgium

ABSTRACT

Digital breast tomosynthesis (DBT) is a relatively new diagnostic imaging modality for women. Currently, various models of DBT systems are available on the market and the number of installations is rapidly increasing. EUREF, the European Reference Organization for Quality Assured Breast Screening and Diagnostic Services, has proposed a preliminary guideline—protocol for the quality control of the physical and technical aspects of digital breast tomosynthesis systems, with an ultimate aim of providing limiting values guaranteeing proper performance for different applications of DBT. In this work, we introduce an adaptive toolkit developed in accordance with this guideline to facilitate the process of image quality evaluation in DBT performance test. This toolkit implements robust algorithms to quantify various technical parameters of DBT images and provides a convenient user interface in practice. Each test is built into a separate module with configurations set corresponding to the European guideline, which can be easily adapted to different settings and extended with additional tests. This toolkit largely improves the efficiency for image quality evaluation of DBT. It is also going to evolve with the development of protocols in quality control of DBT systems.

Keywords: digital breast tomosynthesis, quality assurance, image quality

1. INTRODUCTION

In diagnostic radiology, digital breast tomosynthesis (DBT) is a relatively new imaging modality for women. It measures the x-ray transmission through the breast over a limited range of angles, followed by reconstruction of a series of images at different heights of the breast above the detector. These images represent the breast tissue at the level of corresponding focal planes as well as a remaining portion of the overlying tissue. As a reconstructive imaging modality, DBT is distinct from computed tomography (CT) in which a 3D image is reconstructed using x-ray transmission data of at least 180° around the object.[1-3]

Currently, various models of DBT systems are available on the market and the number of installations is rapidly increasing. Although its clinical role has not yet been clearly defined, DBT is already considered for procedures such as breast cancer screening and further assessment of suspicious findings. Given the large difference among DBT systems, such as the angular range, the step-and-shoot versus continuous motion of the tube, the target/filter combination, the automatic exposure control (AEC) behaviors, with or without anti-scatter grid, etc., guidance on quality control (QC) for DBT systems becomes necessary. Recently, EUREF, the European Reference Organization for Quality Assured Breast Screening and Diagnostic Services, has proposed a preliminary guideline—protocol for the quality control of the physical and technical aspects of digital breast tomosynthesis systems, with an ultimate aim of providing limiting values guaranteeing proper performance for different applications of DBT.[4] It is the most comprehensive guideline that is available today for system characterization, performance test, stability test, and dose measurement of DBT systems.

To fulfill the aim of finally determining the limiting technical requirements for DBT, more experience has to be obtained through extensive measurement and test. One major part is to evaluate various technical parameters of the DBT images, including both the projection data and the reconstructed data. This can be a rather tedious process, due to the amount, size, and variety of the DBT datasets. In addition, methods to evaluate relatively complex parameters, such as the modulation transfer function (MTF), may not be readily available as convenient tools in QC practice. To this end, we have developed a dedicated software toolkit following the European guideline for image quality evaluation in system performance and periodic constancy test of DBT systems. A draft version of this toolkit was first presented on the annual meeting of the Radiological Society of North America (RSNA) in 2015.[5] A number of changes and extensions have been made since

* Email: guozhi.zhang@uzleuven.be

Medical Imaging 2017: Physics of Medical Imaging, edited by Thomas G. Flohr,
Joseph Y. Lo, Taly Gilat Schmidt, Proc. of SPIE Vol. 10132, 1013249 · © 2017 SPIE
CCC code: 1605-7422/17/$18 · doi: 10.1117/12.2253871

then, based on feedbacks from the EUREF community. In this paper, we describe the most recent features of the toolkit in greater detail.

2. METHODS AND MATERIAILS

2.1 Technical specifications

This toolkit software was developed fully in C/C++. It deals with image data in format of the Digital Imaging and Communications in Medicine (DICOM). Decoding and interpretation of the DICOM data format rely on the DCMTK libraries (v3.6, OFFIS, Germany). The FFTW library[6] (v3.3.5) was employed for the fast Fourier transform and the GNU scientific library (GSL) was used for part of the numerical calculations that are involved in the evaluation. The Qt libraries (v5.7, Digia Plc.) are used for designing the graphical interface. Algorithms implemented in the toolkit are mostly based on researches that are reported in the literature.[7,8] The toolkit and associated source codes are available to the community upon request.

The toolkit is delivered as a complied program that runs on Microsoft Windows 7 operation system, or higher. A separate version for current Linux systems is made available as well. The required memory (RAM) depends on the size of the image data to be loaded in the test. The RAM needed to launch the software alone is negligible, namely < 50 MB.

2.2 Test modules

According to the European guideline, eight tests have been made available in the current version of the toolkit. Table 1 shows the name of the test, abbreviations and the type of data that are used as input. The 'projection image' refers to the 'for processing' projection data. Each measurement and its associated parameter settings are built into a separate module, allowing the configuration of one measurement to be adjusted without affecting the others and further measurements to be easily added. In practice, each measurement requires a specific dataset to be acquired with a particular object (phantom) and a certain scanning protocol. The European guideline provides explicit instructions on phantoms, image acquisition, and exposure settings.

Table 1. Name, abbreviation, and input data type of the test modules that are currently included in the toolkit.

Test	**Abbreviation**	**Data type**
Linearity	Lin	Projection image
Detector modulation transfer function	MTF	Projection image
Horizontal direction	MTF(H)	
Vertical direction	MTF(V)	
Noise power spectrum	NPS	Projection image
Signal difference to noise ratio	SDNR	Projection image
Reproducibility	Reprod	Projection image
Local dense area	LDA	Projection image
In-plane modulation transfer function	MTFxy	Reconstructed image
Horizontal direction	MTFxy(H)	
Vertical direction	MTFxy(V)	
Z-resolution	Z-Res	Reconstructed image

2.3 Graphical user interface

The toolkit starts up with a small operation panel as shown in Figure 1. Below the buttons is a text bar showing the current status of the operation. The first button launches a system dialog to help select DICOM image files and arrange them in proper order, as shown in Figure 2. It is also possible to drag-and-drop images or folders directly onto the panel, after which the images will be opened in order of the DICOM unique identifiers (UID). Buttons 2 to 9 correspond to the measurements as listed in Table 1 and are used to set the region of interest (ROI) on the image that is open. The MTF and the MTFxy button toggle between the horizontal and the vertical direction of the measurement. The second last button is to carry out the measurement when the ROI has been set properly. The last button shows the records of measurements that have been performed and are ready for export, as shown in Figure 3.

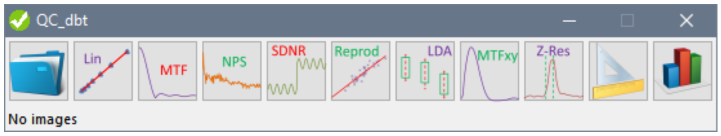

Figure 1. The operation panel of the toolkit.

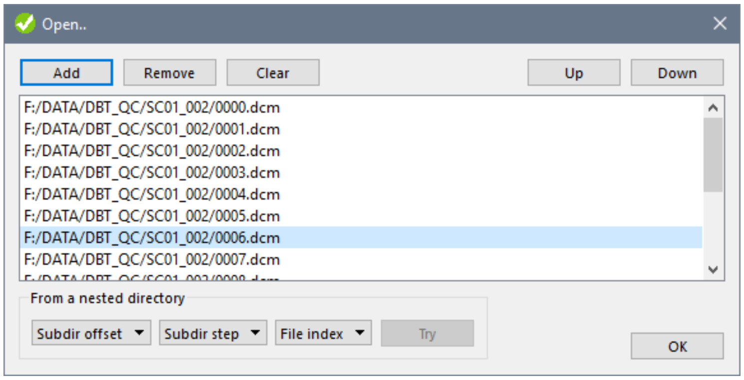

Figure 2. File browser to select and arrange the input DBT images. Images can be added to the list directly with the 'add' button or automatically from a nested directory with specific offset, step, and index.

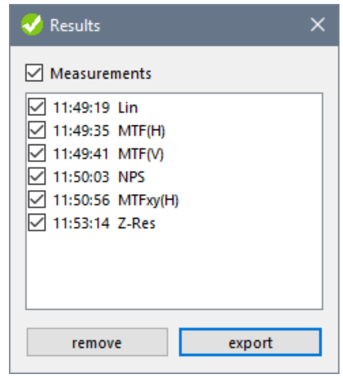

Figure 3. List of records for the measured results in order of time.

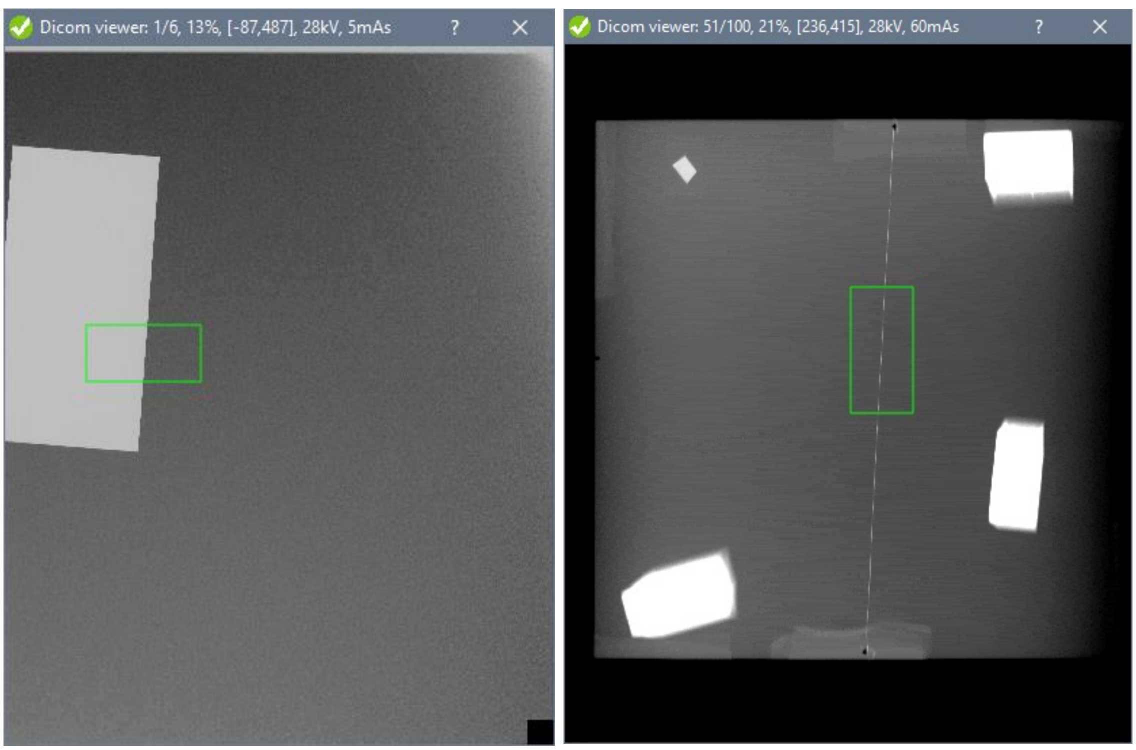

Figure 4. Examples of the image viewer in measuring the horizontal MTF on a projection image containing an edge (left), and in measuring the horizontal MTFxy in reconstructed images using a wire phantom (right).

Images are opened as a stack of frames in a separate viewer as shown in Figure 4. The viewer supports a number of keyboard and mouse controls for adjusting the image display, as listed in Table 2. To set a measurement, click on the corresponding button on the operation panel. This draws a pre-defined ROI on the image that is currently open in the viewer, as shown in Figure 4. Both the size and the location of the ROI are pre-defined according to the European guideline but may be manually repositioned if necessary. The ROI configuration is test-specific and can be easily changed as well. Measurement takes place after clicking on the second last button on the panel.

Table 2. Image viewer control of the toolkit.

Mouse	
Left button	Panning or move the ROI if present
Right button	Adjust the window/level for DICOM display
Wheel	Scroll between frames
Keyboard	
+/-	Zoom in/out
R	Reset to default display settings
W	Set window/level based on the ROI
I	Show DICOM header information
M	To measure
Page up	Go one frame backward
Page down	Go one frame forward
Left arrow	Move ROI left for one pixel
Right arrow	Move ROI right for one pixel
Up arrow	Move ROI up for one pixel
Down arrow	Move ROI down for one pixel

2.4 Algorithms

The linearity test measures the detector response and checks if the system is a linear imaging system. It is performed by fitting a linear function through the mean pixel values measured in a series of homogeneous projection images acquired at different doses, i.e. different levels of detector air kerma. A small ROI, namely 5 × 5 mm, is applied in order to avoid any background gradient or other low frequency variations that may affect the measurement. The coefficients and goodness of the fit are reported. Once the linear function has been established, it is used for linearization and offset correction of the pixel values in projection images. Practically, the pixel values are converted to the corresponding dose values and this is automatically done in all subsequent evaluations. This test, therefore, is recommended to be performed in the first place. Figure 5 shows the response function measured for two DBT systems that are available in our hospital.

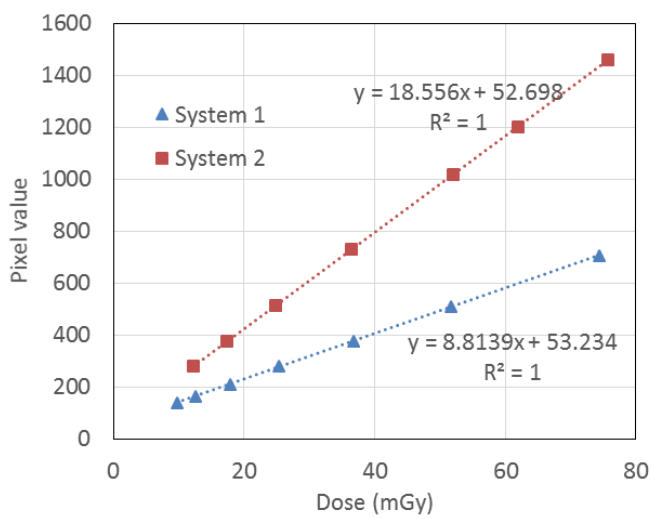

Figure 5. Detector response function measured in the linearity test for two DBT systems.

While more advanced measurements are being developed, the performance of the automatic exposure control (AEC) of the DBT system is currently tested with SDNR, LDA, and Reprod, as suggested in the European guideline. Projection data are acquired with PMMA phantoms containing different inserts, using the clinical AEC mode. The SDNR is calculated with the mean pixel value (μ) and standard deviation (σ) in a small attenuating plate (e.g. 10 × 10 mm Al) and the background region in the projection image:

$$SDNR = \frac{|\mu_{obj} - \mu_{bkg}|}{\sigma_{bkg}}$$

The positions of the ROIs are illustrated in Figure 6. The mean and standard deviation for the background are calculated as the numerical average of the two background ROIs.

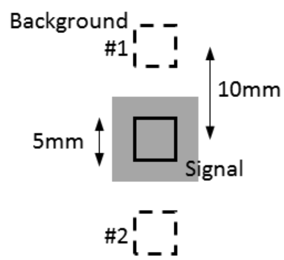

Figure 6. Positions of one ROI on, one above, and one below the Al plate (in dark) in measuring the SDNR.

The LDA requires a larger attenuating plate, namely 20 × 40 mm, in order to represent an area of high granularity in the breast. The signal to noise ratio (SNR) of a 5 × 5 mm ROI within the plate is calculated:

$$SNR = \frac{\mu}{\sigma}$$

The reproducibility (Reprod) test is also based on calculating the mean and standard deviation of a 5 × 5 mm ROI, except it is measured through projection data from repeated acquisitions, in which the exposure setting is held constant. The resulting variation in current-time product (mAs) and in SNR are investigated.

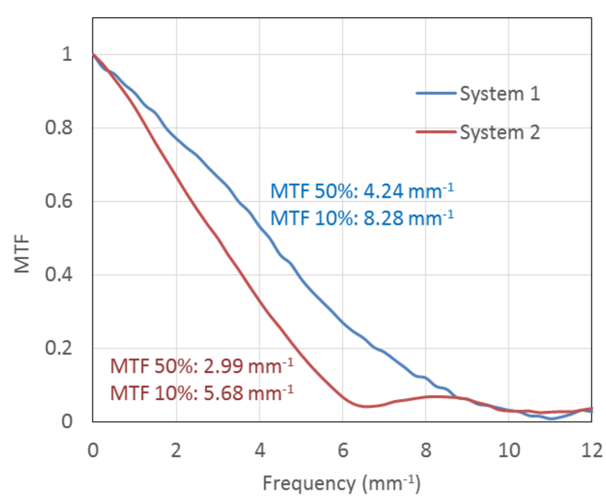

Figure 7. Measured detector MTF in horizontal direction for two DBT systems.

The pre-sampled detector MTF is evaluated with the projection image of an ‘edge’ phantom, in which the edge is created by a 1 mm thick steel sheet with a minimum size of 50 × 50 mm and straight edges. The edge is placed on top of the detector and is slanted for a small angle, namely 1 to 5 degrees, with respect to the pixel matrix. The MTF is calculated using a 25 × 50 mm ROI on the edge using the standard methods.[9] Two separate measurements are needed in order to determine the MTF in two orthogonal directions. The calculated MTF values are rebinned down to 0.25 mm^{-1} frequency intervals at output. Characteristic frequencies at 50% and 10% MTF are also found and reported. Comparison of the detector MTF in horizontal direction measured for two DBT systems are shown in Figure 7.

The detector NPS is evaluated with a 512 × 512 pixel homogeneous area in the projection image. To remove the background gradient, this ROI is first flattened with two consecutive linear fittings in two orthogonal directions. The 2D NPS is then calculated from 3 × 3 half-overlapping regions, each with 256 × 256 pixels. The results are averaged and normalized against the squared mean pixel value of the large ROI. If the pixel values have been calibrated in terms of dose, as in linearity test, the squared mean pixel value is actually the squared dose. The horizontal and vertical NPS is formed by the central row and column of the 2D NPS. The radial average of the 2D NPS is also found to provide a smooth representation. The results of NPS measured for one DBT system is plotted in Figure 8.

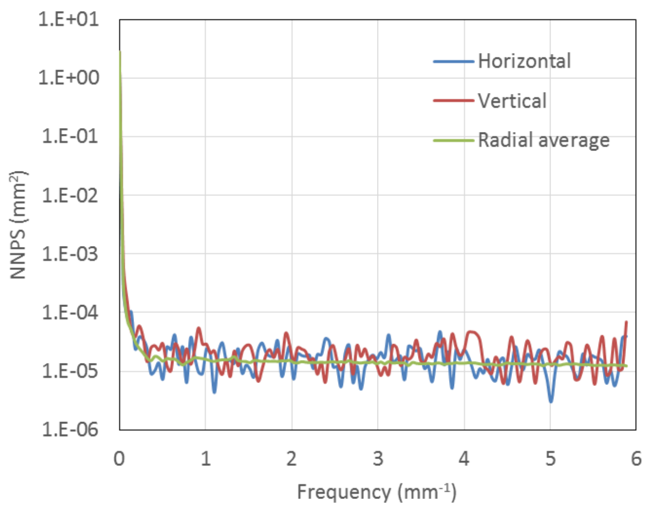

Figure 8. Measured horizontal, vertical, and radial average of the detector NPS for one DBT system.

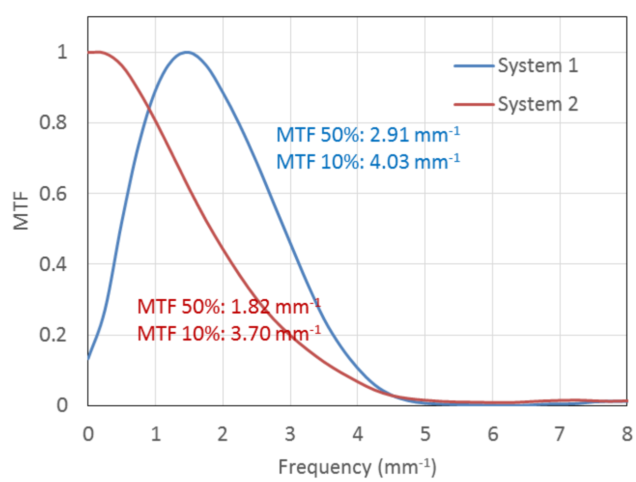

Figure 9. The horizontal in-plane MTF in reconstructed image measured for two DBT systems.

The in-plane MTF (MTFxy) of the reconstructed image includes the detector MTF and all additional sources of resolution loss and the reconstruction algorithm. It is evaluated using a method similar to the 'slanted-edge' method, except the edge is formed by a wire instead of a steel sheet. The MTFxy is calculated using a 25 × 50 mm ROI extracted from the focal plane where the wire is located in the reconstructed image. The ROI is positioned in a way such that the edge runs next to the long axis of the ROI, as opposed to detector MTF measurement where the edge runs next to the short axis of the ROI, as shown in Figure 4. Two separate measurements are performed for the two orthogonal directions. Comparison of the in-plane MTF in horizontal direction of the reconstructed image for two DBT systems are shown in Figure 9. Large difference is found between the two systems, due to rather different post-processing and reconstruction algorithms.

While MTFxy characterizes the in-plane blurring of the reconstructed DBT image, the Z-resolution test is to evaluate the sharpness across reconstructed planes. It is quantified with the inter-plane spread of the reconstruction artefacts using a 3D phantom containing a 1 mm diameter sphere. The reconstruction artefacts typically stretch the sphere into a faint line in the direction of tube motion. There is often also a shift in the position of the artefact in adjacent focal planes, relative to the position of the sphere in focus, due to the magnification effects. Therefore, the maximum pixel value in a 5 × 5 mm neighborhood of the sphere is found on each plane of the reconstructed image. These local maxima are lined up to represent the vertical component of the signal, where the highest is assumed to be the actual position of the sphere. The spread is then characterized in terms of the full width at half maximum (FWHM) and full width at quarter maximum (FWQM). In practice, a polynomial function is fitted through the maxima to help determine the FWHM and FWQM. The values of FWHM and FWQM are given in units of planes, which can be easily translated into mm if the reconstruction slice thickness is available. An example is shown in Figure 10.

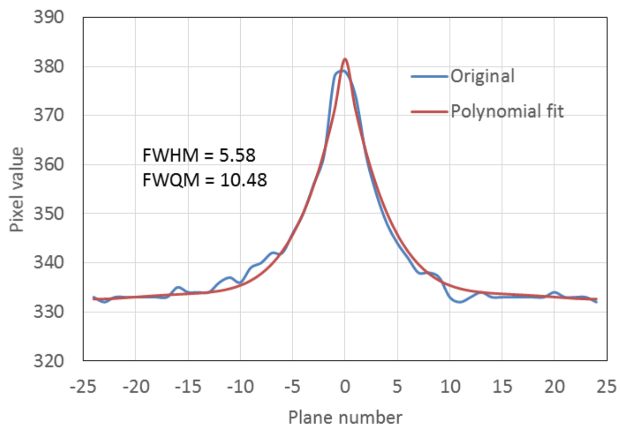

Figure 10. Z-resolution with FWHM and FWQM of the vertical signal spread measured with the reconstruction image of one DBT system.

2.5 Report

Successful measurements are recorded in order of time, as shown in Figure 3, where the user can select to export or to remove. The exported results are in CSV format that can be conveniently accessed and further processed with application such as Microsoft Office Excel and LibreOffice Calc. Figure 11 shows an example.

3. DISCUSSION AND CONCLUSION

We have presented a dedicated easy-to-use toolkit for evaluating various technical parameters of DBT images. The toolkit was developed in accordance with the European guideline and covers most measurements in current quality control practice for DBT. The toolkit design makes it possible and relatively easy to adapt to different test configurations and to be extended with additional test modules. The toolkit has a powerful DICOM image viewer with large flexibility in tuning various display settings. The toolkit is light, portable, and independent of other third-party platforms except the operation system. This toolkit is undergoing continuous improvement and evolves with the latest development of protocols for system characterization and periodic constancy test of DBT systems. It is going to largely improve the efficiency of image quality evaluation for DBT. The toolkit can be obtained from the authors for test and training purposes.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Linearity						MTF(H)			MTF(V)			NNPS			
2	Slope	8.80906					MTF 50%	4.45227		MTF 50%	1.57827		/mm	Horz	Vert	Rad
3	Intercept	53.2486					MTF 10%	8.24537		MTF 10%	2.58287		0	0.000325	0.000325	0.000325
4	R2	0.999963					/mm	MTF		/mm	MTF		0.045956	0.000239	0.000649	0.000298
5	uGy	PV	SD	PV'	SD'		0	1		0	1		0.091912	7.18E-05	0.000135	6.74E-05
6	9.7	137.621	5.52052	9.57796	0.626687		0.25	0.967329		0.25	0.96584		0.137868	8.90E-05	4.08E-05	4.41E-05
7	12.6	162.977	6.11032	12.4564	0.69364		0.5	0.944702		0.5	0.917142		0.183824	2.09E-05	3.67E-05	2.80E-05
8	17.9	211.177	7.14181	17.928	0.810735		0.75	0.928235		0.75	0.839921		0.229779	3.47E-05	5.07E-05	2.16E-05
9	25.4	278.239	8.43795	25.5408	0.957872		1	0.903494		1	0.748443		0.275735	3.14E-05	3.46E-05	1.78E-05
10	36.7	377.834	9.8189	36.8468	1.11464		1.25	0.87248		1.25	0.646787		0.321691	2.21E-05	1.47E-05	1.46E-05
11	51.7	509.755	11.9419	51.8224	1.35564		1.5	0.845227		1.5	0.534612		0.367647	8.49E-06	2.04E-05	1.29E-05
12	74.3	706.244	14.0663	74.1277	1.5968		1.75	0.810394		1.75	0.420324		0.413603	1.10E-05	2.40E-05	1.56E-05
13							2	0.775517		2	0.318057		0.459559	1.23E-05	2.08E-05	1.46E-05
14							2.25	0.750537		2.25	0.21495		0.505515	5.48E-06	3.04E-05	1.32E-05
15							2.5	0.726691		2.5	0.127882		0.551471	1.78E-05	1.26E-05	1.41E-05
16							2.75	0.703708		2.75	0.05537		0.597426	1.85E-05	7.74E-06	1.37E-05
17							3	0.681012		3	0.046444		0.643382	3.70E-05	2.62E-05	1.40E-05
18							3.25	0.653162		3.25	0.06888		0.689338	1.19E-05	2.17E-05	1.26E-05

Figure 11. An example of the output, including the linearity test, the measured detector MTF, and the normalized NPS.

REFERENCES

[1] Dobbins, J. T., "Tomosynthesis imaging: At a translational crossroads," Med. Phys. 36, 1956-1967 (2009).

[2] Sechopoulos, I., "A review of breast tomosynthesis. Part I. The image acquisition process," Med. Phys. 40, 014301 (2013).

[3] Sechopoulos, I., "A review of breast tomosynthesis. Part II. Image reconstruction, processing and analysis, and advanced applications," Med. Phys. 40, 014302 (2013).

[4] EUREF, Protocol for the quality control of the physical and technical aspects of digital breast tomosynthesis systems (version 1.01, June 2016). http://www.euref.org/european-guidelines/physico-technical-protocol

[5] Zhang, G., *et al.* "Challenges and solutions for periodic constancy testing of breast tomosynthesis systems," 101st Scientific Assembly and Annual Meeting, Radiological Society of North America, Chicago, Illinois, November 29 – December 4, 2015.

[6] Frigo, M. and Johnson, S. G., "The Design and Implementation of FFTW3," Proceedings of the IEEE 93 (2), 216–231 (2005).

[7] Samei, E., *et al*, "Intercomparison of methods for image quality characterization. I. Modulation transfer function," Med. Phys. 33, 1454-1465 (2006).

[8] Dobbins, J. T., *et al*, "Intercomparison of methods for image quality characterization. II. Noise power spectrum," Med. Phys. 33, 1466-1475 (2006).

[9] IEC 62220-1 "Medical electrical equipment—characteristics of digital x-ray imaging devices—Part 1: Determination of the detective quantum efficiency," International Electrotechnical Commission, Geneva, Switzerland, 2003.