Image evaluation method for digital mammography with soft-copy reading using a digital phantom

Norimitsu Shinohara[1], Katsuhei Horita[2] , Tokiko Endo[3]

[1]Department of Radiological Technology, Faculty of Health Sciences, Gifu University of Medical Science

[2]The Japan Central Organization on Quality Assurance of Breast Cancer Screening

[3]Department of Radiology, National Hospital Organization Higashi Nagoya National Hospital

ABSTRACT

Mammograms are evaluated on soft-copy films or hard copies. In Japan, soft-copy diagnoses shift rapidly, and the method for facilities applying it is necessary for soft-copy diagnosis. Digital mammography has high resolution and a large matrix size. On a monitor, the image is either displayed partially at 1:1 pixel mapping or narrowed to fit the screen, resulting in loss of image quality. Therefore, we developed a digital phantom for soft-copy diagnosis in digital mammography.We developed the digital phantoms used by every mammographicdetector sold in Japan. For our digital phantom, we used C to create signals, which we converted to DICOM using Osirix. This phantom is like the Contrast Detail Phantom and comprises 12 different shapes and eight different brightness levels. It becomes one group of nine, and each signal is located at the prime number coordinate from a central signal coordinate. Visual evaluation refers to the visibility of the nine signal coordinates when the image is adjusted to fit the monitor's display. A digital phantom is useful not only for evaluating display systems that feature reducing functions and monitor resolution but also for educational purposes such as confirming the effects of the monitor's resolution and reducing functions as well as for precision management with regard to deterioration and malfunction. Although digital phantoms have been implemented at 120 facilities, at two other facilities, viewer problems were detected.

Keywords: digital phantom, soft-copy diagnosis, mammography, visual evaluation

1. BACKGROUND

In Japan, the number of breast cancer patients is on the rise, and the incidence and mortality rates are extremely high [1].Breastcancerinparticularisthe most common type of cancerin women, who are at greater risk of dyingfrom their 30s through to their 60sthanfromanyotherformofcancer.Inrecent years,arisingnumberofwomenhavebeen developingbreastcancerintheir40s,andimproved methodsofbreastcancerscreeningareunder consideration [2]. The technology of mammography in Japan islagging in terms of digitizingdiagnostic radiography. However, systems Equipmentped with flat-panel detectors are spreading rapidly, and although only 4.0% were Equipmentped with flat-panel detectors in 2005 [3], more than 14.8% (675 machines) had them as of December 31, 2011 [4]. Moreover, due to revision of the medical payment system in April 2010, a large number of facilities are transitioning to soft-copy diagnosis.

Spatial resolution in mammography requires a high spatial frequency depending on the characteristics of the lesion visualized. The digital mammography detectors currently used in Japan feature pixel sizes of25–100μm [5] with a matrix size that increases accordingly. Some detectors have a matrix size as large as 7080×9480. In contrast, a 5MP monitor, which has the highest resolution of any monitor, has a resolution of only 2560×2028.

Soft-copy diagnosis in mammography requires the following: 1) recognition of the lesion characteristics by displaying it in as much detail as possible; and 2) recognition of bilateral symmetryand structural continuity by displaying the entire breast. In criterion 1), displaying the mammography information in its entirety requiresobservation with 1:1 pixel mapping [6] in which a single pixel corresponds to a single pixel on the display. However, in 1:1 pixel mapping, observing the entirebreast requires shifting of the effective field of view and other cumbersome tasks. In criterion 2), even if the facility is able to conduct a soft-copy diagnosis with a 5MP monitor, if the detector uses a matrix size of 2560×2048 or greater,the image must be decreased in sizeto observe the entire breast. This means that the entire breast image fits the screen using the maximum monitor display size [5]. Reducing functions (methods) for the image interpreting workstation (hereafter "viewer") includes the nearest neighbor algorithm, linear interpolation, bicubic interpolation, and data thinning. It is widely known in engineering that reducing images via these functionsresults in signal loss. However, medical professionals have little interest in reduction functions and little understanding of the differences in image visibility [7]. Furthermore, there is currently no established method or tool for assessing this. Therefore, we developed a digital phantom for soft-copy diagnosis in digital mammography and describe it here.

2. METHODS

The objective of visual evaluation is to evaluate the viewer rather than themonitorquality alone. Therefore, display systems are defined as “monitors” and “viewers”; the objective is to evaluate various conditions related to display systems, such as image interpolation, display libraries, OpenGL, and video cards. What is assessed here is whether the imaging device can display the recorded signals without deficiencies. This is determined by the correlation between monitor resolution (pixel count) and mammogram pixel count. In particular, the disappearance of high-frequency signals (determination of microcalcifications) in a full-image display necessitates the development of a tool for determining image scope and the establishment of a visual evaluation method. However, since images shot on film are subjected to shooting conditions and various other factors, the present method evaluates the response (output) from when the digital images are inputted (physical quantity).

2.1. Digital phantom

For our digital phantom, we used C to create signals, which we converted to DICOM (tagging information such as secondary capture and spacing) using Osirix. In doing so, we used a window center (0028, 1050) and window width (0028, 1051) of 2048 and 4096, respectively. However, to avoid display problems in the viewer, the tags for the detector used in the mammography were analyzed, and the DICOM tags for imager pixel spacing (0018, 11164), detector element physical size (0018, 7020), detector element spacing (0018, 7022), rows (0028, 0010), columns (0028, 0011), pixel spacing (0028, 0030), bits allocated (0028, 0100), bits stored (0028, 0101), and high bit (0028, 0102) were set to be identical to these detector tags.

The vertical and horizontal components of the digital phantom include 12 different signal shapes (A, B, C, D, E, F, G, H, J, K, L, and M) (Fig. 1) and eight different signal brightness values (1, 2, 3, 4, 5, 6, 7, 8); a single group comprises

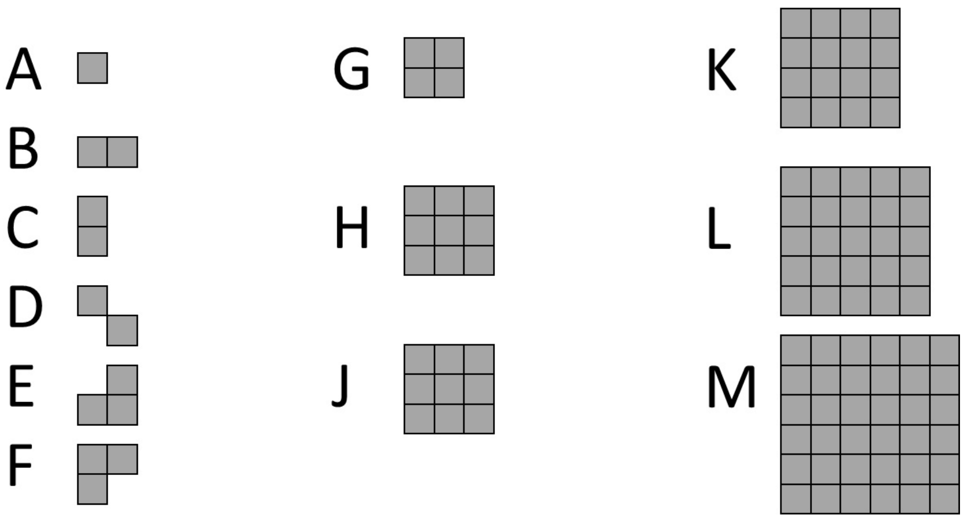


Figure 1 The shape of the signal on digital phantom for evaluation. A, B, C, D, E, F, G, J, and K are signals.H, L, M are reference signals.

nine signals in a dot shape. The dots for A, B, C, D, E, F, G, H, J, K, L, and M connote different signal sizes (different pixel sizes) according to the individual detector. Therefore, a different digital phantom is prepared for each individual detector used for mammography. The digital phantoms that have been created to date are shown in Table 1. The digital phantom is tailored to the matrix size of the detector used in mammography; thus, it is possible to perform evaluations per detector used at a given facility.

Table 1: Relation between Equipments and the pixel size of each signal

	Equipment 1	Equipment 2	Equipment 3	Equipment 4	Equipment 5	Equipment 6
Pixel size	25um	50um	70um	85um	85um	100um
Matrix X	9480	4740	3328	2816	2812	2294
Matrix Y	7080	3540	2560	2016	2012	1914

A	25x25	50x50	70x70	85x85	100x100
B	25x50	50x100	70x140	85x170	100x200
C	50x25	100x50	140x70	170x85	200x100
D-G	50x50	100x100	140x140	170x170	200x200
H, J	75x75	150x150	210x210	255x255	300x300
K	100x100	200x200	280x280	340x340	400x400
L	125x125	250x250	350x350	425x425	500x500
M	150x150	300x300	420x420	505x505	600x600

An overview of the digital phantom is shown in Figure 2. The basic form of a digital phantom resembles a contrast detail phantom in which the steps are annotated on the left margin and C1, C3, C5, and C7 are annotated in the four corners. We created 20 steps, with a step increased every 51pixel value. With a matrix size of m×n, C1, C3, C5, and C7

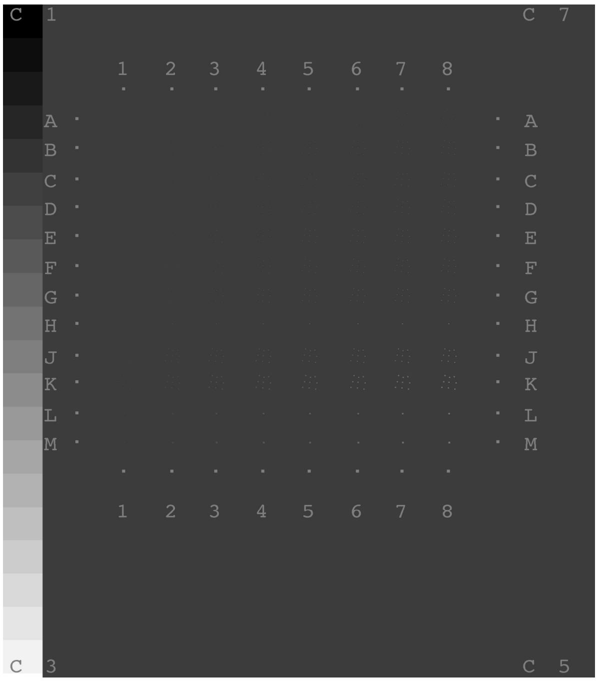
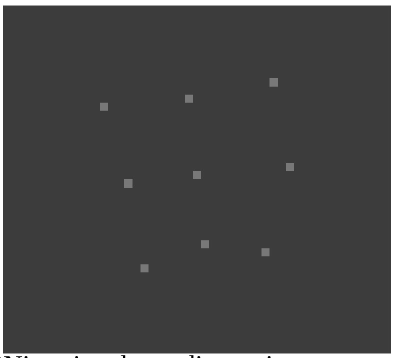


Figure 2 An overview of the digital phantom

are tagged as C1 (10, 10), C3 (10, n-70), C5 (m-240, n-70), and C7 (m-240,10); these tags are used to confirm the image margins. To prevent signal lossat a specified reduction rate, the nine signal coordinates in a group were placed on prime number coordinates (Fig. 3). Therefore, although the signal configuration is distorted, this configuration avoids problems with reduction functions and rates.



(-13,-23)	(2,-17)	(17,-19)
(-17, -2)	(0, 0)	(23, 2)
(-23, 17)	(-2, 19)	(19, 23)

Figure 3 Nine signal coordinates in a group. (a)Image of a group (b) coordinates of a group

2.2. Preparations for the evaluation

Evaluation preparation consists of the following four steps:

I. Load the digital phantom into the viewer.

II. Resize the full-screen display to fit the monitor's maximum display.

III. Confirm that C1, C3, C5, and C7 are displayed on the screen.

IV. When adjusting window width (WW) and window level (WL), theymust be displayed in a way that enables visual confirmation of the differences in brightness in the 20-step grayscale. Essentially, WW and WL do not require adjustment.

Digital phantoms can be loaded easily in most viewers. However, there may be demands for non-type 1 DICOM tagsdepending on the viewer, so some DICOM tags may require modification.

2.3. Visual evaluation

Visual evaluation refers to the visibility of the nine signal coordinates when the image is adjusted to fit the monitor's display. At this time, visibility is both a sensory and a subjective index; therefore, using the relatively large digital phantom signals H, L, and M as reference signals, if the above-mentioned nine signal coordinates are equivalent to H, L, and M, they are considered visible. Thus, visual evaluation is the selection of dots deemed equivalent to H, L, and M (i.e. visible dots). Depending on the reduction rate and function, some dots are easily visible, while others have weak signal values and some even disappear due to the reduction. A samplevisual evaluation is shown in Figure 4. Visible signals are circled, while signals that have disappeared are not marked. We chose not to use expansion tools or perform gradation processing for the visual confirmations.

Figure 4 Example of the visual evaluation

A total of 96 signal groups and the display systems that feature reduction functions can be compared by confirming the visibility of signals of the same size. The correlation between the sampling pitch of a detector and the signal size of the digital phantom using a 5MP monitor is shown in Table 2. For example,when the actual size of the microcalcification to be detected is 100 μm based on a radiology consultation, a comparison can be made by evaluating the visibility at an equivalent of 100 μm in a digital phantom.

Table 2: The correlation between Equipmentments and the signal size of the digital phantom using a 5MP monitor

		Maximum length of the signal [mm]					
	Pixel size	0.025	0.05	0.1	0.2	0.3	0.5
Equipment 1	25um	A-C	D-G	K	L,M	–	–
Equipment 2	50um	–	A-C	G	H-K	L,M	–
Equipment 3	70um	–	A	B,C	H-K	L,M	–
Equipment 4	85um	–	A	B,C	H-K	L,M	–
Equipment 5	85um	–	A	B,C	H-K	L,M	–
Equipment 6	100um	–	–	A	B-G	H-J	L

3. RESULTS AND DISCUSSION

A digital phantom is useful not only for evaluating display systems that feature reducing functions and monitor resolution but also for educational purposes such as confirming the effects of the monitor's resolution and reducing functions as well as for precision management with regard to deterioration and malfunction.

Although digital phantoms have been implemented at 120 facilities, 43 facilities are unsuited for its implementation. At 41 facilities, the evaluator did not receive a sufficient explanation of the evaluation methods and tools described above. However, at two other facilities, viewer problems were detected. Therefore, while the visual image evaluation was mostly subjective, it has becomepossible to replace some of these subjective elements with certain objective evaluations.
The digital phantom proposed in the present study is currently being adopted for soft-copy image evaluations and put into practical use by the nonprofit organization Facility Image Evaluation Committee of the Japan Central Organization on Quality Assurance of Breast Cancer Screening. However, because the visual evaluation technique proposed in the present study is self-assessed, a proper evaluation may not be possible if the group composed of nine signals shown in Figure 3 is presented as-is. Therefore, this assessment must be made accurately, not by creating a model that uses fixed signal values for the nine signal values that comprise a digital phantom group but rather by creating 1) a model that combines weak and strong signal values and changes the balance, or 2) a partial disappearance model in which some of the nine signal values are changed to 0. In future, we intend to evaluate the differences between specific monitor resolutions and reduction functions using a digital phantom.

4. CONCLUSION

Here we reported the development of a digital phantom for soft-copy diagnosis in digital mammography as well as the involved evaluation method. Many facilities have transitioned to soft-copy diagnosis to date. In addition, there have beenmanyinstances of image interpretation by remote diagnosis as well as the interpretation of images from multiple devices with a viewer. Therefore, we anticipate that the present study's findings will contribute to the precision management of these new breast cancer diagnostic methods.

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AUTHOR

Norimitsu Shinohara received the B.S.degrees in Health physics from Fujita Health University in 2000, M.S. and Ph.D. degrees in Engineering from Gifu university in 2002 and 2006, respectively. During 2006-2007, he stayed inGifu University, Office of Society-Academia Collaboration for Innovation to study processing and recognition of a breast imaging. He now with Gifu University of Medical Scienceand moreover educates a doctor and a medical staff about breast cancer.