

# Optical density analysis of standard phantom for mammography quality control

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## Abstract

**Background/Objectives:** The objective of this study was to analyze optic density of dummy lesions in breast phantom by mammography and understand whether the objectivity of visual inspections on dummy lesions upon appropriate and inappropriate decisions was correct quantitatively.

**Methods/Statistical analysis:** Study subjects were 165 phantom images in 74 hospitals nationwide that passed the test of special medical equipment by Korean Institute for Accreditation of Medical Image from May 2016 to April 2017. Min (A), Max (B), Mean (C), and StdDev (D) were measured using color level information. Fibers, specks, and masses divided dummy lesions determined as appropriate or inappropriate in 165 images. For each divided dummy lesion, Min, Max, Mean concentration, and concentration difference summarized it.

**Findings:** There was a significant difference in Max concentration (B) between dummy lesions of 9 (specks 3) and 10 (specks 4). In dummy lesion 12 (mass 1), there was no significant difference by each step, although the deviation between black and white was high since the scope of lesion was big. Upon analysis of optic density divided by appropriate and inappropriate decisions, there were significant differences in concentration difference (D) for fibers, Min (A) and Max (B) concentrations as well as concentration difference (D) for specks, and Max (B) and Mean (C) concentrations with concentration difference (D) for masses.

**Improvements/Applications:** Visual inspections appeared to have difficulty in analyzing lesions due to the ambiguity of quantitative differences. Further developments of quantitative programs are needed to replace visual inspection for breast phantom lesions in mammography.

**Keywords:** *Optical Density; Mammography; Standard Phantom; Quality Control; Dummy Lesion*

## 1. Introduction

Breast cancer has the highest incidence rate among all cancers in Korea [1-2]. Mammography is the most frequently utilized method to detect breast cancer among a variety of radiographies using x ray [3-4]. Among various radiographies using X ray, mammography is the most commonly used method to detect breast cancer [5-6]. For mammography to be useful for screening breast cancer, it should have suitable image quality<sup>7,8,9</sup>. Since direct quality control cannot be performed in patients, alternatively mammo phantom (4.5-cm compressed breast containing 50 % of breast parenchyma and 50 % of lipid) can be used<sup>10</sup>. Mammo phantom consists of 16 dummy lesions inside, including 6 fibers, 5 small speck groups, and 5 masses<sup>11</sup>. Ten or more dummy lesions should be detected to meet the standard of phantom image in quality control test in Korea, including over [4] fibers, over 3 small speck groups, and over 3 masses<sup>12</sup>. Currently, Korean Institute for Accreditation of Medical Image recommends evaluators including radiologists to evaluate breast phantom images to determine whether phantom image test is a failure depending on whether they meet the standard<sup>13</sup>. In case of failure, the device cannot be used under current regulations<sup>14</sup>. Radiologist's visual reading is definite when diseases are diagnosed with special medical devices.

Therefore, visual inspection itself is very important when evaluating the capacity of the mammography device<sup>15</sup>. However, it is crucial to secure the objectivity of visual inspection since the device is determined to be appropriate or inappropriate for usage based on qualitative evaluation of phantom image test. The objective of this study was to analyze optic density of dummy lesions in breast phantom by mammography and understand whether the objectivity of visual inspections on dummy lesions for appropriate and inappropriate decisions was correct quantitatively.

## 2. Materials and methods

### 2.1. Research subject

According to the Ministry of Health and Welfare, hospitals must conduct phantom image evaluation every six months and document the inspection for Korean Institute for Accreditation of Medical Image, a quality management inspection institution. Visual (qualitative) evaluation figures of the phantom and its images need to be provided by a radiology specialist. In this study, subjects were 165 phantom images in 74 hospitals nationwide that passed the test of the special medical equipment by Korean Institute for Accreditation of Medical Image from May 2016 to April 2017.

## 2.2. Research method

### 2.2.1. Optical density difference analysis of dummy lesions and background

For images submitted to Korean Institute for Accreditation of Medical Image, optic densities of 16 dummy lesions in 165 images were measured using PiView STAR version 5.0, PACS system (Infinitte Co., Ltd). Digital image has pixel value reflecting density [16-17]. Upon quantifying the density within the region of interest (ROI), black represents lower value while white represents higher value. ROI histogram can then be made and concentrations of black and white can be calculated based on the highest and lowest values. The background is shown as black while dummy lesion is as white.

ROI was developed with an area of approximately 353 mm<sup>2</sup> and a length of 75 mm to show the dummy lesion well in the phantom image after reversing it as Figure 1 and Figure 2. Min (A), Max (B), Mean (C), and StdDev (D) were measured using color level information. The darkest black (the lowest concentration), the brightest white (the highest concentration), the average concentration, and the difference in concentration between the darkest black and the brightest white in the region of interest are shown as Min (A), Max (B), Mean (C), and StdDev (D), respectively. Optic density per each dummy lesion was measured by drawing ROI from the first to the sixteenth dummy lesion. Min (A), Max (B), Mean (C) concentrations of the background, and concentration difference (D) were measured by drawing ROI area of approximately 35 mm<sup>2</sup> with length of 7 mm without overlapping with the area between the 12<sup>th</sup> and the 16<sup>th</sup> dummy lesions.

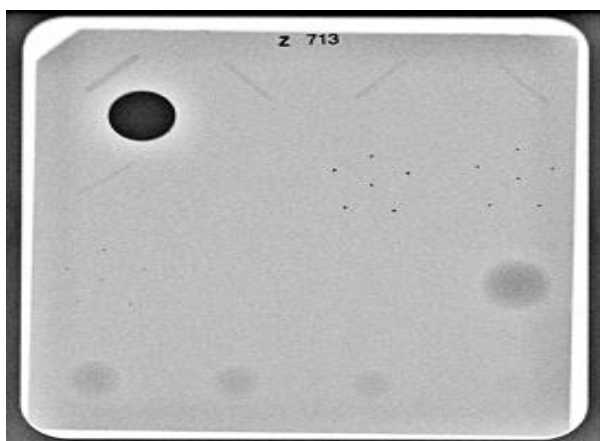


Fig. 1: ACR Phantom Images.



Fig. 2: Optical Density.

ROI was developed and optic density was measured to quantitatively analyze whether 17 regions (including 16 dummy lesions and 1 background) could be identified visually. Mean and Standard Deviation (SD) were calculated to show descriptive statistics. After analyzing the brightness of ROI, 165 data were collected for variables in regions of interest, including Min (A), Max (B), Mean (C) concentrations, and concentration difference (D). One-way analysis of variance (ANOVA) was performed for validation. Least significant difference (LSD) post-hoc analysis was performed for one-way ANOVA data.

### 2.2.2. Analysis of optical density between appropriate and inappropriate decisions by dummy lesions

Dummy lesions determined as appropriate or inappropriate in 165 images were divided by fibers, specks, and masses. For each dummy lesion, it was summarized by Min (A), Max (B), Mean (C) concentration, and concentration difference (D). Differences in optic density were investigated for determinations of appropriate and inappropriate by visual identification. To demonstrate descriptive statistics, Mean and SD were calculated. Paired t-test was performed to determine whether those were different between the two groups.

## 2.3. Statistical analysis

All data were analyzed using Statistical Package for Social Science (SPSS) for Windows version 21.0 (SPSS Inc., Chicago, IL, USA). P value of less than 0.05 was considered statistically significant.

## 3. Results

### 3.1. Optical density difference analysis of dummy lesions and background

To understand whether optic densities in 17 regions were different, one-way ANOVA analysis was performed. Results are shown in Table 1.

Mean values of minimum (A) concentration of pixel values in 17 regions ranged from  $1,474.8 \pm 814.3$  for the first dummy lesion to  $1,502.7 \pm 864.81$  for the 16<sup>th</sup> dummy lesion without showing statistically significant differences among regions. That means Min(A) concentrations were not different in 17 regions.

Mean values of maximum (B) concentration of pixel values for the 17 regions ranged from  $2,256.2 \pm 431.4$  for the first dummy lesion to  $2,183.3 \pm 558.3$  for the 16<sup>th</sup> dummy lesion with statistically significant differences among some regions. Based on post-hoc analysis of one-way ANOVA, the background had the lowest value at 2,041. For other regions, the follow result was obtained:  $1=2=3=4=5=6=11=13=14=15=16 \leq 10 = 12$ . Values of regions 10 and 12 ranged from 2,183 to 2,368 without significant difference. Values of the 8<sup>th</sup> and the 9<sup>th</sup> dummy lesions were 2,685 and 2,804, respectively, without showing significant difference. The 7<sup>th</sup> dummy lesion had the highest

value at 3,043 (the brightest).

Analysis results by each group of dummy lesion revealed no significant difference in white value among fibers (1 to 6). However, there were significant differences in white value among specks 7 to 11 with the following order:  $7 > (8=9) > (10=11)$ . Therefore, there were remarkable difference in the brightest value between the 9<sup>th</sup> and 10<sup>th</sup> dummy lesions for visual inspection. With respect to mass (12 to 16), there were no significant differences in the brightest value:  $12=13=14=15=16$ . In summary, Max (B) concentration were not significantly different between fiber 4 and fiber 5 or between masses 3 and 4 determined to be appropriate by dummy lesion but found to be different between specks 3 and 4.

Mean values of Mean (C) concentrations of pixel values for 17 regions ranged from  $1,822.1 \pm 625.9$  for the first dummy lesion to

1,795.3 ± 740.7 for the 16<sup>th</sup> dummy lesion without any statistically significant difference (p = 0.998) among regions. Therefore, Mean (C) concentration of each ROI region was not significantly different among the 17 regions.

Mean values of difference (D) between Max (B) and Min (A) concentrations of pixel values for the 17 regions ranged from 100.9 ± 80.3 for the first dummy lesion to 77.7 ± 59.1 for the 16<sup>th</sup> dummy lesion with statistically significant differences among some regions. Post-hoc analysis of one-way ANOVA showed the following results: (background=2=3=5=6=9=10=11=13=14=15=16) ≤ (1=4=7=8) < 12. Values of background and other dummy lesions varied from 73 to 105 without statistically significant difference. Only the value of the 12<sup>th</sup> dummy lesion was 122 which was the highest. There were no significant differences in (D) value (difference between Max (B) and Min (A) concentrations) among fibers (1 to 6). There were no significant difference in (D) value among specks (7 to 11) ei-

ther. Deviations were high among masses (12 to 16). However, only the 12<sup>th</sup> dummy lesion was significantly different from others. This means that the area between black and white in the 12<sup>th</sup> dummy lesion has significant difference. However, differences (D) between Max (B) and Min(A) concentrations were not significant between fiber 4 and fiber 5, between specks 3 and 4, or between masses 3 and 4 determined to be appropriate by dummy lesion.

In summary, there were no significant differences in optical density for 17 regions (including 16 dummy lesions and background), between fibers 4 and 5, between specks 3 and 4, or between masses 3 and 4 determined to be appropriate by dummy lesion. However, there were significant differences in Max (B) concentration between the 9<sup>th</sup> (specks 3) dummy lesion and the 10<sup>th</sup> (specks 4) dummy lesion with large deviation between black and white.

**Table 1:** Optical Density - Continued

Variable	Dummy lesions	N	mean	± SD	Multiple comparisons†	F	p*
A	1	165	1474.8	± 814.3		0.326	0.995
	2	165	1481.7	± 807.6			
	3	165	1471.3	± 805.6			
	4	165	1461.6	± 796.9			
	5	165	1511.3	± 822.2			
	6	165	1500.6	± 828.0			
	7	165	1368.4	± 882.7			
	8	165	1402.2	± 845.9			
	9	165	1452.5	± 840.7			
	10	165	1509.4	± 855.7			
	11	165	1476.0	± 850.7			
	12	165	1463.2	± 832.8			
	13	165	1519.9	± 861.4			
	14	165	1519.3	± 873.4			
	15	165	1496.2	± 870.1			
	16	165	1502.7	± 864.8			
	17	165	1590.9	± 834.2			
	Total	2805	1482.5	± 838.0			
B	1	165	2256.2	± 431.4	a,b	21.709	<0.001
	2	165	2252.0	± 530.8	a,b		
	3	165	2187.9	± 479.1	a,b		
	4	165	2223.5	± 471.2	a,b		
	5	165	2212.0	± 513.6	a,b		
	6	165	2286.7	± 1004.1	a,b		
	7	165	3043.2	± 465.2	d		
	8	165	2804.1	± 352.1	c		
	9	165	2685.5	± 382.3	c		
	10	165	2344.3	± 488.1	b		
	11	165	2201.4	± 558.6	a,b		
	12	165	2368.0	± 465.8	b		
	13	165	2255.9	± 535.0	a,b		
	14	165	2192.4	± 573.4	a,b		
	15	165	2203.6	± 578.8	a,b		
	16	165	2183.3	± 558.3	a,b		
	17	165	2041.7	± 609.6	a		
	Total	2805	2337.8	± 599.5			
Variable	Dummy lesions	N	mean	± SD	Multiple comparisons†	F	p*
C	1	165	1822.1	± 625.9		0.271	0.998
	2	165	1977.9	± 1869.5			
	3	165	1784.1	± 639.5			
	4	165	1797.1	± 619.0			
	5	165	1822.0	± 685.4			
	6	165	1820.1	± 693.7			
	7	165	1793.7	± 675.7			

	8	165	1802.1	± 662.7			
	9	165	1822.5	± 732.9			
	10	165	1816.1	± 735.3			
	11	165	1798.2	± 722.9			
	12	165	1834.3	± 673.8			
	13	165	1821.8	± 739.2			
	14	165	1822.8	± 754.4			
	15	165	1799.0	± 745.1			
	16	165	1795.3	± 740.7			
	17	165	1794.0	± 736.7			
	Total	2805	1819.0	± 813.9			
D	1	165	100.9	± 80.3	a,b	0.322	<0.001
	2	165	91.1	± 71.8	a		
	3	165	88.0	± 67.9	a		
	4	165	92.2	± 74.4	a,b		
	5	165	83.4	± 65.6	a		
	6	165	81.5	± 63.2	a		
	7	165	105.3	± 81.2	a,b		
	8	165	95.7	± 75.9	a,b		
	9	165	82.2	± 62.6	a		
	10	165	77.2	± 58.9	a		
	11	165	78.5	± 60.7	a		
	12	165	122.6	± 86.5	b		
	13	165	88.4	± 64.8	a		
	14	165	81.3	± 60.9	a		
	15	165	79.3	± 60.8	a		
	16	165	77.7	± 59.1	a		
	17	165	73.1	± 55.7	a		
	Total	2805	88.1	± 69.0			

\* By one-way analysis of variance at  $p < 0.05$ .

† least significant difference : LSD

- a) Min., The value of most of the black of ROI(lowest density)
- b) Max., The value of most of the white of ROI(maximum density)
- c) Mean, The average brightness level of ROI
- d) S.D., The difference between the black and the white of the ROI (Difference between the highest and lowest density)

### 3.2. Analysis of optical density between appropriate and inappropriate decisions by dummy lesions

Analysis results on whether there were differences in optical density between appropriate and inappropriate decisions by dummy lesions for fiber, specks, and masses are shown in Table 2.

For fibers, there were no statistically significant differences in Min (A) concentration between appropriate decision (1,275.3) and inappropriate decision (1,310.2) ( $p = 0.074$ ). There were no statistically significant differences in Max (B) concentration between appropriate decision (2,047.6) and inappropriate decision (2,111.3) ( $p = 0.418$ ) either. There were no statistically significant differences in Mean (C) concentration between appropriate decision (1,612.5) and inappropriate decision (1,632.6) ( $p = 0.311$ ) either. On the other hand, there were statistically significant differences in concentration difference (D) between appropriate decision (93.1) and inappropriate decision (86.0) ( $p < 0.001$ ).

For specks, there were statistically significant differences in Min (A) concentration between appropriate decision (1,274.5) and

inappropriate decision (1,305.6) ( $p = 0.025$ ). There were also significant differences in Max (B) concentration between appropriate decision (2,354.2) and inappropriate decision (2,092.3) ( $p < 0.001$ ). However, there were no significant differences in Mean (C) concentration between appropriate decision (1,627.9) and inappropriate decision (1,625.2) ( $p = 0.297$ ). On the other hand, there were statistically significant differences in concentration difference (D) between appropriate decision (82.4) and inappropriate decision (81.2) ( $p = 0.019$ ). Therefore, mean differences between appropriate and inappropriate decisions were shown in Min (A), Max (B), and concentration difference (D).

For masses, there were no statistically significant difference in Min (A) concentration between appropriate decision (1,274.5) and inappropriate decision (1,305.6) ( $p = 0.252$ ). There was a significant difference in Max (B) concentration between appropriate decision (1,947.1) and inappropriate decision (1,886.5) ( $p < 0.001$ ). There was also statistically significant difference in Mean (C) concentration between appropriate decision (1,687.5) and inappropriate decision (1,641.1) ( $p < 0.001$ ). In addition, statistically significant difference in concentration difference (D) between appropriate decision (82.4) and inappropriate decision (80.3) ( $p = 0.025$ ) was found. Therefore, mean differences between appropriate and inappropriate decisions were shown in Max (B), Mean (C), and concentration difference (D).

**Table 2:** Comparison between Appropriate and Inappropriate Decisions

Dummy lesions	Variable	N	Appropriate decisions		Inappropriate decisions		F	p*
			mean	± SD	mean	± SD		
Fiber	A	165	1275.3	± 786.8	1310.2	± 821.7	-1.804	0.074
	B	165	2047.6	± 529.3	2111.3	± 966.4	-0.813	0.418
	C	165	1612.5	± 646.7	1632.6	± 704.4	-1.018	0.311
	D	165	93.1	± 65.9	86.0	± 58.6	5.021	<0.001
Specks	A	165	1274.5	± 831.1	1305.6	± 845.1	-2.265	0.025
	B	165	2354.2	± 494.2	2092.3	± 573.1	11.304	<0.001
	C	165	1627.9	± 745.7	1625.2	± 743.2	1.047	0.297
	D	165	82.4	± 54.5	81.2	± 53.2	2.373	0.019
Masses	A	165	1623.7	± 2060.1	1433.3	± 803.4	1.150	0.252
	B	165	1947.1	± 589.1	1886.5	± 609.4	6.547	<0.001
	C	165	1687.5	± 702.9	1641.1	± 716.6	6.588	<0.001
	D	165	82.4	± 53.1	80.3	± 52.4	2.274	0.025

\* By paired t-test  $atp < 0.05$ .

- Min., the value of the most for black of ROI (lowest density)
- Max., the value of the most for white of ROI (maximum density)
- Mean, average brightness level of ROI
- S.D., the difference between black and white of ROI (Difference between the highest and lowest density)

## 4. Conclusion

During the process of quality control, phantom image test in mammography may encounter error due to subjective decision of the evaluator upon visual eye inspection. Therefore, quantitative analysis method is required to evaluate the image quality by optic density digitalization of breast images<sup>18</sup>. Based on results of analysis for optic density differences using color level to understand whether visual identification of dummy lesion has objectivity quantitatively, we have the following results: 1) There were significant differences in Max (B) concentration between dummy lesions 9 (specks 3) and 10 (specks 4); 2) In dummy lesion 12 (masses 1), there was no significant difference by each step, although deviation between black and white was high since the scope of lesion was big; 3) Analysis results of optic density divided by appropriate and inappropriate decisions showed that there were significant differences in concentration difference (D) for fibers. There were also significant difference in Min (A) concentration, Max (B) concentration, and concentration difference (D) for specks. In addition, there were significant differences in Max (B) concentration, Mean (C) concentration, and concentration difference (D) for masses.

In conclusion, visual inspections appeared to have difficulty in analyzing lesions due to the ambiguity of quantitative differences. Therefore, further developments of quantitative programs are needed to replace visual inspection for breast phantom lesions in mammography.

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