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Research Article

Quantitative Assessment of Iodine Intensity of Different Types of Lesions in the Low-Energy (LE) Images of Contrast-Enhanced Spectral Mammography (CESM)

Sachila Niroshani^{1,2*}, Tokiko Nakamura^{1,3}, Nikaidou Michiru¹ and Toru Negishi¹¹Department of Radiological Sciences, Graduate School of Human Health Sciences, Tokyo Metropolitan University, Tokyo, Japan²Department of Radiography and Radiotherapy, Faculty of Allied Health Sciences, General Sir John Kotelawala Defence University, Werahera, Sri Lanka³Department of Radiology, Juntendo University Shizuoka Hospital, Japan

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ABSTRACT

Purpose: To assess the iodine enhancement intensity of breast lesions in low energy (LE) images obtained in contrast-enhanced spectral mammography (CESM) with different tissue compositions.**Materials and Methods:** A 50 mm dedicated phantom with different lesion insert and iodine insert were used to assess the enhancement intensity quantitatively. The target slab of the phantom consists of three lesions + iodine inserts together and 100% adipose equivalent, 100% glandular equivalent inserts alone to mimic the adipose and glandular lesion without contrast-enhancement. Each iodine inserts having a concentration of 0.5 mgI/cm³, 1.0 mgI/cm³, 2.0 mgI/cm³. The phantom was exposed under semiautomated function at 28 kV, 30 kV, and 32 kV with Mo/Rh target/filter combination. Iodine intensity was estimated for three types of lesions at three breast equivalent compositions.**Results:** Lesions with fatty tissue had high intensity while lesions with glandular tissues had the minimum intensity. Among fatty lesions, highest mean intensity value (0.972±0.003) observed with minimum iodine concentration (F + 0.5 mgI/cm³). The highest mean intensity value (0.882±0.001) was found related to the glandular lesion with maximum iodine concentration (G + 2.0 mgI/cm³). The one-way ANOVA statistical test confirmed that mean intensity values were significantly varied among different lesions (P < 0.05).**Conclusion:** LE images obtained in CESM can be used to identify the different types of lesions without performing the full field digital mammography (FFDM) as an additional examination prior to the CESM procedure.

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Introduction

Contrast-enhancement spectral mammography (CESM) is a recently developed advanced technology in mammography to improve the identification of breast cancers [1-3]. Prior administration of intravenous contrast agent is required to obtain a pair of low-energy (LE) and high energy (HE) images [4]. Then, LE and HE images are combined to produce the final image which clearly demonstrates the lesion enhancement by eliminating the overlapping breast tissues in the background [5-7]. LE images provide the morphological information of

the breast lesion as similar to the full-field digital mammography (FFDM) [7, 8]. HE images are only used for post-processing since they contain only iodine enhancement information [9]. CESM is more important in the diagnosis of breast cancers in dense breasts [10]. According to the previously published research, contrast-enhancement intensity is a reliable factor for differentiating benign and malignant lesions in the breast. And their results have concluded that contrast-enhancement intensity was usually stronger in malignant lesions than that of benign lesions [11-13].

*Correspondence to: Sachila Niroshani, Department of Radiological Sciences, Graduate School of Human Health Sciences, Tokyo Metropolitan University, Tokyo, Japan

Department of Radiography and Radiotherapy, Faculty of Allied Health Sciences, General Sir John Kotelawala Defence University, Werahera, Sri Lanka; E-mail: sach06025@gmail.com

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Moreover, Luczynska *et al.* have proved that invasive carcinomas showed strong enhancement than non-invasive carcinomas and benign lesions [13]. Yakoumakis *et al.* concluded that LE imaging mainly contributes to the average glandular dose received from complete CESM procedure [14]. LE images are equivalent to the FFDM images [8]. Therefore, lesion morphology can be assessed by performing LE image instead of additional FFDM when patients with suspicious breast mass [15]. Hence additional radiation dose from standard FFDM can be minimized. Therefore, it is important to assess the contrast-enhancement intensity of different lesions in LE images. The aim of this study was to compare the degree of intensity according to different lesion types with different iodine concentrations in LE images and to establish the lesion type which can identify with high intensity in LE images.

Materials and Methods

The present study used a 50 mm dedicated phantom and MGU-1000D MAMMOREX *pe.ru.ru* digital mammography machine. The target slab

of the phantom consists of three lesions + iodine inserts together and 100% adipose equivalent, 100% glandular equivalent inserts alone to mimic the adipose and glandular lesion without contrast-enhancement. Each iodine inserts having a concentration of 0.5 mgI/cm³, 1.0 mgI/cm³, 2.0 mgI/cm³. The phantom was exposed under semiautomated function at 28 kV, 30 kV, and 32 kV with Mo/Rh target/filter combination. Three phantom designs were created by using different lesion composition inserts per one tissue composition of the phantom (Table 1) and exposed at each selected peak tube voltages. Iodine intensity was estimated for three types of lesions in three breast equivalent compositions and all the exposure conditions. The intensity of the lesion of acquired images was obtained by using the tools available with the Fiji image J software platform. Lesion inserts of 10 mm in diameter have been selected as the region of interest (ROI) to assess the intensity. Intensity values obtained from each lesion type were normalized to background intensity. Mean glandular dose (MGD) was calculated using a Dance method to assess whether the MGD is varied according to different types of lesions [16].

Table 1: Details of patterns of the phantom used for exposure.

Phantom composition	Lesion pattern in the phantom		
100% adipose	F + 0.5 mgI/cm ³	G + 0.5 mgI/cm ³	FG + 0.5 mgI/cm ³
	F + 1.0 mgI/cm ³	G + 1.0 mgI/cm ³	FG + 1.0 mgI/cm ³
	F + 2.0 mgI/cm ³	G + 2.0 mgI/cm ³	FG + 2.0 mgI/cm ³
50% adipose- 50% fibroglandular	F + 0.5 mgI/cm ³	G + 0.5 mgI/cm ³	FG + 0.5 mgI/cm ³
	F + 1.0 mgI/cm ³	G + 1.0 mgI/cm ³	FG + 1.0 mgI/cm ³
	F + 2.0 mgI/cm ³	G + 2.0 mgI/cm ³	FG + 2.0 mgI/cm ³
100% fibroglandular	F + 0.5 mgI/cm ³	G + 0.5 mgI/cm ³	FG + 0.5 mgI/cm ³
	F + 1.0 mgI/cm ³	G + 1.0 mgI/cm ³	FG + 1.0 mgI/cm ³
	F + 2.0 mgI/cm ³	G + 2.0 mgI/cm ³	FG + 2.0 mgI/cm ³

**F: Fatty tissue lesion; G: Glandular tissue lesion; FG: Fatty tissue + Glandular tissue lesion.

Results

I Quantitative Analysis of the Intensity of the Iodine in Different Lesion

The intensity of the lesion was calculated according to the below equation. Total mean intensity values for different types of lesions and mean intensity values according to breast equivalent compositions are summarized in (Tables 2 & 3).

$$\text{Lesion intensity} = \frac{\text{Mean pixel value of the lesion (I)}}{\text{Mean pixel value of the back ground (B)}}$$

Table 2: Total mean intensity values of the iodine in different lesions.

Lesion pattern in the phantom	Mean intensity
F + 0.5 mgI/cm ³	0.972 (±0.003)
F + 1.0 mgI/cm ³	0.963 (±0.006)
F + 2.0 mgI/cm ³	0.959 (±0.004)
G + 0.5 mgI/cm ³	0.895 (±0.009)
G + 1.0 mgI/cm ³	0.890 (±0.011)
G + 2.0 mgI/cm ³	0.882 (±0.001)
FG + 0.5 mgI/cm ³	0.939 (±0.006)
FG + 1.0 mgI/cm ³	0.933 (±0.009)
FG + 2.0 mgI/cm ³	0.926 (±0.007)

Table 3 Mean intensity values of the iodine in different lesions in three different breast equivalent phantom.

Lesion pattern in the phantom	Tissue composition of the phantom		
	100% adipose	50%adipose-50%glandular	100% glandular
F + 0.5 mgI/cm ³	0.970(±0.002)	0.972(±0.005)	0.974(±0.003)
F + 1.0 mgI/cm ³	0.958(±0.003)	0.962(±0.002)	0.973(±0.007)
F + 2.0 mgI/cm ³	0.956(±0.003)	0.958(±0.004)	0.964(±0.004)
G + 0.5 mgI/cm ³	0.889(±0.007)	0.894(±0.007)	0.905(±0.006)
G + 1.0 mgI/cm ³	0.882(±0.007)	0.887(±0.007)	0.906(±0.006)
G + 2.0 mgI/cm ³	0.877(±0.008)	0.881(±0.009)	0.895(±0.006)
FG + 0.5 mgI/cm ³	0.934(±0.004)	0.939(±0.005)	0.944(±0.004)
FG + 1.0 mgI/cm ³	0.928(±0.004)	0.930(±0.004)	0.946(±0.003)
FG + 2.0 mgI/cm ³	0.921(±0.005)	0.925(±0.006)	0.933(±0.004)

II Statistical Analysis

The one-way ANOVA statistical test was performed to determine whether there are significant differences between the mean intensity values of iodine in different lesions and to determine that mean intensity values of iodine in the same lesion have significant differences among different breast tissue equivalent composition of the phantom. Results confirmed the significant difference among the mean intensity values of iodine in different lesions ($P < 0.05$) (Figure 1). And it has not been changed with the varying iodine concentration in the lesion. The mean iodine intensity of F + 1.0 mgI/cm³, G + 1.0 mgI/cm³ and FG + 1.0 mgI/cm³ lesions has shown a significant difference between 100% adipose and 100% glandular equivalent phantom and 50% adipose-50% glandular and 100% glandular equivalent phantom ($P < 0.05$) while not significant between the 100% adipose and 50% adipose -50% glandular equivalent phantom (Figure 2). The mean intensity of iodine concentration of 0.5 mgI/cm³ and 2.0 mgI/cm³ in different mass compositions not significantly varied according to the different tissue compositions of the phantom.

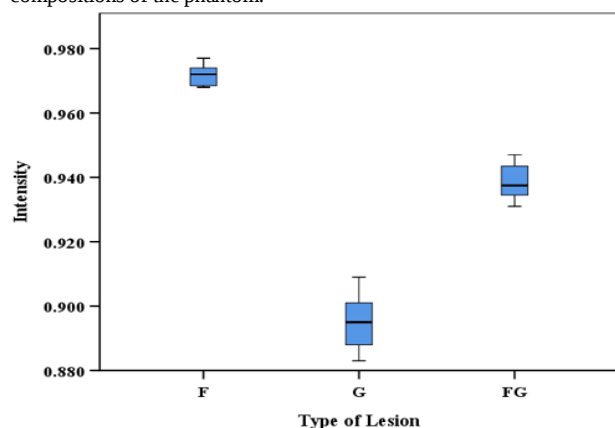


Figure 1: Box-whisker plot of iodine intensity values of different types of lesions by tissue composition. Boxes are not overlapping; hence intensity values are significantly varied among three lesion groups. The graph has been plotted for lesions with minimum iodine concentration (0.5 mgI/cm³).

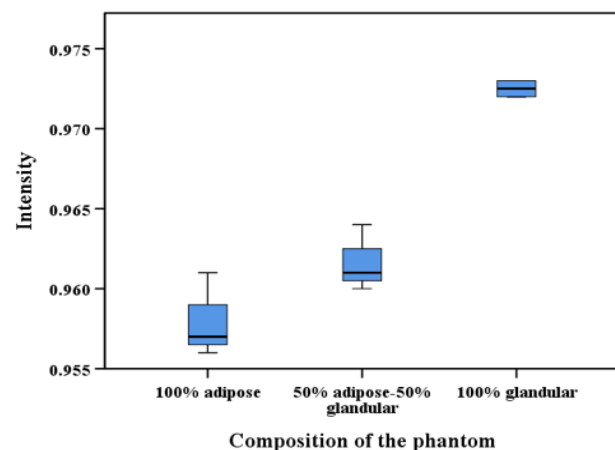


Figure 2: Box-whisker plot of iodine intensity values of different types of lesions in the varying composition of breast equivalent phantom. The intensity of all types of lesions was highest in the 100% glandular phantom. The graph has plotted for lesions with 1.0 mgI/cm³ iodine concentration.

III Assessment of Mean Glandular Dose (MGD)

MGD values were not significantly changed according to lesion patterns. It was varied only with the amount of glandularity of the phantom. Mean MGD values are summarized in (Table 4).

Table 4: Summary of the mean MGD values of the phantom with different composition.

Composition of the phantom	Mean MGD (mGy)
100% adipose	1.35 ± 0.17
50% adipose - 50% fibroglandular	1.53 ± 0.19
100% glandular	1.75 ± 0.21

Discussion

CESM is a superior imaging tool to non-contrast conventional mammography in the detection of breast lesions [17]. Since LE image of CESM can avoid the performing of FFDM prior to the start of the CESM procedure, it can be used to provide diagnostic information regarding the lesion. Therefore, the present study quantitatively assessed the intensity of iodine in lesions with different tissue compositions in order to determine the enhancement variation according to iodine concentration in different types of lesions. According to Li, *et al.*, mammographic texture analysis is a well-founded technique for distinguishing between benign and malignant breast tumors [18]. Therefore, pixel value or intensity is one of the reliable features for differential diagnosis of benign and malignant tumors. The present study, therefore, compared the effect of the intensity of iodine in the differentiation of lesions according to its composition. The study found that iodine in the fatty tissue mass has the highest intensity than the glandular and fatty tissue + glandular tissue lesions. The minimum mean intensity value of iodine was observed with glandular lesions (Table 2, Figure 3).

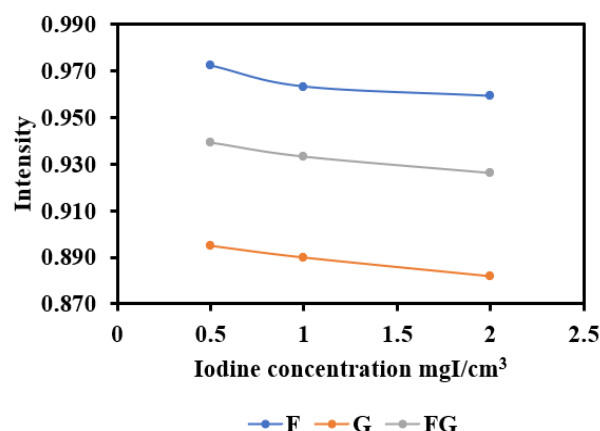


Figure 3: Intensity of iodine in different lesions versus iodine concentration.

Therefore, contrast-enhanced fatty tissue lesions are well visualized in LE images. LE images acquire by using low-energy X-rays just below the k-edge of iodine (Approximately 33 keV) [19]. Since LE imaging is less X-ray absorbed, LE images are not mainly used to visualize the contrast-enhancement information. Hence the visual appearance of the iodine is dependent on the X-ray absorption properties in two acquisitions, and it is identical to two acquisitions. According to (Figure

3) intensity of iodine decreases with increased concentration of iodine for three types of lesions. When the amount of glandular tissues within the lesion increased mean intensity value further decreased. It could be due to decreasing of X-ray absorption by the high concentration of iodine and glandular tissues at low energies. The present study confirmed that a low concentration of iodine in lesions provides better visualization in LE images. Although there were no previously published similar results to compare with the present study, few studies are investigated the clinical images to assess the contrast-enhancement intensity and pattern in the differential diagnosis of breast lesions in dual-energy contrast-enhanced spectral mammography [20, 21].

Published results concluded that contrast-enhancement intensity and pattern allow more accurate evaluation of breast lesions in CESM. This conclusion is comparable with the present study findings that lesion intensity values were significantly different according to the tissue composition of the lesion. Rudniki *et al.* also compare the mean intensity value of the lesion quantitatively to differentiate the lesions as the present study [11]. Moreover, the present study results confirmed that the contrast intensity of different lesions do not significantly change with the composition of the breast except at an iodine concentration of 1.0 mgI/cm³ (Figure 2). Lesions that are having 1.0 mgI/cm³ iodine demonstrate a significant difference in mean intensity value among 100% adipose and 100% fibroglandular tissue equivalent phantom and 50% adipose-50% glandular - 100% glandular phantom (Figure 2). The calculated MGD values were almost consistent with the varying lesions and iodine contrast. But it was significantly changed with the percentage of glandularity in the phantom for the same thickness (Table 4). This present study recommended that the evaluation of enhancement intensity of the recombine image parallel to LE image intensity evaluation to confirm the optimum iodine concentration required to produce adequate intensity in recombining image and this will be considered in the future research study.

Conclusion

Contrast-enhancement intensity on LE images has relevance to the tissue composition of the lesion, and it is good at identifying different lesions without performing additional FFDM examination prior to the CESM procedure. Hence it will lead to reduce the additional radiation dose to the patient already referred to as suspicious of breast mass. Furthermore, present study found that less iodine concentration is required to make a considerable difference of intensity among different types of lesions in LE images.

Conflicts of Interest

None.

Abbreviation

LE: Low Energy

CESM: Contrast-Enhanced Spectral Mammography

FFDM: Full Field Digital Mammography

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