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Dose reduction in Full-Field Digital Electromagnetic Radiation Mammography using Noise reduction Method: Phantom Study

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The purpose of study is to investigate optimal exposure parameters for full-field digital electromagnetic radiation mammography (FFDM) and to reduce the average glandular dose (AGD) by applying a noise reduction algorithm. To find an optimal exposure parameter, filtration-target material combinations (Mo/Rh, Mo/Mo, W/Rh) were applied by each tube voltages (23-35 kVp). AGD, Noise, Figure-of-merit (FOM) were measured. The experimental results, using 29 kVp of W/Rh was found to be best in all cases before and after applying the denoising filter. With a denoising filter, noise decreased 76.44 % and SNR increased 76.18 %, which improved image quality. If a denoising method is suggested for images of 35 kVp of W/Rh (SNR: 3.58, AGD: 0.67 mGy) using the smallest AGD when using FFDM, better picture quality (SNR 9.73, ADG: 0.67 mGy) could be gotten than 23 kVp of Mo/Mo combination. From this study, it is possible to obtain good quality images with a lower dose than FFDM used in the clinic.

Keywords : high energy electromagnetic beam, electromagnetic beam image, electromagnetic radiation, mammography

1. Introduction

Breast cancer is a kind of malignant tumor diagnosed commonly in women. Mammography reduces breast cancer mortality, largely through its ability to depict subtle soft-tissue masses and microcalcifications that may represent early breast cancer and Detection of mammary cancer at an early stage has the advantage of improving the probability of survival considerably [1]. However as use of mammograms is increasing every year, interest in the issue of long-term effects of radiation is also increasing. Therefore, the importance of investigating the electromagnetic radiation dose to breasts is required to be emphasized.

To diagnose cancer of mammography, use of full-field digital electromagnetic radiation mammography (FFDM) is increasing in comparison with the use of screen/film mammography (SFM) in the past. Digital detectors used in FFDM has a feature of a linear response over a wide range of electromagnetic radiation intensities and can be used in manually or automatically by setting up the exposure parameters of digital mammography [2].

FFDM system which is now being used and equipped with a function of Automatic exposure control (AEC) calculate milliampere by sec (mAs) automatically by breast thickness to apply and in many cases, it is designed to use Tube potential (kilovoltage peak; kVp), filtration-target material optionally. This capability has prompted a discussion about the possibility of dose reduction. A dose reduction in digital electromagnetic radiation mammography by lowering the mAs results in loss of microcalcifications detectability due to an increase in noise [3]. However it is very important to use the best exposure parameter which can get by using filtration-target material and proper kVp considering Average Glandular Dose (AGD) which patients get exposed radiation dose as well as making efforts of the optimal picture quality [3, 6, 7, 9, 11]. AGD is a quantity used to describe the absorbed dose of radiation dose in mammography. On the other hand, attempts at improving picture quality through denoising would be of great help in reducing AGD.

This study intends to understand the optimal filtration-target material and kVp after measuring noise, contrast, signal to noise ratio (SNR) and figure-of-merit (FOM) from a phantom image and to improve SNR of images by suggesting a denoising method. In this study, we investigate

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the optimal parameters and reduce the AGD using our proposed noise reduction method.

2. Materials and Methods

2.1. FFDM Protocols and Dose Report

This experiment used FFDM of Siemens Mammomat Inspiration (Siemens, Erlangen, Germany) to achieve images. This experiment was performed by applying a focal spot of 0.3 and 3 kinds of Mo/Mo, W/Rh and Mo/Rh for combinations of filtration-target material.

There are manual mode and AEC mode in FFDM system used in the clinic and when AEC mode is used kVp and filtration-target material is designed to be used optionally. This study investigates to examine the optimal exposure parameter which can reduce AGD when AEC mode is used in the clinic and to investigate results after application of the denoising method.

Images to be used in the experiment were collected by using phantom (CIRS, Virginia, USA) of Nuclear Associates Model 18-222 (Fig. 1). At the same time, entrance surface air kerma (ESAK) and AGD were measured which were automatically reported directly from the DICOM (digital imaging and communication in medicine) metadata. Then, the phantom was fixed in the same spot and images were taken from several voltages (23-35 kVp). When an experiment was finished, experiments were progressed changing filtration-target material and Tube potential. Test images collected were evaluated repeated applying the denoising algorithm.

2.2. Denoising with Total Variation (TV)

Uncorrelated noise includes high-energy electromagnetic wave beam quantum noise, electronic noise, and thermal noise which have primary and scatter noise in a detector [6]. Also, uncorrelated noise which arises in the FFDM system affects image quality. To improve this problem, we need to select of high kVp, but cause high dose exposure problem.

For optimal denoising, this study suggests the total variation method [8]. Our interest is to denoise an image. The denoising process should recover the edges of the image. The model of degradation we assume is

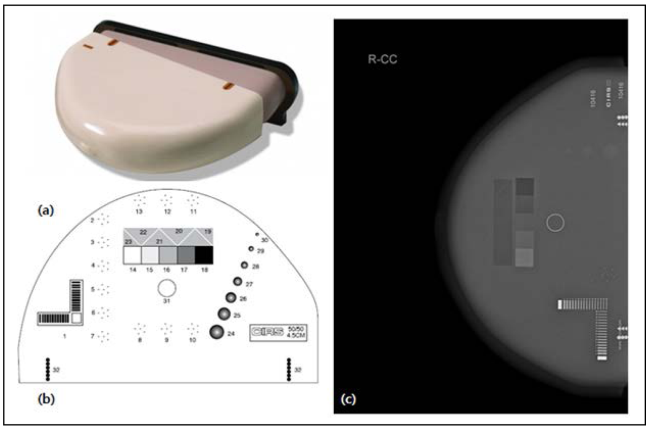

Fig. 1. (Color online) Photograph shows the phantom (Siemens Mammomat Inspiration) used in the experiment. (a) phantom appearance. (b) phantom schematic. (c) FFDM phantom image.

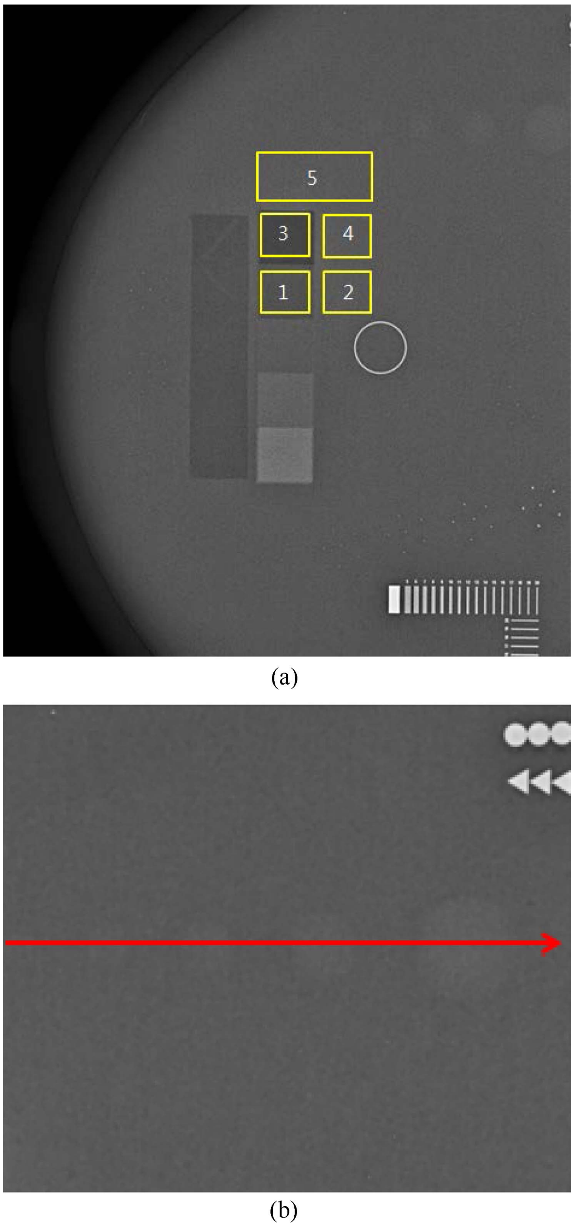

Fig. 2. (Color online) (a) Schematic shows measurement of image quality evaluation indexes in mammography phantom. Regions of interest have 90×90 pixels area. (b) Schematic shows profile information for resolution analysis of mass.

Table 1. Image quality for the FFDM images obtained at various voltages with AEC Mode. (FFDM images)

kVp	Mo/Mo			W/Rh			Mo/Rh		
	Signal	Noise	SNR	Signal	Noise	SNR	Signal	Noise	SNR
23	23.50	3.77	6.23	22.90	4.33	5.29	22.95	3.93	5.84
24	23.12	3.83	6.04	21.94	4.47	4.91	21.94	4.01	5.48
25	22.28	3.93	5.67	21.36	4.31	4.95	21.70	3.93	5.52
26	21.57	3.84	5.62	21.00	4.35	4.83	21.61	4.04	5.32
27	20.69	3.82	5.41	20.59	4.32	4.77	21.02	4.04	5.21
28	19.82	3.85	5.15	20.38	4.36	4.67	20.78	4.08	5.09
29	18.50	3.89	4.76	19.98	4.35	4.59	20.26	4.10	4.94
30	17.92	3.94	4.55	19.78	4.45	4.45	19.53	4.10	4.76
31	16.82	3.96	4.24	19.17	4.43	4.33	19.14	4.16	4.60
32	16.07	3.97	4.04	18.90	4.50	4.20	18.64	4.16	4.48
33	15.52	4.06	3.82	18.15	4.51	4.02	17.83	4.21	4.24
34	14.71	4.10	3.59	17.04	4.57	3.78	17.30	4.26	4.06
35	14.15	4.17	3.39	16.76	4.68	3.58	16.68	4.29	3.89

SNR: signal to noise ratio,
Mo/Mo: molybdenum-molybdenum,
W/Rh: tungsten-rhodium
Mo/Rh: molybdenum- rhodium

Table 2. Image quality for the FFDM images obtained at various voltages with AEC Mode. (Denoised FFDM images)

kVp	Mo/Mo			W/Rh			Mo/Rh		
	Signal	Noise	SNR	Signal	Noise	SNR	Signal	Noise	SNR
23	23.59	1.70	13.89	22.88	2.21	10.81	22.98	1.85	12.42
24	23.13	1.73	13.34	21.94	2.20	9.96	21.90	1.86	11.76
25	22.27	1.82	12.26	21.45	2.11	10.15	21.65	1.81	11.97
26	21.54	1.76	12.23	20.95	2.11	9.92	21.60	1.89	11.44
27	20.70	1.73	11.99	20.51	2.09	9.81	21.01	1.90	11.09
28	19.78	1.74	11.38	20.37	2.09	9.75	20.73	1.95	10.65
29	18.44	1.77	10.44	20.00	2.09	9.57	20.16	1.96	10.31
30	17.93	1.79	10.02	19.76	2.19	9.03	19.54	1.94	10.06
31	16.78	1.80	9.32	19.23	2.14	8.97	19.14	2.01	9.53
32	16.03	1.84	8.69	18.90	2.24	8.43	18.63	1.99	9.36
33	15.55	1.87	8.31	18.11	2.25	8.05	17.86	2.04	8.77
34	14.72	1.94	7.60	17.13	2.30	7.45	17.36	2.07	8.40
35	14.13	1.95	7.26	16.73	2.37	7.05	16.72	2.08	8.04

SNR : signal to noise ratio
Mo/Mo: molybdenum-molybdenum,
W/Rh: tungsten-rhodium
Mo/Rh: molybdenum-rhodium.

$$u + n = u_0 \tag{1}$$

Where n is noise, u_0 is the observed image and u is original image.

Image can be interpreted as a real function defined on a bounded and open domain of Ω.

The notation of $|u|$ stands for the 2-norm of the function u.

$$TV(u) = \int_\Omega |\nabla u| dxdy \tag{2}$$

TV from signals indicates the change of pixel values from neighboring pixels in the images.

In Fig. 2(a), To evaluate picture quality from collected images, signals of electromagnetic mammography image required for image evaluation can be got by calculating the information of regions of interest (ROI) which is acquired as through the following Formula (Eq. 3-7).

$$\text{Signal} = [\text{avg}(\text{ROI}_2) - \text{avg}(\text{ROI}_1)] - [\text{avg}(\text{ROI}_4) - \text{avg}(\text{ROI}_3)] \tag{3}$$

$$\text{Noise} = \frac{\text{Stddev}(\text{ROI}_5)}{\sqrt{2}} \tag{4}$$

$$\text{Contrast} = \frac{[\text{avg}(\text{ROI}_2) - \text{avg}(\text{ROI}_1)]}{\text{avg}(\text{ROI}_1)} \quad (5)$$

$$\text{SNR} = \text{Sognal/Noise} \quad (6)$$

$$\text{FOM(mGy}^{-1}) = \frac{\text{SNR}}{\text{AGD(mGy)}} \quad (7)$$

To get average signal intensity from the phantom, 90×90 pixel was used in all ROI. Location of ROI 1 is set up in a step-wedge which exists within phantom, ROI 2 was set up at the same size with background around ROI 2 through ROI 4 and ROI 5 was set up with 260×220 in a separate location. In general, the signal value is achieved by getting the difference between step-wedge ROI 1 and background ROI 2. However regions such as ROI 3 and ROI 4 were added and calculated to correct Heel Effect and background trends (6). Noise value can be achieved by having a standard variation value of ROI 5 pixels value and making a square root of 2 in it. SNR is shown by the ratio of signal power against noise power. If SNR higher than 1 it indicates more signal than noise.

This study employed a FOM which Williams [6] suggested to study the tradeoff between SNR and AGD. FOM is an indicator which is used for deciding a maximum SNR while minimizing AGD and it becomes better to indicate as a result value is higher.

In this study, we analyzed the significance of the difference using IBM SPSS Statistics 25 (IBM, Seoul, Korea) for the results of the quality analysis indexes according to

Table 3. AGD and FOM at various voltages with AEC Mode. (FFDM images)

kVp	Mo/Mo			W/Rh			Mo/Rh		
	ESD (mGy)	MGD (mGy)	FOM (mGy^{-1})	ESD (mGy)	MGD (mGy)	FOM (mGy^{-1})	ESD (mGy)	MGD (mGy)	FOM (mGy^{-1})
23	12.3	2.77	14.00	3.1	1.32	21.18	7.1	2.19	15.57
24	10.5	2.42	15.08	2.6	1.06	22.76	5.8	1.81	16.57
25	8.7	2.1	15.33	2.3	1.05	23.36	5.4	1.72	17.72
26	8	1.98	15.94	2.3	0.99	23.58	4.9	1.57	18.25
27	7.1	1.79	16.35	2.2	0.95	23.95	4.6	1.5	18.06
28	6.4	1.63	16.25	2.1	0.92	23.73	4.3	1.45	17.86
29	5.8	1.51	14.98	2	0.88	23.99	4.1	1.39	17.56
30	5.3	1.39	14.91	1.9	0.85	23.29	3.9	1.34	16.92
31	4.8	1.3	13.85	1.8	0.81	23.14	3.8	1.29	16.40
32	4.5	1.22	13.40	1.7	0.78	22.63	3.6	1.25	16.09
33	4.2	1.16	12.60	1.6	0.74	21.84	3.5	1.21	14.86
34	4	1.13	11.39	1.5	0.71	19.57	3.3	1.18	14.00
35	3.8	1.06	10.85	1.4	0.67	19.13	3.2	1.15	13.16

Table 4. AGD and FOM at various voltages with AEC Mode. (Denoised FFDM images)

kVp	Mo/Mo			W/Rh			Mo/Rh		
	ESD (mGy)	MGD (mGy)	FOM (mGy^{-1})	ESD (mGy)	MG (mGy)	FOM (mGy^{-1})	ESD (mGy)	MGD (mGy)	FOM (mGy^{-1})
23	12.3	2.77	46.82	3.1	1.32	88.61	7.1	2.19	70.40
24	10.5	2.42	73.50	2.6	1.06	93.65	5.8	1.81	76.37
25	8.7	2.1	71.63	2.3	1.05	98.09	5.4	1.72	83.37
26	8	1.98	75.50	2.3	0.99	99.49	4.9	1.57	83.34
27	7.1	1.79	80.30	2.2	0.95	101.37	4.6	1.5	81.96
28	6.4	1.63	79.48	2.1	0.92	103.40	4.3	1.45	78.17
29	5.8	1.51	72.13	2	0.88	104.02	4.1	1.39	76.42
30	5.3	1.39	72.27	1.9	0.85	95.88	3.9	1.34	75.46
31	4.8	1.3	68.86	1.8	0.81	99.41	3.8	1.29	70.41
32	4.5	1.22	61.96	1.7	0.78	91.15	3.6	1.25	70.15
33	4.2	1.16	59.47	1.6	0.74	87.54	3.5	1.21	63.53
34	4	1.13	51.17	1.5	0.71	78.10	3.3	1.18	59.83
35	3.8	1.06	49.73	1.4	0.67	74.20	3.2	1.15	56.23

FOM : Figure-of-merits AGD : Average glandular dose

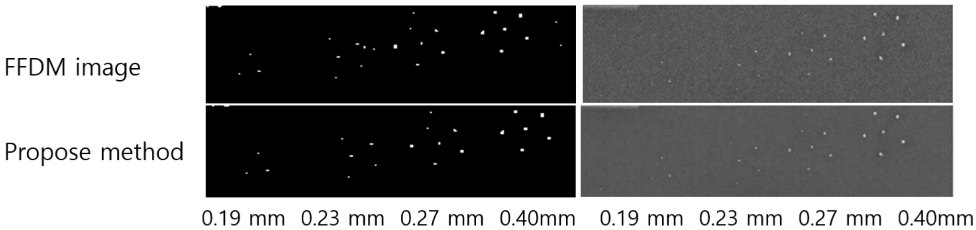

Fig. 3. (Color online) The results of microcalcification binary images before and after applying the noise reduction method. The microcalcification was not compromised even after the noise was removed. (Mo/Mo, 35 kVp)

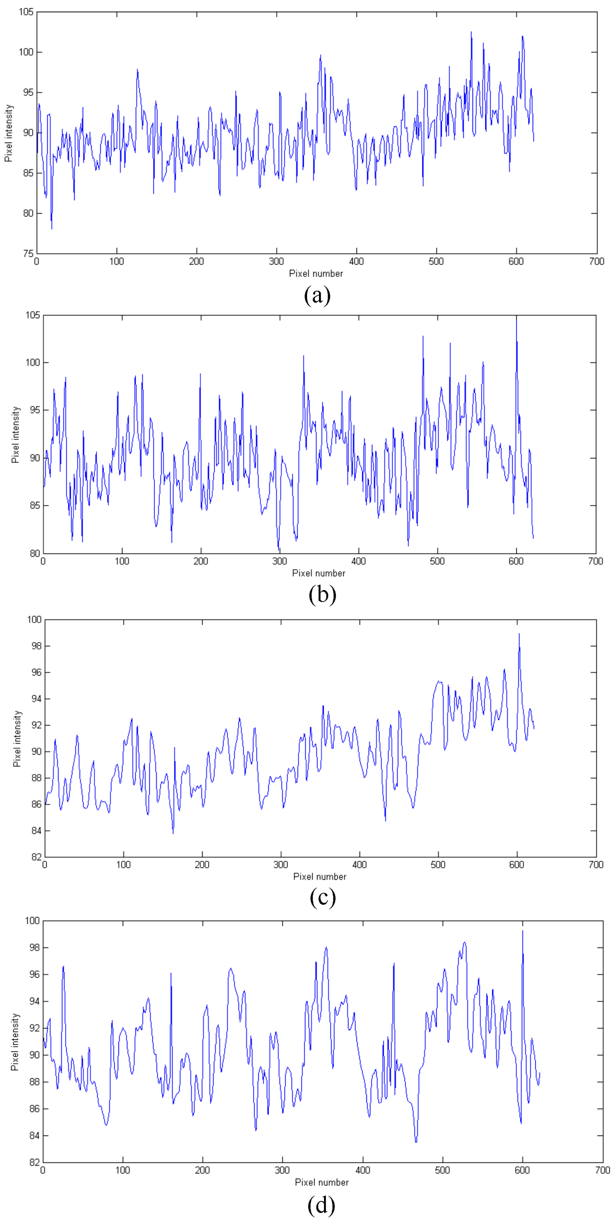

Fig. 4. (Color online) Breast mass profile before and after noise reduction. The profile represents the pixels intensity of the across the mass. (a) Mo/Mo, 35 kVp (FFDM image), (b) W/Rh, 27 kVp (FFDM image), (c) Mo/Mo, 35 kVp (Denoised image), (d) W/Rh, 27 kVp (Denoised image)

the filter target combinations. The nonparametric T-test method, Mann-Whitney method, was used and was determined to be significant when P < .001.

3. Experiment and Discussion

FOM is an indicator in which SNR and AGD are considered simultaneously enables to get optimal exposure parameter for minimizing high energy electromagnetic radiation dose of patients (Table 3). FOM was shown to be highest at 29 kVp of W/Rh with 23.95 mGy^{-1} before applying denoising. At this time, SNR fell to 4.59 from 6.22 and AGD decreased to 0.88 mGy from 2.77 mGy. Then, results of FOM were high in the order of 18.25 mGy^{-1} at 26 kVp of Mo/Rh and 16.35 at 27 kVp of Mo/Mo.

To consider AGD after denoising (Table 4 and Fig. 8(b)), FOM was highest at 29 kVp of W/Rh with 89.48 (mGy^{-1}). At this time SNR improves to 9.57 from 6.22 and AGD decreases into 0.88 mGy from 2.77 mGy. To see the results at Mo/Rh and Mo/Mo, FOM of Mo/Rh is a

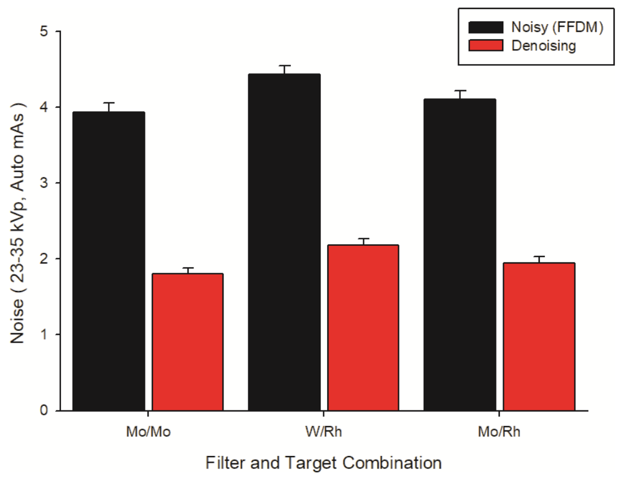

Fig. 5. (Color online) Noise values, the error bar shows the standard deviation between 23-35 kVp in the parameters. Denoising showed significantly lower scores for TV algorithms compare to noisy images (P < 0.01).

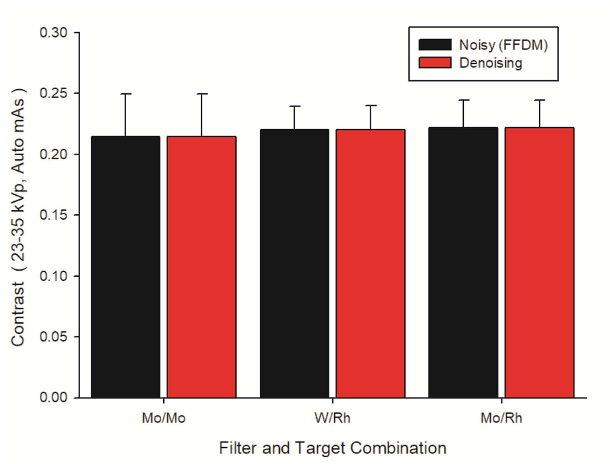

Fig. 6. (Color online) Contrast values, the error bar shows the standard deviation between 23-35 kVp in the parameters. Contrast showed not different scores for TV algorithms compare to noisy images (P > 0.01).

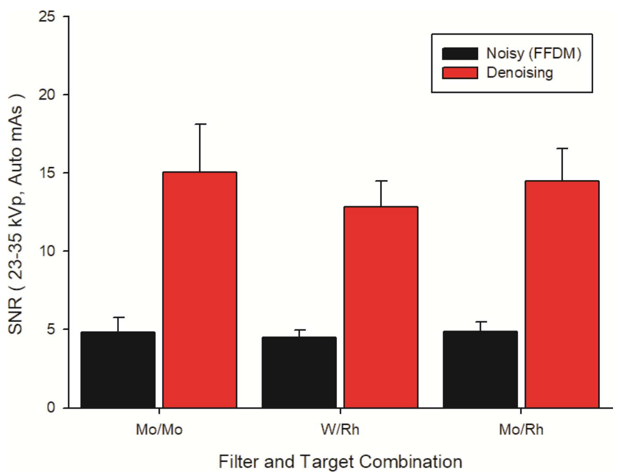

Fig. 7. (Color online) Signal to noise ratio values, the error bar shows the standard deviation between 23-35 kVp in the parameters. Denoising showed significantly higher scores for TV algorithms compare to noisy images (P < 0.01).

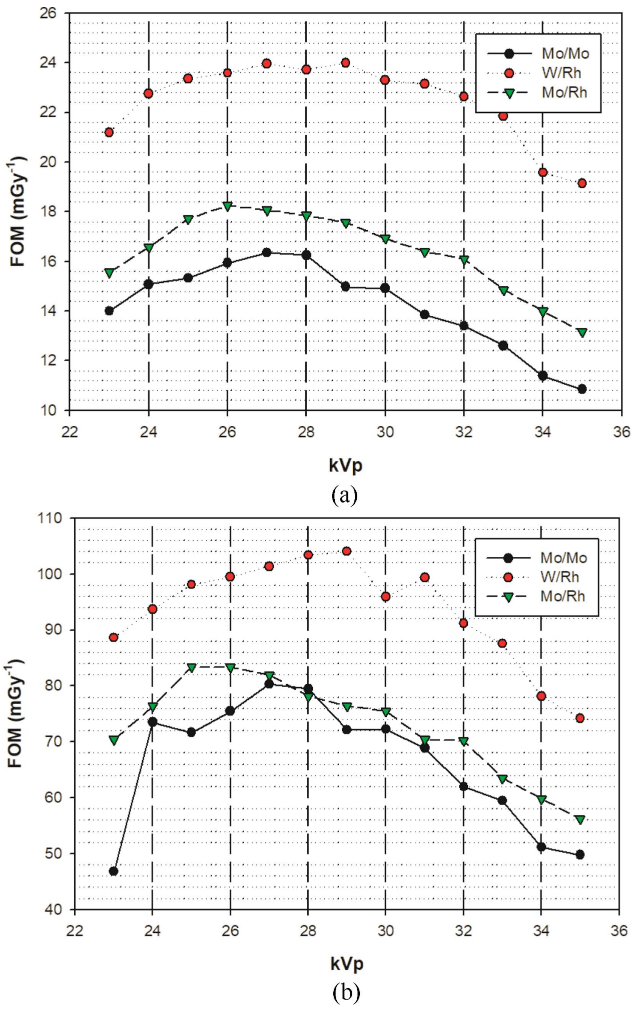

Fig. 8. (Color online) (a) FOM results for all conditions, FOM is an indicator which is used for deciding a maximum SNR while minimizing AGD and it becomes better to indicate as a result value is higher. (a) FFDM images (b) denoised images, (b) FOM results for all conditions, FOM is an indicator which is used for deciding a maximum SNR while minimizing MGD and it becomes better to indicate as a result value is higher. (a) FFDM images (b) denoised images

little bit larger until 24-26 kVp but they are similar above 27 kVp.

To consider minimization for radiation exposure dose of patients preferentially, 35 kVp of W/Rh at this time AGD was 0.67 mGy. When denoising is applied (noise 2.37, SNR 9.73), better picture quality can be achieved than 23 kVp of Mo/Mo (noise 3.77, SNR 6.23) which showed the best SNR before applying and can reduce AGD by 2.10 mGy after denoising process.

FFDM system which is now being used typically is designed to calculate mAs according to breast thickness of patients and used when AEC mode is used and to use kVp and combinations of filtration and target material optionally. This study aims at suggesting denoising filtering and finding optimal exposure parameter to achieve the best picture quality from electromagnetic beam with a low dose. It was evaluated using FOM which considered SNR, a method of evaluating objective picture quality from collected images and AGD, a method of radiation exposure dose.

We compared the Wiener filter [12], Wavelet [13] which was suggested previously with our denoising method (Fig. 9 and Table 5). The noise was worst in Wiener filter with the mean value of 2.6 ± 0.13 and was best in our method with the mean value of 1.56 ± 0.07 (Fig. 2). In FOM in which ADG values are reflected, our method was

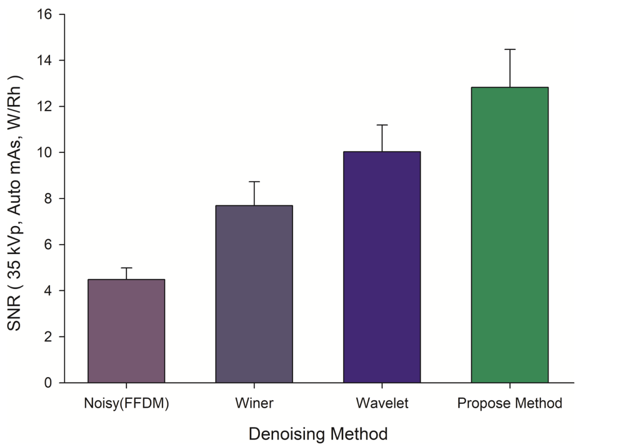

Fig. 9. (Color online) Signal to noise ratio values, the error bar shows the standard deviation between 23-35 kVp in the parameters. *Proposed method showed significantly higher values compare to other methods (Noisy, Winer, Wavelet) ($P < 0.01$).

found to be most outstanding with the mean value of 183.73 ± 22.37 mGy^{-1} followed by median filter with 80.21 ± 7.47 mGy^{-1} and Wiener filter with 65.98 ± 6.02 mGy^{-1} (Fig. 3).

This study suggested a nonlinear TV method [8] for denoising and got results before and after application. According to the results of the experiment, using W/Rh (29 kVp) was found to be best in all cases before and after applying the denoising filter. After applying the denoising filter, noise decreased (76.44 %) into 1.46 from 4.35 and SNR increased (76.18 %) to 13.6 from 4.6, which improved the picture quality of images. If denoising method is suggested (Table 2, Table 4) for images of 35kVp of W/Rh (SNR: 3.58, AGD: 0.67 mGy) with the smallest AGD when using FFDM, better picture quality (SNR 9.73, ADG: 0.67 mGy) could be gotten than 23 kVp of Mo/Mo which showed the best SNR before application and at this time it was found that AGD could be used by decreasing 75.81 %. The noise distribution for our algorithm was approximately 50 % less than the Wiener filter and Wavelet filter. According to the results, we able to reduce noise performance. Both algorithms are good at removing noise but are less than TV and lack edge-preserving capabilities.

Table 5. Comparision of denoising processing (35 kVp, W/Rh).

Filter	Signal	Noise	Contrast	SNR
Original image	16.76	4.68	0.19	3.58
Wiener filter	16.78	2.90	2.89	5.80
Wavelet	16.79	2.47	0.19	6.79
Proposed Method	16.72	1.72	0.19	9.73

When the noise is removed by the algorithm, the contrast of the image may be changed or the spatial resolution may be degraded. Our method does not deteriorate in contrast (Fig. 6) even though the noise is removed. In figure 3, the microcalcification model was analyzed. Even though the noise was removed, the microcalcification information did not disappear with the noise, and the spatial resolution was maintained well enough to detect the microcalcification better than the existing FFDM image. If the method proposed in this study is applied to the clinic, it would be very helpful for diagnosis.

4. Conclusion

In conclusion, the choice of low tube voltage when examining the breast with FFDM produces a noisy image, because low voltage electromagnetic wave radiation produce scattered rays which make noise in images. However, it is advantageous for humans with the use of low radiation doses from interactions of electromagnetic wave beam into human body. Removing the noise while maintaining the image information can provide the best image quality at a low dose. As a result of this study, the selection of the lowest dose from high energy electromagnetic wave beam may allow the diagnosis of the patient. At the lowest dose with the result of this study, good quality images can be obtained, which can help diagnosis.

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References

[1] H. Y. Tsai, N. S. Chong, Y. J. Ho, and Y. S. Tyan, Radiation Measurement **45**, 726 (2010).
[2] B. Chen, Y. Wang, X. Sun, W. Guo, M. Zhao, G. Cui, L. Hu, P. Li, Y. Ren, J. Feng, and J. Yu, Eur. J. Radiol. **81**, 868 (2012).
[3] Silvia Obenauer, Klaus-Peter Hermann, Eckhardt Grabbe, Brit. J. of Radiol. **76**, 145 (2003).
[4] S. E. Skubic and P. P. Fatouros, Radiology **61**, 263 (1986).
[5] P. P. Fatouros, S. E. Skubic, and H. Goodman, Radiology **32**, 157 (1985).
[6] M. B. Williams, P. Raghunathan, M. J. More, J. A. Seibert, A. Kwan, J. Y. Lo, E. Samei, N. T. Ranger, L. L.

Fajardo, A. McGruder, S. M. McGruder, A. D. Maidment, M. J. Yaffe, A. Bloomquist, and G. E. Mawdsley, Med. Phys. **35**, 2414 (2008).
[7] M. Adel, D. Zuwala, M. Rasigni, and S. Bourennane, Image and Vision Comput. **26**, 1219 (2008).
[8] Lenid I. Rudin, S. J. Osher, and E. Fatemi, Physica D. **60**, 259 (2009).
[9] F. J. Engelken, H. Meyer, R. Juran, U. Bick, E. Fallenberg, and F. Diekmann, Acad Radiol. **16**, 1272 (2009).
[10] J. Chen, J. Benesty, Y. Huang, and S. Doclo, Proceedings of Symposium-IEEE Transactions on, Audio, Speech, and Language Processing (2006).
[11] P. Baldelli, N. Phelan, and G. Egan, The British Journal of Radiology **83**, 290 (2010).
[12] Marwa A. Abd El-Fattah, Moawad I. Dessouky, Alaa M. Abbas, Salaheldin M. Diab, El-Sayed M. El-Rabaie, Waleed Al-Nuaimy, Saleh A. Alshebeili, and Fathi E. Abd El-samie, International Journal of Speech Technology **17**, 53 (2014).
[13] A. C. To, J. R. Moore, and S. D. Glaser, Signal Processing **89**, 144 (2009).