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EVALUATION OF NEW IMAGE PROCESSING CONDITIONS FOR DIGITAL MAMMOGRAMS FROM FUJI COMPUTED RADIOGRAPHY

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ABSTRACT

Purpose: A new processing parameter (T-type parameter) setting for gray scale was developed to improve the image quality of digital mammograms. To clarify the usefulness of this parameter setting, we have evaluated the image quality of digital mammograms (hard copy images) processed with this parameter, and compared it with S/F mammography.
Material and Methods: Mammograms were made under the same radiographic conditions by the S/F and FCR systems (type 1, S/F; type 2 and 3, FCR with new T-type parameters; type 4 and 5, FCR with conventional parameters).
A total of 49 images from 10 cases was selected for evaluation testing. Evaluation items were the contrast visibility of mammary glands and adipose tissues together with their granularity and sharpness. Eleven medical doctors participated in evaluating the images.
Results: The FCR hard copy images processed with the T-type parameter settings were significantly preferred over the conventional S/F images for the contrast visibility of mammary glands and adipose tissue. As for the other items (except for granularity), the FCR hard copy images processed with the T-type parameter settings were subjectively evaluated as slightly better than or equal to the S/F images. In contrast, the conventional S/F images were significantly preferred over the FCR hard copy images processed with the conventional parameter settings.
Conclusion: The image quality of FCR hard copy images processed with the T-type parameter settings was preferred over that of conventional S/F images as evaluated by medical doctors who specialized in mammography interpretation.

Key Words: Image quality, FCR digital mammogram, S/F mammogram, T-type parameter

INTRODUCTION

The incidence rates of breast cancer have recently been increasing in Japan. To address this

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situation, breast cancer screening using mammary gland radiography (that is, mammographic screening) was introduced for women over the age of 50 starting April 1, 2000 according to the Guidelines for Cancer Screening and Health Education with Particular Emphasis on Cancer Prevention. In April 2004, the Japanese Ministry of Health, Labour and Welfare further reviewed the guidelines and discontinued breast cancer screening by inspection and palpation alone, while reducing the age requirement to 40 years of age or older. Further improvement in the breast cancer screening system remains an urgent need.

Mammography targets the mammary gland, which is an internal organ consisting of tissues with only a few X-ray absorption differences. Thus, mammography must detect very subtle lesions, which calls for an image with higher quality compared with other radiographic images. The Japan Radiological Society and the Japanese Society of Radiological Technology now advocate the control of image quality and the diagnostic accuracy of screen-film (S/F) mammography throughout Japan.

Moreover, recent advances in information technology have prompted the digitalization of medical images, and digital mammography has been gradually replacing S/F mammography. However, although the image quality of digital mammography has improved, the ideal gray scale needed to optimize image quality has yet to be developed. S/F mammography is still the standard and the model of excellence for measuring image quality and diagnostic performance.

More recently, a new processing parameter setting for gray scale was developed to improve the image quality of digital mammograms by Fuji computed radiography (FCR); this new processing parameter setting is called T-type in the FCR system. Since its usefulness and efficacy have not yet been established, we have evaluated by subjective assessment the image quality of FCR mammography processed with this parameter setting and compared it with S/F mammography.

MATERIALS AND METHODS

Image acquisition and processing

For this study, cases featuring the medial lateral oblique (MLO) view acquired with both S/F and FCR mammography systems under the same radiographic conditions were retrospectively selected from among mammograms obtained at the National Hospital Organization, Nagoya Medical Center. The corresponding mammograhic examinations were all performed with the same unit (Mammomat 3000; Siemens, Erlangen, Germany). S/F mammographic images were acquired using film (Min-R 2000; Kodak, Rochester, NY) and screens (Min-R 2190; Kodak), and processed for 150 sec at 34°C by an automatic developing machine (Miniloader 2000P; Kodak). Digital mammographic images were obtained with a unit (FCR 5000MA Plus; Fujifilm Medical, Tokyo, Japan), and their hard-copy images were developed with dry imaging film (CR-DPL; Fujifilm Medical).

We obtained three types of mammograms for each case, i.e., an S/F mammogram and two different hard copies of FCR mammograms each using one of two different T-type parameter settings. In addition, for some cases, two other hard copies of FCR mammograms using two different old parameter settings were also obtained. Thus, three and sometimes five types of mammographic images were obtained for each case, all of which were the same size. These five types were: type 1, conventional S/F images; type 2, FCR images processed with a parameter setting of 1.2T/GR1.5 (i.e., a standard T-type parameter setting in the FCR system); type 3, FCR images processed with 1.2T/CR1.2 (i.e., a T-type parameter setting of lower-frequency components less enhanced than those in the standard T-type parameter setting); type 4, FCR images processed with 1.4O/3P0.8 (i.e., a conventional parameter setting with a priority on contrast); and type 5,

Table 1 Breast parenchyma density of cases.

Breast density	No. of cases	Cases with 5 types of mammograms
Fatty	2	2
Scattered mammary gland	14	3
Heterogeneous density	9	3
High density	4	2
Total	29	10

FCR images processed with 1.1R/7T1.2 (i.e., a conventional parameter setting commonly used for mammography).

A total of 107 images from 29 cases was obtained for this study. The distributions of breast parenchyma density among those cases are shown in Table 1. Two images were lost before the evaluation, leaving a total of 105 images from 29 cases from which 49 images from 10 cases (with no findings), with a maximum of five types of images, were selected for inclusion in the final evaluation.

Image evaluation study

Eleven medical doctors agreed to participate in this study as observers to evaluate the image quality. All of them had achieved the highest rank in radiographic interpretation qualifying tests conducted by the Central Committee on Quality Control of Mammographic Screening (the most qualified organization in Japan), and were experienced lecturers or associate lecturers. Eight of the 11 observers routinely interpreted S/F mammograms, two interpreted both S/F and FCR mammograms, and the remaining one interpreted FCR mammograms.

The 105 medial lateral oblique mammograms were viewed on high-luminance viewing boxes shielded from light and were presented in a random order that differd for each observer. Unlike the usual clinical reading, only a one-sided image was presented for each case. Each observer was asked to subjectively grade the contrast visibility of mammary glands and adipose tissue, and the granularity and sharpness of the mammographic image as well as its overall quality. The observers had clinical information about the image nor any knowledge of the processing parameter setting. The evaluations were conducted in a film-reading room with no windows and low ambient illumination. During each session, the use of a magnifying glass was allowed and no time constraints were imposed.

We used a continuous rating scale from a line-marking method to indicate each observer's subjective evaluation of contrast visibility, granularity, sharpness, and overall image quality. In this method, the observers were asked to mark the appropriate rating scales that represented their subjective evaluations with a pencil on a line 10 cm long. This line scale corresponded to a linear continuous rating on the scale ranging from 0 (left end) to 100 (right end); 0 denoted extremely poor visibility, granularity, sharpness, and overall image quality, while 100 represented overall excellence, and ratings between 0 and 100 represented intermediate levels.

In the following analysis, we evaluated the image quality of the five types of mammographic images, based on the data from 49 images of 10 cases.

Data analysis

To assess the statistical significance of subjective evaluation ratings among the five types of mammographic images, an analysis of variance (ANOVA) for a five repeated-measures design was performed with the subjective evaluation rating scales as the dependant variable and the types of mammographic images as the within-subjects factor. In this study, if the null hypothesis in Mauchly's test of sphericity were rejected, the adjustments to degrees of freedom of the F test statistics were made using the Greenhouse-Geisser epsilon, the Huynh-Feldt epsilon, and the lower-bound epsilon. In addition, pairwise comparisons among means of subjective evaluation rating scales for the five types of mammographic images were performed using the Bonferroni adjustment.

We used SPSS 12 software (SPSS Inc., Chicago, IL) for all statistical analyses, and adopted 5% as our significance level for statistical testing.

RESULTS

Regarding the contrast visibility of mammary glands, the means of the observers' subjective rating scales showed the following rank order: type 3 > type 2 > type 1 > type 5 > type 4 (Table 2). The overall ANOVA for repeated-measures design showed a statistically reliable difference in the rating scales on the contrast visibility of mammary glands among the five types of mammographic images (P < 0.001, for all three types of adjustments to degrees of freedom of F test statistics). Furthermore, from pairwise comparisons among the means of rating scales, there was a statistically reliable difference in rating scales for types 2, 3, 4, and 5 compared with type 1; for types 4 and 5 compared with type 2; and for types 4 and 5 compared with type 3.

On the contrast visibility of adipose tissue, the means of the observers' subjective rating scales showed the following rank order: type 3 > type 2 > type 1 > type 5 > type 4 (Table 3). The overall ANOVA for repeated-measures design showed a statistically reliable difference in rating scales on the contrast visibility of adipose tissue among the five types of mammographic images (P < 0.001, for all three types of adjustments to degrees of freedom of F test statistics). Furthermore, from pairwise comparisons among means of rating scales, there was a statistically reliable difference in those for types 2, 3, 4, and 5 compared with type 1; for types 4 and 5 compared with type 2; for types 4 and 5 compared with type 3; and for type 5 compared with type 4.

Regarding the degree of granularity on the mammographic image, the means of the observers' subjective rating scales showed the following rank order: type 2 > type 1 > type 3 > type 5 > and type 4 (Table 4). The overall ANOVA for repeated-measures design showed a statistically reliable difference in rating scales on granularity among the five types of mammographic images (P < 0.001, for all three types of adjustments to degrees of freedom of F test statistics). Furthermore, from pairwise comparisons among means of rating scales, a statistically reliable difference was found in those for types 3 and 4 compared with type 1; for types 3 and 4 compared with type 2; for type 4 compared with type 3; and for type 5 compared with type 4.

On the sharpness of the mammographic image, the means of the observers' subjective rating scales showed the following rank order: type 3 > type 2 > type 1 > type 5 > and type 4 (Table 5). The overall ANOVA for repeated-measures design showed a statistically reliable difference in the rating scales on image sharpness among the five types of mammographic images (P < 0.001, for all three types of adjustments to degrees of freedom of F test statistics). Moreover, pairwise comparisons among means of rating scales revealed a statistically reliable difference in those for types 2, 4 and 5 compared with type 1; for types 4 and 5 compared with type 2; and for types 4 and 5 compared with type 3.

As for the overall quality of the mammographic image, the means of the observers' subjective rating scales showed the following rank order: type 2 > type 3 > type 1 > type 5 > and type 4 (Table 6). The overall ANOVA for repeated-measures design showed a statistically reliable

Table 2 Ratings on contrast visibility of mammary gland.

Image type	Mean	Standard error	95% Confidence interval	
			Lower limit	Upper limit
Type 1 (F/S)	53.232	1.890	49.481	56.984
Type 2 (FCR, 1.2T/GR1.5)	60.818	1.660	57.523	64.113
Type 3 (FCR, 1.2T/CR1.2)	61.202	1.475	58.275	64.129
Type 4 (FCR, 1.4O/3P0.8)	37.232	2.087	33.090	41.374
Type 5 (FCR, 1.1R/7T1.2)	42.495	2,172	38.185	46.805

Table 3 Ratings on contrast visibility of adipose tissues.

Image type	Mean	Standard error	95% Confidence interval	
			Lower limit	Upper limit
Type 1 (F/S)	52.859	1.781	49.325	56.392
Type 2 (FCR, 1.2T/GR1.5)	58.141	1.573	55.019	61.264
Type 3 (FCR, 1.2T/CR1.2)	60.071	1.457	57.180	62.961
Type 4 (FCR, 1.4O/3P0.8)	24.505	1.858	20.817	28.193
Type 5 (FCR, 1.1R/7T1.2)	42.586	2.043	38.531	46.640

Table 4 Ratings on granularity.

Image type	Mean	Standard error	95% Confidence interval	
			Lower limit	Upper limit
Type 1 (F/S)	59.879	1.791	56.324	63.433
Type 2 (FCR, 1.2T/GR1.5)	60.798	1.455	57.910	63.686
Type 3 (FCR, 1.2T/CR1.2)	52.848	1.622	49.629	56.068
Type 4 (FCR, 1.4O/3P0.8)	24.919	1.715	21.515	28.323
Type 5 (FCR, 1.1R/7T1.2)	47.323	5.701	36.009	58.638

Table 5 Ratings on sharpness.

Image type	Mean	Standard error	95% Confidence interval	
			Lower limit	Upper limit
Type 1 (F/S)	51.859	1.680	48.525	55.192
Type 2 (FCR, 1.2T/GR1.5)	58.222	1.564	55.119	61.325
Type 3 (FCR, 1.2T/CR1.2)	64.747	5.169	54.489	75.006
Type 4 (FCR, 1.4O/3P0.8)	36.465	1.927	32.641	40.288
Type 5 (FCR, 1.1R/7T1.2)	41.354	1.988	37.407	45.300

Table 6 Ratings on overall image quality.

Image type	Mean	Standard error	95% Confidence interval	
			Lower limit	Upper limit
Type 1 (F/S)	61.320	2.079	57.194	65.445
Type 2 (FCR, 1.2T/GR1.5)	63.835	1.838	60.187	67.483
Type 3 (FCR, 1.2T/CR1.2)	61.969	1.631	58.732	65.206
Type 4 (FCR, 1.4O/3P0.8)	35.536	2.189	31.191	39.881
Type 5 (FCR, 1.1R/7T1.2)	47.588	2.312	42.998	52.177

difference in the rating scales on overall image quality among the five types of mammographic images ($P < 0.001$, for all three types of adjustments to degrees of freedom of F test statistics). In addition, based on pairwise comparisons among means of rating scales, there was a statistically reliable difference in those for types 4 and 5 compared with type 1; for types 4 and 5 compared with type 2; for types 4 and 5 compared with type 3; and for type 5 compared with type 4.

DISCUSSION

Our results show that FCR hard copy images processed with the T-type parameter settings were significantly preferred over the conventional S/F images for the contrast visibility of mammary glands and adipose tissue. As, for the other items, the FCR hard copy images processed with the T-type parameter settings were subjectively evaluated as slightly better than or equal to the S/F images, although the latter were significantly preferred over the FCR hard copy images processed with 1.2T/CR1.2 for granularity. Accordingly, our results indicate that the image quality of the FCR hard copy images processed with T-type parameter settings was subjectively evaluated as superior to that of the S/F images. In contrast, the conventional S/F images were significantly preferred over the FCR hard copy images processed with conventional parameters.

For hard-copy interpretation, digital images are printed on film with a laser imager. In mammography, film density plays a very important role in the detection of abnormalities. The maximum density, D_{max}, of the currently available laser imagers is 3.6, whereas the required D_{max} of S/F mammograms is more than 4.0. Since film density is usually expressed as the logarithm of the ratio of incidence to transmitted or reflected irradiance, a difference of 0.4 has a significant impact on the available range of gray scale. In this study, the D_{max} of the images of types 2, 3, 4, and 5 (i.e., the FCR hard copy images) was 3.6. Thus, in terms of physical properties, the quality of FCR hard copy images is inferior to that of S/F images, as the results of this study confirmed when the former were processed with conventional parameter settings and judged to be inferior to S/F films by medical specialists in mammography interpretation.

It is worth noting that, although the T-type parameter settings were developed for dry films with a D_{max} of 3.6, the conventional parameter settings were developed for a wet film with a D_{max} of 3.0. That situation will do much to explain the low rating scores for the FCR hard copy images processed with conventional parameter settings.

Eliminating dissatisfaction with the quality of FCR hard copy images requires overcoming limitations originating from the D_{max}, which eventually led to the development of a new processing parameter setting in the FCR system.[1] In the T-type parameter settings, the regions with an optical density between 1.2 and 3.0 were approximated to the corresponding density distributions on S/F images. Then, while maintaining the contrast in the mammary gland, the gradient of the high-density regions was lowered to achieve a more natural representation of the peripheral image near the skin, while the gradation of those regions with an optical density of less than 1.4 was approximated to that of the corresponding S/F image to diminish the glare in the highly dense regions of the mammary gland. Thus, using the T-type parameter settings, the image quality of the highly-dense breast tissue of the mammary gland and the peripheral region of the skin will theoretically be improved. In type 2, multi-objective frequency processing (MFP)[2] and pattern enhancement processing for mammography (PEM)[3] were also incorporated to visualize subtle differences in the density of breast tissue.[4] The results of this study lead us to firmly conclude that the aim of developing a new processing parameter setting in the FCR system has been achieved. Finally, FCR mammograhic images with a D_{max} of 4.0 or greater are now available. Other parameter settings for FCR mammograms with a D_{max} greater than 4.0 may be required in the future.

For the FCR mammography in this study, dual-side light converging imaging plate (IP) reading techniques[5,6] and MFP were used. Yasuda *et al*. reported in his study on CD-MAM phantoms that the contrast resolution in digital images with dual-side light converging IP reading techniques and MFP, even with a lower maximum density compared to the present one, was higher than that of S/F images.[7] The results of our study are compatible those reported by Yasuda *et al*.

Previously, we showed the effectiveness of FCR mammograms processed with T-type parameter settings in the detection of tumors and for morphologic evaluation.[8,9] However, in our previous study, both S/F and digital mammograms processed with the T-type were not evaluated independently, and the survey of readers participating in the evaluation revealed a disparity between the image evaluations and the actual impressions from use. Therefore, further evaluation was needed, which prompted us to conduct the present study.

Although digital mammography has not yet been widely-accepted clinically as a diagnostic tool, the advantages of digital mammography, including the large throughput capacity for examinations, easy storage and retrieval of image data, remote diagnosis, and computer-aided diagnosis (CAD)[10,11] application, are likely to promote the digitalization of mammography.[12] In fact, it is estimated that digital mammography systems already account for over 30% of the more than 3200 mammography systems installed in Japan.[13] The results of this study convince us that digital mammography will continue to spread rapidly.

In conclusion, the quality of FCR hard copy images processed with T-type parameter settings was preferred over that of conventional S/F images by medical doctors specialising in mammography interpretation.

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