Characteristic curve measurement based on bootstrap method using a new calcium phosphate stepwedge in mammography

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ABSTRACT

A method for measuring the characteristic curves generated by the mammography imaging systems has not yet been well established due to poor quality control over X-ray exposure in the range of kV values, which is lower than the conventional quality. In this paper, we proposed a bootstrap method using a "stepwedge" designed for characteristic curve measurement in mammography. A ten-step stepwedge containing calcium phosphate, with each step having a different density of material, was employed. In our experiment, the tube voltage and mA values were changed in the range of 25 to 32 kV at increments of 1 kV and in the range of 20 to 100 mAs at increments of 20 mAs, respectively. The results of the curve measurements indicated that our method might be useful to both screen-film mammography and computed radiography (CR), although additional experiments to evaluate the accuracy and precision of the acquired data are required.

Keywords: mammography, characteristic curve, stepwedge, bootstrap method, calcium phosphate

1. INTRODUCTION

Along with Western countries, the incidence rate of breast cancer, one of the highest-risk cancers in women, is steadily increasing in Japan due to a change in life style — westernization. Conventionally, palpation has been exclusively used to detect breast cancer although it is generally useful only to detect lesions at an advanced stage. Currently, mammography is considered to be the most effective method for detecting breast cancer at an early stage. In Western countries, mammography has been effectively employed as a principal screening procedure for the detection of breast cancer since many years. Similarly, in Japan, mammography has been increasingly considered as a useful diagnostic imaging tool. Therefore, it is imperative to establish an accuracy control and quality control system including X-ray exposure for the mammography system. Quality assurance and quality control (QA/QC) are the most important issues involved in the clinical application of mammography. The measurements of characteristic curves can be often used to address this issue as well as facilitate image quality evaluation by any other technique.

Generally, the characteristic curves obtained from the screen-film system are measured by the inverse-square-law technique, e.g. the "distance method," which corresponds to the so-called intensity-scale method. However, it is difficult to apply this method to mammography because of the geometry of the mammography imaging equipment. For example, a report on the measurements of characteristic curves using the distance method has been presented by Maruyama et al. [1], in which the inverse-square-law did not reflect the correct results due to the absorption of air in the X-ray range with kV values lower than the conventional quality. Therefore, the values for relative X-ray exposure were calculated by measuring the dose at each exposure distance. However, the quality of an irradiated X-ray exposure continuously varied with air absorption, suggesting that it might influence the accuracy of the characteristic curves [2]. Asahara et al. [3,4] proposed a method for measuring characteristic curves while ensuring an X-ray quality of 80 kV, which has been conventionally used in the field of sensitometry. However, this method could not yield characteristic curves identical to

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those measured at the desired X-ray quality for the clinical application of mammography. Moreover, several researchers used the time-scale method to measure the characteristic curves due to its easy applicability [5]. However, the curves are subject to change due to the reciprocity-law-failure phenomenon, which implies that this method has the disadvantage of poor measurement accuracy. Therefore, the bootstrap method can be considered suitable for mammography. In this study, we developed a simple and useful method for measuring the characteristic curves in the mammography imaging systems by employing the bootstrap method.

2. METHODS

The photograph of the stepwedge phantom originally developed by Horita et al. [6] with the aim of improving quality management is shown in Fig. 1 (a). The stepwedge has ten steps, each made from urethane resin or calcium phosphate with differing material densities. The 1st step contains urethane resin (1.061 g/cm^3). From the 2nd step onwards, calcium phosphate is added to the steps with increasing material density at an increment of 0.0243 g/cm^3. Each step has a thickness of 15 mm, which is different from that of a conventional aluminum stepwedge. The mammography equipment employed in the experiment was DMR (Mo/Mo) (GE Co.). The values for tube voltage and mAs were changed in the range of 25 to 32 kV at an increment of 1 kV and in the range of 20 to 100 mAs at an increment of 20 mAs, respectively. A Min-R/Min-R (Kodak Co.) screen-film system was employed. The automatic processor was Miniloader 2000P (Kodak Co.); its development temperature and processing time were set at 36.8 degrees and 150 seconds, respectively. The radiograph of the stepwedge phantom obtained at exposure conditions of 27 kV and 60 mAs is shown in Fig. 1 (b).

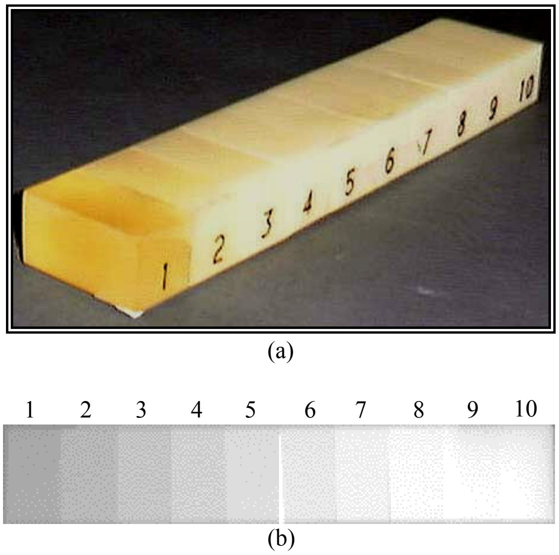

Fig. 1 Photograph of a “stepwedge” made from calcium phosphate with 10 steps of varying densities is shown in (a) and its radiograph is presented in (b).

Using the stepwedge at different exposure conditions, the curves were measured to reflect the relationship between the material density of individual steps and their corresponding optical densities and then the bootstrap method was applied. Although any of several different techniques could be included in the bootstrap method, we conducted our experiment based on the stepwedge bootstrap method, which was the one originally proposed by Kodak Co. using stepwedge made from aluminum [7].

Five samples obtained under the same conditions of tube voltage and mAs were prepared, and an averaged optical density was measured for each step. Three combinations of multiple exposure ratios were obtained: 40 mAs (2-fold) and 80 mAs (4-fold) to 20 mAs, and 80 mAs (2-fold) to 40 mAs. Based on this result, two characteristic curves were produced. First, the characteristic curve created the 1st step of average optical density as logarithm 0 of log relative X-ray exposure. Then, it was shifted in parallel along with log relative X-ray exposure (horizontal axis)so that the curves might overlap, and the average of two curves was taken to obtain the final characteristic curve. Under the condition of the tube voltage being set in the range of 25 to 32 kV, the same experiment was repeated and eight characteristic curves were obtained.

3. RESULTS AND DISCUSSION

The relationship between the individual steps identified by the differences in tube voltage and the averaged optical density, when the mAs was fixed at 20, is shown in Fig. 2. As the tube voltage increased with an increase in the amount of irradiated beam (exposure dose), the curve shifted to the left, although no change was observed in its curve shape. Similar results were observed when the measurements were conducted at other mAs.

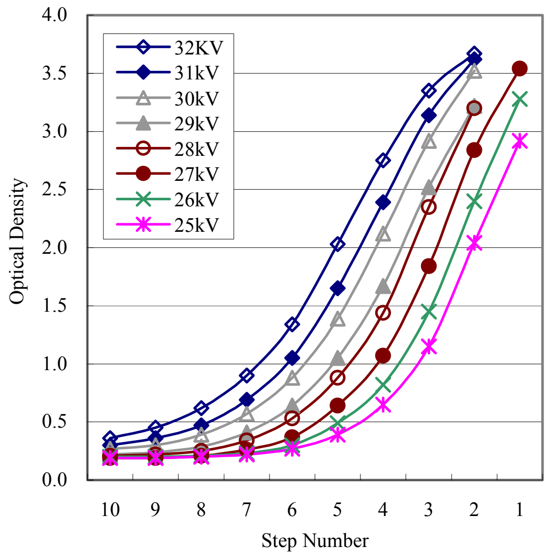

Fig. 2 The relationship between density and step number at 20 mAs across eight different kV settings.

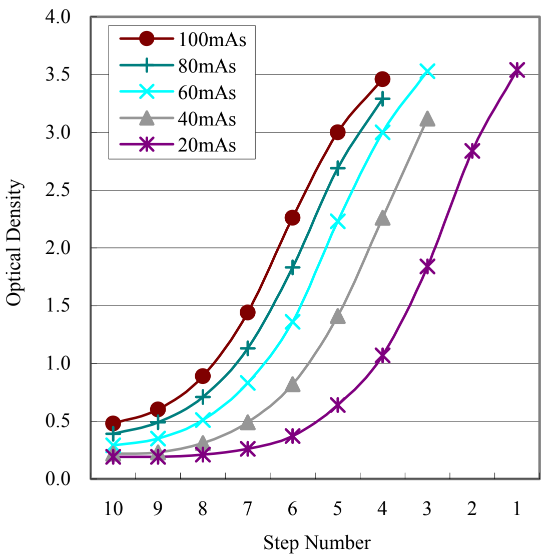

Fig. 3 The relationship between density and step number at 27 kV across five mAs settings.

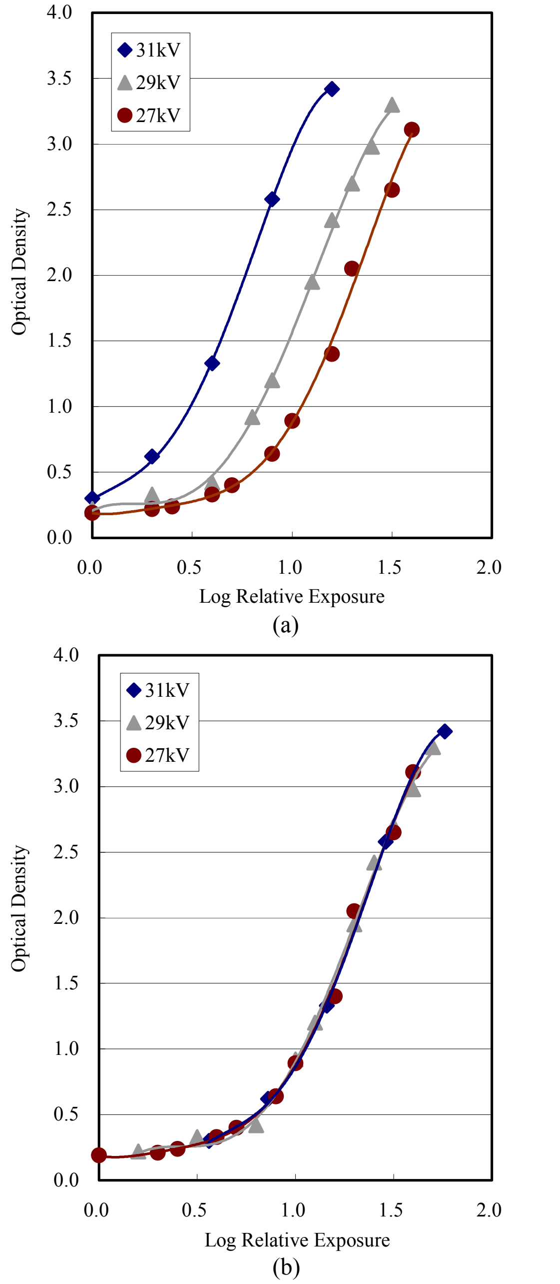

Fig. 4 Characteristic curves for three different kV settings ranging from of 27 to 31 kV. The original curves shown in (a) are relatively shifted along the horizontal axis for easy comparison of the curve shape as shown in (b).

The relationship between individual steps identified by the differences in mAs and averaged optical density, when the tube voltage was fixed at 27 kV, is shown in Fig. 3. Since the exposure dose increased with an increase in the mAs, the curve shifted to the left, although no change was observed in its shape. Similar results were observed when measurements were conducted at other tube voltages.

Characteristic curves obtained at three different kV settings of 27, 29, and 31 kV are shown in Fig. 4 (a). These curves were relatively shifted along the horizontal axis for easy comparison of the curve shape, and the curves overlapped with each other as shown in Fig. 4 (b). As clearly evident from Fig. 4 (b), the shapes of the characteristic curves do not depend on the kV settings (X-ray quality) for application of mammography.

The ten steps of the stepwedge did not always measure a sufficient range of optical densities to cover the entire characteristic curve by the conditions of tube voltage and mAs employed. In this case, when compounding two characteristic curves, the characteristic curves were determined. It is necessary to use a stepwedge that could consider many points across a wide range of optical densities. This stepwedge can allow us to create more accurate characteristic curves by reducing the difference in material density across adjacent steps from 0.0243 g/cm^3 and increasing the number of steps.

This method was also applied to measure "digital characteristic curves" of a computed radiographic image (CR, REGIUS Model 150, Konicaminolta Co.) for its application to mammography. The results are shown in Fig. 5, which demonstrate the linearity between the pixel values and log values for relative X-ray exposures. At each tube voltage, the digital characteristic curves have a similar linearity with the same slope, clearly indicating that the curves do not depend on the tube voltage selected. Due to the wide dynamic range of the CR system, the curve did not cover the entire range of the pixel values, and a further experiment is being carried out to address this issue.

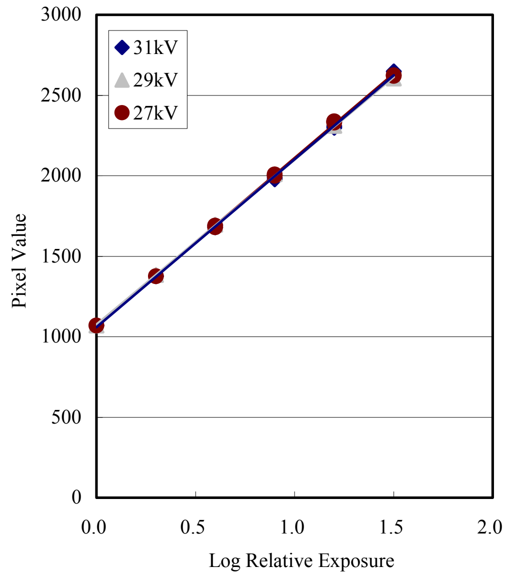

Fig. 5 Digital characteristic curves of a computed radiographic image at three different kV settings in the range of 27 to 31 kV.

4. CONCLUSION

We proposed the bootstrap method for measuring the characteristic curves in mammography using the "stepwedge," in which the material density of calcium phosphate was changed [8]. The effectiveness of our method in measuring the characteristic curves of both analog and digital imaging systems, for the application of mammography, has been successfully proved. However, some additional experiments are required to verify the accuracy and precision of the measurements. In addition, this stepwedge can be applied to an algorithm for improving the performance of computer-aided detection (CAD) systems for microcalcifications [9].

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