A Method for Simultaneous Measurement of Air Kerma, Half Value Layer and Tube Potential in Quality Control Procedure of Diagnostic x ray units

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ABSTRACT

For the quality control procedure of diagnostic x ray units, a method for simultaneous measurement of air kerma, half value layer and tube potential was developed utilizing a computed radiography system for intraoral radiography and film badge case. The response of average pixel values under the windows were calibrated by x rays generated at tube potentials from 40 to 140 kV with filtration from 1.5 to 3.7 mmAl. The calibration curves for half value layer and tube potential were derived as functions of attenuation factors by the 1.4 mmAl filter and the 0.2 mmCu filter. The energy dependency of the open window response was corrected by the calibration factor as a function of the attenuation factor by the 1.4 mmAl filter. The uncertainty of the estimated half value layer, tube potential and air kerma were 0.2 mmAl, 3.6 % and 5 %, respectively. It was thus suggested that this system could be applied to quality control program to detect the variation of working condition of x ray units in clinical use.

Keywords: quality control, patient dose, beam quality, tube potential, computed radiography, film badge.

1. INTRODUCTION

Though quality control (QC) procedures have been strongly recommended in x ray diagnosis, few hospitals perform them. It is perhaps because the procedure essentially includes the measurement of x ray intensity, beam quality and tube potential, for which an expensive dosimeter and additional labor of staff are required. We applied a mailing personal monitoring service utilizing radiphotoluminescent dosimeter (RPLD) to evaluate the half value layer (HVL) and the entrance surface dose of patient in intraoral radiography and found that the RPLD badge showed a high performance [1,2)]. On the other hand, computed radiography (CR) has been widely used in recent years. If the dosimetry utilizing CR system is as stable as film dosimetry, measurements in QC procedure may be easily performed in hospitals using CR systems without significant expense. In addition, an image filing computer system and QC supporting software may save much labor of staff for the QC procedure. We investigated, therefore, the basic properties of CR system as a dosimeter and developed a method for simultaneous measurement of air kerma, HVL and tube potential in QC procedure of diagnostic x ray units.

2. MATERIALS AND METHOD

2.1. Computed radiography system

In this study, a dental CR system (DenOptix™ Scanner: Dentsply) was used, because the size of an intraoral size imaging plate (IP) was the same as that of the film package for film badge. An IP with a size of 31 X 41 mm (Size 2: Dentsply) wrapped by white light shielding packet was set into a JIS Z-4301 film badge case (Chiyoda Tecnol Corp.). The case had four measuring windows with filters 1.40 mm thick aluminum (Al), 0.20 mm thick copper (Cu) + 1.20 mmAl, 2.0 mm thick lead (Pb), and the open window (OW). The pixel size of the scanned image was 0.042 mm and saved in 16 bit TIFF format file. An image processing software was developed to calculate the average pixel value in the measuring windows automatically. Some basic properties of the CR system were investigated by preliminary experiments. The reproducibility of pixel value for a given dose and the individual deviation of sensitivity for IPs were about 3 % for both. The feeding during the first 5 minutes was about 7 % and that during the following 1 hour was less than 1 % at room temperature. Differences up to 7% in read out sensitivity caused by the IP setting position in the scanner were observed. The deviation up to 5% in attenuation factor by Cu filter among the badge cases were also observed.

2.2. Calibration

A constant potential x ray generator (MG165: Philips) with tungsten target (angle 17°) and 1 mm thick beryllium window was used for x ray irradiation. The tube potential and the filtration were varied from 40 to 140 kV and from 1.5 to 3.7 mmAl, respectively. The exposures were measured by an ionization chamber dosimeter (RAMTEC 1000D: Toyo Medic Corp. / A4: Exradin), whose calibration factor was traceable to the national standard. HVLs were measured in a narrow beam geometry using a smaller ionization chamber (TN30001: PTW) and 99.99% pure Al attenuator. The attenuation factors were measured at four intervals of 0.2 mmAl covering the HVL. The HVL was evaluated by four points Lagrange's interpolation formula. Three badge cases were simultaneously irradiated in a x ray field of 30cm in diameter at 180 cm from the focus by about 1 mGy in air kerma in free air at air kerma rate of about 4 mGy/min. The irradiated IPs was stored in a dark box for 5 min before scanning. The average pixel values of measuring windows were extracted by the software described above. Number of pixels in a region of interest was about 20,000 and the coefficient of variance (CV) was less about 1.5 % for open window (OW) and about 2.5 % for Cu filtered window. The following analyses were processed by Micro Soft Excel. The scanning position correction factor and the correction factor for Cu filter attenuation were multiplied.

3. RESULTS

3.1. Estimation of Half Value Layer

Fig. 1 showed the variation of pixel value ratio $R_{\mathrm{Al/OW}}=p_{\mathrm{Al}}/p_{\mathrm{OW}}$ and $R_{\mathrm{Cu/OW}}=p_{\mathrm{Cu}}/p_{\mathrm{OW}}$ against the HVL, where p denoted the average pixel value in the window and the suffix OW, Al, Cu denoted filter material of the window. The experimental deviation in $R_{\mathrm{Al/OW}}$ was smaller than that of $R_{\mathrm{Cu/OW}}$ in the thin HVL region. The gradient of $R_{\mathrm{Al/OW}}$ against HVL, however, reduced in the thick HVL region, while $R_{\mathrm{Cu/OW}}$ kept appropriate gradients. Hence, $R_{\mathrm{Al/OW}}$ was better argument for HVL estimation of soft x rays and $R_{\mathrm{Cu/OW}}$ was better for hard x rays. By means of least squares method using the calibration data, we parameterized HVL as a function of the two arguments as:

$$HVL_{\mathrm{fit}} = \exp\{10.50 - 5.20R_{\mathrm{Cu/OW}} + 0.606R_{\mathrm{Cu/OW}}^2 - 13.72R_{\mathrm{Al/OW}} + 36.82R_{\mathrm{Al/OW}}^2 - 22.80R_{\mathrm{Al/OW}}^3\} \qquad (1)$$

The maximum difference between a single value and the value of the fitting function defined was 0.62 mmAl and the RMS uncertainty defined by Equation (2) was 0.17 mmAl.

$$E_{RMS} = \sqrt{\frac{\sum_i (y_i - Y_i)^2}{n}} \qquad (2)$$

where y_i and Y_i were measured and calculated values, respectively, and n was the number of data points.

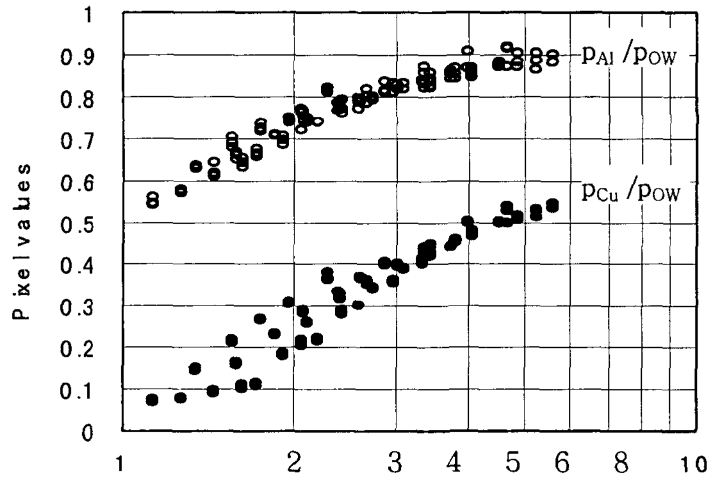

Fig. 1 Pixel values ratio vs HVL

3.2. Respose of Open Window

Fig. 2 showed the average pixel value responses r_{OW} at the OW against the air kerma in free air as a function of $R_{\mathrm{Al/OW}}$. Though a slight dependency on the filtration could be observed, r_{OW} were approximated by a polynomial of $R_{\mathrm{Al/OW}}$ as:

$$r_{OW\,fit} = -7366 + 75287R_{Al/OW} + 129.79R_{Al/OW}^2 \qquad (3)$$

The solid curve in Fig. 2 indicated the values of the polynomial. The maximum relative fitting error was 13 % and the RMS uncertainty was 4.8 % in the range of HVL form 1.14 to 5.67 mmAl. The air kerma in free air K_{CR} measured by the CR system would be finally determined as:

$$K_{CR} = \frac{p_{OW}}{r_{OW\,fit}(R_{Al/OW})} \qquad (4)$$

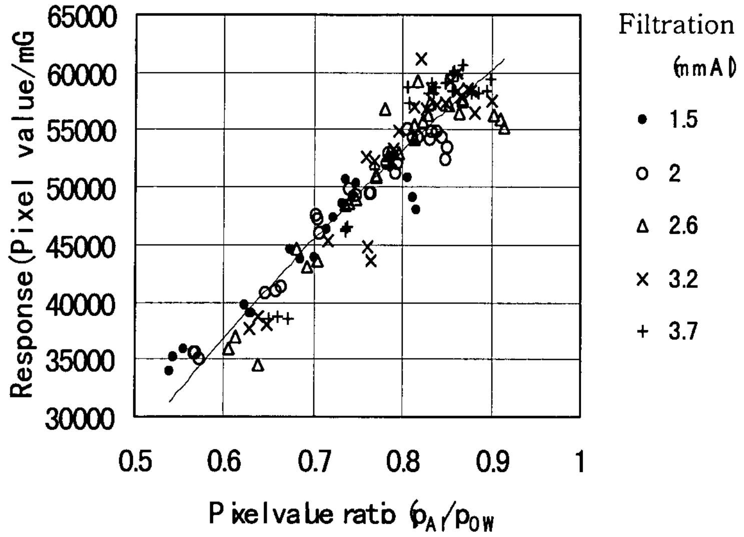

Fig. 2 Response of the CR system

3.2. Tube Potential

Fig. 4 showed the average pixel value ratio $R_{Cu/Al}=p_{Cu}/p_{Al}$ as a function of the tube potential V. The solid curve indicated the crude approximation of $\log_e V$ as a polynomial of $R_{Cu/Al}$. A slight but clear dependency on the filtration was observed. The tube potentials were parameterized as a function of $R_{Cu/Al}$ and filtration f as:

$$V_{fit} = \exp\{C_0 + C_1 R_{Cu/Al} + C_2 R_{Cu/Al}^2 + C_3 R_{Cu/Al}^3\} \qquad (5)$$

where, $C_0 = 3.344 + 0.124f - 0.511f^2$

$C_1 = 2.954 - 0.942f + 0.410f^2$

$C_2 = -0.257 - 0.348f - 0.753f^2$

$C_3 = 1.170 + 2.478f + 0.268f^2$

The maximum fitting error was 7.6 % and the RMS uncertainty was 2.0 %. In the practical use, the nominal total filtration in aluminum equivalent thickness would be substituted for the value of f, which might include an error from the actual value. In order to estimate the error propagation of the error, f was varied by ±0.3 mm. The variations of V_{fit} were 4.8 % at maximum and the average was 3 %. Thus, the total uncertainty of the potential was estimated to be 9 % in the worst case and the CV to be 3.6 %, when the uncertainty of the total filtration was 0.3mmAl.

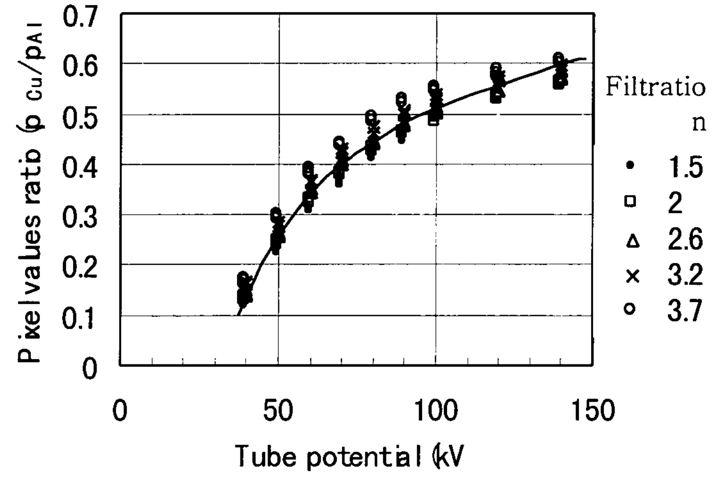

Fig.3 Pixel values ratio vs tube potential

4. DISCUSSION

Because the filter configuration of the badge case was designed for personal monitoring, it was not optimized for our purpose. The results suggested that thicker filters would represent a higher performance. The fitting parameters for tube potential evaluation would vary by the tube potential wave form. Nevertheless, this system could be applied to QC procedure, at least, for the detection of relative variation of the working condition of the equipment including the read out sensitivity rather than the evaluation of the absolute value. Comparing the precision of the air kerma measurement with the exposure time variation by one step of a diagnostic unit (about 20%), we could consider that this method had a practical sensitivity to the variation of x ray intensity. Since the variation of the x ray intensity reflected all variation of the working condition of the x ray unit, the detected variation would provide important information to CQ procedure. The precision of tube potential measurement was also smaller than or comparable to10 %, the allowed error in nominal tube potential by JIS standard Z-4702. This method was easily applicable to any other digital radiography system including flat panel detectors.

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