DR Responses to X-Ray: in Terms of Absorbed Energy

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ABSTRACT

Digital radiography (DR) is being developed for numerous applications in medical imaging. For understanding DR image, it is necessary to comprehend DR responses to X-ray in terms of absorbed energy. This study reports on the relationship of absorbed energy in the scintillator vs. pixel value of detector. Pixel value and exposure were measured from 50 kVp to 120 kVp until the detector was saturated. For representing radiation produced at the X-ray tube, we used program Srs-78 and compared experimental exposure with calculated exposure. Absorbed energy was acquired using spectrum and we got the relation between the two values.

Keywords: digital radiography, CsI(Tl), pixel value, absorbed energy, exposure

1. INTRODUCTION

Medical X-ray diagnosis with digital solid-state detectors has begun to penetrate the market. For the acquisition of the signal the solid-state detector with a-Si:H used the scintillator. Normally the CsI(tl) is used to the scintillator and the photons collided with the CsI(tl) produce the visible lights to correspond to their energy. The visible lights produce the electric signal in the amorphous silicon (a-Si) and then the image is acquired. Therefore, to understand the DR, it is important that we catch the absorbed energy of the scintillator for various X-ray spectra, Also this is important for the processing of the image to be acquired.

2. THEORETICAL BACKGROUND

2.1. Exposure

Exposure was defined by the International Commission on Radiological Units and Measurements (ICRU) as dQ/dm where dQ is the absolute value of the total charge of ions of one sign produced in air when all of the electrons liberated by photons in a volume element of air having a mass dm are completely stopped in air. By definition, exposure (X) is given by :

$$X=\Psi_{air}\cdot\left(\frac{\overline{\mu}_{en}}{\rho}\right)_{air}\Bigg/\left(\frac{\overline{W}}{e}\right)_{air} \tag{1}$$

where, Ψ_{air} is the photon energy fluence, $\left(\frac{\overline{\mu}_{en}}{\rho}\right)_{air}$ is the average mass energy absorption coefficient and $\left(\frac{\overline{W}}{e}\right)_{air}$ is the average energy required per unit charge of ionization produced. Because we use the spectrum produced by X-ray tube, Equation (1) can't be used. We must consider the average mass energy absorption coefficient and photon energy fluence spectrum. So Equation (1) is modified to :

$$X=\int_0^{E_{Max}}\left[\frac{d\Psi_{air}(E)}{dE}\left(\frac{\overline{\mu}_{en}}{\rho}\right)_{air}(E)\Bigg/\left(\frac{\overline{W}}{e}\right)_{air}\right]dE \tag{2}$$

$\left(\frac{\overline{W}}{e}\right)_{air}$ is almost constant for all electron energy, so we need not consider its variation as the energy.

2.2. Absorbed Energy

The absorbed energy of the scintillator can be calculated with the average mass energy absorption coefficient. If the photon which energy is E_{in} collides on the medium which thickness is Δx, density is ρ and the average mass energy absorption coefficient is $\frac{\bar{\mu}_{en}}{\rho}$, the absorbed energy ($E_{ab}$) will be given by :

$$E_{ab} = E_{in} \cdot \left[1 - \exp\left(-\frac{\bar{\mu}_{en}}{\rho} \cdot \rho \cdot \Delta x\right)\right] \quad (3)$$

Now, We must consider the X-ray spectrum. Also we can get the energy which enters the medium per an unit area with dividing calculated value into the area which the X-ray photon really comes in to the detector. If incident X-ray spectrum is described by $X_{in}(E)$, the absorbed energy will be given by :

$$E_{ab} = \int_0^{E_{Max}} X_{in}(E) \cdot \left\{1 - \exp\left[-\left(\frac{\bar{\mu}_{en}}{\rho}\right)_{CsI} (E) \cdot \rho_{CsI} \cdot \Delta x_{CsI}\right]\right\} dE \cdot \frac{1}{S} \quad (4)$$

where, S is the area which the X-ray photon really comes in to the detector.

3. MATERIALS AND METHODS

We used Trixell detector (pixium 4600) which has a pixel size of 143 micrometers, X-ray tube (Eureka), and dosimetry equipment (Radcal, 2026C: 20X6-60). The sensor array of the detector was made of hydrogenated amorphous silicon (a-Si:H) and the scintillating layer was CsI(Tl). The detector and ion chamber were set up at 180 cm in front of X-ray tube. The pixel value and air exposure were acquired for the energies ranging from 50 to 120 kVp and the mAs increasing until the pixel value of the detector was saturated. For calculating the air exposure and absorbed energy of the detector, we need X-ray spectrum of each kVp and the mass energy absorption coefficient of CsI(Tl). The former was acquired with the program SRS-78, the latter was obtained at National Institute of Standards and Technology (NIST). The data of SRS-78 is the number of photon at the 75cm front of X-ray source per an energy, 1 mAs, $1mm^2$. Therefore, the real number of incident photon to the detector is obtained with dividing the data of SRS-78 into the area which calculated with the inverse square rule. Also each data were subdivided and added by interpolation using natural cubic spline function because of more accurate integration and then we have got the characteristic curve of detector to the absorbed energy vs. pixel value.

4. RESULT AND CONCLUSION

4.1. Pixel Value

The pixel value was obtained with taking the mean of the 12500 pixel values. Because the number of the photon was augmented as a mAs increased, the pixel value increased. Also, the pixel value increased as the kVp increased because the energy of photon increased although it was the same mAs.

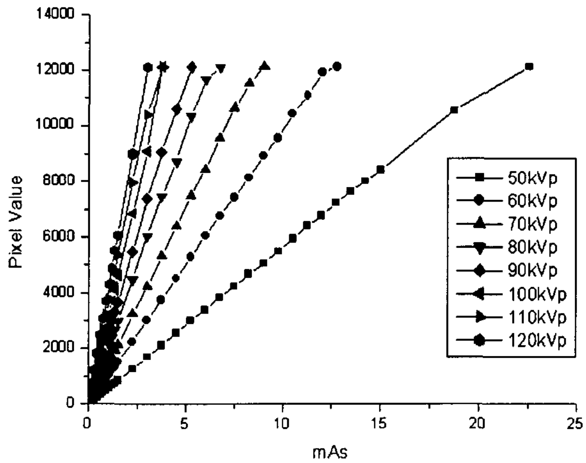

Fig. 1. The relations between mAs and pixel value.

4.2. Calculated and Experimental Exposure vs. mAs

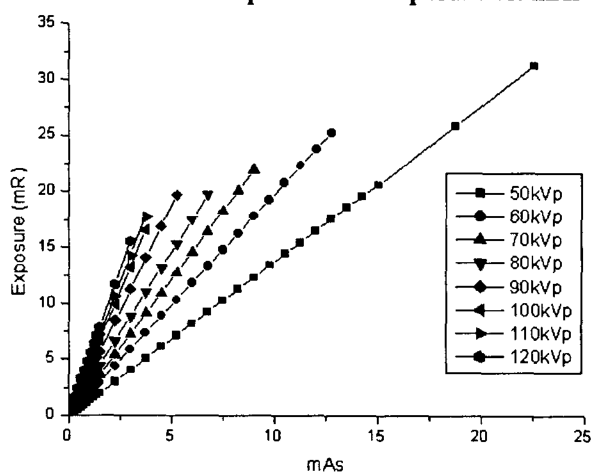

Fig. 2. The relations between mAs and exposure

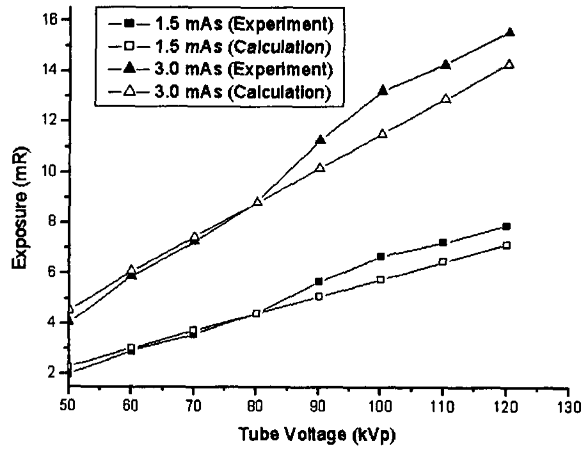

Fig. 3. The comparison between calculated and experimenta exposure.

The experimental exposure is shown in Fig. 2. The high exposure was measured at the high kVp that made the energy of the photon much. The calculated exposure showed almost same form. Because of comparison between two data, the exposure at 1.5 mAs, 3 mAs is represented in Fig. 3. Although the difference between two data is a small, it is larger at high kVp than low. This is due to the error of the measurement, but it is incapable of explaining the tendency. It is necessary that we introduce a different factor.

4.3. The Relation of the Absorbed Energy and the Pixel Value

The absorbed energy with using SRS-78 is shown in Fig. 4. The absorbed energy increased as the number and energy of the photon like the exposure. The relation between absorbed energy and pixel value is shown Fig. 5. Expectedly, the pixel value linearly increased relative to absorbed energy. We can consider some oscillation as the error of the measurement. This data will be used importantly at image processing.

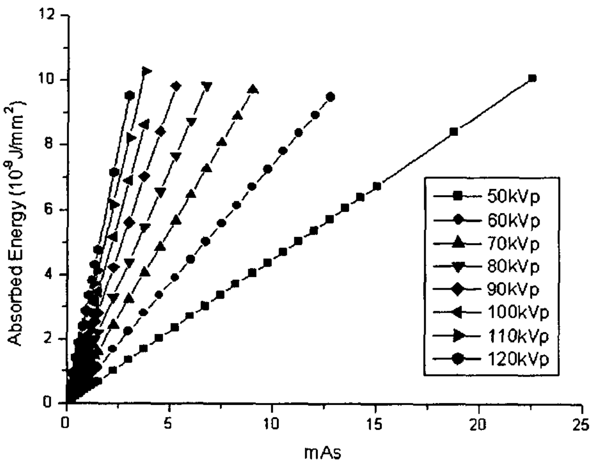

Fig. 4. The relations between mAs and absorbed energy.

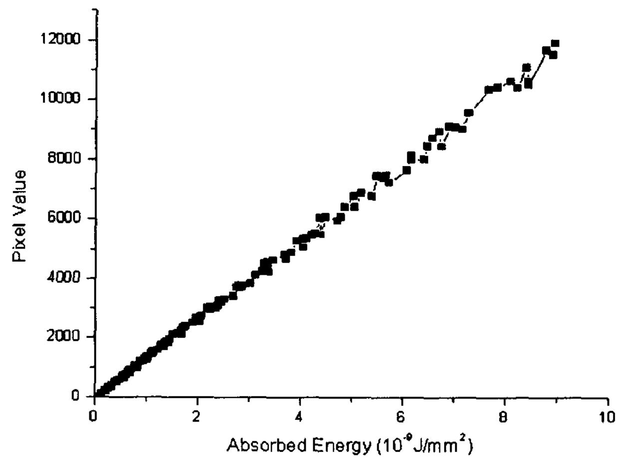

Fig. 5. The relation between absorbed energy and pixel value.

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