Effective energy evaluation of 320-multidetector CT using Radiochromic Film

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Aims and objectives

The effective energy of X-ray beams is one of a number of standard quality assurance (QA) and quality control (QC) tests for various X-ray imaging systems [1]. In the radiation quality management of the 320-multidetector Computed Tomography (CT), the half-value layer (HVL), which is used to calculate the effective energy, is important. In general X-ray generators, HVLs are measured by means of an ionization chamber (IC) dosimeter. However, the method to measure precise HVLs of the CT is complicated due to the configuration. To solve these problems, a method using radiochromic film and step-shaped aluminum (SSAl) filters has been developed in a previous experiment with a diagnosis X-ray photography [2, 3]. This method was able to measure within an error range of less than 5 % using only GAFCHROMIC EBT2 Dosimetry (EBT2) film that has a weak energy dependence and a low sensitivity for scattered radiation [4].

In this study, GAFCHROMIC EBT3 Dosimetry (EBT3) film, which has a similar characteristic to EBT2, was used as the radiochromic film because it exhibits only slight energy dependency errors in comparison with other radiochromic films [5-7]. In a previous experiment, there was an energy-dependent error of approximately 0.2% from 30 to 60 keV [8].

The purpose of this study is to evaluate the effective energy of the CT by applying this method.
Methods and materials

1. GAFCHROMIC EBT3 Dosimetry film

The EBT3 film is rectangular in shape with dimensions of 8 in. × 10 in. (20.5 cm × 25.5 cm), and is yellow before irradiation. EBT3 film is suitable for the absorbed dose measurement in the diagnostic range because it is recommended for dosimetry over a wide dose range (0.01-40 Gy) [9]. In addition, the density-absorbed dose calibration curve exhibits a straight line in a low dose range such as the diagnostic range (<100 mGy) [10]. EBT3 has a low energy-dependent characteristic, approximately 0.2% from 30 to 60 keV [11].

2. HVL measurement of the 320-multidetector CT

A. Exposure method

The exposure parameters of 320-multidetector CT were 120kV, 300mA, 3.0 seconds, and the scout view system was used. The SSAl was set up near the X-ray tube, and EBT3 was set up in the isocenter of the CT. The anode-cathode direction of the X-ray tube was set parallel to the long axis of the EBT3 film to minimise the impact of the X-ray heel effect for each Al filter. The SSAl filter has a rectangular form with dimensions of 20 mm × 100 mm, and its thickness increases from 1 mm to 25 mm (the specific thicknesses are 1, 2, 3, 5, 7.5, 10, 12.5, 15, 20, and 25 mm) [3]. The thickness of the Al filter was varied in the long-axis direction of the EBT3 film.

The geometric arrangement of the experimental set-up of the exposure method for measuring the HVL of CT is shown in Fig. 1. The distance from the SSAl filter to the EBT3 was set at 200 mm. The distance from the CT isocenter to the EBT3 was set at 50 mm. To avoid back-scattered radiation from the bed, the distance between the bed and the EBT3 was set at 200 mm.

B. Scanning and analysis of the EBT3 film

A central 100 mm band of the EBT3 was set as the exposure area, and lead masking plates (thickness 2 mm) were placed on either side of the exposure area to create unexposed areas. The SSAl filter was placed in the center of the exposure area. Full exposure area, unexposed area, and step-shaped Al filter area were set in the EBT3. The full exposure area was used to compensate for a non-uniformity error caused by the active layer of the EBT3, while the unexposed area was used to compensate for a non-uniformity error caused by protective layer of the polyester.
The EBT3 was scanned using a A3 flat-bed scanner (Fig. 2) in RGB (48 bit) mode, 100 dpi, with the protection of a film of liquid crystal for removal of the Moire artifact. The EBT3 was scanned with a reflection mode. To scan the EBT3 film using this setting, regular white paper with a uniform density was attached to the back of the EBT3 film (Fig. 3). In addition, the EBT3 film was scanned both before and after exposure to eliminate the non-uniformity error of the film layer. EBT3 film was scanned 24 h after exposure. The EBT3 was kept at room temperature (20±25 °C) in a shaded bag.

The image data from the EBT3 film was divided into R, G, and B modes (16 bits each), and the R mode was used for high density contrast. It was converted to a grey scale and analysed using ImageJ version 1.48v image analysis software (National Institute of Health, Maryland). To measure the increase in the density of the EBT3 film, the image data before exposure were subtracted from the after-exposure data in terms of pixel units in two dimensions.

The ROI was set at each thickness of the SSAl filter and was sized 900 pixels (152.4 mm) × 20 pixels (3.4 mm). The ROI on the GAF-EBT2 included a sequence of an unexposed area, a full-exposure area, the SSAl filter area, a full-exposure area, and an unexposed area. In terms of density, the densities of an exposure area and an unexposed area were set at 100% and 0%, respectively, and the density ratio of the SSAl filter area could then be calculated. The attenuation curve was obtained using the density ratio of each SSAl filter thickness. The HVL was then calculated using the attenuation curve. In addition, the effective energy was obtained from the HVL.
Fig. 1: Geometric arrangement of the exposure method for measuring the HVL of CT

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Fig. 2: Flat-bed scanner of A3 size
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Fig. 3: Scan method of EBT3

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Results

Figure 4 shows the density profile curve with each ROI for Al thickness from the SSAI filter area, the full exposure areas, and the unexposed areas. The center of the profile curve corresponded to high density and it was flanked by regions of low density, because of wedge filter of the 320-multidetector CT.

Figure 5 shows the attenuation curve of the 320-multidetector CT. The HVL and the effective energy of the 320-multidetector CT were 9.14 mm and 58.4 keV, respectively.
Fig. 4: Density profile curves

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Fig. 5: Attenuation curve of the 320-multidetector CT

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Conclusion

There is no standard method to measure the effective energy of the 320-multidetector CT. It was considered that the method using EBT3 and the SSAl was able to be measured with similar precision in the 320-multidetector CT, because it was able to be measured with precision of less than 5% in general X-ray generators. As a result, the effective energy of the 320-multidetector CT could be easily and quickly measured using EBT3 and the SSAl. Therefore, it is considered that the method using EBT3 and the SSAl offers a facile means of determining the effective energy of the CT for QA and QC.
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