SHEET ROLL PHANTOM WITH RADIOCHROMIC FILM OF COMPUTED TOMOGRAPHY

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Abstract: In general, computed tomography (CT) dosimetry phantoms have been made of solid acrylic. Therefore, the phantom diameter and dose measurement positions in the phantom are limited. A *Sheet Roll Phantom* made from a vinyl chloride sheet has been developed for radiochromic film dosimetry at any phantom diameter and measurement position, including the phantom surface. In this study, surface doses and center doses (at 5 mm radius) of phantoms were measured. The phantom diameters were 16 - 6 cm (every 2 cm). Scanning parameters of CT were 120 kV, 300 mA, 0.5 sec/rot, pitch 0.875 and 2 mm x 4 detectors. The radiochromic films were scanned using a flat bed scanner in RGB mode, 300 dpi, and data were analyzed with a personal computer by image analysis software. The ratios of the center to surface doses of 16, 14, 12, 10, 8, 6 cm diameters were 80, 83, 88, 93, 105, and 111 %, respectively. When using this system, the maximum and minimum exposure doses of a CT examination can be measured separately at any position.

Introduction

The computed tomography dose index (CTDI) and its variations (CTDIw, CTDIvol), and dose length product (DLP) are mainly used for CT dose evaluation. A pencil type ionization chamber and CT dose phantom have been used for measurement of CTDI [1, 2].

The CT dose phantom consists of two parts, a body phantom and a head phantom. The phantoms are circular cylinders of polymethl-methacrylate, density of 1.19 ± 0.01 g/cm^3, at least 14 cm length, with diameters of 32 cm and 16 cm, respectively.

Each phantom has five probe holes (inside diameter 1.31 cm). One hole is at the center and the other four holes are at peripheral positions, 90° apart and 1 cm from the outer surface [1]. The phantom diameter and dose measurement positions in the phantom are thus quite limited. In addition, evaluation of the absorbed dose in a local area and the detailed dose distribution in a phantom are difficult.

In this study, a new CT dose phantom that can be set to a variety of diameters was experimentally developed for radiochromic film dosimetry. It could be used for the measurement of any position from center to surface and could also be used evaluate local dose.

Materials and Methods

The CT dosimetry phantom was made by bending a 100% vinyl chloride sheet (specific gravity was about 1.3 g/cm^3). The thickness of the sheet was 0.5 mm and width was 30 cm. The phantom center core consisted of a plastic hose; outside diameter 14 mm, inside diameter 12 mm. In addition, a 10 mm acrylic pipe could be inserted in the hose and radiochromic dosimetry film was put on the acrylic pipe. The two ends of the hose could be closed in order to fill the hose with water and remove the influence of air.

The phantom diameters were freely set by controlling length of the sheet. A measurement position of absorbed dose was freely decided. The depth of measurement position was decided at 0.5 mm intervals by inserting radiochromic film between the sheets. The new phantom was named Sheet Roll Phantom (SRP).

In this study, GAFCHROMIC XR Type R Film (Type R-film: Lot No: L04B50XRR, ISP, Wayne, NJ) was used as a dosimeter. It was a reflected-type film, and an economical flatbed scanner can be used for measurement of film density [3, 4, 5].

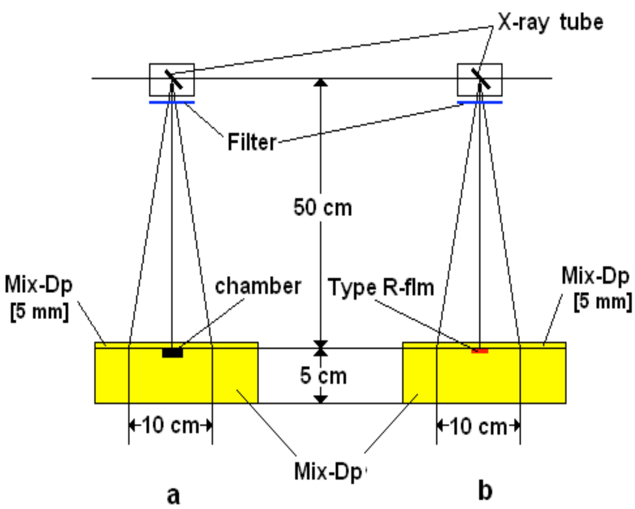


Figure 1: Exposure method for calibration curve
a. Measurement method of absorbed dose
b. Exposure method of Type R-films
*Field size: 10 x 10 cm^2

ISSN: 1727-1983 © 2005 IFMBE

The effective energy of an inverter type X-ray generator (KXO-50G, TOSHIBA, Tochigi) was set at 46 keV, the same as the X-ray CT scanner (Aquilion 4, TOSHIBA, Tochigi). The exposure parameters were 120 kV, 2.0 mm Al filter, 200 mA, 0.28 sec. The absorbed dose of single exposure, approximately 2.7 cGy, was measured by dosimeter (Ionex 2500/3) with a 0.03 cc shallow chamber. A schematic arrangement of the exposure method to the generating calibration curve is shown in Figure 1. Twelve pieces of Type R-film were cut to 2 cm x 2 cm along with Down-Web direction. Each film was exposed by increasing the number of exposures (from 2.7 cGy to 32 cGy, in steps of 2.7 cGy).

A schematic arrangement of the exposure method for CT dose dosimetry is shown in Figure 2. The SRP was held on the CT bed, and the center of SRP was always located at the isocenter of the gantry at each diameter. The SRP diameter was changed from 6 cm to 16 cm (every 2 cm). Center and surface doses of each diameter were measured by a Type R-film. Center dose was measured at 5 mm radius of SRP because Type R-film can be bent at a 5 mm radius. The surface dose was measured by setting film on the surface of a SRP. Type R-films were cut to 2 cm width, and lengths of each film were valied according with diameter of SRP, as shown in Table 1. The dose measurement range was set at 0-180 degrees in consideration of scattered radiation from the CT bed. Marks were made at 0 and 90 degrees on each film as reference points for the analysis. Arrangement of films was as shown in Figure 2. Scanning parameters of the CT were 120 kV, 300 mA, 0.5 sec/rot, pitch 0.875, 2 mm x 4 detectors, and exposure range was 16 cm.

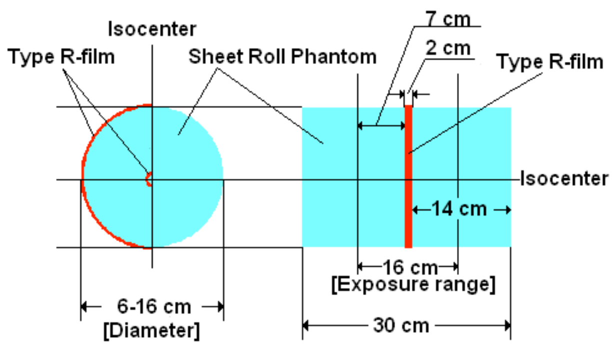


Figure 2: Exposure method of CT dose dosimetry

Table 1: Length of Type R-films

Phantom diameter [cm]	6	8	10	12	14	16
Center [cm]			2			
Surface [cm]	11	14	17	20	23	26

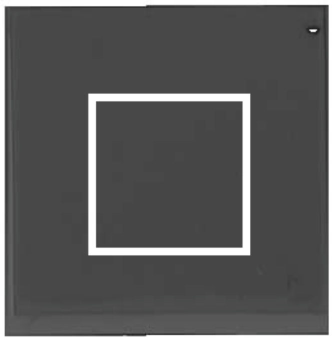
Center：at 5 mm radius

Type R-films were scanned using a flat bed scanner (EPSON ES-2200, Seiko Epson Co. Nagano) in RGB (48 bit) mode, 300 dpi, with a GAFCHROMIC COLOR MASK (ISP, Wayne, NJ) [5]. Films were scanned before and after exposure. To remove any density increase error due to time difference, films were scanned at a constant time (48 hours) post-exposure [3].

Image data of the Type R-film were changed into 8 bit gray scale in Adobe Photoshop 6.0 (Adobe Systems Incorporated, San Jose, CA) and were analyzed with image analysis software SCION image (Scion Corporation, Frederick, Maryland).

A region of interest (ROI) for analysis was determined for each film, and the mean pixel value of the ROI was measured. To adjust the color shading at the yellow polyester layer of Type R-film, the mean pixel values of ROIs on pre-exposure films were subtracted from the mean pixel values of ROIs on 48 hours post-exposure films. The pixel values after this subtraction were defined as net pixel value (NPV). In addition, NPV indicated the practical density increase of each film.

For generation of a calibration curve, the size of ROI was defined as 120 pixel x 120 pixel, and it was placed on the center of each film as shown in Figure 3. NPV of each film was measured and the calibration curve corresponding to the absorbed dose was generated.



120 pixel x 120 pixel

Figure 3: Position of ROI for calibration curve

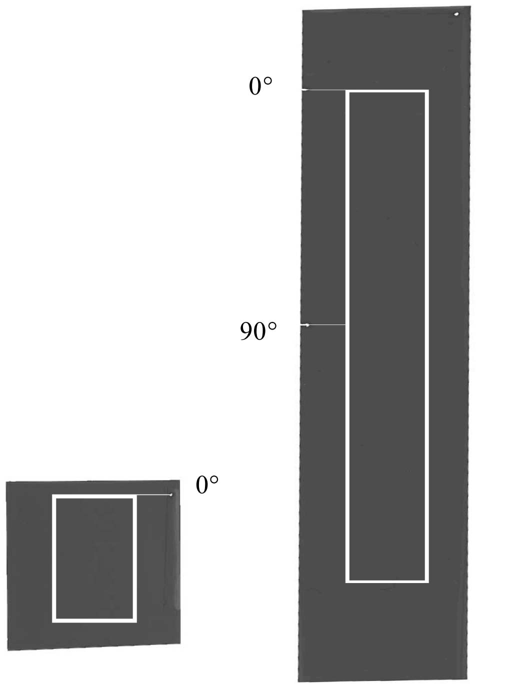
For measurement of CT dose, the size of the ROI at 2 cm width was set at 120 pixels and the sizes of the long axes are shown in Table 2. The ROI was placed on the center of each film on the basis of the mark as shown in Figure 4. NPV of each film was analyzed and center dose and surface dose at each phantom diameter were calculated using the calibration curve. The relationship between phantom diameter and CT dose was analysed using spreadsheet software (Excel 2002, Microsoft Co. Redmond, WA).

ISSN: 1727-1983

Table 2: Size of ROI (long axis)

Phantom diameter [cm]	6	8	10	12	14	16
Center [pixel]	185					
Surface [pixel]	1112	1483	1854	2225	2595	2966

Center：at 5 mm radius



120 pixel x 185 pixel
Center

120 pixel x 1112 pixel
Surface

Figure 4: Position of ROI in CT dose dosimeter Type R-film (at 6 cm diameter) and mark of reference point for analysis

Results

A photograph of SRP is shown in Figure 5. The SRP diameter could be set at 1 mm intervals from 15 mm by controlling length of the sheet. In addition, measurement positions were determined at 0.5 mm interval in depth and surface on the phantom.

The calibration curve is shown in Figure 6. Although the measuring dose range of Type R-film was designed to be 0.1-15 Gy, it was available at a low dose range (2.7-32 cGy) in this study. NPV was correlated with absorbed dose. The coefficient of determination (r^2) was 0.985. However, density fluctuation by nonuniformity of the coating in the active layer was most obvious in the low dose range.

NPV, center dose, and surface dose for each phantom diameter are shown in Table 3. The ratios of center and surface dose are shown in Figure 7. When the surface and center doses for 16 cm diameter were takes as a 100%, surface and center doses of 14, 12, 10, 8, and 6 cm diameters were 107, 111, 123, 125 and 136%, and 111, 123, 142, 165 and 189% respectively. In addition, the ratios of center to surface dose for each phantom diameter are shown in Figure 8. Center dose become similar to surface dose with decreasing diameter of the phantom to 8 cm. Additionally, the center dose was larger than the surface dose with decreasing diameter.

Figure 5: Sheet Roll Phantom (6 cm diameter)

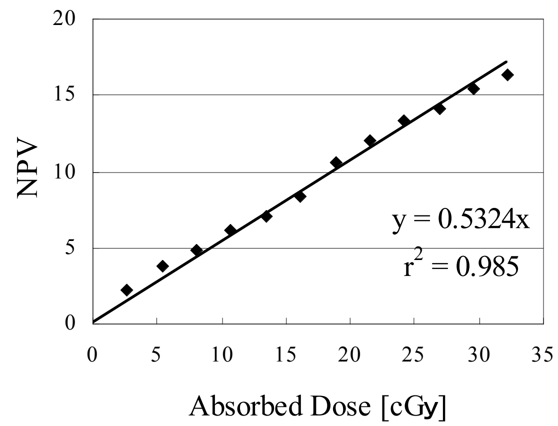


Figure 6: Calibration Curve of Type R-film to 46 keV
r^2: Coefficient of determination

Table 3: NPV and Absorbed dose

Phantom diameter [cm]	6	8	10	12	14	16
Center [NPV]	3.3	2.88	2.49	2.15	1.94	1.75
(cGy)	(6.2)	(5.41)	(4.68)	(4.04)	(3.64)	(3.29)
Surface [NPV]	2.96	2.73	2.68	2.43	2.34	2.18
(cGy)	(5.56)	(5.13)	(5.03)	(4.56)	(4.4)	(4.09)

Center: at 5 mm radius

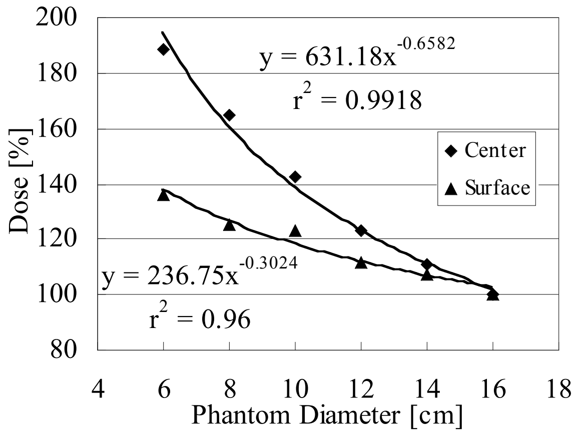


Figure 7: Ratio of surface and center radiation dose
r^2: Coefficient of determination

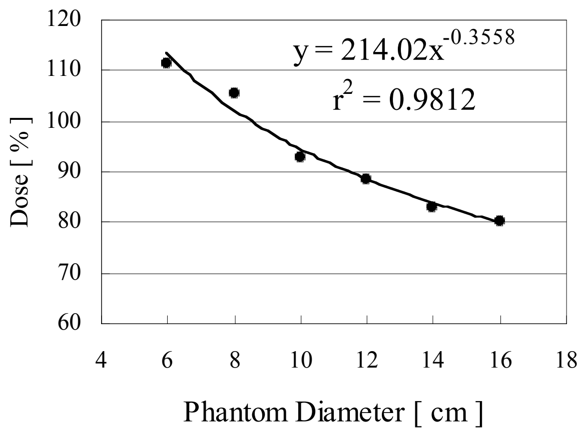


Figure 8: Ratio of center to surface radiation dose
r^2: Coefficient of determination

Discussion

The 100% vinyl chloride sheet that was used for SRP is MG film (MEIWA GRAVURE CO. Osaka). MG film can be purchased almost anywhere, in various thicknesses. Thus, the depth of measurement position can be freely set using the thickness of the sheet. In addition, SRP is simple to make at a reasonably low cost.

The specific gravity of the 100% vinyl chloride sheet (1.3 g/cm^3) is higher than that of the CTDI phantom (1.19 ± 0.01 g/cm^3) used for defining in FDA. The purpose of this study was the experimental structural development of a new CT dose phantom. Therefore, the 100% vinyl chloride sheet was appropriate for this study.

In this study, film dosimetry was used for measurement of CT dose, rather than an ionization chamber. The measurement position in the phantom could be freely set because film dosimetry could be set between the sheets. In addition, radiochromic film could be used to evaluate local dose. Therefore, radiochromic film is suitable for dosimetry of SRP.

The high dose areas in the phantom varied with changes of phantom diameter. Therefore, measurement using a SRP and radiochromic films is suitable for dosimetry of CT.

Conclusions

This study indicated that this SRP with radiochromic film is useful for the measurement of the radiation dose from CT examination. Measurement positions could be freely decided at any position and any depth including the surface of the SRP phantom. When using this system, the maximum and minimum exposure doses of a CT examination could be measured separately.

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 ISSN: 1727-1983