The method of incorporating the effect of the beam-shaping filter in Monte Carlo simulation

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Purpose

There is specific beam molding filter called beam-shaping filter or Bow-tie filter in front of an X-ray tube of X-ray CT device. This filter equalizes radiation quality after X-rays penetrated an object and reduces patients’ exposure to radiation. This filter is essential to make an accurate computation in X-ray CT Monte Carlo simulation. The structure of the filter is not published in each manufacturer and is complex. Therefore, it is difficult to build in mathematical model of the actual beam shaping filter in the simulation. In general, the geometry of the beam-shaping filter is thin in the center and is thickened with increasing distance from the center. We attempted to simulate using measured value of X-rays after transmitted the filter instead of modeling the actual filter. To assess the agreement between measurement and simulation, comparing computed tomography dose index (CTDI) was used.
Methods and Materials

2.1 Measurement of the beam-shaping filter by using Rapidose

A fan angle of X-ray CT device used for measurement is 38°. An angle of an X-ray from the center of the fan angle was defined "beam angle". X-ray tube was stated at top position of rotation angle while the measurement. Along the beam angle, the data of the exposure dose and the AL Half Value Layer were gotten from 0° to 19°. This measurement was used a semiconductor dosimeter called Rapidose (radcal corp. Monrovia, CA). This dosimeter can obtain the exposure dose, AL Half Value Layer and wave of tube voltage. This dosimeter is connected to PC by USB wire and these data are displayed on a PC screen (Fig.1). We attempted to simulate phantom irradiation of the X-ray CT using these data obtained from the semiconductor dosimeter.

Fig.: 1. Overview of Rapidose

References: - Nagoya/JP

2.2 Measurement of the beam-shaping filter by using CT pencil ionization chamber

Beam-shaping filter of the Toshiba Aquilion 64 CT was measured by using the CT pencil ionization chamber. Fig. 2 shows a Schematic model of the measurement. An instrument made of a polystyrene foam for measurement was located on the CT table. The edge on right and left and bottom of the instrument was covered with lead because of shielding scattered photon. There are seven holes at 3 degrees intervals from 0 degree to 18 degree along a fan beam in the instrument. The ionization chamber inserted in the hole and air-kerma and AL HVL was measured at the hole position.
2.3 Method to incorporate the effect of the beam-shaping filter in the EGS5 simulation

In the EGS5 simulation, the geometry of the situation as actual survey was made. A fan beam angle is 38 degree (-19 degree to +19 degree). The distance between the source and isocenter was 60 cm. The x-ray source was moved along an x-ray tube orbital at 1-degree intervals, and photons were emitted at each position. It is difficult to construct actual shape of the filter in the simulation because information of detailed structure of the filter is not published. Therefore, by incorporating transmitted photons and energy spectrums at each beam angle, the effect of the beam-shaping filter is taken into account in the simulation. Relative photon number along the fan beam was determined based on measured rate of air-kerma by using dosimeter. The number of photons at the center...
of the fan beam was dense and the number of photons at the fringe of the fan beam was sparse. Energy spectrums were calculated by Birch's formula to correspond with measured AL HVL and applied calculated spectrum according to a beam angle.

2.4 Effect of the attenuation of X-ray by CT table

CT table reduces intensity of the x-ray beam. The quantity of that depends on the geometry and composition of the table. Inside of the table is complex and it is not easy to know that information. Therefore, air-kerma after transmitted from the table and air-kerma when the table doesn’t exist were measured by using CT pencil ionization chamber, and a ratio with or without CT table was calculated. We postulated that the material of the table is made of carbon, density of the carbon was modified to correspond with measured ratio in the simulation.

2.5 Computed tomography dose index (CTDI) measurements

The Computed Tomography Dose Index (CTDI) is used to express dose values in CT. CTDI is based on measured absorbed dose in a cylindrical acrylic phantom with a 10 cm pencil ion chamber in the phantom’s center hole and four phantom’s peripheral holes (0°, 90°, 180°, 270°). This is useful when comparing several different CT (computed tomography) units. CTDI is derived from measuring the dose from a single slice.

The average of four doses is CTDI peripheral (CTDI100, p), dose at center position is CTDI center (CTDI100, c). P-c ratio was given by

\[
p-c \text{ ratio} = \frac{\text{CTDI}_{100,p}}{\text{CTDI}_{100,c}} \tag{1}\n\]

Similar geometry was constructed in the simulation and the relative value was calculated. With this relative value, we compared the measurement value with the EGS5 calculation value.
Results

3.1 Measured data of the beam-shaping filter

The exposure dose and the effective energy calculated from AL Half Value Layer at each point were shown in Fig.3. Distribution of the exposure dose by rapidose was flat up to about 4 degrees of the beam angle and at angles higher than 4 degrees, the exposure dose decreased with increasing the beam angle. Distribution of the exposure dose by CT ion chamber was similar trend as it by rapidose but slightly greater than rapidose (Fig.4). The effective energy was flat up to about 4 degrees of the beam angle and at angles higher than 4 degrees, the effective energy increased with increasing the beam angle.

![Graph showing dose distribution](image)

*Fig.: 2.Dose distribution of TCT-300 scanner along the fan beam*

*References: - Nagoya/JP*
Fig.: 3. Effective energy change of TCT-300 scanner along the fan beam

References: - Nagoya/JP
Fig.: 4. Dose distribution of Aquilion 64 scanner along the fan beam

References: - Nagoya/JP
3.2 Comparison of P-C ratio

Table 1 (Toshiba TCT-300 scanner) and Table 2 (Toshiba Aquilion 64 scanner) show the comparison between measured P-C ratio and simulated P-C ratio. Both results of the differences between measurement and simulation were within 5%. Dose of bottom direction was relatively lower than that of other direction because of attenuation by CT table.

Table 1 Comparison of measured p-c ratio and simulated p-c ratio using the Toshiba TCT-300 scanner

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Table.2 Comparison of measured p-c ratio and simulated p-c ratio using the Toshiba TCT-300 scanner
Conclusion

From the results of measurement of beam-shaping filter, after transmitted thorough the beam-shaping filter, photon number around the center were significantly large and photon number rapidly decreased with increasing beam angle from the center. Effect of the beam-shaping filter could be incorporated in the simulation. by using measured dose distribution and effective energy change. It is important to incorporate the effects of the beam shaping-filter and the CT table for accurate CT simulation. The benefit of our method is that the effect of the beam-shaping filter can be incorporated easily if there isn't information like material or shape of the actual beam-shaping filter.

In recent years, the organ dose has been measured by placing the dosimeter in the anthropomorphic phantom with improved measurement technology. The organ dose has been estimated using voxel phantom in the Monte Carlo simulation. In order to calculate the accurate organ dose in X-ray CT simulation, consideration of the beam-shaping filter is absolutely necessary.
Images for this section:

**Fig. 0: 1. Overview of Rapidose**

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**Fig. 0: 2. Dose distribution of TCT-300 scanner along the fan beam**

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**Fig. 0:** Effective energy change of TCT-300 scanner along the fan beam

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References


