Kumamoto University

Determination of backscatter factors in diagnostic kilovoltage x-ray beams

R. Tanabe[1], F. Araki [1] and T. Ohno[1]

[1]Kumamoto University, Kumamoto, Japan

JULY 12–16 2020 VIRTUAL
JOINT AAPM | COMP MEETING
EASTERN TIME [GMT-4]

INTRODUCTION

Current reference dosimetry for diagnostic kilovoltage x-ray beams has been conducted as an in-air measurement using the air kerma calibration. The absorbed dose to water at the phantom surface is calculated by an ionization chamber reading in free air, backscatter factors, and the water/air-mean mass energy-absorption coefficient ratio according to the various dosimetry protocols [1]. In the AAPM TG-61 dosimetry protocol [2], backscatter factors are determined as a function of the Al half-value-layer (Al-HVL) values and irradiation field sizes. However, it is known that backscatter factors depend not only on Al-HVL and irradiation field size, but also on the tube voltage (kVp) [3].

In this study, the quality index (QI) [4] was used as an indicator of the x-ray beam quality, which is specified by the ratio of effective photon energy and tube voltage.

AIM

This study aims to investigate the correlation between backscatter factors and Al-HVL using QI as a parameter for diagnostic kilovoltage x-ray beams.

METHOD

Backscatter factors, B_w, for x-ray fluence spectra were calculated from the weighted average [5] using air kerma (K_{air}) free-in-air (FIA) and B_w for monoenergetic photons of between 8 and 140 keV with field sizes of 10 × 10 to 40 × 40. cm^2 according to

$$B_w = \frac{\sum K_{air}(E_i)B_w(E_i)\Delta E_i}{\sum K_{air}(E_i)\Delta E_i} = \frac{\sum E_i[\Phi(E_i)]_{FIA}[\mu_{en}(E_i)/\rho]_{air}B_w(E_i)\Delta E_i}{\sum E_i[\Phi(E_i)]_{FIA}[\mu_{en}(E_i)/\rho]_{air}\Delta E_i} \qquad (1)$$

where E_i is the photon energy at the midpoint of the energy bin i, $[\Phi(E_i)]_{FIA}$ is the photon fluence in free air, $[\mu_{en}(E_i)/\rho]_{air}$ is the the mass energy absorption coefficient in free air, and ΔE is the width of the energy bin i. The value of B_w for monoenergetic photons was calculated from the ratio of the water kerma at the surface of a water phantom and water kerma at the same FIA point using the EGSnrc/cavity Monte Carlo code [6].

The weighted average B_w was validated by comparing it with that calculated directly through Monte Carlo calculations using the x-ray fluence spectra. Monte Carlo calculations were conducted with the same geometric arrangement and calculation parameters as those applied for monoenergetic photons.

Finally, B_w for the x-ray fluence spectra was classified by a QI of 0.35, 0.4, 0.5, 0.6 and 0.7. The correlation between B_w and Al-HVL was evaluated using the QI as a parameter. The x-ray fluence spectra were generated for tube voltages of 40–140 kVp with Al-HVLs of 0.5–13.2 mm using the SpekCalc program [7].

RESULTS AND DISCUSSION

Figure 1 presents the B_w for monoenergetic photons of 8–140 keV with a field size of 10 × 10 to 40 × 40 cm^2 .The values of B_w for monoenergetic photons increased rapidly at a low energy of 8–40 keV, reached the maximum within the energy range of 50–70 keV, and decreased gradually thereafter.

Figures 2 (a) and (b) show a comparison between B_w for the x-ray fluence spectra obtained from the weighted average and direct Monte Carlo calculations for field size of 10 × 10 cm^2. The x-ray fluence spectra were created for tube voltages of 60,120 kVp and Al-HVLs of 2.0–9.5 mm by the SpekCalc program. Both backscatter factors are in good agreement of within 0.7%. Therefore, the backscatter factors for the x-ray fluence spectra obtained from the weighted average make it possible to significantly reduce the time and effort in comparison to direct Monte Carlo calculations.

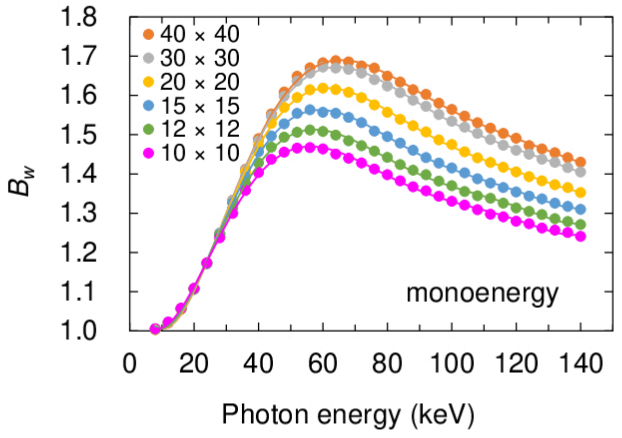

Fig.1. Backscatter factor for monoenergetic photons of 8–140 keV at the surface of water for field sizes of 10 × 10 to 40 × 40 cm^2 at an SSD of 100 cm.

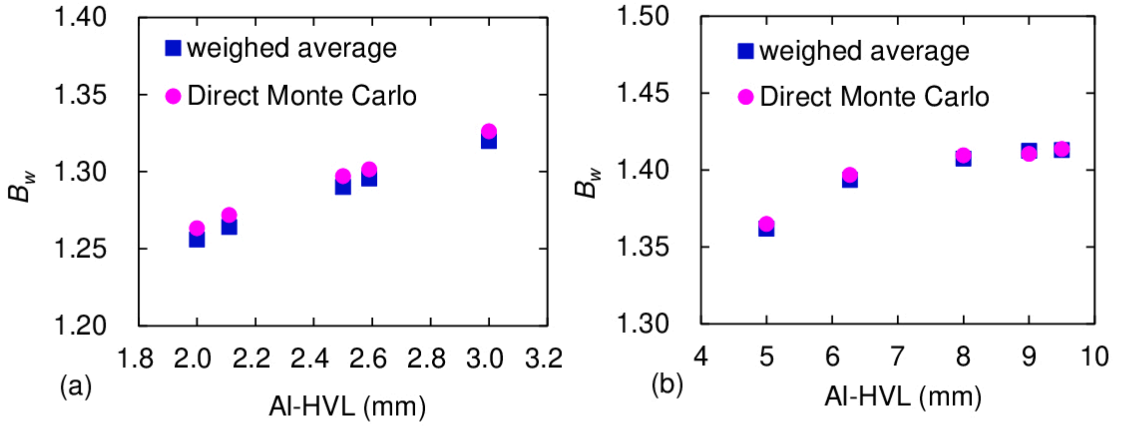

Fig. 2. Comparison between backscatter factors of x-ray fluence spectra obtained from the weighted average and direct Monte Carlo calculations, (a) 60 kVp and (b) 120 kVp for field size of 10 × 10 cm^2 .

Figures 3 (a)-(d) represent the B_w as a function of Al-HVL for x-ray fluence spectra with a QI of 0.4, 0.5 and 0.6, and with monoenergetic photons, respectively. Values of B_w were indicated for field sizes of 10 × 10 to 40 × 40 cm^2 at an SSD of 100 cm. The value of B_w showed a good correlation with Al-HVL by the parameter, QI, for the x-ray spectra with different tube voltages. In addition, the correlation between B_w and Al-HVL represents a similar correlation to those for monoenergetic photons shown in Fig. 2 (d). The tube voltage and the effective photon energy have a same linear relationship with the monoenergetic photon beams by using a parameter, QI. Therefore, B_w and Al-HVL for the x-ray fluence spectra showed a good correlation as well as monoenergetic photon beams.

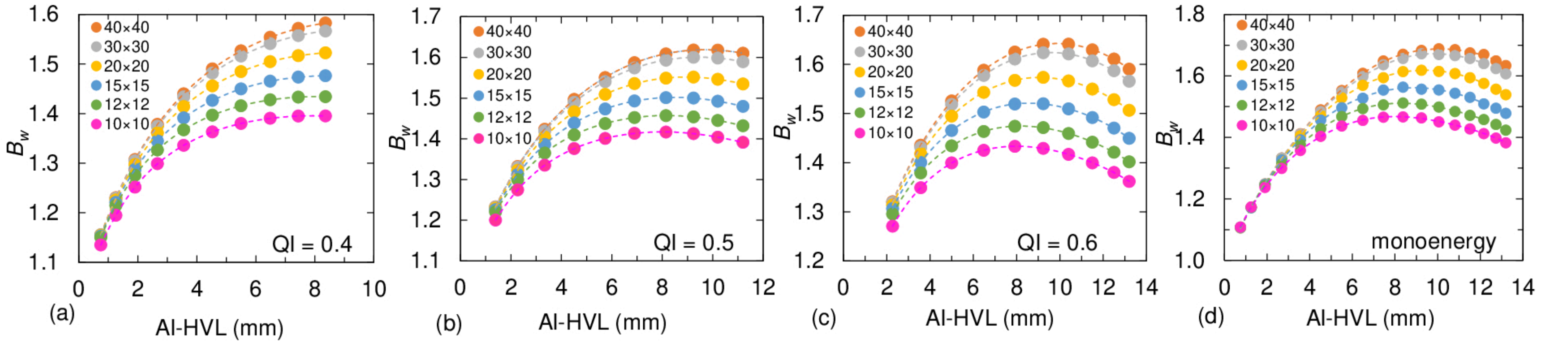

Fig. 3. Backscatter factors, B_w, as a function of Al-HVL for x-ray fluence spectra with QI of (a) 0.4, (b) 0.5 and (c) 0.6, and (f) monoenergetic photons, for field sizes of 10 × 10 to 40 × 40 cm^2 at an SSD of 100 cm.

CONCLUSIONS

In this study, backscatter factors of diagnostic kilovoltage x-ray beams were calculated from the weighted average using backscatter factors for monoenergetic photon beams. The weighted averaged backscatter factors were validated by comparing them with those of direct Monte Carlo calculations for the x-ray fluence spectra. Both backscatter factors were in good agreement of within 0.7%. In addition, the backscatter factors for x-ray fluence spectra showed a good correlation with Al-HVL using the QI as a parameter. The backscatter factors can be determined accurately as a function of Al-HVL by this parameter.

REFERENCES

[1] Andreo P, Burns DT, Hohlfeld K,et al. International Atomic Energy Agency (IAEA). Absorbed dose determination in external beam radiotherapy: An International Code of Practice for dosimetry based on standards of absorbed dose to water. IAEA Technical Reports Series no. 398. Vienna: IAEA; 2000.

[2] Ma C-M, Coffey C, DeWerd L, et al. AAPM TG-61 protocol for 40-300 kV x-ray beam dosimetry in radiotherapy and radiobiology. Med Phys 2001; 28(6).

[3] Andreo P. Data for the dosimetry of low- and medium-energy kV x rays. Phys Med Biol 2019;64(20):205019.

[4] Kurosawa T, Takata N. Estimation of electron-loss and photon-scattering corrections for parallel-plate free-air chambers. J. Nucl. Sci. Technol. 2005;42(12): 1077–1080.

[5] Benmakhlouf H, Bouchard H, Fransson A, et al. Backscatter factors and mass energy-absorption coefficient ratios for diagnostic radiology dosimetry. Phys Med Biol 2011; 56 (22): 7179–7204.

[6] Kawrakow I. Accurate condensed histry Monte Carlo simulation of electron transport. EGSnrc, the new version. Med Phys 2001; 27(3): 485–498.

[7] Poludniowski G, Landry G, DeBlois F, et al. *SpekCalc*: A program to calculate photon spectra from tungsten anode x-ray tubes. Phys Med Biol 2009;54(19):N433–N438..

CONTACT INFORMATION

Email: jackmen7441@gmail.com