Comparison of Air Kerma and Absorbed Dose to Water Based Protocols for High Energy Photon Beams : Theoretical and Experimental Study

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ABSTRACT

New types of protocols have been recently in development, all based on an absorbed dose-to-water with the aim of improving the accuracy of measurements of absorbed dose to water. IAEA TRS-277, the air-kerma standard-based present protocol, and IAEA TRS-398 and AAPM TG-51, the absorbed dose-to-water standard-based new one, were studied and compared theoretically and experimentally for photon beams of 6, 10, and 15 MV. NE 2571 and 3 Farmer types of ionization chambers in widely commercial use were used to determine an absorbed dose to water at the reference depth in water. Two different kinds of calibration factors were given respectively for every chamber calibrated in ^{60}Co gamma ray beams from a Korean Secondary Standard Dosimetry Laboratory (KFDA). This work shows that there is around 1% of difference of absorbed doses measured between two different types of calibration systems owing to different physical parameters and reference conditions used. We hope this work to help form the basis on development of new type of protocol in Korea.

Keywords: Air Kerma standard, Absorbed dose to water standard, Dosimetry, Photon.

1. INTRODUCTION

In the twenty first century the paradigm of a dosimetric protocol changing from an air-kerma standard to an absorbed dose-to-water standard was released in many an advanced country and related academical associations.[1,2] An AAPM TG-51 and an IAEA TRS-398, a new concept of protocols based on an absorbed dose-to-water standard, have been released recently. They only need an absorbed dose-to-water calibration factor and a beam quality correction factor to make an easy and correct calculation of an absorbed dose at a reference depth in water and receive careful study prior to a clinical application.[3-6]

This work presents the analysis of formulae system and the comparison of an absorbed dose-to-water measured at a reference depth between IAEA TRS-277 used widely in korea and IAEA TRS-398 and AAPM TG-51 based on an absorbed dose-to-water and is hoped to be the groundwork for developing and building up a new korean dosimetric protocol based on an absorbed dose-to-water standard. We expect this new protocol to be applicable to the measurement of an absorbed dose for the high energy photon beams to attain an international level of accuracy.

2. MATERIALS AND METHODS

2.1 General Formalism

The formalisms of 3 different types of protocols to determine an absorbed dose to water at a reference depth[1-3] are now provided. Not entire factors are described.

2.1.1 IAEA TRS-277 Protocol

IAEA TRS-277, a dosimetric protocol based on an air kerma standard, takes two steps to determine an absorbed dose to water at an effective depth of measurement.

$$N_{D,air} = N_k \times (1-g) \times k_{att} \times k_m \tag{1}$$

$$D_w^D(P_{eff}) = M \times N_{D,air} \times (s_{w,air})_Q \times p_Q \text{ [Gy]} \quad (2)$$

2.1.2 IAEA TRS-398 Protocol

The absorbed dose to water at the reference depth z_{ref} in water for a reference beam quality Q_o and in the absence of the chamber is given by

$$D_{w,Q_o} = M_{Q_o} \times N_{D,w,Q_o} \text{ [Gy]} \quad (3)$$

When a dosimeter is used in a beam of quality Q different from that used in its calibration, Q_o, the absorbed dose to water is given by

$$D_{w,Q} = M_Q \times N_{D,w,Q_o} \times k_{Q,Q_o} \text{ [Gy]} \quad (4)$$

where the beam quality correction factor k_{Q,Q_o} corrects for the effects of difference between the reference beam quality Q_o and the actual user quality Q and is defined as

$$k_{Q,Q_o} = \frac{N_{D,w,Q}}{N_{D,w,Q_o}} \approx \frac{(s_{w,air})_Q \times p_Q}{(s_{w,air})_{Q_o} \times p_{Q_o}} = \frac{(s_{w,air})_Q \times (p_{wall}\, p_{cav}\, p_{ceo}\, p_{dis})_Q}{(s_{w,air})_{Q_o} \times (p_{wall}\, p_{cav}\, p_{ceo}\, p_{dis})_{Q_o}} \quad (5)$$

2.1.3. AAPM TG-51 Protocol

TG-51 provides the following formula of an absorbed dose to water for photon beams for the beam quality Q.

$$D_w^Q = M \times k_Q \times N_{D,w}^{^{60}Co} \text{ [Gy]} \quad (6)$$

where $N_{D,w}^{^{60}Co}$ is an absorbed-dose to water calibration factor for a reference condition in a ^{60}Co beam and the beam quality correction factor k_Q is defined as

$$k_Q = \frac{N_{D,w,Q}}{N_{D,w,Q_o}} \approx \frac{(L/\rho)_{air}^{water} \times (p_{wall}\, p_{rep}\, p_{ceo})_Q}{(L/\rho)_{air}^{water} \times (p_{wall}\, p_{rep}\, p_{cel})_{Q_o}} \quad (7)$$

A ^{60}Co beam is usually used as the reference beam quality Q_o for the calibration of an ion chamber. The beam quality correction factor should be ideally measured in the same as a user's beam quality for each ion chambers. The values of the beam quality correction factor are theoretically calculated and provided in each new protocols.

2.2 Experimental methods

This was performed in a 6 and 15 MV X-rays from Varian 2100C and in a 6 an 10 MV X-rays from Varian 2100CD with MLC. Four different Farmer types of cylindrical ionization chambers of NE 2571, PTW 23333, PTW 30006, and PR 06C were used. Measurements were performed at SSD 100 cm in a $10 \times 10\ cm^2$ field at the same depth of 10 cm and an absorbed dose to water was calculated using IAEA TRS-277 and protocols of a new concept of IAEA TRS-398 and TG-51 and intercompared between the protocols used. Two different kinds of calibration factors of an air kerma calibration factor N_k and an absorbed dose to water $N_{D,w}$ were given from korean SSDL for four chambers calibrated in a ^{60}Co beam, respectively. N_k and $N_{D,w}$ were 4.0444 x 10^7 Gy/C and 4.4438 x 10^7 Gy/C for NE 2571, 4.6042 x 10^7 Gy/C and 5.0588 x 10^7 Gy/C for PTW 23333, 4.7043 x 10^7 Gy/C and 5.1426 x 10^7 Gy/C for waterproof PTW 30006, and 4.2377 x 10^7 Gy/C and 5.1426 x 10^7 Gy/C for PR 06C. The percentage depth dose(%dd) were measured at the point shifted 0.6r considering the effective point of measurement. The beam quality was determined by TPR_{10}^{20} for IAEA for TRS-277 and TRS-398 and by $\%dd(10)_x$, the percentage depth dose at 10 cm $10 \times 10\ cm^2$ in a field in a water phantom due to photons only using 1 mm lead foil, for AAPM TG-51. TPR_{10}^{20} and $\%dd(10)_x$ measured from Varian 2100C were 0.673 and 67.0 for 6 MV X-ray and 0.761 and 78.4 for 15 MV X-ray respectively and those from Varian 2100CD with MLC were 0.672 and 66.8 for 6 MV X-ray and 0.741 and 74.3 for 10 MV X-ray respectively. 1 mm PMMA was used as a waterproof sleeve material in every chamber chosen to intercompare an absorbed dose to water at a reference depth in water between the protocols different from a calibration system.

3. RESULTS AND DISCUSSION

N_k and $N_{D,w}$ of four cylindrical ionization chambers traceable to KFDA, the koean national SSDL, and those calculated theoretically were compared with the result that the values from SSDL and those calculated showed the difference of 0.34 to 1.27% depending on ion chambers. This difference was due to different formalism of correction factors between protocols and systemic effects from different calibration systems of standard laboratories.

This difference of k_Q values between two standard protocols for four ionization chambers shows a trend to increase with X-ray energy owing to different kinds of beam qualities for high energy photon beams recommended by IAEA TRS-398 and AAPM TG-51. k_Q values between two standard protocols were in good agreement in every ion chambers for 6 MV X-rays and especially PR 06C showed 0.3% for 10 MV X-ray and maximum difference was 0.7% for 15 MV X-ray. It means that k_Q depends on ion chambers as well as beam qualities.

Absorbed doses calculated according to the procedures of IAEA TRS-277 and TRS-398 showed the difference of 1.3-1.5% between two protocols but the difference can be accepted within an uncertainty. Intercomparison of an an absorbed dose between IAEA TRS-398 and AAPM TG51 showed the difference of 1.000 for 6 MV X-ray, 1.002 for 10 MV X-ray and 1.005 for 15 MV X-ray with the good agreement of within 0.5% even though the protocols had different systems of beam quality. The different system of calibration and different stopping ratios and perturbation correction factors used are thought to be the main cause of the difference.

4.CONCLUSION

The theoretical difference and similarity of physical correction/conversion factors between an air kerma based protocol and an absorbed dose to water based protocols were in this work studied for high energy photon beams. Also, absorbed dose to water at a reference depth were determined according to the procedures recommended by each protocols and intercompared.

Results of intercomparison between IAEA TRS-277 and TRS-398 say that the differences are due to the different system of calibration of ion chambers as well as different system of formalism, different correction factors and physical data. Those values were in good agreement within an uncertainty of measurement. The index of beam quality was the fundamental difference between IAEA TRS-398 and TG-51 and The index was applied to calculate stopping power ratios and perturbation correction factors, which led to the 0.7% of maximum difference between factors but results of measurement showed good agreement within 0.5%.

The korean Standard Laboratory has also established the calibration system based on an absorbed dose-to-water standard and we hope this work could be the little help of developing the protocol of new concept based on an absorbed dose-to-water standard and suitable to korean situation and that the new protocol could be clinically applied for the measurement of an absorbed dose and an international level of accuracy be attained.

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