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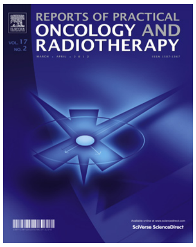

Original research article

Uncertainty in positioning ion chamber at reference depth for various water phantoms

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ABSTRACT

Background: Uncertainty in the calibration of high-energy radiation sources is dependent on user and equipment type.

Aim: We evaluated the uncertainty in the positioning of a cylindrical chamber at a reference depth for reference dosimetry of high-energy photon beams and the resulting uncertainty in the chamber readings for 6- and 10-MV photon beams. The aim was to investigate major contributions to the positioning uncertainty to reduce the uncertainty in calibration for external photon beam radiotherapy.

Materials and methods: The following phantoms were used: DoseView 1D, WP1D, 1D SCANNER, and QWP-07 as one-dimensional (1D) phantoms for a vertical-beam geometry; GRI-7632 as a phantom for a fixed waterproofing sleeve; and PTW type 41023 and QWP-04 as 1D phantoms for a horizontal-beam geometry. The uncertainties were analyzed as per the Guide to the Expression of Uncertainty in Measurement.

Results: The positioning and resultant uncertainties in chamber readings ranged from 0.22 to 0.35 mm and 0.12–0.25%, respectively, among the phantoms (using a coverage factor $k = 1$ in both cases). The major contributions to positioning uncertainty are: definition of the origin for phantoms among users for the 1D phantoms for a vertical-beam geometry, water level adjustment among users for the phantom for a fixed waterproofing sleeve, phantom window deformation, and non-water material of the window for the 1D phantoms for a horizontal-beam geometry.

Conclusion: The positioning and resultant uncertainties in chamber readings exhibited minor differences among the seven phantoms. The major components of these uncertainties differed among the phantom types investigated.

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1. Background

Calibration for external beam radiation therapy is performed with ionization chambers calibrated in absorbed dose-to-water standards.[1–3] Ionization chambers are commonly calibrated by primary standards dosimetry laboratories or secondary standards dosimetry laboratories in terms of the absorbed dose to water in a cobalt-60 beam. Currently, several standards laboratories offer direct calibration services.[4,5] An addendum to AAPM's TG-51 provided new data on the beam quality conversion factor k_Q for photon beams based on Monte Carlo calculations.[6,7] Because the uncertainty in the absorbed dose calibration coefficient obtained from direct megavoltage calibration or the new k_Q values would be small, most of the uncertainty in the determination of the absorbed dose-to-water at a reference depth may depend on the users' methods and equipment.

Today, users can choose from various water phantoms. Because users' settings and the inherent characteristics among phantoms differ, the positioning uncertainty could change. Although some reports have described the measurement uncertainty, to our knowledge, the uncertainties associated with various types of equipment have not been discussed in detail.[8–11]

2. Aim

We assessed the uncertainties in the positioning of an ion chamber at the reference depth of clinical reference dosimetry for seven phantoms and the resulting uncertainties in the chamber readings. The aim was to investigate the major contributions to the positioning uncertainties for the seven phantoms to reduce the measurement uncertainty.

3. Materials and methods

3.1. *Overview*

This work focused on the uncertainty in the positioning of an ion chamber at the reference depth of 10 g/cm^2 for clinical reference dosimetry of high-energy photon beams and the resulting uncertainties in the chamber readings for 6- and 10-MV photon beams. Because radiation doses in megavoltage photon beams are best measured with Farmer-type chambers, a PTW 30013 chamber (PTW, Freiburg, Germany) was selected to evaluate the positioning uncertainty. The photon beams were generated by a Siemens Artiste linear accelerator (Siemens AG, Erlangen, Germany). Furthermore, we verified the validity of the estimated reading uncertainties.

3.2. *Phantoms investigated*

Tables 1 and 2 summarize both the characteristics of the phantoms investigated and the procedures. The five phantoms were used for a vertical-beam geometry: DoseView 1D (Standard Imaging, Middleton, WI), WP1D (IBA Dosimetry, Schwarzenbruck, Germany), 1D SCANNER (Sun Nuclear, Melbourne, FL), QWP-07 (Qualita, Nagano, Japan), and GRI-7632 (Nichigen, Tokyo, Japan). The other two were used for a horizontal-beam geometry: PTW type 41023 (PTW, Frieburg, Germany) and QWP-04 (Qualita, Nagano, Japan).

3.3. *Uncertainty analysis*

The positioning uncertainties and the resulting uncertainties in the chamber readings were analyzed following the recommendations of the Guide to the Expression of Uncertainty in Measurement.[12] The limits of the variation in an estimated component could be accurately known while its distribution is unknown. In such cases, the components classified as type B were assumed to have a rectangular distribution. The reading uncertainties were estimated by the law of propagation of uncertainty. A coverage factor of $k = 1$ was assumed for every uncertainty, corresponding to a confidence limit of 68.3%.

3.3.1. *Uncertainty in the users' techniques*

Table 3 summarizes the techniques considered for the phantoms. Before the techniques were performed, all the tested phantoms were leveled after the water was poured. The origin for the QWP-04 phantom was determined by the contact between the inner surface of the phantom window and a distance calibration disk to set the origin.

The techniques were performed by nineteen operators; six junior-level, seven intermediate-level, and six senior-level operators at five facilities. Additionally, these techniques were repeated ten times by one of the operators to assess the uncertainties in their repeatability. The chamber positions that defined the origin for the five phantoms were read from the display of the chamber position. 10-cm adjustments of a caliper on the PTW 41023 phantom top for setting the chamber depth were assessed with an IL-300 laser distance meter (Mitutoyo Corporation, Kanagawa, Japan), whereas determinations of the water surface position for the GRI-7632 phantom were measured with a QWP-43 water-level indicator (Qualita, Nagano, Japan). The uncertainties in the equipment used for assessing these uncertainties were taken from their specifications and classified as type B.

3.3.2. *Uncertainty in the inherent characteristics of the phantom*

Table 4 summarizes the uncertainties in the inherent characteristics of the phantoms considered. All water phantoms have an uncertainty in the chamber depth as the temperature-induced water density changes. For the water temperature of approximately 24 °C used in this work, the water density was approximately 0.9972 g/cm^3. When the chamber was positioned at a depth of 10 cm from the surface, the real position was approximately 0.3 mm shallower. This uncertainty was assessed as type B. The movement distances from the origin to a depth of 10 cm were measured 10 times by using the IL-300 laser distance meter. The length of the analog scale for the PTW type 41023 and GRI-7632 phantoms was measured with a 30-cm ruler certified as Japanese Industrial Standards Grade 1. For the PTW type 41023 and GRI-7632 phantoms, the air gap between the chamber wall and the waterproofing sleeve was obtained from the manufacturer and user manuals.