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Development of Dual-Window Phantom for Output Measurement of Medical Linacs

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A small water phantom (dual-window phantom) was developed to improve the output measurement efficiency of medical linacs. This phantom is suitable for determining the quality index and output dose for high-energy photon beams. The phantom has two opposite windows and two independently rotating axes. The two axes measure the tissue phantom ratio (TPR) and the percentage depth dose (PDD) simply without requiring chamber movement by rotating the phantom around its axis. High-energy photon beams from a Co-60 irradiator and a medical linac were used to evaluate the phantom. The measured quality index is in good agreement with the reference values; the measured and reference values are within 0.2% of each other for the Co-60 gamma rays and within 1.4% for 6 and 10 MV X-rays. This phantom is more practical for routine output measurements, resulting in the prevention of potential human errors.

Key Words: Dual-window phantom, Output measurement, Beam quality

INTRODUCTION

In the radiotherapy field, it is important to periodically measure the output dose of photon beams from medical linear accelerators, also known as medical linacs.[1] The periodic machine output measurement verifies that the absorbed dose rate and the field size at a specified depth in water match the reference values. Generally, the absorbed dose is determined within a given uncertainty by applying a dosimetry protocol used in the facility. In order to minimize the overall uncertainty for this measurement procedure, the worker complies with recommendations for the chamber positioning, beam quality determination, and various corrections described in the protocols. In particular, the establishment of precise geometric conditions for each procedure prevents human-induced geometric errors. For this reason, the beam quality determination is often omitted during routine output measurements in a busy clinic. This study describes the development of a small water phantom for practical and quick output measurements for routine quality assurance. Use of this phantom, enables convenient measurement of the beam quality index, thereby reducing the geometric errors from the operator miscalculating the ionization chamber positioning. This phantom can be used for the IAEA TRS-398 protocol,[2] which is a well-known international dosimetry protocol.

MATERIALS AND METHODS

The primary purpose of this phantom is to efficiently and quickly determine the photon beam quality from medical linacs. The beam quality in high-energy photon beams is measured by the tissue phantom ratio (*TPR*) of the absorbed dose, more specifically, by $TPR_{20,10}$, which is the ratio of the *TPR* at two depths, 20 cm and 10 cm, in a water phantom.

The *TPR* is measured with a constant source-to-chamber distance (SCD) of 100 cm and a reference field size of 10×10 cm.[2] The direct determination of $TPR_{20,10}$ is difficult and im-

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practical because of the difficulty in accurate phantom movement during the positioning of the chamber at the rotation axis of the accelerator. Therefore, an indirect method is introduced that utilizes the percentage depth dose (PDD) ratio. According to the IAEA TRS-398 protocol,[2)] the $TPR_{20,10}$ can be determined by

$$TPR_{20,10} = 1.2661 PDD_{20,10} - 0.0595 \, , \qquad (1)$$

where the $TPR_{20,10}$ ratio is the dose ratio at each depth, 20 cm and 10 cm, with a constant source-to-surface distance (SSD). The phantoms designed and fabricated In the present study are shown in Fig. 1. The phantom is named a dual-window phantom because it contains two windows.

Farmer type ionization chambers are fixed at the water-equivalent thicknesses of 10 g/cm^2 for one side and 20 g/cm^2 for the other side, as shown in Fig. 1. Axis-A at the bottom of the phantom is located at the chamber axis and axis-B is located in the middle of the phantom. Because the total water-equivalent thickness of the chamber in the direction of measurement is 30 g/cm^2, the distance from both sides of the phantom to axis-B is 15 g/cm^2. The phantom wall and waterproof sleeve of the chamber are made of acrylic with a geometric accuracy of approximately ±0.2 mm. The window thickness of this phantom is 0.3 cm and its water-equivalent thickness is 0.34 g/cm^2. The $TPR_{20,10}$ and the $PDD_{20,10}$ ratios can be determined without moving the chamber by rotating the phantom as described in Fig. 2 and 3. If the phantom axis is positioned at axis-A and the chamber is positioned at an SCD of 100 cm, $TPR_{20,10}$ can be determined directly by measuring the two depths with a rotation of the phantom around axis-A in between measurements, as shown in Fig. 2. In this way, if the phantom axis is positioned at axis-B with an SSD of 100 cm, the $PDD_{20,10}$ ratio can be determined, as shown in Fig. 3,

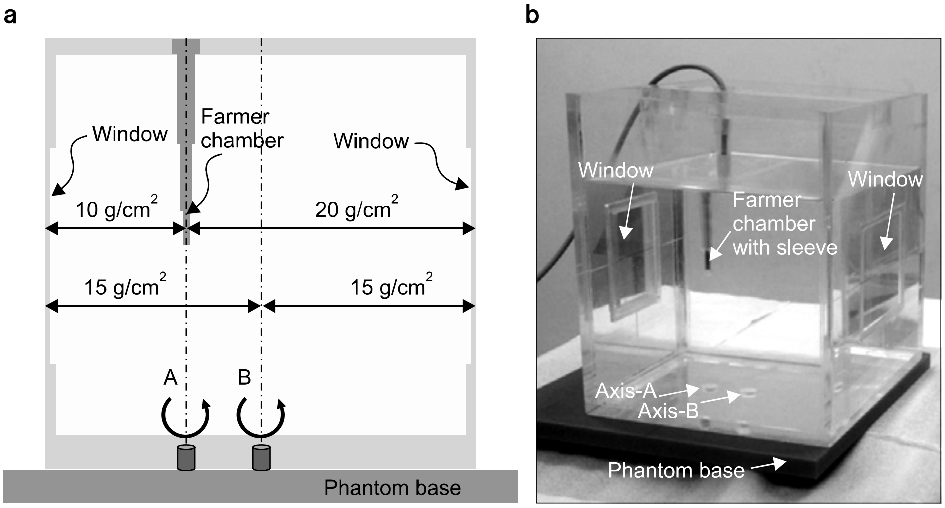

Fig. 1. (a) Design of dual-window phantom, (b) fabricated phantom.

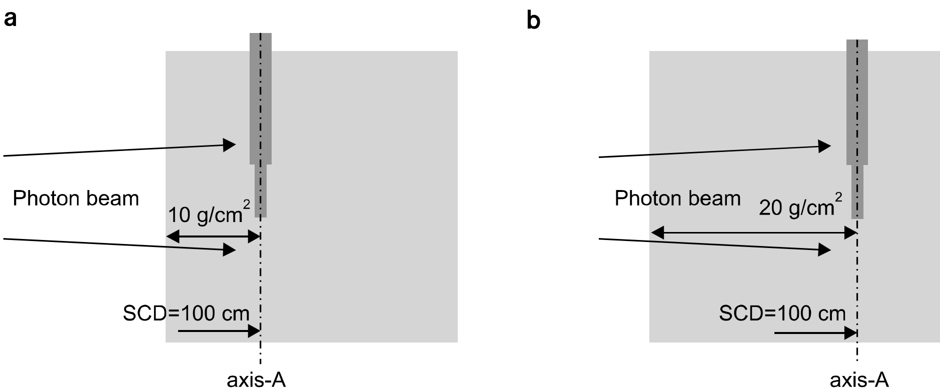

Fig. 2. Measurement of TPR using the dual-window phantom. It is possible to measure two doses at ecach depth, (a) 10 g/cm^2 and (b) 20 g/cm^2, without chamber movement and with the same SCD by rotation around axis-A.

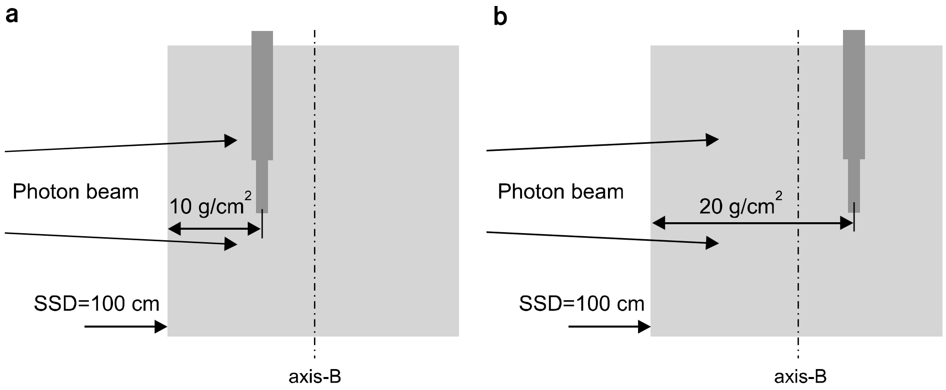

Fig. 3. Measurement of PDD ratio using dual-window phantom. It is possible to measure two doses at the depths of 10 g/cm^2 (a) and 20 g/cm^2 (b) without chamber movement with the same SSD by rotation around axis-B.

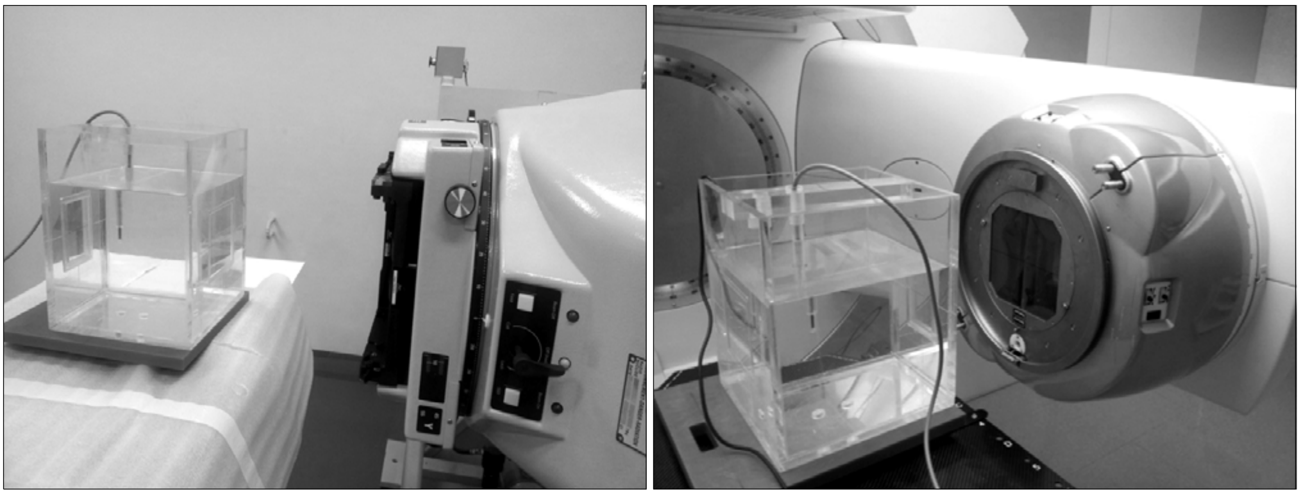

Fig. 4. Performance testing of dual-window phantom with Co-60 gamma rays (left) and high-energy photon beams from a medical linac (right).

and the $TPR_{20,10}$ ratio can be determined from $PDD_{20,10}$ using the conventional method in (1).

The $TPR_{20,10}$ and $PDD_{20,10}$ ratios were measured to evaluate the performance of the dual-window phantom with Co-60 gamma rays from a GBX-200 irradiator (Best-Theratronix, Canada) and high-energy photon beams of 6 MV and 10 MV from a medical linac (Infinity, Elekta, England), as shown in Fig. 4. A PTW-30013 Farmer type chamber and a PTW-UNIDOS electrometer were also used in this measurement. The measurements were compared to results from PTW-41023, which is a small water phantom. In particular, the $TPR_{20,10}$ value for the Co-60 beams in the present study was compared to the value acquired by the National (NPL, United Kingdom) as a reference.[3,4] The measurements were repeated more than four times for each measurement configuration while monitoring air pressure and temperature the arithmetical mean of the measured values was calculated.

RESULTS

The results listed in Table 1 and 2 are those obtained from the Co-60 and linac beams of 6 MV and 10 MV, respectively. The directly determined $TPR_{20,10}$ values from the Co-60 beam are in agreement with the NPL results within 0.2%, as shown in Table 1. The indirectly determined $TPR_{20,10}$, which was calculated from the measured $PDD_{20,10}$ ratio, is also in agreement with the results from the PTW-41023 phantom within 0.2%. However, the $TPR_{20,10}$ values derived from the $PDD_{20,10}$ ratio had a larger deviation from the NPL results, 0.51～0.70%, when using Co-60 gamma rays. For the 6 MV and 10 MV

Table 1. Measured results of quality index for Cobalt-60 gamma rays.

		$TPR_{20,10}$ for Co-60	Difference (%)
Dual-window phantom	Direct determination	0.569	+0.17
	From $PDD_{20,10}$	0.564	−0.70
PTW-41023 phantom	From $PDD_{20,10}$	0.565	−0.51
NPL[a]	Reference	0.568	

[a]National Physics Laboratory, United Kingdom.

Table 2. Measured results of quality index for 6 MV and 10 MV photon beams from medical linac.

			$TPR_{20,10}$	Difference (%)
6 MV	Dual-window phantom	Direct determination	0.678	−0.73
		From $PDD_{20,10}$	0.674	−1.32
	PTW-41023 phantom	From $PDD_{20,10}$	0.683	
10 MV	Dual-window phantom	Direct determination	0.730	−0.95
		From $PDD_{20,10}$	0.727	−1.36
	PTW-41023 phantom	From $PDD_{20,10}$	0.737	

beams in the medical linac, the directly determined $TPR_{20,10}$ values were 0.678 and 0.730 and the indirectly determined $TPR_{20,10}$ values were 0.674 and 0.727, respectively, as shown in Table 2. The difference with the results of the PTW-41023 phantom is less than 1.36%, which is clinically acceptable.[1)]

DISCUSSION AND CONCLUSION

The quality index when applying the dosimetry protocol should be determined at every output measurement for the following reasons: to correct the beam quality for the determination of the absorbed dose in water and to verify the beam quality as a quality assurance measure for the linear accelerator.[2)] The designed phantom is conceptually more practical for busy clinic environments because it has the advantage of reducing measurement time. Additionally, it is important that the potential human error from positioning the chamber in water be reduced, which can be achieved using a dual-window phantom. The presented design contains no fixation tools for attachment of the phantom to the couch surface therefore, small variations during the rotation of the phantom in the measurement geometry are possible. This explains the occurrence of the differences between the PTW-phantom and linac beam measurement results. In the future, additional tools should be developed to avoid geometric variations and to improve the efficiency of routine output measurements. Furthermore, this phantom can be effectively applied for the purpose of dose surveys or the intercomparison of radiotherapy facilities.

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광자선 출력측정시 업무 효율을 높이기 위한 소형 물팬톰(듀얼윈도우 팬톰)을 개발하였다. 이 팬톰은 고에너지 광자선의 출력측정뿐만아니라 선질지표의 결정에 적합하다. 이 팬톰은 두개의 창을 가지고 있으며 독립된 두 축에 의해 회전할 수 있도록 제작되어있다. 이 때 두 축은 전리함 이동 없이 조직팬톰선량비와 깊이선량율비를 결정하기 위한 것이다. 코발트조사기와 선형가속기의 고에너지 광자선을 이용하여 팬톰을 평가하였으며, 기준값과 비교할 때 Co-60의 경우 0.2% 그리고 가속기 x-선에 대해 1.4% 이내로 일치하였다. 이 팬톰은 발생 가능한 인적오차를 방지할 수 있기 때문에 일상의 출력측정에 매우 실용적이라고 본다.

중심단어: 듀얼윈도우팬텀, 출력측정, 선질