Volume 13, No 3 | International Journal of Radiation Research, July 2015

# Comparison of the photon charge between water and solid phantom depending on depth

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▶ ***Original article***

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**Revised:** Sept. 2014
**Accepted:** Oct. 2014

***Int. J. Radiat. Res., July 2015; 13(3): 229-234***

**DOI:** 10.7508/ijrr.2015.03.005

## ABSTRACT

***Background:*** This study assessed the clinical usefulness of the solid phantom, which may compensate for the disadvantages of the water phantom, by comparing the radiological doses between the two depending on their depths. ***Materials and Methods:*** The experimental equipment used was a linear accelerator for medical use, water phantom, solid phantom, Farmer type ion chamber and electrometer. The distance between the ray source and the center of the ion chamber was fixed to a SAD of 100 cm during the experiment. The field size was 10 x 10 $cm^2$ and the radiation energies of the photon rays were 6 MV and 15 MV. The depth interval was 1cm (range 1-10 cm) for each energy. The relative deviation ratio of the water phantom to the solid phantom was calculated. ***Results:*** The measurement at 100 MU was performed more than five times to calculate the average charge and absorbed dose, and the relative deviation was analyzed based on the water phantom. The results obtained at depths from 1 to 10 cm were 0.034%, -0.457%, -0.167%, 0.011%, 0.117%, 0.271%, 0.349%, 0.709%, 0.376% and 0.611% at 6 MV and those obtained at 15 MV were 1.199%, 0.033%, 0.166%, 0.496%, 0.556%, 0.705%, 0.656%, 1.071%, 0.7% and 1.057%, respectively. ***Conclusion:*** In conclusion, the solid phantom is useful and may complement the disadvantages of the water phantom, including the time required for its installation and errors in the measurement depth, and may precisely measure the radiological dose.

***Keywords:*** *Water phantom, solid phantom, charge, absorbed dose.*

## INTRODUCTION

The ability to diagnose cancer has improved with the development of medical technologies. This optimism has prompted interest in radiotherapy as a cancer treatment method. Radiotherapy is a clinical method that involves radiation with a very short wavelength and high energy, which reacts with water in the human body and affects the cells through physical, chemical and biological processes (1-3). Radiation destroys cancer cells and normal cells, requiring exact dose management during the radiotherapy to maximize cancer eradication while sparing as many non-cancer cells as possible.

In particular, the high energy photons used in radiotherapy form a build-up area where the surface dose is low and the dose sharply increases from the surface to the maximum depth (4). Also, the distribution of the absorbed dose in the build-up area of the photon beam varies depending on the irradiation level and energy and shows very abrupt changes even with small changes in the depth. Therefore, it is very difficult to exactly measure the distribution of the absorbed dose.

In terms of the management of high energy radiotherapy, it is very important to precisely measure the dose of the treatment source of origin and assess the error. Currently, the water phantom is the benchmark phantom most similar to the human body that is used for the quality control of the absorbed dose management of the X-rays in the linear accelerator [5, 6]. However, it takes a long time to perform the test with the water phantom, due to its complicated implementation procedure and this causes errors in the measurement depth, resulting from the formation of waves from the surface of the water phantom caused by the movement of the measurement position of the ionization chamber and stabilization of the water temperature [7].

Other than for special purposes, the solid phantom is effective for saving time and easy to use, including for obtaining the beam data for the treatment plan system or calibrating the output of the linear accelerator [8]. Recently, the solid water equivalent phantom has been used in the normal quality control procedure as an alternative to the water phantom.

The purpose of the study was to assess the clinical usefulness of the solid phantom, which may compensate for the disadvantages of the water phantom, by comparing their radiological doses depending on their depths.

## MATERIALS AND METHODS

The solid phantom, the water phantom used for the calibration and the ionization chamber (PTW, farmer type waterproof 0.6cc ionization chamber, Freiburg, Germany) were placed in the treatment room with the vertical direction of the beam radiation against the linear accelerator manufactured by Varian Medical Systems and a voltage meter (PTW, Freiburg, Germany) in the control room, and connect them with the cable of the triaxial ion chamber.

The experimental equipment used in the study was a linear accelerator for medical use, water phantom, and solid phantom and Farmer type ion chamber. The solid phantom used in the experiment consisted of a slab with a thickness of 0.2 - 0.6 cm and area of 30×30 cm (figure 1).

First, the distance between the ray source and the center of the ion chamber was fixed at a SAD of 100 cm. The field size was 10×10 cm$^2$ and the radiation energies of the photon rays were 6MV and 15MV. The depth interval was 1 cm (range, 1 10 cm) for each energy. The thickness of the phantom bottom was set to 5 cm to reduce the effect of the backward scattering when using the solid phantom (figure 2). In addition, the

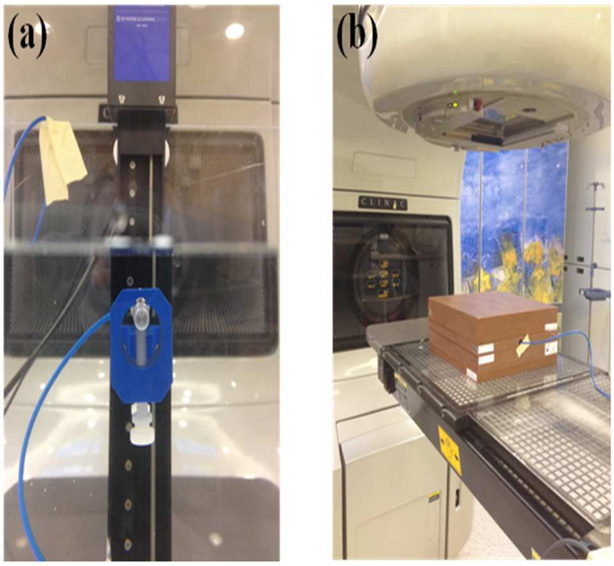


**Figure 1.** The water phantom (a) and solid water phantom (b) used in the study.

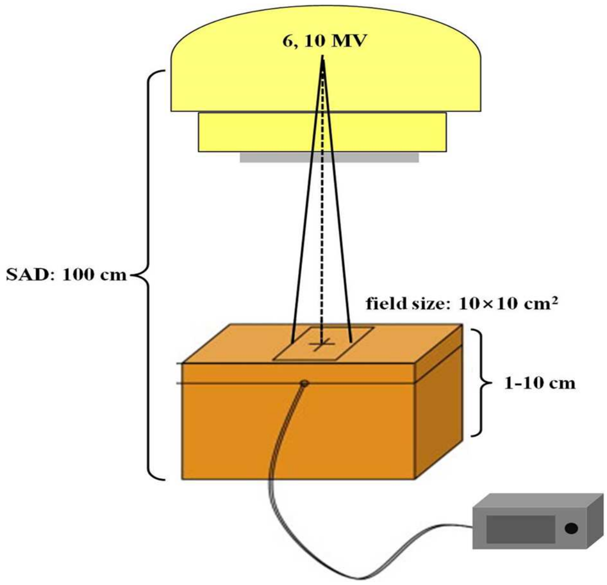


**Figure 2.** The distance between the ray source and the center of the ion chamber was fixed at a SAD of 100 cm. The field size was 10x10 cm$^2$ and the radiation energies of the photon rays were 6 MV and 15 MV.





[ DOI: 10.7508/ijrr.2015.03.005 ]

phantom was placed in the treatment room for more than 1 week to minimize the impact of temperature changes on the measurements and keep the temperature changes during the measurement as small as possible when using the solid phantom.

The water temperature was kept within 0.1℃ of that of the treatment room to maintain the thermal equilibrium between the treatment room and the water when using the water phantom. The depth in each case was considered to be from the center of the ionization chamber to the source of the rays in each phantom during the measurement.

All the experiments were performed at a dose rate of 600 MU/min and irradiation doses of 100 MU and 80 MU to measure the charge against the benchmark irradiation surface and the output factor on the irradiation surface, respectively. The experiment at 100 MU was performed 30 times to calculate the average charge and the results were analyzed based on the water phantom. Then, the charge was measured and the measured charge (nC) In the first highlighted sentence, the “respectively” seems to indicate that irradiation dose of 100 MU refers to the charge against the benchmark irradiation surface and that of 80 MU refers to the output factor on the irradiation surface. Is that correct? was converted to the absorbed dose (μGy) by multiplying it by the SAD factor. This study only considers the SAD factor, because it does not use the tray, block and MLC. The SAD factors at 6 MV and 15 MV were 1.03 and 1.055, respectively. The difference in the mean charge and absorbed dose at each depth as a function of the energy was tested by ANOVA (SPSS win 18.0, USA) and, to obtain a more accurate difference, a post-hoc analysis was conducted. ($p<0.05$) Also, the relative deviation ratio of the water phantom to the solid phantom was calculated.

The ionization values at the depth of the solid phantom were proportional to the water equivalent depth and were obtained by multiplying the calibration factor by the ionization measurement at an arbitrary depth (z). The calibration factor ($h_{w,s}$) was calculated from equation 1 [5, 9].

$$h_{w,s}(z) = \frac{M_W(z)}{M_S(z)} \qquad (1)$$

where Mw(z) and Ms(z) are the ionization measurements from the water and solid phantoms for each irradiation surface size, respectively. The relative deviation at a depth of z of material m is defined as equation 2.

$$\text{Relative deviation}_m(z) = \frac{M_m(z)}{M_m(z_{ref})} \qquad (2)$$

where M is the ionization value at a depth of z and $z_{ref}$. Deriving the percentage deviation Δ(z) from the relative deviation between the water and solid phantoms is achieved using equation (3) with the calibration factor obtained from equation 1 [5, 9].

$$\Delta(z) = 100 \times \left(1 - \frac{h_{w,s}(z_{ref})}{h_{w,s}(z)}\right) \qquad (3)$$

## RESULTS

The average values of the charge at depths in the range from 1 cm to 10 cm with intervals of 1 cm measured 30 times at each depth with a radiation energy of 6 MV for the water and soild phantoms are shown table 1. The highest dose when using the water phantom was 111.03±0.0047 cGy at a depth of 2 cm and the lowest dose was 87.03±0.0073 cGy at a depth of 10 cm ($p<0.05$). The highest dose when using the solid phantom was 111.64±0.0047 cGy at a depth of 2 cm and the lowest dose was 86.59±0.0046 cGy at a depth of 10 cm ($p<0.05$).

The average values of the charge at depths in the range from 1 cm to 10 cm with intervals of 1 cm measured 30 times at each depth with a radiation energy of 15 MV for the water and soild phantoms are shown in table 2. The highest dose when using the water phantom was 107.08 cGy at a depth of 4 cm and the lowest dose was 81.94 cGy at a depth of 1 cm ($p<0.05$). The highest dose when using the solid phantom was 107.29 cGy at a depth of 3 cm and the lowest dose was 82.50 cGy at a depth of 1 cm ($p<0.05$).

The relative deviations in the measurements between the two phantoms for each energy based on the water phantom were measured every 1 cm from 1 cm to 10 cm and the results were 0.034%, -0.457%, -0.167%, 0.011%, 0.117%, 0.271%, 0.349%, 0.709%, 0.376% and 0.611% at 6 MV (figure 3) and 1.199%, 0.033%, 0.166%, 0.496%, 0.556%, 0.705%, 0.656%, 1.071%, 0.7% and 1.057% at 15 MV (figure 4), respectively.

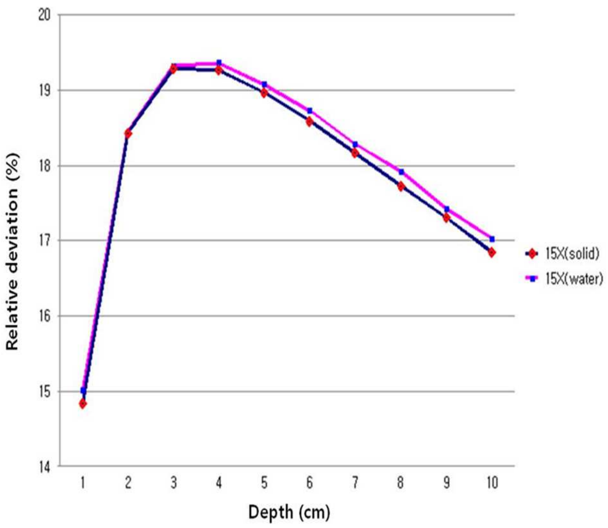


**Figure 3.** Comparison of the charge depending on the depth at a radiation energy of 6 MV in the case of the water phantom / solid water phantom.

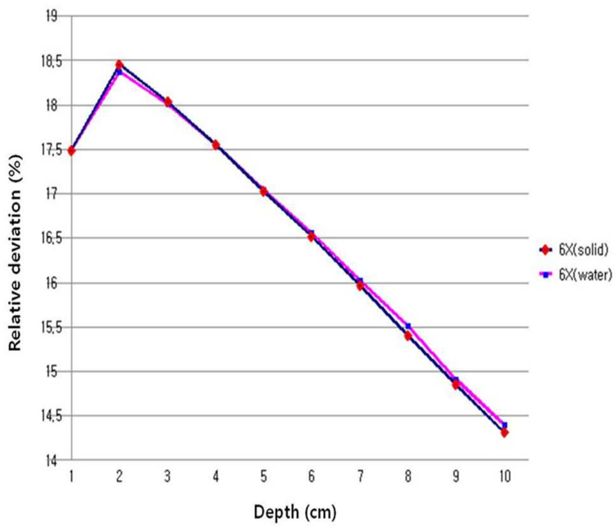


**Figure 4.** Comparison of the charge depending on the depth at a radiation energy of 15 MV in the case of the water phantom / solid water phantom.

**Table 1.** The measured charge and absorbed dose at a depth of 6 MV for the water phantom and solid phantom.

| Phantom | Division | Depth (cm) | | | | | | | | | | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| water phantom | charge (nC) | 17.49± 0.0055 | 18.36± 0.0045 | 18.00± 0.0045 | 17.54± 0.0084 | 17.04± 0.0045 | 16.55± 0.0045 | 16.02± 0.0055 | 15.51± 0.0045 | 14.91± 0.0045 | 14.4± 0.0071 | 0.400 |
| | absorbed dose (cGy) | 105.77± 0.0057 | 111.03± 0.0047 | 108.85± 0.0047 | 106.01± 0.0087 | 102.9± 0.0047 | 100.0± 0.0057 | 96.88± 0.0057 | 93.74± 0.0047 | 90.11± 0.0047 | 87.03± 0.0073 | |
| soild phantom | charge (nC) | 17.49± 0.000 | 18.45± 0.0045 | 18.03± 0.0084 | 17.54± 0.0055 | 17.02± 0.011 | 16.51± 0.0089 | 15.97± 0.000 | 15.40± 0.0045 | 14.85± 0.0089 | 14.31± 0.0045 | 0.035 |
| | absorbed dose (cGy) | 105.83± 0.000 | 111.64± 0.0047 | 109.16± 0.0087 | 106.19± 0.0057 | 103.05 ±0.011 | 99.96± 0.009 | 96.63± 0.000 | 93.19± 0.0047 | 89.92± 0.009 | 86.59± 0.0046 | |

**Table 2.** The measured charge and absorbed dose at a depth of 15 MV for the water phantom and solid phantom.

| Phantom | Division | Depth (cm) | | | | | | | | | | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| water phantom | charge (nC) | 15.01± 0.0044 | 18.43± 0.0044 | 19.28± 0.044 | 19.26± 0.0044 | 18.96± 0.0054 | 18.72± 0.008 | 18.28± 0.0044 | 17.92± 0.0070 | 17.42± 0.0054 | 17.02± 0.0083 | 0.045 |
| | absorbed dose (cGy) | 83.016± 0.024 | 101.96± 0.024 | 10666±0 .024 | 106.51± 0.024 | 104.88± 0.030 | 103.53± 0.046 | 101.09± 0.0024 | 99.09± 0.039 | 96.36± 0.0030 | 94.16± 0.046 | |
| soild phantom | charge (nC) | 14.83±0 .010 | 18.43± 0.0045 | 18.03± 0.0084 | 17.54± 0.0055 | 17.02±0 .011 | 18.59±0 .000 | 18.16±0 .004 | 17.72± 0.008 | 17.30± 0.0054 | 16.84± 0.008 | 0.040 |
| | absorbed dose (cGy) | 82.02±0 .060 | 101.929 ±0.024 | 109.16± 0.0087 | 106.19± 0.0057 | 103.05± 0.011 | 102.80± 0.000 | 100.43± 0.024 | 98.0.±0 .046 | 95.69± 0.030 | 93.16± 0.0046 | |

## DISCUSSION

It is very important to precisely measure the treatment dose and assess the error in high energy radiotherapy. Water is normally recommended for the absolute measurement of the absorbed dose, but its disadvantages include the waterproof nature of the ionization chamber and the time required to place the ionization chamber at the correct position in the water [7, 8, 12, 13]. Therefore, except for special purposes, the solid phantom is efficient in terms of the time required and ease of use, including for achieving the beam data for the treatment plan system or calibrating the output of the linear accelerator. The purpose of this study was to assess the clinical usefulness of the solid phantom, which may compensate for the disadvantages of the water phantom, by comparing the radiological doses between the two types of phantom depending on their depths. The results obtained at depths from 1 to 10 cm were 0.034%, -0.457%, -0.167%, 0.011%, 0.117%, 0.271%, 0.349%, 0.709%, 0.376% and 0.611% at 6 MV and 1.199%, 0.033%, 0.166%, 0.496%, 0.556%, 0.705%, 0.656%, 1.071%, 0.7% and 1.057% at 15 MV, respectively. Kim *et al.* [5] compared the relative deviation depending on the depth with a white-colored polystyrene phantom and water phantom using a 10 MV X-ray beam and reported that the percentage deviation was < 0.53%. The relative deviations in (their?) study were < 0.611% and (<?) 1.057% for the 6 MV and 15 MV X-rays, respectively, where the different range of the deviation was due to the different energy intensities and depths.

Thomadsen *et al.* [14] compared the relative deviation for each energy level using the solid and water phantoms for electron beams ranging from 6 to 18 MV and reported that the percentage deviation ranged from 0.46 - 0.68%. This variation of the deviation comes from the measurement with the electron beam and not that with the X-rays. Huang *et al.* [15] compared the relative deviations for each energy level using the solid phantoms with the common slab and acryl and reported a result of 0.48%. As shown above, it is found that the relative deviation depends on the phantom material.

The measurements confirm that the solid and water phantoms show different relative deviations depending on the energy level and the depth. Also, another study showed that the relative deviation depends on the phantom element and the type of radiation.

## CONCLUSION

The recommended value of the relative error in the absorbed dose based on the water phantom is ±2%. The present study shows that the minimum and maximum errors depending on the depths of the measurement for the various mediums and energy levels are -0.457% and 1.199%, respectively, which conform to the recommended values. It is considered that the solid phantom is useful and may overcome the disadvantages of the water phantom, including the time required for its installation and errors in the measurement depth, while allowing the radiological dose to be precisely measured. The data from the present study may be directly employed in the assessment of the dose by measuring the output of the linear accelerator using the solid phantom, as well as the data analysis.

## ACKNOWLEDGEMENTS

*Joo-Wan Hong and Hae-Kag Lee contributed equally to this work. They are co-first authors. This work was supported in part by the Soonchunhyang University Research Fund.*

***Conflicts of interest:*** *none to declare.*

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[ DOI: 10.7508/ijrr.2015.03.005 ]

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[ DOI: 10.7508/ijrr.2015.03.005 ]