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Comparative Studies of Absolute Dose in Water Phantom, Solid Water Phantom and MatriXX with MULTICube Phantom

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Abstract

Introduction: Radiotherapy is one of the important treatment modalities in cancer treatment. To maintain the treatment procedure accuracy, the phantom is an essential tool for absolute dosimetry conformation and Quality Assurance routine cheek up. This work aims to study the absorbed dose of various phantoms and hence to make a comparison of the result with the IAEA recommendation (TRS 398) for daily QA of Linac. **Materials and Methods:** The experiment has been done at the Institute of Nuclear Medical Physics (INMP), AERE, Savar, Dhaka, under the Bangladesh Atomic Energy Commission. For external beam radiation, 6 MV and 15 MV photon beams of Varian Clinac iX Linear Accelerator (Linac) were used. One dimensional (1D) water phantom, solid water phantom, and MatriXX with MULTICube phantom and associate accessories were used to experiment. **Results:** We have measured and compared the absorbed dose data of the phantoms. The variation of sold water phantom from the 1D water phantom is +2.8% at 6 MV and +3.5% at 15 MV. The variation MatriXX with MULTIcube phantom from the 1D water phantom is +8.0% at 6 MV and +3.2% at 15 MV. This study revealed that the 1D water phantom was the best absolute dose conformation among the other phantoms and the deviation was within the acceptable limit (±5%), except MatriXX with MULTICube Phantom for low energy beam (8%). **Conclusion:** It was observed that the accuracy of dose estimation was better in the 1D water phantom rather than the other two. It is also known that the 1D water phantom is low cost but needs a long time to set up for the experimental arrangement. Solid water or MatriXX with MULTICube phantom can be used to overcome this problem, which takes only a

few minutes for setup and is comparatively faster than 1D water phantom.

Keywords

Phantom, Quality Assurance, Dosimetry, Absorbed Dose

1. Introduction

Radiation is the energy of emission or transmission in electromagnetic waves or particles [1]. Ionizing radiation like X-ray, Gamma-ray, etc., has a shorter wavelength and higher energy than easily penetrated in the human body to damage living cells. As a result, it can be created many diseases like cancer. Cancer is a complex disease for the human body. It is not only occurring due to radiation but also has many reasons like smoking, changing lifestyle such as diet, virus, etc. [2]. As per IAEA recommendation, the total effective dose equivalent in the whole body for mass people is 1 mSv (0.1 rem) per year, and for occupational workers, it is 20 mSv per year [3]. Above this effective dose, any dose is harmful to the human body and can increase cancer risk. Medical Physics technologies are improving day by day by adopting modern treatment modalities worldwide for better cancer treatment. Radiotherapy treatment is one of the best inventions of clinical methods for cancer treatment. It involved radiation with a very short wavelength and high energy, which reacts with water in the human body. As a result, the human body cells are affected through the physical, chemical, and biological processes [4] [5]. The main motto of radiation therapy is that the maximum dose delivers to the cancer cell and the minimum dose is delivered to the normal cell. In radiotherapy, the high-energy photons are used to form a buil-dup area where the dose rate is low at the surface and increases with depths. At a specific depth, the dose rate is maximum. These absorbed dose distributions are varied depending on the energy and irradiation level and instantaneously change with changes of the depths [6]. Therefore it isn't easy to count the absorbed dose distribution unerringly. For this reason, it is essential to unerringly measure the dose of the treatment source of the origin. The dose delivered to the human body involves many steps, parameters, and factors.

Quality assurance checkup is one of the essential factors. For therapeutic purposes, before any radiation exposure, the dose should be planned and checked carefully then delivered to the patient. Phantom is required to measure and verify the dose. Many kinds of Phantoms are consisted like as water phantom, solid water phantom, MULTICube phantom, CIRS phantoms, RANDO phantom, etc. [7] [8] [9]. Water phantom is similar to the human body that is used to quality control of the Linac and IAEA recommended phantom. It takes long time to perform the test by water phantom due to its complex procedure. Other than particular purposes, sold and MatriXX with MULTIcube phantoms is effective for saving time and easy to use.

In past years, several measurements of absorbed dose of Linac using various phantoms have been reported. J.W. Hong *et al.* have reported absorbed dose between solid and water phantom and concluded that solid water phantom is clinically helpful and may compensate for the disadvantage of water phantom [10]. Rahman *et al.* have studied the comparison of absorbed dose in different phantom materials (water, solid water, PMMA, and paraffin wax). They concluded that paraffin wax could be used in radiotherapy centers instead of solid water phantoms with comparatively high accuracy and the lowest time consumption [11]. Thwaites *et al.* have studied the comparison of absorbed dose among water, solid water and polystyrene phantom [12]. He shows 3% differences on average at 5 - 10 MV energies, ionization in water being higher. Kim *et al.* reported the deviation of solid phantom from water phantom was 0.53% at 10 MV [13]. Chang Heon *et al.* have reported the results of an external audit on the absorbed dose of radiotherapy beams independently performed by third parties. They developed a method to measure the absorbed dose to water in an easy and convenient setup of solid water phantom [14].

Jan Seuntjens *et al.*, Dengsong Zhu *et al.* and Chris Constantinoua *et al.* have studied the measurement of absorbed dose for various phantoms [15] [16] [17]. C. Borcia and D. Mihailescu have measured the absorbed dose between water and solid phantoms (polystyrene, PMMA, and solid water WT1) using EGSnrc and DOSXYZnrc Monte Carlo codes [18].

In this work, we tried to measure the absorbed dose in a 1D water phantom, solid water phantom, and MatriXX with MULTICube phantom for the beam energies 6 MV and 15 MV. The purpose of our study was the clinical usefulness of different phantom depending on the absorbed dose. We also attempt to make an evaluation among the three phantoms based on precision, time, and user friendly.

2. Materials and Methodology

The absorbed dose of 1D water phantom, solid water phantom and MatriXX with MULTICube phantom was measured using the Linac facility of the Bangladesh Atomic Energy Commission (BAEC). In the present study, we used a photon beam of dual-energy 6 MV and 15 MV. The 1D water phantom, namely WP1D (IBA Dosimetry), is made of transparent PMMA, and the phantom was filled with water. In solid water phantom, this material is a water equivalent solid. Solid water phantom is square blocks of varying thickness which may be a buildup of different materials. Its chemical composition is an Epoxy Resin-based mixture. In MatriXX with MULTICube phantom, MatriXX is an ionization chamber, and MULTICube is a phantom, combined both called MatriXX with MULTICube phantom. For this study, we used the MatriXX FFF ion chamber. These three phantoms are examined for suitability in routine quality assurance of the irradiation system. The absorbed dose based absolute dosimetry protocols TRS-398 have been followed for all these measurements [19].

Farmer types ionization chamber of model no. FC65P was used for the detection of ionization. The pulse created by the chamber was measured by DOSE-1 Electrometer. For all the three cases, the source to surface distance was 100 cm, the depth was 10 cm, the field size was 10 cm × 10 cm, and the monitor unit was 100, shown in **Figure 1**.

At first, the WP1D phantom was placed on the couch of the Linac. Then an ionization chamber is properly placed into the one-dimensional (1D) water phantom. This ionization chamber was taken in the 10 cm depth from the water surface like **Figure 1**. The phantom surface center was aligned with the central axis of the beam from the gantry at a zero-degree angle. The distance between the phantoms' surfaces to the source was kept 100 cm with the help of an optical mark reader by moving the couch vertically. The field size was made 10 cm × 10 cm with the use of collimator jaws. For each photon beam energy of 6 MV and 15 MV, the radiation dose was recorded for 100 monitor units (MU). The ionization chamber detects this radiation and converts it to an electric charge. For our study, we took charge of the Nano Columb (nC).

For solid water phantom, the block of the slab is placed on the couch of the Linac. The ionization chamber was placed in 10 cm depth from the surface of the slab-like as in **Figure 1**. For 10 cm depth, we used different depth slabs. In this experiment, we used the number of nine slabs which depth was 1 cm. The ionization chamber was inserted into a slab of 2 cm thickness. By following the aforementioned procedure, the readings were taken for the measurement of the absorbed dose.

For MatriXX with MULTICube Phantom, the MULTICube slab is divided into two parts. The first part was placed on the couch of the Linac. Then place MatriXX FFF Ionization chamber, then 2nd part place up ionization chamber *i.e.*, MatriXX ionization chamber place into the middle to the MULTICube slab like **Figure 1**. The depth from the upper surface of the slab to the ionization chamber is 10 cm. Then the MatriXX was warm-up for 30 minutes, and after that, 400

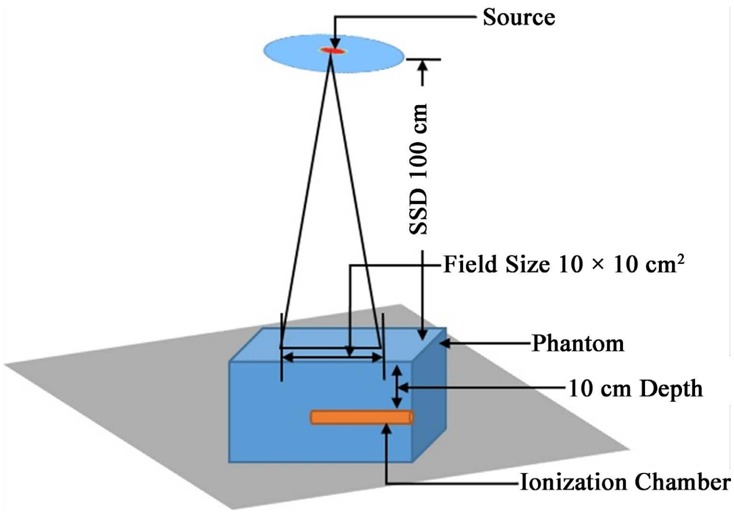

Figure 1. Schematic diagram for the absolute dose measurement.

MU was delivered to check the response of the detectors. The field size was made 10 cm × 10 cm, and SSD was 100 cm. Finally, 100 MU was delivered for each 6 MV and 15 MV to the MatriXX, and the corresponding dose was recorded and reported.

Absorbed dose $D_{W,Q}$ to water at the reference depth, Z_{ref}, in water phantom irradiated by a beam of quality Q is

$$D_{W,Q} = M_Q \times N_{D,W} \times K_{TP} \times K_S \times K_{Pol} \times K_{Q,Q} \quad (1)$$

where, M_Q—Monitor reading,

$N_{D,W}$—Calibration factor in terms of absorbed dose to water,

K_{TP}—Temperature Pressure correction factor,

K_S—Ion recombination correction factor of an ionization chamber,

K_{Pol}—Voltage polarity correction factor,

$K_{Q,Q}$—Beam quality correction factor.

3. Results

According to IAEA guideline TRS 398, the absorbed dose for 10 × 10 cm^2 field size and 10 cm depth should be varied up to 65% - 68% by 6 MV photon beam and that for 15 MV photon beam is up to 78%.

In our study, we find the average absorbed dose at 6 MV photon beam is 68.42 cGy, 66.50 cGy, and 62.93 cGy. On the contrary, at 15 MV photon beam, we get the average absorbed dose 77.83 cGy, 75.08 cGy, and 75.34 cGy for 1D water phantom, solid water phantom, and MatriXX with MULTICube phantom, respectively. The graphical representation of the average absorbed dose for 6 MV, and 15 MV photon beam is shown in Figure 2 and Figure 3.

We know that water is recommended for absolute dosimetry calculation by TRS: 398 and TG-51. If we want to set water as standard, then the variation with

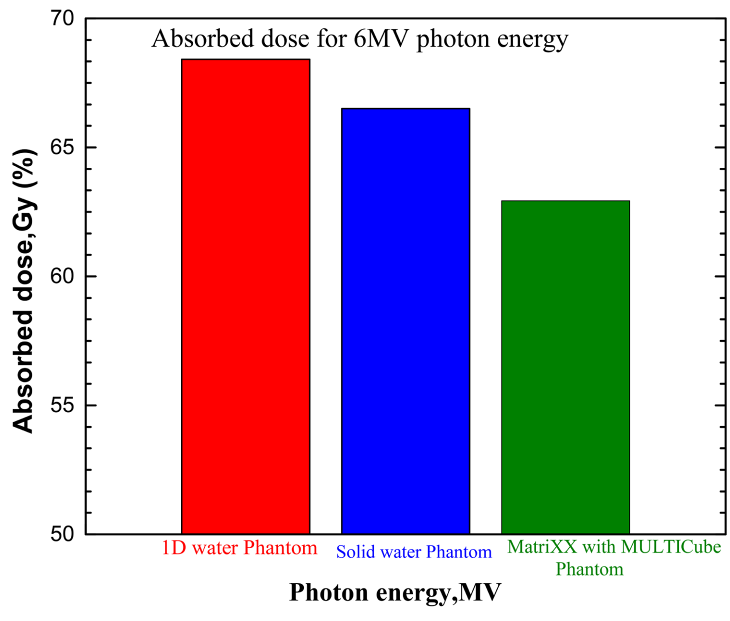

Figure 2. Absorbed dose for 6 MV photon beam.

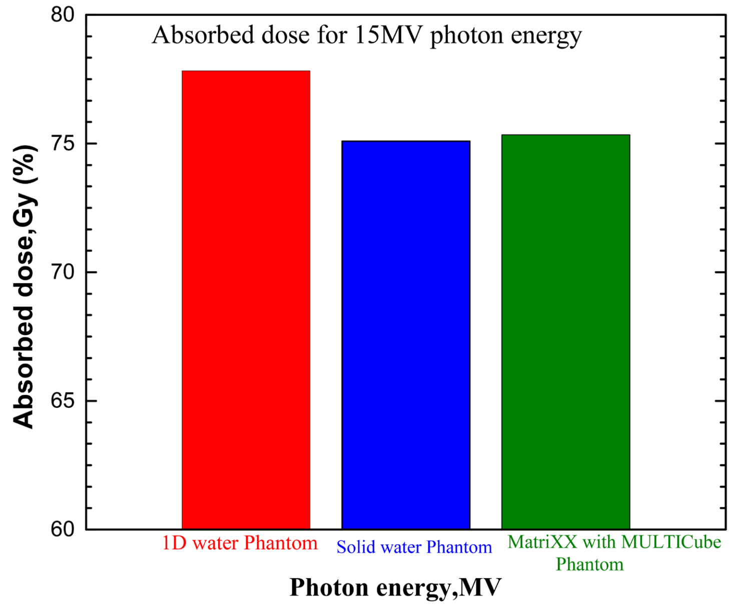

Figure 3. Absorbed dose for 15 MV photon beam.

Table 1. Variation from 1D water phantom.

Energy	1D water phantom	Solid water Phantom			MatriXX with MULTICube Phantom
		Our data	Hong *et al.* (2015)	Rahman *et al.* (2016)	
6 MV	0	+2.8%	0.611%	+2.0%	+8.0%
15 MV	0	+3.5%	1.05%	+5.9%	+3.2%

solid water phantom for 6 MV is 2.8%, and that for 15 MV is 3.5%. Again, the variation with MatriXX with MULTICube phantom for 6 MV is 8%, and that for 15 MV is 3.2%. These variations are within the acceptable limit (±5%) and are shown in Table 1.

4. Discussion

Above results, it is observed that the accuracy of dose estimation is better in 1D water phantom rather than solid water phantom and MatriXX with MULTIcube phantom. Water phantom is the best absorber among them. Also, it is recommended for absolute dose measurement. The variation of sold water phantom from the 1D water phantom is +2.8% at 6 MV and +3.5% at 15 MV. The variation MatriXX with MULTIcube phantom from the 1D water phantom is +8.0% at 6 MV and +3.2% at 15 MV. Rahman *et al.* compared the deviation of solid water phantom from water phantom were +2.0% at 6 MV and +5.9% at 15 MV [11]. For 15 MV photon energy, our deviation is smaller compared to theirs, but 6 MV photon energy is tiny different from theirs. Huang *et al.* compared the relative deviation of solid phantom from water phantom for each energy level was 0.48% [20]. Their relative deviation is small with our deviation because of a change of solid phantom material. Hong *et al.* compared the relative deviations of sold water phantom from water phantom were 0.611% at 6 MV and 1.05% at 15 MV [10], which are small differences in our variation. Thomadsen *et al.* compared the relative deviation of solid phantom from water phantom for electron beams ranging from 6 to 18 MV were 0.46% - 0.68% [21]. This variation of the deviation comes from the measurement with the electron beam and not with the X-rays. As shown above, it is found that the relative deviation depends on the phantom material.

In solid water phantom and 1D water phantom, only one ionization chamber is used, but in the case of MatriXX with MULTICube phantom, multiple ionization chambers (MatriXX containing a total of 1024 detectors about 400 detectors) have been worked simultaneously. So, the average dose by 400 detectors has measured by MatriXX with MULTICube phantom. Hence larger variation (8%) by MatriXX with MULTICube Phantom may occur for that reason. It is also known that the 1D water phantom takes a comparatively long time for setup arrangement and data collection. To overcome this type of problem, we can use solid water phantom or MatriXX with MULTICube phantom; those are faster in setting up than 1D water phantom.

5. Conclusion

This study is focused on the measurement of absorbed dose for photon beam of 6 MV and 15 MV at 10 cm depth of field size 10 cm × 10 cm using 1D water phantom, solid water phantom, and MatriXX with MULTICube phantom and making a correlation among them. All phantoms can be used in radiotherapy centers for quality assurance cheek and dosimetry conformation. According to TRS 398, water is recommended for the absolute dosimetry of clinical photon beams. In this study, a comparison was made for the aforementioned three phantoms and found that the average absorbed for all three cases is found to be compatible with the IAEA TRS 398 recommendation. So that, solid water phantom and MatriXX with MULTICube phantom can be used instead of water phantom in the radiotherapy centers for daily QA check and few specific dosimetry calculations. In the case of MatriXX with MULTICube Phantom, the percentage of deviation at low energy (6 MV) is found to be 8%, but this should be within ±5%. Further study should design to rectify the problem and identify the cause behind the dose variation.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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