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Measurement of Percentage Depth Dose using Fabricated Water Phantom Tank for 6 MV Photon Beam

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ABSTRACT

Radiotherapy phantoms are utilized to estimate radiation dose delivered to patients, and to improve the accuracy and measurement of radiation dosimetry. The aim of this research is to measure the Percentage Depth Dose (PDD) using a locally designed and fabricated water phantom tank as a cost-effective alternative to the commercially available water phantom used for calibrating therapeutic radiation doses from a linear accelerator. Acrylic material was used to construct the 30 × 40 × 30 cm^3 water tank, and tests were conducted on the fabricated phantom using the Elekta linear accelerator at the National Cancer Center Benghazi (NCCB). An IBA FC65-P ionization chamber was used to measure the dose at depths ranging from 0 to 16 cm in 1 cm intervals for 6 MV photon energy at 10 x 10 cm^2 field size, and 100 cm Source Surface Distance (SSD). The results indicated that the dose values obtained from the locally fabricated water phantom closely matched those from the commercially installed water phantom and were consistent with values reported in the literature.

INTRODUCTION

Radiation therapy is a vital medical procedure that utilizes radiation to treat and manage diseases associated with cancer cells and tumors. It is one of the essential components of modern cancer care, commonly used to reduce the size and control the spread of cancerous tumors, eliminate residual cancer cells after surgery, or serve as a standalone treatment for inoperable tumors. Additionally, it plays a role in palliative care by alleviating painful symptoms in certain patients. [1-2]. Radiation therapy uses highly energetic ionizing radiation, such as X-rays and radioactive particles, to deliver a definitive radiation dose to a specific diseased organ or tissue target area with high precision and accuracy. The goal is to destroy the DNA of cancer cells, leading to their death and inhibiting their ability to grow and spread, while minimizing damage to surrounding normal tissues [3].

It is difficult to directly measure dose distribution in patients undergoing radiation therapy; therefore, dose distribution is primarily determined using measurements taken from phantoms, which are tissue-equivalent materials designed to simulate radiation interaction. Basic dose distribution data are typically measured in a water phantom due to its similarity to the absorption and scattering properties of radiation in soft tissues, as well as the global availability of water with consistent radiative properties. However, the water phantom presents practical challenges, leading to the development of solid phantoms as alternatives.

To achieve water equivalence for high-energy beams, the substitute material must have the same electron density to ensure accurate and effective delivery of the target radiation dose while minimizing damage [4]. Phantoms are designed to simulate the physical properties of human body tissues, enabling healthcare teams to assess and control the quality of radiation therapy. They are used to measure radiation doses, analyze dose distribution, and evaluate the performance of radiation therapy systems. Those data are the

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components used in the dose calculation system to predict the dose distribution for the actual patient [5].

A Linear Accelerator (LINAC) is an essential device in external radiation therapy, engineered to accurately deliver high-energy X-rays or electron beams to target tumors while reducing harm to nearby healthy tissue. Before each treatment session, the device is meticulously programmed to match the tumor's exact dimensions and shape, ensuring effective cancer cell destruction. LINAC is widely used in treating various cancers, including those of the brain, spine, and lungs. It incorporates advanced safety features and undergoes regular inspections by medical physicists to guarantee precise dose delivery [6].

The ionization chamber is the most important dose measurement device. Gas-filled detectors take advantage of the ionization produced when radiation passes through the gas between two electrodes, across which an electric potential is applied. The radiation induces the formation of electron-ion pairs that move under the influence of the electric field, generating an electrical current that can be measured. The charge produced by ionization can also be converted into electrical pulses, enabling the individual counting of particles. These detectors are classified into two main types: "current chambers" or "integrating chambers," which measures continuous current, and "pulse chambers," which measures pulses individually [7]. The aim of this research is to fabricate a water tank phantom from primary materials available in the local market and test its performance in a practical setting by measuring the Percentage Depth Dose (PDD) in the well-established cancer treatment center; National Cancer Center Benghazi (NCCB) in Benghazi, Libya.

METHODOLOGY

The dose measurement was conducted on the locally made water phantom tank using a 6 MV x-ray photon beam from the Elekta linear accelerator facility located at NCCB.

Fig. 1. The locally fabricated water phantom.

A water phantom tank with a dimension of 30 x 40 x 30 cm was made of acrylic material, as shown in Fig. 1. The tank contains an aluminum holder at the top, a DC-powered motor, and a plastic holder mounted on a rotating axis to move the holder vertically inside the phantom, as well as a water pump.

Percentage Depth Dose (PDD)

Percentage Depth Dose (PDD) measurement is an essential procedure carried out by medical physicist and is typically performed along the beam's central axis. One way to characterize the dose distribution (%) is to normalize the dose at each depth with a dose at a depth that is used as a reference (reference depth). Reference depth that can be used in radiotherapy with low energy (≤ 999 keV) is the phantom surface [8]. PDD is defined as the percentage ratio of the absorbed dose at any depth at point Q equal to Z to the absorbed dose at a constant reference depth at point P, equal to Z_{max}, along the central axis of the beam, as shown in Fig. 2 [9]. There are three main areas which can explain the PDD. First, the skin surface dose. It is the electrons liberated by photon interactions that deposit most dose within the tissue, there is remaining residual dose at the patient skin surface. This is due to radiation backscattered within the patient and contamination of the photon beam with electrons and low energy photons from the treatment head and surrounding air. The surface dose decreases as photon beam energy increases.

Second, build-up region from surface to d_{max}. In this region, the electrons that have been liberated in the preceding layers deposit their dose, reaching a maximum at a depth d_{max} below the surface, which can be estimated for lower energies using the rule of thumb d_{max} = MV/4 (in cm).

Third, fall-off in dose after d_{max} – beyond d_{max} the dose falls off due to attenuation of the photon beam and the inverse square law. It is the same for all beams at a given distance, but attenuation will be affected by many factors, including the energy of the beam and the composition of the patient's tissues.

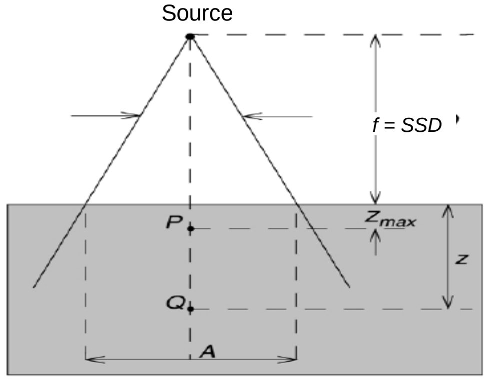

Fig. 2. The parameters of Percentage Depth Dose (PDD).

Percentage Depth Dose (PDD) was calculated using Eq. (1).

$$PDD = \frac{D_Q}{D_p} X100\% \quad (1)$$

where D_Q is the absorbed dose at any depth, Z, and D_P is the absorbed dose at a fixed reference depth P given by Z_{ref}.

PDD measurement setup

The water phantom tank was placed on the treatment couch below the treatment head of the linear accelerator and filled with distilled water at a SDD distance of 100 cm from the water surface as shown in Fig. 3. The absorbed dose at the reference depth Z_{ref} and the absorbed dose at any depth Z in the fabricated water phantom tank were calculated by multiplying the reading from the ionization chamber with the appropriate dose conversion factor from the calibration certificate.

An IBA FC65-P ionization chamber was used in the entire dose measurement procedures. The ionization chamber was positioned aligning the central beam axis of the linac system. The ionization chamber, therefore, moves vertically through the water phantom tank in steps using the motor. The dose measurement was done at a 6 MV photon beam energy and field size of 10 x 10 cm^2. Depth Z was selected, ranging from 0 to 16 cm at 1 cm intervals using the motor. Water was employed as the substitute tissue material for measuring photon doses, and pure distilled water was used in the experiment as non-distilled water contains various concentrations of natural contaminants such as mineral salts, iron, magnesium, calcium, and many other elements, so it is preferable to use distilled water for accurate measurements.

Fig 3. Phantom setup for PDDs measurements.

Linear accelerator

Elekta Infinity from Elekta AB (Stockholm, Sweden) is a type of linear accelerator used in radiation therapy at NCCB. This system is part of modern devices employed in the field of radiation therapy. It provides high-energy X-ray photons in the range of 6, 10, and 15 MV and electrons for radiotherapy treatment of cancer patients. Elekta Infinity is used for treating cancerous tumors and delivering precise radiation doses.

The IBA FC65-P ionization chamber

The Farmer ionization chambers are used for dosimetry of photon and electron beams at therapy-level dose rates. They are also suitable for dosimetry in proton fields, depth dose measurements, and field profile analysis. The IBA FC65-P chamber is used for daily checks of treatment machines. It is designed for photons, X-rays (from 70 kV), gamma radiation (^{137}Cs and ^{60}Co), electrons, and proton beams (50–250 MeV).

RESULTS AND DISCUSSION

The locally fabricated water phantom was utilized to measure the percentage depth dose (PDD). The PDD curve for a 10 x 10 cm^2 field size at 100 cm Source-to-Surface Distance (SSD) for 6 MV photon energy is presented in Fig. 4. The maximum depth dose (D_{max}) and the PDD at a depth of 10 cm D_{10} (%) for 6 MV photon energy and for a 10 x 10 cm^2 field size are provided in table 1.

For a 10 × 10 cm^2 field size, the depth dose (D_{max}) for 6 MV is 2 cm, while the PDD at 10 cm depth (D_{10}) is 68.26%. According to BJR 25, the tolerance values for 6 MV photon energy are 1.5 cm for D_{max} and 67.5% for D_{10}, respectively [9].

Table 1. Measured D_{max} and D_{10} for 6 MV.

Energy (MV)	Field size (cm^2)	Depth dose (d_{max}) (cm)	PDD at 10 cm depth D_{10} (%)
6	10x10	2	68.26

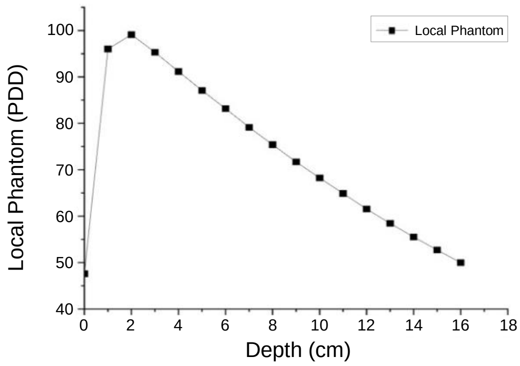

Fig. 4. The relationship between PDD and depth for a locally fabricated water phantom.

For the surface dose, the value of BJR 25 was 50.7%, which decreased in the local phantom to 47.62. The values from previous study by Chowdhury et al. (2024) [12] matched BJR 25, while the other studies recorded the highest surface dose at 59.81%, ±9.11% [13], and the lowest surface dose at 40.12%, ±10.58% [14]. The locally fabricated phantom can be a viable option, especially prioritizing the radiation depth penetration capability of the radiation in depth. However, results related to the surface dose should be carefully considered, and the accuracy of the simulation should be periodically reviewed to ensure it meets the requirements of specific applicationa.

Figure 5 shows the comparison of local phantom and other studies, where significant overlap is observed between the results. At a depth of 0 cm, the local phantom recorded a value of 47.62%, while the comparison value from Al-Naqqash et al. (2018) [10] was 42.56%, indicating a notable difference of 5.06%. At a depth of 2 cm, the local phatom recorded a value of 99.12 %, compared to the previous studies, 99.5% by Al-Naqqash et al. (2018) [10] and 99.56% by Li et al. (2022) [14], showing a high degree of similarity in measurements, with differences of less than 0.5%. At depths from 3 cm to 8 cm, the local phantom values continued to align closely with the measurements by Al-Naqqash et al. (2018) and Li et al (2022), as well as the actual plan. At depths from 9 cm to 16 cm, a higher level of convergence was achieved, with generally smaller differences, indicating better agreement in measurements. The compared curves shows that the local fabricted phantom have good agreement with the results of previous studies by Al-Naqqash et al. (2018) [10] and Li et al. (2022) [14], particularly at deeper depths.

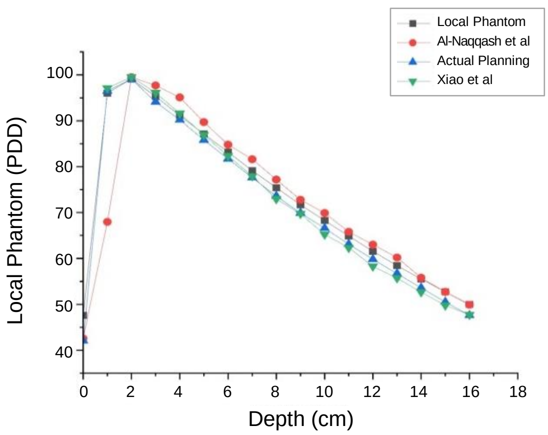

Fig. 5. Comparison between local planning, actual planning, Al-Naqqash et al., (2018) [10] and Li et al. (2022) [14].

The increasing and decreasing patterns observed in the local phantom results align closely with the general shape of PDD curves [9,11] confirming its validity and reliability in measurements. The local phantom is considered simple in its strcucture, yet its results are highly impressive compared to commercial phantoms and some provious studies. It can be used as an alternative to commercial phantoms.

CONCLUSION

The results showed that the locally fabricated water phantom provided dose values that were in good agreement with the BJR 25 in deep dose measurement at 10 cm which is 68.26-% compared with 67.5-%, with a slight difference, and its performance was comparable to other studies. In value than BJR 25 which is 47.62-% compared to 50.7-% BJR 25. Overall, the local phantom shows good accuracy in deep dose measurement but needs improvements to ensure better agreement in surface dose. The locally fabricated water phantom is an effective alternative to the dedicated water phantom and can be used to measure therapeutic radiation doses. In addition to the acceptable physical parameters of the fabricated water phantom tank, the economic value of manufacturing such a phantom is definitely much lower than that of commercially purchased phantoms. This research will encourage researchers to investigate more materials and designs for future use in radiotherapy in particular and in other scientific applications in general.

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AUTHOR CONTRIBUTION

Abdelkader. M. conducted the research and worte the first manuscript. Youssef. A. Abdulla, N. A. Hussein and F. H. A. El-Tashani performed the revision and improved the manuscript.

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