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DOSIMETRIC CHARACTERIZATION OF CUSTOMIZED PLA PHANTOM FOR RADIOTHERAPY

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ABSTRACT

The purpose of this study was to assess the dosimetric properties of PLA (polylactic acid) phantom in comparison to solid water phantom for photon and electron beam radiotherapy. The standard solid water and PLA phantom were characterized for their uniformity and Hounsfield Unit (HU) using SOMATOM computed tomography (CT) scanner. Ionization chamber and Gafchromic EBT3 films were used to measure the dose delivered at the depth of maximum dose in the solid water and PLA phantom. The dose prescribed during the irradiation with photon and electron beams were set from 50 to 1000 cGy. The results show the percentage dose difference measured using ionization chamber for 6 and 10 MV photon beams between solid water and PLA phantom was less than ± 4%. Meanwhile, for 6 and 12 MeV electron beams, the percentage dose differences measured for both phantoms was within ±2%. Measurement using Gafchromic EBT3 films also agreed with ionization chamber results with percentage dose differences between solid water and PLA phantom less than ± 4%. In conclusion, the PLA phantom could potentially be applied for routine quality assurance check and dosimetry confirmation in radiotherapy as an alternative to standard solid water phantom.

Keywords: Gafchromic EBT3, markus ionization chamber, polylactic acid, radiotherapy, solid water phantom

INTRODUCTION

The aim of radiotherapy is to treat cancer using high doses of radiation in the form of photon and electron beam. Radiation is known to cause damage to biological materials in which the requirement for accurate dosimetry is very crucial in radiotherapy. Therefore, tissue equivalent phantom is fundamentally important in radiation dosimetry to replace human for quality assurance and quality control in radiotherapy. Commercial radiotherapy phantoms are available in many different types and shapes such as slab phantom, water phantom, anthropomorphic phantom, and organ-specific phantom. Basic phantom such as bolus plays an important role in sparing the skin effect (Kim et al., 2014).

However, the commercial phantoms are usually expensive, bound to standard factory specification, not flexible in physical properties and materials limitation. Standard bolus used in electron beam therapy had an issue of unable to form precise contact with the irregular surface of the patient's skin contributing an air gap that affects the skin sparing effect and decreases both surface and maximum dose (Vyas et al., 2013). Recent evidence suggested by the International Atomic Energy Agency

(IAEA) Code of Practice Technical Report Series No.457 (TRS 457), standard phantoms should be designed and constructed so that they have identical primary attenuation and scatter production as the relevant body section of a representative patient and the energy range according to the prescribed treatment (IAEA, 2007). In this study, 3D printed slab phantom made of polylactic acid (PLA) materials were characterized for their potential application in radiotherapy. Dosimetric characterizations were performed using Marcus ionization chamber and Gafchromic EBT3 films for photon and electron beams radiotherapy.

MATERIALS AND METHODS

Phantom Preparation and Characterization

The PLA phantoms were designed with a dimension of 30 × 30 cm^2 with a thickness of 1 mm as shown in Figure 1. The phantoms were 3D printed using MyVista Cube 200 with a PLA (Polylactic Acid) plastic materials.

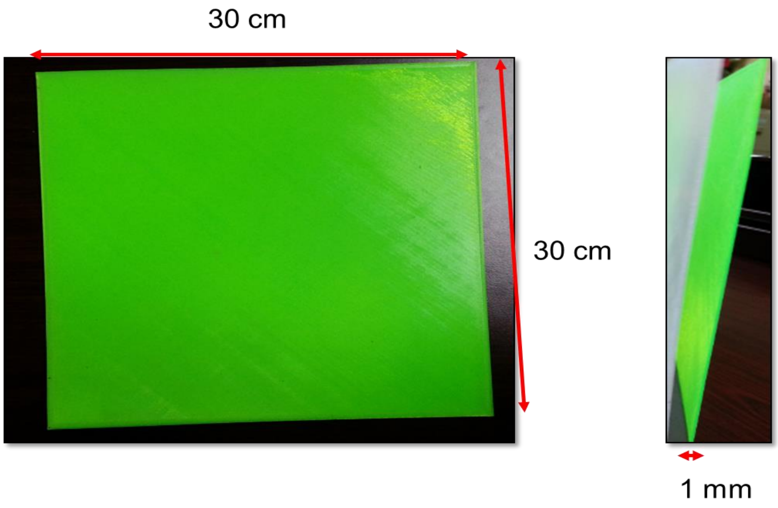

Figure 1: The PLA solid water phantom

The PLA phantoms were characterized using computed tomography (CT) scanning by comparing the Hounsfield Unit (HU) and internal uniformity with standard commercial solid water phantom. CT images of the standard commercial solid water phantom and PLA phantom were obtained using SOMATOM CT scanner. The CT scanning conditions were as follows: slice thickness: 0.1 cm, peak voltage: 120 kVp, current: 210 mAs, window width: 1200 mm, window level: 600 mm and field of view: 424 mm and 422 mm for solid water phantom and PLA phantom, respectively.

Dosimetric Characterization Using Ionization Chamber and Gafchromic EBT3 Films

Dosimetric characterization was performed using Markus ionization chamber with PTW Unidos electrometer. Irradiation was performed using photon (6 MVand 10 MV) and electron (6 MeV and 12 MeV) beams from Siemens Primus Linear Accelerator. Measurement of the dose was done at depth of maximum dose (d_{max}) in both solid water and the PLA phantom. The source to surface distance (SSD) was fixed at 100 cm and field size at 10 × 10 cm^2. The radiation doses used were 50, 100, 150, 200, 400, 600, 800, 900 and 1000 cGy. Figure 2 shows the dosimetric measurement set up using ionization chamber. The experiments were repeated using Gafchromic EBT3 films as shown in Figure 3. The films were scanned 24 hours after irradiation using EPSON 10000 XL flatbed scanner. Verisoft Software Version 5.1 was used to analyse the films.

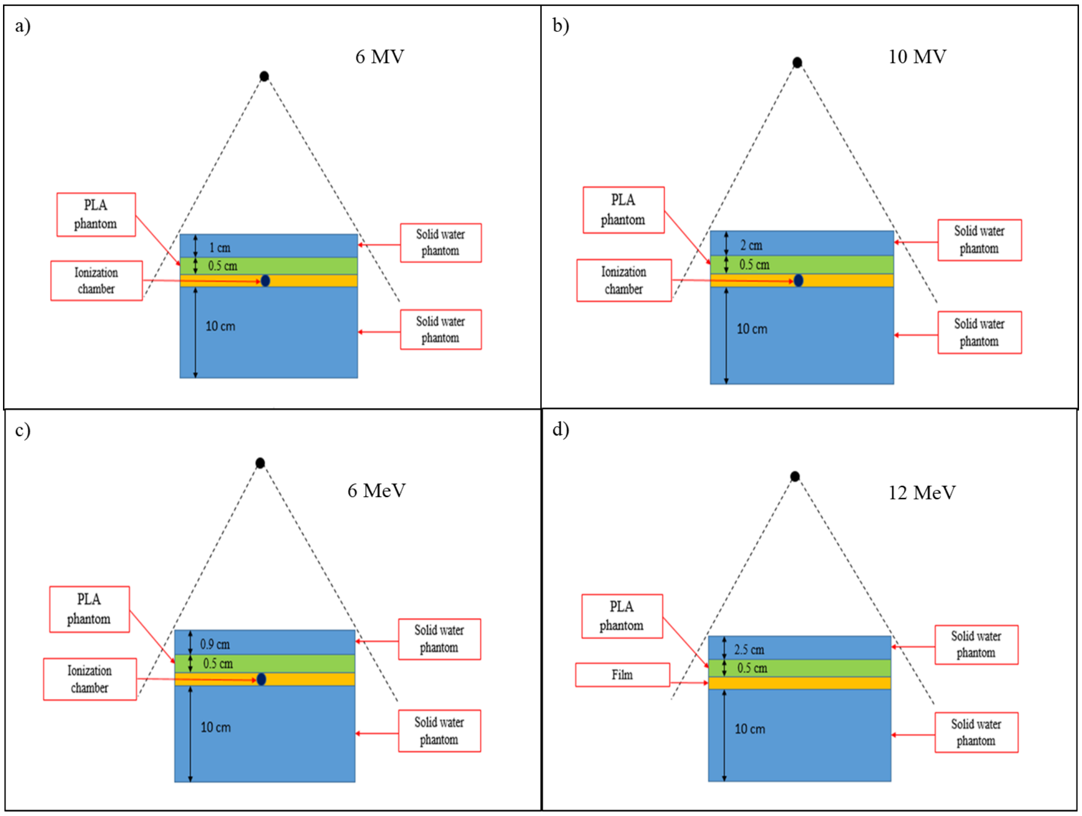

Figure 2: Dosimetric characterization using ionization chamber a) 6 MV photon beam, b) 10 MV photon beam, c) 6 MeV electron beam and d) 12 MeV electron beam

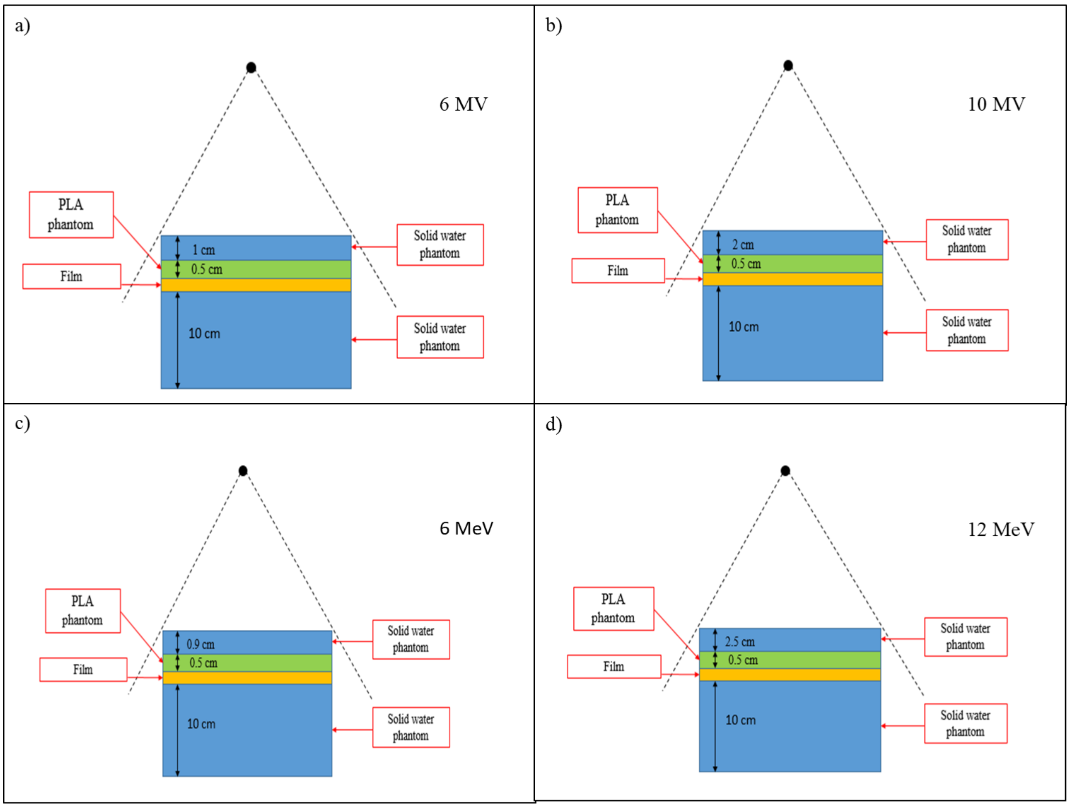

Figure 3: Dosimetric characterization using Gafchromic EBT3 films a) 6 MV photon beam, b) 10 MV photon beam, c) 6 MeV electron beam and d) 12 MeV electron beam

RESULTS AND DISCUSSION

Phantom has been used to substitute human in radiotherapy for dosimetric measurements. However, commercial phantoms are usually expensive and cannot be customized according to specific applications. 3D printing technology provides an alternative to construct a custom-made phantom from a different anatomical site (Zhang et al., 2019). PLA has been used as a material for 3D printed phantom with HU of 274 (Park et al., 2016). Another study determined the average HU of the PLA cubes were around 130.1 ± 10.1 (Zou et al., 2015). In this study, the PLA phantoms were characterized for their uniformity and Hounsfield Unit (HU) was measured using CT scanner. Figure 4 shows the CT image of solid water phantom with HU of 285 and CT image of PLA phantom with HU of 349. There are slight differences between the HU of both phantoms, but the PLA phantom shows uniform density across the scanned slices. Kim et al. (2014) reported that the commercial flat bolus and 3D printed flat bolus that do not have completely homogenous HU values can potentially increase the measured dose at the central axis (Kim et al., 2014). Clear PLA generally has 14% higher electron density and 20% higher physical density than water. Burleson et al. (2015) had found that a phantom material with an electron density ratio compared to water around 1.14 and mass density ratio of 1.2 is equivalent to a material that has 260 HU (Burleson et al., 2015).

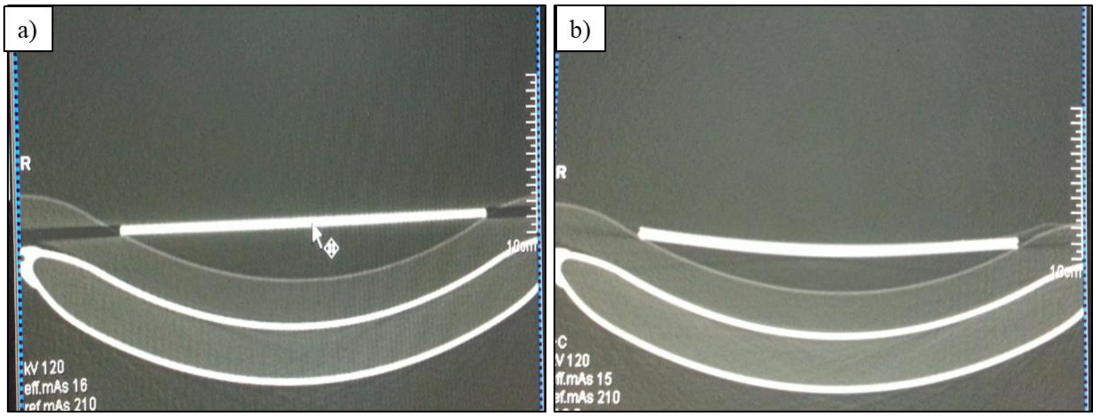

Figure 4: a) CT image of a solid water phantom. HU was 285 b) CT image of PLA phantom. HU was 349

The dosimetric characterization by the ionization chamber of the PLA phantoms in comparison to standard solid water phantoms is shown in Figure 5. The dose measured for 6 MV and 10 MV photon beams for solid water phantom and PLA phantom indicates percentage dose differences of less than 3% and 4% respectively. Meanwhile, for 6 MeV and 12 MeV, electron beams indicate percentage dose differences of less than 2% and 1% respectively. Figure 6 shows dosimetric characterization by Gafchromic EBT3 films of the PLA phantoms in comparison to standard solid water phantoms. The dose measured for 6 MV and 10 MV photon beams shows a percentage dose differences less than 5% and 3%, respectively. Then, for 6 MeV and 12 MeV, electron beams provide percentage dose differences of less than 2% and 1.5%, respectively. In average percentage of the dose differences for photon and electron beams agrees within ± 5% which passes the recommended value of the relative error in dose measurements in radiotherapy (ICRU, 1976).

Therefore, PLA phantom can be potentially applied in radiotherapy for quality assurance (QA) check and dosimetry confirmation as an alternative to solid water phantom. Besides, PLA phantom is much cheaper compared to solid water phantom. However, the durability of the PLA phantom was not tested in this study and need to be further explored.

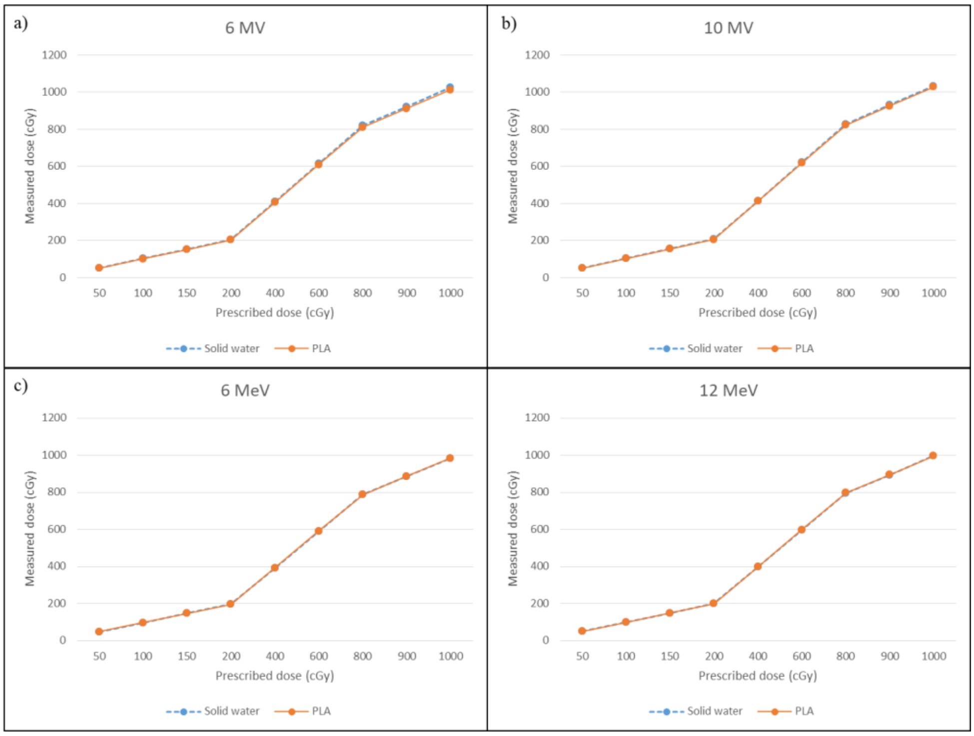

Figure 5: The graph of a comparison of dose measured by ionization chamber in solid water phantom vs PLA phantom for a) 6 MV photon beam, b) 10 MV photon beam, c) 6 MeV electron beam and d) 12 MeV electron beam

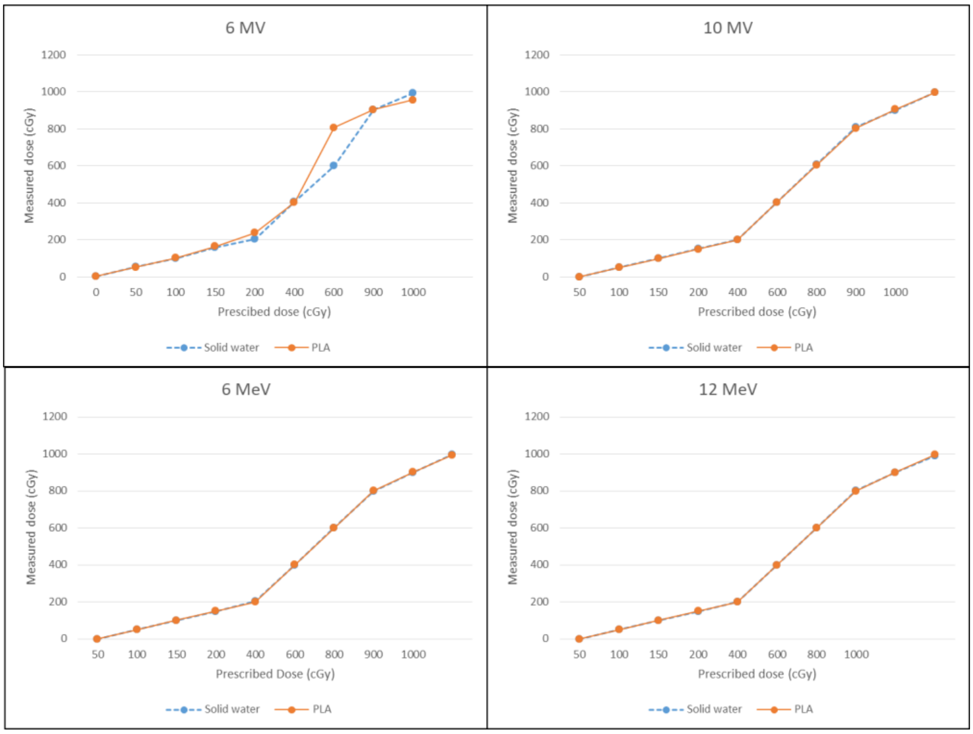

Figure 6: The graph of a comparison of dose measured by EBT3 films in solid water phantom vs PLA phantom for a) 6 MV photon beam, b) 10 MV photon beam, c) 6 MeV electron beam and d) 12 MeV electron beam

CONCLUSIONS

In conclusion, the inexpensive PLA phantom could potentially replace solid water phantom in dose verification for photon and electron beam radiotherapy due to its dosimetric accuracy and ability to be custom made according to the specific requirement.

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