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IONIZATION CHAMBERS MODELING FOR DOSIMETRY PHANTOMS DEVELOPMENT

Abstract

Radiation treatment is an important modality in treating diseases especially cancer. Although it is important in medicine, improper use can lead to unnecessary dose exposure, cancer or in extreme cases, death. Therefore, treatment plans are tested and verified with phantoms and detectors before they are administered to patients. Ionization chambers are detectors used to measure the quantity of ionization radiation that is deposited in the patient. Three dimensional (3D) printing on the other hand is a manufacturing technique that has revolutionized medical physics through the production of patient specific phantoms with accuracy compared to other methods. This method is cheap, fast, allows the production of complex geometries with precision and the use of different printing materials, and less time consuming. Incorporating cavities for detectors in 3D printed phantoms allows precise positioning of detectors for accurate dose measurements and verification. The study aimed at investigating the feasibility of using 3D printing to replicate the structure of original ionization chambers. Models of three different ionization chambers were designed with computer aided design (CAD) software, and printed. The printed prototypes were then examined using computed tomography scanner to access their accuracy. The result confirms that 3D printing can produce ionization chamber prototypes. When developing 3D printed phantoms with cavities for the insertion of original ionization chambers, these printed prototypes can provide accurate reference dimensions for the cavities.

Key words: Dosimetry phantoms, fused filament fabrication, ionization chamber, 3D printed prototype

Introduction

Radiotherapy is a crucial treatment modality in cancer treatment, using ionizing radiation to kill or reduce tumor size. The aim of radiotherapy is to deliver maximum dose to the target without damaging surrounding tissues. A crucial aspect of this modality is dosimetry, which ensures that the proposed dose is accurately delivered to the patient with minimal or no complications. As a results, dosimetry experiments are conducted verify treatment plans before they are administered to patients. Over the centuries, traditional phantoms such as water phantom and detectors have been used for these experiments. However, these phantoms are expensive and lack patient anatomy specificity. This sometimes compromise dose measurements results as they are unable to represent the unique anatomy of a patient [2].

3D printing, a manufacturing method which prints objects layer-by-layer using digital models, offers a solution to this problem. This technique allows the production of highly detailed and customized phantoms that suits a patient or a group of patients with accuracy [3], thereby improving personalized radiotherapy. 3D printed phantoms are cost effective and requires less time to manufacture compared to conventional manufacturing methods [4]. Since the production time is less and cheap, it is quick to modify and adjust parameters based on imaging and testing feedback. In 3D printing, different materials can be used to match the radiological properties of human tissues and also the printing parameters such as infill density and pattern can be adjusted to produce heterogeneous phantoms and desired radiologic characteristics [5], which better represent the human body than traditional phantoms. 3d printed phantoms are more durable than traditional and hence fit for routine quality assurance procedures.

An integral part of phantom creation is the construction of cavity for the placement of detectors for dose measurement. These detectors are placed inside the phantoms; hence the creation of cavities in the phantoms with precise dimensions for the positioning of the detectors in the region of interest is very important. Precise cavity dimension ensures accurate dose measurement, reduce errors due to misalignment or movement, ensures repeatability of the exact positions in experiments. One of the most commonly used detectors is ionization chamber. Ionization chambers are gas filled detector that measure the ionization produced by radiation, and they come in different shapes and sizes depending on the type of measurement it is made for [6]. 3D printing can be used to produce phantoms with cavities for the insertion of ionization chambers. However, one challenge faced is the shrinkage of the internal size of the cavities during cooling, thus preventing real ionization chambers from fitting properly. To overcome this challenge, it was proposed to 3D print ionization chamber prototype that can serve accurate reference for the designing of phantoms with cavities. These prototypes can provide accurate reference dimensions for the cavities.

This work focuses on 3D printing prototypes of cylindrical ionization chambers with different active area volumes for the design of 3D printed phantom inserts.

Materials and Methods

Three different cylindrical ionization chambers with different sensitive volumes of 0.01 cm^3 (Razor, IBA), 0.13 cm^3 (CC13, IBA), 0.65 cm^3 (FC65-P, IBA) were chosen for the prototype creation. The 3D models of the chambers were made using computer-aided design (CAD) software (fusion 360) and saved as stereolithography (STL) files. The prototypes were created using Original Prusa XL printer. The 3D designs of the ionization chambers are shown in Fig. 1.

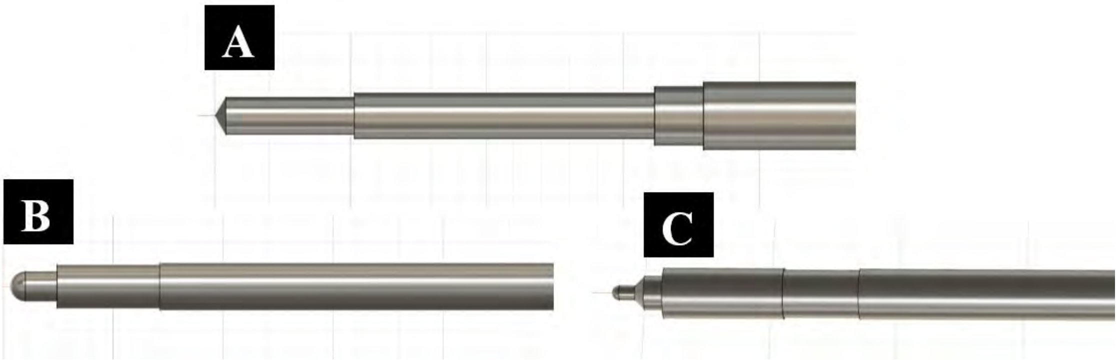

Fig. 1. Images of digital models of ionization chamber designed in Fusion 360 software:
(A) FC65-P ionization chamber (sensitive volume – 0.65 cm^3);
(B) CC13 ionization chamber (sensitive volume – 0.13 cm^3);
(C) Razor ionization chamber (sensitive volume – 0.01 cm^3)

The STL files were then imported into a slicer software (PrusaSlicer -2.8.1) where the material for the extruder with 0.4 mm nozzle and printing settings were set. Support was added to keep it stable during printing. The printing settings included a temperature range of 210–215 C, a first layer speed of 25 mm/s, and a first layer height of 0.2 mm. Infill of 90 percent was used, and the top and bottom fill pattern was configured to use monotonic lines. The models with their settings were converted to G-code file and printed using fused filament fabrication (FFF) technique. Polylactic Acid (PLA) filaments with a diameter of 1.75 mm and density of 1.24 g/cm^3 was used to print them. PLA filament was used because it is biodegradable, easy to print, has good tensile strength and rigidity, relatively cheap, and widely available.

The 3D printed prototypes of three ionization chambers are shown in Fig. 2.

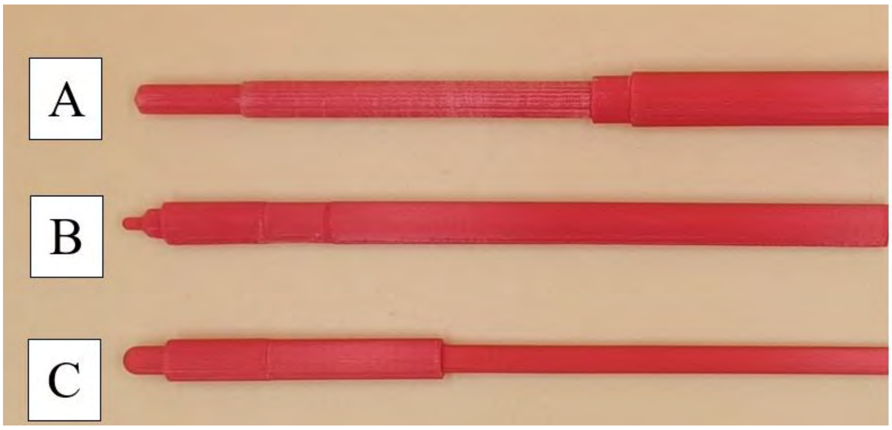

Fig. 2. 3D printed prototypes of ionization chambers: (A) FC65-P ionization chamber;
(B) Razor ionization chamber; (C) CC13 ionization chamber

Results and Discussion

The created prototypes were then placed into a 3D printed phantom insert for real ionization chambers and investigate with Siemens Somatom Confidence computed tomography (CT) scanner at the X-ray tube voltage of 120 kV to access the precision of the 3D printed prototypes.

An example of the CT scan image of the prototype of FC65-P ionization chamber in 3D printed insert for customized dosimetry phantom is shown in Fig. 3.

Fig. 3. CT scan data of 3D printed prototype of the FC65-P ionization chamber in 3D printed phantom insert

From the CT scan data (Fig. 3), the ionization chamber prototype is clearly distinguishable from the phantom material. The cylindrical shape is maintained and it is geometrically similar to the original FC65-P ionization chamber. In addition, no air gap was seen. Based on these observations, it can be concluded that the prototype successfully mimicked the shape and structure of the original chamber, thereby validating the proposed idea that 3D printing can be used to create prototypes of ionization chambers.

Conclusion

This study has proved the ability to 3D print ionization chamber prototypes for the development of 3D printed dosimetry phantoms. The CT scan result of the prototype of FC65-P ionization chamber in 3D printed insert further confirmed that, the printed prototype and the original ionization chamber are structurally similar. These prototypes can serve as accurate references for designing the cavities in 3D printed phantoms, ensuring precise detector placement for dosimetric measurements. As a result, measurement errors can be reduced while enhancing accuracy and efficiency of dosimetry measurements. The printed prototypes are intended for use in the designing of accurate cavities in 3D printed phantoms.

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THERMAL ANALYSES OF UNIFORMLY HEATED FUEL PIN CELL, INVERTED CELL, AND DUAL SURFACE COOLED CELL GEOMETRIES USING COMSOL MULTI-PHYSICS

Abstract. This study examines the thermal performance of pin cells, inverted cells, and dual surface-cooled cells under high heat conditions. We analysed key thermal properties, including linear heat generation rate and heat flux, by applying a uniform volumetric heat generation rate (VHGR) of $4 \cdot 10^7$ W/m³ to a pin of length 0.1 m. The results revealed a radial temperature drop of 65 °C for the inverted fuel pin, 26 °C for the normal pin, and 11°C and 13°C for the inner and outer surfaces of the dual surface-cooled pin, respectively. Thus, the dual surface-cooled pin had the lowest thermal loss, while the inverted pin had the highest thermal loss, despite achieving a higher surface temperature than the maximum of the dual surface-cooled pin.

Introduction

The thermal behavior of fuel materials is critical for nuclear reactor core design due to the thermal stress experienced during operation. In land-based light water reactors, fuel is cladded within a rod, shielded by zirconium layers and a gas gap. In maritime nuclear reactors, cladding wear may occur from fretting between the spacer grid