Material Evaluation of PC-ISO for Customized, 3D Printed, Gynecologic ^{192}Ir HDR Brachytherapy Applicators

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Abstract

Purpose: To evaluate the radiation attenuation properties of PC-ISO, a bio-compatible, sterilizable 3D printing material and its suitability for customized gynecologic (GYN) brachytherapy applicators.

Method: A custom radiochromic film dosimetry apparatus was 3D-printed in PC-ISO. The apparatus contained a single catheter channel and a slit to hold a radiochromic segment. A brachytherapy dose plan was computed to deliver a cylindrical dose distribution to the film. The dose plan used an ^{192}Ir source and was normalized to 1500 cGy at 1 cm from the channel. The material was evaluated by comparing the film exposure to an identical test done in water. The Hounsfield unit (HU) distribution was computed from a CT scan of the apparatus and compared to the HU distribution of water. The durability of PC-ISO was evaluated through multiple sterilization procedures.

Results: The dose-depth curve of PC-ISO was within 1% of water between 1 cm and 6 cm from the channel. The mean HU was -10 for PC-ISO and -1 for water. There was no visible damage to the apparatus after five sterilizations.

Conclusions: PC-ISO is sufficiently water equivalent to be compatible with our HDR brachytherapy planning system and workflow, and therefore it is suitable for creating custom GYN brachytherapy applicators. We have since treated several patients with custom GYN applicators made of PC-ISO when we felt it would improve their treatment.

Keywords: brachytherapy, 3D printing, custom applicators, sterilization, radiochromic

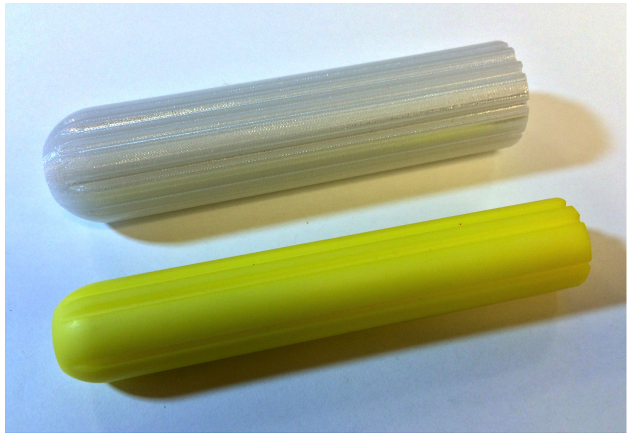

FIG. 1. 3D printing allows surgeons to customize the size and shape of brachytherapy applicators to improve treatment. Shown above is a 3D printed applicator made of PC-ISO (white). This applicator was designed to fit a patient with a very wide vaginal canal, which was too large for the largest commercial applicator of the same type at our clinic (yellow).

I. INTRODUCTION

Gynecologic (GYN) brachytherapy applicators come in a variety of shapes and sizes to accommodate different patient scenarios. However, there is little opportunity to customize the shape of these applicator and their internal structure to the needs of each patient. As a consequence, a fixed applicator might fit too loosely, which allows movement between scanning and treatment, and therefore increases dose uncertainty; it might fit too tightly, which can cause patient discomfort; or it might require extra interstitial catheters to ensure that dose objectives can be met.

Rapid prototyping, or 3D printing, has the potential to address the customization limitation of current GYN brachytherapy applicators. With 3D printing, it is possible to construct conformal applicators with customized channels [1]. There is currently a wide range of printing materials available for this purpose. However, to be suitable for clinical use, the material must be compatible with the brachytherapy workflow. Specifically, it must be biocompatible, sterilizable, free of CT scanning artifacts, and have similar dose attenuation properties as water, which is the medium assumed by most brachytherapy planning systems.

The purpose of this study is to evaluate PC-ISO (Stratasys, Eden Prairie, MN), a biocompatible, thermoplastic, 3D printing material, for use in printing custom GYN brachytherapy applicators. Previous studies have shown that PC-ISO can be sterilized in multiple ways [2], including STERRAD (Advanced Sterilization Products, Irvine, CA), which is the preferred sterilization method at our institution. This study compares CT scans and dose-depth curves for PC-ISO and water. Although this study focuses on PC-ISO, the same tests can be used to evaluate other materials for this purpose. Figure 1 shows an example of a customized GYN cylinder applicator printed in PC-ISO (white) next to a commercial applicator of the same type (yellow).

II. BACKGROUND

There are currently many medical applications of 3D printing in development [3–12]. This surge of interest includes medical modeling for maxillofacial surgical management [6, 13], bone reconstructions [8, 14], and oral surgeries [15]. There is evidence of this interest in radiotherapy applications [5, 9, 10, 16–18] and specifically in brachytherapy [4, 19–22]. There is even interest in using 3D printing to construct custom GYN applicators [3, 23]. However, to our knowledge, a 3D printed, GYN applicator has not been used to treat a patient yet.

Manufacturers have supported medical interests in 3D printing by introducing printing materials that pass the International Standard ISO-10993 for biocompatibility [24]. PC-ISO has ISO 10993 Class VI Certification, meaning it is approved for temporary skin contact. The material is also sterilizable and has high strength [14, 25]. These properties make PC-ISO ideal for constructed custom GYN applicators except that the radiation attenuation properties must still be evaluated, which is the focus of this study.

III. METHODS AND MATERIALS

A. Testing apparati

To evaluate PC-ISO, a custom testing apparatus was designed in CAD. This apparatus is shown in Figure 2 (left). The apparatus consisted of a pair of identical L-shaped blocks designed to snap together. Each block contained a single, straight channel 2 mm in diameter, which tightly held a 6F endobronchial brachytherapy catheter (Nucletron, Sunnyvale, CA). When snapped together, the blocks held a 3 cm by 6 cm radiochromic film segment in a 6 cm long shallow gap between the blocks. The blocks were 1 cm thick on each side of the film to provide side scatter on the scale of a typical brachytherapy applicator radius. The 6

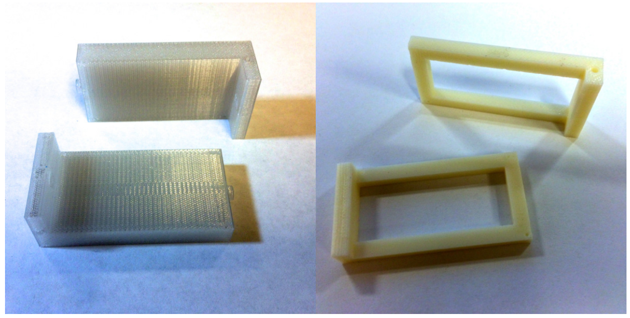

FIG. 2. A set of testing apparati were designed and 3D printed for this study to measure the depth-dose curve for ^{192}Ir. The apparati held a piece of radiochromic film and an endobronchial brachytherapy catheter. The left picture shows testing blocks printed in PC-ISO, and the picture on the right shows control blocks used to suspend a piece of radiochromic film in water. The blocks were scanned in a helical CT to compute the Hounsfield unit distribution.

cm side of the film was radial to the channel, and 3 cm side of the film was 2.5 mm away from the central axis of the channel.

A nearly identical control apparatus was designed to leave most of the surface area of the film exposed. This apparatus was used to perform a control experiment in water. This apparatus is also shown in Figure 2 (right).

The testing apparatus was printed in PC-ISO using a Fortus 400mc (Stratasys), and the control apparatus was printed in ABS plastic using uPrint Plus (3D Systems, San Francisco, CA). The stereolithography (STL) files for the testing and control blocks are available from the authors upon request.

B. Method evaluation

A helical CT was used to scan the testing apparatus and a cup of water. A visual assessment of each CT slice determined the presence of artifacts, and the distribution of Hounsfield units (HU) was computed within the apparatus and the water.

A size 6 French endobronchial brachytherapy catheter was placed in the testing apparatus. The opposite channel was left empty. There was 3 cm of channel length inside the apparatus, which allowed for 13 dwell positions spaced 2.5 mm apart. Figure 3 shows the experimental setup. A dose plan with a cylindrical dose distribution was computed in Oncentra (Nucletron, Sunnyvale, CA) assuming an ^{192}Ir source. This dose plan was normalized

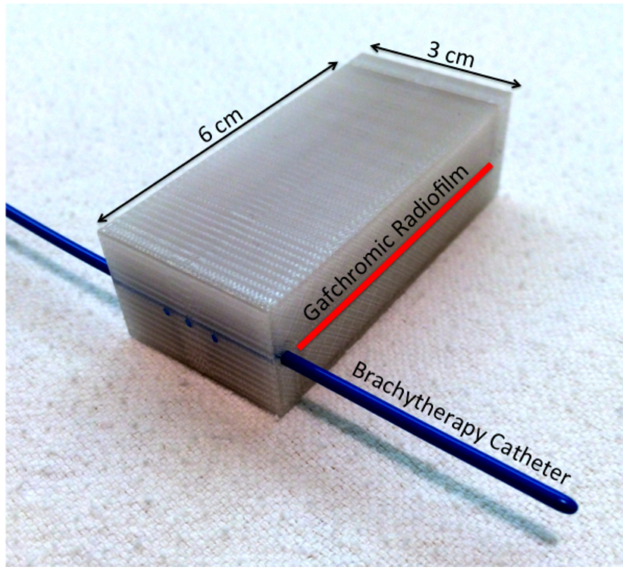

FIG. 3. A size 6 French endobronchial brachytherapy catheter was inserted into the block. The PC-ISO and control apparati were suspended in water before the dose was delivered.

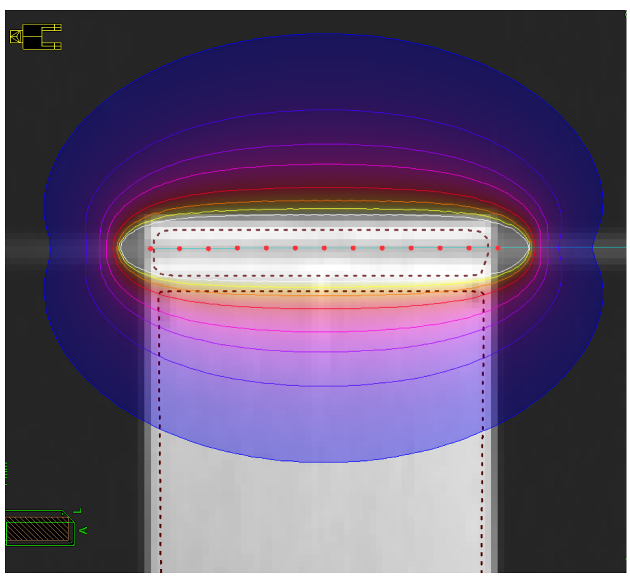

FIG. 4. A dose plan was computed in Oncentra to deliver 1500 cGy at 1 cm from the center of the catheter channel. The dwell positions and radial dose distribution for the radiochromic film study are shown above as seen on the planning system. The films were developed for 24 hours after exposure before they were scanned to find the dose-depth curve.

to 1500 cGy at 1 cm from the channel. Figure 4 shows this dose distribution.

A 3 cm $\times$ 6 cm radiochromic film segment was placed between the blocks and snapped

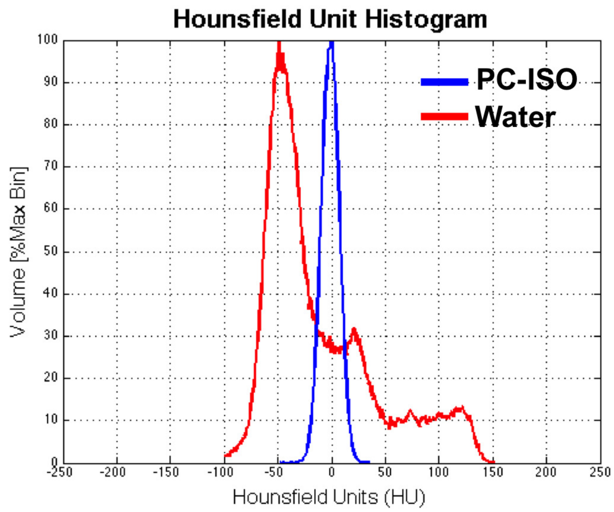

FIG. 5. Shown above is the distribution of Hounsfield units (HU) inside the PC-ISO apparatus. The mean was -1 HU for water and -10 HU for PC-ISO. This mean HU value is closer to water than air (≈ -1000 HU) or bone (≈ 1000 HU).

together. The entire apparatus was submerged in water, and the dose plan was delivered to the film using a microSelectron V2 digital afterloader. The same test was repeated on the control apparatus directly afterwards. The films were allowed to develop for 24 hours after exposure. Then they were processed to find the dose-depth curve.

The blocks were sterilized fives times using the STERRAD procedure to ensure that the sterilization process did not have adverse effects on the material.

IV. RESULTS

There were no visible CT artifacts inside the testing apparatus. The distribution of the Hounsfield units (HU) inside the apparatus is shown in Figure 5. The mean Hounsfield unit was -1 HU for water and -10 HU for PC-ISO. This mean HU value is closer to water than air (≈ -1000 HU) or bone (≈ 1000 HU).

The percent dose depth for the testing apparatus (PC-ISO) and the control apparatus (water) is shown in Figure 6. The two curves are within 1% of each other between 1 cm and 6 cm from the channel. Doses closer than 1 cm were excluded because that region of the film was over-saturated.

The testing apparatus was sterilized five times without any visible damage.

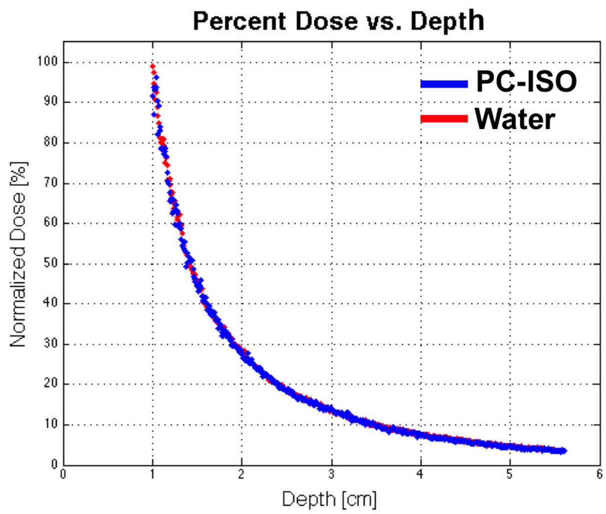

FIG. 6. The percent dose depth from the radiochromic film test for the testing apparatus (PC-ISO) and the control apparatus (water). The two curves were within 1% of each other between 1 cm and 6 cm, showing that the TG-43 planning system, which assumes a water medium, can be used as normal.

V. DISCUSSION

To be compatible with current dose planning systems, PC-ISO should be radiologically equivalent to water within the energy range of interest, which for ^{192}Ir is approximately 10^2 keV with an average gamma emission energy of 380 keV. The results showed a 1% difference in dose attenuation over the range of interest, which for brachytherapy is not a significant source of error compared to other sources of error such as catheter movement and contouring uncertainty. The dose attenuation results are corroborated by the HU distribution, which did not show any very-high density regions in the printed medium that could effect the dose attenuation in an unexpected way. The spread seen for PC-ISO (Figure 5) is due to the honeycomb internal structure characteristic of 3D printing, which creates small regular-patterned regions of higher (material) and lower (air) density. Based on this evaluation of PC-ISO's radiation properties, it is suitable for clinical use.

Since the conclusion of these tests, we have printed several GYN applicators in PC-ISO. We printed a simple, 2.75 cm diameter, segmented cylinder, which is between two standard sizes from our regular vendor. We printed a 3.5 cm diameter Vienna applicator, which is larger than the maximum diameter Vienna applicator in our clinic. We also printed a 2.7

cm diameter Miami applicator. These applicators were built for a specific patient from measurements taken during examination.

It is worth noting that PC-ISO applicators are virtually tissue-equivalent under CT scan – more tissue-equivalent than commercial applicators at our clinic. This level of tissue equivalence can make it difficult to find the boundary of the applicator during segmentation, especially at the tip of the applicator where the surface is curved. To address this issue, it may be possible to cover the applicators in a radio-opaque dye and condom before insertion.

VI. CONCLUSION

PC-ISO was evaluated for use in a brachytherapy environment. It was shown that PC-ISO has sufficiently equivalent dose attenuation properties to water at ^{192}Ir energies to be compatible with the brachytherapy planning system and workflow. It also does not produce CT artifacts. Given these results, we printed several customized cylinders and used these cylinders on patients when it would improve their treatment.

VII. ACKNOWLEDGEMENTS

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