CHARACTERIZATION OF 3D PRINTING MATERIALS FOR USE IN RADIATION THERAPY

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Abstract

Purpose: To characterize the radiation response of 3D printed materials for photon, electron, proton, and CT in absolute terms and as compared to a *Plastic Water®* baseline for extrapolation to clinical use.

Methods: Six materials were 3D printed into blocks using a Fused Deposition Modelling printer. Measurements were made using electron beam to create PDD curves, using photon beam to create TMR curves, and using proton beam to determine the RSP of the materials. The materials were also scanned using CT to examine the variations in HU value within each block and between blocks. The effective density of each printed block was determined to examine the variations in the printing. The densities of the block were used to analyze the results of the CT, electron, photon, and proton results.

Results: The effective density of each material varied widely between blocks and within each block. All results for each radiation type were dependent on the effective density of the 3D printed material, with an approximately linear relationship with the average HU value of the material, the R50 of the PDD curves for electron, and the RSP of the block using proton beam. Materials with densities lower than Plastic Water exhibited a negative percent difference trend compared with *Plastic Water®*, and materials with densities higher exhibited a positive trend.

Conclusion: Although 3D printing has much promise for use in radiation oncology, establishing a solid quality assurance protocol prior to its implementation is key to an accurate and successful clinical application. It is recommended that each 3D printed object be properly characterized before clinical use, including determining the effective density. Through the implementation of these measures, 3D printing in the clinical setting has the potential to further improve patient care within radiation oncology departments.

Introduction

The goal of our investigation is to characterize materials by determining their response to clinical electron, photon, and proton treatment beams and CT imaging. Each material will undergo a CT scan prior to being 3D printed into standard blocks; a subsequent CT of each block will permit pre- and post-printed comparisons. The materials will be characterized for electron beams via percent depth dose (PDD) curve; for photon beams, the materials will be characterized by a tissue-maximum ratio (TMR) comparison relative to commercially available *Plastic Water®* [29]; and for proton beams, the materials will be characterized by determining their water equivalent relative-stopping-power. For each respective modality, the geometry and setup conditions of the water measurements and material measurements will be unchanged. In this way, the materials' response relative to water will be substantiated, as results can be extrapolated to other setup conditions for the given treatment beam. Through these measurements, the response of these materials will be characterized for future clinical use, increasing the efficiency of clinical implementation, and may increase modeling accuracy within treatment planning systems

Methodology

Four 10x20x1 cm^3 blocks of each material were printed at 100% infill using fused deposition modelling printing technique (Table 1). Each block was scanned using CT and the effective density was determined.

Table 1: Printing parameters and purchasing information for each material

Material	Abbrev.	Printer	Nozzle Temp Used (°C)	Bed Temp Used (°C)	Print Speed (mm/s)	Price ($)/kg	Bed Adhesion Used	Manufacturer
Acrylonitrile Butadiene Styrene	ABS	Artillery	245	110	50	18.99	Hairspray	Hatchbox
Algae based PLA	Algae PLA	Artillery	205	45	100	34.99	None	3DPrintLife
Composite Iron PLA	Iron PLA	Artillery	245	70	100	80	None	Proto-Pasta
Polylactic Acid	PLA	Fusematic	225	70	100	18.99	None	Hatchbox
Armadillo Thermoplastic Polyurethane	TPU	Artillery	220	45	30	62	Hairspray	NinjaTek
Wood particles in PLA	Wood PLA	Artillery	240	70	100	34.99	None	Hatchbox

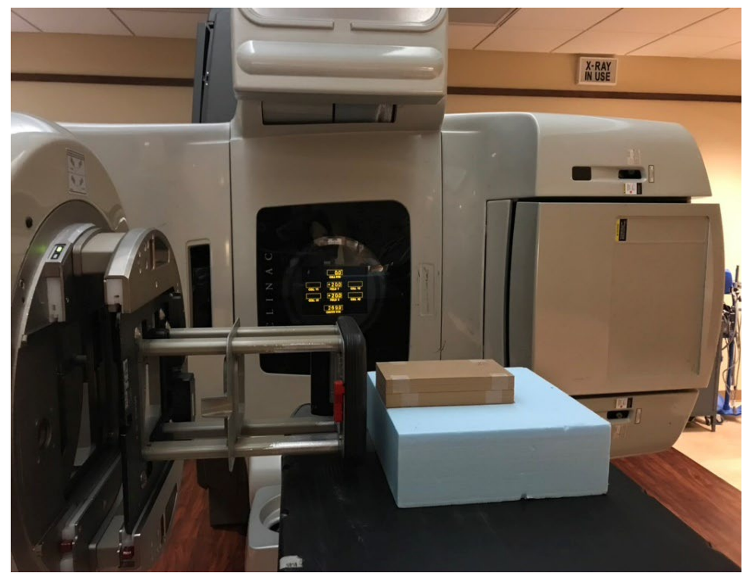

Figure 1: Electron measurements: gantry 270°, collimator 0°, SSD 100 cm, 10x10 cm^2 field size using film

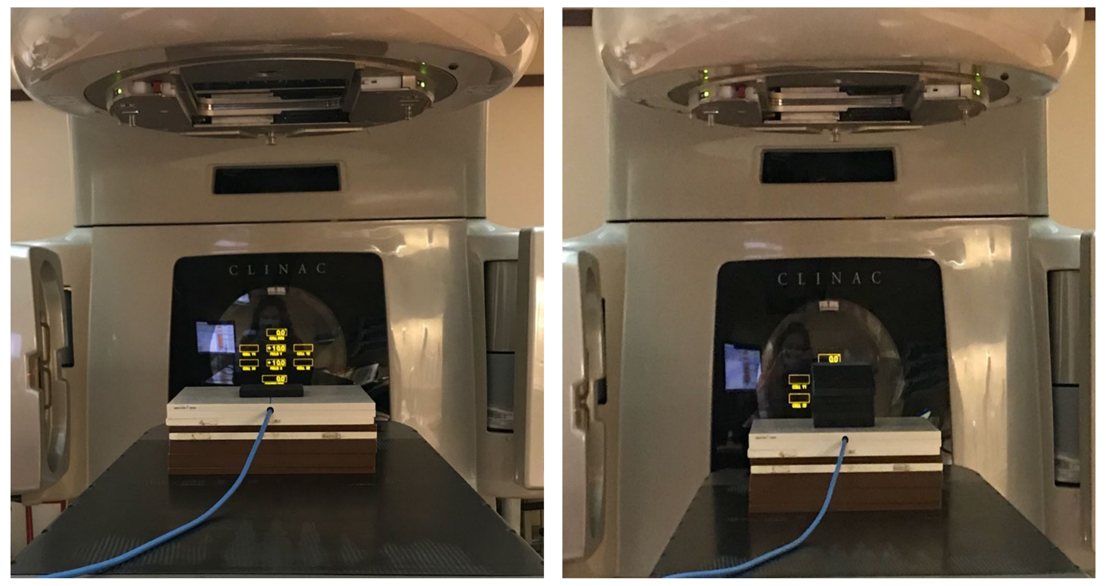

Figure 2: Photon measurements: gantry 0°, collimator 0°, SAD 100 cm, 10x10 cm^2 field size, 1 cm bock added after each measurement

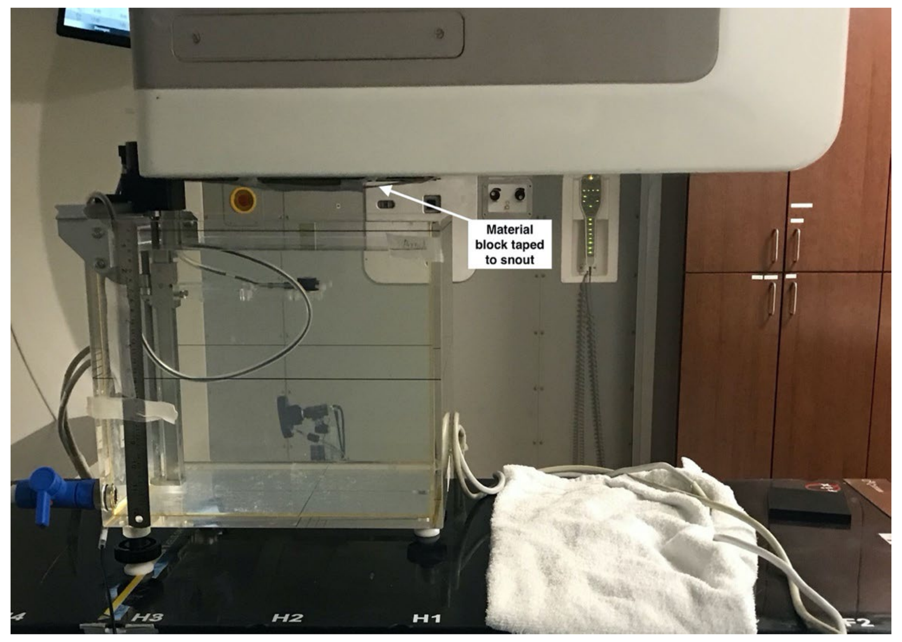

Figure 3: Proton measurements: gantry 0°, 8x8 cm^2 field size, 33x33 spots, 2.5 mm spot spacing, and 1 MU/spot

Results

The HU values between the blocks, and occasionally within a given block, span an extended range. The majority of blocks are poorly defined by a single HU value, and no material demonstrated a controlled range of HU values (Figure 4). As shown in Figure 5, PLA average HU value represents close to 100% infill whereas ABS HU value was not representative of the infill it was which it was printed.

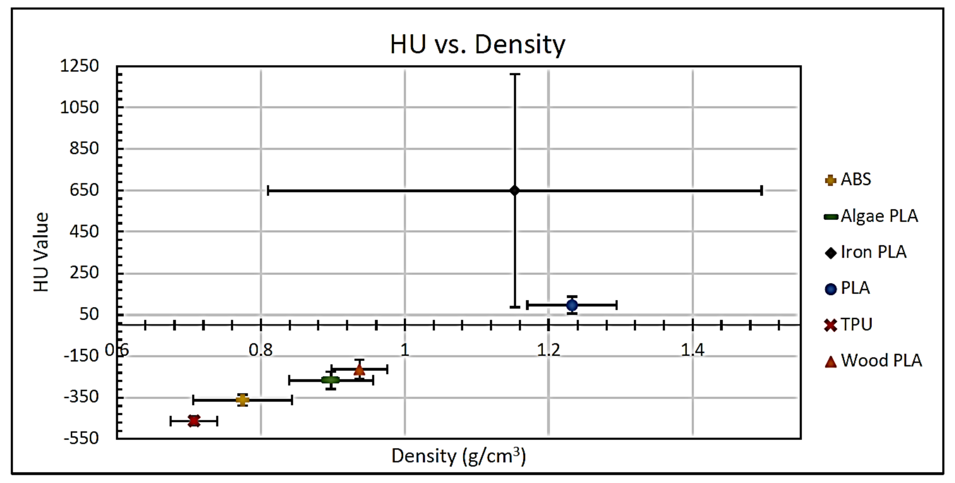

Figure 4: Density vs HU for each material

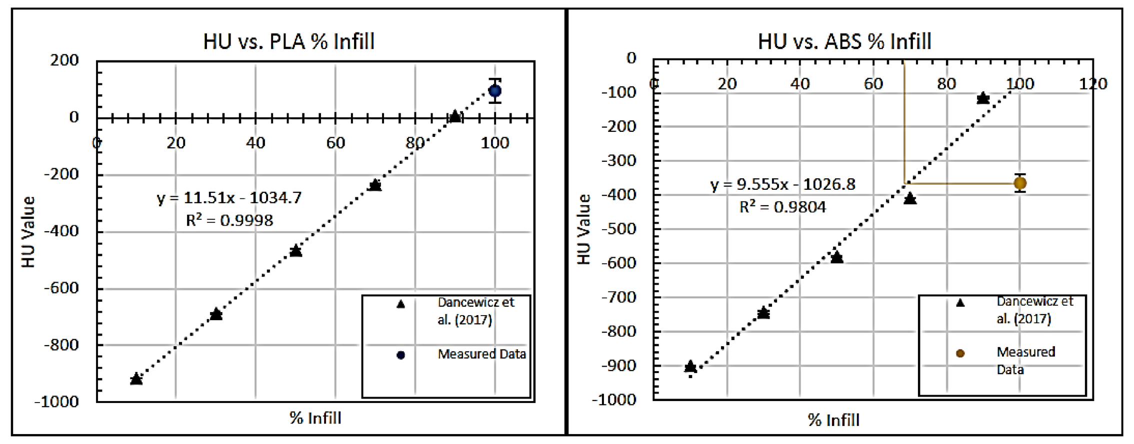

Figure 5: Percent infill of (A) PLA and (B) ABS compared to published data

The relationship between R_{50} and density exhibits a negative linear trend, in which the R_{50} decreases with increasing density for all energies (Figure 6). This relationship is to be expected because higher density materials attenuate more particles at shallower depths, causing the dose fall off to occur earlier, giving smaller R_{50} values. The results of RSP versus show a positive linear trend between materials (Figure 7). Within a given material, the RSP proves to have no energy dependence.

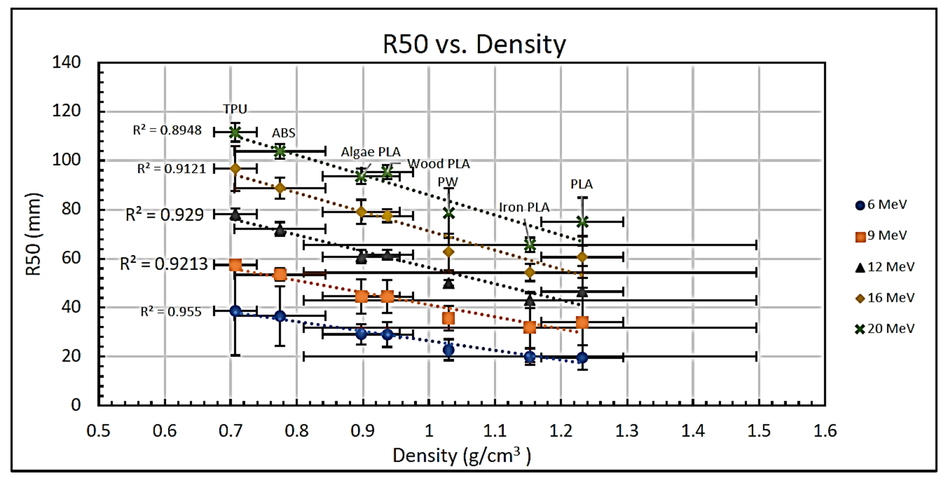

Figure 6: Comparison of the electron PDD R_{50} values and the material densities

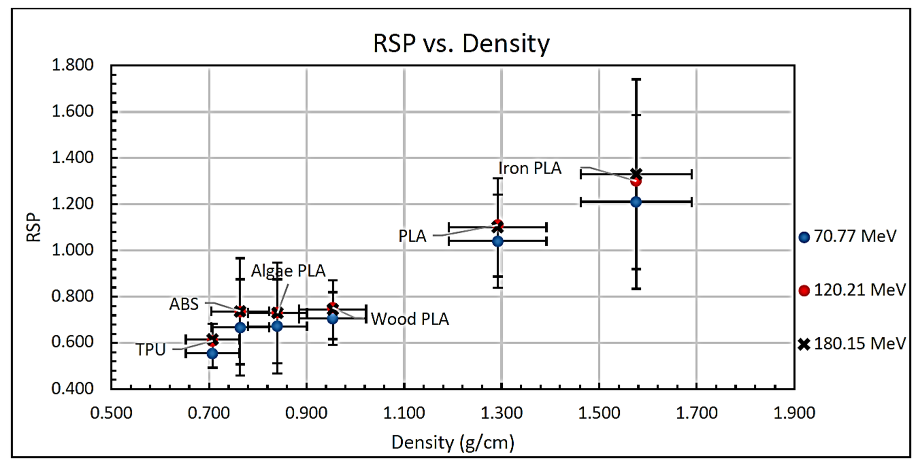

Figure 7: Comparison of proton RSP values and the material densities

Conclusion

The uses of 3D printing are rapidly expanding to include applications in radiation oncology. As 3D printing becomes more commonplace in the realm of radiation treatment, the printed materials being used should be characterized to adequately implement 3D printing successfully in the clinic. The goal of this project was to 3D print clinically relevant materials in order to characterize them using various methods. The materials were printed in blocks such that the geometric setup matched that of available plastic water equivalent blocks. This was to provide relevant results when compared with established water standard. From the measurements made, the average HU value of each material was determined, electron PDD curves were generated, photon TMR curves were compared with those of water, proton RSP values were calculated, and the density was determined for each material. The measured HU values for each material varied widely, making it unreliable for each material to be defined by a single, averaged value. The electron PDD results provided depth dose curves characteristic of the material. Iron PLA exhibited a large horn in the PDDs for all energies and the other materials all exhibited a dip in the dose to some extend at a very shallow depth. The TMR and percent difference plots aided in illustrating how the materials compared with the PW values. Wood PLA and PLA proved to have the most similar values compared with the PW values. This data also demonstrated how the PW values were equivalent to the commissioning TMR values within the given uncertainty. RSP values aid in implementing material characteristics into treatment plans to provide correct dose distributions. The RSP values were shown to have no energy dependence within the given uncertainty, and so these values can be used for treatment plans of all proton energies. The PDD, TMR, and RSP results, as well as the average HU values, provide a clinical reference for dose distribution compared with water for implementation in clinical settings. Each of these results were affected by the density of the materials. The density of the material is the most influential characteristic and may vary substantially between prints of the same material. Directly determining the density and HU value of each 3D printed object to be used in a clinical setting should be performed after printing and before implementation into patient treatment. Although 3D printing has much promise for use in radiation oncology, it is important to note that establishing a solid quality assurance protocol prior to its implementation is key to an accurate and successful clinical application. It is recommended that each 3D printed object be properly characterized before clinical use. Through the implementation of these measures, 3D printing in the clinical setting has the potential to further improve patient care within radiation oncology departments.

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