Radiation Physics and Chemistry 167 (2020) 108227

Contents lists available at ScienceDirect

Radiation Physics and Chemistry

journal homepage: www.elsevier.com/locate/radphyschem

Evaluation of 3D printing filaments for construction of a pediatric phantom for dosimetry in CBCT

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ARTICLE INFO

Keywords:
3D printing
Cone-beam computed tomography
Dosimetry

ABSTRACT

Cone-beam computed tomography (CBCT) has been widely used in orthodontics, due to the ability to provide visualization of mineralized tissues in high definition and consequently the identification and delimitation of three-dimensional irregularities. Compared with 2D imaging techniques, the doses used in CBCT exams are higher.

Considering that the pediatric and adolescent population routinely receives orthodontic treatments, it is important to note that the cellular development phase of the organs is associated with increased tissue sensitivity to radiation, and that cancer is one of the main long-term effects caused by exposure to X radiation.

In recent years, the 3D printing technique has been used in the medical industry because it allows the reproduction of structures of the human body, enabling detailed studies in several application areas. The objective of this work was to study the different types of filaments available for 3D printing of structures that will compose a phantom for dose evaluation in the pediatric and adolescent population who undergo CBCT exams.

1. Introduction

3D printing technology has proven to be important for medical industry due to the myriad possibilities that this technique offers. With scanners and printers that have brought more cutting-edge technology to the industry in general, the use of 3D printing could not fail to be an important tool for the medical field. The possibility of obtaining structures of the human body, whether for the manufacture of prosthesis made with synthetic materials or even for prototypes that will be used in a didactic way, have aroused society's interest in the use of this technology.

There are several types of printers on the market, which use several techniques for printing, the most used is Fused Deposition Modeling (FDM). FDM is a technique that uses a thermoplastic filament, which is heated to its melting point and then extruded, onto a platform to create the individual layers of a three dimensional model, created by specified software (Kapila et al., 2011).

The most commonly used thermoplastics for FDM printing are Acrylonitrile Butadiene Styrene (ABS) and Polylactic Acid (PLA). There are other materials for printing, such as PLA with wood fiber and PLA with metallic charge. In the scope of radiation dosimetry, 3D printing technology is an important tool in the construction of phantoms for use in quality control testing and radiation dose measurements delivered to patients undergoing diagnostic imaging using x-ray.

Cone-beam computed tomography (CBCT) has been widely used in orthodontics, due to the ability to provide visualization of mineralized tissues in high definition and consequently the identification and delimitation of three-dimensional irregularities. Compared with 2D imaging techniques, the doses used in CBCT exams are higher. Considering that the pediatric and adolescent population routinely receives orthodontic treatments, it is important to note that the cellular development phase of the organs is associated with increased tissue sensitivity to radiation, and that cancer is one of the main long-term effects caused by exposure to X radiation (Smith-Bindman et al., 2009; Brenner et al., 2001).

2. Materials and methods

The Pantak/Seifert X-ray system, model Isovolt HS, was used in the clinical diagnostic radiology (40 kV-160 kV) operating range located at the Instrument Calibration Laboratory of the Institute of Energy and Nuclear Research (LCI/IPEN). The applied current was 10 mA, for the series of implanted Radiation Qualities for CT applications (RQT), listed in Table 1, where RQT 9 is the reference quality.

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https://doi.org/10.1016/j.radphyschem.2019.03.031
Received 14 December 2018; Received in revised form 4 March 2019; Accepted 23 March 2019
Available online 27 March 2019
0969-806X/ Published by Elsevier Ltd.

Table 1
Characterization of radiation quality series RQT.

Radiation quality	X ray tube voltage (kV)	Added filtration (mm Cu)	Nominal first HVL (mm Al)
RQT 8	100	0.20	6.9
RQT 9	120	0.25	8.4
RQT 10	150	0.30	10.1

Table 2
Densities of the materials of the cylinders printed for tests.

Material	Density %
ABS	90
PLA	90
PLA + AL	10

Using the UP 3D plus 2 printer model and filaments composed of ABS and PLA were printed cylinders with 10 cm long, 5 cm external diameter and 10.5 mm internal diameter for accommodating the pencil-type ionization chamber. The technique used for printing was FDM. The cylinders were designed in free open Scad software. Different print parameters were selected so that the densities of the materials were changed. The densities of used materials are listed in Table 2.

For a technical reason, it was necessary to print the cylinder composed of PLA with metallic charge of aluminum, with 10% of density.

Cylinders with different designs were printed, as shown in Fig. 1. It was necessary to print cylinders with different designs in order to enable filling with water and checking the behavior of the material as a basis for phantoms.

Five samples were designed: PLA, PLA with water, ABS, ABS with water and PLA with metallic charge (Fig. 2). In addition to these samples, readings were made with cylinders of PMMA that is a tissue material equivalent to human body (International Commission, 2005) in order to obtain kerma rates and CT number. In Fig. 3, the assembled arrangement for carrying out the readings with the pencil-type ionization chamber in the LCI-IPEN standard beams is shown.

For evaluation in clinical beams, tests were performed with the samples in a computed tomography equipment (SOMATOM Spirit, SIEMENS®), to evaluate the equivalence of the materials to human tissues by CT number, as shown in Fig. 4.

3. Results

After the readings with the ionization chamber of the pencil type,

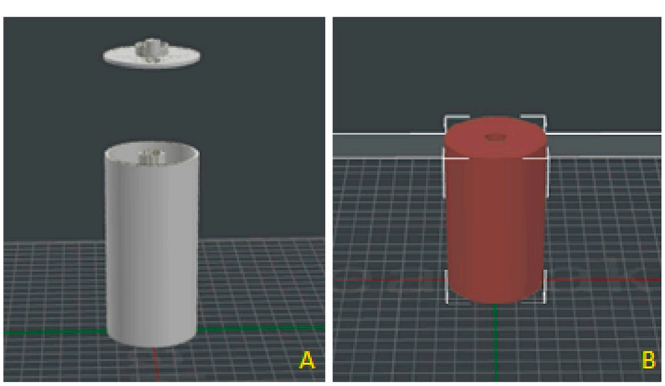

Fig. 1. A) Design of cylinder with structure to fill with water. B) Design of the cylinder with a structure completely filled with the material of the filament chosen.

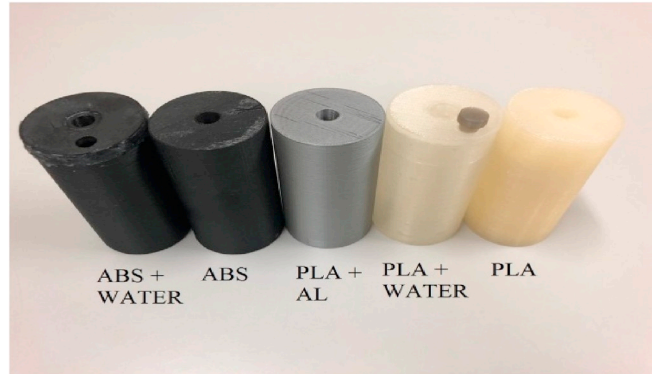

Fig. 2. Samples of the cylinders printed.

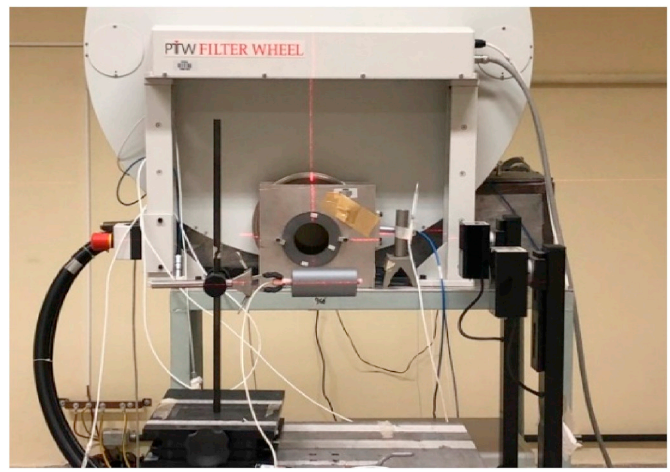

Fig. 3. Assembled arrangement for carrying out the readings with the pencil-type ionization chamber in the LCI-IPEN standard beams.

correction factors were applied, in order to obtain the Kerma rates values to evaluate the materials.

Table 3 shows the results obtained for each material in the RQT radiation qualities of the LCI-IPEN equipment.

Observing the values obtained for the kerma rates with the studied materials and, considering the comparison with the PMMA, main material used in phantoms for dosimetry in CBCT, it was perceived the materials that have higher approximation to kerma rates values with the values obtained for PMMA sample. The results for PLA and ABS, showed better equivalence to be used like a phantom's structure, when filled with water. In Fig. 5, the curves behavior obtained for the kerma rates for each material can be observed.

The results for CT number of each material can be seen in Table 4. The values were obtained through of a Region of Interest (ROI) of each image.

As observed in both methodologies, the PLA was the material that demonstrated better results considering the reference material (PMMA). These were alternative methodologies to evaluate the printed samples.

4. Conclusion

Preliminary tests using commercially available filaments for 3D printing showed good results, especially PLA, which indicated compatibility with soft tissue structures accordingly to the CT number. Specific studies are required for each desired application and the use of different methodologies for filament characterization. The use of the CT

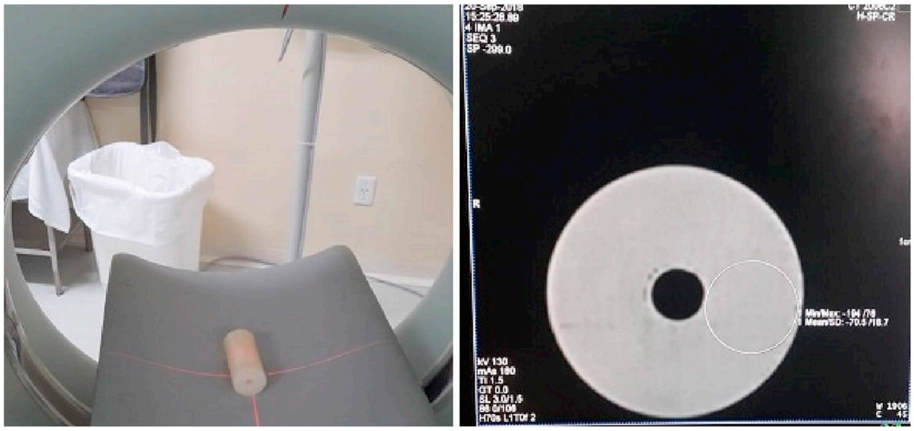

Fig. 4. Tests with the samples in a computed tomography equipment to obtain the equivalence of the materials to human tissues by CT number.

Table 3
Kerma rates obtained for different materials.

Material	Kerma Rates (mGy/min)		
	100 kV	120 kV	150 kV
PLA	21 ± 0.01	32 ± 0.01	50 ± 0.03
PLA + Al	21 ± 0.01	30 ± 0.01	55 ± 0.01
PLA + H2O	21 ± 0.01	33 ± 0.01	54 ± 0.02
ABS	21 ± 0.06	32 ± 0.01	50 ± 0.06
ABS + H2O	21 ± 0.01	41 ± 0.01	55 ± 0.01
PMMA	23 ± 0.01	35 ± 0.01	58 ± 0.01

Table 4
CT number minimum and CT number maximum obtained through image region of interest (ROI) for each material.

Material	CT number min	CT number max
PLA	98	269
PLA + Al	−1024	−161
PLA + H2O	−44	118
ABS	−68	30
ABS + H2O	−44	118
PMMA	100	218

number and kerma rates to evaluate the equivalence of the available filaments for 3D printing with reference material (PMMA) was an alternative way of separating materials with better dosimetric performance for more detailed studies. The use of different methodologies, such as the study of linear attenuation coefficients of materials, together with the methodologies used in this work, can be a way to obtain more information about the characteristics of the materials used for 3D printing.

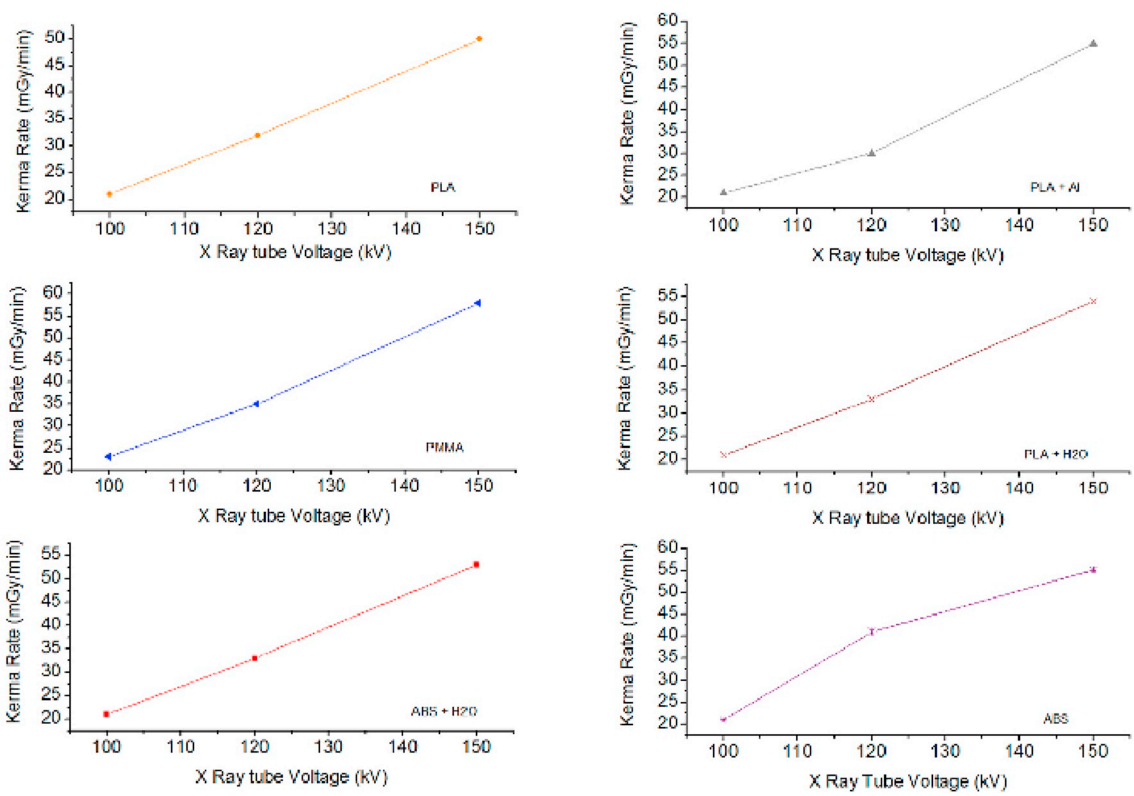

Fig. 5. Curves obtained for the Kerma rates for each material.

Acknowledgement

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

References

Brenner, D., Elliston, C., Hall, E., Berdon, W., 2001. Estimated risks of radiation-induced fatal cancer from pediatric CT. AJR Am. J. Roentgenol. 176, 289–296.

International commission on radiation units and measurements. J. ICRU 5 (2) Report 74 Oxford University Press, 1989.

Kapila, S., Conley, R.S., Harrel Jr., W.E., 2011. The current status of cone beam computed tomography in orthodontics. Dentomaxillofacial Radiol. 40, 24–34.

Smith-Bindman, R., Lipson, J., Marcus, R., Kim, K.P., Mahesh, M., Gould, R., et al., 2009. Radiation dose associated with common computed tomography examinations and the associated lifetime attributable risk of cancer. Arch. Intern. Med. 169, 2078–2086.