Attenuation coefficient determination of printed ABS and PLA samples in diagnostic radiology standard beams

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Attenuation coefficient determination of printed ABS and PLA samples in diagnostic radiology standard beams

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Abstract. IAEA code of practice TRS-457 states that standard phantoms should offer the same primary attenuation and scatter production as relevant body section of a representative patient. Material cost, availability and dimensional stability must also be considered. The goal of this study is to determine the attenuation coefficient of printed ABS and PLA samples in standard X-ray beams, verifying if phantoms printed with these materials could be an easier-handle substitute for PMMA, enabling the creation of different designs in an easier and cheaper way. Results show that PMMA presents higher attenuation coefficient, followed by PLA and ABS, which means that thinner PMMA layer creates higher radiation attenuation.

Keywords: Half-value layer, quality assurance, 3D printer, phantom, diagnostic radiology

1. Introduction

According to 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 offer the same primary attenuation and scatter production as the relevant body section(s) of a representative patient* [1], and the energy range should also be considered.

Other important characteristics to be considered when building a phantom is the material cost, availability and dimensional stability [1]. A good option in this case is the polymethylmethacrylate (PMMA), which shows all characteristics presented previously.

However, in the past years, 3D printers have been applied in medicine. When technology began to be used for dental implants and prostheses customization this technology has been rapidly expanding and revolutionizing the field of health, being used for several purposes such as organs, implants, anatomical models, customization of prosthetic, to design drugs formats, among other applications [2].

An important use is phantoms construction from magnetic resonance, tomography, and X-ray images converted into printer compatible files. Another application is the construction of anatomical models for use in surgical preparation such as craniofacial, pelvic, spine and brain surgery. This is possible through diagnostic images acquisition and structure reconstruction in software and 3D printing [3, 4].

Two materials are the cheapest and the most commonly used in this kind of 3D printer. ABS (Acrylonitrile Butadiene Styrene), which presents a density from 1060 kg/m³ to 1080 kg/m³ [5], and PLA (Polylactic Acid), which density varies from 1210 kg/m³ to 1430 kg/m³ [6].

The goal of this study is to determine the attenuation coefficient for both ABS and PLA in standard diagnostic radiology X-ray beams, verifying the 3D printed phantom use viability as an easier-handle substitute for PMMA, enabling the creation of different designs in an easier and cheaper way.

2. Materials and methodology

2.1. Materials

The plates used in this study were printed in an UP 3D printer, plus 2 model (figure 1).

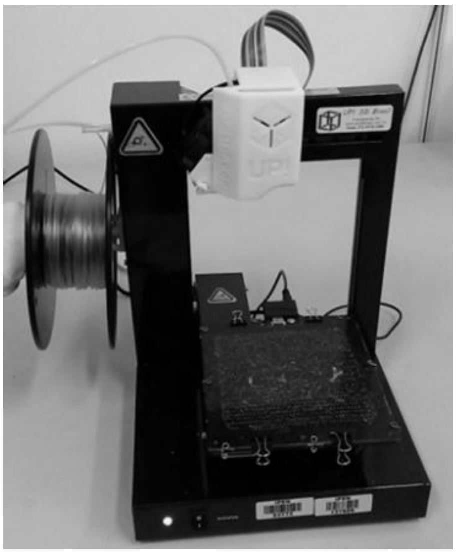

Figure 1. UP 3D printer, plus 2 model.

Different thicknesses of ABS and PLA plates (from 2.0 to 10.0 mm) were printed, and seven commercial PMMA plates of 4.7 mm each were also used (figure 2) for results comparison.

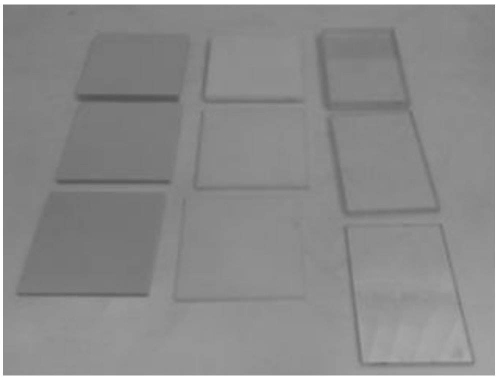

Figure 2. From left to right: PLA, ABS and PMMA plates.

Irradiation tests were performed using an industrial X-ray system Pantak/Seifert used for instruments calibration in different energy ranges [6-8]. The diagnostic radiology qualities main characteristics are presented in table 1.

Table 1. Diagnostic radiology qualities main characteristics

Radiation quality	Tube voltage (kV)	HVL (mmAl)
RQR-3	50	1.78
RQR-5	70	2.58
RQR-8	100	3.97
RQR-10	150	6.57

X-ray beam intensity was measured using a Radcal ionization chamber, RC6 model, connected to a Keithley electrometer, 6517A model.

2.2. Methodology

X-ray beam attenuation measurements were performed using a plate-holder (figure 3), designed using SolidWorks® software and printed specifically for this procedure. This holding device was placed in half distance from the X-ray anode and measurement surface.

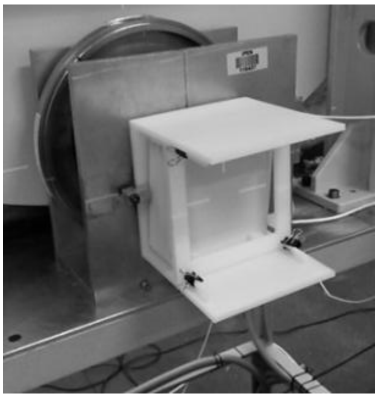

Figure 3. Printed plate-holder used in beam attenuation measurements for different sample plates.

The sample thickness was increased from zero (without filter) to a value high enough to reduce the beam intensity in more than 50 %.

The values obtained in this procedure were analyzed using Origin® software. For each quality an exponential fit was performed in order to obtain the attenuation coefficient (μ), according to equation 1:

$$I = I_0 e^{-\mu x} \tag{1}$$

where I_0 is the initial beam intensity, and I is the beam intensity when some material of thickness x is placed between radiation source and ionization chamber.

3. Results

Attenuation curves of ABS, PLA and PMMA for 50 kV, 70 kV, 100 kV and 150 kV for X-rays beams are shown, respectively, in figures 4, 5, 6 and 7.

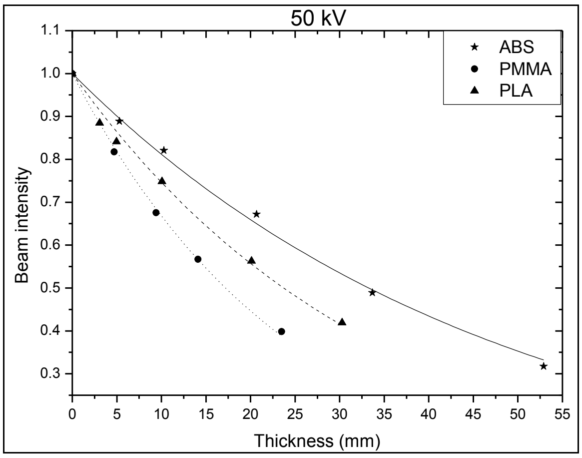

Figure 4. Attenuation curves for 50 kV X-ray beam.

The exponential fit provided attenuation coefficients of 0.020 mm^{-1}, 0.029 mm^{-1} and 0.040 mm^{-1} for ABS, PLA and PMMA, respectively.

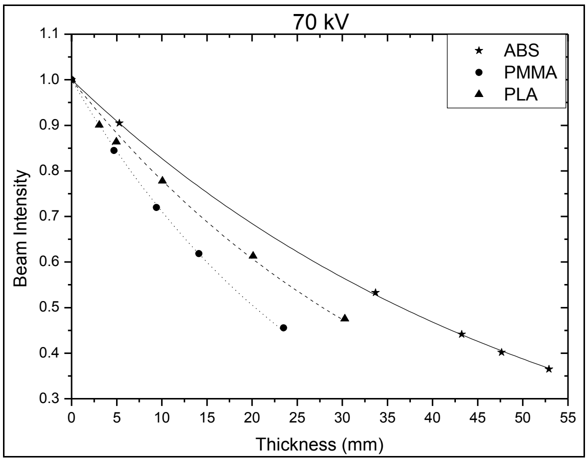

Figure 5. Attenuation curves for 70 kV X-ray beam.

The exponential fit provided attenuation coefficients of 0.018 mm^{-1}, 0.024 mm^{-1} and 0.030 mm^{-1} for ABS, PLA and PMMA, respectively.

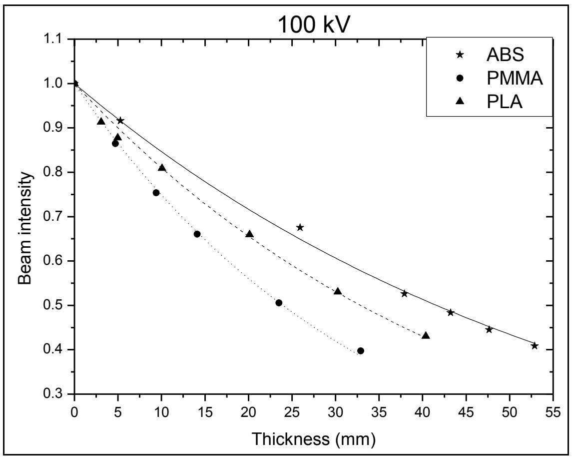

Figure 6. Attenuation curves for 100 kV X-ray beam.

The exponential fit provided attenuation coefficients of 0.016 mm^{-1}, 0.021 mm^{-1} and 0.028 mm^{-1} for ABS, PLA and PMMA, respectively.

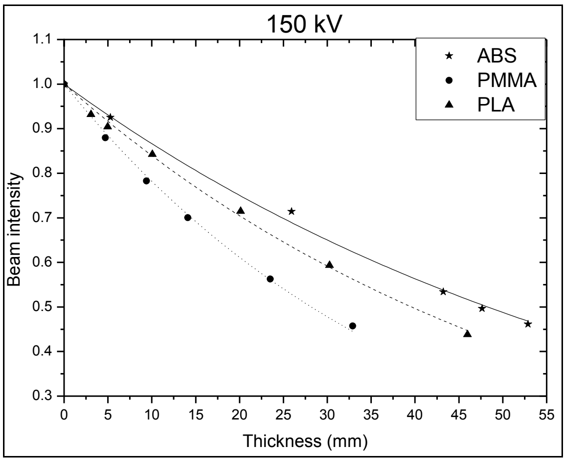

Figure 7. Attenuation curves for 150 kV X-ray beam.

The exponential fit provided attenuation coefficients of 0.014 mm^{-1}, 0.017 mm^{-1} and 0.024 mm^{-1} for ABS, PLA and PMMA, respectively.

The obtained results show a clear difference between materials attenuation coefficients. PMMA presented a higher attenuation coefficient, followed by PLA, from 20 % to 30 % lower, and ABS, from 40 % to 50 % lower, which means that a thinner layer of PMMA creates higher radiation attenuation.

In order to design and print a phantom a thickness correction, for different materials, must be made.

4. Conclusions

Easier access to 3D printers, followed by comparable attenuation coefficient values and ease of design make the use of printed phantoms applied to quality control in diagnostic radiology a reality.

New phantoms could be printed in different dimensions and at relatively low cost considering the large number of different shapes applicable.

Acknowledgments
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