Evaluation of the impacts caused by the "warp" effect on 3D printed phantoms for clinical application of photon beams

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Abstract. This work aims to evaluate the impact of the warp effect on printed phantoms with tissue equivalence to be used in radiotherapy. The "warp" effect is caused by several parameters that directly interfere in the printing process. The "warp" effect causes a warping or slanting of the outer edges of the parts being printed, this occurs when there is no adherence of the part to the printer platform. The tendency to distort a printed object to simulate a patient is great because the warp effect occurs due to the way the objects will be printed, especially if they are to be printed in successive layers. Despite the difficulties of printing the phantoms with tissue equivalence for clinical application with 100% filling, it is possible to use this technology to simulate a patient and obtain advantageously a phantom for clinical photon beam dosimetry.

1. Introduction

The modelling methodology of 3D printed phantoms has become something fundamental in radiotherapy departments, having an essential role in determining the dose applied to the patient, as it can be subjected to real treatment conditions, proving its effectiveness in determining various factors that may cause error in the prescribed dose.

Some published studies have demonstrated the advantages of 3D printed phantoms for use in radiotherapy and other areas of medicine [1,2,3]. Despite the great technological advance and the conceptual simplicity of phantoms applied in radiotherapy sectors, they have several considerable limitations. The biggest impact factor regarding the printing of the phantoms is to minimize the "warp" effect.

The "warp" effect is caused by several parameters that directly interfere in the printing process. The "warp" effect causes a warping or slanting of the outer edges of the parts being printed, this occurs when there is no adherence of the part to the printer platform. Several factors can cause this effect among them stand out:

- Printed material filled with 100% infill.
- Thickness of the wall that serves as lateral bases to support the print.
- Do not use (Raft or Brim) that serves as structures to support the piece to avoid "warp".

Deformation occurs when objects are printed in successive layers (Fig. 1). This effect happens with the adhesion of the first layer, that is, when the first layer does not stick to the surface of the printing platform. The result is to push the structure upward causing it to curve from the platform. If the deformation (warp) is not contained, it can cause the extruder to stop and cause the model to stop printing. But if the "warp" effect is minimal, it will only affect some lower layers. If the printed object has large dimensions (Relatively large objects at the base) and is totally solid, the prevalence of distortion is very high [4, 5].

a)

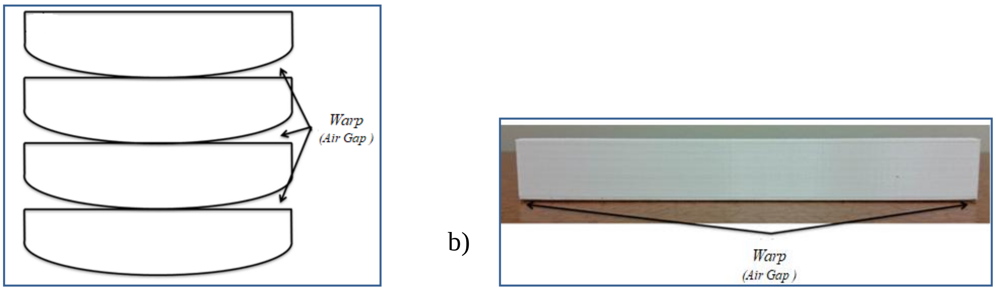


Figure 1. a) and b) Layered representation of a printed part demonstrating how warp can affect a 3D printed object[4].

3D prints are generally not made with a fill of 100% infill, because the parts will be completely solid inside without any spacing between them [6]. The higher the filling percentage (infill), the more resistant and heavier the object will become, in addition to requiring a long printing time and the use of a lot of material for the filling to be carried out. Another factor involved is the type of material used. PLA when used with a 100% filling has denser characteristics facilitating the “Warp” effect [4, 6].

Wall thickness is another parameter that must be considered, as thickness is one of the main factors related to print resistance, that is, increasing this number creates thicker walls, improving the resistance of the part, especially if it will be printed with 100% filling [4, 6]. This can be changed in the printing software so that the number of times the outside line will be drawn can be compatible with the printing percentage of the centre of the part, thus preventing the part from not sticking to the printer platform.

The base usage for platform adhesion is a parameter that directly affects the printing result. For adhesion to occur, two configurations can be used that allow the piece to stick to the printing platform:

- Raft: It is a type of horizontal filament grid located under its lower part acting as a platform that adheres to the table during printing (Fig. 2). The object will be printed over the raft and not directly on the print platform. Raft is a very useful configuration to print small parts on the base of a 3D model and its practice is often used mainly with the material used is ABS, due to the characteristics that ABS presents [6,7].

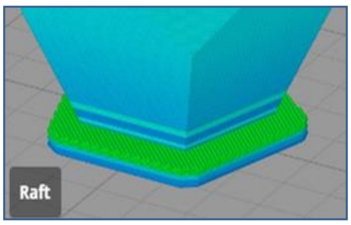


Figure 2. Model being printed with Raft in the lower region of the piece.

https://www.simplify3d.com/support/articles/rafts-skirts-and-brims/.

- Brim: It is a special type of flap that is fixed on the edges of the model that will be printed, usually the flap is printed with a greater number of contours around the base of the print whose assignment is to keep the edges of the print fixed on the base, leaving less brands (Fig. 3). It is a good option to keep the object attached to the printing platform [6, 7, 8].

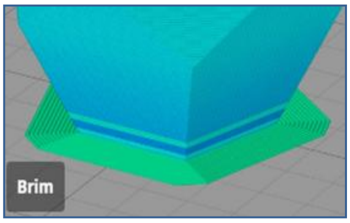


Figure 3. Model being printed with the Brim in the lower part of the piece.

https://www.simplify3d.com/support/articles/rafts-skirts-and-brims/.

This work aims to evaluate the impact of the warp effect on printed phantoms with tissue equivalence to be used in radiotherapy

2. Materials

The different print settings as the percentage fill of the parts can be exploited to achieve different attenuations of the materials. For this study was chosen the PLA, as it can be considered an excellent substitute for PMMA for application in different photon beams [11].

2.1 3D printing system

- 3D UP Printer RAISE 3D MODEL – PRO2.

Figure 4. 3D UP Printer RAISE 3D MODEL – PRO2[9].

2.2 3D Design and printing software

- Autodesk fusion 360 (License educational – USP).

- IdeaMAKER® 4.1.1;

2.3 Accessory Construction Materials for Attaching TLDs

- Filaments of Polylactic Acid (PLA) 3D Printer.

3. Methods

The support was developed with the purpose of coupling thermoluminescent dosimeters for irradiation in clinical photon beams, aiming at the possible effects caused by warp. The accessory was designed with dimensions of 61.5 mm height and 85 mm width, being printed in two parts, both printed with a 100% filling (infill), in the same way that the phantom was printed. The printed prototype was made in Autodesk Fusion 360 (Educational License – USP) (Fig. 5), where the dimensional characteristics of the support were determined. After that the ideaMAKER® 4.1.1 printing software was used, this software is used as a slicer, since it can demonstrate how the object will be printed and whether it will be printed in layers. The slicer (software ideaMAKER® 4.1.1) is a converter, that is, it has the objective of converting the drawing that will be printed to a code (Gcode) that the 3D printer can read. Figure 6 shows the printing schedule, starting with the Brim that serves to adhere the piece on the table, following the layers which are made to provide greater support to the object that will be printed. This layer parameter can be changed as needed for each piece that will be printed. Once the number of layers is finished, the infill filling process (%) starts with the schedule defined in the printing program. The print setting was set starting with five layers and 100% infill fill.

a) b)

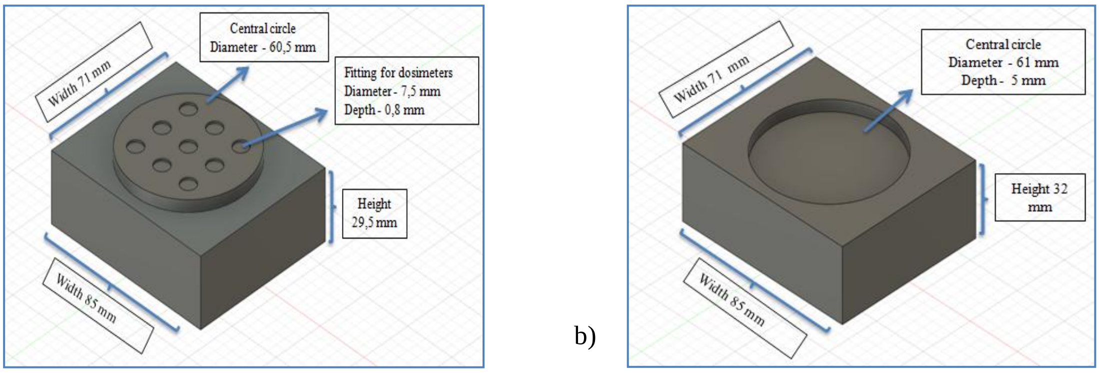


Figure 5. a) and b) Accessory printing prototype for coupling TL dosimeters.

a) b)

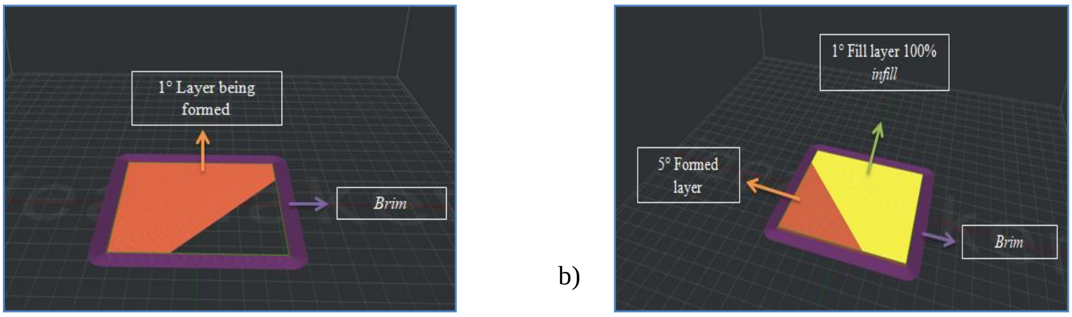


Figure 6. a) and b) Print programming, starting with the Brim that serves to adhere to the piece on the table.

So that the first printing layers are not directly affected, a distance setting between the extrusion nozzle and the printing platform is necessary. If the extrusion nozzle is too close to the table, the material may be prevented from exiting, causing the extrusion nozzle to be occluded. The inverse effect can also cause a problem, as if the extrusion nozzle is too far from the printing platform, the part can move causing a bending or loss of the part being printed [6,10]. Aiming at this possibility of occurrence, some distancing tests were carried out to verify which is the best distance is indicated in this impression. The printer manual indicates to use a distance between the extrusion nozzle and the print platform of 0.2 mm (Printer Manual). In this study, the distance chosen was 0.3mm.

Another parameter analysed was the heating of the extruder nozzle that the part would be printed on, as this is something that also influences the printing process. In this case, we must consider the type of material that will be used. To support the dosimeters, PLA was used throughout the printing. The Craft (2017)[4] indicates a heating of 225°C for the extruder nozzle if using PLA. Figure 7 presents an extrusion nozzle temperature test that was carried out with temperature going from 190ºC to 220ºC.

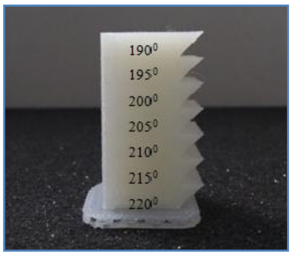


Figure 7. Printer Extruder Nozzle Temperature Test.

The chosen temperature was 205ºC, as the piece showed good adhesion without any complications capable of harming the printed piece.

With the printing parameters defined, a model support was printed to verify if the established standards would be sufficient for the final printing of the piece (Fig. 8 and 9). Printing parameters are described in table 1.

Table 1. Technical characteristics of printing parameters for PLA.

Material	Colour	Nominal Density (g. cm^{-3})	Extrusion temperature (^{0}C)	Print table temperature (^{0}C)	Print speed (mm.s^{-1})
PLA	Transparent	1.24	205	60	70

a) b)

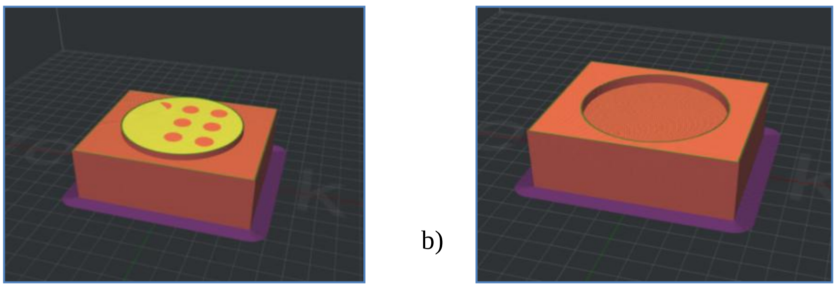
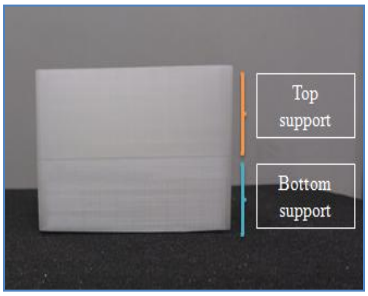


Figure 8. a) and b) Print prototype of a test piece.

a) 

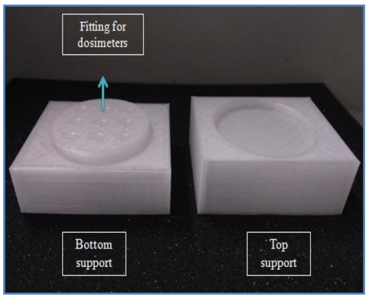
b) 

Figure 9. a) and b) Test piece printed with 15% infill.

With the printed model, it was possible to change small flaws, such as the height dimensions of the piece to better fit one piece to the other, such as the possibility of increasing the diameter of inserting the $CaSO_4$:Dy and LiF:Mg,Ti dosimeters. To use the µLiF, it was necessary to print a new support due to the dimensions of the µLiF, as it would be free to move inside the support without precision when taking any measurements. In the development of the lower support, only the insertion diameter of the µLiF was changed so that it can be symmetrical in such a way in the centre of the simulator that it is possible to carry out a comparative study of the performance of the three detectors.

4. Results

The tests carried out earlier have enabled a better understanding of the problems during the printing process. In figure 10 it is possible to see the first part being printed with a filling of 100% infill of the accessory to couple the dosimeters. In this first piece, the warp effect is noticeable at the beginning of printing. For this reason, the tests were essential to verify how the printing would be possible without affecting it to lose the part.

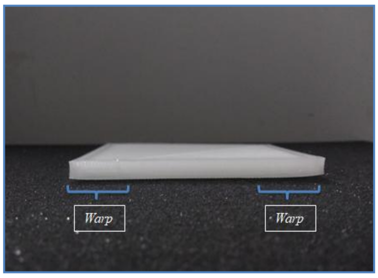


Figure 10. First attempt to print the accessory to couple the dosimeters, showing a warp on the sides of the piece.

The configuration was adapted so that the next print takes place in a continuous, uneventful manner. The figure below shows the printing of the lower accessory where the dosimeters will be coupled, being printed without problems related to the warp effect. For this, the denim with a greater number of turns was used to obtain the piece fixed on the printing platform.

Figure 11 demonstrates the finished accessory with a small finish on the lower outer part due to the removal of the denim. The format to which the accessory was printed and the reinforcements on the external walls allowed for a more homogeneous finish without the need for a finish along the entire length of the piece.

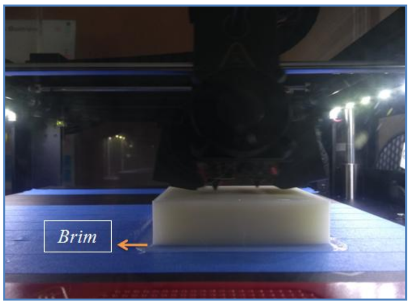


Figure 11. Object being printed using Brim.

Even using the settings to minimize the warp effect, one of the printed pieces had a high prevalence of warping on the front edges, among the problems reported above, the cooling process is also a factor that interferes with the deformity of the piece, as it does not happen uniformly along the different axes resulting in the warp effect, how is possible see in the figure below.

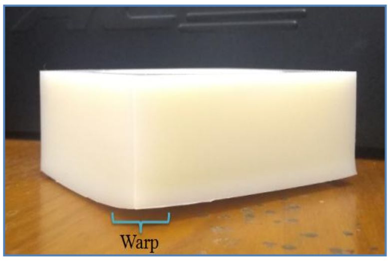


Figure 12. Printed piece with 100% filling, demonstrating the warp effect on the side.

Figure 13 demonstrates the finished accessory with no damage caused to the part when the denim from the side edges was removed. The format in which the accessory was printed and the reinforcements on the external walls allowed for a more homogeneous finish without the need to finish the entire length of the piece.

a)  b) 

Figure 13. a) and b) Finished piece presented an excellent finish without the warp effect.

As shown in Figure 13, the object printed with 100% infill fill was possible, but with reprinting required due to the warp effect in the first print attempts. Parts printed with a lower fill, such as the model shown in Figure 9, are less likely to have the warp effect due to the density of the PLA, because the larger the infill fill, the more likely the warp effect is to occur.

5. Conclusion

Despite the difficulties of printing the phantoms with tissue equivalence for clinical applications with 100% filling, it is possible to use this technology to simulate a patient and obtain advantageously a phantom for clinical photon beam dosimetry. However, to obtain a 3D printed object with greater precision and minimize the warp effect, it is necessary to study the characterization of the printer in relation to the type of phantom will be printed, as well as the choice of filling that will be used in the printing. Another factor that needs to be investigated is the way in which the object will be printed and how the adhesion to the printing platform will be made, where Raft or Brim can be used to minimize the warp effect.

Keywords: 3D printed phantoms, warp effect, phantoms tissue equivalent.

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