



Technical note

Development of a 3D printed quality control tool for evaluation of x-ray beam alignment and collimation

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ABSTRACT

The aim of this work was to develop a low-cost, 3D printed tool to evaluate X-ray beam alignment and collimation. The study was divided into two phases: 1) the development of 3D printed prototypes; and 2) a comparison with a commercial test object. A 3D printer was used to develop two objects that utilized 40% infill and were each printed with a different filament: PLA (polylactic acid) and ABS (acrylonitrile butadiene styrene). Two pieces of X-ray equipment were used for the beam collimation and beam alignment tests. For validation, a standard commercial tool was used, and the evaluation results of the prototypes were compared with those of the commercial tool. The tests performed with both the prototypes and the standard tool showed a deviation of ± 1 cm between the light field and the radiation field. The central ray's perpendicularity was evaluated through the coincidence between the rod and the metallic circle. The test of central ray alignment conducted with a standard tool revealed an axis perpendicularity of 1.5° , while both prototypes presented axis perpendicularities of less than 3° . The prototypes proved to be effective tools and were easy to handle. The variety of printing materials that can be used and the ease with which the filaments can be acquired contribute to a low cost of production.

1. Introduction

Incorrect determination of radiographic techniques, such as the delimitation of field size borders (collimation), affects radiation doses to organs as well as image quality. With the advent of computed radiography and direct digital radiography, overexposure is now common in the practice of radiographic examination [1]. Furthermore, collimation is very important in digital radiography because image receptors are highly sensitive at low levels of radiation. Therefore, every centimeter of incorrect collimation reflects an increase in radiation dose [2]. The radiation dose related to X-ray examination is relatively low, but its contribution to the collective radiation dose should be considered [3].

In order to provide the lowest possible radiation exposure to patients and to ensure that diagnostic images are of an acceptable quality, all efforts should be made with regard to quality assurance [4]. Performance tests on X-ray equipment should be conducted to ensure the proper operation of the equipment [5]. For this purpose, specific tools and methods are used [6,7].

Currently, the application of 3D printing in medicine has provided

many research opportunities related to radiology [8,9]. The extensive growth of 3D printing has led to the creation of 3D objects for transplants, pediatrics, and surgery [10,11]. In terms of quality control phantoms, 3D printed objects have been developed mainly for positron emission tomography (PET) and single photon emission tomography (SPECT) imaging [12,13]. However, there are still few studies [14] of 3D objects that have been developed for quality control in the context of X-ray equipment. Therefore, the aim of this work was to develop a low-cost 3D printed tool designed to evaluate X-ray beam alignment and collimation.

2. Materials and methods

The study was divided into two phases: 1) the development of the 3D printed prototypes; and 2) comparison of these prototypes with commercial test objects.

2.1. 3D printed prototype design

A 3D model was created using FreeCAD (version 0.16, <http://www>).

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Table 1
Printer parameters used for 3D manufacturing of test tool using PLA and ABS plastic.

Printer Parameters	ABS	PLA
Extrusion temperature	220 °C	190 °C
Bed temperature	90 °C	40 °C
Top layer	2	2
Infill	40%	40%
Layer height	0.3 mm	0.3 mm
Travel speed	100 mm/s	100 mm/s
Raft and Brim	Yes	No
Extruder nozzle diameter	0.40 mm	0.40 mm

freecadweb.org/). After this virtual 3D model was created, the object was saved in STL format. A 3D printer (GeeTech, i3, Shenzhen, China) was used to print two different versions of the object. PLA (polylactic acid) filament was used for one version, and ABS (acrylonitrile butadiene styrene) filament was used for the other. The selected 3D printer parameters are shown in Table 1.

The model is 14 cm × 14 cm in width and length, and it has a height of 0.6 cm. There is a cavity (1.03 cm in diameter) at the center of the model, where the beam alignment tool can be fitted. The cavity also has a metallic ring around its wall. The beam alignment tool model is 5 cm in height and 0.6 cm in diameter. There is a metallic rod inside the alignment tool that indicates the deviation in perpendicularity of the beam. Four groups of four metallic rods were inserted along the four edges of the collimation. These rods, which are placed along a scale of 4 cm with 2 cm outside the board and 2 cm inside the board, allow the deviation of the collimation to be evaluated (Fig. 1). The design is accurate to within 0.40 mm, a diameter that corresponds to the printer's nozzle size. The metallic rods were made from paperclip wire and were inserted at intervals that were marked out in the design of the object in order to ensure that the rods were placed in the correct position. The rod diameter was 0.6 mm, while the depth was 6 mm. The distance between the rods was double checked against that of the standard tool to ensure that it was correct.

Two pieces of X-ray equipment (Siemens, model Multix B, Medical Solutions Erlangen, Germany) were used for the beam collimation and beam alignment tests. The images were scanned using a computed radiography system by means of a 24 cm × 30 cm cassette. Technical parameters for a hand radiography (60 kVp and 4 mAs) were applied. The tests were performed according to International Commission on Radiological Protection recommendations [6]. The beam alignment and collimator test tools were placed on an examination table along with the radiographic cassette (Fig. 2).

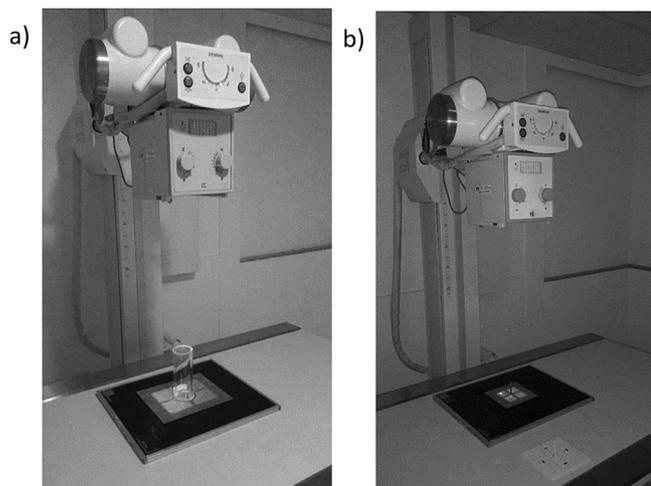


Fig. 1. Setup of study with a) standard tool and b) prototypes.

The collimator test tool consisted of a flat plate with a rectangular outline on its surface. The same method was applied to both the prototype tools presented in this study and the standard tools. The collimation light was aligned with the collimation test tool's edges. To delimit the collimation field, metallic rods were inserted horizontally into the prototype's borders, which have dimensions of 10 cm × 10 cm.

The source detector distance was set at 1 m from the table. The central ray (CR) was placed at 0° and was perpendicular to the table.

2.2. Comparison with the commercial testing tool

The collimator/beam alignment test tool used as the standard tool for comparison was the Nuclear Associates model 07-661-7662 (Fluke Biomedical Radiation Management Services, Cleveland, OH, USA). This tool consists of a plastic cylinder that measures 6 in. in height and has a 1/16 in. diameter steel ball at the top and bottom.

3. Results

For both versions of the prototype, the pre-printing time (printer nozzle and bed heating time) was less than five minutes. In total, the printing time of the models was 250 min for the PLA version and 300 min for the ABS version.

Table 2 shows the findings from the radiographic tests conducted using the prototypes and the standard tool to evaluate the collimated field and CR alignment.

In this study, the prototype allowed the coincidence between the collimation field and the radiation field to be measured by means of the distance markers inserted on the plate. Therefore, if the radiation field fell at the first mark, it meant the light field and radiation field had ± 1 cm of deviation.

The prototypes allowed beam misalignment to be evaluated through the overlap between the rod and the metallic circle.

Fig. 3 shows a sample of six images from the prototype and the standard tools that were used to assess the deviation of collimation and CR alignment.

4. Discussion

The considerable growth of 3D printing has stimulated the creation of a variety of 3D objects [11]. However, there remains a lack of 3D objects developed for quality control in relation to X-ray equipment. Recently, Shin et al. [15] evaluated the properties of 3D printed materials in computed tomography equipment, using PLA and ABS. The authors concluded that PLA and ABS reached the range on the Hounsfield scale for displaying calcified structures (151 to 345 HU) and fat attenuation (−85 to 10 HU) respectively.

These two plastic materials are easily available and can be used in most 3D printers for personal use [16]. Warping may occur during the manufacturing process, but it mostly occurs in 3D objects with large faces that are positioned next to the print bed. One way to avoid object deformation is to use a raft and a brim for additional support. In this case, the 3D printer creates a horizontal mesh of filament deposited directly on the bed platform. This support is a simple way to keep the printed item grounded to the bed. Because ABS contracts, use of a raft and a brim in order to reduce warping and lost details is highly recommended. In this study, a raft and a brim were used with ABS, but this practice is not necessary for PLA. For this reason, the ABS printing took more time. Moreover, PLA requires less filament, which makes it more suitable for production of the test tool. As this prototype is considered to be an innovation, any comparisons with other studies are limited. However, according to the medical diagnostic task to be performed, collimation of the primary beam has been strongly recommended as an effective method of reducing the dose of radiation to which the patient is exposed and improving the quality of the image produced [17].

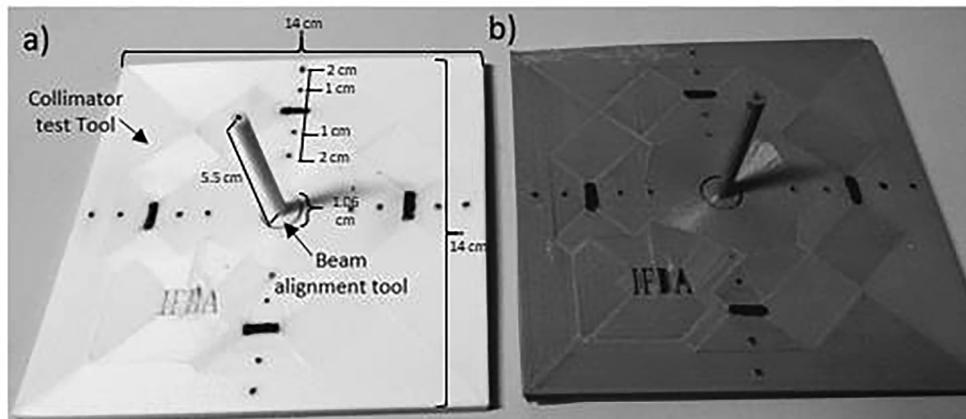


Fig. 2. 3D printed prototype designs a) ABS and b) PLA.

Table 2
Comparison between the tests performed with the prototypes and the standard tool in both pieces of X-ray equipment (XR1-XR2).

Test tool	X Ray Equipment			
	XR1		XR2	
	Deviation of Collimation	CR alignment	Deviation of Collimation	CR alignment
Standard	1.0 cm	< 1.5°	1.0 cm	< 1.5°
PLA	1.0 cm	< 3°	1.0 cm	< 3°
ABS	1.0 cm	< 3°	1.0 cm	< 3°

To evaluate light field/X-ray field alignment, the prototype has a scale limited to 2 cm from the selected collimation edge. The AAPM (American Association of Physicists in Medicine) [18] recommends the X-ray field and light field borders agree to within $\pm 2\%$ of the source

image receptor distance. Therefore, the source detector distance should always be 1 m for the prototype. In terms of comparison between the standard and prototype tools, the same value (1.0 cm) of beam/collimation coincidence deviation was found in both pieces of X-ray equipment for the three tools (see Table 1). However, with regard to the perpendicularity of the beam, there were differences in the value of the measurements. For both prototypes, if the rod was projected to the inside of the circle, it meant that the beam had a misalignment of less than 3° relative to the perpendicularity of the image detector. By contrast, if there were two circles and if the images of the two steel balls overlapped, the beam was perpendicular within 0.5° relative to the standard tool. If the image of the sphere intersected with the first circle, the angulation was 1.5° (see Fig. 3). In this study, the test of CR alignment performed with a standard tool revealed an axis perpendicularity of 1.5°, while for both prototypes it was less than 3°. This difference is related to the lack of markers for 1.5° in the prototypes. The limitation of the prototypes is related to guidelines that suggest 1.5 degrees of axis perpendicularity tolerance (e.g. Radiation Protection No

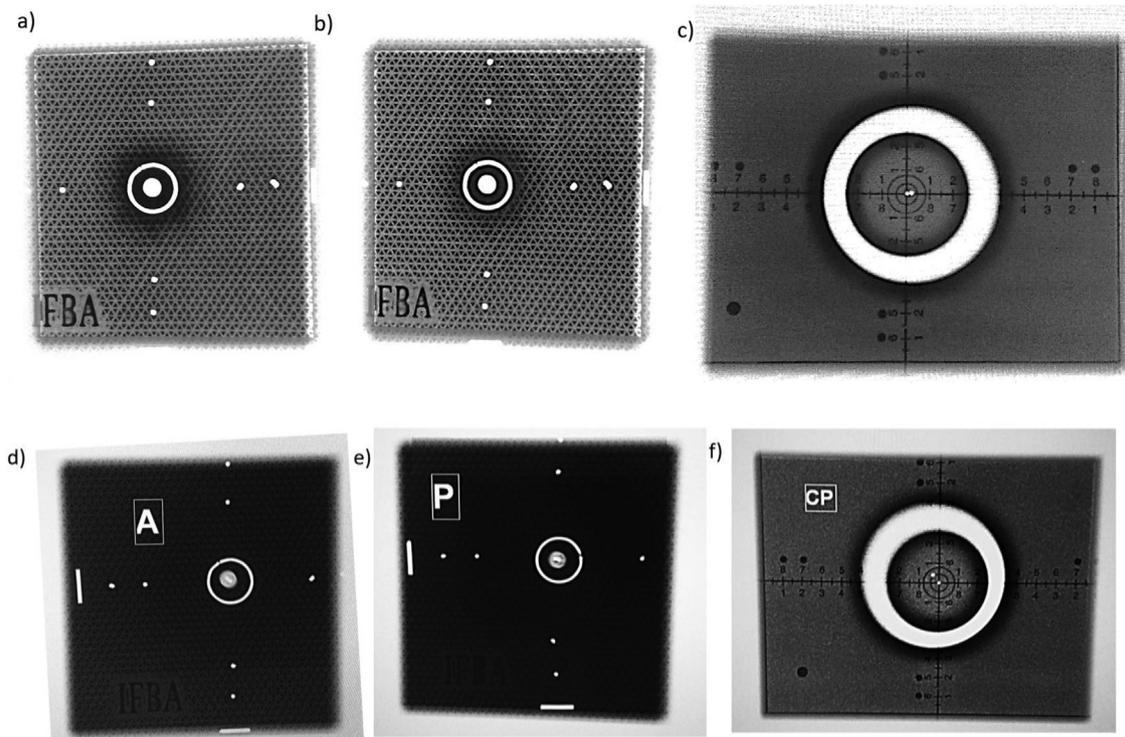


Fig. 3. Images from two pieces of X-ray equipment: a) and d) ABS; b) and e) PLA; c) and f) standard tool.

91 [19]). However, the prototype was designed according to Spanish quality control protocols [20] and Brazilian national directives [21], which both suggest a misalignment tolerance of 3°. Nevertheless, the prototype could be useful for the evaluation of beam alignment measurement tests. The performance of this test is important because incorrect beam alignment may lead to inaccurate depictions of anatomical structures due to geometric distortion.

An updated version of the prototype might be developed to improve the current design. Improvements could take the following forms: 1) the insertion of a ruler with large range of distances; 2) the addition of 1.5° mark for evaluation of the beam's perpendicularity.

A great advantage of the prototypes was the materials chosen for their manufacture. The plastic materials used have a low cost; it is also easily found on the Internet and is compatible with several 3D printers. Therefore, the prototypes can be considered to be an accessible tool.

Although the PLA and ABS prototypes developed in this study and the standard tool were made from different materials, the results were similar. Therefore, the two prototypes may provide a feasible alternative tool for testing collimation and CR alignment if the high cost of tools places limitations on performing quality control tests. The prototypes demonstrate the effective use of a 3D printed tool for quality control of X-ray imaging. They were cost effective (given that the 3D printer can be found for a few hundred dollars) and quick to produce. And it is easy to share their digital designs between different locations via online repositories. In addition, the two plastic materials were suitable for the performance of quality control tests and showed no mechanical constraints; these considerations indicate a more accessible tool.

5. Conclusions

The prototypes proved to be an effective tool and were easy to handle. The variety of printing materials that can be used and the ease with which the filaments can be acquired contribute to a low cost of production. Therefore, the use of these tools would allow more X-ray equipment to be evaluated in order to improve the quality of images at the lowest reasonable dose. The vast increase in the availability of 3D printing also allows greater accessibility to quality control tools for radiographic images.

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