Journal of Engineering and Applied Sciences 12 (12): 3137-3141, 2017
ISSN: 1816-949X

Evaluation of Usefulness for Quality Control Phantom of Computed Tomography Produced by Using Fused Deposition Modeling 3D Printing Technology

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Abstract: The purpose of this study was to evaluate of usefulness for developed Computed Tomography (CT) phantom using Fused Deposition Modeling (FDM) 3-Dimensional (3D) printing technology with the same quality performance as American Association of Physicists in Medicine (AAPM) CT performance phantom. The phantom by using modeler program was the 180 mm in diameter, 50 mm height cylinder shape and constructed by making 30.6 mm in diameter round holes in the middle of inside of the cylinder and 4 spots on surrounding. To measure slice thickness and spatial resolution, we designed the cylinder shaped sub phantom to let it locate inside the round hole. This study was showed the CT phantom with the same quality performance as AAPM CT performance phantom using FDM 3D printing technology. The results of CT number of and noise were passing the criterion with 3.10 and 2.66 HU. The uniformity of CT number was a difference within ±5 HU between the centers. The study of spatial resolution was suited because the 1.0 mm thick wall of the cylinder with 5.0, 3.0 and 2.0 mm in grid size was distinguishable. In terms of the measuring slice thickness, the result was passing meeting the criterion; it came to 4.5 and 9.1 mm from 5.0 and 10.0 mm with deviation of ±1 mm. The comparing with AAPM CT performance phantom all categories were suitable for the AAPM CT evaluation criterion. We could expect that developed CT phantom was cheaper up to 80% than AAPM phantom so the small-medium size the hospitals can easily equip the high quality medical image technology devices.

Key words: Computed tomography, phantom, fused deposition modeling, 3D printing technology, quality control, American Association of Physicists in medicine

INTRODUCTION

It was possible for the Computed Tomography (CT) scanner to scan rapidly CT images and reconstruct them. It is used to examine the medical imaging of diseases on the nervous system, the respiratory system, the digestive system, the urinary system, the muscular skeletal system, the cardiac condition and the blood vessel condition (Pomerantz *et al*., 1996; Jang and Kweon, 2007). In many aspects of medication, CT scanners are highly used with the radiographic method furthermore error images from the CT scanner could cause the diagnostic errors. Also in this case, it is apprehended that the repetitive radiographic inspections will increase medical radiation exposure to the patients. Therefore, it is strongly recommended that the Quality Control (QC) in CT scanner should be performed frequently which means it can help to minimize the CT imaging errors and the radiation quantity from CT test (McCullough, 1980; Payne *et al*., 1977). Initial QC in CT scanner was also implemented to target self-made phantom and patients. A few years after, the quantitative analysis of the quality control of the match of Ho Unsfield (HU), image noise, spatial resolution, sensitivity profile, etc. were performed (Huda, 1987; Droege, 1983; Jessen *et al*., 1993). Currently, the QC phantom in CT scanner Named American Association of Physicists in Medicine (AAPM) CT performance phantom that AAPM invented is widely in use. In Korea as well, AAPM CT performance phantom is used as the standard of the QC phantom with CT in accordance with regulations about setup and operation of special medical equipment (Jang and Kweon, 2007). AAPM CT performance phantom is composed of 5 blocks; CT number calibration block, spatial resolution block, contrast resolution block, beam alignment block and noise measurement block. But CT performance phantom designed by AAPM had some problem. It was heavy because filled with water in the phantom. So, the phantom must setting on the CT scanner table. The results of this method caused inhomogeneity of image by supporter of the phantom on the table edge of CT scanner. Several solid phantoms were developed for this problem. One of the most familiar solid quality assurance CT phantom was proposed based on the works of Goodenough and collaborators using a tissue-equivalent epoxy resin developed by white (Goodenough *et al*., 1990). The phantom was made from solid-cast materials, elimination material absorption of water and leaks associated with water bath phantom as well as problems related to varied water sources. But these phantoms were the high cost equipment so generally it is hard for the small and medium-sized hospitals to be fully equipped. Recently, the application of 3D printing technology to medical field has been gradually increasing with the commercializing 3D printer (Schubert *et al*., 2013).

In this study was to evaluate of usefulness for developed solid CT phantom using Fused Deposition Modeling (FDM) 3D printing technology with the same quality performance as AAPM CT performance phantom.

MATERIALS AND METHODS

Equipment and materials: In this study is used 4-channel MDCT(MX8000-IDT, Philips, USA) scanner. The phantom is produced by 3D printer (Fortus 360/400 mc, Stratasys, USA), modeler (CADian 3D Ver. 2.0) and slicer program (CreatorK Ver. 9.6.0). To compare phantom, CT evaluation phantom, AAPM CT performance phantom is used like Fig. 1.

Fig. 1: AAPM CT performance phantom

3D modeling: The production of phantom by FDM 3D printing technology followed the procedure like Fig. 2. First, it is converted into STereo Lithography (STL) file through modeling with modeler program. The proposed CT performance phantoms were consisting of the main phantom and sub-phantom by solid type. The main phantom is designed the 180 mm in diameter and 50 mm height cylinder shape and constructed by making 30.6 mm in diameter round holes in the middle of inside of the cylinder and 4 spots on surrounding (Fig. 3). And then, we designed the cylinder shaped sub-phantom to let it locate inside the round hole which could measure slice thickness and spatial resolution.

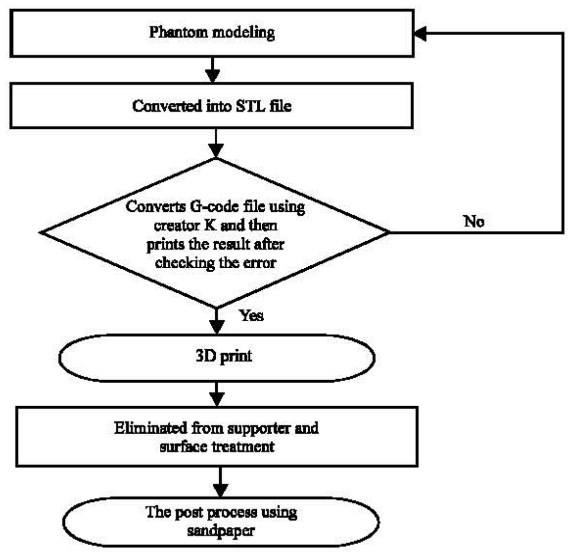

Fig. 2: The flow chart of 3D printing by manufacturing phantom

Secondly, we converted STL file into G-code file using creator K, the control program of 3D printer and then printed the result after checking the errors. In this study, the main phantom is made with Acrylonitrile poly Butadiene Styrene (ABS) and the cylinder shaped phantom uses Poly Lactic Acid (PLA). Thirdly, the produced phantom is done with the surface after being eliminated from supporter. Finally, to obtain research completeness we implement the post process using sandpaper.

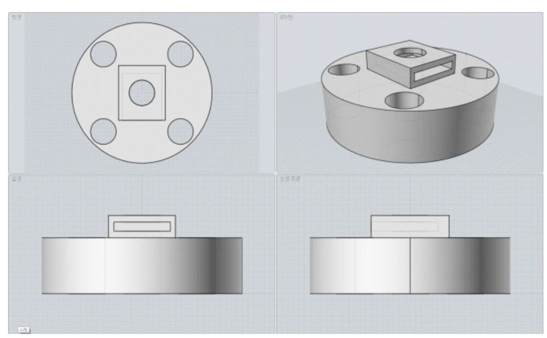

Fig. 3: Phantom modeling by modeler program

Performance test: The condition of performance evaluation resulted from investigation X-ray applying 120 kVp, 250 mAs, 10 mm thickness, 50 cm scan Field of View (FOV) and 25 cm display FOV, standard reconstruction algorithm. Additionally in terms of slice thickness measure, a 5 mm thickness is fulfilled. To measure a water attenuation coefficient and an image noise, we checked out X-ray to the filling syringe of distilled water in the middle of our proposed CT phantom and on 4 circle spots of outside surrounding. For checking the degree of image uniformity, we put the same quality of material cylinder into each circle of the main phantom and then investigate X-ray. And CT number is measured respectively after locating the square shape the Region of Interest (ROI) on the direction of 12, 9 and 3 o'clock which is the spot about two-thirds distance of the surrounding from the middle at the main phantom. To survey spatial resolution, we checked out X-ray putting the sub-phantom of 9 cylinders in total into the middle of the main phantom. These phantoms are consisted by 5, 3 and 2 mm in grid size and each 1, 0.75 and 0.5 mm in the wall thickness of grid. Also for the clear distinction of wall thickness, Window Width (WW, 300~400 HU), window level (WL, -200~-100 HU) is adjusted on spatial resolution. Slice thickness is measured with 5 and 10 mm slice thickness by investigated X-ray through put the manufactured the cylinder of sub-phantom as the same thickness as slice thickness in the middle of the main phantom. Also for the clear distinction of wall thickness, WW (1900~2000 HU), WL (0~100 HU) is adjusted on spatial resolution.

Fig. 4: Proposed CT phantom by 3D printing technology equipped at the CT scanner table-edge

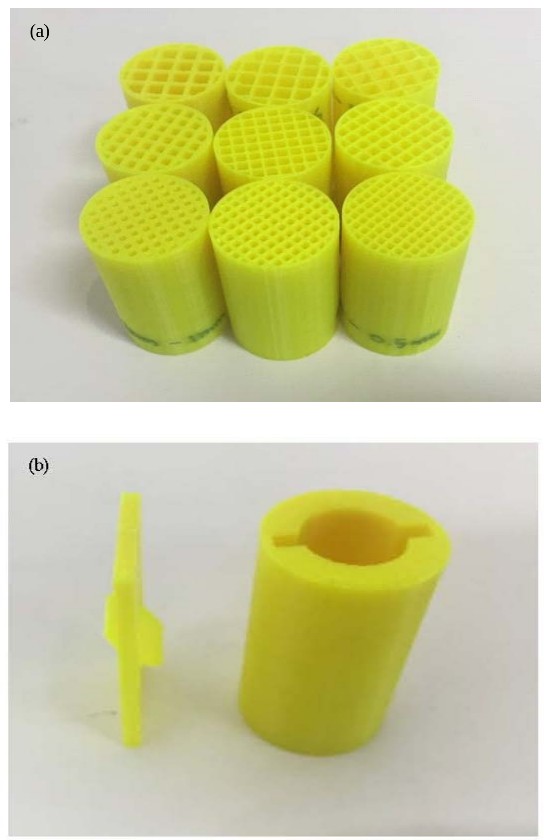

Fig. 5: Proposed CT sub-phantom by 3D printing technology: a) sub-phantom for spatial resolution and b) sub-phantom for slice thickness

RESULTS

Results of 3D printing: We successfully manufactured our proposed CT phantom by using 3D printer and equipped at the CT scanner table-edge like Fig. 4. The cylinders of sub-phantom and the main phantom are made using the 3D printing technology like Fig. 5. The cylinders of sub-phantom in each hole can evaluate the quality of image about spatial resolution and slice thickness.

Results of evaluating images: The 4-channel MDCT is tested by AAPM CT performance phantom and gets through in all categories. So, it was proper in this study. As Table 1, the suitability of the developed CT phantom meets acceptance criterion of AAPM CT performance phantom.

As Fig. 6, the measurements of water attenuation coefficient and image noise are checked investigating the average and the standard deviation of CT number in the interested region. The result 3.10 and 2.66 HU is accepted. As the result of the degree of image uniformity the CT numbers of the direction of 12, 9 and 3 o'clock were -111.98, -115.37, -110.62 HU and the center CT number in the main phantom was -112.23 HU by a difference within ±5 HU between the center and the peripherals which means the test passes. The study of spatial resolution suited because the 1 mm thick wall of the cylinder with 5, 3 and 2 mm in grid size were distinguishable with the naked eyes. In terms of the measuring slice thickness, the result passes meeting the criterion; it came to 4.5 and 9.06 mm from 5 and 10 mm with deviation of ±1 mm.

Table 1: AAPM CT evaluation criterion and the measured value of AAPM CT performance phantom and proposed phantom

Categories	Criterion	AAPM CT phantom	Proposed CT phantom	Results
Water attenuation coefficient	0±7 HU	-5.7 HU	3.10 HU	Pass
Noise	Below 7 HU	5.7 HU	2.66 HU	Pass
Image uniformity	±5HU	Mean -2.2 HU	Mean 1.7 HU	Pass
Spatial resolution	1.0 mm	Below 7.5 mm	Below 1.0 mm	Pass
Contrast resolution	6.4 mm	Below 6.4 mm	-	N/A
5 mm thickness	±1 mm	4.8 mm	4.6 mm	Pass
10 mm thickness	±1 mm	9.2 mm	9.1 mm	Pass
Artificial substances	None	None	None	Pass

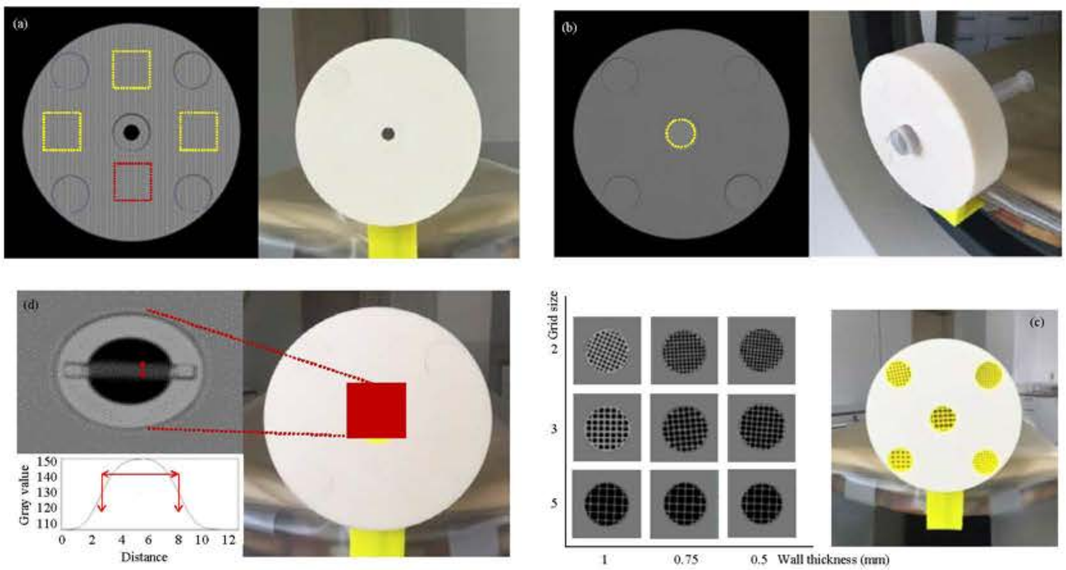

Fig. 6: CT phantom produced by 3D printer: a) CT image for uniformity of CT number and phantom appearance; b) CT image for water attenuation coefficient with image noise and phantom appearance; c) CT image for spatial resolution and phantom appearance and d) CT image for slice thickness with sensitivity profile and phantom appearance

DISCUSSION

The purpose of this study was to evaluate of usefulness for developed CT phantom using 3D printing technology. After the introduction of the commercial CT scanner in the early 1970s, the scientific community started to evaluate the capabilities and limitations of that new image modality. However, the previously known image quality evaluation techniques were not adapted to the geometric characteristics of the CT scanners neither to their physical and architectonic properties such as voltage and current range and gantry geometry. This situation resulted in proposals for geometric apparatus intending to quantify the main image properties of the CT images such as spatial resolution and contrast resolution, image noise, slice thickness and also some kind of artifacts. The McCullough and colleagues, proposed have contributed to the AAPM task force on CT phantoms and their progresses were adopted on the first guide for QC and dosimetry in CT published by AAPM (McCullough, 1980; Payne *et al*., 1977). The AAPM CT performance phantom included many interesting inserts for evaluation of the CT scanners in terms of its image quality. The ACR phantom is also endorsed by the American college of radiology for CT accreditation in the United States. This phantom was used by the physics group to establish baseline values for all scanners under the group's responsibility. For CT number accuracy, the ACR recommends that scans are performed between 120 and 130 kVp and gives CT number ranges which are based on the average values obtained from multiple scanner models (McCollough *et al*., 2004). Recently, CT scanners have been gradually developing with detectors and scanning technology. So, various CT scanners required develop more practical methods for evaluation image quality in CT scanners. For example such as the catphan (The Phantom Laboratory, Salem, NY) or ACR Accreditation Phantom (model 464, Gammex, Middleton, WI) are typically used by physicists to monitor image quality on various scanners (Cropp *et al*., 2013). We suggested that 3D printing technology applied for manufacture of the CT performance phantom. The greatest advantage that 3D printing technology provides is the freedom to produce custom-made equipment (Banks, 2013). Another important benefit offered by 3D printing is the ability to produce items cheaply (Schubert *et al.*, 2013). Traditional manufacturing methods remain less expensive for large-scale production. However, the cost of 3D printing is becoming more and more competitive for small production runs (Mertz, 2013). Therefore, the results of this expects that our proposed CT phantom was cheaper up to 80% than AAPM phantom, so the small-medium size the university hospitals and the general hospitals can easily equip the high quality medical image technology. Also because lightweight and compact by 3D printing technology than conventional AAPM phantom, the phantom can equipped at the CT scanner table-edge. As a result, it was decreased beam-hardening artifact by the supporter of CT phantom. Comparing with AAPM phantom, all categories of CT number, image noise, the degree of uniformity, spatial resolution and slice thickness were suitable for the AAPM CT evaluation criterion. These findings were applicable to CT performance phantom by using ABS and PLA with FDM 3D printing technology. On the other hand, this study showed the limit to fail on developing the sub-phantom for measuring contrast resolution. But future studies will keep on the study about it.

CONCLUSION

The 3D printing technology has become a useful in the medicine field (Kim *et al.*, 2016; Woo and Kim, 2016). Especially, we confirmed that 3D printing technology can utilize the radiation field. The results of this study demonstrated that recommends the low price evaluation phantom with the same quality performance as AAPM CT performance phantom using FDM 3D printing technology. Future work will focus on the various the design of the CT performance phantom.

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