Annals of R.S.C.B., ISSN: 1583-6258, Vol. 26, Issue 1, 2022, Pages. 917 – 927
Received 08 November 2021; Accepted 15 December 2021.

A Study on the Development of Human Phantom for CT through Material Analysis of Medical 3D Printers

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ABSTRACT

In CT, the primary radiation generated from the X-ray tube is irradiated to the tissue through a collimator, and since X-rays are continuously irradiated to the tissue while the X-ray tube rotates 360°, the radiation exposure is very high. However, since the training of CT examination cannot be performed on humans, it must be replaced by a human phantom. However, the types of phantoms are not diverse, and the educational phantoms are expensive, so it is difficult to use them for actual education, and there is a point that is not similar to the human body. Accordingly, it has been reported that phantoms manufactured using 3D printers are widely used and helpful. However, there is no phantom with similar density in CT number and similar only in shape and touch. Therefore, this study tried to solve the insufficient spread of educational phantoms by suggesting a manufacturing method that measures and evaluates filament, which is a material, using a 3D printer to produce a human body model phantom similar to human tissue density. HU results similar to anatomical organs according to the measured CT number results for each filament ABS, TPU-95A, and Nylon measured +40 ~ +60 HU, indicating similar values to Liver and Soft tissue, and Wood fill was +30 HU was measured and it was confirmed that it represents a similar value to Blood, and in the case of Steel, Bronze, and Brass, HU of 3071 was measured and it was measured much higher than the CT number of 1000 HU of bone, so it could not be used as a human tissue phantom. I knew there wasn't. Through this study, CT number according to the density of filament material used in the 3D printer was confirmed, and filaments similar to human tissue CT number were confirmed. In the future, if this study is presented as a basic study and fused to 3D printer research, it is thought that it will be used in various ways.

Keywords
3D printing, 3D printer Filament, Hounsfield unit, Phantom, CT number,

Introduction

With the remarkable development of CT, the importance of diagnosis using CT is gradually increasing. Recent developments reduce the patient’s radiation dose and increase the scan speed to examine within the time of holding one breath. By using a new material for the detector, the sensitivity to low doses was improved, thereby reducing the patient's exposure dose and improving the resolution at the same time. Diagnosis of a three-dimensional lesion has become possible with a two-dimensional image and a three-dimensional reconstruction image, and as a result, the use of CT is increasing every year. CT can represent the internal structure of a cross-section as an image by reconstructing it by a mathematical technique using the attenuation data that has passed through the subject. It is possible to acquire high-resolution images and manage the quality of not only the structure of bones but also exercise organs such as the cardiovascular system. In the CT image, each pixel is expressed as a CT number, and the CT number uses a series of counting values for each pixel for the reconstruction of the data acquired by attenuation in the subject. CT number (Hounsfield unit, HU) is expressed from -1000 to +3071 and is monitored in grayscale through this. The Grayscale is the brightness corresponding to the CT number, that is, the expression of the CT number expressed in gradual gray. And the contrast value of each pixel is expressed in a grayscale. Recently, to obtain more precise information in all equipment, the ratio was applied as 0 for water, +1000 for bone, and -1000 for air (Hounsfield scale) with an enlargement constant of 1,000 to obtain more precise information. For example, among the organs of the human body, the Liver shows a HU value of about +60 and gray matter shows a HU value of about +37 ~ +45. Due to the difference in CT number, abnormalities can be identified or bleeding can be recognized. In CT, the primary radiation generated from the X-ray tube is irradiated to the tissue through the collimator, and the radiation exposure is very high because X-rays are continuously irradiated to the tissue while the X-ray tube rotates 360°. To scan accurately at one time, it must be examined by an experienced radiologist, but the training of CT examination cannot be performed on humans, so it must be replaced by a human phantom. However, the types of phantoms are not diverse, and educational phantoms are expensive, so it is difficult to use them in actual education and there is a point that is not similar to the human body. It has been reported that phantoms made using 3D printers are used a lot and are helpful. Since phantom training does not pose a risk of radiation exposure, several image acquisition parameters can be arbitrarily adjusted to quantitatively measure the effect of each parameter on image quality and radiation dose. A 3D printer can print digital data designed by a computer into the desired model at any time, anywhere by additive processing and lamination. However, only the shape and feel are similar, there is no phantom with similar density in CT number on CT. Recently, with the development of 3D printers, not only materials such as PLA and ABS that are easy to print but also mixed filaments of various plastics are being developed. Therefore, this study aims to solve the insufficient spread of educational phantoms by presenting a manufacturing method that measures, evaluates, and provides material for manufacturing a humanoid phantom similar to the human tissue density using a 3D printer.

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Material & Method

This study analyzes the CT number value using a filament compatible with a 3D printer to find a substance similar to the average CT number of the human body. The experiment was conducted in the same order as in Fig. 1.

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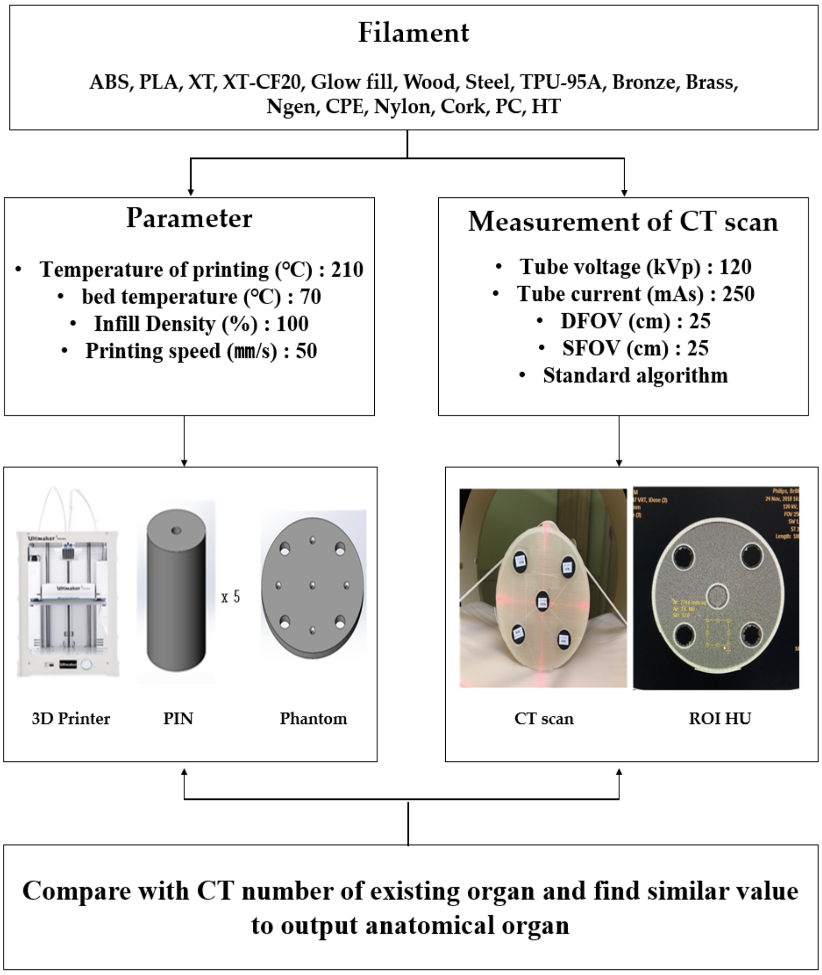

Fig.1 Flow chart of CT Number measurement for each filament in 3D printer

In this experiment, a 3D printer (Ultimaker3 extended) was used, and the materials were ABS, PLA, XT, XT-CF20, Glow fill, Wood, Steel, TPU-95A, Bronze, Brass, Ngen, CPE, Nylon, Cork, PC, and HT materials were used and the same output was performed.

(a) (b) (c)

Fig. 2 Proposed CT phantom modeling for CT number measurement.

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It is the density of filament ABS, PLA, XT, XT-CF20, Glow fill, Wood, Steel, TPU-95A, Bronze, Brass, Ngen, CPE, Nylon, Cork, PC, HT used for evaluation (Color fabb, Netherland). , (Table 1)

Table 1. Filament type

filament	density
ABS	1.10 g/㎤
PLA	1.24 g/㎤
XT	1.24 g/㎤
XT-CF20	1.35 g/㎤
Glow fill	1.43 g/㎤
Wood	1.25g/㎤
Steel	3.13 g/㎤
TPU-95A	1.22 g/㎤
Bronze	3.9 g/㎤
Brass	3.9 g/㎤
Ngen	1.20 g/㎤
CPE	1.27 g/㎤
Nylon	1.14 g/㎤
Cork	3.9 g/㎤
PC	3.9 g/㎤
HT	3.9 g/㎤

CURA (1.54, Ultimaker, Netherlands) was used to set the output temperature, bed temperature, internal filling, etc., and then G-code conversion was performed and sent to the printer. (Table 2)

Table 2. The output parameters of 3D printing

parameter	value
Temperature of printing (℃)	210
bed temperature (℃)	70
Infill Density (%)	100
Printing speed (㎜/s)	50

Tocheck the density of each filament, the inner filling of the pin was changed to 20%, 40%, 60%, 80%, and 100%, and 5 pieces per filament were manufactured. After the can, ROI was set in the image and the CT number value was measured. Because 3D printing technology produces objects in

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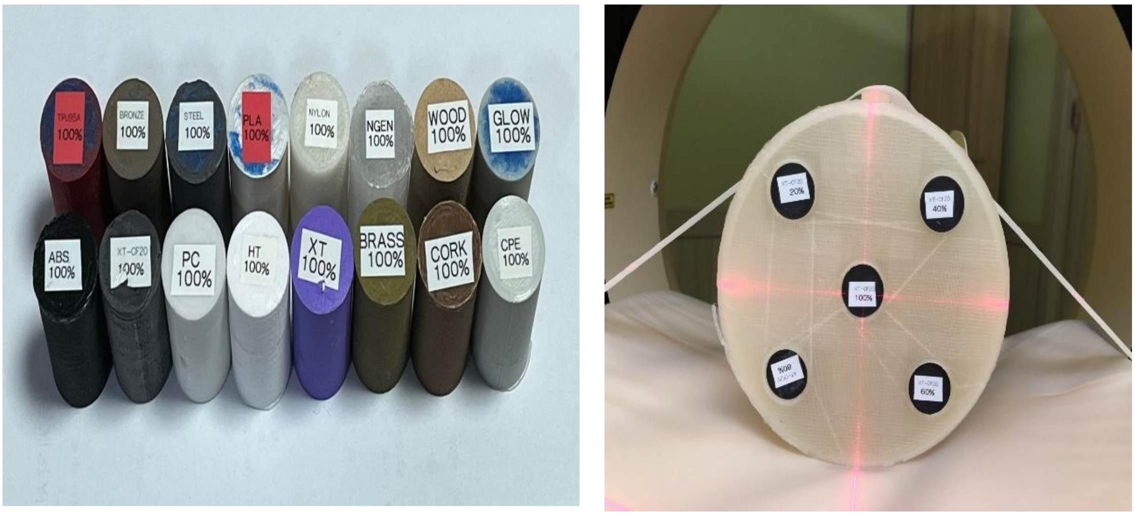
the form of a grid, it was produced to confirm that the filling rate increases as the internal filling increases when checking the CT image. (Fig. 3)



(a) (b)

Fig. 3CT scan by using 3D printed CT phantom.

The conditions used in the experiment are as follows (Table 3).

Table 3. Parameter for dose measurement

Parameter	Value
Tube voltage [kVp]	120
Tube current [mAs]	250
DFOV [cm]	25
SFOV [cm]	25

Compare with CT number of existing organ, find similar value, output anatomical organ, and compare and analyze the output phantom after CT scan.

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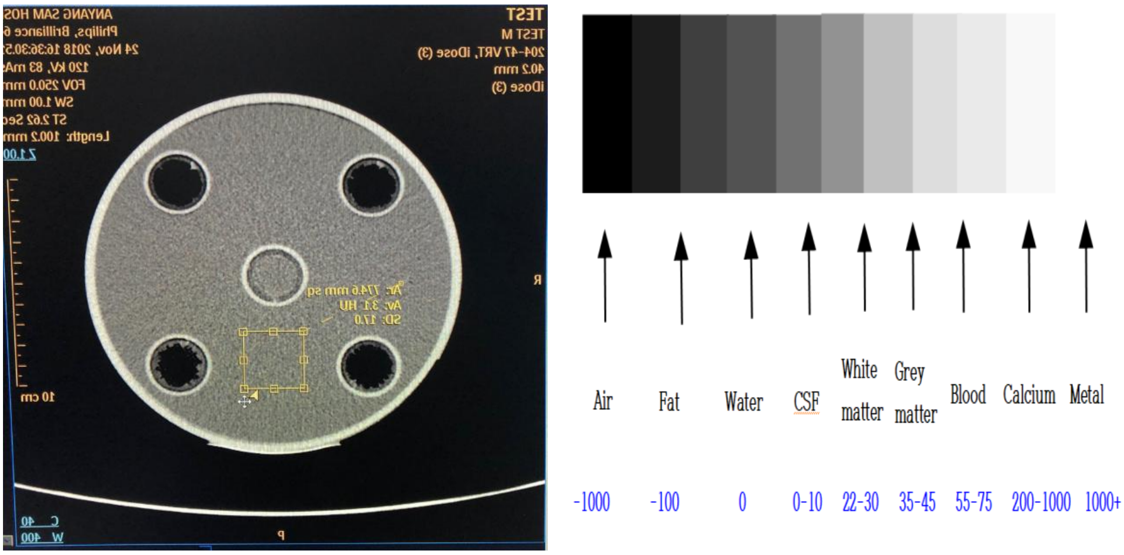

(a) (b)

Fig. 4 After analyzing the printed human phantom by CT scan, comparative analysis with human organs

Result

1. Measurement result of CT number for each channel according to filament material

Table 2 shows the results of measuring the CT number for each filament output using a 3D printer. This is the CT number measurement result at 100% of internal filling for each filament in 64ch.For ABS, it was 43.77±0.64, for PLA, it was 135.43±0.34, and for XT, it was 149.39±0.06, and for XT-CF20, it was 6.97±0.09, for glow fill 289.75±0.13, and for wood it was 36.48±0.10. and 56.55 ± 0.36 for TPU-95A, 120.0 ± 0.09 for Ngen, 147.71 ± 0.12 for CPE, 63.91 ± 0.12 for Nylon, 122.61 ± 0.09 for Cork, 106.89 ± 0.14 for PC and HT case was measured to be 100.62 ± 0.44. In the case of filament measured as 3071±0, the maximum value measured by CT number, Steel, Bronze, and Brass filaments were found.This is the CT number measurement result at 100% of internal filling for each filament in 256ch. ABS was 38.52 ±1.64, PLA was 177.18 ±0.11, XT was 189.06 ± 0.19, XT-CF20 was 10.24 ± 0.18, Glow fill was 326.20 ± 2.35, and Wood was 33.50 ± 0.95. and 50.70 ± 0.70 for TPU-95A, 115.35 ± 0.23 for Ngen, 188.28 ± 0.30 for CPE, 62.63 ± 0.55 for Nylon, 122.70 ± 0.72 for Cork, 98.63 ± 0.06 for PC and HT. the case was measured to be 94.60 ± 0.26. In the case of filament measured at 3071±0, the maximum value measured by CT number, Steel, Bronze, and Brass filaments were found. (Fig. 5)

Table 2. The results of CT number measurement by 100% infill.

CT number / Filament	64ch	256ch
ABS	43.77 ± 0.64	38.52 ±1.64
PLA	135.43 ± 0.34	177.18 ±0.11

XT	149.39 ± 0.06	189.06 ± 0.19
XT-CF20	6.97 ± 0.09	10.24 ± 0.18
Glow fill	289.75 ± 0.13	326.20 ± 2.35
Wood	36.48 ± 0.10	33.50 ± 0.95
Steel	3071 ± 0.00	3071 ± 0.00
TPU-95A	56.55 ± 0.36	50.70 ± 0.70
Bronze	3071 ± 0.00	3071 ± 0.00
Brass	3071 ± 0.00	3071 ± 0.00
Ngen	120.0 ± 0.09	115.35 ± 0.23
CPE	147.71 ± 0.12	188.28 ± 0.30
Nylon	63.91 ± 0.12	62.63 ± 0.55
Cork	122.61 ± 0.09	122.70 ± 0.72
PC	106.89 ± 0.14	98.63 ± 0.06
HT	100.62 ± 0.44	94.60 ± 0.26

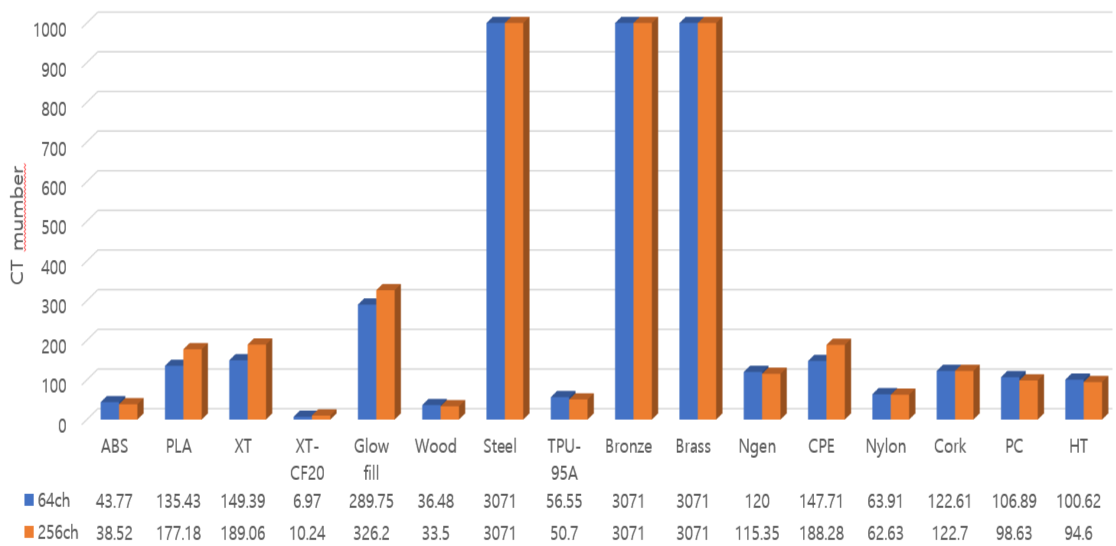

Fig. 5.HU value according to the channel for each filament

2. HU is similar to anatomical organs according to the measured CT number results for each filament

Table 3 shows the results of comparing the HU (House filed unit) similar to an anatomical organ by calculating the average CT number result of 100% internal filling for each filament.ABS, TPU-95A, Nylon filaments showed +40 to +60 HU values similar to Liver, and Wood and ABS filaments showed +30 to +45 HU values similar to Blood, PLA, XT, Cork, Ngen in the case of CPE, -100 to 300 HU similar to soft tissue were measured. In the case of Steel, Brass, and Bronze filaments, it was measured with HU as 3071±0, the maximum value of CT number measurement.

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Table 3. Comparative analysis of anatomical organ HU according to CT Number results

CT number / Filament	64. 256 ch. median	Tissue	HU
ABS	41.145±1.14	Lung	-500
PLA	156.305±0.22	Fat	-50 to -100
XT	169.225±0.12	CFS	+15
XT-CF20	8.605±0.13	Water	0
Glow fill	307.975±1.24	Soft tissue	-100 to 300
Wood	34.99±0.52	Blood	+30 to +45
Steel	3071±0.00	Muscle	+10 to +40
TPU-95A	53.625±0.53	Adrenal tumor	Less than +10
Bronze	3071±0.00	White matter	-20 to -30
Brass	3071±0.00	Grey matter	-37 to -45
Ngen	117.675±0.16	Liver	+40 to +60
CPE	167.995±0.21	Bone	+700 to +3000
Nylon	63.27±0.33	-	
Cork	122.655±0.40	-	
PC	102.76±0.10	-	
HT	97.61±0.35	-	

Discussions

CT is a two-dimensional planar image or three-dimensional, four-dimensional image of a multislice image of a diagnostic site due to the use of multiple detectors, which improves detection efficiency as well as data processing capability. You can observe the volumetric image. The image reconstruction technique for multi-slice made it possible to obtain various information about the heart and large blood vessels in a short scan time.To maintain a high diagnostic value of these CT systems, image evaluation is carried out according to a set period, and various program development and research are in progress.[19]. Usman Mahmood, et al. reported that the tissue morphology shown in the CT scan was reproduced using Voxel-based 3D printing technology. [20]. ColienHazelaar, et al. reported that they made a life-size phantom based on a clinical CT scan of the chest of a lung cancer patient using 3D printing technology.[21]. However, the existing experiment using the phantom has a limitation in that it cannot accurately simulate the patient's organ structure. To make a CT phantom, the internal filling of the 3D printer must be 100%, Tomanufacture an educational phantom, an anatomical part should be included, not just a single organ as in previous studies. In the case of chest CT phantoms, from Mandible to Kidney, and for Abdomen CT phantoms, phantoms ranging from the diaphragm to pubic symphysis must be manufactured, so the density of various tissues should be made similar. Therefore, the purpose of this study is to use a 3D printer to create a human body model phantom similar to human tissue density.To check whether the material filament is similar to the human tissue density, the density of each filament was measured and evaluated. As a result, when each filament HU is measured, in the case of filaments similar to an anatomical organ, ABS, TPU-95A, and Nylon measured +40 ~ +60 HU, indicating similar values to Liver and Soft tissue., Wood fill was measured at +30 HU, and it was confirmed that it represents a similar value to Blood, In the case of Steel, Bronze, and Brass, the HU of 3071 was measured and it was measured much higher than the CT number of the bone of 1000 HU, indicating that it cannot be used as a human tissue phantom.However, Kim et al. et al. reported that the test result of a 5mm shield made of brass filament showed a shielding rate of 97.9% at 60 kV, 40 mA, and 60 mA. Therefore, it was possible to confirm the possibility as a shielding body study through the HU of +3071, which is the maximum CT number measurement of Brass Filament.[23] In this study, when the filament, the material, was measured and evaluated using a 3D printer, a material for making a humanoid phantom similar to the tissue density of each human body.It was possible to implement various HUs with 100% internal filling, and the possibility of making a humanoid phantom similar to the tissue density was confirmed.In addition, if this is used, it is believed that quality control can be performed instead of the existing standard phantom by producing a phantom at a lower cost than the standard phantom price.There were several limitations while conducting this study. With the current software development, 3D modeling is easily possible using continuous DICOM format CT images, and modeling data can be output with a 3D printer of the same size. It has become an easy task, but there are still not enough materials that can accurately represent human organs. In addition, the material cost of the filament is expensive, and the filament used in 3D printers has many options due to the wide range of materials available. However, since the density and physical properties are different depending on the filament used, the material must be appropriately selected for the purpose. [22]. In the case of materials that did not show HU results similar to human tissue density, it is thought that the application of 3D printing technology or the use of silicon and barium to increase the similarity to the human body is necessary for future studies. Depending on the condition of the 3D printer or the output settings, the reproducibility of the internal filling may be lowered, and the composition such as density may change, so there may be a possibility of a change in the result value, so only one FDM printer was used. In addition, since metal filaments are not flexible, it is thought that they will be used in various fields of research is conducted on them by appropriately mixing with other materials.

Conclusion

Through this study, the CT number according to the density of the material used in the 3D printer was confirmed and filaments similar to the human tissue CT number were identified. In the future, if this study is presented as a basic study and fused to 3D printer research, it is thought to be used in various ways.

Acknowledgement

This paper was supported by Eulji University in 2022

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