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<원저>

3D 프린팅을 이용한 한국인 골밀도 맞춤 팬텀 개발

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Developing Customized Phantom for Korean Bone Density Using 3D Printing

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Abstract In order to reduce the radiation exposure dose of the patient and to obtain accurate diagnosis results, the quality control of the diagnostic radiation generator must be conducted periodically In particular, bone density test equipment could be influenced by many factors, and it is far more important because inaccurate measurement would eventually affect the result value. However, the cross-correction phantom of DXA equipment is poorly penetrated due to lack of awareness of the industry and the high cost. Therefore, this study developed a BMD phantom using a 3D printer and Korean BMD phantom with low cost by cross analyzing Korean BMD value from The Korean National Health and Nutrition Examination Survey and evaluated it. The L1, L2, and L3 BMD values of phantoms produced with the 3D printer were measured to be 0.887±0.006 g/cm^2, 0.927±0.006 g/cm^2, and 0.960±0.005 g/cm^2, at 215 mm height and 0.882±0.011 g/cm^2, 0.914±0.005 g/cm^2, 0.933±0.008 g/cm^2 at 155 mm height displaying statistically significant relevance. The result suggests that a proper quality control and cross calibration of DXA device be possible and expected to be an essential data for various medical phantom manufacture development using 3D printer.

Key Words: 3D printer, KNHANES, Medical phantom, DXA, Cross-calibration

중심 단어: 3D 프린터, 국민건강영양조사, 의료용 팬텀, DXA, 교차보정

Ⅰ. Introduction

Bone Mineral Density (BMD) is the amount of bone mass in unit area and osteoporosis is bone metabolic disease which alters the bone composition resulting in BMD decrease[1,2]. There are many factors to osteoporosis and it is classified into primary osteoporosis and secondary osteoporosis. The primary osteoporosis is caused by either menopause or aging, however, it is ambiguous to specify because it progresses at almost the same time. Secondary osteoporosis is due to an exposure to a drug or disorder that interferes with the acquisition of the maximal bone mass or reduction of bone mass[3]. In addition, previous research suggests that various factors such as sex, smoking, drinking, and exercise, menopause, calcium, vitamin D and caffeine intake also affected osteoporosis[4−8].

According to the Health Insurance Review and Assessment Service, the number of patients with osteoporosis increased by 12.58% from 805,304 in 2013 to 906,631 in 2017. In 2017, the number of treatment

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of women in age of 50, the age women normally reach menopause, was significantly higher than that of 40, and the number of men in age of 40 was lower than that of women, but it increased significantly after the age of 50[9].

Osteoporosis and osteopenia are one of the main factors for the diagnosis of bone mineral density, and it is very important to prevent and treat fractures [10-11]. Bone mineral density (BMD) is measured with vrious means such as radiographic absorptiometry, dual energy X-ray absorptiometry (DXA), quantitative ultrasound (QUS), quantitative computed tomography (QCT). DXA displays the multiple level of energy intensities according to the distribution of bone density through two different kinds of energy X-rays passing through the human body. It is the most commonly used measurement device for diagnosis of osteoporosis for used to quantify the bone density and. DXA bone density measurement devices should be its capability to maintain the accuracy and reliability of the test[12]. However, since the bone density measurement value requires certain level of periodic maintenance, there is a risk of misdiagnosis by inaccurate result of the test if it is not properly maintained[13]. Moreover, general-purpose phantoms are not easy to secure for with its expensive prices[14].

Therefore, the study developed a bone density phantom using 3D printer for efficient quality control for DXA device. In order to solve the cost problem which is the major issue of the conventional phantom diffusion, 3D printer has been employed to manufacture a cross calibration phantom with FDM 3D printer which is simple and costs less to manufacture, and evaluate the capability of Korean bone mineral density by linear regression analysis of DXA phantom measurements obtained from the Korea National Health and Nutrition Examination Survey (KNHANES).

Ⅱ. Materials and Methods

1. Evaluating Korean Bone Mass Density through The Korea National Health and Nutrition Examination Survey

In this study, the results of the National Health and Nutrition Survey were used to create Korean bone mineral density custom phantom. The National Health and Nutrition Examination Survey was conducted to ascertain the health and nutritional status of the people based on Article 16 of the National Health Promotion Act, the raw data from the first period of 1998 to the seventh periodical data of the year 2017 is open to the public[15]. The study was conducted with the raw data from the fourth period (2008 ~ 2009) and the fifth period (2010 ~ 2011) in which BMD was performed and 21,072 subjects who measured vertebral bone density were selected. The data of 16,906 persons were analyzed as shown in Table 1, except for those who have the double missing value and are younger than 20 years and those older than 80 years.

2. Equipment and materials

The phantom was printed with personal FDM 3D printer (3DP-210F, Cubicon, Republic of Korea) of Cubicon. The maximum printer size of the 3D printer is 150 × 150 × 150 mm (W × H × D), and the X and Y positioning accuracy is 12.5 ㎛, and the Z positioning precision is 2.5 ㎛.

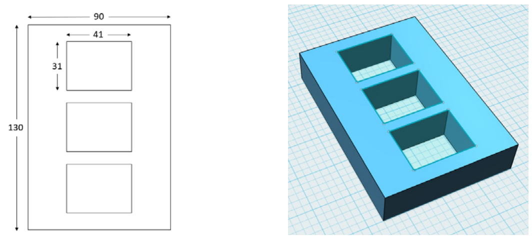
PLA filaments in a diameter of 1.75 mm and 30% Cu-PLA filaments were used to print out the soft tissue model and the bone tissue model, and the phantom modeling and slicing has been conducted with 123D design (v2.2.14, Autodesk, USA) and Cubicreator (v2.5.3.2, Cubicon, Republic of Korea).

Table 1. Number of subjects and BMD density (unit: g/cm^2)

	N	L1	L2	L3
Male	7,331	0.920±0.132	0.966±0.143	0.990±0.150
Female	9,575	10.860±0.150	0.903±0.161	0.933±0.165
Total	16,906	0.886±0.146	0.930±0.157	0.958±0.161

3. Phantom production with 3D printer

The study has been conducted with the size of models; the width and depth of the soft tissue model used for phantom production are shown in Fig. 1, 90 mm and 130 mm, and the height was 215 mm and 155 mm. The bone tissue model was placed in the center of the phantom, and it was produced in size of 40 × 30 × 25 mm (W × D × H) to fit into the soft tissue model. Table 2 shows the printing conditions of the soft tissue and bone tissue model. The 30% Cu-PLA used in the bone model was printed by infilling from at beginning 70% and increased by 5% up to 100% in order to evaluate the Hounsfield Unit (HU).



(a) 2D Top view (b) 3D view

Fig. 1. Diagram of phantom

Table 2. Output parameters of phantom

Parameter	Value	Parameter	Value
Printing type	FDM	Layer height	0.4 mm
Nozzle diameter	0.4 mm	Infill	70% ~ 100%
Nozzle temperature	210 ℃	Heating bed temperature	65 ℃
Chamber temperature	40 ℃	Printing speed	100 mm/s

4. Evaluation the usability of the phantom

The 30% Cu-PLA was photographed with a 16-ch CT (Alexion, TOSHIBA) to obtain DICOM and the HU was evaluated using Image J 1.52a (National Institutes of Health, USA). Hologic's Discovery device has was employed and measured 10 times respectively to compute the cross sectional analysis and evaluate the BMD of the National Health and Nutrition Examination Survey and the printed phantom model. Linear regression analysis was performed using SPSS 23.0 (SPSS Inc. Chicago, IL, USA) to determine the relevance of the measured values.

Ⅲ. Results

1. HU Evaluation by bone model infilling

In Fig. 2, HU of 30% Cu-PLA was measured three times to simulate the bone tissue of BMD phantom. As shown in Table 3, 1,011.60 ± 3.80 at 70%, 1,139.55 ± 9.08 at 75%, 1,288.39 ± 6.25 at 80%, 1,376.20 ± 16.33 at 85%, 1,497.51 ± 2.04 at 90%, and 1,624.52 ± 5.52 at 95%, and 1,772.21±11.74 at 100% respectively. The study was conducted with phantom produced with 80%, 85% and 90% infilling rate. In addition, PLA was measured three times with 100% internal filling to simulate soft tissue, and HU was 36.73 ± 0.89.

2. Phantom print

Fig. 3(a) is a model with 80%, 85%, and 90% infilling of 30% Cu-PLA, and Fig. 3(b) is a bone mass model stacked with 95 mm a soft tissue phantom top and bottom. Fig. 3(c) is a model with 65 mm a soft tissue phantom.

The total output of time and usage of 215 mm height phantom was about 61 hours 9 minutes for ABS and 3,039.83 g. The total output of time and usage of 155 mm height phantom was 44 hours 11 minutes and 2,160.37 g. 30% Cu-PLA was used for about 2 hours and 26 minutes, 97.27 g.

3. Phantom BMD measurement and linear regression analysis

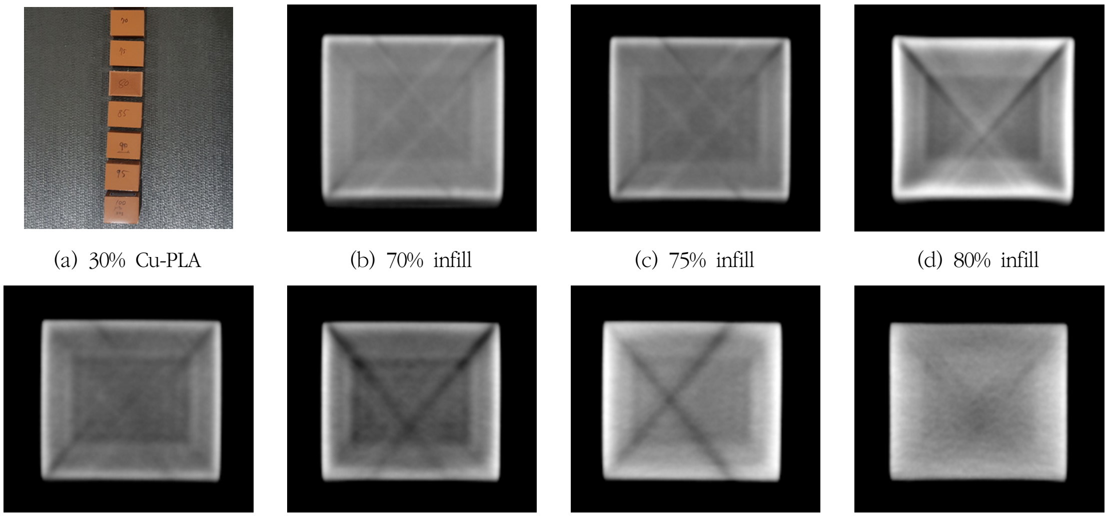
The L1, L2, and L3 BMD values of phantoms produced with the 3D printer were measured to be 3.015±0.049 g/cm^2, 3.353±0.047 g/cm^2, and 3.631±0.042 g/cm^2 at 215 mm height and 2.973±0.094 g/cm^2, 3.247±0.046 g/cm^2, 3.405±0.064 g/cm^2 at 155 mm height.

BMD values from KNHANES were 0.886±0.146 g/cm^2, 0.930±0.157 g/cm^2 and 0.958±0.161 g/cm^2. Therefore, a linear regression analysis was conduct to examine the relevance with the phantom model. As a result in Fig. 4, R^2 was 0.995 at 215 mm height and computed the equation to predict the existing result as Eq. (1), and R^2 was 0.9994 at the height of 155 mm and computed the equation as Eq. (2).

$$y = 0.1174 \times 3D value + 0.5333 \quad (1)$$

$$y = 0.1658 \times 3D value + 0.3928 \quad (2)$$

As Table 4 shows, with Eq (1), the BMD values of L1, L2 and L3 were 0.887 ± 0.006 g/cm^2, 0.927±0.006 g/cm^2 and 0.960±0.005 g/cm^2 respectively, and there are value difference from those of KNHANES which were 0.15% and −0.32% , And 0.16%. In addition, with Eq (2) applied, The BMD values of L1, L2 and L3 were



(a) 30% Cu-PLA (b) 70% infill (c) 75% infill (d) 80% infill

(e) 85% infill (f) 90% infill (g) 95% infill (h) 100% infill

Fig. 2. CT scan by infill of 30% Cu-PLA

Table 3. HU measurement result by infill of 30% Cu-PLA

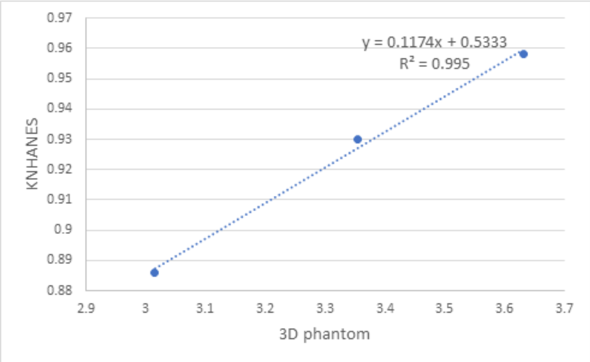
Infill	HU	Infill	HU
70%	1,011.60±3.80	90%	1,497.51±2.04
75%	1,139.55±9.08	95%	1,624.52±5.52
80%	1,288.39±6.25	100%	1,772.21±11.74
85%	1,376.20±16.33		

(a) Bone model (b) 215 mm height phantom (c) 155 mm height phantom

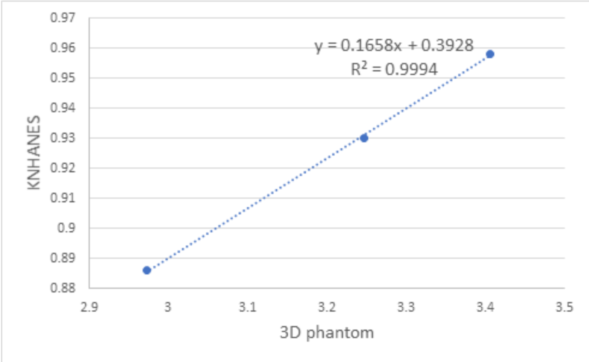
Fig. 3. Completed device in use for examination

Table 4. result of BMD Measurement and Apply linear regression model (unit: g/cm^2)

	215 mm height 3D phantom	Apply linear regression model	155 mm height 3D phantom	Apply linear regression model
L1	3.015±0.049	0.887±0.006	2.973±0.094	0.882±0.011
L2	3.353±0.047	0.927±0.006	3.247±0.046	0.914±0.005
L3	3.631±0.042	0.960±0.005	3.405±0.064	0.933±0.008



(a) 215 mm height phantom



(b) 155 mm height phantom

Fig. 4. Linear regression model

0.882±0.011 g/cm^2, 0.914±0.005 g/cm^2 and 0.933±0.008 g/cm^2, respectively, and the values difference were −0.42% and −1.67% % And −2.60% from those of KNHANES.

Ⅳ. Discussions

In order to reduce dose exposure of patient and obtain accurate diagnosis result, quality control and maintenance of diagnostic radiation generator should be performed periodically. In particular, bone density test equipment could be influenced by many factors, and it is far more important because inaccurate measurement would eventually affect the result value.

The International Society for Clinical Densitometry (ISCD) suggests to conduct cross-analysis of DXA equipment when conducting comparative analysis with BMD values of different facilities or when the same manufacturer or others equipment is introduced[16]. However, the cross-correction phantom of DXA equipment is poorly penetrated due to lack of awareness of the industry and the high cost[17]. Therefore, the study has developed a low-cost cross-calibration phantom using 3D printing technology.

The density of the PLA material is 1.24 g / cm3, which is similar to that of the human tissue. The previous study have used it to produce X-ray dosimetry phantoms for radiotherapy and phantom for diagnostic X-ray devices [18-20]. Moreover, it has the similar density to PMMA which is used for soft tissue and tissue equivalent phantom, and is used for soft tissue mimic material. 30% Cu-PLA whose HU is relatively larger was used as a bone morphogenetic material to effectively display the difference in the radiation transmittance. However, in order to use the phantom as a substitute for the Korean BMD value, a crossover analysis must be performed and the result is shown in Fig 4. In the linear regression analysis, R^2 was 0.995 at 215 mm height, and R^2 was 0.9994 at 155 mm height, and 215 mm and 155 mm height which displays the statistically significant with the mean value of Korean bone density values. It proves that the produced phantom can be utilized on DXA cross correction by applying Eq (1) and Eq (2) and 3D phantom with a thin 155 mm height soft tissue model had a stronger correlation.

This suggests that the periodical error measurement enable to calibrate the reading and continuous maintenance of the patient's bone density value by calibrating the measurd value of same models and same BMD value measured from different facilities before and after the measurement. However, the study was performed with the discovery device of Hologic, and the incompatibility between heterogeneous BMD measurement devices should be improved in future studies.

V. Conclusions

This study has produced a DXA cross correction phantom based on Korean BMD with 3D printer. A linear regression analysis of the bone density of the phantom produced by the 3D printer and the Korean bone density displayed a high correlation respectively, and it was slightly higher when using 155 mm height of soft tissue than of 255 mm height.

It would be possible to conduct proper quality control and maintenance and cross – analyze using DXA device, and it is expected to be used as fundamental data for various medical phantom manufacturing using Korean standard numerical value and 3D printer.

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REFERENCES

[1] Kim YR, Park CS. A convergence study of age-related bone loss and peak BMD in Korean. Journal of the Korea Convergence Society. 2018;9(5):77-83.

[2] Kanis JA. Assessment of fracture risk and its application to screening for postmenopausal osteoporosis. Osteoporosis International. 1994;4(6):368-81.

[3] Chung HY. Osteoporosis diagnosis and treatment 2007. Endocrinology and Metabolism. 2008;23(2): 76-108.

[4] Lee HS. The factors influencing the bone mineral density in korean adult men: Based on Korea national health and nutrition examination survey 2010-2011 Data. Korean Journal of Community Nutrition. 2017;22(2):136-44.

[5] Kim YR, Lee TY, Park YS, Cheon HK. The effect of lifestyle habits and nutrient intake conditions of female shift workers at general hospitals on bone mineral density values. Journal of Radiological Science and Technology. 2012;35(1):9-15.

[6] Kim MS, Koo JO. Comparative analysis of food habits and bone density risk factors between normal and risk women living in the Seoul area. Korean Journal of Community Nutrition. 2008;13(1):125-33.

[7] Cho DS, Lee JY. Bone mineral density and factors affecting in female college students. Korean Journal of Women Health Nursing. 2008;14(4):297-305.

[8] http://opendata.hira.or.kr/op/opc/olapMfrnIntrsDiagBhvInfo.do.

[9] Gates BJ, Das S. Management of osteoporosis in elderly men. Maturitas. 2011;69(2):113-9.

[10] Dong KR, Kim HS, Jung WK. A study of equipment accuracy and test precision in dual energy X-ray absorptiometry. Journal of Radiological Science and Technology. 2008;31(1):17-23.

[11] Kang BM, Kwon ST, Kim DY, Kim EH, Kim IJ, Kim JG, et al. Manual of bone densitometry. Cheongwoon; 2009.

[12] Glüer CC, Blake G, Lu Y, Blunt BA, Jergas M, Genant HK. Accurate assessment of precision errors: How to measure the reproducibility of bone densitometry techniques. Osteoporosis International. 1995;5(4):262-70.

[13] Kim HS, Dong KR, Ryu YH. Accurate quality control method of bone mineral density measurement – Focus on dual energy X-ray absorptiometry. Journal of Radiological Science and Technology. 2009;32(4):361-70.

[14] https://knhanes.cdc.go.kr/knhanes/main.do.

[15] http://www.iscd.org/official-positions/2015-iscd

-official-positions-adult.

[16] Kim HS. Research on the bone mineral densitometer quality control and the precision test of radio-tech-nologists by Dual Energy X-ray Absorptiometry (DXA) at metropolitan area hospital. Journal of Radiation Industry. 2017;11(4):283-289.

[17] Yoon MS. A Study on CT image quality and dose measurement Phantom using 3D printer [master's thesis]. Perth: University of Eulji; 2018.

[18] Seo JN, Nha JE, Bae SM. A phantom production by using 3-dimentional printer andIn-vivo dosim-etry for a prostate cancer patient. Journal of Korean Society for Radiotherapeutic Technology. 2015;27(1):53-60.

[19] Yoon MS, Kang SH, Hong SM, Lee Y, Han DK. A study on the fabrication and comparison of the phantom for CT dose measurements using 3D printer. Journal of the Korean Society of Radiology. 2018;12(6):737-43.