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Development of a Medical Phantom to Evaluate the Function of Low Dose 3D MDCT

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Abstract

Background/Objectives: Low dose radiation-based CT imaging is a technology that dramatically improves the information on borders between similar substances but with difference in density. The findings will serve as basic data in developing a CT phantom dedicated for X-ray phase differential imaging.

Method/Statistical Analysis: To evaluate the benefits of a phantom for low dose 3D MDCT, SOMATOM Definition ASH (Siemens, Germany) CT scanner that produces 128 slices of images with one rotation was used. The auto-exposure condition (AEC) was applied as it is frequently used in clinical settings for high dose CT. After the image was acquired, a qualitative analysis was conducted to verify the practical use in a clinical setting.

Findings: In order to evaluate the images acquired from the in-house produced medical phantom and the resolution in the image space, the phantom must be made of substances that have a similar actual atomic number as water. It is practical to produce the phantom for 3D CT by mixing a pure liquid and powder. The absorption, dispersion and phase differential images acquired through the low dose X-ray device were analyzed on a 5 point Likert scale. The absorption image scored 4.3 points for liquid form and 3.50 points for powder form. Both the dispersion image and the phase differential image scored 3.00 points for the liquid form and 4.50 points for the powder form, indicating that the liquid form produces better quality images in the absorption image, while the powder form produces better images in dispersion or phase differential images. The differences were statistically significant ($p<0.05$).

Improvements/Applications: The findings show that for dispersion and phase differential images, compared to the absorption images, substances in powder form rather than liquid form are conducive to better images. These findings are expected to be of use in the field of medical imaging to produce images with high diagnostic value using low dose radiation.

Keywords: *Low dose CT, image quality, phantom, performance evaluation, radiation.*

Introduction

CT tests have the patient enter a column-shaped machine that generates X-rays to produce a cross-section of the human body. CT, unlike the simple X-ray, has less overlapping of structures and thus allows for more accurate viewing of the lesion[1, 2].

With the progress made in CT technology, CT can be used for early detection of diseases no matter where the site is, present an approach to invasive tests and facilitate follow-up after treatment. It is thus often used for the diagnosis, treatment and management of any small diseases that cause anatomical changes. With such progress, it is expected that CT will become within several years, an essential part of early radiological tests or initial tests upon admission, just as liver function tests[3-10].

X-ray is classified as a grade 1 carcinogen by the WHO, along with alcohol and tobacco. As such, when

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undergoing CT or PET-CT imaging, great care is needed. The total number of CT's taken in Korea increased from 5.25 million cases in 2010 to 7.7 million in 2015. The number of CT equipment, too, increased from 2147 units in 2011 to 2300 units in 2016. This translates into 4.5 units for every 100,000 citizens, which is higher than the OECD average of 2.5 units per same number of people. But during individual check-ups, often CT tests are done unnecessarily. According to a survey by Seoul Medical Center in 2015, the maximum exposure to radiation through optional tests such as CT on the abdomen, lungs or PET CT is on average 14.82mSv. This is four times the radiation exposure Korean citizens are subject to during their daily life over a year (3.6mSv)[4,11].

The biological effects caused by ionizing radiation in medical setting can be categorized as definitive effects and possible effects. The former is the radiation that goes over the threshold of when the radiation absorbed by the human body triggers a response in the tissue. In most cases, it causes the death of cells and can only occur when a majority of cells exposed to radiation die[12].

X-ray phase differential imaging technology dramatically improves the information on borders between similar substances but with a difference in density, using data from phase differentials. It is applied to low dose CT imaging. Compared to existing imaging technologies that leverage the difference in the level of X-ray absorbed, low dose radiation can be used to generate high quality images [8-12]. However, there is a lack of studies on phase differential CT imaging, and no studies on CT phantoms where phase differential imaging has been applied.

As such, in this study, a CT phantom for the exclusive use of X-ray phase differential imaging was produced to acquire an absorption image and a phase differential image and evaluate the image quality and amount of data from the images. The findings will provide basic data for the development of CT phantoms used in phase differential imaging.

Subjects and Methodology

1. **Evaluation of the function of CT using an in-house produced phantom:** To evaluate the benefits of a phantom for low dose 3D MDCT, SOMATOM Definition ASH (Siemens, Germany) CT scanner that produces 128 slices of images with one rotation was used [Fig. 1]. The auto-exposure condition (AEC) was applied as it is frequently used in clinical settings for high dose CT [Table 1].

Table 1. Table title

Parameter	Value
Technique	Adult-Helical
kVp	80
mA	84
Time per rotation (sec)	0.6
mAs_{eff}	35
Scan Field of View	66×66
exposure time(sec)	0.416
Table speed (mm/rot)	26.5
Pitch	0.828
Reconstructed Scan Width (mm)	5

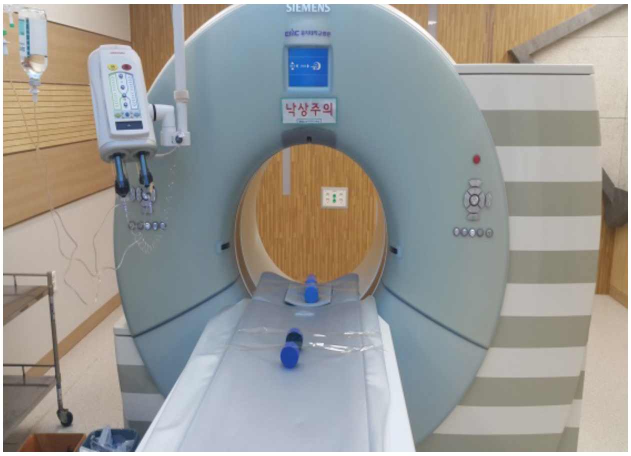

Figure 1.3D MDCT imaging device

2. **Production of a phantom for the evaluation of low dose CT:** A phantom was produced in the lab to evaluate the function of low dose 3D MDCT. To evaluate images, the phantom was produced in two types – one made with powder materials and another made of liquid materials. The phantom consisting of polyethylene was made into a column with a diameter of 3×1cm and five holes with a diameter of 0.5cm. Phosphor, calcium, calcium from anchovies, aluminum and carbon powder were placed in the holes, To acquire absorption, dispersion and phase differential images, the distance between the focal point and the object was set at 300mm, the fixed grid was placed at 700mm, and the distance between the focal point and the director was set at 1,448mm. The exposure conditions were 22kVp, 20mA and 630msec.

   For the liquid phantom, a column with a diameter of 3×1cm and five holes with a diameter of 0.5cm.

Water, sodium chloride, soybean oil, silicone oil and a phosphor solution were placed in an envelope and placed inside the holes. The conditions were set as the same for the powder phantom. The distance between the focal point and the object was set at 300mm, the fixed grid was set at 700mm, and the distance between the focal point and the director was set at 1,448mm to acquire an image under the exposure conditions of 22kVp, 20mA and 630msec.

3. **Image evaluation method:** After the image was acquired, a qualitative analysis was conducted to verify the practical use in a clinical setting. The contrast, detection rate of lesions, and the distinctness of the borders were reviewed for five groups (1: Very low, 2: Low, 3: Average, 4: High, 5: Very high). A team consisting of two medical doctors in radiology and three radiologists with more than 10 years of experience conducted the evaluation.

4. **Statistical Analysis:** For data analysis, SPSSWIN (Ver 13.0) was used. Verification of the significance of the mean value of the radiation exposure measured in the control group and the experiment group was done through a t-test and ANOVA. The significance level of all statistics was set at $p<0.05$.

Study Results and Review:

1. **Evaluation of the practical benefits of an in-house produced medical phantom for low dose 3D CT:** The phantom consisting of polyethylene was made into a column with a diameter of 3×1cm and five holes with a diameter of 0.5cm. Phosphor, calcium, calcium from anchovies, aluminum and carbon powder were placed in the holes. This phantom was used to evaluate the low dose 3D CT.

The liquid phantom is a column with a diameter of 3×1cm and five holes with a diameter of 0.5cm. Water, sodium chloride, soybean oil, silicone oil and a phosphor solution were placed in an envelope and placed inside the holes. In addition, to evaluate the image spatial resolution, phosphor, calcium, aluminum and barium were placed in holes with a diameter of 0.1 cm, 0.2 cm, and 0.3 of the medical phantom produced.

For the liquid phantom, a column with a diameter of 5×10 cm made of polyethylene and holes with a diameter of 0.5 cm were created. Water, phosphor, calcium, aluminum and barium in liquid form were injected into the holes for the images to be acquired.

The images acquired from high dose CT using a medical phantom in powder form were as seen in [Fig. 2]. An image of the water, phosphor, calcium, aluminum and carbon substances showed that a distinction of concentration was possible for water and carbon, while for phosphor, calcium and aluminum the high unit density led to images with beam hardening.

The high dose CT imaging test results using a medical phantom in powder form are as seen in [Fig. 2]. Depending on the type of substance, due to beam hardening, evaluation on the image's spatial resolution varied. This shows that to evaluate the spatial resolution in images from CT, substances with a similar actual atomic number to that of water must be used. This finding is expected to be important when producing a medical phantom for CT in the future.

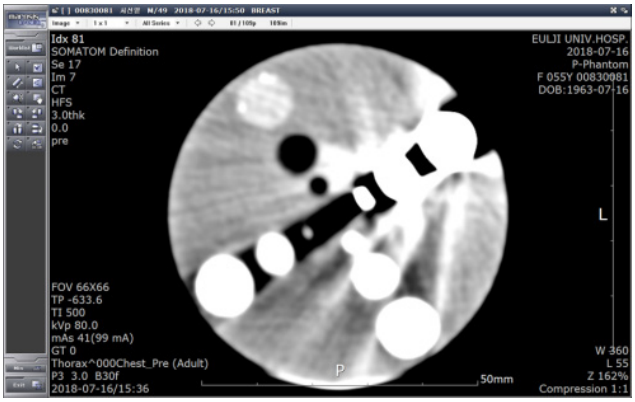

Figure 2. Images acquired from the medical phantom in powder form to evaluate the spatial resolution

To evaluate the practical benefits of a medical phantom made of liquid substances, a 3D CT image was acquired after placing water, phosphor, calcium from anchovies, aluminum and carbon powder inside the phantom. The 3D CT image of a liquid phantom [Fig. 3] shows that for substances with a similar valid atomic number to that of water, three dimensional distinction was difficult. Meanwhile, images acquired when water and powder were mixed, showed a decent three dimensional distinction as seen in [Fig. 3]. This finding indicates that when producing a medical phantom for low dose 3D CT, a mix of liquid and powder is beneficial.

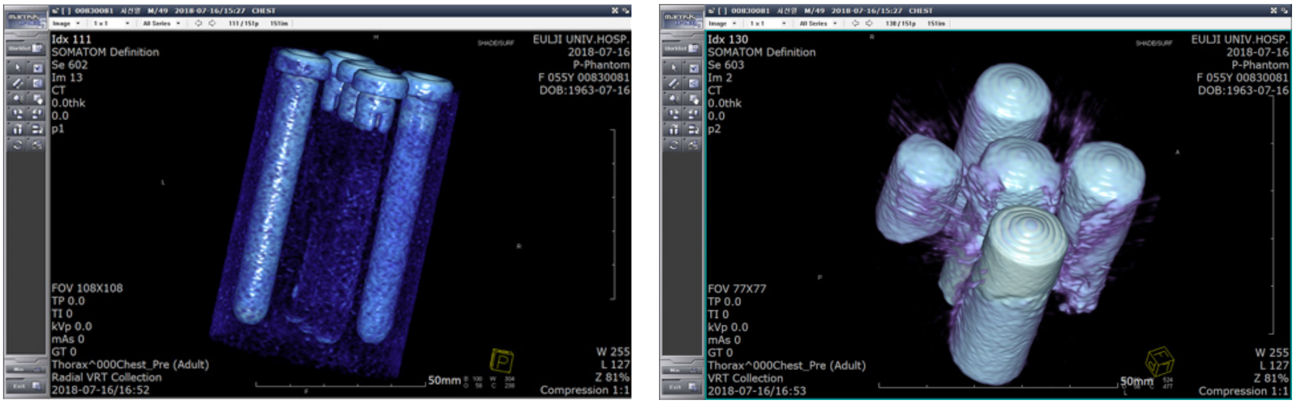

Figure 3. Image acquired for the medical phantom made of a mix of liquid and powder substances

2. **Findings from the evaluation of low dose X-ray images:** To produce a phantom that would enable evaluation of the function of low dose 3D MDCT, absorption, dispersion and phase differential images were acquired using low dose X-ray. The liquid phantom is a column with a diameter of 5×1cm and five holes with a diameter of 0.5cm. Water, sodium chloride, soybean oil, silicone oil and a phosphor solution were placed in an envelope and placed inside the holes.

Absorption, dispersion and phase differential images were acquired using the in-house produced phantom. The distance between the focal point and the object was set at 300mm, the fixed grid was set at 700mm, and the distance between the focal point and the director set at 1,448mm. Radiation was applied under the conditions of 22kVp, 20mA and 630msec.

Images acquired from a medical phantom made of liquid substances showed that there was a distinction in contrast for different substances in the absorption image. In the dispersion and phase differential images, more difference was found in the amount of data provided rather than in the contrast [Fig. 4]. In particular, when industrial silicone oil was used, there was a distinct difference in the dispersion and phase differential images compared to in the absorption image. This seems to be due to the difference in the valid atomic number.

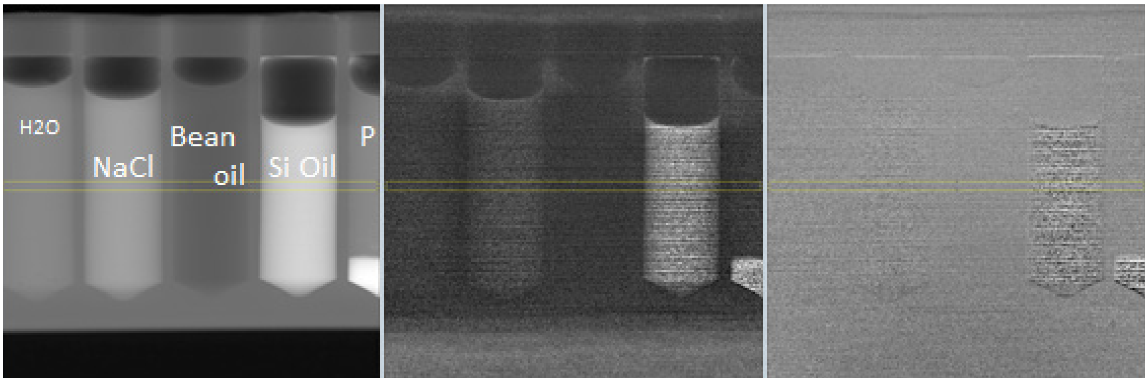

Figure 4. Image Absorption, dispersion and phase differential images of the liquid phantom

The powder medical phantom is a column with a diameter of 5×1cm and five holes with a diameter of 0.5cm. Phosphor, calcium, calcium from anchovies, aluminum and carbon powder were placed in the holes, To acquire absorption, dispersion and phase differential images, the distance between the focal point and the object was set at 300mm, the fixed grid was placed at 700mm, and the distance between the focal point and the director was set at 1,448mm. The exposure conditions were 22kVp, 20mA and 630msec.

While in the absorption image there was a difference in contrast for different substances of the powder phantom, the distinctiveness in contrast between calcium orphosphor was subtle, making it difficult to tell them apart. Meanwhile, in the dispersion and phase differential images, there was a relatively greater difference in the amount of data provided in the image, rather than a difference in contrast [Fig. 5].

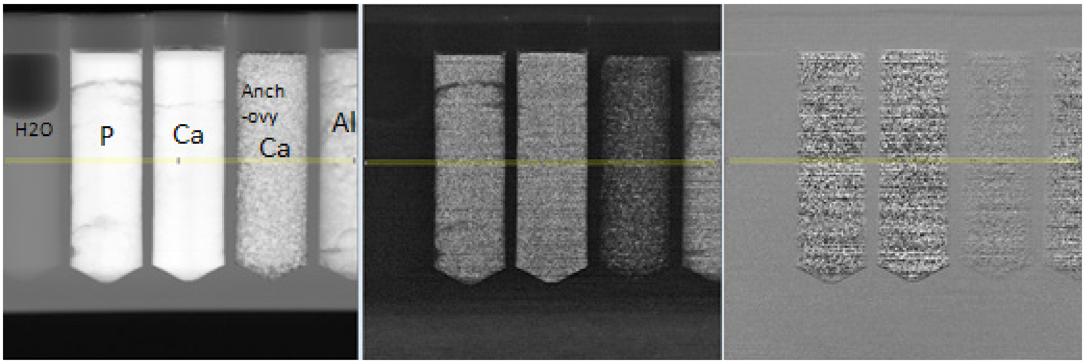

Figure 5. Image Absorption, dispersion and phase differential images of the liquid phantom

The absorption, dispersion and phase differential images acquired using a low dose X-ray imaging device were analyzed on a 5 point Likert scale. In the absorption image, the score was 4.30 points for the liquid phantom and 3.50 points for the powder phantom. In the dispersion and phase differential images, the score was 3.00 points for the liquid phantom and 4.50 points for the powder phantom. The image quality was higher in the liquid phantom for the absorption image and in the solid phantom for the dispersion and phase differential images. There was also a statistically significant difference ($p<0.05$).

The findings suggest that compared to the absorption image, in the dispersion image and phase differential image, the powder phantom is more conducive to higher quality images. As such, it is expected to usemore widely in acquiring images that offer high diagnostic value through low dose X-ray imaging.

Conclusion

A CT phantom for X-ray phase differential imaging was produced in the lab to analyze its practical benefits in high dose CT. The absorption, dispersion and phase differential images were acquired from low dose X-ray devices to evaluate the image quality and the amount of information provided by the image.

The evaluation showed that in order to evaluate the spatial resolution of images acquired, the medical phantom for the CT must be made of substances with a similar valid atomic number to that of water, and that it is best that the phantom be made with a mix of liquid and powder substances.

An analysis of the absorption, dispersion and phase differential images acquired from low dose X-ray imaging devices on a 5 point Likert scale showed that the score for the absorption image was 4.30 points for the liquid phantom and 3.50 points for the powder phantom. In the case of dispersion and phase differential images, the score was 3.00 points for the liquid phantom and 4.50 points for the powder phantom, this indicates that the liquid phantom is more beneficial for the absorption image and the powder phantom is more beneficial for dispersion and phase differential images in acquiring high quality images. There was a statistically significant difference in this ($p<0.05$).

In the above experiments, the dispersion and phase differential images, compared to the absorption image, was better at producing images for substances in powder form rather than in liquid form. This finding is expected to have many applications in the field of imaging technologies to produce images with high diagnostic value using low dose X-ray.

Ethical Clearance: Not required

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Conflict of Interest: Nil

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