Phantom design for analysis of CT image quality from Single-source and Dual-source CT scan

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Abstract. Computed Tomography (CT) Scanner is a three-dimensional body imaging modality. For observation of moving organs, in addition to using Single-source CT (SSCT), Dual-source CT (DSCT) has been developed which is equipped with primary and secondary x-ray sources. The position of the two DSCT sources forms an angle of 90°, and at the time of image acquisition both rotate 90°. Thus the process of image acquisition of a moving body can be carried out in a relatively short time. If the same examination using SSCT, it is necessary to decrease the movement of organs which generally use beta blockers. In this research, in-house phantom has been designed to analyze the image quality character of the two types of CT which will then be compared. Phantom is cylindrical in shape and has a diameter of 20 cm and a length of 12 cm, divided into three sections of 4 cm each. The first module, phantom is intended for noise measurement, in the phantom implanted 16 cylindrical objects with diameters of 10 mm and 15 mm, made of 4 types of material with different Hounsfield Unit (HU) values, namely teflon (941.31 ± 14.61) HU, water (0.548 ± 0.43) HU, polystyrene (-26.38 ± 13.55) HU, and air (984.32 ± 27.97) HU. The second module, phantom will be used to assess the detectability. This section is filled with 26 cylindrical pipes with diameters, 2, 3, 4, 5, 6 mm for each of the 5 pipes and one other pipe with a diameter of 10 mm. All of these pipes will be filled with contrast media Iodine with varying concentrations. The third module, phantom will be used to measure spatial resolution and homogeneity. In this section copper ball objects will be implanted with a diameter of 0.19 mm and a length of 4 cm. Furthermore phantom will be used for measurement of noise, spatial resolution and detectability of this CT image from dual-source and single-source CT scans with the exposure conditions adjusted for clinical use.

1. Introduction
At the present time, there is a CT Scan tool with Multi Slice Computed Tomography (MSCT) advantage. Basically, the basic principles of MSCT are the stationary movement of x-ray tube and the continuous emit of x-ray, accompanied by the patient’s movement by control table, through the irradiation tube so it will produce more slices (multi slice) in every of the patient’s movement [1]. On the MSCT, other than using one source within the gantry, two sources and two detectors in one gantry have also been developed and known as Dual-source (DSCT).

Dual-source CT Scan uses two x-ray sources and two set of detectors simultaneously in different exposure conditions. The position of the two DSCT sources forms 90° angle and during acquisition, both source and detectors rotate 90°. During the acquisition, two sets of data spiral images were obtained...
from these two energies, attributed from 80 kV and 140 kV. By using this dual source, it enables the image acquisition to be faster, it can be done in 83 ms. DSCT is generally used for cardiac imaging involve with small arteries which require faster acquisition and high resolution images. Because the image acquisition is faster so it can be used for cardiac arteries that are relatively smaller and faster in high resolution [2]. Other than for cardiac examination, DSCT can also be used as general by using one x-ray source.

In order to maintain the image quality, the CT scan reliability and certainty has to be ensured. Quality Control (QC) for the CT scan is really necessary to ensure the produced image quality did not have any changes during the operation. Therefore, QC is really necessary for CT scan, as written in AAPM Report 39, IAEA No. 19 of 2012, Western Australia Compliance Testing Protocol 2006 and Perka BAPETEN No.9 of 2011. The determination of the image quality depends on several parameters, such as spatial resolution, noise, and detection ability. Each of these parameters has their own determination method [3].

In order to ensure the quality of CT Scan’s image, there needs to be a QC program on the image quality parameter to monitor the imaging device periodically [4]. Various tests to analyse the image quality are generally conducted using phantoms. Various types of QC phantoms for CT Scan are developed using materials equivalent to tissues for radiation dosimetry study. The most important principles in designing phantom with high accuracy rate is by selecting materials that are equivalent to human body’s tissues, both physically or its response towards x-ray [5].

In this study hybrid phantom for QC SSCT and DSCT has been designed. By using this phantom several parameters indicating quality images can be measured, particularly noise, spatial resolution and object detectability. The materials of this phantom and objects were selected as various tissue material. Furthermore, geometrical aspects such as object’s size, shape, spatial position and other specifications had become considerations in constructing this phantom.

The in-house phantoms made and developed in this research were made for DSCT’s QC that was specifically made for cardiac examination, therefore these phantoms were designed to be able to detect the image of cylinder pipe with media contrast of various object sizes, in form of cylinder pipe as the simulation for arteries. Meanwhile for SSCT scan examination, the phantoms were designed to have different CT numbers as the simulation of soft tissue, bone, water and air. As a result, the in-house phantoms were able to be used to measure the image quality of the CT scan in the image quality assurance program.

2. Material and Method

2.1. In-House Phantom’s Designing and Construction

The materials used in making this phantom consisted of acrylic or Polymethyl methacrylate (PMMA) as the basis for the phantom. PPMA material was used for the simulation of soft tissues and several materials were used to be insert to the phantom as the detection object, such as teflon, polystyrene, air, water, and 0.19 mm copper wire, as well as cylinder pipes filled with iodine.

Before making the in-house phantom, the phantom materials were scanned to know the value of HU and electron density from the used materials. The HU values of each sample were evaluated and compared with the HU values of the material of the reference phantom. CIRS phantom was used to calibrate the HU value with the material’s electron density.

The phantom’s design was made by considering the shape geometry, object’s size, object’s position, material type, and the type of test. The shape and size of the phantom complied with the standard phantom qualification. The material density used within the in-house phantom was measured and weighed using digital scale for mass test, while the volume measurement was conducted using graduated cylinder. The measurement of the mass and volume was repeated 5 times for each sample.

The in-house phantom was made in the shape of cylinder with 20 cm diameter and 12 cm length, divided into 3 modules: A, B, and C with 4 cm thickness for each module. Module A was insert with 16 cylinders object with 8 detection objects at the center part and 8 at the periphery parts with 10 mm and
15 mm diameter. The detection object on module A was made of teflon, polystyrene, air and water materials, as shown in Figure 1(a). Module A phantom was used to assess the noise and accuracy of CT number from each material. For detection, the CT number value at the center and periphery, as displayed in Figure 1a. Module B was filled with 26 cylinder pipes with 2, 3, 4, 5, 6 mm diameter for each of the 5 pipes and one pipe had 10 mm diameter. The use of cylinder pipes of various diameter sizes was used as the simulation for artery. All of these pipes were to be filled with iodine at various concentrations. The contrast media used was Ultravist 300 mg/l, varied on 2 concentrations, which were the comparison of 1 ml iodine: 1000 ml aquabidest and 1 ml iodine: 500 ml aquabidest. Module B phantom was used for low contrast detectability test. Module C with in solid shape would be planted on copper bead object with 0.19 mm diameter and 4 cm length, as displayed in Figure 1b. Module C was used to conduct the uniformity test to see the uniformity of CT number values on the phantom, both at the centre or periphery part. Meanwhile, the bead object was used to evaluate MTF measurement, as displayed in Figure 1c.

![image](image1.png)

**Figure 1.** In-house phantom slice for each part (a) Modul A (Left: Schematic design, Right: Real phantom photo) for noise analysis, (b) Modul B for detectability analysis (c) Modul C for spatial resolution and uniformity measurement.

2.2. **In-House Phantom Trial Test**

The test on the in-house phantom was conducted by scanning the phantom modules, as displayed in Figure 2. Each phantom module had its own function to assess the image quality from the CT scan. Module A was to evaluate the image quality on SSCT in general, module B was specifically used to evaluate the image quality on DSCT, and module C was to evaluate the spatial resolution and uniformity.

The scanning of phantom was conducted on the CT scan single-source and CT scan dual-source by placing the phantom’s center at the rotation center. The parameters of the scanning complied with the
standard criteria for cardiac imaging based on the clinical condition and there were several variations of exposure factors to see the effects of exposure factors towards the produced image quality.

![Image of phantom images](image1.jpg)

**Figure 2.** The image result from the scanning test on phantom by using SSCT. (a) Module A phantom image (b) Module B phantom image (c) Module C phantom image

3. Results and Discussions

3.1. In-House Phantom Construction

For in-house phantom, the local materials used in the phantom making consisted of acrylic or PMMA to simulate soft tissues, teflon was used to simulate bone, polystyrene was used to simulate soft tissue and water and air materials.

The material density used on the phantom was measured at the Biophysics Laboratory of Indonesia University. The samples of the materials were weighed using digital scale for mass test, while the volume was measured using measuring cylinder. The data from the mass and volume test were calculated to obtain the material density value, in accordance to the following equation:

$$\rho = \frac{m}{v} \quad \text{(gr/cm}^3)$$  \hspace{1cm} (1)

The density value of these phantom materials were compared with the material density of standard phantom (CIRS) and default phantom from several CT vendors, as shown on Table 1.
Basically, the organ density on each human is different, either for the soft tissue, bone or lung. This is affected on several factors, such as the factor of environment, food intake, or body activities. Table 1 shows that there was deviation on the value of local material’s density on the CIRS standard phantom.

Table 1. The comparison of phantom material’s density value

| Material type | Organ simulation | CIRS density (gr/cm³) | Local Material density (gr/cm³) | Deviation (%) |
|---------------|------------------|-----------------------|---------------------------------|---------------|
| Acrylic/PMMA  | Soft tissue      | 1.04                  | 1.15 ± 0.01                     | 10.58         |
| Acrylic/PMMA  | Tumor tissue     | 1.06                  | 1.15 ± 0.01                     | 8.49          |
| Teflon        | Bone             | 1.91                  | 2.17 ± 0.02                     | 13.61         |
| Polystyrene   | Soft tissue      | 1.05                  | 1.16 ± 0.005                    | 10.48         |

Table 1 shows the differences in the value of local material’s density and CIRS phantom’s materials. The acrylic/PMMA materials were used to simulate soft tissue and the obtained density was 1.15 ± 0.01. Teflon materials were used to simulate bone and the obtained density was 2.17 ± 0.02 gr/cm³. Polystyrene materials were used to simulate soft tissue and the obtained density was 1.16 ± 0.005 gr/cm³. In 1992, Lohman et al conducted the measurement on the estimation of bone mineral’s density and the obtained density for normal bone, the average bone mineral’s density was around 3.88 gr/cm³ for men and 2.9 gr/cm³ for women [6]. A research conducted by Cameron et al (1999) obtained the density of the cortical bone of 1.9 gr/cm³ [7].

The measurement on the Hounsfield Unit (HU) and CT number was conducted by scanning on the phantom samples using the Philips CT scan and using exposure factor at 120 kV and 100 mA. In order to obtain the HU value for each material, we conducted Region of Interest (ROI) and the average value of each material was taken.

Table 2. The comparison of Hounsfield Unit (HU) on local materials with organ

| MATERIAL        | ORGAN SIMULATION | HU VALUE     | Organ     |
|-----------------|------------------|--------------|-----------|
| Acrylic/PMMA    | Soft tissue      | 123.82 ± 2.49| + 25 to +300 |
| Teflon          | Bone             | 941.31 ± 14.61| +300 to +2000 |
| Polystyrene     | Mass/tumor       | -26.38 ± 13.55| -50 to -25 |
| **Hole**        | Air              | -984.32 ± 27.97| -1000 to -980 |
| Water           |                  | 0.548 ±0.43  | -7 to +7  |

Table 2 shows the comparison between HU value of the local materials of the phantom and the organ’s HU. The measurement of HU value shows that the HU value of this material was still within the proper range of the HU from the simulated tissues. H. Jiang et.al obtained the HU value of air at around -1000 to -950, while for lung tissue was -949 to -120, for soft tissue was -119 to +120, and for bone was +121 to +1600 [8]. Siemens Medical Solution, Germany also produced the CT number value ranging from 110 kVp – 130 kVp, solid bone 250 – 1000 HU, soft bone 50 – 200 HU, water 0 HU, fat (-80) – (-100) HU, lung (-950) – (-550) HU, air (-1000) – (-990) HU and intra-abdominal organ (kidney, pancreas, blood, liver) around 20 – 70 HU. If these two parameters were compared (Siemens Medical Solution and H. Jiang. et.al 2007), the HU value of the local materials used in the in-house phantom was still in accordance with the simulated organ.

The result from this density and HU test was one of the essential parameters that influence the measured CT scan dose as well as the produced images. Each material had different electron density which affected the absorption and scattering towards the incoming radiation. The HU value depends on the composition of the tissue and material, kV usage.
3.2. Result of In-House Phantom Trial Test
The test that was conducted on the in-house phantom provided three different module images as shown on Figure 2. Every module had its own functions to analyse the image quality on DSCT and SSCT. The images from Module A phantom could be used to analyse noise measurement and to measure the accuracy CT Number on each material. The placement of detection objects at the centre and periphery part of the phantom was meant to see the effect of object’s position towards the measured noise value, and the determination of detection objects at different sizes was intended to see the effect of object’s size towards noise value, as shown on Figure 2a. Module B phantom image could be used to analyse the low contrast detectability by using iodine contrast media. The placement of detection objects with 6 different diameter sizes was meant to see to what extent CT scan was able to detect the object at the smallest size by using contrast media. The use of contrast media with different variations on module B phantom can be seen on the produced image, as shown on Figure 2b. Module C phantom image could be used to analyse the uniformity of the CT number, both for those on the centre or periphery parts. Meanwhile, the point object was used to evaluate the spatial resolution with MTF measurement, as shown on Figure 3c.

Based on the conducted test on the in-house phantom and the image result from every module, the produced in-house phantom could be considered as good and usable for performing the analysis on the image quality of SSCT and DSCT in hospitals.

4. Conclusions
In this research, an in-house phantom for CT scan by using local material. This phantom has been designed for as SSCT and DSCT, for analysing several parameter QC for image quality. The designed in-house phantom had been tested and it could be used to evaluate the image quality of SSCT and DSCT.

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