Distribution dose profile of Computed Tomography (CT) along the z-axis with pitch variation: in-house phantom study

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Abstract. Computed Tomography (CT) is an x-ray modality for scanning organ in three dimensional images. Image acquisition is performed by rotating x-ray tube that match with table movements, the tube can cover patient body in a spiral scan. Patient table movements by gantry rotation divided by the width of the collimator on the isocenter is known as a pitch, which affects the quality of image and radiation dose in the patient. A dose distribution profile has been observed along the z-axis of the in-house thorax phantom simulation in an elliptical cylinder form with the size of 28 cm x 21 cm and 22 cm length. Phantom was equipped with a lung simulation object using a cork with a Hounsfield Unit (123.1 HU), a spine using Teflon material (918.6 HU), and 9 bar and a cylinder to place 1 cm x 25 cm gafchromic films. The position of the film was marked with point position 1–9 for the series of coordinates (0,0), (5, 0), (10, 0), (-5, 0), (-10, 0), (0, 4), (0, 8), (0, -4), (0, -8) cm. The phantom images were performed with an exposure condition by 120 kV, 100 mAs and pitch variations (0.8, 1.0 and 1.5). The minimum dose occurred at the beginning and end of the scan for all profiles and pitch values. The average dose of lung material (1, 2, 4, and 5) in the range 2.32–2.88 mGy for pitch 0.8 and 1.0 respectively, and 2.25–2.68 mGy for pitch 1.5. The dose in lung was relatively lower compared to the dose in soft tissue and bone. The maximum dose does not always occur in the middle of the z-axis, but it was fluctuated as it was influenced by the pitch values in the range of 10 - 12 cm. It can be concluded that the use of pitch 0.8 and 1.0 did not provide a significant dose difference and reduced the average dose on pitch 1.5. Moreover, the maximum dose does not always occur in the middle of the z-axis due to an isotropic material.

1. Introduction
Computed Tomography (CT) is x-rays modality for scanning organ in three dimensions. The image acquisition is done by the rotation of x-rays tube with the table movement, so the tube will circle around the patient in spiral-shape. The ratio of the patient’s table motion (mm) per rotation of 360° gantry to collimator width (mm) on the isocenter is known as pitch, which affects the quality of image or radiation dose to the patient [1].

In this work dose profile along z-axis of in-house thorax phantom has been studied. Two major factors that have been considered were pitch and several selected axial positions that profiles measured. Phantom is cylinder-ellipse shape; measurement is done by gafchromic film from dose profile information along axis-z in 9 different positions from the image acquisitions to various pitches.
Dose profile image, generally is an arranged sinusoidal wave. In certain positions, dose profile has a shape near the line. The position and pitch affected the amounts of periods and amplitude of the wave.

2. Material and Method

2.1 Material

This research uses CT-scan Philips 128 slices belongs to RSUD Cibinong Bogor, in-house phantom, gafchromic film XR-QA2, and ion chamber Unfors-XI. In-house phantom is made from PMMA equipped with lungs simulation objects from cork with Hounsfield Unit (123.1 HU) and a spine from teflon (918.6 HU). Phantom is elliptical shape with minor axis 28 cm, major 21 cm, and 22 cm length, which obtained from the result of CT image survey from 40 patients in RSUD Cibinong Bogor. In-house phantom is shown in figure 1. In the phantom, there are 9 holes with 4 bars and 5 cylinders for the film gafromic house. The position of the films is marked by coordinat system 1 (0, 0), 2 (5, 0), 3 (10, 0), 4 (-5, 0), 5 (-10, 0), 6 (0, 4), 7 (0, 8), 8 (0, -4), 9 (0, -8) cm. The position of the hole on phantoms can be seen in figure 1.

This research uses Gafchromic film XR-QA2. The film is used to measure the dose distribution profile in in-house phantom. This Gafchromic XR-QA 2 film works in 20 kVp energy until 200 kVp energy and has a sensitivity in 0.1 cGy dose up to 20 cGy. The film is cut with size about 1 cm × 5 cm for calibration, then to measure it, the dose profile is cut with size 1 cm × 25 cm [2].

![Figure 1](image1.png)

**Figure 1.** (a) Thorax in-house phantom with 4 bars and 5 cylinders (b) The hole position of film placing on in-house phantom

2.2 Method

In-house phantom image acquisition using an exposure factor of 120 kV and 100 mAs, usually used for clinical chest CT images. Pitch variations used in this study were 0.8, 1.0 and 1.5. For collimation wide uses 16 × 0.625 mm. Measurement of the dose distribution profile is focused on the thorax that is simulated with in-house phantom. In measuring the CT-scan radiation of dose distribution is divided into two parts; film calibration and measurement of in-house dose distribution. Film calibration is done to determine the relation between pixel value and radiation dose. Calibration process is done using ion chamber Unfors-XI which is placed on the centre of phantom to get a radiation dose on phantom. During the calibration process, the Gafchomic film is placed on the centre of phantom in the same position as the dose measurement using ion chamber. Film is placed perpendicular toward ray beams and scanned using the same protocol as ion chamber. The scanning repetition is done 3 times with range 25-500 mAs [3].

In-house phantom is measured by measuring radiation dose distribution profile using the piece of Gafchomic film. The long piece of Gafchomic film is inserted into 4 bars and 5 cylinders and into 9 different phantom holes along axis-z on in-house phantom. The insertion of film is placed on decided coordinate system 1 (0, 0), 2 (5, 0), 3 (10, 0), 4 (-5, 0), 5 (-10, 0), 6 (0, 4), 7 (0, 8), 8 (0, -4), 9 (0, -8) cm.

The phantom is exposed with decided parameter with pitch variation times repetitions of 0.8, 1.0, and 1.5 and 3. The exposed film is saved 2 x 24 hours, and scanned by using flatbed scanner Epson.
Perfection V700 photo. The film is scanned in reflective mode with resolution 72 dpi and pixel depth 48-bit. The result of the film is saved in TIFF format and analysed using ImageJ software.

3. Result and discussion

3.1 Dose profile

Dose profile has maximum dose in the middle and decreased dose toward the edge. The minimum dose is shown in the beginning and end of scan to get a whole profile and pitch value [4]. Dose profile image, generally is an arranged sinusoidal wave. In certain positions, dose profile has a shape near the line. In certain positions, dose profile has a shape near the line. The dose profile for pitch 0.8, 1.0 and 1.5 in position 2 illustrated in figure 2.

![Figure 2](image_url)

**Figure 2.** The comparison of dose profile with 3 times repetitions (a) position 2 pitch 0.8, (b) position 2 pitch 1.0, (c) position 2 pitch 1.5.

In pitch 0.8 and 1.5, dose profile has a sinusoidal shape and amplitude on position 2, 3, 4, 5, 7, and 9 while pitch 1.0 has a sinusoidal shape and amplitude on position 2 and 4. For position 6 and 8 on pitch 0.8 and 1.5 dose profile has a shape near the line while pitch 1.0 dose profile has a shape near the line on position 1, 3, 5, 6, 7, 8, and 9. For position 2, 3, 4, 5, 7, and 9 in pitch 1.5 has a bigger amplitude compared pitch 0.8.
The number of wave in pitch 0.8 is more compared pitch 1.0 and 1.5. The bigger the pitch value, the number of wave is fewer. Pitch 0.8 has the most number of wave because of the overlapping among the scan beam, so it results in better image quality but absorbs more for the long-time of scanning. Pitch 1.5 has a fewer absorbency dose because there is a gap in each pieces and results in the distance between the scan beam and the timing of scanning needed is shorter so it decrease the absorbency dose of the patient. The shape and character of dose profile for pitch 0.8, 1.0, and 1.5 can be seen on table 1.

Table 1. The shape and character of dose profile for pitch 0.8, 1.0, and 1.5.

| Pitch | Position | Shape       | Number of wave | Amplitude (mGy) | Description                                                                 |
|-------|----------|-------------|----------------|-----------------|-----------------------------------------------------------------------------|
| 0.8   | 1        | close to the line | -              | -               | Dose profile has similarities for position 2 with 4, 3 with 5, and 1 with 6, and 8 dose profiles have line shape. |
|       | 2        | Sinusoidal  | 28             | 0.30            |                                                                             |
|       | 3        | Sinusoidal  | 28             | 0.24            |                                                                             |
|       | 4        | Sinusoidal  | 28             | 0.20            |                                                                             |
|       | 5        | Sinusoidal  | 28             | 0.38            |                                                                             |
|       | 6        | close to the line | -              | -               |                                                                             |
|       | 7        | Sinusoidal  | 28             | 0.30            |                                                                             |
|       | 8        | close to the line | -              | -               |                                                                             |
|       | 9        | Sinusoidal  | 28             | 0.25            |                                                                             |
| 1.0   | 1        | close to the line | -              | -               | Dose profile has similarities for position 2 with 4, and for position 1, 3, 5, 6, 7, 8 and 9 dose profiles have line shape. |
|       | 2        | Sinusoidal  | 22             | 0.19            |                                                                             |
|       | 3        | close to the line | -              | -               |                                                                             |
|       | 4        | Sinusoidal  | 22             | 0.22            |                                                                             |
|       | 5        | close to the line | -              | -               |                                                                             |
|       | 6        | close to the line | -              | -               |                                                                             |
|       | 7        | close to the line | -              | -               |                                                                             |
|       | 8        | close to the line | -              | -               |                                                                             |
|       | 9        | close to the line | -              | -               |                                                                             |
| 1.5   | 1        | close to the line | -              | -               | Dose profile has similarities for position 2 with 4, 3 with 5, and for position 1,6 and 8 dose profiles have line shape. |
|       | 2        | Sinusoidal  | 15             | 0.31            |                                                                             |
|       | 3        | Sinusoidal  | 15             | 0.39            |                                                                             |
|       | 4        | Sinusoidal  | 15             | 0.36            |                                                                             |
|       | 5        | Sinusoidal  | 15             | 0.41            |                                                                             |
|       | 6        | close to the line | -              | -               |                                                                             |
|       | 7        | Sinusoidal  | 15             | 0.50            |                                                                             |
|       | 8        | close to the line | -              | -               |                                                                             |
|       | 9        | Sinusoidal  | 15             | 0.30            |                                                                             |

3.2 The average dose and maximum dose
The average dose of the lung objects (position 2, 3, 4, and 5) in range 2.39-2.88 mGy for pitch 0.8 and 2.32-2.80 mGy for pitch 1.0, and 2.25-2.68 mGy for pitch 1.5. The average dose on soft tissue (position 1, 6, 7, and 8) in range 3.04-3.36 mGy for pitch 0.8 and 2.98-3.29 mGy for pitch 1.0 and 2.77-3.21 mGy for pitch 1.5. Then, the average dose on spine object (position 9) 2.58 mGy for pitch 0.8 and 2.52 mGy for pitch 1.0, and 2.39 mGy for pitch 1.5. The amount of average dose on all positions can be seen on the figure 3. From figure 3, it can be seen that the average dose on all positions among pitches, the
smaller the pitch value, the received dose is bigger while the bigger the pitch value, the dose is smaller [5]. For the lungs object on the position 2 and 4, and 3 and 5 have the average dose that close to pitch 0.8, 1.9, and 1.5. The biggest average dose is on the soft tissue (position 7) on every position. This happens because on the position is close with ct-scan collimator since the phantom elliptical cylinder. For the spine object (position 9), it has the lower average dose compared to soft tissue (position 7) because of the attenuation of patient table [3]. for soft tissue (position 6), it receives the higher average dose compared to soft tissue (position 8). This is caused by the near position of ct-scan collimator, while position 8 is close to the patient table.

Figure 4 shows the maximum dose on the lungs object (position 2, 3, 4, and 5) in range 3.19 – 3.73 mGy for pitch 0.8 and 2.82 – 3.47 mGy for pitch 1.0, and 2.92 – 3.49 mGy for pitch 1.5. The maximum dose on the soft tissue (1, 6, 7, 8) in range 3.66-4.23 mGy for pitch 0.8 and 2.99 mGy for pitch 1.0, and 2.98 mGy for pitch 1.5 [6]. The amount of maximum dose on all positions can be seen on graphic 2. The highest maximum dose for pitch 0.8 and 8 are on soft tissue (position 7) while for pitch 1.5 is on position 6. The smallest maximum dose for pitch 0.8 is on the lungs object (position 5), for pitch 1.0 and 1.5 are on position 3. The average of the smaller maximum dose is caused by heterogeneous and the possibility of the gap among slices on in-house phantom [7].

![Graph 3](image3.png)

**Figure 3.** Graphic the average dose relations among film positions on pitch 0.8, 1.0, and 1.5.

![Graph 4](image4.png)

**Figure 4.** Graphic the maximum dose relations among film positions on pitch 0.8, 1.0, and 1.5.
Figure 5. Graphic the maximum dose distance relations among film positions on pitch 0.8, 1.0, and 1.5.

Figure 5 is a graphic of relations among the distance of the maximum dose on the phantom. The maximum dose on phantom is in range 10.70-11.78 cm for pitch 0.8 and 10.65-11.76 cm for pitch 1.0, and 10.29-11.99 cm for pitch 1.5. The maximum dose generally occurred at close to the middle of the to distance because at the region scattered radiation is the maximum.

4. Conclusion
This research gives information that the amounts of periods on pitch 0.8 is more compared to pitch 1.0 and 1.5. The bigger the pitch value, the amount of the periods is fewer; otherwise the smaller pitch value so the amount of the periods is bigger. For the lungs object on position 2 and 4; and 3 and 5 have the average dose near the pitch 0.8, 1.0, and 1.5. The biggest average dose is on the soft tissue (position 7) on every position. This happens because on the position is close with ct-scan collimator since the phantom elliptical cylinder. The maximum dose generally occurred at close to the middle of the to distance because at the region scattered radiation is the maximum.

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References
[1] Bushberg J, Boone J 2011 The essential physics of medical imaging, 2nd edition, (Philadelphia: Lippincott Williams & Wilkins) pp 262-264
[2] Ashland, "Gafchomic™ XR film State-of-the-art processor-less products for radiology applications (US:Wilmington) pp 1-4
[3] Alvaro Mauricio, Ladino Gómez, Arnaldo Prata Mourão 2016 Proceedings of the ISSSD (Mexico: ISSD) vol 3 pp 17-26
[4] Steven R. Jackson, Salahuddin Ahmad, Yida HuEvaluation 2013 Journal Of Applied Clinical Medical Physics 14 227
[5] Hunt D C, Easton. H, Caldwell. C B 2011 Recent Advances in Biomedical & ChemicalEngineering and Materials Science (Lebanon: ResearchGate) pp. 51-54
[6] Mourão A P, Alonso T C, DaSilva T A, 2014 Radiation Physics and Chemistry, 95 254
[7] Paramita N, Mulyono N, Hidayanto E 2014 Youngster Physics Journal, 3 357