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Comparison of CTDIw and Homogeneity Index on CTDI Phantoms

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Abstract

The study was conducted to compare the Computed Tomography Dose Index Weighted ($CTDI_w$) value values and homogeneity index on head and body phantoms with tube voltage variations. Two CTDI phantoms are Gammex (Sun Nuclear, Florida, United States) and IBA (IBA Dosimetry, Schwarzenbruck, Germany). The pencil ionization chamber was used for the measurement of CTDI. The measurements were carried out with a Toshiba Alexion 16 MSCT in a single rotation of axial mode with detector position in the phantom's center, top, bottom, right, and left. Tube voltage values are 80 kVp, 100 kVp, and 120 kVp. Then, the homogeneity test of the phantom was carried out. The homogeneity value was obtained by measuring the average CT number in the image by determining the region of interest (ROI) at positions namely a, b, c, d, and e, In addition the ratio of the two phantoms was also carried out. The ratio was obtained from the difference of the $CTDI_{100}$ value at the edge to the $CTDI_{100}$ value at the center of the head and body phantom from Gammex and IBA. The results showed that the $CTDI_w$ of the Gammex head phantom are 26.83 mGy (80 kV), 53.32 mGy (100 kV) and 83.32 mGy (120 kV). While the $CTDI_w$ of the Gammex body phantom are 11.73 mGy (80 kV), 21.58 mGy (100 kV) and 36.45 mGy (120 kV). In comparison, $CTDI_w$ of the IBA head phantom are 27.01 mGy (80 kV), 55.33 mGy (100 kV) and 81.69 mGy (120 kV). While the $CTDI_w$ of the IBA body phantom are 11.85 mGy (80 kV), 23.32 mGy (100 kV) and 35.00 mGy (120 kV). The differences in $CTDI_w$ of the two phantoms were within (head phantom is 0.18 % – 2.01 %) and (body phantom is 0.13 % – 1.75 %). The difference below 5% with the p-value of the head phantom is 0.87 and body phantom is 0.89 (more than 0.05) indicates that the two phantoms are not significantly different because the two phantoms are made of the same material. The average ratio for the Gammex head phantom is 1.12 – 1.28, while the IBA head phantom is 1.07 – 1.28. Then the average ratio for the Gammex body phantom is 2.03 – 2.56, while for the IBA body phantom is 1.91 – 2.59 which indicates that the head phantom produces a more uniform dose distribution compared to a body phantom. The average homogeneity value of the IBA phantom is 90.52 % and the average homogeneity value of the Gammex phantom is 87.15 % (a difference of around 3.37%). This value shows that Gammex and IBA phantom have fairly good homogeneity

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INTRODUCTION

Computed Tomography (CT) scan is a useful diagnostic tool that uses a combination of X-rays through tomography and computer techniques to obtain images in the form of anatomical information and abnormalities that exist in the human body (Bontrager et al., 2010).Tomography is an X-ray imaging technique that produces a cross-sectional view of a patient (Allisy-Roberts et al., 2008). CT scans can be used in various types of examinations such as examination of the head (head), thorax (chest cavity), abdomen (abdominal cavity), and others. Since being introduced for the first time in 1972 by Dr. Godfrey Hounsfield, CT scaning has developed into a very important diagnostic imaging tool for several medical applications. In addition to its benefits, CT scaning contributes a higher dose of radiation to patients compared to other imaging modalities (Hausleiter et al., 2009) (Mulkens et al., 2011).

Therefore, it is necessary to measure the amount of radiation dose received by the patient for each examination. Measurement of the dose of a CT scan is also used as a quality control (QC) procedure to ensure the availability of medical devices comply with service standards, quality requirements, security, benefits, safety, and are suitable for use in health care facilities. In measuring the radiation dose of a CT scan, the index used to describe the output dose of a CT scan is called the computed tomography dose index (CTDI).

CTDI measurements consist of two measurements, namely CTDI measurements in the phantom and CTDI measurements in the air. A phantom is a device that is used as an object that can represent a model of the human body (Bauhs et al., 2008). There are many types of phantoms that have different shapes and compositions. Some of the phantoms that are usually used are American College of Radiology (ACR) phantom, American Association of Physicists in Medicine (AAPM) phantom CTDI and others. The CTDI phantom is a phantom used to measure the radiation output from a CT scan. The standard CTDI phantom has a cylindrical shape and is made of polymethyl methacrylate (PMMA) material with a diameter of 16 cm for an adult head and 32 cm for an adult body.

Scan parameters that can influence the radiation dose received by CT scan patients are exposure factors, namely tube voltage and X-ray tube current. An increase in the voltage of the X-ray tube on a CT scan can improves image quality but also increase the dose produced (Söderberg M et al., 2008). Based on the description above, this study aims to compare the values of the Computed Tomography Dose Index Weighted $CTDI_w$ and homogeneity index from CTDI head and body phantoms from Gammex and IBA to determine the uniformity of the material of the two phantoms.

METHODS

Phantoms

The phantom used in this study is CTDI phantom from (Sun Nuclear, Florida, United States) and IBA (IBA Dosimetry, Schwarzenbruck, Germany) which consists of a head phantom and a body phantom. The diameter of the head phantom is 16 cm and 32 cm for the body phantom. Both of phantoms are made of Polymethyl methacrylate (PMMA/Acrylic) with density of 1.19 gr/cm^3 (Sun Nuclear, 2023) and (Iba Dosimetry, 2023) The Gammex and IBA phantoms used in this study are shown in figure 1.

(a) (b)

Figure 1. (a) CTDI Phantom from Gammex (b) CTDI Phantom from IBA

Detector

The dose measurement on the phantom used a DCT10-MM pencil ionization chamber dosimeter (IBA Dosimetry, Schwarzenbruck, Germany) with a length of 100 mm which is connected to a MagicMaX Universal IBA (IBA Dosimetry, Schwarzenbruck, Germany). The dosimeter recorded the dose in units of mGy. The dosimeter can be inserted into the holes of the PMMA phantom. The dosimeter was connected to the computer using a micro USB cable. Measurement results are displayed with the MagicMaX software.

Input parameters

Measurements were performed on the CTDI head and body phantoms. The scanning parameters used for head and body phantoms are shown in the table 1.

Table 1. The scanning parameters used for CTDI head and body phantoms

CT Scan Parameters	Setting
Tube Voltage (kVp)	80, 100, 120
Tube Current (mA)	200
Rotation time (s)	1
Slice Thickness (mm)	1
Mode	Axial
Beam collimation (mm)	4

CTDI Measurement

$CTDI_{100}$ measurements were carried out by inserting a detector into each phantom hole alternately. With five phantom hole positions, namely in the middle center (a), top (b), right (c), bottom (d) and left (e) which can be seen in figure 2. Tube voltage variations was set at 80 kVp, 100 kVp, and 120 kVp with a tube current of 200 mAs and a slice thickness of 1 mm.

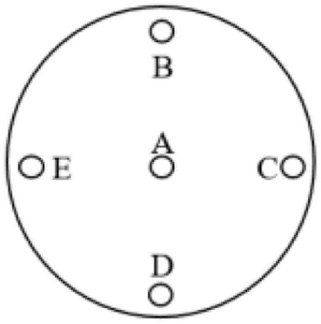


Figure 2. Measurement positions on CTDI phantoms

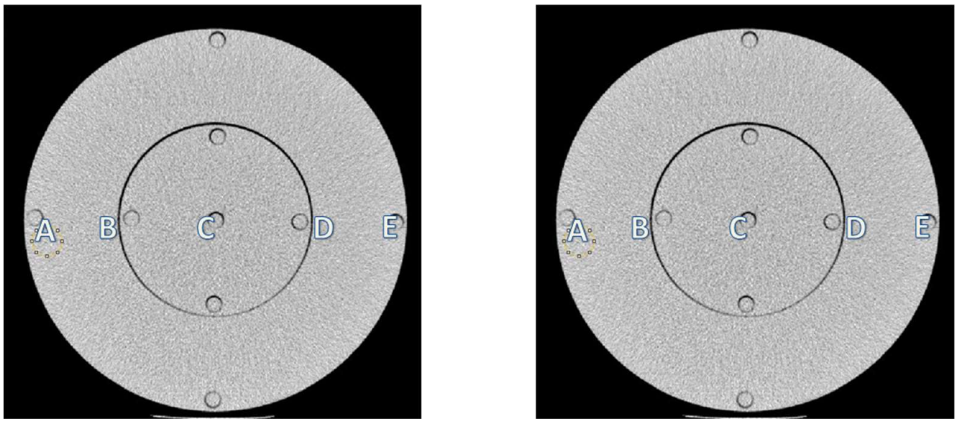
The $CTDI_{100}$ data obtained was processed to obtain the $CTDI_w$ value. The $CTDI_w$ value is obtained from the weighting of the $CTDI_{100}$ value in the center and peripheral of the phantom. The $CTDI_w$ was calculated using equation 1 (AAPM. 2008):

$$CTDI_W = \frac{1}{3}CTDI_{100,c} + \frac{2}{3}\overline{CTDI}_{100,p} \quad (1)$$

Where $CTDI_{100,c}$ is the $CTDI_{100}$ measured at the center of the phantom and $CTDI_{100,p}$ is the average $CTDI_{100}$ measured at the edges of the phantom (AAPM. 2008).

Phantom homogeneity testing

The phantom homogeneity test aims to determine the uniformity of the material in the phantom, this is because material homogeneity will affect the distribution of doses in the phantom. Scanning was performed using the protocol parameters shown in table 1. Homogeneity testing was carried out by measuring the average value and standard deviation of the CT number on the phantom image by determining the ROI was made in seven loction areas using ImageJ software oftwareWayne Rasband, National Institutes of Health (NIH) and the Laboratory for Optical and Computational Instrumentation (LOCI), University of Wisconsin, USA). Seven ROIs were made with the same area of 500 mm^2. ROIs were also made to be close to each phantom hole horizontally, namely at positions a, b, c, d, and e as shown in the following figure.



(a) (b)

Figure 3. The position of the region of interest (ROI) to determine the value of the CT number/Hounsfield Unit (HU) (a) CTDI Phantom from Gammex (b) CTDI Phantom from IBA

Homogeneity values were measured for each slice. As for the values of HU_{max} and HU_{min} on the slices obtained from observations at 7 ROI positions. After obtaining the CT number and standard deviation values, homogeneity will be compared between the Gammex phantom and the IBA phantom.

Statistical analysis

To determine whether the Gammex phantom and IBA phantom are significantly different or not, statistical tests are needed. The t-test is used for this purpose and was performed with Matlab R14 software (Mathworks Inc., Natick, MA, USA). We set the significance level to 0.05. When the p-value less than 0.05 was considered significant. Whereas, if the p-value more than 0.05 was considered not significant.

RESULTS AND DISCUSSION

The $CTDI_w$ value is the weighting of the $CTDI_{100}$ value in the center and the peripheral of the phantom. The scanning mode used in this study is the axial mode. In axial mode, the x-ray tube and detector rotate around the phantom then the tube stops and the patient table will move again when the first scan has been completed. Table 2 shows the results of $CTDI_w$ measurements on head and body phantoms from Gammex and IBA.

Table 2. $CTDI_w$ measurement results on CTDI head and body phantoms

kVp	CTDIw (mGy)			
	Gammex (head phantom)	IBA (head phantom)	Gammex (body phantom)	IBA (body phantom)
80	26.83	27.01	11.73	11.85
100	53.32	55.33	21.58	23.32
120	83.32	81.69	36.45	35.00

From the table 2 it is obtained that the difference in the $CTDI_w$ of the head phantom is 0.18% at 80 kVp, 2.01 % at 100 kVp and 1.63 % at 120 kVp. While the difference in the $CTDI_w$ of the body phantom is 0.13 % at 80 kVp, 1.75 % at 100 kVp and 1.45 % at 120 kVp. It is shown that $CTDI_w$ differences are about 2 %. The difference below 5 % with the p-value of head phantom is 0.87 and body phantom is 0.89 (more than 0.05) indicates that the two phantoms are not significantly different because the two phantoms are made of the same material.

Table 3. The ratio of the $CTDI_{100}$ value at the edge to the $CTDI_{100}$ value at the center of the head phantom from gammex and IBA

Position	Gammex			IBA		
	80 kVp	100 kVp	120 kVp	80 kVp	100 kVp	120 kVp
Top (12 o'clock)	1.58	1.35	1.24	1.59	1.25	1.22
Right (3 o'clock)	1.30	1.16	1.25	1.26	1.09	1.22
Bottom (6 o'clock)	0.96	1.00	0.95	1.01	0.91	0.97
Left (9 o'clock)	1.27	1.13	1.06	1.25	1.02	1.11
Average	1.28	1.16	1.12	1.28	1.07	1.13

Table 3 shows that the average ratio of the $CTDI_{100}$ value at the peripheral of the phantom to the value of $CTDI_{100}$ in the center of the phantom for each voltage from 1.12 – 1.28 on the Gammex head phantom while for IBA head phantom is 1.07 – 1.28. It is obtained that the value of $CTDI_{100}$ at the peripheral and the center of the phantom is uniform in size. This is consistent with the results obtained by Michael F. McNittt-Gray (APPM/ RSNA Physics Tutorial for Residents: Topic in CT, Radiation Dose in CT, 2002) that a 16 cm diameter head phantom produces a more uniform dose distribution compared to a 32 cm diameter body phantom (Mcnitt-gray et al., 2022). Table 4 presents the ratio of the $CTDI_{100}$ value at the edge to the $CTDI_{100}$ value at the center of the body phantom from gammex dan IBA.

Table 4. The ratio of the $CTDI_{100}$ value at the edge to the $CTDI_{100}$ value at the center of the body phantom from gammex dan IBA

Position	Gammex			IBA		
	80 kVp	100 kVp	120 kVp	80 kVp	100 kVp	120 kVp
Top (12 o'clock)	2.60	2.25	2.50	2.70	2.24	2.01
Right (3 o'clock)	3.01	2.05	1.97	2.70	2.44	2.06
Bottom (6 o'clock)	2.13	2.05	1.74	2.47	1.88	1.68
Left (9 o'clock)	2.49	2.25	1.92	2.50	2.83	1.91

Average	2.56	2.15	2.03	2.59	2.34	1.91

Table 4 shows the average ratio for the Gammex body phantom is 2.03 – 2.56, while for the IBA body phantom is 1.91 – 2.59. It was found in a typical CT dosimetry phantom that is 32 cm in diameter and made of polymethyl methacrylate (PMMA) usually referred to as the body phantom measurements of CT dose, obtained at the center are typically about 50% of the measured value obtained at one of the peripheral positions (Mcnitt-gray et al., 2022).

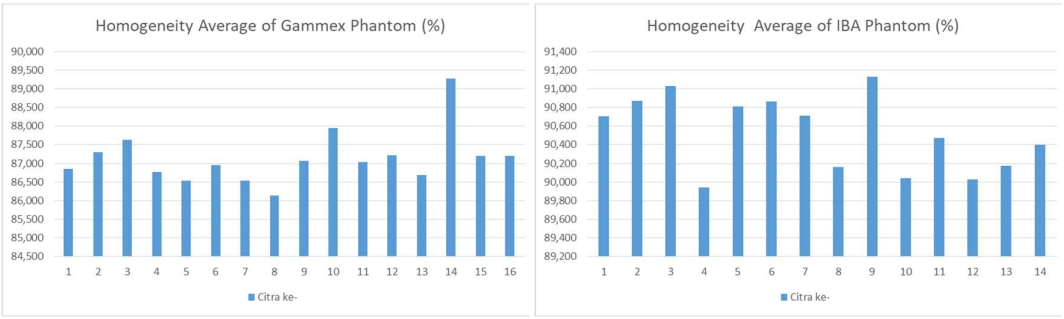
The smallest $CTDI_{100}$ value on the periphery position of the phantom is on the periphery (6 o'clock). This is influenced by the position of the detector which is blocked by the patient's table. The radiation emitted by the source does not directly hit the phantom because of the attenuation of the patient's table. The interaction with the patient's table makes the dose value received by the detector on the lower edge smaller. Meanwhile, the value of $CTDI_{100}$ on the periphery (3 o'clock) and periphery (9 o'clock) is almost the same.

To determine homogeneity, CT number data is needed for each ROI position (a, b, c, d, and e) which has been shown in figure 3. Table 5 presents the CT Number value obtained from the ROI results.

Table 5. CT Number value from phantom at each positions

Position	The Average of CT Number (HU)		Difference
	Gammex	IBA	
A	136.07 ± 27.76	134.95 ± 28.01	1.12
B	124.89 ± 29.49	125.13 ± 29.75	-0.23
C	120.90 ± 29.59	123.32 ± 29.80	2.41
D	124.80 ± 28.08	125.45 ± 28.10	-0.64
E	134.21 ± 25.13	133.63 ± 24.84	0.58

Table 5 shows that the average value of the CT number on the Gammex phantom for each ROI position has a value in the range of 120 – 136 HU. While the average value of the CT number on the IBA phantom for each ROI position has a value in the range of 123 – 134 HU. According to the American College of Radiology Acceptance Criteria, the average CT number for PMMA / Acrylic materials ranges from 110 to 135 HU. The CT number value of the measurement results when compared with the reference CT number is still appropriate because it is still within the specified reference range. It can be seen in Table 5 that the value of the difference between the average CT number value of Gammex and the average value of CT number IBA is smaller when compared to the standard deviation value obtained.



(a) (b)

Figure 4. Homogeneity average of (a) Gammex phantom (b) IBA phantom

Figure 4 (a) shows the results of the percentage homogeneity of each image on the Gammex phantom and Figure 4 (b) shows the results of the percentage homogeneity of each image on the IBA phantom. From the results obtained, the average homogeneity values for the Gammex and IBA

phantoms are 87.15% and 90.52%, respectively. This value can be said that the Gammex and IBA phantoms have fairly good homogeneity.

CONCLUSION

The differences in $CTDI_w$ of the two phantoms were within (head phantom is 0.18% – 2.01%) and (body phantom is 0.13% – 1.75%). The difference below 5% with the p-value of head phantom is 0.87 and body phantom is 0.89 (more than 0.05) indicates that the two phantoms are not significantly different because the two phantoms are made of the same material. The average ratio for the Gammex head phantom is 1.12 – 1.28, while the IBA head phantom is 1.07 – 1.281. Then the average ratio for the Gammex body phantom is 2.03 –2.56, while for the IBA body phantom is 1.91 – 2.59 which indicates that the head phantom produces a more uniform dose distribution compared to a body phantom. The average homogeneity value of the IBA phantom is slightly higher than the homogeneity of the Gammex phantom. Where the average homogeneity value of the IBA phantom is 90.52 % and the average homogeneity value of the Gammex phantom is 87.15 % (a difference of around 3.37 %). This value shows that Gammex and IBA phantoms have fairly good homogeneity.

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