The effect on CT size-specific dose estimates of mis-positioning patientsfrom the iso-centre

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Running title: Effect of mis-positioning from iso-centre to SSDE

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Abstract

This study evaluates the effect of mis-positioning of patients in relation to the iso-centre in CT examinations on the dose received by phantoms with various diameters. Phantoms with water-equivalent diameters (D_w) ranging from 8.5 cm to 42.1 cm were scanned using a GE Optima CT scanner with exposure factors as follows: 200 mA, 120 kVp, 1.375 Pitch, 50 cm field of view (FOV), 5 mm beam collimation, and 1 s rotation time. Doses were measured using the CT dose profiler (RTI Electronics). After obtaining doses in every hole of the phantoms, weighted doses were computed. It is found that the dose decreased with an increase in the D_w. The ratio of the doses when positioned off-centre by 2 cm and 4 cm with respect to the iso-centre have p-values of 0.914 and 0.919, which shows no significant difference (p> 0.05).

Keywords: computed tomography, CT dose, CTDIvol, SSDE, mis-positioning

Introduction

Currently, various metrics for quantifying dose in computed tomography (CT) are utilised, such as volume CT dose index (CTDI$_{vol}$) [1-3], size-specific dose estimates (SSDE) [4-6], and effective dose [7]. The CTDI$_{vol}$ is for quantifying the output of CT dose, the SSDE is for quantifying the average patient dose [8-10], and the effective dose is for quantifying the risk to the patient [11]. CT effective dose has been reported to be as high as 10 mSv, which is approximately 10 times higher when compared to general radiography of the same area, and equivalent to one year of background radiation [11, 12]. Thus, radiation dose optimisation in CT examination is compulsory as is justification of the examination [12, 13].

One simple technique of radiation optimisation in CT examinations is to accurately position the patient at the iso-centre of the gantry of the CT system [14]. It was reported that any displacement from iso-centre either vertical or horizontal could change the radiation dose received by any particular organ and could degrade the image quality [15].Surprisingly, it was reported that about 95% of patients were not accurately positioned at the gantry iso-centre [16].

Comprehensive studies using a 32-cm PMMA phantom reported that if the phantom position is above the iso-centre, then the dose to the upper portion of the phantom decreases. Conversely, the dose at the lower end increases. Hence, the overall dose does not change [17-19]. Some researchers, however, reported that a change from the iso-centre leads to a change of the SSDE value [20-22].The change in SSDE is presumably not due to changing dose values. The change in the SSDE value is solely due to the inaccuracy of the size-conversion factor (to convert CTDI$_{vol}$ to SSDE)due to the magnification or minification of the phantom size.We hypothesize that SSDE does not actually change due to mis-centring. Therefore, an evaluation of doses due to mis-centring with direct measurement on phantomshaving various sizes is important.Thus, the objective of this study is to evaluate the effect of mis-positioning from iso-centre in CT examinations to the dose received by various sizes of phantoms.

Methods

Phantoms and CT scanner

In this research, we used phantomsconstructed inhouse, consisting of 5 phantoms made of acrylic material with water-equivalent diameters (D$_w$) of 8.5, 16.9, 25.4, 33.9, and 42.1 cm. Each phantom had a length of 15 cm. A photograph of the phantoms is shown in Figure 1 (a). Each phantom had one hole in the middle and four holes peripherally at 1 cm from the surface as in the standard CTDI body phantom.
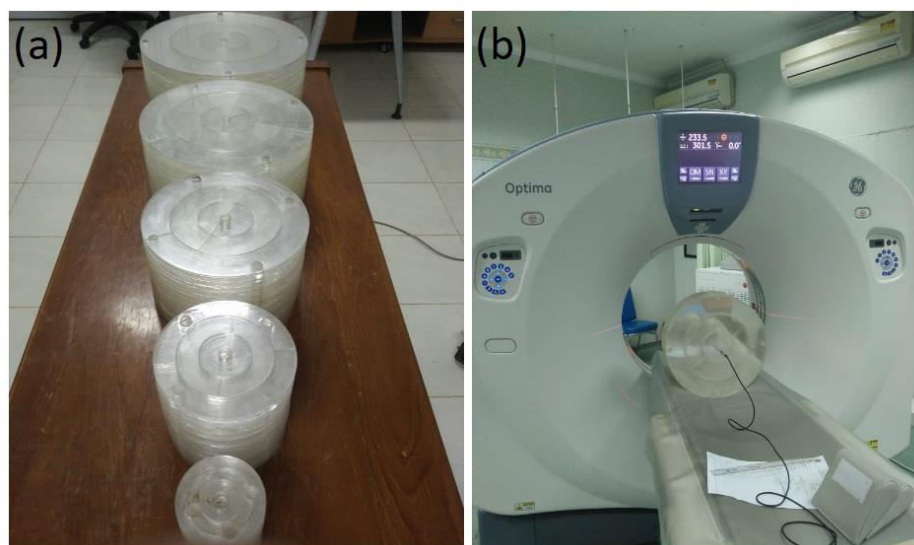
Figure 1. (a) Acrylic phantoms with variations in water-equivalent diameter from 8.5 cm to 42.1 cm, (b) CT Optima GE scanner.

Phantoms were scanned using a GE Optima CT scanner installed at Dr KariadiNational Hospital, Semarang, Central Java, Indonesia, as shown in Figure 1 (b). The exposure factors for all phantoms were 200 mA, 120 kVp, 1.375 Pitch, 50 cm FOV, 5 mm beam collimation, and 1 s rotation time.

Dose measurement

Dose measurements for each phantom were carried out in every hole of the phantom using the CT dose profiler (RTI Electronics, Sweden). The CT dose profiler was then connected to the Piranha electrometer (RT Electronics, Sweden). The CT dose profiler uses a point detector made of solid-state material, and it was placed in a container similar to the pencil chamber commonly used in CT dose index (CTDI) measurements. Radiation dose measurement using CT dose profiler differs from the pencil chamber where measurements are carried out in axial mode, measuring the dose with CT dose profiler is done using in spiral mode[1].In every measurement, the data was transferred to the electrometer and stored as a function of time. The dose-time can then be converted to the dose-distance.The dose-distance was called as dose profile. The dose profile was then integrated at 100 mm to obtain a dose-profile integral (DPI_{100}). If the DPI_{100} was divided by the width of the collimation, a CT dose index ($CTDI_{100}$) was obtained. However, because the radiation dose was measured with phantoms of various sizes, the resulting dose did not only show the CT dose index, but also showed a size-specific dose (D_s).

The dose measured at the phantom centre was called the central D_s ($D_{s,c}$) and the dose on the edge was called the peripheral D_s ($D_{s,p}$). The weighted D_s ($D_{s,w}$) was calculated as follows:

$$D_{s,w} = \frac{1}{3}D_{s,c} + \frac{2}{3}\overline{D_{s,p}} \qquad (1)$$

Where $\overline{D_{s,p}}$is the average of the four peripheral $D_{s,p}$ values. The $D_{s,w}$ was measured for several phantom positions, namely: phantom in the iso-centre position (the resulting $D_{s,w}$ is

called $D_{s,w,0}$), and phantom at 2 cm ($D_{s,w,2}$) and 4 cm below the iso-centre position ($D_{s,w,4}$). The phantom position of the iso-centre is shown in Figure 2.
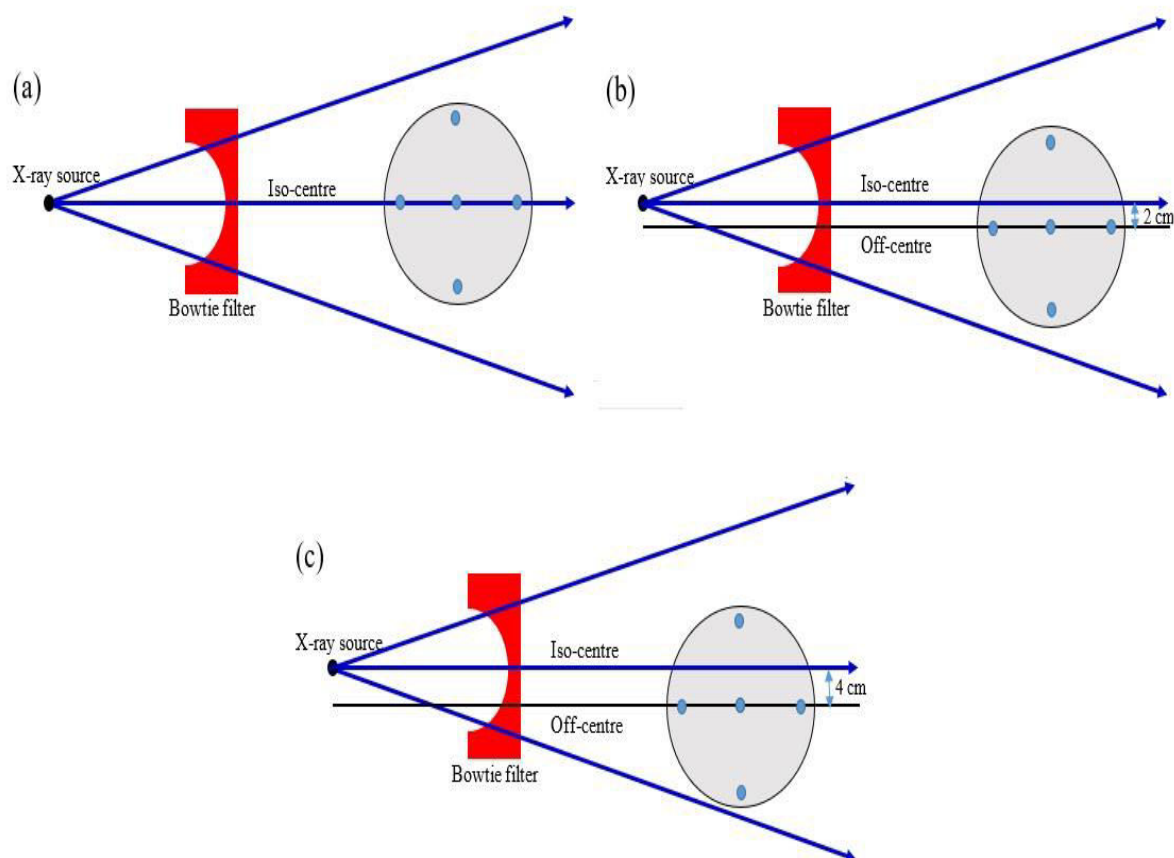

Figure 2. Phantom position. (a) The position of the iso-centre, (b) 2 cm below the iso-centre, and (c) 4 cm below the iso-centre.

Results
Weighted D_s

The results of radiation dose measurements done in each hole of the phantoms are used to calculate weighted D_s ($D_{s,w}$). The $D_{s,w}$ results in the iso-centre position are shown in Figure 3 (a). It appears that the dose decreases exponentially with an increase in the diameter.

To validate these measurements, the normalized doses at the iso-centre were compared to those in the AAPM No. 204 [4]. There are two normalisations, namely normalisation of body phantom and normalisation of the head phantom. The normalization doses for body and head phantoms are shown in Figure 3 (b). In the body phantom, the unity appears in the water-equivalent diameter of 33.9 cm, and in the head phantom, the agreement appears in the water-equivalent diameter of 16.9 cm.
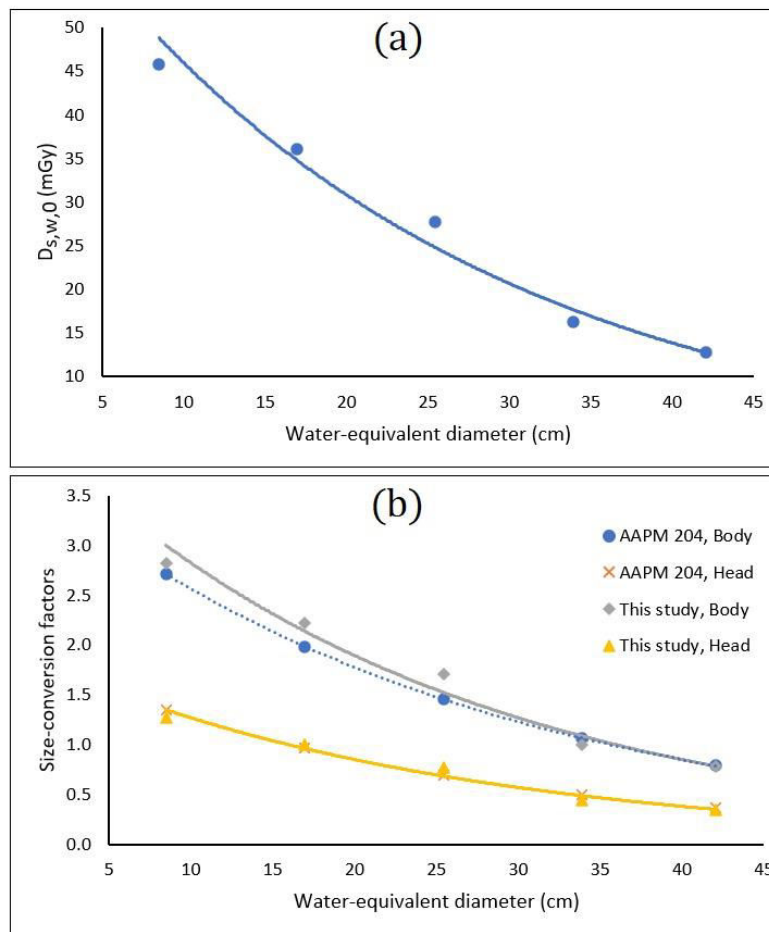
Figure 3. (a) $D_{s,w}$ results in the iso-centre position. (b) The size-conversion factor values for body and head phantoms.

It appears that the normalized doses are very comparable both for the body and for the head. Relatively large differences only occur in body phantom for very small phantom sizes, while for head size-conversion factors, the results obtained in this study coincide with those obtained by AAPM 204. P-values for body and head phantoms are 0.844 and 0.966, respectively. These results indicate that there was no significant difference between the results obtained by this study and those obtained by AAPM 204.

$D_{s,w}$ for variation of the phantom position

The average radiation doses ($D_{s,w}$) for various water-equivalent diameters at the iso-centre ($D_{s,w,0}$), 2 cm below the iso-centre ($D_{s,w,2}$), and 4 cm below the iso-centre ($D_{s,w,4}$) are shown in Figure 4. It appears that at a water-equivalent diameter equal to 16.9 cm, the radiation dose is the same for all phantom positions. While at water-equivalent greater than 16.9 cm, the radiation dose at the phantom position outside the iso-centre is slightly larger than the dose received at the phantom position at the iso-centre. Conversely, at a water-equivalent smaller than 16.9 cm, the radiation dose at the phantom position outside the iso-centre is slightly smaller than the dose received at the phantom position at the iso-centre. However, the dose difference is very small, which is only around 8% compared to the radiation dose at the

phantom position in the iso-centre. Statistically, the difference between the doses at the 4 cm and 2 cm positions with respect to the iso-centre has a p-value of 0.914 and 0.919, which shows no significant difference (p> 0.05).
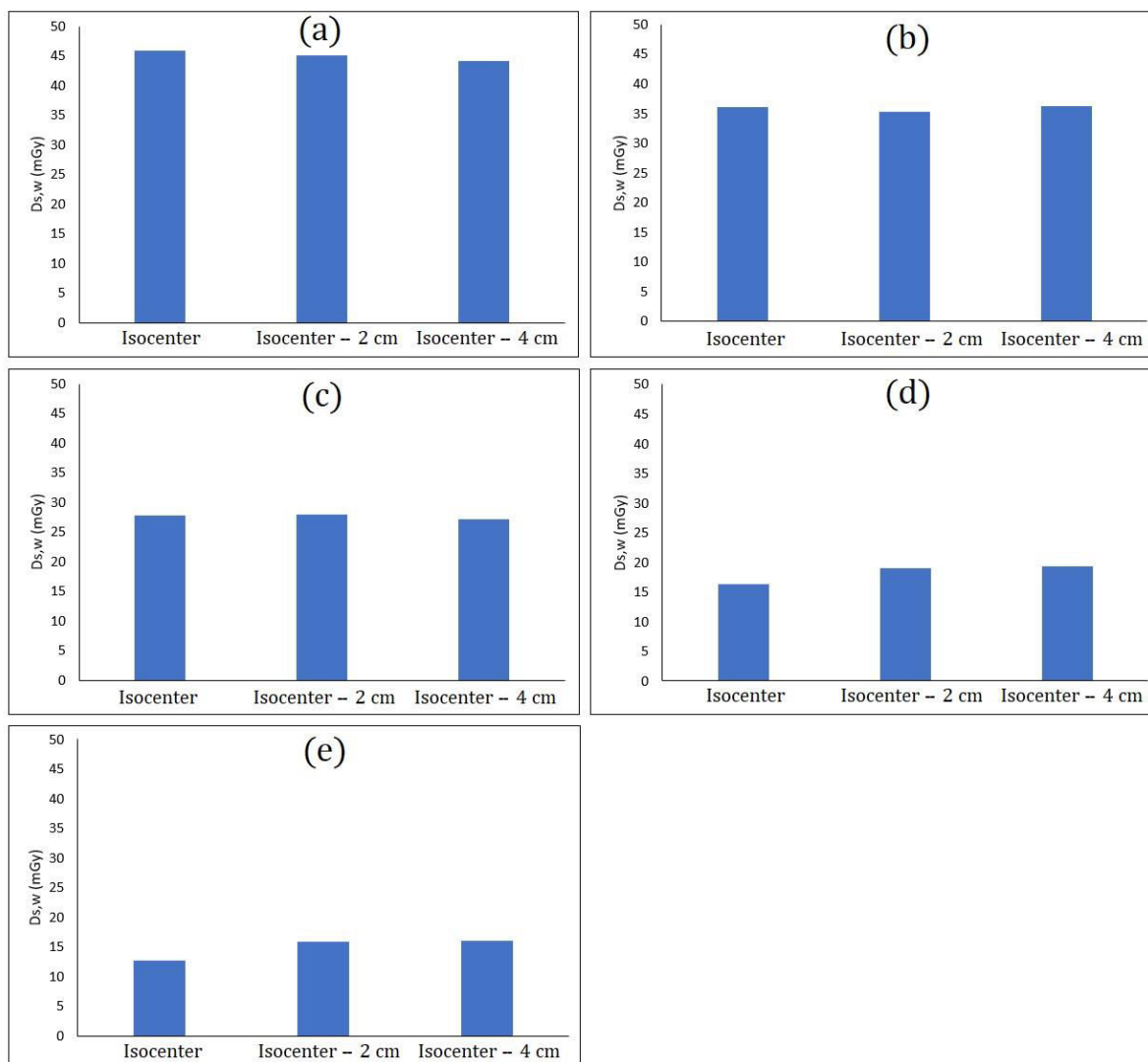

Figure 4. Dose values for the phantom at iso-centre ($D_{s,w,0}$), 2 cm below iso-centre ($D_{s,w,2}$), and 4 cm below iso-centre ($D_{s,w,4}$) and for various water-equivalent diameters: (a) 8.5 cm, (b) 16.9 cm, (c) 25.4 cm, (d) 33.9 cm, and (e) 42.1 cm.

Discussion

Some studies reported that mis-centring causes changes in dose on surface of the patient or phantom [18, 20-23]. For example, the dose of the eye or upper surface increases when the patient or phantom has been mis-centring downwards. Anam et al. [23] reported that in the phantom head mis-centring down about 2 cm, the dose in the eye increased to 20%, and mis-centring 4 cm caused the eye dose to increase by 30%. Habibzadeh et al. [18] reported the same results that a decrease in the position of phantom bodies by 2, 4 and 6 cm caused an increase in surface doses by 13.5%, 33.3%, and 51.1% respectively. The same results were reported by Kaasalainen et al [20] and Toth and Ge [22]. The opposite results, i.e. a decrease

in surface dose occurs when mis-centring above the iso-centre. Anam et al [23] reported that a 2 cm increase in iso-centre caused a dose decrease of about 10% and a 4 cm increase in iso-centre caused a decrease in dose of about 20%. The same results were reported by several researchers [18, 22, 24].

The variations of dose reading at the different areas in a phantom occurbecause of the nature of the bowtie filter used on CT scans. It is thin in the middle and thick at the edges. When a phantom or the patient is mis-centred downward, it means that the surface of the patient or the upper phantom will be closer to the centre of the iso-centre, which means it is close to the thin bowtie filter, so the dose goes up. Conversely, when a phantom or patient experiences mis-centring upward, it means that the surface of the patient or upper phantom will increasingly move away from the iso-centre which means it approaches the thick bowtie filter section, so the dose drops [18, 25, 26].

In addition, it should be noted that when the dose on one surface (top surface) rises, the opposite occurs on the other side surface (bottom surface), the dose decreases. Thus, although mis-centring causes an increase or decrease in the dose in certain organs, the total dose received by the patient or phantom is relatively unchanged. The current study found that off-centring did not cause significant changes in the mean dose. In other words, the SSDEw value is relatively unchanged due to mis-centring (See Figure 5). The same result was reported by Cheng [27], that vertical mis-centring did not affect the value of the weighted dose in terms of $CTDI_{vol}$.

In the literature, several researchers have evaluated the effect of mis-centring on SSDE values [28-30]. Generally, they reported that mis-centring has a major effect on the value of SSDE, especially if SSDE is calculated based on the scanogram image both in antero-posterior (AP) or posterior-anterior (PA). Terashima et al [28] reported that when mis-centring 4 and 8 cm above the iso-centre, radiograph size changes occurred, causing the size-conversion factor to change by 4% and 7% respectively. Marsh and Silosky [29] also reported that vertical mis-centring in phantoms could cause errors in the estimated phantom size up to a factor of 1.5, and this error is greater in the radiograph in the PA direction than in the AP direction.

It should be noted that the decrease or increase in SSDE values does not reflect the actual patient's doses, instead, it is due to inaccuracies of the size estimation from the magnification and demagnification of the image sizes. If the object is at a position close to the source of X-rays, then the formed image experiences magnification [31]. If the image is magnified, the size-conversion factor decreases, resulting in a reduced dose. On the other hand, for objects that move away from the source of X-rays, the image is minimised, and the dose is increased [31]. The current research found that the average dose actually does not change due to off-centring up to 4 cm. P-values above 0.05 indicate there is no significant difference between the dose at the iso-centre and whenoff-centring. However, for accurate SSDE calculations when using scanogram images or localiser radiographs (SPR), objects must be carefully placed in an iso-centre position [32]. While SSDE calculations use axial images, off-centring does not cause differences in patient diameter values and consequently does not change SSDE values. However, when mis-centring occurs, the axial images might

be truncated. If the image is truncated, the measured diameter value will be smaller than it really is, so the SSDE dose becomes greater [33].

This research has some limitations. First, the evaluation of the effect of off-centring on SSDE is only performed on one type of scanner. For more convincing results, research on several types of scanners needs to be done. Second, this research is only conducted using a single set of exposure parameters (i.e.All exposure factors were kept constant, namely:kVp, current, rotation time, slice thickness, beam collimation, FOV, and pitch.). Changes in the exposure factor, especially kVp, might produce different values of $D_{w,s}$, because changes in the kVp value changes the dose distribution in phantom.

Conclusion

The doses decrease exponentially with an increase in the diameter. The differences between the dose due to off-centring of 2 cm ($D_{s,w,2}$) and 4 cm ($D_{s,w,4}$) positions with respect to the iso-centres ($D_{s,w,0}$) position have p-values of 0.914 and 0.919. Therefore, the doses at off-centring up to 4 cm compared to at iso-centre are not significantly different ($p > 0.05$).

Acknowledgments

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