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Accuracy of IndoseCT for Measuring Effective Diameter from axial CT Images

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ABSTRACT

We investigated the accuracy of automatic measurements of the effective diameter (D_{eff}) using IndoseCT software with axial computed tomography (CT) images of polyester-resin (PESR) phantoms of various diameters. The phantoms used PESR as the base material mixed with Methyl Ethyl Ketone Peroxide (MEKP) as the catalyst. The phantom diameters were 8, 16, 24, and 32 cm. The phantoms were scanned with a CT scanner from edge-to-edge position with field of views (FOVs) of 30, 35, 40, 45, and 50 cm. The D_{eff} was measured from all slices along the z-axis. It was found that the automatic D_{eff} measurements were very accurate. The D_{eff} values were different by less than 0.02 cm for all diameters and all FOVs used. The maximum difference was obtained a ta diameter of 16 cm and FOV of 35 cm. We found that the precision of D_{eff} measurements along the z-axis was very good with a maximum standard deviation of 0.01 cm. The relationships between phantom diameter and measured D_{eff} for all FOVs had p-values < 0.001 and $r^2 = 1.000$. Therefore, the IndoseCT is able to accurately and precisely measure D_{eff} to facilitate estimating the patient dose in the SSDE metric.

Keywords: IndoseCT, effective diameter, PESR phantom

I. INTRODUCTION

Computed tomography (CT) is a powerful radiological imaging modality due to its excellent image quality. However, it provides the highest radiation dose to patients [1]. Over the decades, the use of CT has had a constant rate of increasing radiation exposure within a range of populations [2]. As a consequence, the radiation dose received by a patient must be accurately measured so that risk estimation is accurately predicted. Accurate dose estimation is one way to reduce a patient's dose in a CT examination [3]. Currently, CT dose index volume ($CTDI_{vol}$) and dose-length product (DLP) are the most commonly used metrics to surrogate doses from CT examination. However, $CTDI_{vol}$ is only measured using a standard phantom made of polymethyl methaacrylate (PMMA) with diameters of 16 and 32 cm and a 100 mm ionization chamber pencil detector [4]. And DLP is obtained from the results of multiplication between $CTDI_{vol}$ with the scan length [5]. As a result, both $CTDI_{vol}$ and DLP cannot accurately estimate the quantity of radiation dose absorbed by the patient, but rather are only indicators of the output dose alone. The radiation dose absorbed by the patient from CT is reported to be strongly influenced by the different characteristics and sizes of each individual patient [6]

The American Association of Physicists in Medicine (AAPM) Task Group 204 [7] adapted the $CTDI_{vol}$ value with the effective diameter (D_{eff}) of the patient and introduced a new metric, the size-specific dose estimate (SSDE). The D_{eff} of the patient is defined as the diameter of the circle equal to the cross-sectional area of the patient. D_{eff} can be easily calculated from the anterior-posterior (AP) and lateral (LAT) dimensions. D_{eff} can be derived from either axial image or CT localizer radiograph. Fukunaga et al. [8] reported limitations in determining the D_{eff} from CT localizer radiograph because of magnification errors caused by patient mis-centering. Pourjabbar et al. [9] also reported that the measurements of D_{eff} from the CT localizer radiograph should be carried out carefully. The center point of the patient must be set correctly because it can produce magnification in the image. Wang et al. [10] showed that placing the cylindrical water phantom (30 cm long) 5 cm or 9 cm closer to the X-ray tube led to an over estimate of effective diameter by 4.5% and 9.9%, respectively. In contrast, the D_{eff} measurement from the axial image does not require the patient's center point to achieve high accuracy.

D_{eff} can be found ether manually or automatically. Since the AAPM report 204 was published, automated D_{eff} measurements have been proposed [10]. Christianson et al. [11] proposed automated D_{eff} measurements, but the measurements are performed on the CT localizer radiograph using an adaptive threshold algorithm with a threshold limit of up to 30% of the maximum pixel value. Anam et al. [12] introduced a method to automatically measure D_{eff} from an axial CT image. It should be noted that manual measurement of every slice along the z-axis is very time-consuming, since hundreds of images can be obtained from each CT scan [12,13].

Currently, software to automatically measure D_{eff} are available, such as IndoseCT [14]. It is reported that software errors are less than 0.4% compared to manual measurements [15]. However, automated D_{eff} measurements using the IndoseCT have only been performed on standard PMMA phantoms with diameters of 16 and 32 cm [16]. Automatic measurements of D_{eff} with IndoseCT to date have not been validated on phantoms having different diameters, from a small diameter of less than 10 cm (which represents a newborn) to a diameter representing adult patients. This study aims to investigate the D_{eff} accuracy of the IndoseCT using polyester-resin (PESR) phantoms which have different diameter sizes, namely 8, 16, 24, and 32 cm.

II. METHODS AND MATERIAL

D_{eff} accuracy was investigated using in-house phantoms developed from polyester-resin (PESR) mixed with Methyl Ethyl Ketone Peroxide (MEKP). The phantom diameters were 8, 16, 24, and 32 cm (Figure 1). The PESR phantoms had an average density equivalent to the standard PMMA phantom. The phantoms were scanned using a Siemens Somatom Perspective DE 128-Slice at RSUD Koja, North Jakarta. The scan protocol was a standard routine examination of the abdomen using the parameters listed in Table 1. The first step of the phantom scan procedure was to adjust the phantom position on the CT table. The second step after the scanning process was reconstruction of the phantom image for variations of field of view (FOV) using Syngovia software (Figure 2).

A. Effective diameter accuracy calculation

After all the stages of scanning had been carried out, the images of the phantoms were analyzed automatically using IndoseCT software. The D_{eff} was calculated by the equation (1) and (2).

$$r_1 = \frac{LAT}{2} \quad (1)$$

$$r_2 = \frac{AP}{2} \quad (2)$$

The area A was taken into account based on the equation (3).

$$A = \pi r_1 r_2 \quad (3)$$

D_{eff} was obtained by combining the equations (1) to (3), as shown in equation (4).

$$D_{eff} = \sqrt{AP\ x\ LAT} \quad (4)$$

IndoseCT provides three choices of calculation methods with "Auto", "Manual", and "Auto 3D" calculation capabilities. In this study, the calculation used "Auto 3D" in which D_{eff} is calculated automatically from the contours of the images of the phantoms for all slices. "Auto 3D" calculated D_{eff} along the z-axis with a very fast time. Figure 3 shows a graphical user interface (GUI) of the IndoseCT software for measuring D_{eff} from the square root of the product of the AP and LAT dimensions.

B. Statistical analysis

The correlation between the D_{eff} of the phantoms and the automated calculation of D_{eff} for various values of FOV was performed using Pearson correlation (Table 2) [17]. Statistical analysis was carried out using SSPS software version 10. The correlation coefficient (r) was used to find out the closeness of the relationship between two variables [17]. The p-value was also calculated. A p-value < 0.05 indicates that there is no significant different between two variables.

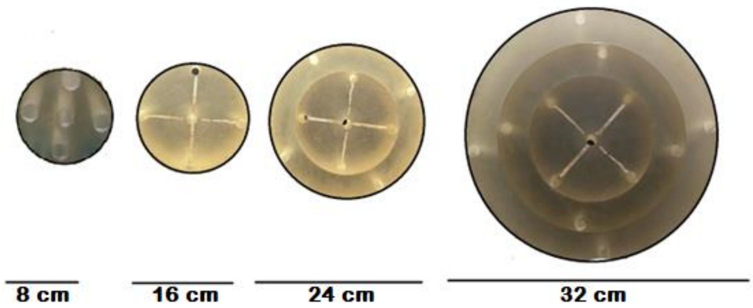

Figure 1. In-house phantoms with various diameters of 8, 16, 24, and 32 cm. Note that the sizes of the phantoms are not scaled in this figure.

Table 1. Scan parameters for scanning of the in-house phantoms

Scan parameter	Setting
Protocol	Abdomen routine
Tube current	300 mA
Tube potential	130 kV
Slice thickness	1.0 mm
Rotation time	1 s
Field of view (FOV)	30, 35, 40, and 45 cm

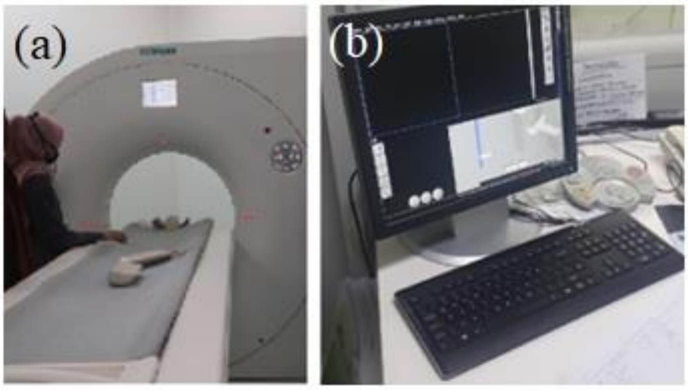

Figure 2. (a) A phantom on the CT scanner table, and (b) workstation for determination of scan parameters using Syngovia software.

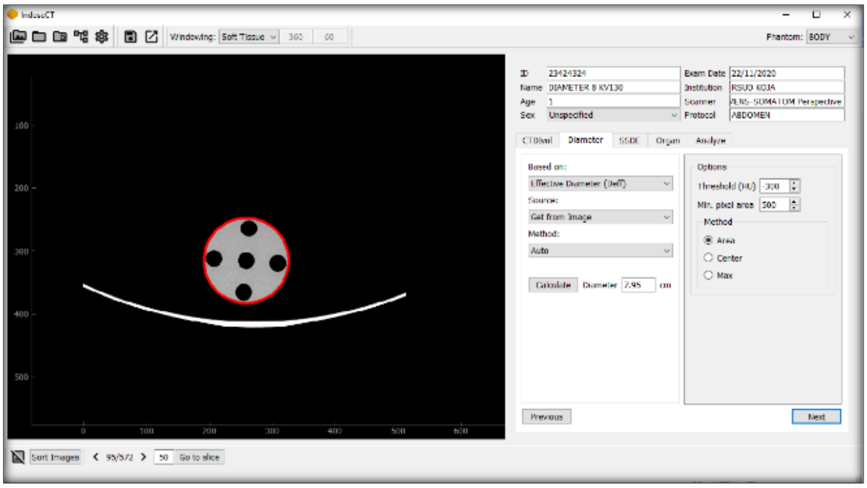

Figure 3. The graphical user interface (GUI) of IndoseCT to automatically measure D_{eff}.

III.RESULTS AND DISCUSSION

A. Phantom's diameter variation

The automated contouring results of the in-house phantoms with different diameters using IndoseCT for a FOV of 30 cm are shown in Figure 4. It is clear that contouring of the phantoms is accurately fitted to the border of the phantoms. The Deff values for every in-house phantom along the z-axis are shown in Figure 5. The Deff for a phantom diameter of 8 cm is 7.94 ± 0.00 cm, for a phantom diameter of 16 cm it is 16.16 ± 0.01 cm, for a phantom diameter of 24 cm it is 24.00 ± 0.00 cm, and for a phantom diameter of 32 cm it is 31.99 ± 0.01 cm.

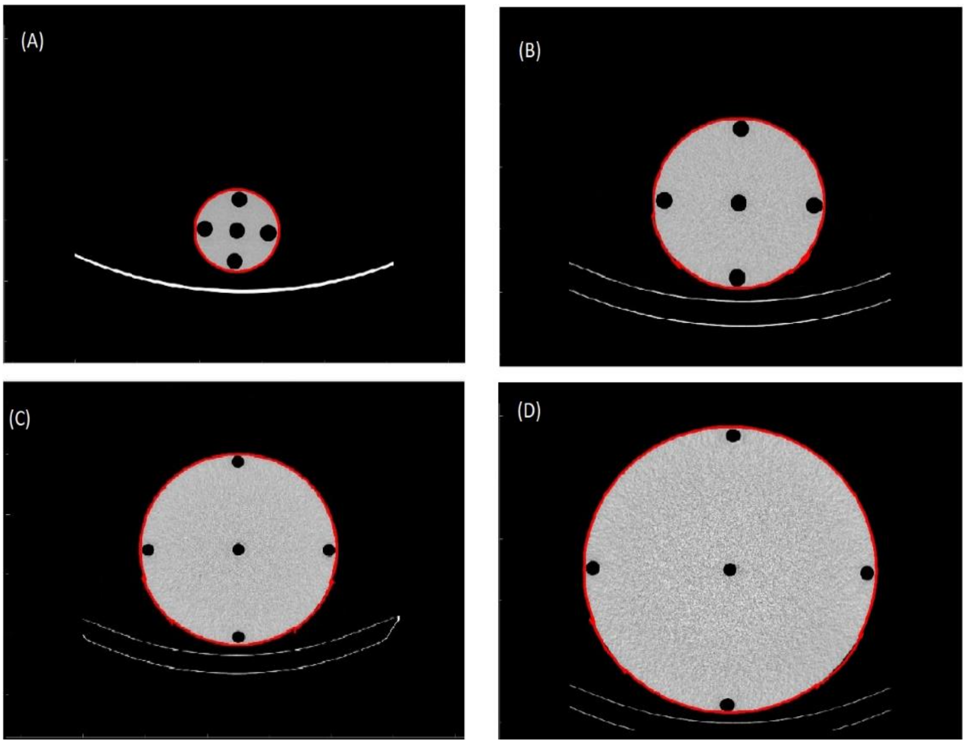

Figure 4. Contours of images of phantoms for different diameters. (a) 8 cm, (b) 16 cm, (c) 24 cm, and (d) 32 cm

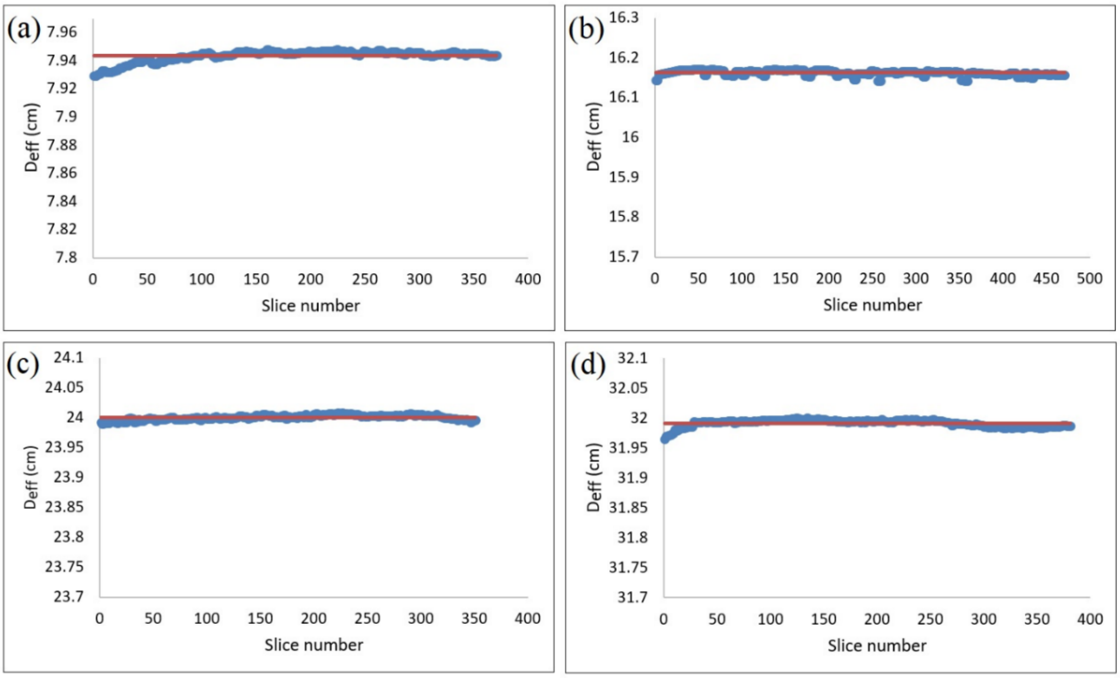

Figure 5. D_{eff} profiles along the z-axis of the phantoms for different diameters. (a) 8 cm, (b) 16 cm, (c) 24 cm, and (d) 32 cm.

B. FOV variations

The automated contouring results for the in-house phantoms of different diameters using IndoseCT for various FOVs from 30 to 45 cm are shown in Figure 6. It can be seen that the contouring of all phantoms for various FOVs are accurate. The D_{eff} profiles along the z-axis for the 8 cm in-house phantom for various FOVs is shown in Figure 7, for the 16 cm phantom in

Figure 8, for the 24 cm phantom in Figure 9, and for the 32 cm phantom in Figure 10.

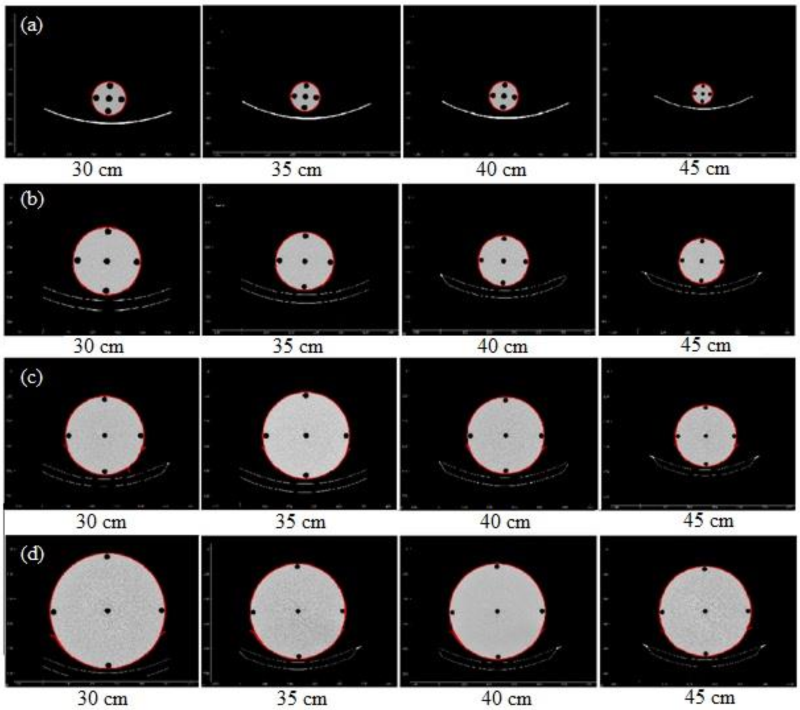

Figure 6. Results of automated contouring using IndoseCT for various FOVs from 30 to 45 cm for four phantoms. (a) 8 cm, (b) 16 cm, (c) 24 cm, and (d) 32 cm.

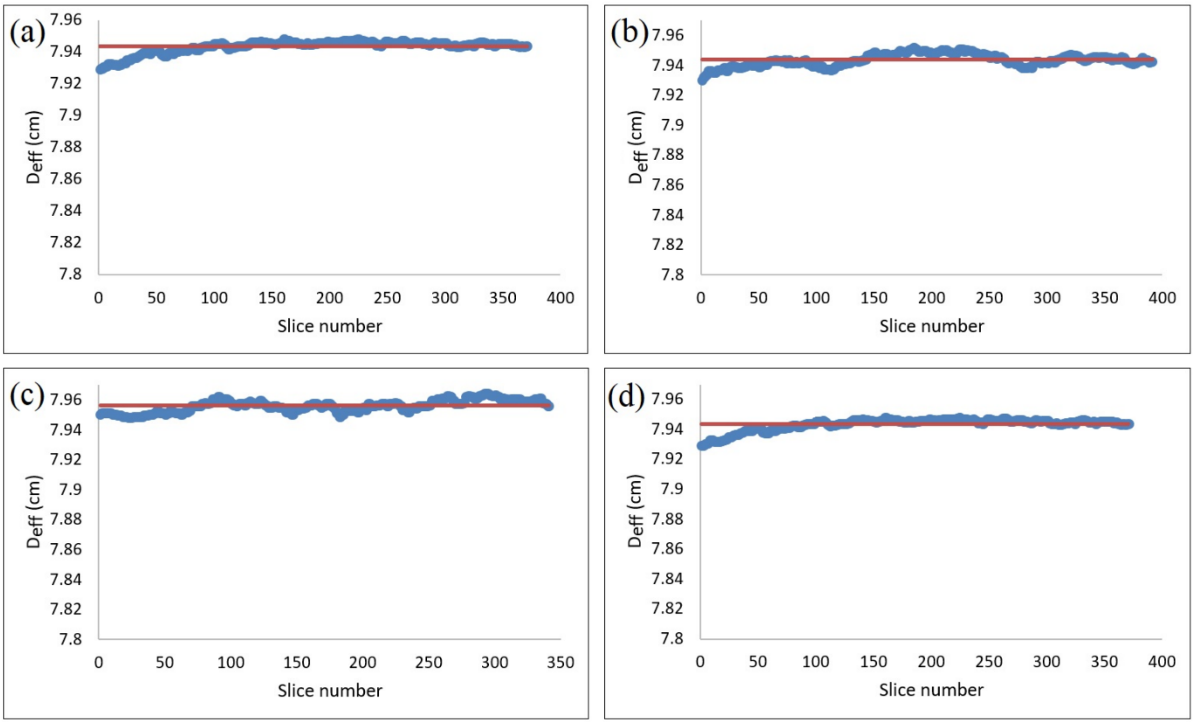

Figure 7. D_{eff} profiles along the z-axis for the 8 cm phantom diameter for different FOVs. (a) FOV of 30 cm, (b) FOV of 35 cm, (c) FOV of 40 cm, and (d) FOV of 45 cm.

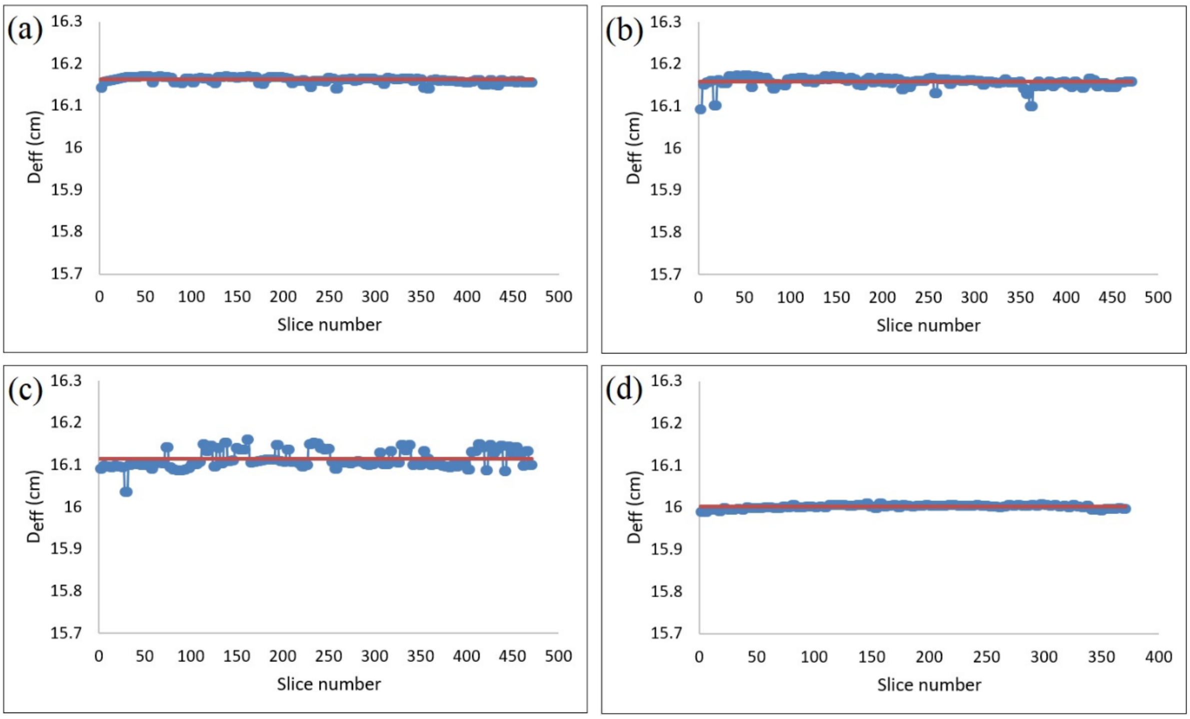

Figure 8. D_{eff} profiles along the z-axis for 1the 6 cm phantom diameter for different FOVs. (a) FOV of 30 cm, (b) FOV of 35 cm, (c) FOV of 40 cm, and (d) FOV of 45 cm.

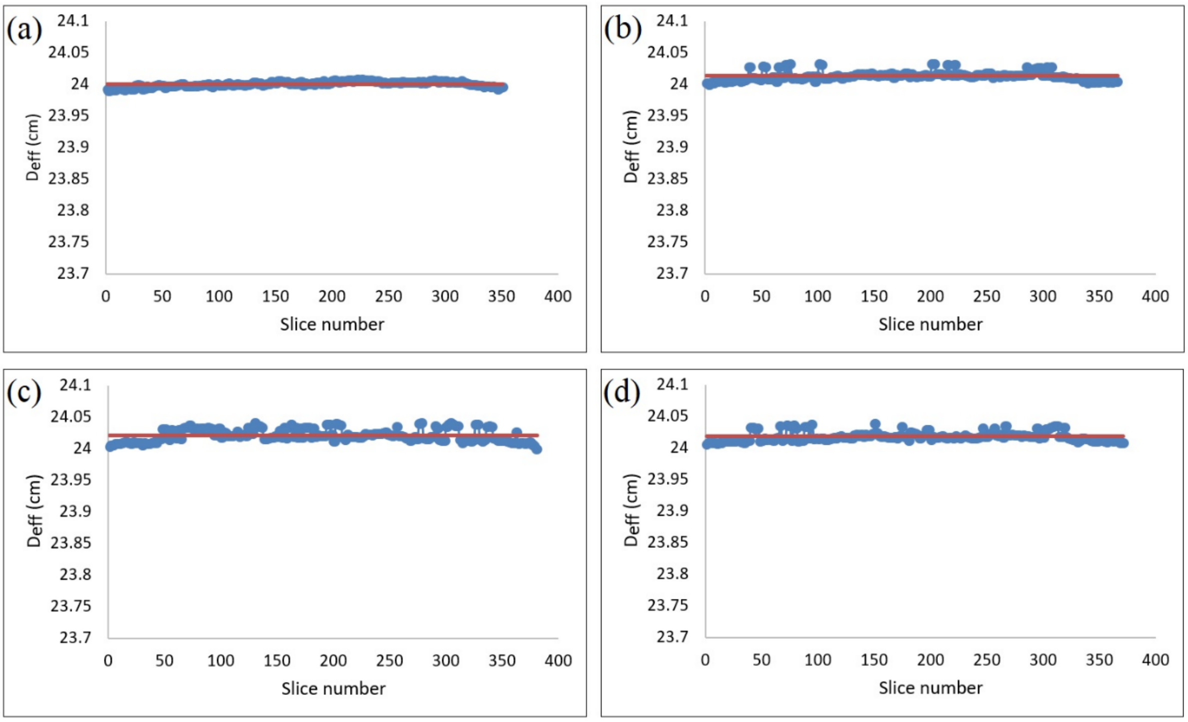

Figure 9. D_{eff} profiles along the z-axis for the 24 cm phantom diameter for different FOVs. (a) FOV of 30 cm, (b) FOV of 35 cm, (c) FOV of 40 cm, and (d) FOV of 45 cm.

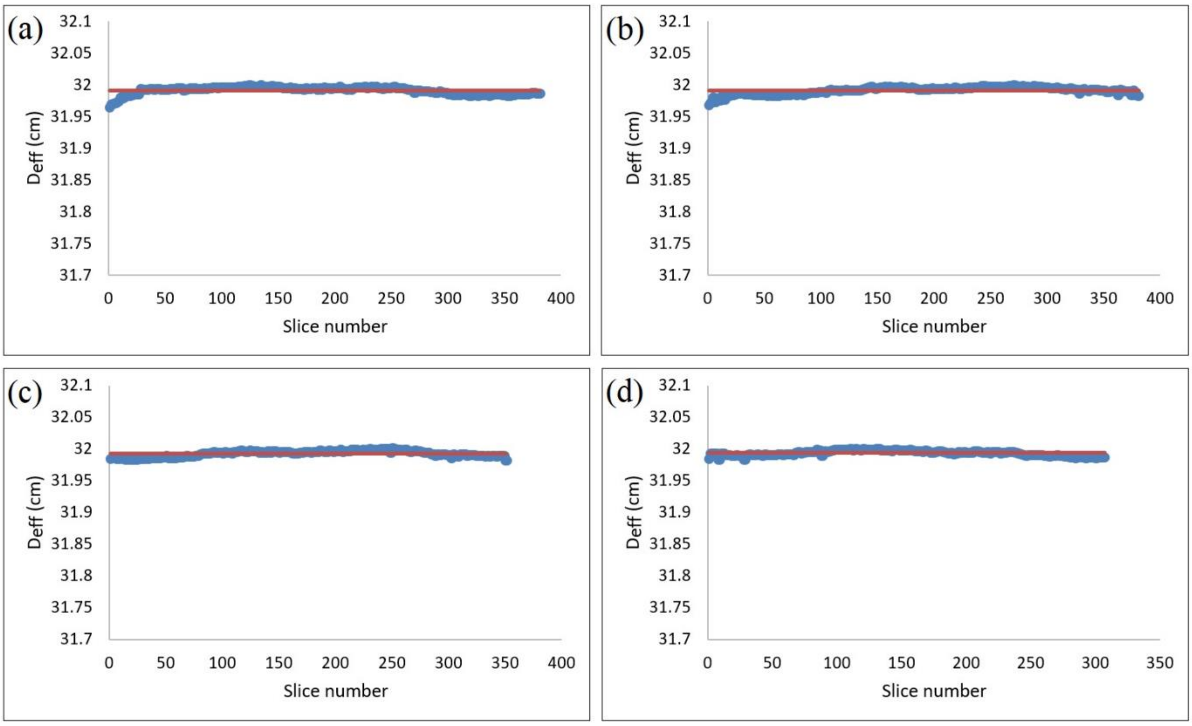

Figure 10. D_{eff} profiles along the z-axis for the 32 cm phantom diameter for different FOVs. (a) FOV of 30 cm, (b) FOV of 35 cm, (c) FOV of 40 cm, and (d) FOV of 45 cm.

C. Correlation between D_{eff} phantom and D_{eff} measured

Table 2 shows the results of the automated D_{eff} measurements on the in-house phantoms of diameters from 30 to 45 cm for various FOVs. It is clear that the results of the automated D_{eff} are independent of the various FOVs used. All the D_{eff} values were within 0.02 cm of the physical diameter of the phantom for all diameters and all FOVs. The maximum difference was obtained for the 16 cm phantom at a FOV of 35 cm. The standard deviation of the D_{eff} measurements along the z-axis were very small with a maximum of ± 0.01 cm.

The relationships between the diameter of phantoms and the measured D_{eff} are shown in Figure 11. The $p < 0.001$ and $r^2 = 1.000$ in all FOVs indicate the measured D_{eff} values are not statistically different from physical diameter of the phantoms.

We investigated the accuracy of the IndoseCT software for calculating D_{eff} by comparing the results with the physical diameters (8, 16, 24 and 32 cm) of in-house phantoms for various FOVs (30, 35, 40, 45, and 50 cm). A previous study had conducted an investigation on head and body phantoms only [12]. Accurate D_{eff} measurements are important for the accurate estimation of patient dose using SSDE.

The smallest in-house phantom (8 cm) mimicks a newborn patient whose diameter is about 10 cm [7]. And our widest in-house phantom (32 cm) mimicks a large patient reaching a diameter of 32 cm. It is necessary to increase the phantom diameter to about 40 cm in the next study in order to mimick the dose for an obese adult patient.

We found that the results of the automated D_{eff} measurements were accurate for all diameters and FOVs to within less than 0.02 cm for all diameters and FOVs used. The maximum difference was obtained for a diameter of 16 cm and a FOV of 35 cm. The precision of D_{eff} values taken along the z-axis was better than 0.01 cm. The results are consistent with a previous study [12]on a head and body phantom, which found the differences between automated D_{eff} and physical diameter to be within 0.1 cm. However, in the previous study [16], automatic measurement was only conducted on 10 images (slices), whereas in the current study, measurement automated D_{eff} was conducted on more than 300 slices along the z-axis taken within a very short time (around 15 s).

Table 2. Average results of the automated D_{eff} measurements on the in-house phantoms.

Diameter (cm)	FOV (cm)	Mean (cm)	SD (cm)	Difference (cm)
8	30	7.94	0.00	0.06
	35	7.94	0.00	0.06
	40	7.94	0.00	0.06
	45	7.95	0.01	0.05
16	30	16.01	0.01	0.01
	35	16.15	0.01	0.15
	40	16.03	0.00	0.03
	45	16.00	0.00	0.00
24	30	24.00	0.00	0.00
	35	24.00	0.00	0.00
	40	24.00	0.00	0.00
	45	24.00	0.00	0.00
32	30	32.00	0.00	0.00
	35	32.00	0.00	0.00
	40	32.00	0.00	0.00
	45	32.00	0.00	0.00

In this study, we did not evaluate the composition of the in-house phantom's ingredients. Based on previous studies [18]; [19], the PESR-MEKP phantoms with a ratio of 300:1 were reported to be little different in performance from the standard PMMA phantom. The $CTDI_{vol}$ for the diameter of 16 cm was 6% slightly higher than the standard PMMA phantom [19].

The acquisition parameters on the CT scan, other than FOV, were kept constant. The FOV affects the radiation dose and image quality [20]). It is important to investigate the accuracy of D_{eff} for various scan parameters, such as slice thickness, tube current, tube voltage, reconstruction filter, pitch, and so on [21], although in the current study we only varied the FOV.

The D_{eff} only takes into account the geometrical size of the patient, and not the composition of the patient. The water-equivalent diameter (D_w) is the parameter that takes into account both factors. Automatic calculation of D_w is also available in IndoseCT and an evaluation of D_w accuracy using IndoseCT was carried out in a previous study [22].

We investigated the accuracy of the IndoseCT software for calculating D_{eff} by comparing the results with the physical diameters (8, 16, 24 and 32 cm) of in-house phantoms for various FOVs (30, 35, 40, 45, and 50 cm). A previous study had conducted an investigation on head and body phantoms only [12]. Accurate D_{eff} measurements are important for the accurate estimation of patient dose using SSDE.

The smallest in-house phantom (8 cm) mimicks a newborn patient whose diameter is about 10 cm [7]. And our widest in-house phantom (32 cm) mimicks a large patient reaching a diameter of 32 cm. It is necessary to increase the phantom diameter to about 40 cm in the next study in order to mimick the dose for an obese adult patient.

We found that the results of the automated D_{eff} measurements were accurate for all diameters and FOVs to within less than 0.02 cm for all diameters and FOVs used. The maximum difference was obtained for a diameter of 16 cm and a FOV of 35 cm. The precision of D_{eff} values taken along the z-axis was better than 0.01 cm. The results are consistent with a previous study [12]on a head and body phantom, which found the differences between automated D_{eff} and physical diameter to be within 0.1 cm. However, in the previous study [16], automatic measurement was only conducted on 10 images (slices), whereas in the current study, measurement automated D_{eff} was conducted on more than 300 slices along the z-axis taken within a very short time (around 15 s).

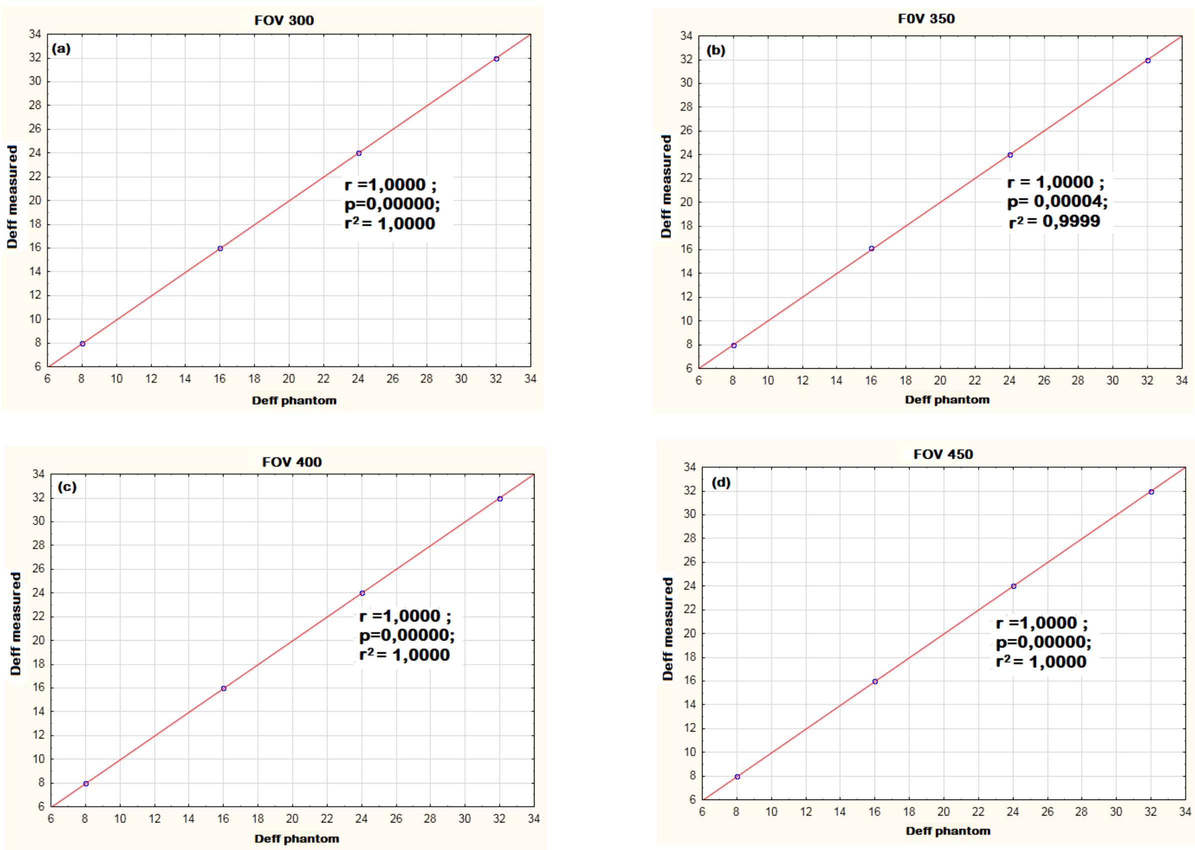

Figure 11. Graphs of the relationships between diameter of phantoms and the measured D_{eff}.

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IV. CONCLUSION

The accuracy of D_{eff} measurements using IndoseCT from axial computed tomography images of PESR phantoms with various diameters (8-32 cm) and FOVs (30-45 cm) was investigated. The D_{eff} values were accurate to within 0.02 cm for all diameters and all FOVs used. The precision of D_{eff} along the z-axis wasvery good with a maximum SD of 0.01 cm. The relationships between phantom diameter and measured D_{eff} for all diameters and FOVs have p-value < 0.001 and $r^2 = 1.000$ which indicates no statistical difference between both.

V. ACKNOWLEDGEMENTS

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