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Effect of Contrast Agent Administration on Size-Specific Dose Estimates (SSDE) Calculations based on Water Equivalent Diameter in CT Head Examinations

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ABSTRACT

Size-specific dose estimate (SSDE) is dose metrics of computed tomography, to calculate SSDE we first calculate the patient's body size. In CT head examination, the head size is better to use water-equivalent diameter (Dw), because Dw considers tissue attenuation. CT Head examination with contrast agent increased patient attenuation and increased Dw. In this study, we observed the effect of contrast agent on the Dw value on the axial image of patients with CT head examination. A total of 96 patients underwent a CT Head examination with a contrast agent in the two CT scan modalities. 46 patients underwent CT Head examination with contrast agent using CT Scanner Toshiba Alexion 16 and 50 patients underwent CT Head examination with contrast agent using CT Scanner GE Medical System Optima CT660. Dw value is calculated automatically using IndoseCT version 20b. We compared the Dw pre-contrast and Dw post-contrast values with the two independent sample t-test statistical analysis. To consider the effect of changing Dw values on SSDE we normalized dose coefficient (NDC). We did not find a significant difference between Dw pre-contrast and Dw post-contrast. The P-value statistical analysis results for the CT Scanner Toshiba Alexion 16 and the CT Scanner GE Medical System Optima CT660 were 0.65 and 0.45. The NDC change in this study was below 20%. On CT Head examination, the Dw and SSDE pre-contrast values can be used to estimate the Dw and SSDE post-contrast values.

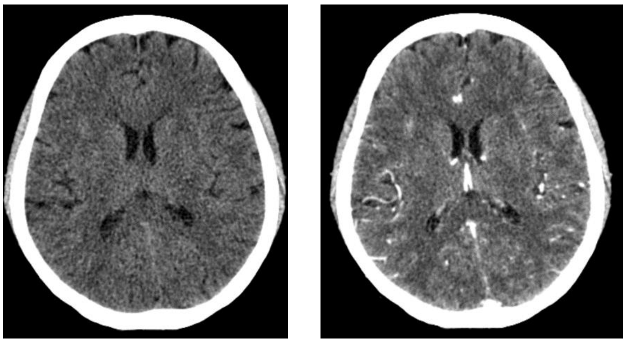
Keywords : CT Head, water-equivalent diameter, size-specific dose estimate

I. INTRODUCTION

CT scanning has been widely used in medical imaging to help detect and make medical decisions [1]. In certain cases, if a suspicious lesion is present on non-contrast computed tomography of the head (NCTH), a contrast agent is required to supplement the information obtained [2]. However, additional exam with a contrast agent on a CT increases the radiation dose received by the patient [3, 4]. Therefore, accurate quantification of the radiation dose received by a patient is crucial.

Volumetric computed tomography dose index (CTDIvol) and dose length product (DLP) are dose metrics that have been used to quantify the radiation dose of CT [5,6]. These two metrics do not take into account patient characteristics, hence the dose metrics only indicate the CT output dose and not the absorbed dose by the patient [7-9]. Meanwhile, the dose absorbed by the patient should take into account the CT output dose and patient characteristics [10-13]. In 2011 the American Association of Physicists in Medicine (AAPM) Report No. 204 introduced a size-specific dose estimate (SSDE) as a dose metric that takes into account the CT dose output and patient characteristics [14]. SSDE is computed from the CTDIvol value multiplied by the patient characteristic conversion factor (f) [15]. The characteristic conversion factor on the AAPM RPT 204 is the patient's body diameter or the patient's effective diameter (Deff) which can be determined by measuring the patient's lateral (LAT) and anterior-posterior (AP) body diameters [16]. The concept of SSDE calculation based on Deff was developed for CT abdomen and pelvic CT examinations, however it can also be used for CT thorax with an error up to 20%. To anticipate this error, AAPM Report No. 220 reported a new concept called water-equivalent diameter (Dw) as an extension of Deff. The Dw considers tissue attenuation to more accurately estimate SSDE in areas of the body that have various tissue densities and compositions, such as when used for CT Thorax examination [17]. Although SSDE has been used to represent organ dose in terms of abdominal scans [18]. AAPM Report No. 204 and AAPM Report No. 220 have limitations only on body CT examinations. Then in 2019, AAPM developed SSDE based on Dw with conversion factors according to CT head examination [19].

The value of Dw depends on the tissue attenuation of the X-rays, and in the image, it is expressed in the Hounsfield unit (HU). When a contrast agent is injected, it will increase tissue attenuation and HU at some areas as shown in Figure 1. Increased tissue attenuation at some areas affects the Dw value. To the best of our knowledge, the scientific papers reporting on the effect of contrast agents administration on Dw are limited to CT abdomen and pelvic regions [20,21]. Therefore, we observed the effect of contrast agent on Dw values based on axial images of patients for CT head examination. In addition, the SSDE represents the absorbed dose along the z-axis of the clinical CT will be examined. We also evaluated the SSDE using AAPM Report No. 293 that determined the new conversion factor value on CT head examination as a function of Dw so that the mire accurate brain estimation will be obtained [19]. It is hoped that this study can be used to consider Dw and SSDE values as a function of head conversion factors for CT head contrast examination.



(a) (b)

Figure 1: Image from CT brain in the same patient at WW/WL 80/40 HU. (a) without contrast agent and (b) with contrast agent.

II. METHODS AND MATERIAL

Patients have collected retrospectively from CT head and CT head contrast images in the DICOM file. We calculated the Dw value of the two CT modalities with a total of 96 patients. 46 patients underwent a CT head contrast examination with a Toshiba Alexion 16 CT Scanner installed at Cideres Hospital, Majalengka, Indonesia and 50 patients underwent a CT head contrast examination with a GE Medical System Optima CT660 CT Scanner which was installed at Permata Cirebon Hospital, Indonesia. Patients who underwent a CT head contrast examination with a Toshiba Alexion 16 CT Scanner consisted of 26 women and 20 men, aged between 15 – 78 years, and a mean weight of 56.58 ± 10.10 kg. Scanning parameters: head helical, tube voltage of 120 kVp, tube current of 200 mA, slice thickness of 1 cm, rotation time of 0.75 s, pitch of 0.688, and convolution kernel of FC64, with CTDIvol 52.9 mGy. Meanwhile, patients who underwent CT head contrast examination with GE Medical System Optima CT660 CT Scanner consisted of 32 women and 18 men, with an age between 16 - 83 years and an average weight of 59.94 ± 10.05 kg. Scanning parameters: head helical, tube voltage of 120 kVp, tube current of 175 mA, slice thickness of 1.25 cm, rotation time of 0.8 s, pitch of 0.53125, and convolution kernel standard with CTDIvol 47.27 mGy. The contrast agent solution of iodine with a concentration of 300 mg / mL (Iohexol, Omnipaque™) has been injected intravenously (IV).

The value of Dw is calculated from the region of interest (ROI) on the axial image of the patient using Equation (1).

$$D_w = 2\sqrt{\left[\frac{1}{1000}\overline{CT} + 1\right]\frac{A_{ROI}}{\pi}} \quad (1)$$

Where $\overline{CT}$ is the mean HU value of the pixels in the patient's ROI, and A_{ROI} is the area of the patient's ROI (mm^2). The shape of the ROI follows the contours of the patient, automatic contouring using the IndoseCT version 20b as shown in Figure 2. Dw values can be calculated using the entire slice or only one middle slice for chest examination [22]. However, in the head examination, the Dw counted on the middle slice is always greater than the Dw counted over the entire slice [23]. Therefore, in this study we used all slices to calculate the Dw value. We assume that calculating Dw on all slices can represent the effect of the contrast agent on the mean value of Dw.

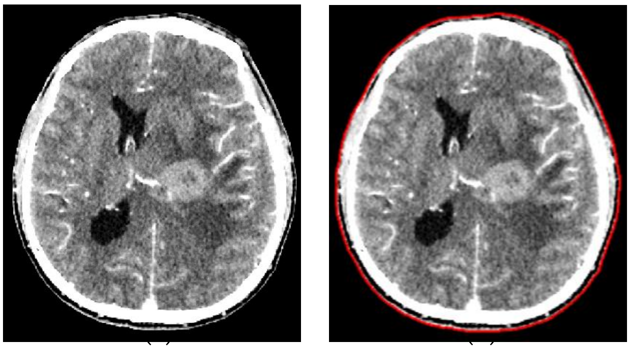


Figure 2: Image Processing by IndoseCT to applied auto-contouring (a) before auto-contouring and (b) after auto-contouring.

The conversion factor (f) used in this study is obtained from the AAPM Report 220 body conversion factor (f^{B16}) Equation (2) [17] and AAPM Report 293 head conversion factor (f^{H16}) Equation (3) [19].

$$f^{B16} = 1.874799 \times e^{-0.03871313 D_w} \quad (2)$$

$$f^{H16} = 1.9852 \times e^{-0.0486 D_w} \quad (3)$$

SSDE is obtained by multiplying the conversion factor value with the CTDIv value from the dose report according to Equation (4).

$$SSDE = CTDI_{vol} \times f \quad (4)$$

The f value affects the absorbed dose received by the patient. This study identified differences in the use of f^{B16} and f^{H16} values to determine the absorption dose received by patients when undergoing CT head contrast examination. The SSDE value with the head conversion factor for the same CTDIv value was approximately 8.7% lower than the body conversion factor value [19].

The method in our study aims to identify differences in Dw CT head pre- and post-contrast agent. The effect of the contrast agent on Dw depends on the tube voltage. However, the effect of tube voltage after administration of contrast agent in Dw is very small, even at 140 kVp there is no significant effect [21,24]. Therefore, we performed at 120 kVp. The data in this study were tested using the Shapiro-Wilk test for normality test. Regression analysis was used to determine the relationship between the Dw pre-and post-contrast values. In addition, a parametric test of two independent samples t-test was also conducted to determine the difference between the Dw pre- and post-contrast agent values. The confidence level is 95% CI or has a P-value of 0.05. If the p-value is < 0.05, the two data tested are significantly different, and if the P-value is $\geq$ 0.05, the two data tested are not significantly different. Statistical analysis was performed using IBM SPSS Statistics version 25 software.

Percent Difference (PD) was used to determine the difference between Dw pre-contrast and Dw post-contrast agent in percent and to calculate the difference between the conversion factors f^{B16} and f^{H16}. PD_{Dw} is calculated using Equation (5), while PD_f is calculated using Equation (6).

$$PD_{Dw} = \left(\frac{DwPOST - DwPRE}{DwPRE}\right) \times 100\% \quad (5)$$

$$PD_f = \left(\frac{f^{H16} - f^{B16}}{f^{B16}}\right) \times 100\% \quad (6)$$

To consider the effect of Dw change on SSDE we normalized dose coefficient (NDC) fit parameters of the Appendix-1 AAPM report 220 for f^{B16} and Equation 1 AAPM report 293 for f^{H16} [17,19,20]. $NDCf^{B16}$ is calculated using Equation (7), while $NDCf^{H16}$ is calculated using Equation (8).

$$NDCf^{B16} = 1 - e^{-\Delta\overline{Dw}\times 0.03871313} \quad (7)$$

$$NDCf^{H16} = 1 - e^{-\Delta\overline{Dw}\times 0.0486} \quad (8)$$

Where $\Delta\overline{Dw}$ is the difference between the mean value of Dw pre- and post-contrast.

III. RESULTS AND DISCUSSION

Figure 3 shows a positive relationship between the Dw pre-contrast value and the Dw post-contrast value for two CT Scan modalities, namely the Toshiba Alexion 16 CT Scanner and the GE Medical System Optima CT Scanner CT660 with R^2 values were 0.9959 and 0.9776. This indicates that the increase in the Dw pre-contrast value is accompanied by an increase in the Dw post-Contrast value. Table 1 reports the statistical analysis of the data tested in this study, the results of the test using two independent samples t-test to determine the difference between the Dw pre- and Dw post-contrast is the P-value for the Toshiba Alexion 16 CT Scanner and the GE Medical System Optima CT660 were 0.65 and 0.45. Figure 4 shows the box and whisker plot of the Dw pre- and post-Contrast values. The difference between the mean Dw pre-contrast and the mean Dw post-contrast for the CT Scanner Toshiba Alexion 16 and the CT Scanner GE Medical System Optima CT660 were 0.43% and 0.73%. From the three statistical analyzes, it was found that there was no significant difference between the Dw pre-contrast and Dw post-contrast values, this indicates that the contrast agent did not significantly influence the increase in the mean value of HU [25].

TABLE I

MEAN AND STANDARD DEVIATION OF THE DW

CT Scanner		Dw (cm)
Toshiba Alexion	Pre	16.14 ± 0.75
	Post	16.21 ± 0.73
	PD (%)	0.43
	P-value	0.65
GE Optima	Pre	16.61 ± 0.82
	Post	16.74 ± 0.78
	PD (%)	0.73
	P-value	0.45

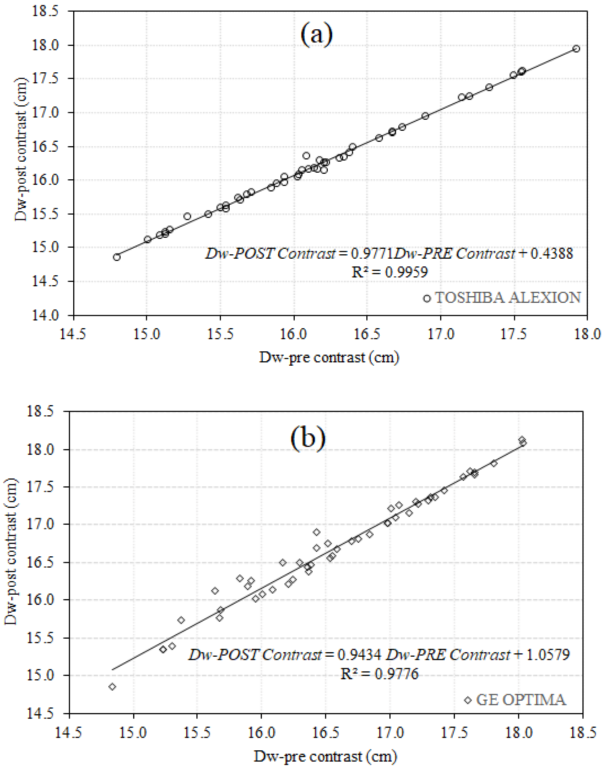


Figure 3: Scatterplot of water equivalent diameter pre-contrast vs water equivalent diameter post-contrast to know the relationship between them both. (a) CT Scanner Toshiba Alexion 16. (b) CT Scanner GE Medical System Optima CT660.

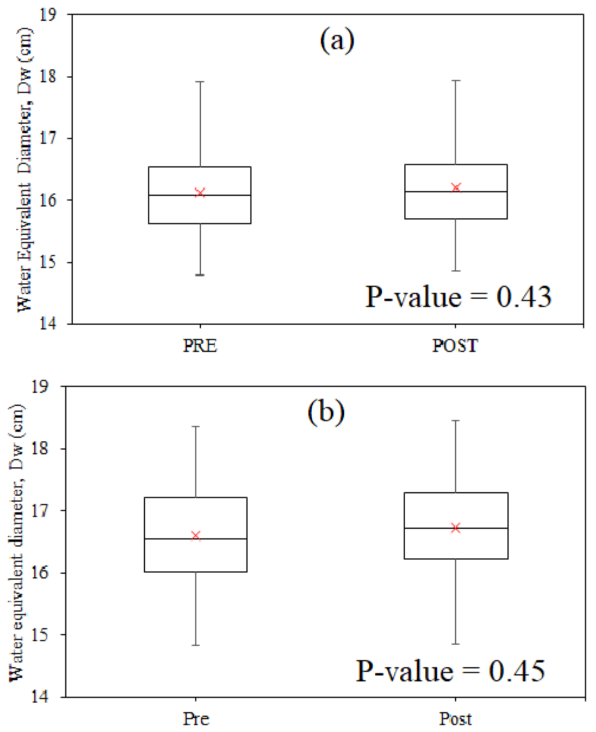


Figure 4: Box and whisker plot of water equivalent diameter pre- and post- contrast to know the relationship between them both. (a) CT Scanner Toshiba Alexion 16. (b) CT Scanner GE Medical System Optima CT660.

Figure 5 shows the conversion factor values (f^{H16} and f^{B16}) vs Dw for the two CT scan modalities. (a) data from Toshiba Alexion pre-contrast CT Scanner, f^{H16} 9.72% smaller than f^{B16} , (b) from CT Scanner, Toshiba Alexion post-contrast, f^{H16} 9.79% smaller than f^{B16}, (c) data from GE Optima pre-contrast CT Scanner, f^{H16} 10.08% smaller than f^{B16}, and (d) data from the GE Optima post-Contrast CT Scanner, f^{H16} 10.19% smaller than f^{B16}. Difference value between f^{H16} and f^{B16} in this study with a different value between f^{H16} and f^{B16} in AAPM Report No. 293 for Toshiba Alexion pre-contrast CT Scanner, Toshiba Alexion post-contrast CT Scanner, GE Optima pre-contrast CT Scanner and CT Scanner GE Optima post-contrast were 1.02%, 1.09%, 1.38%, and 1.49%. The difference in the value of this conversion factor is due to differences in the sampling method, AAPM Report No. 293 uses four sampling methods, the first of which was conducted at St. Jude Children's Research Hospital (Memphis, Tennessee) with physical measurements in Tissue-Equivalent Head Phantoms; the second was done at the Mayo Clinic with physical measurements in Tissue-Equivalent Head Phantoms; the third was conducted at the University of California-Los Angeles (UCLA) performing simulations with Monte Carlo Estimations in Voxelized Head Models; and a fourth performed at UC Davis performing a simulation with Monte Carlo Estimation in Virtual Head CT Phantoms [19]. However, this study took samples from axial images of patients in Indonesia and used a contrast agent.

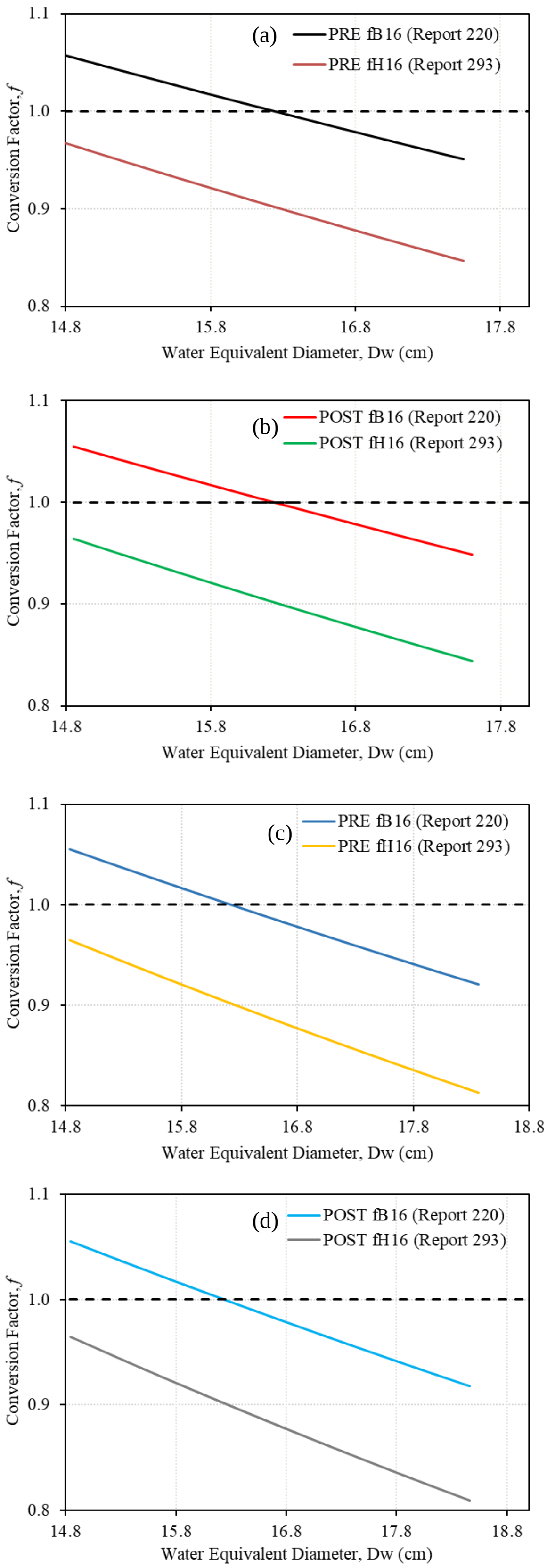


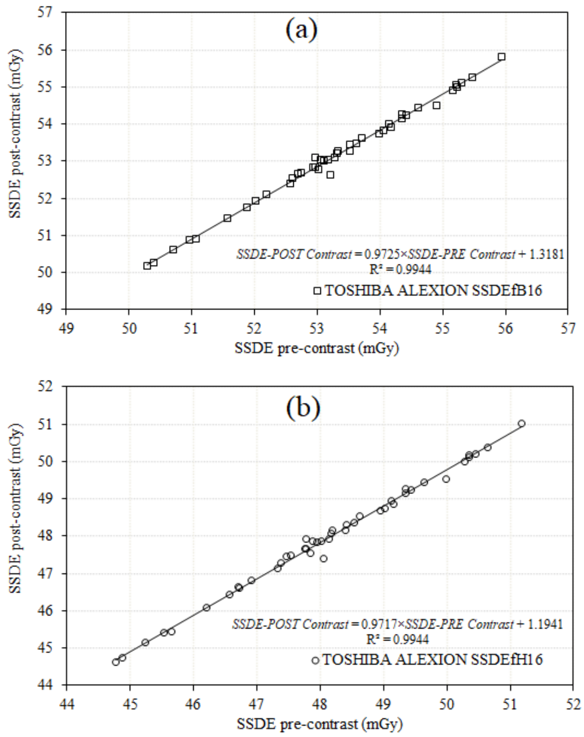
Figure 5: The conversion factor for calculating SSDE based on water equivalent diameter, and the difference absorbed dose between f^{H16} and f^{B16}. (a) CT Scanner Toshiba Alexion 16 pre-contrast with the percentage difference is 9.72%. (b) CT Scanner Toshiba Alexion 16 post-contrast with the percentage difference is 9.79%. (c) CT Scanner GE Medical System Optima CT660 pre-contrast with the percentage difference is 10.08%. (d) CT Scanner GE Medical System Optima CT660 post-contrast with the percentage difference is 10.19%.

Figure 6 shows a positive relationship between the SSDE pre-contrast value and the SSDE post-contrast value for the two CT Scan modalities and the conversion factor values of f^{H16} and f^{B16}, namely CT Scanner Toshiba Alexion 16 f^{B16}, CT Scanner Toshiba Alexion 16 f^{H16}, CT Scanner GE Medical System Optima CT660 f^{B16} and CT Scanner GE Medical System Optima CT660 f^{H16} with R^2 values were 0.9944, 0.9944, 0.9933, and 0.9933. This indicates that the increase in the SSDE pre- contrast value is accompanied by an increase in the SSDE post-contrast value. Figure 7 shows the box and whisker plot of the SSDE pre-contrast agent value and the SSDE post-contrast agent value for the two CT Scan modalities with conversion factor values f^{B16} and f^{H16}. The difference in mean value of SSDE pre-contrast agent and mean value of SSDE post-contrast agent CT Scanner Toshiba Alexion 16 f^{B16}, CT Scanner Toshiba Alexion 16 f^{H16}, CT Scanner GE Medical System Optima CT660 f^{B16} and CT Scanner GE Medical System Optima CT660 f^{H16} were 0.27%, 0.34%, 0.48% and 0.60%. This indicates that the difference between SSDE pre-contrast and SSDE post-contrast is not significant.

Based on AAPM report 220 and AAPM report 293 to calculate the SSDE metric used is Dw because Dw considers tissue attenuation to estimate SSDE can be more accurate in body areas that contain various tissue compositions and densities. Therefore, to consider the change in Dw affecting SSDE we normalized dose coefficient (NDC). The NDC change values were obtained for the CT Scanner Toshiba Alexion with a conversion factor f^{B16}, CT Scanner

Toshiba Alexion 16 conversion factor f^{H16}, CT Scanner GE Medical System CT660 conversion factor f^{B16}, and CT Scanner GE Medical System CT660 conversion factor f^{B16} were 0.27%, 0.34%, 0.47% and 0.59%. The NDC value in this study is acceptable because the SSDE calculation can be accepted with an error below 20% [26].

The results of our study found that the CT head contrast SSDE examination can be calculated using only the Dw pre-contrast or Dw post-contrast values. Because there is no significant effect of contrast agent on Dw value. So that an approach can be made to one of the Dw values on the axial image of the patient. For further studies, the effect of agent contrast on Dw value can be done with variations of kVp. Because when energy decreases, the iodine attenuation increases relative to the air increase [27]. It is hoped that the process of obtaining dose optimization for CT head contrast examination will occur.



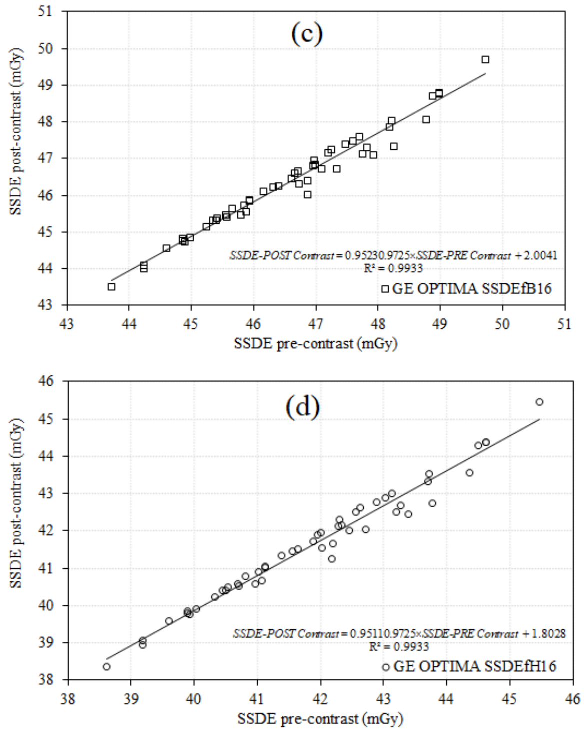


Figure 6: Scatterplot of size-specific dose estimate pre-contrast vs size-specific dose estimate post-contrast for conversion factor value f^{H16} and f^{B16} to know the relationship between them both. (a) SSDE f^{B16} CT Scanner Toshiba Alexion 16. (b) SSDE f^{H16} CT Scanner Toshiba Alexion 16. (c) SSDE f^{B16} CT Scanner GE Medical System Optima CT660. (d) SSDE f^{H16} CT Scanner GE Medical System Optima CT660.

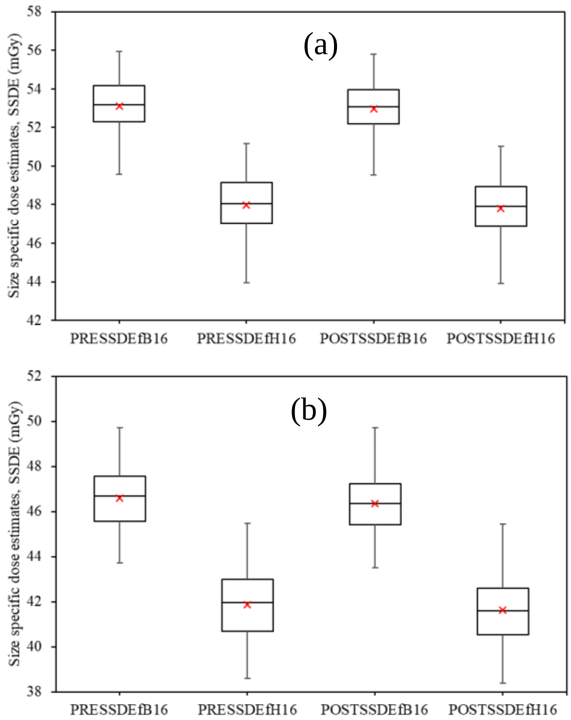


Figure 7: Box and whisker plot of size-specific dose estimates with conversion factor value f^{B16} and f^{H16} to know the relationship between them both. (a) CT Scanner Toshiba Alexion 16. (b) CT Scanner GE Medical System Optima CT660.

IV. CONCLUSION

We did not see the effect of agent contrast on Dw and SSDE values on CT head examination. Statistical analysis showed that the P-value > 0.05 indicated that the difference between Dw pre- and post- contrast was not significant. SSDE on CT head examination with contrast agent can be approached on one of the Dw values.

V. ACKNOWLEDGMENT

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