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Correlation between Age and Abdominal Diameter for Estimating Size-Specific dose in Pediatric CT examination

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ABSTRACT

This study aims to investigate the correlation between abdominal diameter against the their ages in pediatric Computed Tomography (CT) examination. The retrospective images from 96 patients ranging from 0–16 years scanned by the Siemens Somatom Go Top 128 Multi-slice CT scanner were evaluated. In a total of 46 patients were scanned by tube current modulation (TCM) approach and the remaining 50 patients were examined whitout TCM. The effective diameter (D_{eff}) for every patient was automatically calculated using IndoseCT. The evaluation of the size and age correlation was carried out using a regression approach from AAPM Task Group 204. In addition, size-specific dose estimate (SSDE) was also calculated using IndoseCT. The results shows that the patient's diameters increase along the increase of ages ($R^2 > 0.68$) with rapid growth in the ages of 0-1 years. It is also found that the increase in the patient's diameter leds to the decrease of SSDE in the non-TCM protocol, while the trend in the TCM protocol is different. The SSDE had a tendency to increase along with the increase in patient sizes ($R^2 < 0.40$).
Keywords: effective diameter (D_{eff}), size-specific dose estimation (SSDE), tube current modulation (TCM), pediatric CT.

I. INTRODUCTION

The utilization of computed tomography (CT) as an imaging modality has grown rapidly [1-2]. The CT has a great contribution to aiding patient diagnoses [3-4], however CT potentially imposes a ionizing radiation risk [5-6]. Despite the CT imaging only contributes 11% to the total ionizing radiation exposure, the overall radiation dose exceeds two-thirds of the total dose received [7]. Therefore CT examination needs to be monitored since high-dose exposure poses a risk of inducing cancer in patients, especially in pediatric patients [8-9]. The cells in pediatric patients are actively proliferating, therefore a slight radiation exposure has the potential to disrupt cell growth in children [10]. A study by Smoll et al. [11] indicated that head CT examination in pediatric patients potentially increase brain cancer occurrence by 3.7%

among Australians. Therefore, minimizing the received dose in pediatric CT is crucial to adhere to the As Low as Reasonably Achievable (ALARA) principle [12].

The dose quantification in CT examinations generally relies on the Volumetric Computed Tomography Dose Index ($CTDI_{vol}$) and Dose Length Product (DLP) [13]. Unfortunately, both matrices only consider the output dose of CT and do not consider the patient's body geometry which highly contributes to the dose. In the same dose output, the larger patient's diameter, the smaller dose will be absorbed by the patient[14]. Therefore, the American Association of Physicists in Medicine (AAPM) introduced a new matrix for estimating patient dose, known as Size-specific Dose Estimates (SSDE). The patient's diameter for calculating SSDE was initially using the effective diameter (D_{eff}). The SSDE has been reported to effectively estimate absolute organ doses with a difference of ±10% [16]. Another study by Brady et al. [17] also reported that using SSDE resulted in a better agreement (about 50%) with the measured dose by the dosimeter.

Unfortunately, calculating the diameter of each patient manually is tedious and time-consuming, while for a clinical application, the calculation must be fast and effective. Hence, utilizing age as a reference for SSDE measurements has become one alternative to achieve a more efficient dose measurement. Cheng et al. [18] reported that the D_{eff} and age have a high correlation in abdominal examinations, leading to a faster calculation of SSDE. A study by Fahmi et al. [19] also reported that using the age and D_{eff} correlates greater than 0.8 (R^2 >0.8), indicating a strong correlation between the patient's age and D_{eff}. Nevertheless, the previous study [19] was only conducted on pediatric head examinations and did not evaluate other CT examination such as abdominal examination which often occurs in clinical examinations [20-21]. Therefore, this study aims to evaluate the relationship between the age and abdominal size of pediatric patients. This study also evaluates examinations with and without tube current modulation (TCM) features.

II. METHODS AND MATERIAL

A. Patient images

This study utilized retrospective images from 96 pediatric patients, ranging from 0-16 years. A total of 46 patients were scanned with TCM, while 50 patients were examined without TCM (tube current of 240 mA). The scans were performed using the Siemens Somatom Go Top 128 Multi-slice CT installed at Dr. Kariadi Central General Hospital, Semarang, Indonesia. The remaining parameters were set constant for all patients, with a tube voltage of 80-100 kVp, a rotation time of 0.5 seconds, and with axial mode. Both contrast-enhanced and non-contrast images were employed, collected between May 2021 and May 2022, and images were stored in the Digital Imaging and Communications in Medicine (DICOM) format.

B. Correlation between size and ages

For determining the relationship between patient size and age, the patient's body size needs to be measured beforehand. Measurements of D_{eff} were automatically carried out using the IndoseCT software [22] (Figure 1). D_{eff} was measured from the cross-sectional area of the patient's images. Therefore, the measurement was carried out by creating a Region of Interest (ROI) that covers the entire cross-section of the patient's image. The ROI was automatically generated by segmenting the image using a threshold of -300 Hounsfield unit (HU). From the ROI, the area (A) and D_{eff} were calculated using Equation (1).

$$D_{eff,\ A} = 2\sqrt{\frac{A}{\pi}} \quad (1)$$

The correlation between the D_{eff} values with patient age was analyzed using a regression approach defined by AAPM 204, as described by Equation (2).

Parameters a, b, c, and d were calculated using the least squares method, utilizing quadratic regression in Python software. Additionally, the R-squared (R^2) value is also computed to investigate the correlation between two parameters.

$$y = a + bx^{1.5} + cx^{0.5} + de^{-x} \quad (2)$$

Figure 2. Graphical user interface (GUI) on IndoseCT for measuring SSDE.

C. SSDE calculation

The SSDE was calculated using equation (3). The value of $CTDI_{vol}$ is the output from the scanner obtained from DICOM information in mGy units. Meanwhile, the conversion factor (f) is obtained from AAPM Report No. 204 and it is a function of D_{eff}. The example of SSDE measurement using IndoseCT is shown in Figure 2.

$$SSDE = CTDI_{vol} \times f \quad (3)$$

III.RESULTS AND DISCUSSION

A. Relationship between D_{eff} against age

The relationship between D_{eff} and age is depicted in Figure 3. The parameters a, b, c, and d were 5.2427, -0.0602, 6.4361, and 8.5770. Figure 3 shows that the D_{eff} increased with the increase of age with R^2 = 0.6580. This value was much lower than the regression obtained in the head area of R^2 = 0.8 reported previously [19]. A lower correlation on abdominal examination may be due to more variative abdominal sizes than the head for every age. A drastic increase in abdominal diameter occurs in patients aged 0-1 year, while the growth decreases with age. Previous studies by Fahmi et al. [19] reported that the growth of children's heads was massive as the patient ages. While the growth of the thoracic and abdominal areas increases linearly with the patient ages as reported by Kleinman et al [23].

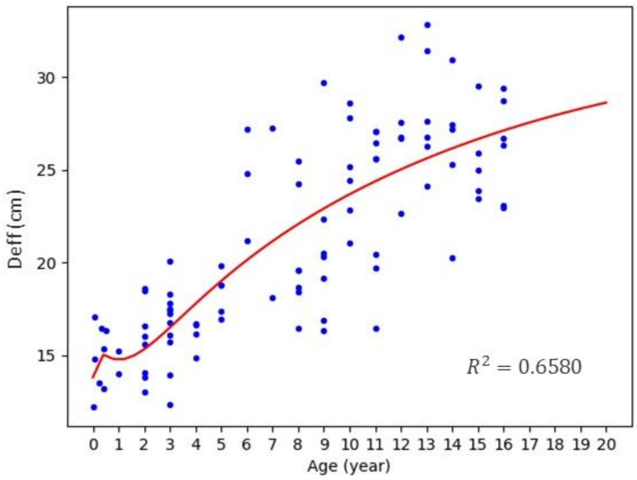

Figure 3. The relationship between D_{eff} against the age.

B. Relationship of $CTDI_{vol}$ against D_{eff}

Figure 4 shows the relationship between $CTDI_{vol}$ and D_{eff} with TCM (a) and without TCM (b). Figure 4(a) shows that the use of TCM causes the $CTDI_{vol}$ is dependent of D_{eff}. For patients with D_{eff} of 15-20 cm, the $CTDI_{vol}$ in the range of 2-3 mGy. Whereas for patients with large diameter of 30-33 cm, the $CTDI_{vol}$ in the range of 6-8 mGy. This is happened because the use of TCM, the tube current changes dinamicallay according to patient size. The increase in tube current, of course, has an impact on the increase in $CTDI_{vol}$ [24]. This was different when the TCM feature is turned off as in Figure 4(b). It shows that without TCM, the $CTDI_{vol}$ was independent of D_{eff}. The $CTDI_{vol}$ was constant around 3.5 mGy for all sizes of patients.

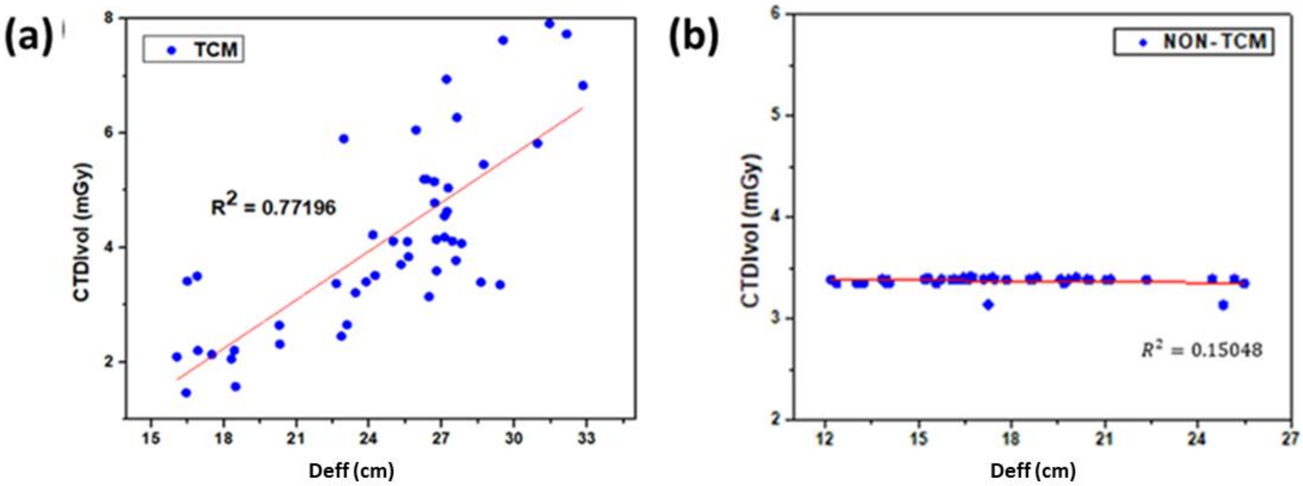

Figure 4. The relationship between the $CTDI_{vol}$ and D_{eff}, (a) with TCM and (b) without TCM.

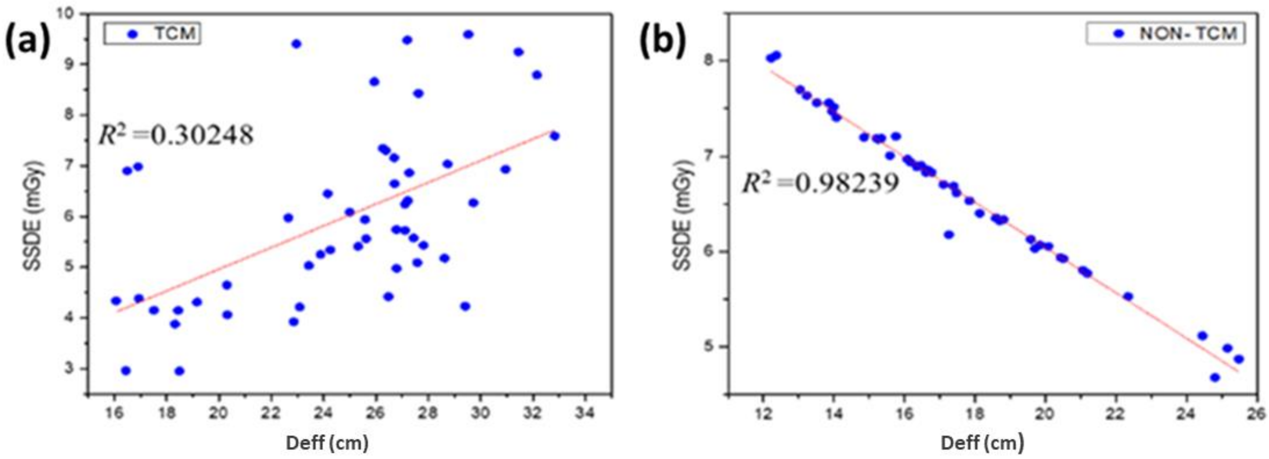

Figure 5. The relationship between the SSDE and D_{eff} with (a) TCM approach (b) and without TCM approach

C. Relationship of SSDE againts D_{eff}

The relationship between SSDE and D_{eff} is shown in Figure 5. When using TCM, SSDE increases linearly with increasing D_{eff}, although with a weak R^2 value (R^2 = 0.30). Meanwhile, in non-TCM, SSDE decreases exponentially with increasing D_{eff} (with R^2 = 0.98).

The use of TCM in pediatric patients can be an alternative to dose reduction. This study found that although TCM was able to reduce the dose in patients with smaller diameters. A study by Papadakis et al. [25] found that the use of TCM in pediatric patients can only reduce 2-10% of the dose received. Another study by Schlattl et al. [26] also found that the use of TCM can only reduce 10% of the organ dose conversion coefficient compared with non-TCM. However, the use of TCM is still recommended for pediatric abdominal CT examinations for dose reduction.

A comparison of the relationship between D_{eff} and the age of patients found in this study and AAPM is shown in Figure 6. Coefficients a, b, c, and d in this study were: 5.2427, -0.0602, 6.4361, and 8.5770. While the coefficients a, b, c, and d in AAPM TG 204 are 18.7885, 0.1948, -1.0600, and -7.6244. The regression value in this study is $R^2 = 0.9466$, slightly more than the regression value generated by AAPM of $R^2 = 0.9714$. The differences may be due to the difference in the posture of Indonesian children (the current study) and American children (the AAPM's report). A study by Nightingale et al. [27] reported that East Asian children have lower bode mass index (BMI) values compared to children from Africa-Caribbean.

This study has some limitations. First, we evaluated a limited number of patients. Evaluation in a wider population from various hospitals and CT scanners is needed to provide more accurate trends. Second, the size of the patient is only represented using D_{eff}, which still ignores the composition of the patient's tissue. The use of water-equivalent diameter (D_w) as a more accurate patient size can be performed in the future study.

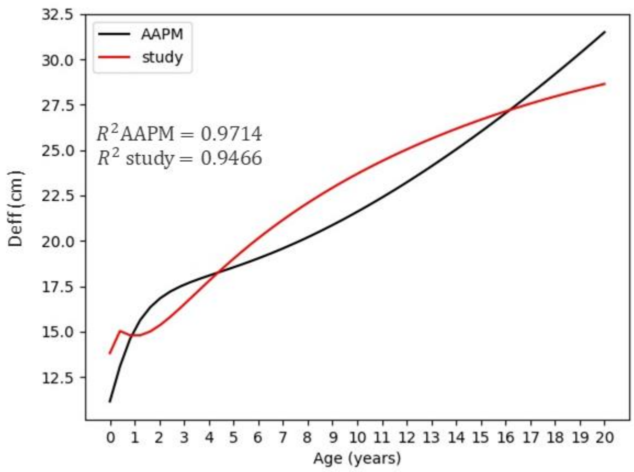

Figure 6. The relationships between D_{eff} and age from this study (red line) and AAPM TG 204 (black line).

IV. CONCLUSION

The relationship between D_{eff} and age is successfully investigated. The D_{eff} increases with the increase of age following non-linear equation with $R^2 = 0.6580$. The use of TCM for pediatric abdominal examination successfully decreased the dose received by patients with small diameters with $R^2 = 0.30248$. Meanwhile, without TCM, the dose increases as the patient's age decreases.

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