The Size-Specific Dose Estimate of Paediatric Head CT Examinations for Various Protocols

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THE SIZE-SPECIFIC DOSE ESTIMATE OF PAEDIATRIC HEAD CT EXAMINATIONS FOR VARIOUS PROTOCOLS

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The purpose of this study was to evaluate the size-specific dose estimates (SSDE) of paediatric patients who underwent head computed tomography (CT) examinations for various protocols in the Patut Patuh Patju Hospital, West Lombok, Indonesia. Three types of protocols commonly used in the paediatric head CT examinations during 2017–2018 were protocols of 1.1 (axial routine head), 1.2 (helical routine head) and 11.1 (paediatric head). Patients were divided into three age groups (0–1.5, 1.5–5 and 5–18 year). Data of computed tomography dose index volume ($CTDI_{vol}$) were obtained from Digital Imaging and Communications in Medicine (DICOM) files of patient CT images. The effective diameter, water-equivalent diameter and SSDE were calculated from the patient's CT image using the IndoseCT software. This research pointed out that SSDE for the paediatric head protocol was far lower than the axial and helical routine head protocols. It was found that the implementation of the 11.1, 1.1 and 1.2 protocols were 20, 37 and 43%, respectively. It is essential for education to the medical personnel involved to implement the protocol of paediatric head CT to avoid an excessive dose of paediatrics in the head CT examination.

INTRODUCTION

At present, the medical application has been the most significant source of ionising radiation exposure for humans[1]. Most of the exposure to medical radiation is dominated by computed tomography (CT) examinations[2]. In many cases, diagnostic procedure with CT has become a choice for various indications due to the fast time and accurate diagnostic information[3]. However, the consequence of the use of CT, the radiation dose received by patients is higher than other radiographic modalities[4]. For example, the typical dose for lung from conventional chest X-rays ranges from ~0.01 to 0.15 mGy, while the typical dose for the lung CT examination is from ~10 to 20 mGy[4].

The radiation dose in CT is quantified using various metrics. One metric to estimate the dose received by a patient in CT examination is a computed tomography dose index volume ($CTDI_{vol}$), which is usually displayed on the CT console when the examination is performed[5]. Previously, the medical community used this metric to estimate and compare CT radiation doses received by patients. Many parameters affect the magnitude of the $CTDI_{vol}$, including tube voltage, tube current, pitch, tube collimation and so on[6]. $CTDI_{vol}$, which is only affected by the input parameters and not by the patient condition, is considered as a metric of the output dose, whereas to estimate an individual's dose it does not only depend on the input parameters but also on the characteristics of the patient[7,8]. The patient dose metric that takes into account both input parameters of CT machine and patient characteristics is a size-specific dose estimates (SSDE)[9].

The size of the patient could be characterised by an effective diameter (D_{eff})[10] or a water-equivalent diameter (D_w)[11]. D_{eff} represents the geometrical patient's diameter in a particular location along the patient's z-axis (in the cranio-caudal dimension), assuming that the patient has a circular cross section. D_{eff} can be considered as a circle diameter whose area is equal to the patient's cross-sectional diameter[10], while D_w is a metric that characterises the size and attenuation of X-rays in patients represented by water cylinders that have the same X-ray absorption[12,13].

There are two possible detrimental effects on patients due to the dose of X-ray radiation, namely stochastic and deterministic effects. At the same dose level received during a CT examination, the risk of radiation is different for paediatric compared to adult patients. Paediatric patients have a higher sensitivity to the radiation, and they have a longer life expectancy. Therefore, they have the possibility of getting stochastic effects higher than adult patients, such as leukaemia, brain tumour and lymphoma[14,15]. Thus, the reduction of radiation doses on paediatric CT examinations gains a significant concern[16].

Table 1. Setting acquisition parameters for the head CT examination.

Protocol name	Scan type	kVp	mA	RT (s)	BC (mm)
1.1 Axial head	Axial	120	300	1.5	10
1.2 Helical head	Helical	120	125	1	20
11.1 Paediatric Head					
(0–1.5 y)	Axial	120	85	1	20
(1.5–5 y)	Axial	120	100	1	20
(5–18 y)	Axial	120	75	1.5	20

RT is rotation time; BC is beam collimation.

For a paediatric CT examination, most radiology facilities recommend an optimised protocol, because the radiation dose received by paediatrics for the same input exposure parameters is usually higher than the dose received by adults. The CT protocol usually set by the CT vendor in computer software, in which there are several settings and scanning parameters to ensure that the image quality is produced at the lowest possible radiation dose[17].

In our hospital, the Patut Patuh Patju Hospital, West Lombok, Indonesia, head CT examinations for paediatrics are not only using specific paediatric protocols, but other protocols are sometimes chosen, namely axial and helical routine head protocols, especially in paediatric patients who are less cooperative to avoid repeated examinations. However, investigation of radiation dose to paediatrics head CT has never been carried out. Therefore, this study was conducted to investigate how much CT axial head protocol, CT helical head protocol and paediatric protocol have been used in our hospital and attempted to calculate the dose received by patients for each protocol using metrics of $CTDI_{vol}$ and SSDE.

MATERIAL AND METHOD

Paediatric CT examinations

In this study, the data were retrospectively collected from serial images of the CT head in the Digital Imaging and Communications in Medicine (DICOM) file. The $CTDI_{vol}$ values were manually recorded from the image dose record. Furthermore, automatic calculation of D_{eff}, D_w and SSDE was carried out from 114 paediatric patients who underwent head examination using the IndoseCT 15a software[5]. In this study, patients with clinical hydrocephalus were excluded. The patients were scanned using a 16 slices CT (Brivo CT385, GE Healthcare, China) installed at our hospital. We chose three types of protocols for heads that are often used by radiographers. The protocols were the axial routine head, helical routine head and paediatric head. The axial and helical routine head protocols were the standard protocol for adult examinations, while the paediatric head protocol was a dedicated protocol for children. In the paediatric head protocol, there are three settings according to the age group of children, namely the age group 0–1.5, 1.5–5 and 5–18 year[18]. Setting acquisition parameters for each protocol were listed in Table 1. The tube current modulation was turned off for head scanning.

D_{eff}, D_w and SSDE calculation

D_{eff} was automatically calculated using the IndoseCT 15a software[5]. The automated D_{eff} calculation was started by an automated contouring of patient images[19], as shown in Figure 1. The first step for the automated contouring was thresholding using a value of −200 HU. Edge detection to identify objects in patients was then performed. Next step was to label them and calculate their areas. The largest defined area was considered to be the border of the patient (Figure 1a).

D_{eff} calculations were completed in several steps. The first step was determining the position of the patient's centre. The second step was determining the diameter in the anterior-posterior (AP) and lateral (LAT) directions (Figure 1b). The last step was the calculation of the D_{eff} of the product root from the AP and the LAT dimension using equation (1)[19]:

$$D_{eff} = \sqrt{AP \times LAT}. \quad (1)$$

The automated D_w calculation was also started by automated contouring patient images[20]. The results of automatic contouring were used to crop the original image. Average of HU value ($\overline{HU}$) and the area of the patient (A) were calculated from the cropped image. D_w was calculated using equation (2)[21]:

$$D_w = 2\sqrt{\left[\frac{1}{1000}\overline{HU} + 1\right]\frac{A}{\pi}}. \quad (2)$$

The IndoseCT 15.a software was used to calculate the SSDE value. The steps were as follows: the

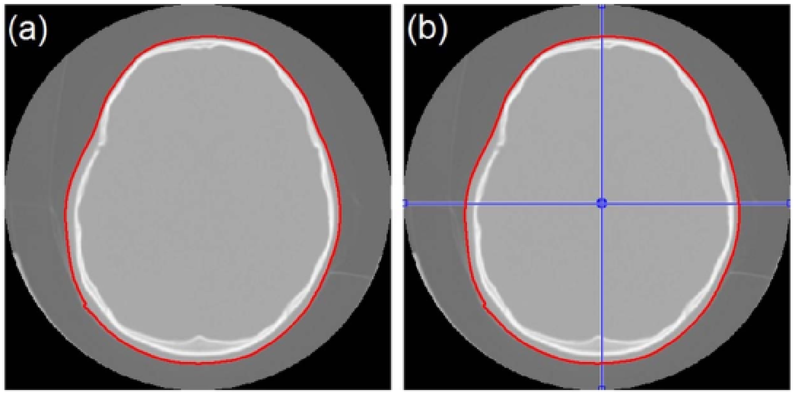

Figure 1. (a) Image of automated contouring, and (b) AP and LAT diameters for D_{eff} calculation.

$\mathrm{CTDI_{vol}}$ values were manually recorded from the image dose record and inputted to the IndoseCT. SSDE was calculated by multiplying the $\mathrm{CTDI_{vol}}$ and the size-conversion factor (f), as given in the following equation:

$$\mathrm{SSDE} = \mathrm{CTDI_{vol}} \times f. \tag{3}$$

f is to translate $\mathrm{CTDI_{vol}}$ into the SSDE[9,10]. The f was adopted from the AAPM report No 204[10]. The f depends on the size-specific of the patient (D_{eff} and D_w)[10]. The SSDE method, which takes body measurements into consideration, is a very adequate index for estimating exposure doses, especially in children[22,23]. To calculate the value of paediatric SSDE, the IndoseCT used the f of the head PMMA phantom with a diameter of 16 cm[12].

RESULTS

For 114 paediatric patients, 37% of patients were scanned with the 1.1 protocol, 43% of patients with the 1.2 protocol and 20% of patients with the 11.1 protocol. Figure 2 shows the D_{eff} and D_w of the patient based on age groups, namely group 1 (0–1.5 year), group 2 (1.5–5 year) and group 3 (5–18 year). As it is expected, the diameter of the patient head depends on the patient age. The diameter increases with the increase in patient age: at the age of 0–1.5 year, the value of D_{eff} is 12.7 ± 1.6 cm; at the age of 1.5–5 year, the D_{eff} is 14.5 ± 1.1 cm; and at the age of 5–18 year, the D_{eff} is 15.7 ± 1.4 cm. While the average value of D_w at the age of 0–1.5 year is 13.0 ± 1.6 cm; at the age of 1.5–5 year, the D_w is 15.2 ± 1.2 cm; and at the age of 5–18 year, the D_w is 16.6 ± 1.4 cm.

Figure 2 shows that D_w is 4% greater than D_{eff}. The relationship between D_{eff} and D_w is depicted in Figure 3. It shows that in the paediatric head size, there is a very strong linear correlation between D_{eff} and D_w ($R^2 = 0.97$).

Based on the age of the paediatric patients, the doses in terms of $\mathrm{CTDI_{vol}}$ and SSDE can be seen in Figure 4. There is a substantial difference in the value of $\mathrm{CTDI_{vol}}$ for a different selection of protocols. The $\mathrm{CTDI_{vol}}$ value in the 1.1 protocol (axial routine head) is highest, followed by the 1.2 protocol (helical routine head) and is lowest in the 11.1 protocol (paediatric head). The $\mathrm{CTDI_{vol}}$ for protocols of 1.1, 1.2 and 11.1 are 39.9 ± 1.2 mGy, 24.3 ± 1.4 mGy and 17.0 ± 24 mGy, respectively. It means that $\mathrm{CTDI_{vol}}$ of the 11.1 protocol is 57% lower than the 1.1 protocol, and 30% lower than the 1.2 protocol.

In the 1.1 and 1.2 protocols, average $\mathrm{CTDI_{vol}}$ is independent of the age of the paediatric patient. While in the 11.1 protocol (paediatric head), average $\mathrm{CTDI_{vol}}$ is dependent on the age of the paediatric patient. The $\mathrm{CTDI_{vol}}$ increases with the increase in the age of the paediatric patient. The averages of $\mathrm{CTDI_{vol}}$ in the 11.1 protocol selection are 15.8 ± 1.8 mGy for the age group 0–1.5 year, 17.7 mGy for the age group 1.5–5 year and 18.9 ± 1.9 mGy for the age group 5–18 year.

The SSDE pattern is different from $\mathrm{CTDI_{vol}}$ for different protocols. However, in the age group of 0–1.5 and 1.5–5 year, the SSDE value for each protocol always higher than the $\mathrm{CTDI_{vol}}$ because the head size of paediatric patients is <16 cm. While in the age group of the 5–18 year, the value of SSDE and $\mathrm{CTDI_{vol}}$ is almost the same because the average diameter of this age group is ~16 cm. According to the SSDE concept, by using the same exposure factor, the smaller diameter of the patient's head will get the more dose. The SSDE in the 1.1 and 1.2 protocols decreases with the increase of the age of the paediatric patient, while in the 11.1 protocol, the SSDE increases with the increase of age.

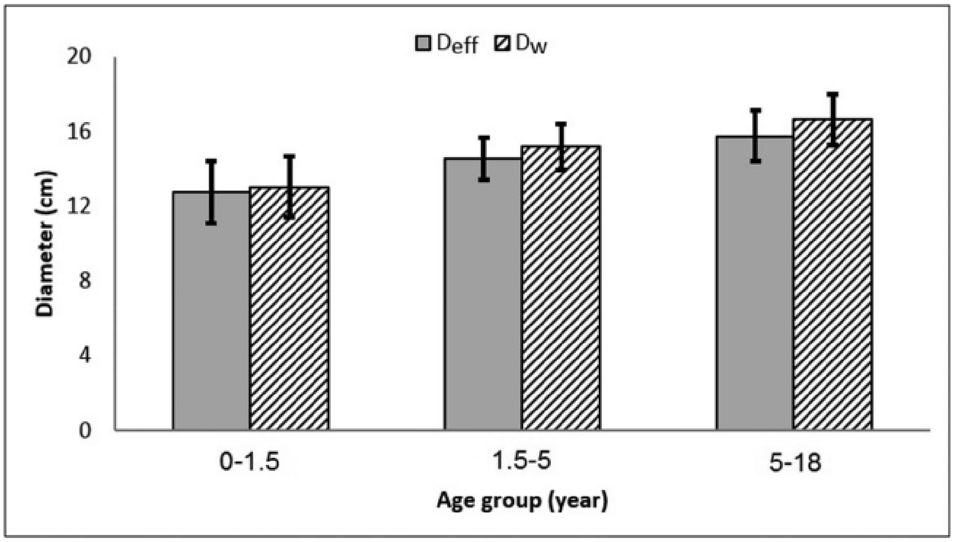

Figure 2. Size of paediatric patients' head based on age groups.

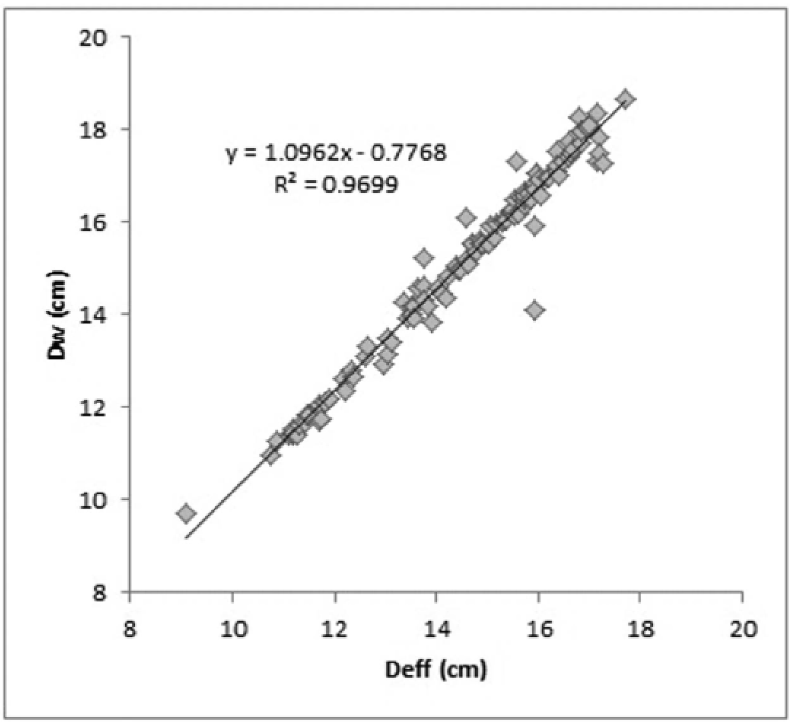

Figure 3. Correlation between the values of D_w and D_{eff}.

Based on D_{eff} of the patient, SSDE values in the 1.1 protocol are 46.9 ± 0.7 mGy for the age group 0–1.5 year, 42.2 ± 1.8 mGy for the 1.5–5 year and 40.4 ± 3.1 mGy for the 5–18 year. The SSDE values in the 1.2 protocol are 27.5 ± 2.7 mGy for the age group 0–1.5 year, 26.8 ± 2.0 mGy

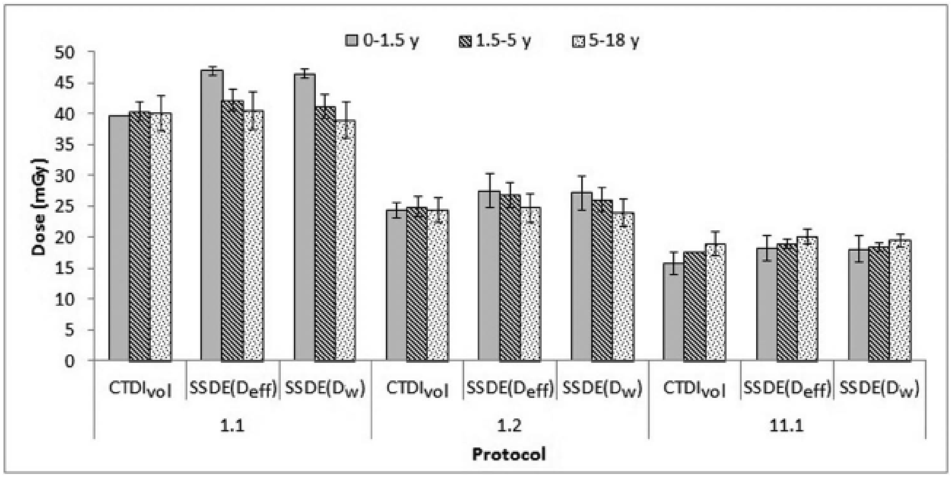

Figure 4. Comparison of CTDI and SSDE based on size-specific of the patient. Note: 1.1 is axial routine head protocol, 1.2 is helical routine head protocol and 11.1 paediatric head protocol.

for the 1.5–5 year and 24.7 ± 2.4 mGy for the 5–18 year. While the SSDE values in the 11.1 protocol selection are 18.2 ± 2.1 mGy for the age group 0–1.5, 18.9 ± 0.7 mGy for the age group 1.5–5 year and 20.0 ± 1.2 mGy for age group 5–18 year.

The SSDE based on D_w is slightly smaller than that based on D_{eff}. Based on D_w of the patient, average SSDE values in the 1.1 protocol are 46.5 ± 0.7 mGy for the age group 0–1.5 year, 41.2 ± 1.9 mGy for the 1.5–5 year and 39.0 ± 3.0 mGy for the 5–18 year. The SSDE values in the 1.2 protocol are 27.1 ± 2.8 mGy for the age group 0–1.5 year, 26.1 ± 2.0 mGy for the 1.5–5 year and 24.0 ± 2.2 mGy for the 5–18 year. While the SSDE values in the 11.1 protocol are 18.1 ± 2.2 mGy for the age group 0–1.5 year, 18.5 ± 0.7 mGy for the age group 1.5–5 year and 19.5 ± 1.0 mGy for age group 5–18 year.

DISCUSSION

Until this study conducted, there was no standard operating procedure regarding the protocol for CT examinations of paediatric heads in the Patut Patuh Patju Hospital. For the year 2017 and 2018, the hospital has utilised three different protocols for that particular examination. The protocols are known as 1.1 (axial routine head), 1.2 (helical routine head) and 11.1 (paediatric head). About 37% of paediatric patients were scanned using the 1.1 protocol, 43% using the 1.2 protocol and only 20% of patients were scanned using the 11.1 protocol. This situation may affect the dose optimisation, which is an integral part of the Radiation Safety and Protection Program.

There are differences in head diameter between three age groups, as indicated in Figure 2. The increasing age group of children increases the diameter of the head. This difference in diameter size results in different dose absorbed by patients in each age group for the same exposure parameters. This finding was consistent with other previous reports[23,24]. However, this difference will certainly not be seen if it is presented using the CTDI_{vol} metric. It is clearly seen if the absorbed dose is presented using the SSDE metric, where the size of the patient's diameter greatly influences the absorbed dose. It is necessary to make adjustments to the exposure factor on paediatric CT head examination. The fact is that no exposure parameter adjustments were made with protocols of 1.1 and 1.2 for different head diameters. Only 11.1 protocol has adjusted to the age of the patient which also means adjusting to the size of the patient's head diameter.

In Figure 3, the D_w is slightly higher than D_{eff} in the paediatric head. This is because the largest contributor to the head is soft tissue with a value ~0 HU and bone with a value of HU ~+1000. Because D_w considers not only the patient's diameter but also the patient's composition and X-ray attenuation in patients[25–27], D_W is considered more robust than D_{eff} [23]. However, there is a strong linear correlation between D_{eff} and D_w (Figure 3). It means that the D_w could be easily estimated by the D_{eff}.

In Figure 4, there is a difference in the value of CTDI_{vol} and SSDE in each age group. In protocols of 1.1 and 1.2, CTDI_{vol} does not depend on the age of the patient. However, the SSDEs depend on the age of the patient. As it has been mentioned, an increase of the age of the patient makes the patient's diameter also increase, so that the f decreases. Therefore, SSDE decreases with the increase of age for the same input exposure except for that 11.1 protocol. In the 11.1 protocol, when the patient's age and the diameter increase, the exposure factor setting has been adjusted (increased), so the $CTDI_{vol}$ value increases. The combination of an increase of $CTDI_{vol}$ and decrease of *f*s has an impact on SSDE[25,28]; consequently, even though SSDE is increasing, the increase is close to flat. So, by just choosing 11.1 protocol that was originally designed specifically for paediatric head examinations, an increased dose in the younger paediatric age group does not occur.

Finally, it is understood that the selection of the protocol for the paediatric head CT dramatically influences the value of the dose received by the paediatric patient. From the current study, it can be found that the use of the 11.1 protocol (paediatric head), which was originally and specifically designed for paediatric patients, is the best choice according to the principle of radiation protection. Therefore, education to the personnel involved in the CT examination of paediatrics is essential for dose optimisation.

CONCLUSION

It was concluded that the choice of the type of protocol leads to significantly different patient doses. From the comparison of individual doses of paediatric patients who underwent head CT examination using three types of examination protocols, namely protocols of 1.1, 1.2 and 11.1, it was found that the 11.1 protocol produced the smallest individual dose. In fact, for all paediatric patients examined in this study, only 20% of patients were scanned with the 11.1 protocol. Therefore, educating radiographers to be more selective in choosing protocols to examine the paediatric head is crucial.

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CONFLICT OF INTEREST

No conflicts of interest.

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