ORIGINAL ARTICLE

Local Diagnostic Reference Levels for Paediatric Craniofacial CT and Head CT Procedures

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ABSTRACT

Introduction: Diagnostic reference level (DRL) is essential to revise dose optimisation strategies in paediatric CT. This study aims to determine the local DRL for craniofacial CT and head CT protocols in paediatric patients and compare the current DRL with the previous reports. **Materials and Methods:** Craniofacial CT procedure cases (n = 232), including petrous bone, facial bone, paranasal sinus, and head CT protocols were retrieved retrospectively through the CT Picture Archiving Communication System (PACS) of a single health institution. Data were retrieved from CT dose index volume (CTDIvol) and dose length product (DLP) and stratified into five age groups based on the ICRP Report 135 recommendation. The local DRL was statistically established based on the 75th percentile dose data. The established DRLs were compared with the previously established DRL reports. Kruskal-Wallis test was performed for dose comparison among the age groups. **Results:** Variance DRL ranges of 14 mGy - 78 mGy CTDIvol and 149 mGy.cm - 1311 mGy.cm DLP were demonstrated in the craniofacial CT while 40 mGy - 75 mGy CTDIvol were in CT head. Higher DRLs were observed in most craniofacial CT and head CT protocols in the present study compared to the previous local and national DRL reports. **Conclusion:** This study established new local DRLs of craniofacial CT and head CT of Malaysian paediatric patients with dose variances among their age groups. The established local DRLs are higher than the previously established DRL reports. Therefore, paediatric CT practices should be routinely reviewed to achieve dose optimisation.

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INTRODUCTION

Computed tomography (CT) imaging has shown a major contribution in medical care since its introduction in 1972 by providing detailed anatomical images that facilitate medical diagnosis. This imaging modality generates cross-sectional images that offer detailed information about specific regions and eliminates superimposition of structure with excellent clinicopathological correlation for suspected illness (1). Thus, CT scans have been used for numerous clinical indications depending on the evaluated region, but the main concern is when it involves ionizing radiation which can lead to biological harm to human tissues. Ionizing radiation has been shown to increase the risk of cancer for those exposed to high radiation doses, especially paediatrics (2). Tissues and organs of children are more radiosensitive than adults, and they are more likely to acquire radiation-induced cancer after a lengthy latency period (3). Due to the wide range in patient sizes and weights from neonates to adult-sized adolescents, the amount of radiation used for paediatric examinations can vary greatly (4).

Diagnostic Reference Level (DRL) has been constructed as an optimisation tool to identify high radiation dose practices where dose reduction techniques can produce the greatest impact (5). According to the International Commission on Radiological Protection (ICRP), the main objective of DRL is to help avoid giving radiation doses that are unnecessary for the clinical purpose of diagnostic tasks for patients (3). The European Guidelines on DRL for Paediatric Imaging (PiDRL) state that DRL optimises radiation dose in CT without compromising image quality or disregarding paediatric patients' care (6). Optimising Paediatric Imaging is particularly crucial because children are more likely than adults to experience harmful radiation effects, and these effects may appear over a longer period (4). The European Commission has recommended the use of age band for establishing DRL values involving head study (6). The primary application of this optimisation principle is to protect patients from unnecessary radiation exposure.

Radiation dose management in CT is accomplished using the volume CT dose index (CTDIvol) and dose length product (DLP). Both dose descriptors are utilized in the establishment of DRL as they provide a comprehensive assessment of the radiation dose delivered to the patient during CT scanning (7).

In Malaysia, the increasing frequency of paediatric CT scans has raised safety concerns due to the potential exposure to ionising radiation during the CT examinations. The Ministry of Health Malaysia (MOH) published the national DRL in 2013, which only reported data on standard adult patients aged 16 years or older within the 40-80 kg range (8). The DRL of adult patients is not appropriate to comply with paediatric patients as different imaging parameters are for different body sizes. Moreover, the national and local DRL datasets should be updated regularly in three to five years, respectively, to ensure all examinations are within limits and allow a lower dose level to be achieved without sacrificing image quality (4). Currently, there are limited studies in Malaysia that report the DRL of the craniofacial and head for paediatric CT, which includes petrous bone, facial bone and paranasal sinus protocols. A Japanese study reported that 76.6% of all paediatric CT procedures are performed in the head region and 43.4% of them are below 1 year old at the initial examination (9). The current study on CT DRL of Malaysian paediatric patients was limited to the brain, thorax, chest, abdomen and pelvis (10). More data related to local DRL needs to be investigated to ensure that the CT dose of paediatric patients is within the established recommended limit. Therefore, this study is aimed to assess the local DRL of craniofacial CT and head CT protocols for paediatric patients and compare the established DRLs with the previously published DRL reports.

MATERIALS AND METHODS

Study design

This retrospective study reviewed the craniofacial CT and head CT images of paediatric patients who underwent CT scans from January 2022 to December 2023 at a single health institution. Research ethics approval was granted from the Faculty Ethics Review of Universiti Teknologi MARA (FERC/FSK/MR/2024/00160) and the National Medical Research Register (NMRR) (NMRR ID-24-01549-LYK).

Samples

Data on paediatric cases of craniofacial CT including petrous bone, facial bone and paranasal sinus CT, and head CT procedures which were performed from January 2022 to December 2023, were retrieved through the Picture Archiving and Communication System (PACS) using the convenience sampling method. Data from paediatric patients aged <1 month to 15 years were included in the study, while follow-up cases were excluded. Patients' ages were classified into five age groups according to the ICRP Publication 135 recommendation, which were <1 year, 1-<5 years, 5-<10 years and 10-<15 years (4). Dichotomisation of age groups is aligned with the typical developmental changes of children. The CT procedures were acquired using Siemens SOMATOM scope 32-slice. The CT scanner has undergone quality control performance and safety standards routinely as recommended by the Ministry of Health Malaysia (11). The effective tube current (mAs), tube voltage (kVp), CTDIvol and DLP of both CT craniofacial (petrous bone, facial bone and paranasal sinus) and CT head protocols were retrieved from the PACS console. Different scanning sequences were applied for each protocol including inner ear with high resolution sequence (petrous bone), orbit and head sequence (facial bone), sinus sequence (paranasal sinus) and head sequence (head). Both non-contrast and contrast-enhanced CT protocols data were pooled for further analysis.

CT dose assessment

Using the ICRP Report 135 on DRLs for paediatric imaging, the third quartile (75th percentile) values of the local dose distribution were identified (4). The third quartile of local CTDIvol and DLP values for craniofacial CT and head CT protocols were compared with the established DRL reports.

Statistical analysis

Descriptive analysis was performed to report the frequency of CTDIvol (mGy) and DLP (mGy.cm)-derived DRL and comparison between the present local DRL and previous DRL reports. The difference of CTDIvol and DLP among various age groups was determined using the Kruskal-Wallis test. The statistical analysis was performed using the Statistical Package for Social Sciences (SPSS) version 27, with $p < 0.05$ deemed statistically significant.

RESULTS

Out of the 232 cases in this study, 22.8% (n = 53) were petrous bone CT, 8.6% (n = 20) were facial bone CT, 7.8% (n = 18) were paranasal sinus CT and 55.6% (n = 129) were head CT. The scanning parameters are summarised in **Table I**. The distributions of local DRL based on 75th percentile values of CTDIvol and DLP in petrous bone, facial bone, paranasal sinus and head CT protocols according to the age groups are shown in **Figure 1**. DRL of CTDIvol ranged from 22 mGy to 45 mGy, 39.5 mGy to 78 mGy, 14 mGy to 24.3 mGy, and 40 mGy to 75 mGy for petrous bone CT, facial bone CT, paranasal sinus CT and head CT, respectively. Likewise, DRL of DLP ranged from 149 mGy.cm to 255.5 mGy.cm, 614 mGy.cm to 1311 mGy.cm and 248 mGy.cm to 363 mGy.cm for petrous bone CT, facial bone CT and paranasal sinus CT. respectively. Due to constant CTDIvol and DLP data in age groups of <1 year and 1-<5 years in facial bone and paranasal sinus, hence no 75th percentile values were established in both age groups of both protocols. Similar constant data (598 mGy. cm) was also observed in all age groups in DLP head CT. Furthermore, Kruskal-Wallis analysis demonstrated significant differences of CTDIvol and DLP among the age groups in petrous bone CT and head CT protocols (both $p < 0.001$, respectively), but no significant changes of CTDIvol and DLP in facial bone CT ($p = 0.083$ and $p = 0.247$, respectively) and paranasal sinus CT protocols ($p = 0.148$ and $p = 0.567$, respectively).

Moreover, almost similar CTDIvol and DLP were observed in the present study and study by Khafaji et al. (12) in petrous bone CT, but the current study presents the highest dose in the age group of 5 - <10 years as compared to Kafaji et al. (12) and Wollschlager et al. (13) (**Figure 2**). In this study, a higher dose was observed in all age groups for paranasal sinus CT compared to the other two studies (12, 13) (**Figure 3**). Similarly, the present study demonstrates higher CTDIvol in all age groups of head CT as compared to most previous studies (10, 14-17) (**Figure 4**).

Table I: Scanning parameters of craniofacial CT and head CT protocols for paediatric patients

CT protocol	Age group (years)	Tube voltage (kV)	Effective tube current (mAs) range
Petrous bone	< 1	110	75 – 166
	1 - < 5	110	93 – 206
	5 - < 10	110 – 130	83 - 306
	10 - < 15	110 – 130	83 – 278
	15 - 18	130	80 – 178
Facial bone	< 1	-	-
	1 - < 5	-	-
	5 - < 10	110 – 130	63 – 362
	10 - < 15	110 – 130	55 – 478
	15 - 18	110 – 130	61 – 454
Paranasal sinus	< 1	-	-
	1 - < 5	-	-
	5 - < 10	80 – 130	47 – 138
	10 - < 15	110 – 130	58 – 106
	15 - 18	110 - 130	53 – 121
Head	< 1	110	120 – 230
	1 - < 5	110	143 – 353
	5 - < 10	110	161 – 387
	10 - < 15	110 – 130	151 – 511
	15 - 18	110 -130	210 – 534

DISCUSSION

This study investigated DRL of three common craniofacial CT protocols including petrous bone CT, facial bone CT and paranasal sinus CT and head CT protocol as well across five age groups of paediatric patients. According to ICRP Publication 135, the DRLs for children are proposed to be defined according to weight (5 kg, 10 kg, 20 kg, 30 kg, 40 kg, 50 kg and 60 kg), classes of weight (<10 kg, 10–15 kg, 15–30 kg, 30–60 kg, 60 kg) or age groups (4). Even though weight-based grouping and size-specific dose estimation methods have been recommended by the ICRP for DRL study in paediatrics, body weight grouping might be an improper method for head region study because head size changes less than body size (4). Since age rather than weight determines head size, the age-based grouping approach is more suitable than the weight-based grouping method (18). The human head exhibits less variation in size in which at six years old, it is 90% mature and adult-sized (19).

For each protocol in this study, the tube voltage and tube current vary across age groups to compensate for

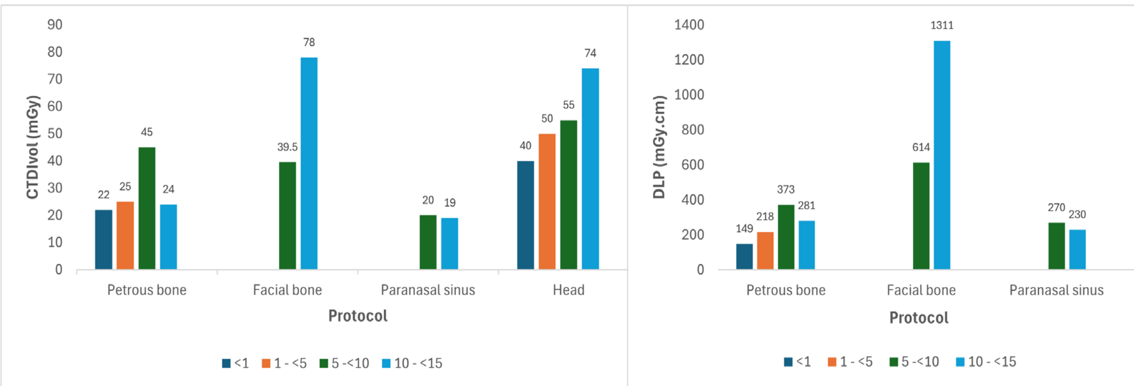

Fig. 1: The distribution of CTDIvol and DLP-derived DRL for numerous craniofacial CT and head CT protocols across age groups in paediatric.

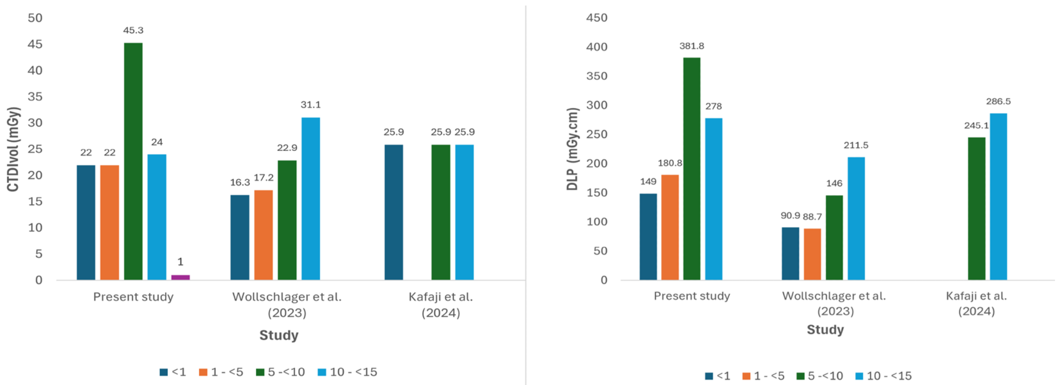

Fig. 2: Comparison of the present CTDIvol and DLP-derived DRL of the petrous bone CT protocol with the previously established DRLs.

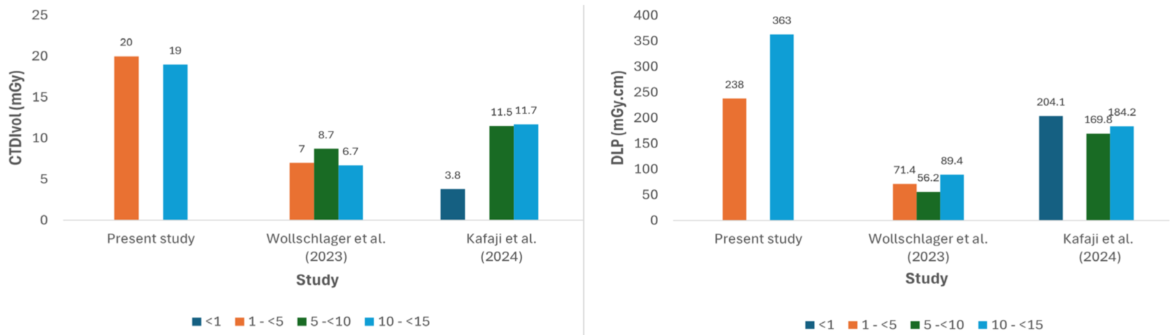

Fig. 3: Comparison of the present CTDIvol and DLP-derived DRL of the paranasal sinus CT protocol with the previously established DRLs.

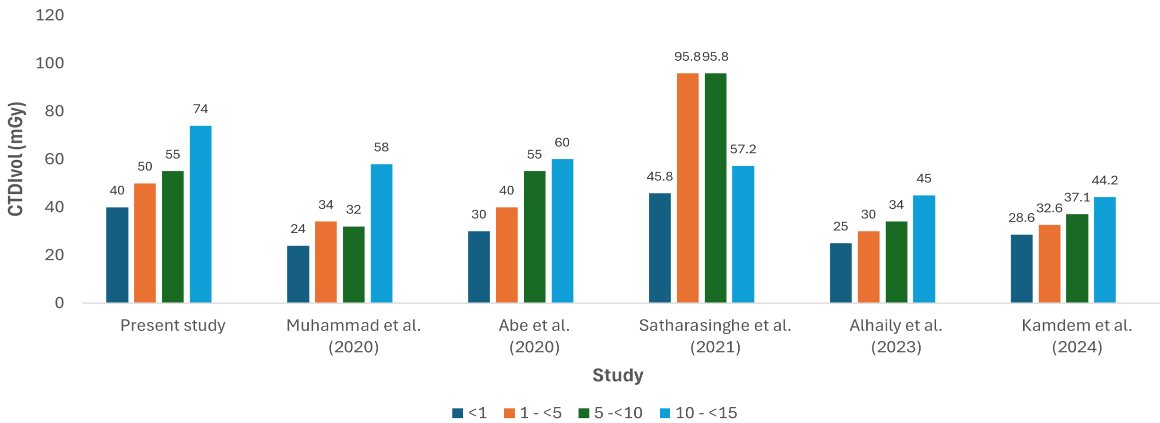

Fig. 4: Comparison of the present CTDIvol-derived DRL of the head CT protocol with the previously established DRLs.

the variation of head size with the development of age. Specifically, 110 kV was applied for the age group of less than 5 years, while 110 kV-130 kV was applied for the remaining age groups. An increase in tube voltage directly increases the produced radiation dose, resulting in higher CTDIvol and DLP. Tube voltage and radiation dose have a quadratic relationship, which means the reduction of 120 kV to 80 kV results in more than a 50% reduction in radiation dose (20). In addition, our CT protocols employed automatic tube current modulation (ATCM), which allows constant image quality at a lower radiation dose. ATCM enables automatic adjustment of the tube current in the xy-plane (angular modulation), along the z-axis (longitudinal modulation), or both (combined modulation) to maintain a user-selected noise level in the image (21). For the contrast-enhanced CT, a lower tube voltage of 80-100 kV should be adequate for the optimisation, resulting in a dose reduction that subsequently improves the image contrast.

In our scanning protocol, the scanning sequences used were similar for petrous bone CT, paranasal sinus CT and head CT, which started with a topogram scan followed by an inner ear high-resolution sequence or a head sequence or sinus sequence for the non-contrast procedures. For contrast-enhanced CT protocol, the scanning sequence was repeated with nearly identical tube voltage and tube current using the intravenous sequence. Instead of facial bone CT, different scanning sequences were applied to different regions covered in the facial bone area including orbit CT and mandible CT. Therefore, the scanning sequence used varies depending on the specific area of the examination.

This study demonstrated inconsistent distribution of CTDIvol-derived DRL in age group of 5 - 10 years and 10 - <15 years in petrous bone CT and facial bone CT protocols, respectively. Technically, a wider range of effective tube current was employed in the 5 – 10 years age group of petrous bone (83 mAs – 306 mAs) and in the 10 - < 15 years age group of facial bone (55 mAs – 478 mAs) as compared to other age groups. Different imaging protocols and scanner settings that can be adjusted by the technologist could contribute to dose variance (7). These large variances should be further revised to minimise the range of effective tube current, particularly for both protocols and age groups. Subsequently, a small sample size in facial bone CT and paranasal sinus CT protocols might result in a non-significant difference in CTDIvol and DLP among age groups. Statistically, the small sample size study is considered underpowered, which leads to Type II error (22). On the contrary, the CTDIvol in head CT consistently increases with age. Increasing age is expected to increase CTDIvol due to the increase in size and tissue density. The average head circumference increases proportionally 0.5 cm - 2 cm between the day of birth and 5 years of age (23). Despite this, the study showed no DLP-derived DRL value in the CT head protocol due to consistent DLP values in all age groups.
To achieve meaningful data comparison, we conducted a comparison with published studies that utilised similar

age groups as recommended by the ICRP Publication 135 and had representative local DRL values at the 75th percentile. It was noted that the present DRL comparison was not attempted with the European Commission (EC) report, as EC age groups were variant of ICRP (6). To illustrate, the petrous bone CT was comparable to the inner auditory canal CT in the Saudi Arabian study (12) as both were in the same region of interest. Petrous bone CT is commonly requested in radiology for patients from the otology clinic as it covers the bony anatomy of the external auditory canal, inner ear, middle ear cleft, ossicles, labyrinth and skull base (23). In addition, this protocol is a valuable tool for diagnosing ear pathologies in children since the external auditory canal, internal auditory meatus and petromastoid canal gradually grow with the petrous bone as it progressess with age (24). Instead, the current study demonstrates higher DRL in paranasal sinus CT and head CT as compared to the previously established local DRLs (10, 13-17). Our data shows a consistent increment of tube current ranges with the increase of age.

Variation of DRL values between different countries occurs due to differences in imaging practices, population characteristics, and regulatory requirements (7). Moreover, different clinical indications, scanner models and radiologist preferences may lead to the dose variance among different institutions (25). Therefore, the current craniofacial and head CT scanning protocols should be further reviewed following the ALARA principle to achieve CT dose optimisation. The primary contributors to dose variability are the choice of scanning parameters, the techniques used, and the alteration of dose decisions by the clinical staff, instead of the scanner's manufacturer and model (26). Several strategies have been implemented to achieve dose optimisation in paediatric CT including automatic tube potential selection, automatic tube current modulation, iterative reconstruction, bowtie filters, optimised scout view, optimised pitch and scan collimation and short scan time (27). Similarly, artificial intelligence (AI)-based deep learning iterative reconstruction has been proposed in CT head of paediatric which offers great image spatial resolution with significant dose reduction (28).

There are several limitations to address in this study. Firstly, the present data is limited to a single institution. Future studies should consider expanding the number of health institutions to establish a national DRL of craniofacial and head CT procedures in paediatric patients. Secondly, a limited number of cases were observed in facial bone CT and paranasal sinus CT, which less than the minimum 10 data per age group for establishing DRL as recommended by the European Commission (6). More cases per age group are recommended in the future investigation to ensure more reliable DRL data in paediatric CT. Thirdly, limited literature has been reported on DRL of craniofacial CT protocols employing the ICRP Report 135 age groups recommendation in paediatric patients, hence inadequate comparable data has been achieved (e.g., facial bone CT).

CONCLUSION

The established local DRLs of the present study could potentially serve as a benchmark for craniofacial and head CT procedures in Malaysian paediatric CT practice. The DRLs significantly vary among paediatric age groups in both petrous bone CT and head CT protocols. The present DRLs are higher than the previously established DRL reports. These findings highlight the importance of continuous monitoring and a protocol review of CT practice for craniofacial CT and head CT in paediatric patients. Age-based CT protocol should be further reviewed to minimise dose without compromising diagnostic image quality acceptability to achieve dose optimisation in paediatric CT.

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