

Characterizing pediatric head patient size in Moroccan population: Establishing age-dependent relationships for accurate CT dose estimation

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Abstract – Accurate dose estimation in computed tomography (CT) scans is crucial and relies on precise normalization of output dose, typically measured by the volume CT dose index (CTDIvol). Key metrics, including effective diameter (Deff) and water-equivalent diameter (Dw), play pivotal roles in characterizing patient size. However, a notable gap exists in delineating the specific relationships between age and head patient size (Deff and Dw) for pediatric patients in Morocco. The primary objective of this study was to establish these critical associations between patient age and head patient size (Deff and Dw), providing a foundation for calculating size-specific dose estimates (SSDE) in pediatric head CT examinations. A retrospective analysis of data from 134 pediatric patients, aged 0–13 yr, comprising 71 males and 63 females who underwent head CT scans, was conducted. Utilizing the Radiant DICOM Viewer, patient sizes were measured in terms of both lateral and anterior-posterior dimensions for Deff and Dw calculations based on CT images in DICOM format. Our analysis revealed robust correlations between patient size (Deff and Dw) and the patient's age, with R^2 values ranging from 0.65 to 0.86. Notably, larger Dw values were consistently observed compared to Deff. For male patients, Deff measurements ranged from 9.02 to 18.77 cm, with Dw values spanning 9.83 to 20.16 cm. Female patients exhibited Deff values ranging from 8.77 to 17.41 cm and Dw values ranging from 8.92 to 18.37 cm. These findings shed light on the crucial relationship between age and patient size, facilitating more precise dose calculations.

Keywords: pediatric head CT / effective diameter / water-equivalent diameter / SSDE

1 Introduction

A computed tomography (CT) scanner, a medical device utilizing X-rays from multiple angles to generate detailed cross-sectional images of the human body, has become an invaluable tool in clinical imaging due to technological advancements enhancing speed and precision (Abdulkadir *et al.*, 2022; El Mansouri *et al.*, 2022, 2024a 2024b; Nhila *et al.*, 2024). However, the escalating use of CT scans, driven by improved technology and image quality, has sparked concerns about heightened radiation exposure risks, particularly in pediatric patients (Brenner *et al.* 2010; Griffey *et al.*,

2009; Kalender *et al.* 2014; Tootell *et al.*, 2017; Saito *et al.*, 2018; Karim *et al.*, 2021; El Mansouri *et al.*, 2022, 2023). The heightened reliance on CT scans, while providing crucial diagnostic information, has amplified worries about elevated radiation risks in pediatric patients. Compared to other diagnostic methods, CT scans subject patients, particularly pediatric individuals, to higher radiation doses, significantly increasing the potential for cancer induction (Griffey *et al.*, 2009). The necessity of CT scans for numerous pediatric cases highlights the importance of justifying and optimizing radiation doses to minimize associated risks. Pediatric patients, with their extended life expectancy and rapid cell replication, face an increased susceptibility to radiation-related diseases like leukemia, thyroid cancer, breast cancer, brain cancer, and skin cancer. Achieving accurate risk assessments necessitates

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precise dose estimation tailored to pediatric patients (Frush *et al.*, 2003; Zacharias *et al.*, 2013).

Accurately evaluating radiation risk mandates precise estimation of absorbed radiation doses by pediatric patients. Common methods for quantifying radiation dose in CT exams, such as volumetric computed tomography dose index (CTDIvol) and dose length product (DLP), lack consideration for individual patient size variations critical for accurate dose estimation. CTDIvol and DLP, derived from measurements with cylindrical phantoms, fail to precisely reflect the actual radiation dose received by a patient, as highlighted in previous studies (AAPM, 2011, 2014).

To determine individual patient radiation doses, the American Association of Physicists in Medicine (AAPM) introduced Specific Size Dose Estimation (SSDE), involving normalizing CTDIvol with size-correction factors like effective diameter (Deff) or water-equivalent diameter (Dw). While effective diameter provides a straightforward measure of patient size, it overlooks patient composition and tissue attenuation. Dw, accounting for X-ray attenuation in patients, offers a more accurate method for estimating patient doses (AAPM, 2011, 2014; Amalaraj *et al.*, 2023). However, measuring Deff and Dw for each patient can be impractical in busy CT centers. As a pragmatic alternative, these values can be estimated using the patient's weight or body mass index (BMI), as proposed in previous studies (Menke, 2005; Boos *et al.*, 2018). Age-based estimation is another practical approach, though it may have some variance. Some studies have provided data tables correlating Deff with the patient's age, such as ICRU 74 and AAPM 204. Additionally, there are reports of a correlation between Deff and age for abdominal examinations, recognizing that the average patient diameter varies with age. However, predicting an individual patient's size based solely on age may not yield consistently accurate results (ICRU, 2005; AAPM, 2011; Cheng *et al.*, 2013).

To date, no information exists regarding the connection between patient size and age among pediatric individuals in Morocco for head CT. Our study aims to automatically compute Deff and Dw from pediatric head CT images and establish correlations with the patient's age.

2 Materials and methods

The research encompassed patients who underwent head CT scans at a pediatric university hospital. The acquisition of head images was in helical mode, ensuring rapid scans and obviating the necessity for sedation in pediatric subjects. Exclusion criteria encompassed patients who underwent contrast-enhanced scans, those exhibiting poor cooperation leading to motion artifacts, and scans with insufficient diagnostic information.

Diameter measurements were executed on axial images obtained from 134 pediatric patients who underwent head CT examinations, utilizing the Siemens Emotion 16-multislice computed tomography (MSCT) scanner. Furthermore, all pertinent scan acquisition parameters and patient details were extracted from the Picture Archiving and Communication System (PACS) (Tab. 1). Patients presenting torch infections such as hydrocephalus, microcephaly, and other congenital abnormalities affecting the brain and calvaria bones, thereby

Table 1. Acquisition parameters used in pediatric head examinations.

Exposure parameters	Head
N	134
Sex	63F–71M
Age (year)	0–13
Tube potential (kVp)	110
Tube current product (mAs)	63–232
Slice thickness (mm)	3
Time of rotation (s)	0.6
Pitch	0.95
Collimation (mm)	0.6

causing abnormal head diameters, were purposefully excluded from the study.

Patient sizes (Deff and Dw) were determined through the measurement of lateral (LAT) and anterior-posterior (AP) dimensions extracted from patient images using the RadiAnt Dicom Viewer. Specifically, Deff was computed as the square root of the product of the LAT and AP diameters (AAPM, 2011), as depicted in (Fig. 1) and following (Eq. (1)):

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

Notably, no established protocol currently outlines the requisite number of images for accurate Deff determination. In a pragmatic approach, we selected the middle slice from the patient's image for analysis. While it remains feasible to calculate Deff from all images to enhance precision, this alternative entails a lengthier processing time.

The calculation of Dw is based on the measurement of the water equivalent area (Aw). The evaluation of (Aw) is based on the CT numbers (CT (x,y)) of the pixels in this area, which are usually expressed in Hounsfield units (HU), and determined by the linear attenuation coefficient of each pixel as:

$$CT(x,y) = \left(\frac{\mu_{(x,y)} - \mu_{water}}{\mu_{water}} \right) \times 1000, \quad (2)$$

(AAPM, 2014)

where $\mu_{(x,y)}$ is the linear attenuation coefficient of a tissue located in the pixel (x,y) at a given photon energy normalized to that of water μ_{water} at the same energy.

(Aw) is assessed by means of the CT numbers over the (ROI) as:

$$A_W = \frac{1}{1000} \times CT(x,y)_{ROI} \times A_{ROI} + A_{ROI}. \quad (3)$$

(AAPM, 2014)

where A_{ROI} is the sum of the pixel areas ($A_{ROI} = \sum A_{pixel}$) of the ROI. Subsequently, Dw of the slice can be calculated as:

$$D_w = 2 \times \sqrt{\frac{A_w}{\pi}}. \quad (4a)$$

(AAPM, 2014)

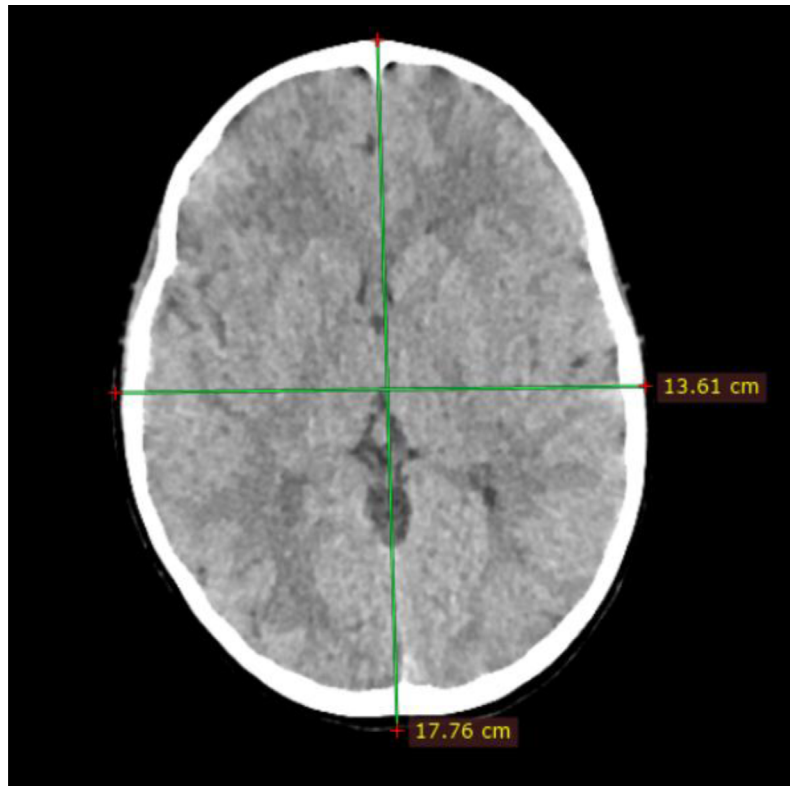


Fig. 1. Lateral and anterior-posterior measurements using RadiAnt Dicom Viewer.

Therefore, the D_w of a patient can be calculated using the following equation:

$$D_w = 2 \times \sqrt{\frac{1}{1000} \times CT(x,y)_{ROI+1} \times \frac{A_{ROI}}{\pi}}. \quad (4b)$$

(AAPM, 2014)

We performed a comprehensive analysis to investigate the correlation between patient age and the values of effective diameter and water-equivalent diameter. This analytical examination was conducted utilizing a regression approach, specifically guided by (Eq. (5)) outlined in the American Association of Physicists in Medicine report number 204 (AAPM, 2011). This regression analysis aimed to elucidate the relationships between patient age and the determined values of D_{eff} and D_w , providing insights into how these parameters vary with the age of the pediatric population under consideration.

$$y = a + bx^{1.5} + cx^{0.5} + de^{-x}. \quad (5)$$

The parameters a , b , c , and d in the equation were determined through a non-linear regression analysis conducted using OriginPro Version 22. This process involved the formulation of a customized non-linear regression equation within the software, tailored to fit our specific model. To expound on the methodology employed by the software for parameter determination, OriginPro utilizes an iterative optimization process, such as the Levenberg-Marquardt

algorithm. Subsequently, the R-squared value, indicative of the goodness of fit, was computed within the same software.

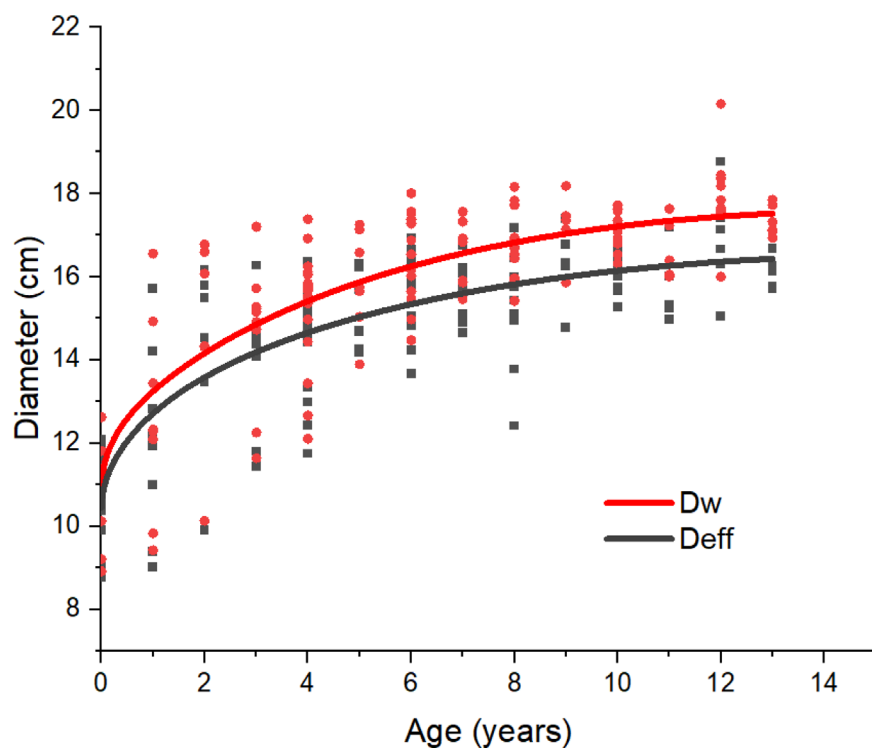
3 Results

The findings of the current study highlight the relationship between D_{eff} and D_w across different age groups and sexes for pediatric patients aged 0 to 13 yr (Tab. 2). Notably, D_w consistently surpasses D_{eff} for patients of the same age, with D_{eff} values ranging from 9.02 to 18.77 cm and D_w values spanning from 9.83 to 20.16 cm for male patients. Similarly, for female patients, D_{eff} values range from 8.77 to 17.41 cm, while D_w values vary from 8.92 to 18.37 cm. The data underlines a consistent increase in head diameter throughout the selected age range, with a notable rapid expansion observed during infancy (0–3 yr) followed by a relatively stable growth rate between ages 3 and 14 yr (Fig. 2). Additionally, our analysis reveals gender-specific variations, particularly regarding D_{eff} values, where males consistently exhibit higher values compared to females from ages 4 to 14 yr (Fig. 3). However, D_w values consistently show males with higher values across all age groups, except around the age of 3 yr, where D_w values for males become roughly equivalent to those of females (Fig. 4). These findings highlight the dynamic nature of cranial development during early life stages and the importance of sex-specific considerations in pediatric radiology.

Figure 5 offers a detailed comparative analysis between the outcomes of our current study and the data outlined in the

Table 2. Regression coefficients and R^2 values for Deff and Dw variations across age groups in male, female and both genders.

	Male		Female		Both genders	
	Deff	Dw	Deff	Dw	Deff	Dw
R^2 value	0.83	0.86	0.71	0.65	0.64	0.67
a value	9.97008	10.25704	10.52196	11.02101	10.64694	10.33249
b value	−0.05614	−0.06101	−0.06665	−0.04867	−0.04463	−0.06026
c value	2.58276	2.87073	2.68613	2.00863	2.1848	2.77693
d value	0.92441	0.81714	−0.54684	−1.22631	−0.20106	0.53055

**Fig. 2.** Variations in (Deff) and (Dw) across age groups in all patients (males and females).

ICRU report 74, which delineates the dimensions of mathematical phantoms representing hermaphrodite humans across five distinct age groups. The visual representation in Figure 7 highlights that our findings, when juxtaposed with the corresponding ICRU data for individuals of equivalent age, consistently exhibit slightly lower values. These variations range from 0.14 to 0.73 cm, highlighting a discernible dimension discrepancy between our study and the established ICRU reference.

4 Discussion

Prior research has investigated the relationship between age and specific patient size metrics, primarily focusing on effective

diameter (Frush *et al.*, 2003; Wang *et al.*, 2012; Anam *et al.*, 2017). Notably, Deff, while commonly used, is less accurate than Dw, which incorporates both physical dimensions and attenuation characteristics of the scanned body. However, there remains a notable gap in the literature regarding the correlation between head size, particularly Dw, and age in pediatric patients. This study addresses this gap, emphasizing the significance of understanding this relationship, particularly for size-specific dose estimates in pediatric head CT scans.

As anticipated, both male and female children exhibit an increase in head diameter with age, with rapid growth observed from birth to 3 yr, followed by a more gradual increase thereafter. Consistently, Dw values indicate that males have greater values than females, suggesting higher bone and brain

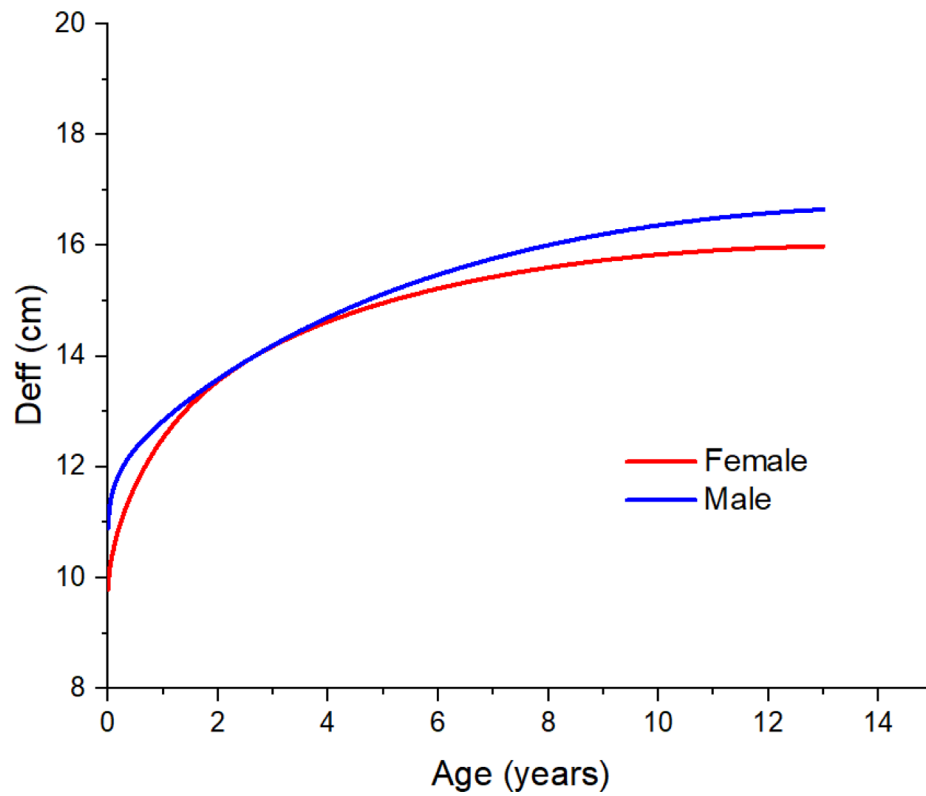


Fig. 3. Gender-based comparison of size-specific head (Deff).

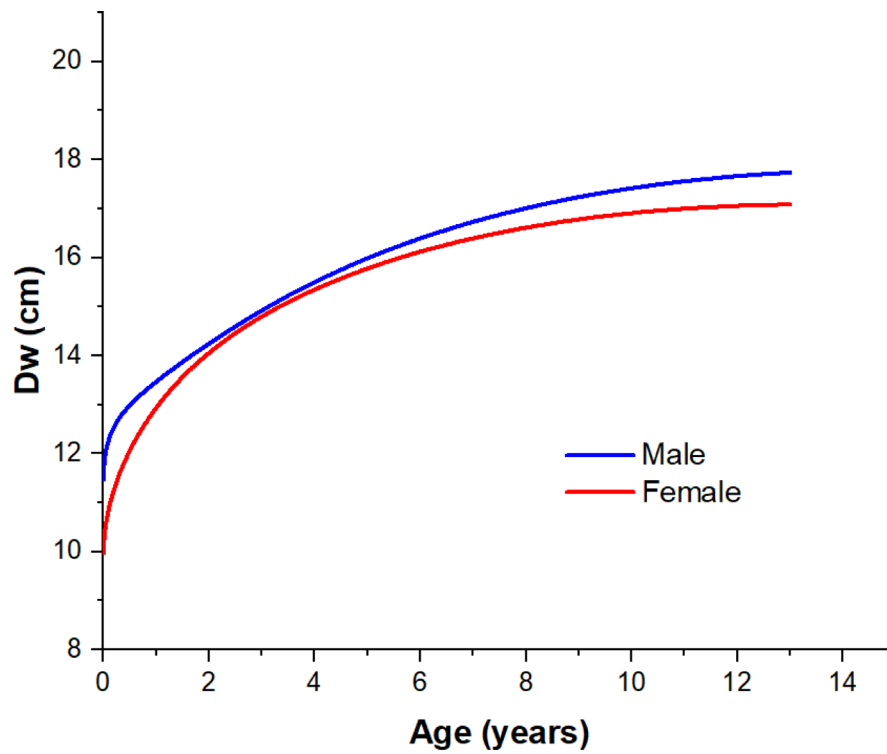


Fig. 4. Gender-based comparison of size-specific head (Dw).

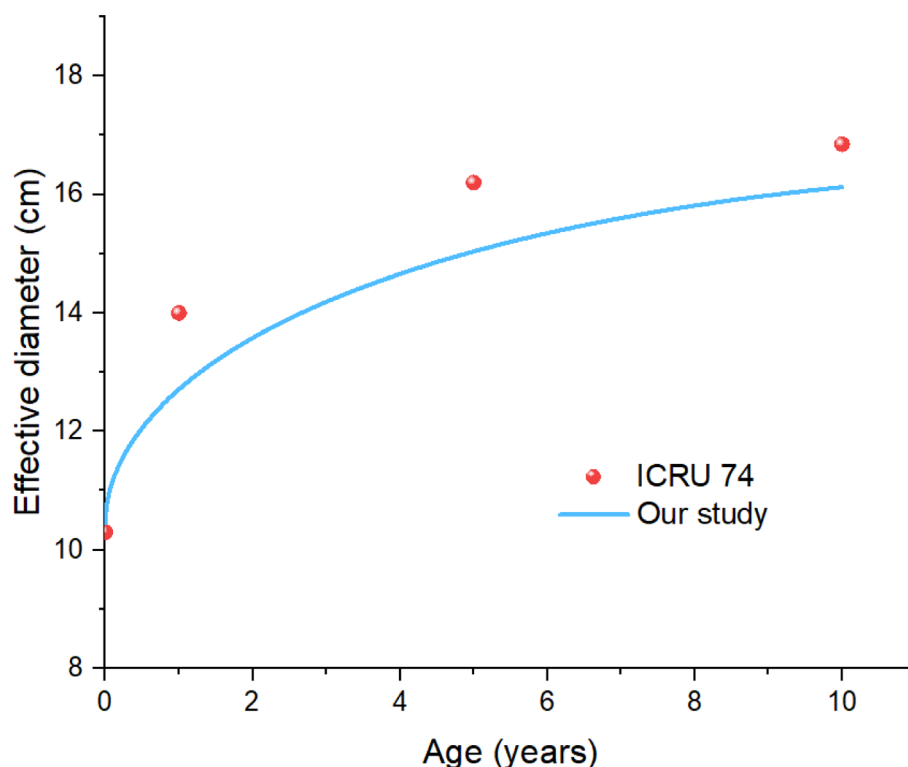


Fig. 5. Comparative analysis of Deff across age groups in our study and ICRU 74.

density in male patients. Importantly, Dw consistently surpasses Deff concerning age, implying a smaller conversion factor for Dw as patients age. Consequently, SSDE calculations using Dw result in lower radiation doses compared to Deff, with an average difference of 4.3% for females and 9.1% for males. This highlights the significance of understanding Dw calculations for precise SSDE determination in pediatric head CT scans, given the substantial difference between Dw and Deff, primarily attributed to the presence of bone and soft tissue.

Comparison with the ICRU 74 report (ICRU, 2005) reveals consistently smaller Deff values in our study, particularly notable in the 1–5 yr age range. This discrepancy is attributed to differences in sample populations, with ICRU 74 utilizing hermaphrodite mathematical phantoms from Europe, while our study sampled patients from the North African region, emphasizing the necessity for tailored pediatric CT protocols in North Africa, particularly in Morocco. Despite the study's insights, a limitation lies in the relatively small sample size from a specific pediatric hospital in one region, warranting further work with a larger and more diverse population, also the method used for measuring patient's head dimensions (LAT and AP) which relies on the central slice with longest diameter, the use of this method is due to the lack of a customized method for this type of measurements in the context of pediatric head, warranting future research to establish it. Additionally, considerations for variables like the correlation between Dw, BMI, and patient body weight should be explored.

It's imperative to acknowledge substantial variations in head dimensions at a given age, particularly during infancy. Therefore, for accurate patient dose estimation, calculated patient sizes (Deff or Dw) from patient images, whether from CT

radiographs or cross-sectional CT scans, are considered more reliable. Patient age serves as an approximation and is only employed when size information from the images is unavailable.

The current work examines the variation in head size among young patients undergoing CT scans, with an emphasis on the consequences for managing radiation exposure. It is acknowledged that there is a lack of defined measuring techniques in pediatric CT scans, underlining the need for additional research to establish guidelines. Comparisons with ICRU guidelines provide information on how well this study's results match accepted standards. Furthermore, the observation regarding the relative stability of head size measurements across different slices compared to other anatomical regions as chest (Boos *et al.*, 2018) highlights the importance of customized measurement methodologies in pediatric radiology.

5 Conclusion

This investigation establishes an important correlation between patient size, as indicated by Deff and Dw, and the patient's age, with R^2 values ranging from 0.64 to 0.86, indicating a good relationship. Importantly, our results underline the prevalence of larger Dw values compared to Deff, due to its consideration of tissue composition and X-ray attenuation in patients. Specifically, in male patients, Deff values range from 9.02 to 18.77 cm, while Dw values span from 9.83 to 20.16 cm. Similarly, female patients exhibit Deff values ranging from 8.77 to 17.41 cm, with Dw values falling in the range of 8.92 to 18.37 cm. Noteworthy is the observation that our study's size measurements are consistently lower than those presented in the ICRU 74 report. This discrepancy

highlights the need for a nuanced approach to size-specific dose estimation in pediatric head CT scans, with a preference for Dw as a more accurate representation of patient size.

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Conflicts of interest

The authors declare that they have no conflict of interest.

Data availability statement

The findings presented in this study are based on a retrospective dataset that is not publicly available due to privacy and confidentiality restrictions. Unfortunately, the data cannot be shared or made openly accessible to protect the privacy of the individuals included in the dataset. However, the authors are committed to providing any necessary information or clarification upon reasonable request.

Author contribution statement

H. Sekkat : Writing original draft, Methodology, Investigation, K. El Mansouri : Conceptualization, A. Khallouqi : Visualization, Methodology, A. Halimi and O. El rhazouani : Supervision, Z. Tahiri and M. Talbi : Writing-Reviewing and editing, M. El Mansouri : Visualization.

Ethics approval

Ethical approval was not required.

Informed consent

This article does not contain any studies involving human subjects.

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