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Optimizing Pediatric Brain CT Scans: A Retrospective Study on Enhancing Image Quality and Minimizing Radiation Exposure Using Acceptable Quality Doses (AQD)

Mengoptimumkan Imbasan CT Kepala Pediatrik: Kajian Retrospektif Mengenai Peningkatan Kualiti Imej dan Pengurangan Pendedahan Radiasi Menggunakan Dos Kualiti Boleh Terima (AQD)

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ABSTRACT

This study introduces the Acceptable Quality Dose (AQD) concept as an alternative to Diagnostic Reference Levels (DRLs) for optimizing radiation exposure in pediatric CT imaging. The AQD approach focuses on analyzing radiation dose indices ($CTDI_{vol}$ and DLP) only for diagnostically acceptable images, as assessed using the Image Quality Scoring Criteria (IQSC). Pediatric patients (0 to 18 years) who underwent CT brain scans were evaluated by two evaluators. Only images with an IQSC score of 3 were included in the AQD determination, categorized by age group. Results showed that younger patients generally received lower $CTDI_{vol}$ values, whereas DLP varied primarily with scan length. Mean $CTDI_{vol}$ (mGy) and DLP (mGy·cm) were: neonates (0–27 days), 21.00 ± 0.00 and 258.00 ± 0.00; infants (28 days–12 months), 21.86 ± 3.05 and 320.56 ± 451.70; toddlers (13 months–2 years), 24.10 ± 5.31 and 190.23 ± 166.31; early childhood (3–5 years), 25.07 ± 4.47 and 391.01 ± 384.76; middle childhood (6–11 years), 38.32 ± 13.25 and 550.60 ± 540.50; and adolescents (12–18 years), 46.30±15.84 and 370.62±370.20. Statistical analysis demonstrated significant differences in $CTDI_{vol}$ across age groups ($p < 0.05$), while no significant variation was observed in DLP. The findings also demonstrated that $CTDI_{vol}$ had a stronger correlation with image quality compared to DLP, suggesting it is a more reliable metric for optimizing radiation dose. The study concludes that the AQD approach effectively prioritizes diagnostically acceptable images over strict radiation limits, and $CTDI_{vo}$l is essential for ensuring optimal pediatric CT imaging.

Keywords: Image quality, Radiation dose exposure, Pediatric brain CT, Acceptable quality doses.

ABSTRAK

Kajian ini memperkenalkan konsep dos kualiti boleh terima (AQD) sebagai alternatif kepada aras rujukan diagnostik (DRL) bagi mengoptimumkan pendedahan radiasi dalam pengimejan CT pediatrik. Pendekatan AQD menumpukan kepada analisis indeks dos radiasi ($CTDI_{vol}$ dan DLP) hanya untuk imej yang diterima secara diagnostik, seperti yang dinilai menggunakan kriteria penskoran kualiti imej (IQSC). Pesakit pediatrik (0 hingga 18 tahun) yang menjalani imbasan CT otak telah dinilai oleh dua penilai. Hanya imej dengan skor IQSC 3 dimasukkan dalam penentuan AQD, dikategorikan mengikut kumpulan umur. Keputusan menunjukkan bahawa pesakit yang lebih muda secara amnya menerima nilai $CTDI_{vol}$ yang lebih rendah, manakala DLP berbeza terutamanya berdasarkan panjang imbasan. Purata CTDIvol (mGy) dan DLP (mGy·cm) bagi neonat (0–27 hari) Adalah 21.00 ± 0.00 dan 258.00 ± 0.00, bayi (28 hari–12 bulan): 21.86 ± 3.05 dan 320.56 ± 451.70, kanak- kanak kecil (13 bulan–2 tahun): 24.10 ± 5.31 dan 190.23 ± 166.31, awal kanak-kanak (3–5 tahun): 25.07 ± 4.47 dan 391.01 ± 384.76, pertengahan kanak-kanak (6–11 tahun): 38.32 ± 13.25 dan 550.60 ± 540.50 dan remaja (12–18

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tahun): 46.30 ± 15.84 dan 370.62 ± 370.20. Analisis statistik menunjukkan perbezaan signifikan bagi CTDIvol antara kumpulan umur ($p < 0.05$), manakala tiada variasi ketara diperhatikan bagi DLP. Dapatan kajian turut menunjukkan bahawa $CTDI_{vol}$ mempunyai korelasi yang lebih kuat dengan kualiti imej berbanding DLP, menunjukkan bahawa ia merupakan ukuran yang lebih boleh dipercayai untuk pengoptimuman dos radiasi. Kajian ini menyimpulkan bahawa pendekatan AQD secara berkesan mengutamakan imej yang diterima secara diagnostik berbanding had radiasi yang ketat, dan $CTDI_{vol}$ adalah penting untuk memastikan pengimejan CT pediatrik yang optimum.

Kata kunci: Kualiti imej, Pendedahan dos radiasi, CT kepala pediatrik, Dos kualiti boleh terima.

INTRODUCTION

Computed tomography (CT) is a vital diagnostic tool, offering high-resolution imaging for various medical conditions, including neurological disorders, trauma, and cancer. However, its use involves ionizing radiation, which poses significant health risks, particularly for pediatric patients (Abuelhia & Alghamdi 2020). Unlike adults, children have a longer life expectancy and are more radiosensitive due to their ongoing growth and development (Smith-Bindman et al. 2019). Studies have demonstrated an association between pediatric CT radiation exposure and an increased risk of radiation-induced malignancies, such as leukemia and brain tumors (Meulepas et al. 2019). Therefore, minimizing radiation exposure while preserving diagnostic accuracy remains a critical challenge in pediatric imaging.

To address radiation safety concerns, the International Commission for Radiological Protection (ICRP) introduced Diagnostic Reference Levels (DRLs) in 1990. DRLs serve as benchmark values to guide radiation dose optimization in medical imaging, assisting healthcare institutions in implementing safe imaging protocols (Tan et al. 2023). However, DRLs are typically established based on surveys of radiation dose metrics ($CTDI_{vol}$ and DLP) across multiple institutions, without considering whether the resulting images meet or exceed diagnostic quality standards (Malik et al. 2024). They do not account for variations in pediatric anatomy, clinical indications, or image quality requirements. Moreover, the assumption that operating below DRLs automatically reflects optimal dose management may lead to inconsistencies in both image quality and radiation safety (Kharita et al. 2021).

To overcome these limitations, the Acceptable Quality Dose (AQD) concept has been introduced. AQD prioritizes both image quality and dose optimization by assessing radiation indices exclusively for diagnostically acceptable images (Yaseen et al. 2024). This approach, guided by the Image Quality Scoring Criteria (IQSC), ensures a balanced evaluation of radiation exposure and diagnostic efficacy (Padole et al. 2019). By integrating objective image quality assessment with dose metrics, AQD minimizes the risk of underquality or overquality, supports consistent diagnostic confidence, and facilitates continuous quality improvement across imaging departments (Kharita et al. 2021). Furthermore, AQD aligns with the ALARA (As Low As Reasonably Achievable) principle by identifying the minimum radiation dose required to maintain diagnostic quality, thereby reducing unnecessary exposure while preserving clinical accuracy.

In Malaysia, standardized pediatric CT protocols remain limited, contributing to variability in image quality and radiation dose management. By evaluating AQD, this study seeks to establish an optimized framework for balancing image quality and radiation exposure in pediatric brain CT scans. Additionally, it will analyze radiation dose indices, specifically $CTDI_{vol}$ and DLP, across different pediatric age groups to assess their impact on dose optimization and diagnostic performance.

This study aims to investigate the application of AQD in pediatric brain CT imaging, a crucial modality for diagnosing congenital anomalies, trauma, and neurological disorders. Given the heightened sensitivity of children to ionizing radiation, achieving high diagnostic accuracy with minimal exposure is essential.

MATERIALS AND METHODS

STUDY DESIGN

This retrospective study aimed to optimize image quality while minimizing radiation exposure in pediatric brain CT imaging. The Acceptable Quality Dose (AQD) concept, first introduced in Qatar, was adopted to evaluate radiation dose parameters based exclusively on diagnostically acceptable images. This study received approval from the Research Ethics Committee Universiti Kebangsaan Malaysia (RECUKM) (Ref. JEP-2025-656).

STUDY POPULATION AND SAMPLING

The study population included pediatric patients (neonates to 18 years old) who underwent plain CT brain examinations in Hospital Tunku Ampuan Besar Tuanku Aishah Rohani (N=43). A sample size of 39 (n=39) data was determined based on a population size of 43, with a 5% margin of error and a 95% confidence level. Inclusion and exclusion criteria were carefully established to ensure the study's relevance and reliability. A purposive sampling method was used to recruit two experienced evaluators, each with over five years of expertise, for the subjective assessment of image quality using the Image Quality Scoring Criteria (IQSC). Evaluators independently reviewed randomly selected brain CT scans to assess interobserver agreement and consistency in image quality evaluation.

METHODE OF DATA SELECTION

CT brain images were retrieved from Syngo Plaza vb.40, a radiology database used at Hospital Tunku Ampuan Besar Tuanku Aishah Rohani, UKM. To minimize selection bias, 39 pediatric CT examinations were randomly selected without consideration of patient demographics or radiation dose parameters. Only scans performed using pediatric-specific protocols; 01_Head_Below_2YO (Child), 01_Head_Below_5YO (Child), and 01_Head_Below_15YO (Child) were included to ensure standardization. All images were acquired in the axial plane with a soft tissue window, utilizing a section thickness of 1.0 mm and an interval of 0.8 mm for high-resolution imaging. Patient demographic data, including age, gender, and radiation dose indices ($CTDI_{vol}$ and DLP), were recorded for subsequent analysis. To facilitate the evaluation process, CT images were systematically organized in a dedicated Google Drive worklist. Each image was assigned a unique code (CT_AA to CT_BM) for efficient retrieval and assessment.

IMAGE QUALITY ASSESSMENT

Image quality was subjectively assessed using the Image Quality Scoring Criteria (IQSC), with scores ranging from 0 to 4. A score of 0s indicates that the desired anatomical features are not visible, while 0i signifies that the relevant anatomy is not included in the image. A score of 1 represents unacceptable quality, where the image is non-diagnostic. Limited quality, characterized by diagnostic usability but high noise levels, is assigned a score of 2. A score of 3 denotes adequate quality, meaning the image is acceptable for diagnosis. Lastly, a score of 4 indicates excessively high resolution, surpassing the necessary quality for diagnostic purposes. Evaluators used RadiAnt DICOM Web for image analysis, ensuring consistency in assessment. The dataset was shared via Google Drive, enabling offline evaluation. Image quality scores were documented in structured evaluation sheets to maintain data integrity and facilitate subsequent statistical analysis.

ACCEPTABLE QUALITY DOSE (AQD) ESTIMATION

AQD estimation was performed exclusively on images with an IQSC score of exactly 3, representing the lowest diagnostically acceptable image quality. In this study, IQSC=3 images were defined as those providing sufficient anatomic detail, adequate contrast enhancement, and acceptable noise levels to enable accurate clinical interpretation without repeat scanning. IQSC ≤2 was excluded due to suboptimal diagnostic quality, while IQSC=4 images, although meeting or exceeding quality standards, were also excluded because they represent unnecessarily high image quality achieved at higher radiation doses. Including such images would shift the reference dose upward, potentially normalizing overexposure and contradicting the ALARA principle. This approach ensures that AQD reflects the minimum radiation exposure capable of producing diagnostically sufficient images. AQD therefore accepts the lowest dose that maintains diagnostic confidence and rejects any higher doses that do not provide additional clinical value. The selected data were categorized into six pediatric age groups include neonates (0–27 days), infants (28 days–12 months), toddlers (13 months–2 years), early childhood (3–5 years), middle childhood (6–11 years), and adolescents (12–18 years) (Yang & Gao 2024). Radiation dose indices ($CTDI_{vol}$ and DLP) were recorded for each group, and median values were calculated to establish AQD benchmarks. These values served as representative measures of optimal radiation dose for pediatric brain CT imaging (Kharita et al. 2021).

DATA ANALYSIS

Statistical analysis was conducted to assess interobserver variability, image quality scores, and radiation dose indices across age groups. The Kappa statistic was utilized to assess interobserver agreement, with value of 0 or less indicates no agreement, while values between 0.01 and 0.20 suggest slight agreement. Fair agreement is represented by a range of 0.21 to 0.40, whereas moderate agreement falls between 0.41 and 0.60. Substantial agreement is indicated by values from 0.61 to 0.80, and a Kappa score between 0.81 and 1.00 signifies almost perfect agreement. Data analysis was performed using SPSS version 25.0. Descriptive statistics was express as mean, standard deviation and frequency distributions of IQSC scores, were computed for each age group. For normally distributed data, a one-way Analysis of Variance (ANOVA) was conducted to compare dose indices across age groups. To control the risk of Type I error arising from multiple pairwise comparisons across 6 age groups, the Bonferroni correction was applied. The significance level (p-value=0.05) was divided by the number of pairwise comparisons (n=15), resulting in a new threshold of p=0.0033. Only p-values below this adjusted threshold were considered statistically significant.

RESULTS

The evaluation of all 39 pediatric brain CT images was conducted by two independent evaluators using the Image Quality Scoring Criteria (IQSC). According to the IQSC scale [0s – Desired features not visible; 0i – Anatomy not included in images; 1 – Unacceptable quality (non-diagnostic images); 2 – Limited quality (diagnostic with high noise); 3 – Adequate quality (acceptable for diagnosis); and 4 – Higher than necessary quality (excessively high resolution)], only images with scores of 3 or 4 were included for further assessment, specifically for radiation dose measurements.

Based on this criterion, 74% of the evaluated images were deemed acceptable, with 29 out of 39 images meeting the inclusion threshold. The median image quality score for pediatric brain CT examinations was found to be 3. The mean percentage of image quality scores assigned by the two evaluators indicated that 47% of the assessed scans received a score of 3, signifying an acceptable diagnostic standard. Additionally, 27% of the images were assigned a score of 4, reflecting higher-than-necessary image quality, while 26% were rated with a score of 2, indicating suboptimal but still interpretable image quality.

The findings demonstrate that a score mean of 3 suggests most scans achieved an adequate diagnostic standard. Both evaluators exhibited consistency in their assessments, particularly in determining which images were diagnostically useful. The distribution of subjective image quality scores shows that most pediatric head CT scans were assigned a score of 3, accounting for nearly half of the total examinations. The clustering of scores around 3 further supports the conclusion that the overall image quality was within an acceptable range, ensuring sufficient detail for reliable diagnostic interpretation. Figure 1 show the frequency distribution (%) of subjective image quality scores assigned by two independent evaluators.

The interobserver variability between the two evaluators was assessed using the kappa statistic, which yielded a value of 0.76, indicating a high level of agreement. This result suggests minimal disagreement between the evaluators, despite some variations in the subjective image quality scores assigned. Notably, both evaluators consistently concurred on images classified as diagnostically useful, particularly those assigned a score of 3.

In alignment with the Acceptable Quality Dose (AQD) framework, which necessitates the inclusion of images with sufficient diagnostic quality for radiation dose assessment, analysis revealed that 29 out of 39 CT scans met the required criteria. Consequently, only these 29 scans were considered for AQD estimation. To facilitate a comprehensive evaluation, the selected examinations were stratified into 6 distinct pediatric age groups. Table 1 shown the mean and standard deviation (SD) of $CTDI_{vol}$ and DLP across different pediatric age groups.

The results show variability in dose indices among the groups. $CTDI_{vol}$ demonstrates a trend in which younger patients generally receive lower radiation doses compared to older patients, likely due to their smaller head size and reduced scanning range. In contrast, the DLP demonstrated a non-uniform trend across the different age groups, indicating variability in cumulative radiation exposure among the classifications. Statistical analysis revealed a statistically significant variation in $CTDI_{vol}$ among the different age groups because p-value was 0.00 less than 0.05 ($p=0.00$, $p<0.0033$), indicating that age-related factors influence volumetric dose exposure. However, no statistically significant differences were observed in DLP values across age groups because p-value was 0.16 more than 0.05 ($p=0.16$, $p>0.0033$), suggesting that scan length and acquisition parameters may contribute to dose variability independently of patient age.

The scatter plot as shown in Figure 2 demonstrates a positive correlation and the data points tend to cluster around a trendline. This suggests a stronger relationship between $CTDI_{vol}$ and image quality. The scatter plot analysis reveals that data points tend to cluster around an IQSC score of 3, which represents adequate image quality, sufficient for accurate diagnostic interpretation. This pattern suggests a threshold beyond which increasing $CTDI_{vol}$ does not necessarily enhance image quality.

The scatter plot plot as shown in Figure 3 also demonstrates a positive correlation however, the presence of outliers and a weak clustering pattern suggests that DLP is not a strong or consistent predictor of image quality compared to $CTDI_{vol}$. This suggests that DLP does not strongly correlate with IQSC compared to $CTDI_{vol.}$ While $CTDI_{vol}$ directly measures radiation dose per scan, DLP is a cumulative metric influenced by both $CTDI_{vol}$ and scan length.

DISCUSSION

The AQD was introduced as a bottom-up approach to radiation dose optimization, in contrast to Diagnostic Reference Levels (DRLs), which use a top-down methodology. Unlike DRLs, which are based on the 75th percentile of dose distributions and may include both underexposed and overexposed images, AQD focuses exclusively on images that meet predefined diagnostic acceptability criteria (Kharita et al. 2021; Yaseen et al. 2024). By doing so, AQD ensures that dose analysis is based on clinically useful images rather than on a broad range of exposures that may not reflect optimal practice (Tsapaki 2020). In clinical practise, AQD helps to identify opportunities for significant dose reduction while maintaining diagnostic integrity. It also supports the development of tailored imaging protocols for different patient groups, such as pediatrics, where radiation sensitivity is higher and dose management is critical. Furthermore, AQD can be used as a benchmarking tool for continuous quality improvement, enabling healthcare facilities to monitor their performance over time, compare results across institutions, and harmonize imaging practices. The findings of this study demonstrate an uneven distribution of patients across six pediatric age groups in the 29 head CT examinations analyzed. Age group classification plays a crucial role in AQD assessment as it facilitates the adjustment of scan parameters according to patient size and anatomical characteristics, thereby ensuring

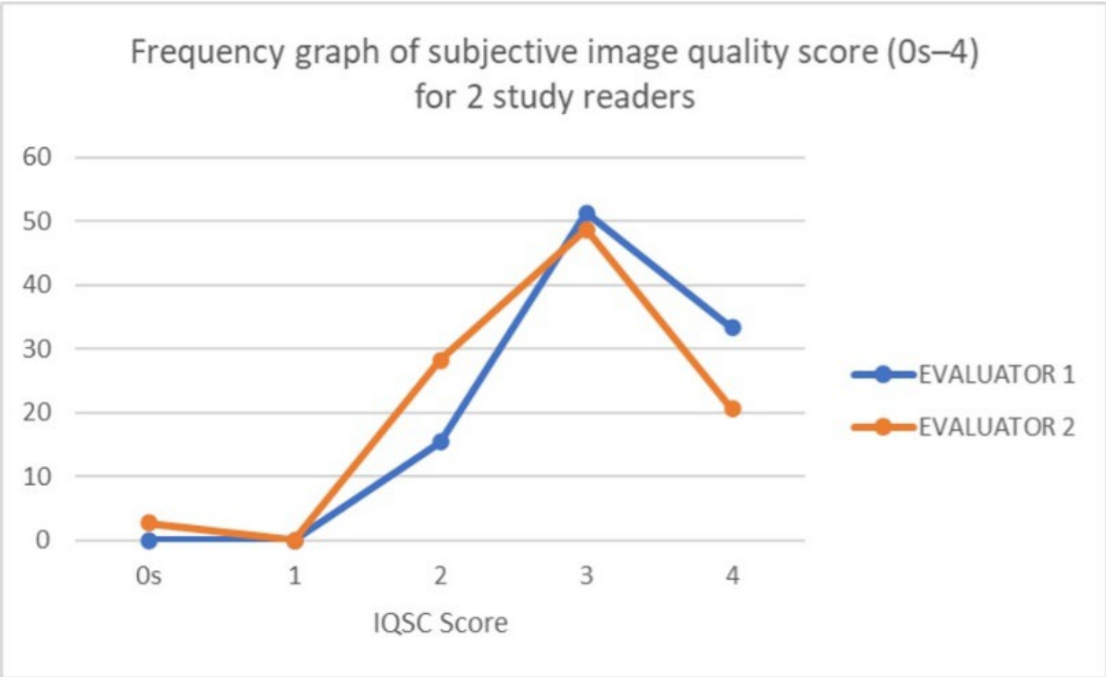

FIGURE 1 Frequency distribution (%) of subjective image quality scores assigned by two independent evaluators. The graph illustrates the percentage of images categorized according to the IQSC scoring criteria. Approximately half of the evaluated images received a score of 3, indicating an acceptable diagnostic quality based on assessments by both evaluators.

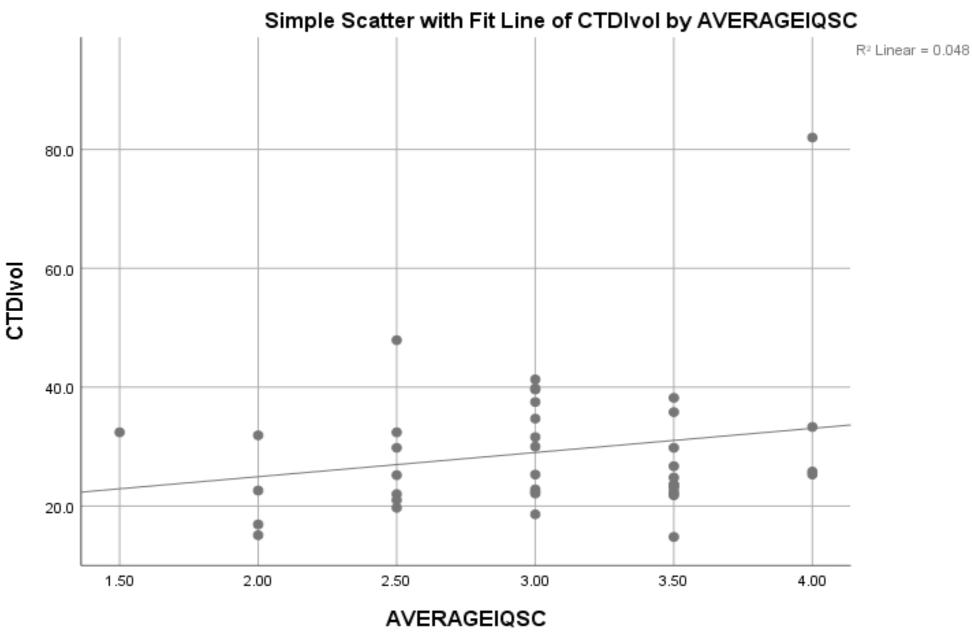

FIGURE 2 Correlation graph between $CTDI_{vol}$ and average image quality score

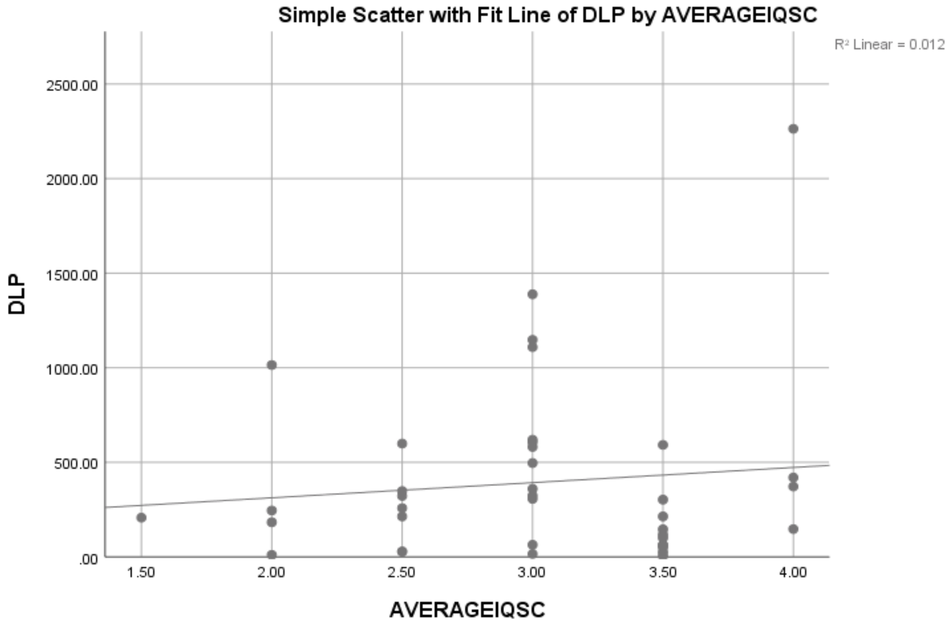

FIGURE 3 Correlation graph between DLP and average image quality score

TABLE 1 Comparison of radiation dose parameters across six pediatric age groups, as defined by the National Institute of Child Health and Human Development. The analyzed dose metrics include the volumetric CT dose index ($CTDI_{vol}$) and dose-length product (DLP) for pediatric brain CT examinations.

Age group (patients)	**0-27D (n=2)**	**28D-12M (n=9)**	**13M- 2Y (n=2)**	**3-5Y(n=4)**	**6-11Y(n=10)**	**12-18Y(n=2)**	**P-value**
Average age (YY, MM, WW, DD)	00,00,00,17	00,07,00,09	02,00,00,00	04,00,00,00	08,08,00,00	14,00,00,00	-
$CTDI_{vol}$ (Mean±SD)	21.00±0.00	21.86±3.05	24.10±5.31	25.07±4.47	38.32±13.25	46.30±15.84	0.00
DLP (Mean±SD)	258.00±0.00	320.56±451.70	190.23±166.31	391.01±384.76	550.60±540.50	370.20±370.62	0.16

D= day, W= week, M= month, Y= year

adequate radiation protection for younger children who are more sensitive to ionizing radiation (Poosiri et al. 2024). This classification also enables more consistent comparison of dose data between age groups and supports the development of tailored imaging protocols. In growing children, variations in skull thickness and brain tissue composition substantially influence image contrast and noise, necessitating appropriate adjustments to technical parameters to achieve optimal image quality (Nagy et al. 2023). Failure to perform such modifications may result in suboptimal imaging and reduced diagnostic confidence. Furthermore, as children mature, higher radiation doses are often required to maintain diagnostic image quality, underscoring the need for a careful balance between image quality and radiation exposure, with dose escalation applied only when clinically justified (Inoue, Itoh, Waga, et al. 2022). The findings of this study show a progressive increase in $CTDI_{vol}$ with advancing patient age. This pattern can be attributed to both anatomical and technical factors. As children grow, head circumference and skull thickness increase, resulting in greater X-ray attenuation and requiring higher tube current or voltage to achieve adequate image penetration. Modern CT systems equipped with automatic exposure control (AEC) respond to this increased attenuation by proportionally raising radiation output, thereby contributing to higher $CTDI_{vol}$ values among older children (Inoue, Itoh, Miyatake, et al. 2022; Nagy et al. 2023). In addition, diagnostic requirements in older pediatric patients often demand clearer anatomical detail, which is achieved through higher exposure settings to reduce image noise and improve contrast resolution. Previous studies have shown that pediatric imaging protocols are systematically adjusted according to patient size, particularly for younger children who have smaller skulls and less dense anatomical structures (Karappara et al. 2020; Nagy et al. 2023; Padole et al. 2019). Therefore, lower radiation doses are generally sufficient to achieve diagnostically acceptable image quality in younger patients, as reduced attenuation allows clearer imaging with minimal exposure (Ploussi et al. 2020). From a clinical perspective, slightly higher radiation doses are considered acceptable in older children because their radiosensitivity is lower compared to infants, thereby reducing the relative risk of radiation-induced stochastic effects.

Interestingly, the DLP values in this study show varied results, with increases or decreases that are inconsistent and not proportional to age groups. DLP, calculated as the product of $CTDI_{vol}$ and scan length, provides an estimate of the total radiation burden for each scan (Smith-Bindman et al. 2019). The total DLP is highly influenced by the scanning range. Theoretically, younger patients should have smaller head sizes and, consequently, shorter scanning ranges, which would result in lower DLP values (Inoue et al. 2023). However, this was not observed in our study, most likely because younger patients often underwent longer scan coverage, possibly due to a wider margin of safety applied by radiographers to ensure complete anatomical coverage. In addition, younger pediatric patients are generally more difficult to position with the skull base parallel to the X-ray beam, which can lead to an extended scan range. Time constraints and concerns about patient movement may further discourage gantry angulation, resulting in longer coverage and potentially higher DLP despite smaller head size. These sources of variability likely contributed to the absence of a statistically significant difference in DLP across age groups. While DLP remains a clinically relevant measure of overall radiation burden, its strong dependence on scan length and operator technique may limit its value as a consistent comparative metric, particularly in studies with small sample sizes or heterogeneous patient populations.

An increase in $CTDI_{vol}$ has been shown to reduce image noise, thereby improving anatomical detail and diagnostic confidence (Malik et al. 2024). However, the clustering of image quality scores around 3 on the IQSC scale suggests that once adequate diagnostic quality has been achieved, further increases in $CTDI_{vol}$ do not provide significant improvements in image interpretation. Instead, excessive radiation exposure without a corresponding enhancement in image quality becomes a major concern, particularly in pediatric imaging, where children are more sensitive to ionizing radiation (Meulepas et al. 2019). The study by Smith-Bindman et al. (2019) highlights the complex relationship between $CTDI_{vol}$ and DLP, showing that DLP is influenced by scan length and patient size, which can lead to variations in image quality even when $CTDI_{vol}$ values are the same. This means that even scans with identical $CTDI_{vol}$ values may produce different levels of image quality due to variations in anatomical coverage. Furthermore, scatter plot analysis revealed the presence of outliers, indicating that an increase in DLP does not necessarily correlate with improved image quality. This can be explained by the fact that DLP is highly dependent on scan length rather than image acquisition parameters alone, extended coverage increases DLP even if it does not contribute to diagnostic value or reduce noise (Inoue 2023). Additionally, patient motion, positioning errors, or reconstruction settings can still degrade image quality regardless of the radiation dose delivered, which explains why higher DLP values may sometimes be associated with images of only average or even suboptimal quality (Varghese et al. 2024).

The relationship between these radiation dose metrics and AQD is particularly relevant in optimizing pediatric imaging. AQD represents the optimal radiation dose required to maintain acceptable image quality while minimizing unnecessary radiation exposure (Kharita et al. 2021; Yaseen et al. 2024). The stronger correlation between $CTDI_{vol}$ and image quality aligns with AQD principles, as $CTDI_{vol}$ directly measures the radiation dose associated with each scan. This suggests that $CTDI_{vol}$ s a more reliable metric for assessing whether the administered radiation dose is sufficient for diagnostic purposes while remaining within safe exposure limits (Malik et al. 2024). In contrast, the weaker correlation between DLP and image quality implies that DLP may not be the most accurate parameter for determining AQD. Since DLP reflects total radiation usage without accounting for scan length variations and patient size, it may not reliably indicate whether a scan meets AQD standards (Arfat et al. 2024). To ensure adherence to AQD principles, radiation dose and image quality must be carefully balanced, with $CTDI_{vol}$ serving as a more precise metric for evaluating dose optimization in pediatric CT imaging.

The present study has several limitations that may affect the generalizability of its findings. First, the relatively small sample size limits the ability to draw definitive conclusions and impacts the statistical power of the analysis. A larger sample would allow for more robust data and a deeper understanding of the relationship between radiation dose and image quality. Second, the study was conducted with a limited number of patients who underwent CT brain scans using a specific imaging protocol at a single institution. Consequently, the results may be influenced by the imaging techniques, equipment, and protocols unique to this setting, reducing the broader applicability of the findings to other institutions using different technologies or protocols. Moreover, there is a lack of sufficient comparable studies in the existing literature, making it challenging to directly compare and validate our results. While similar studies exist, the limited body of research in this area highlights the need for more extensive investigations to strengthen the evidence. Future studies should include larger and more diverse patient cohorts across multiple centers, exploring a wider range of CT protocols and patient populations. Such multicenter investigations would provide a more comprehensive understanding of the relationship between radiation dose and image quality in pediatric brain CT, enhancing the generalizability and robustness of the findings.

CONCLUSION

This study highlights that the AQD approach provides a balanced framework by integrating image quality, radiation dose, and patient body composition, thereby prioritizing diagnostically acceptable images over simple dose reduction. Furthermore, our findings indicate that $CTDI_{vol}$ is a more reliable parameter than DLP for evaluating radiation dose adequacy, as it better reflects the factors that influence image quality. Collectively, these results support the adoption of AQD-guided protocol optimization to ensure safe, consistent, and diagnostically robust pediatric CT imaging.

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