Radiation dose optimization for computed tomography of the head in pediatric population – An experimental phantom study

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▶ ***Original article***

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Received: September 2021
Final revised: March 2022
Accepted: Match 2022

Int. J. Radiat. Res., October 2022; 20(4): 747-751

DOI: 10.52547/ijrr.20.4.3

Keywords: *Computed tomography, pediatric population, radiation dose, dose optimization, CT image quality.*

ABSTRACT

Background: There is an increase in pediatric Computed Tomography (CT) imaging with advancement in technology but CT radiation dose produces significant adverse effects. The objective of this experimental phantom study is to develop an age-based low-dose pediatric CT head protocol. ***Materials and Methods***: Polymethyl methacrylate (PMMA) pediatric head mimicking phantom scanning was performed on a CT scanner using various combinations of tube voltage (kV) and product of tube current and exposure time (mAs) setting. Images were reconstructed by iterative reconstruction iDose^4 level 1-5. Quantitative assessment of image quality (IQ) was done by calculating Signal to Noise Ratio (SNR), Contrast to Noise Ratio (CNR), and Image Noise (IN). Radiation dose indices (RDI) were measured by recording Volumetric CT Dose Index (CTDIv) and Dose length product (DLP). Figure of Merit (FOM) was calculated to study overall effects between IQ and RDI. IQ and RDI obtained using different exposure settings were compared. ***Result***: Optimized age-based low-dose protocols were developed based on IQ analysis and RDI. For pediatric CT head, with age less than one year kV and mAs of 80 and 150 and for one–five years age kV and mAs of 100 and 200 with iDose^4 level-3 was found to be optimum low dose protocol. ***Conclusion***: The experimental phantom study concluded that with use of low kVp and mAs, radiation dose was reduced to 62% for less than 1-year age group and 51% for 1-5 year age group and also with use of iterative reconstruction technique iDose^4 level-3 diagnostic image quality was maintained.

[DOI: 10.52547/ijrr.20.4.3]

INTRODUCTION

Computed Tomography (CT) provides cross-sectional images and aids in a detailed examination of anatomy and diagnosis of pathology. The CT examinations have increased globally by about 700 – 800% with more than 10% of CT scans done in the pediatric group with the advancements in CT technology [1, 2].

There is an increase in pediatric CT scanning with the advancement in CT technology that can provide improved contrast and resolution images with shorter acquisition time and reduced artifacts. Despite its advantages, radiation produces significant adverse effects. Children are very sensitive as they have a long life expectancy for radiation effects to exhibit and also maturing tissues and organs are susceptible to radiation effects [3-7].

International Commission on Radiation Protection (ICRP) proposed radiation protection principles which include justification for the study, optimization of radiation for ensuring the radiation risk to the patients do not offset the benefit gained from the CT imaging. For pediatric CT radiation dose optimization, selection of appropriate acquisition factors such as kilovoltage peak (kVp), tube current exposure time product (mAs), rotation time, thickness, pitch, scan length that corresponds to the age or weight of the patient is necessary [8, 9].

The most common method of reducing radiation dose is by decreasing the exposure factors such as kVp and mAs, which leads to an increase in noise and result in suboptimal image quality which is mainly because of the drawback of Filtered back projection (FBP). This shortcoming of FBP had been responsible for the evolution of iterative reconstruction algorithms. Philips Health care introduced iterative reconstruction techniques in 2010 with iDose^4. This hybrid iterative reconstruction technique- iDose^4 allows optimizing the radiation dose to the patients undergoing CT examination without deteriorating quality of image for different body regions including pediatric CT with reduced exposure factors (kVp and mAs) [10-11].

To our knowledge, the literature search had shown that there are limited studies in India that optimized radiation dose for pediatric CT head in the age group of 0-5 years. The optimization of CT scanning protocols using iDose[4] iterative reconstruction algorithm for pediatric cases was done either by selecting automatic tube current modulation or by reducing mAs or kVp. However, in this present study, the low dose protocol for pediatric CT head was developed by lowering both kVp and mAs using the iDose[4] iterative reconstruction algorithm. Hence, the purpose of this experimental phantom study was to develop an age-based low dose CT head protocol on the phantom for optimizing the radiation dose and evaluate the image quality by using the iDose[4] iterative reconstruction algorithm in the pediatric population.

MATERIALS AND METHODS

An experimental phantom study was performed on 128-slice Scanner Incisive CT (Philips Health care, Netherlands). Polymethyl methacrylate (PMMA) pediatric head mimicking phantom (Model 0143, Unfors, Ray safe Pro-CT dose, Sweden) was placed on the couch and positioned such that the central axis of the phantom is aligned with the isocenter of the gantry. Firstly, the phantom was scanned using standard default Pediatric CT Head protocol (table 1) to identify the threshold values for Image Noise (IN), Signal to Noise Ratio (SNR), and Contrast to Noise Ratio (CNR). Secondly, the phantom was scanned by lowering the tube voltage to 80kV and 100 kV at five mAs settings per voltage (50, 100, 50,200,250) with other parameters same as standard protocol for both the age groups. The acquired CT images were reconstructed by the iterative reconstruction technique (iDose[4] levels 1-5).

Table 1. Standard pediatric CT brain protocol.

Parameters	< 1 year	1 – 5 years
Tube voltage (kVp)	100	120
Tube current (mAs)	200	250
Slice thickness and increment (mm)	3	3
Pitch	0.60	0.60
Rotation time	0.50	0.50
Matrix	512 X 512	512 X 512
Collimation	64 X 0.625 mm	64 X 0.625 mm
FOV (mm)	250	250

Dose indices

The radiation dose was assessed by recording the 'volumetric CT Dose Index (CTDIvol)' and 'Dose Length Product (DLP)' that was calculated by the CT scanner and displayed on the control console.

Image quality analysis

The image quality was evaluated by calculating IN, SNR and CNR. The image noise was measured by calculating the standard deviation (SD) by drawing an ROI (Region of interest) measuring 10 – 20 mm^2 on three successive CT sections and the average of them was taken. SNR was calculated as the mean Hounsfield unit (HU) value of ROI divided by the standard deviation (SNR = Mean HU_{ROI}/SD_{ROI}) [12,13] CNR was calculated as the difference between the mean HU value of the ROI placed in the acrylic object and the mean HU value of the background divided by the standard deviation of the background. (CNR = Mean HU_{object} - Mean $HU_{background}/ SD_{background}$) [11-13]. All the measurements were done on the Philips Intellispace Portal (ISP). Two readers A and B have done the measurements and interrater variability was measured.

Figure of merit (FOM)

To assess the overall effects of image quality and radiation dose, FOM for standard and low dose protocol was calculated as the square of CNR divided by CTDIvol (FOM = CNR^2 / CTDIvol) [13].

Validation of low dose phantom protocol

A small set of pediatric patients (n=5) were scanned using the developed age-based low dose protocol. The subjective image analysis was performed by two radiologists who have experience of more than 10 years. The CT images were graded for subjective noise, grey-white matter differentiation, artifacts, overall image quality on a five-point Likert scale (1 for unacceptable, 2 for suboptimal, 3 for average, 4 for good, and 5 for excellent). The objective image quality parameters (IN, CNR, SNR) was calculated by drawing the ROIs in the grey matter of the thalamus and white matter of the frontal lobe.

Statistical analysis

The data was analyzed using SPSS version 22. The mean and standard deviation of radiation dose descriptors such as CTDIv and DLP value, FOM, and image quality analysis such as IN, SNR, CNR was calculated. The radiation dose and image quality obtained using different levels of iterative reconstruction, tube voltage, and tube current were compared using the Mann-Whitney U test. A p-value <0.05 was considered to indicate statistical significance.

RESULTS

The pediatric head mimicking PMMA phantom was scanned using standard CT Pediatric head protocol. The radiation dose indices such as CTDIv and DLP were recorded for both age groups. The image quality analysis was done to find the threshold

[DOI: 10.52547/ijrr.20.4.3]

values of IN, CNR, and SNR (table 2).

Table 2. Threshold values of Image quality parameters for phantom scanned using standard-dose CT pediatric head protocol.

Age Group	kV	mAs	Threshold attenuation (HU)	Threshold CNR	Threshold SNR	Threshold IN (HU)
<1years	100	200	116.49	1.2	24.78	4.7
1-5 years	120	250	126.85	1.5	25.89	4.9

For <1 year

The study showed that at a tube voltage of 80 kV and different tube current-exposure time (mAs) setting, there was a decrease in radiation doses in terms of both CTDIv and DLP for lower mAs. However, there was a reduction in image quality for lower mAs and hence the images were reconstructed by increasing the levels of idose[4]. It was found that the IN, CNR, SNR in the pediatric age group (< 1 year) are similar to that of the standard dose protocol at low dose parameter of 80 kV and 150 mAs and iDose[4] (Level 3) shown in figure 1A, B, and C.

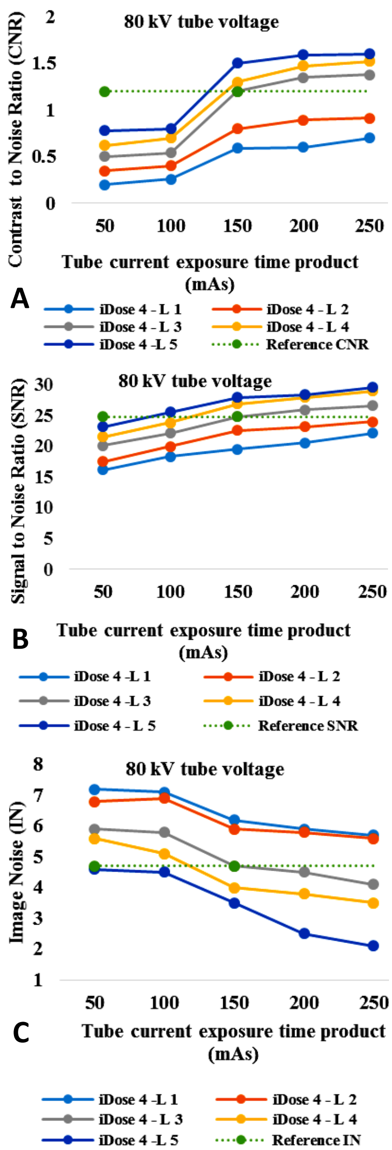

Figure 1. (A) Graph showing CNR values for 80 kV at various mAs settings and different iDose4 levels (1-5) and threshold CNR (green dotted line). **(B)** Graph showing SNR values for 80 kV at various mAs settings and different iDose4 levels (1-5) and threshold SNR (green dotted line). **(C)** Graph showing IN values at 80Kv at various mAs settings and different iDose4 levels (1-5) and threshold IN (green dotted line).

For 1-5 years

The study showed that at a tube voltage of 100 kV and different tube current-exposure time (mAs) setting, there was a decrease in radiation doses in terms of both CTDIv and DLP for lower mAs. However, there was a reduction in image quality for lower mAs and hence the images were reconstructed by increasing the levels of idose[4]. It was found that IN, CNR, SNR in the pediatric age group (1 -5 years) are similar to that of the standard dose protocol at low dose parameters of 100 kV and 200 mAs and iDose[4] (Level 3) shown in figure 2A, B and C.

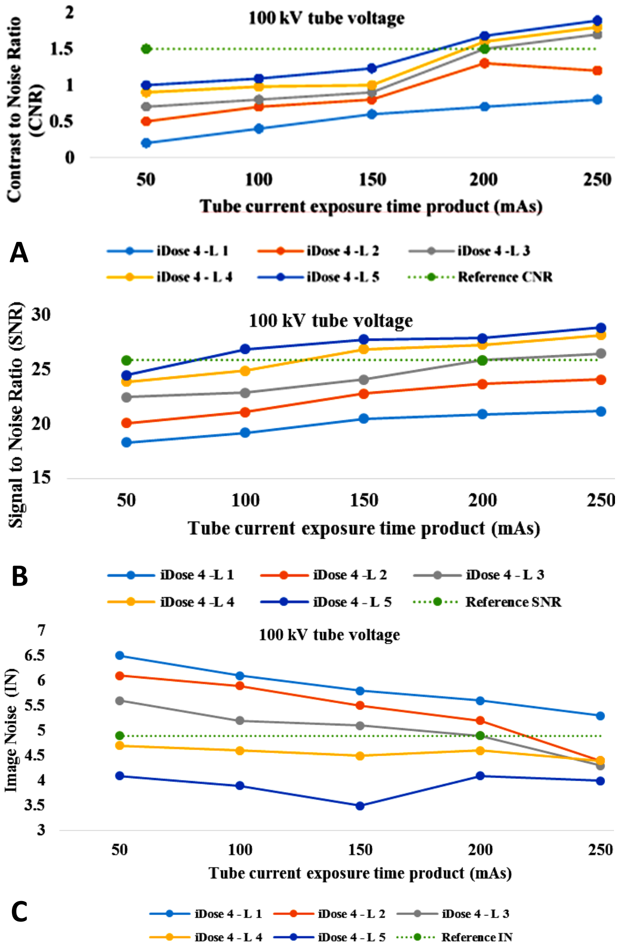

Figure 2. (A) Graph showing CNR values for 100 kV at various mAs settings and different iDose4 levels (1-5) and threshold CNR (green dotted line). **(B)** Graph showing SNR values for 100 kV at various mAs settings and different iDose4 levels (1-5) and threshold SNR (green dotted line). **(C)** Graph showing IN values for 100 kv at various mAs settings and different iDose4 levels (1-5) and threshold IN (green dotted line).

Mann – Whitney U test was used for comparing the radiation dose indices and objective image quality measurements between standard and low-dose CT pediatric head protocol. The study noted no significant difference in objective image quality analysis such as SNR (p = 0.781 for < 1year, p= 0.647 for 1-5 years), CNR (p = 0.962 for < 1 year, p = 0.435 for 1-5 years), IN (p = 0.634 for < 1year, p = 0.753 for 1-5 years) between standard dose and low dose protocol for both the age groups. The study noted

[DOI: 10.52547/ijrr.20.4.3]

significant difference in radiation dose (CTDIv $p<0.05$, and DLP $p<0.05$) and FOM ($p<0.05$) between standard dose and low dose protocol for both the age groups (table 3). Our study noticed low dose protocol at 80kVp/150 mAs/iDose^4 (level 3) and 100kVp/200 mAs iDose^4 (level 3) for less than 1year and 1-5-year age group showed 62% and 51% reduction in radiation dose respectively compared to standard dose protocol with optimum diagnostic image quality as shown in figure 3A and B.

Table 3. Radiation doses and Figure of merit for standard and low dose Pediatric CT Head protocol.

Age group	Standard dose protocol			Low dose protocol			p-value
	CTDIv (mGy)	DLP (mGy.cm)	FOM	CTDIv (mGy)	DLP (mGy.cm)	FOM	
<1year	17.28± 6.2	353.34± 131.5	0.11	6.46± 2.4	132.94± 56.9	0.22	<0.05
1-5 year	35.17± 14.8	717.71± 279.4	0.10	17.28± 6.2	353.34± 13.5	0.13	

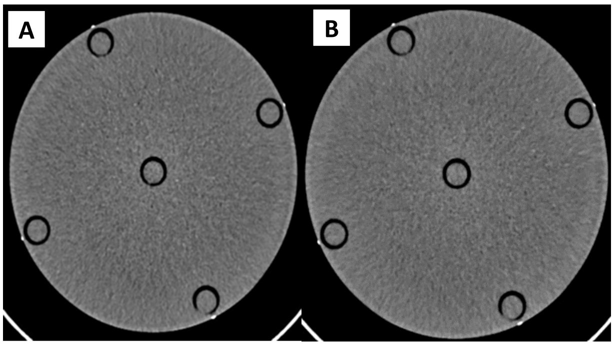

Figure 3. Phantom CT images were taken using **(A)** standard dose protocol and **(B)** low dose protocol.

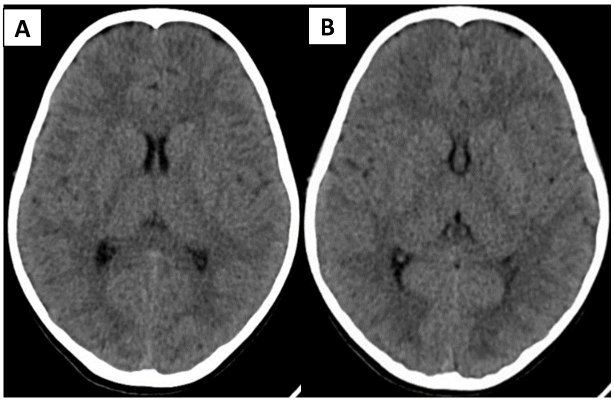

Figure 4. Axial CT brain image of the 3-year-old patient taken using **(A)** standard pediatric brain protocol **(B)** low dose pediatric brain protocol.

The kappa value was 0.81, which shows good agreement in objective image quality analysis between two readers. There was no statistical difference between the image quality analyses performed by Reader A at different periods, according to paired Student's *t*-test. (P-value >0.05).

The low dose protocol developed on the phantom was validated on a small set of the pediatric population of < 1year (n=2) and 1-5 years (n=3). The subjective image quality analysis showed good overall image quality and grey-white matter differentiation with reduced artifacts and subjective noise compared to standard dose protocol (figure 4A and B). The objective image quality parameters (CNR 1.5 and 1.7, SNR 8.1 and 8.67, IN 4.6 and 4.1, attenuation 32.98 and 34.02 respectively for > 1 year and 1-5 years) was similar to that of standard-dose pediatric CT head protocol and also noticed 62% and 51 % reduction in radiation dose respectively.

DISCUSSION

In the current study, we developed a low dose protocol for the pediatric CT head by scanning the phantom with lower tube voltage (kV), tube current-exposure time (mAs), and reconstructing the image with different iDose 4 levels (1-5). The results indicate that with the use of iDose^4 (level 3), the radiation dose was reduced to 62% and 51% compared with the standard protocol. We also validated the developed low dose protocol on a small set of pediatric patients and observed the same diagnostic image quality and reduction in radiation dose. The findings of our study are in agreement with previous studies which reported that the iterative reconstruction technique would help reduce radiation dose with maintaining the diagnostic image quality [12-15].

In the present study, the quantitative assessment of image quality was performed using the IN, CNR, and SNR. We found that there was no statistical difference in quantitative image analysis between low and standard-dose protocol which was similar to the results of Baskan *et al.* [12], Chang *et al.* [13], Kordolaimi *et al.* [14]. We also noticed CNR and SNR (20 to 30%) were considerably higher with an increase in idose^4 level in low dose compared to standard dose. Further, we noticed a reduction of image noise with an increase in idose^4 levels, kVp, and mAs.

We also evaluated the FOM which signifies overall effects and possible tradeoffs between quality of image and radiation dose and found that there is an increase in FOM in low dose compared to standard dose. The results are similar to the findings published by Chang *et al.* [13]

In a study done by Seon *et al.* [15] and Bodelle *et al.* [16] the image quality was maximum when the images were reconstructed with iDose^4 levels between 3 and 4. Similarly in the current study, the image quality was maximum for the images reconstructed with iDose^4 (level 3). However, it was found that higher reconstruction levels such as iDose levels between 5 and 6 produce smoothing of images and reduce image quality.

Seon *et al.* [15], reported that the use of advanced iterative reconstruction techniques for low radiation dose CT abdomen with the patient positioned with arms - down position can reduce the beam hardening artifacts and an intermediary level of iterative

[DOI: 10.52547/ijrr.20.4.3]

reconstruction helps in obtaining the optimum image quality. Similarly, in the present study, the beam hardening artifacts were reduced by reconstructing the images with iterative reconstruction techniques.

The current study has a few limitations. First, the proposed method might be applicable for the specific patient size that matches that of the CT phantom. Second, the low dose protocol developed on the phantom need to be validated on human studies with an increased sample size for identifying the effectiveness of low dose protocol.

CONCLUSION

Our study concludes that the low dose protocol at 80kVp/150 mAs/iDose ^{4} – level 3 and 100kVp/200 mAs/iDose^{4} level 3 for less than 1year and 1-5-year age group showed 62% and 51% radiation dose reduction respectively with optimum diagnostic image quality compared to standard pediatric CT head protocol. Thus, for optimizing the protocol for CT head examinations in the pediatric population, the findings of our study can be used as a reference in radiation dose optimization by maintaining the diagnostic image quality.

ACKNOWLEDGEMENTS

None.

Conflicts of interest: None.

Ethical considerations: The study was approved by the institutional ethics committee.

Funding: None.

Author contribution: All authors (P), (RK), and (SS) have contributed equally to this work. (P) and (RK) conceived and designed the study. (P) carried out the experiment. (RK) and (SS) analyzed the data. (P) and (RK) drafted and revised the manuscript. All authors read and approved the final manuscript.

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[DOI: 10.52547/ijrr.20.4.3]