A Preliminary Study of Personalized Head CT Examination in Pediatric

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Research article

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Abstract

Background: Same head CT examination protocol was employed for pediatric patients who's skull sizes are different , this could be excessive radiation doses because they usually have smaller head circumference. In our study, we investigate if mAs according to head circumference(HC) reduce radiation doses of sensitive organs including brain, eye lens and salivary glands, but could keep the image quality.

Methods: 83 pediatric patients were prospectively selected. Without limiting the head circumference, 15 pediatrics were selected as conventional group by random number method and received routine head CT examination protocol (250mAs). Low-dose group including remaining 68 patients were divided into 3 subgroups based on HC: 54.1-57.0cm for group A(200mAs), 51.1-54.0cm for group B(150mAs), 48.1-51.0cm for group C(100mAs). The Image quality was assessed by subjective and objective image score. Radimetrics was used to calculate radiation doses of sensitive- organs.

Results: In the conventional group, pediatric patients with smaller head circumference receive higher radiation doses of sensitive-organs. Radiation doses of brain and salivary glands were negatively correlated with HC. The radiation dose of sensitive-organs in 3 low-dose subgroups were significantly lower than conventional group. The subjective image quality scores in group A and B was no statistical different than conventional group. The SNR of thalamus and centrum ovale in low-dose subgroups were no statistical differences compared with conventional group.

Conclusions: Our research indicates that personalized brain CT examination in pediatrics can reduce the radiation doses of sensitive-organs but keep image quality. HC can serve as an effective index to guide personalized head CT scan.

Background

Head CT scan has become a routine clinical examination in neurosurgery, neurology and emergency department. Although head CT is a relatively efficient diagnostic procedure as well as offers high diagnostic value, it is also a major contributor to collective radiation dose in daily diagnostic radiology practice [1 – 3]. Thus, the increasing use of brain CT scans raises the concern of a possible health impact of ionizing radiation exposure. Pediatrics are in growth stage, the speed and proportion of cell division and renewal are much faster than adults, therefore, they are more sensitive to X-ray exposure [4,5]. Receiving the same radiation doses, pediatrics have a higher risk of radiation exposure injury than adults, meanwhile, a lifetime risk of cancer is much higher compared with adults [6 – 9]. Thus, reducing radiation doses from pediatrics' brain CT under optimal image quality has been a hot research topic [10,11]. Personalized brain CT examination protocol is required in clinical practice but an effective index factor to guide the brain CT protocol has not been established [12]. $CTDI_{vol}$ is not a direct measurement or estimate of patient absorbed radiation doses. The size of patient may affects the absorbed dose: if all other factors remain the same, the smaller patient scanned with the same $CTDI_{vol}$ will have a higher absorbed dose than a lager patient [13].

In this study, we use head circumference (HC) as an index to determine the mAs of brain CT. The sensitive organs including brain, eye lens, salivary glands employed to evaluate the radiation exposure. Subjective and objective image quality score was used to evaluate the image quality.

Methods

Participants

This research was approved by the ethics committee of Jilin University (date of approval: February 1th 2017) and written informed consent was provided to every participant. During a 7-month period from February to September 2017, pediatric patients were recommended to undergo a non-contrast head CT examination for various clinical symptoms form neurosurgery, neurology and emergency department. Finally, 83 patients are recruited in the study, male 47, female 36, age 1-17 years old, their demographic characteristics are summarized in Table1. 15 patients were selected as the conventional group by random number method, who receive standard brain CT protocol(tube current 250mAs). The range of head circumference is 48.1-59.2cm (53.75±3.14cm). The other 68 patients were randomly separated into 3 low-dose group based on the HC: group A, 54.1-57.0cm, (56.00±0.24cm); group B, 51.1-54.0 cm, (52.98±0.20cm); group C, 48.1-51.0cm, (49.54±0.23cm). General information and scan parameters for conventional and low-dose group is in Table2.

Scanning Protocol

All subject's head CT examination were performed with a 64-slice MDCT scanner (Light Speed, GE Healthcare, USA) in the axial plane with the patient in the supine position. The tube current in conventional group was 250mAs. The tube currents in low-dose groups were 200mAs, 150mAs and 100mAs for group A, B and C, respectively. The following remaining scanning parameters were the same for four groups: 120 kVp, 5mm section thickness, 0.45mm interval, 360ms rotation time and a FOV of 38mm×38mm.

Organ-Specific-Radiation Dose Levels Estimation

Radimetrics, researched and developed by Byer Healthcare from Germany, an analysis platform based on Monte-Carlo-Simulation was used to calculate the radiation doses of sensitive organs.[14, 15] The total organ dose is calculated first for each slice using the $CTDI_{vol}$ at that slice and then summed over the slices that all into the scan region:

See Formula 1 in the Supplemental Files

Where coeff is the ratio of the simulated organ to the simulated $CTDI_{vol}$ as described above, and *i* indicates slice specific values.

Subjective image quality score assessment

Subjective image quality analysis was performed by two neuroradiologists with 8 and 20 years' experience, respectively. The neuroradiologists were blind to the scanner, scan parameters and slice thickness . Images were displayed using a fixed brain window setting (window width, 80Hu; window level, 40Hu). In the subject image quality assessment (1) severity of background noise, (2) severity of imaging artefacts, and (3) clarity of demonstration of lesions and anatomical structure were taken into account. Five grade were designed to each factor with 5 representing the best quality (Table 3). The scores from the three domains determined by the two neuroradiologist were then averaged to generate an overall score for image quality. An image quality score ≥3 was consider a qualified image for the demand of diagnostic.

Objective image quality score assessment

All head CT images measurement were carried out on GE workstation ADW4.4 in our department. The bilateral thalamus and centrum ovale were selected to place equal ROIs by a 10 years' experience neuroradiologist who were blind to the scanner, scan parameters and slice thickness. Average values on both sides. The standard deviation (SD) of mean CT density (Hounsfield unit) was used to measure the noise. The signal to noise ratio (SNR) was the HU/SD . The representative image measurement in FIG 1.

Statistical analysis

All data were analyzed using SPSS (Version 22; IBM, New York, USA). An initial analysis was performed using the Anderson–Darling test to evaluate whether the data were normally distributed. Numerical data were expressed as means ± standard deviation (SD) and compared by Mann–Whitney U test or ANOVA, as appropriate. ANOVA test was used to compare the difference of radiation dose and image quality score of sensitive organs in each group. When the difference was significant, tukey-kramer pairwise comparison would be conducted. Wilcoxon rank sum test was used for non-normal distribution. The consistency of the analysis results of two radiologists was checked by Kappa-test. The K value > 0.6 was good, 0.4≤ K value ≤0.6 was moderate, and the K value < 0.4 was poor. The statistical significance level was set as $P<0.05$.

Results

The relationship between head circumference and radiation doses of sensitive organs

In the convention group, we found that the radiation doses of sensitive-organs of pediatric patients with smaller HC increase under same mAs. The radiation doses of brain fell a negative liner correlation with the HC ($R^2=0.565$). F-test showed that the HC has a significant impact on the brain radiation doses ($P=0.00124$). The radiation doses of salivary glands also showed a negative liner correlation with the HC ($R^2=0.268$, $P=0.048$). On the other hand, the radiation doses of eye lens were not linearly correlated with the HC ($R^2=0.096$, $P=0.26$), although the radiation dose seems decrease for larger HC, as shown in FIG 2.

Radiation absorption benefit of low-dose head CT scan

With the decrease of mAs, the radiation doses of sensitive-organs also decreased. Compared with the convention group, the radiation doses of brain, eye lens and salivary glands in low-dose group decreased significantly (*P*□0.05), as shown in Table 4. When tube current have reduced to 200,150 and 100 mAs, the radiation doses respectively decreased 25%□33%□49% in brain□20%□37%□50% in eye lens□26%□34%□57% in salivary glands compared with 250mAs.

Subjective image quality in convention and low-dose head CT scan

There was not significant disagreement between the two radiologists. The Kappa value of the analysis results of two radiologists was K=0.741. The average subjective image quality score of convention and low-dose group were shown in Table 5. Subjective image quality score of A (200 mAs) and B (150 mAs) group was lower than convention group, but there was no statistical difference (*P*□0.05). Image quality score of C group (100 mAs) was significantly lower than convention group ($P<0.05$). Although the mAs had been decreased, the image quality score didn't fell lower than 3 score and are acceptable for diagnose purpose.

Objective image quality in convention and low-dose head CT scan

With the increase of mAs in low-dose group, the SNR of thalamus and centrum ovale increased gradually. The mean CT density, SD and SNR of thalamus and centrum ovale in convention and low-dose group were shown in Table 6. In the evaluation of thalamus and centrum ovale, there were no significant differences in SD and SNR (*P*□0.05).

Discussion

Head CT scan accounted for more than 50% of pediatric total CT examination [11, 16, 17]. The gene mutation and cancer risk related with X-radiation is 10 times higher than adults, especially, brain, eye lens and salivary glands are sensitive to radiation in head CT scan [18, 19]. Pediatrics are in the stage of growth and development, even in the same age group, the HC will vary greatly, so age is not an indicator of the HC. It is unreasonable for pediatric patients at different age to use same mAs when performing head CT examination. Age is not a reasonable indicator for choosing mAs.

One of the most important reasons is that it is impossible/difficult to accurately estimate the radiation doses of each organ, so it is impossible to quantitatively evaluate the benefits of low-dose brain CT examination. $CTDI_{vol}$ is not an accurate representation of the dose absorbed by individual patients, and dose not provide dose to the organ or allow a comparison of dose across different modalities that deliver ionizing radiation.

We use Radimetrics software to evaluate radiation doses of sensitive-organs. Our found that brain radiation doses varied among pediatric patients of conventional group, this indicate that some patients might have received excessive radiation doses during head CT scan using 250mAs. Pediatrics with smaller HC may receive overdose for brain, eye lens and salivary glands. One possible explanation for the negative correlation between brain radiation doses and HC is that the skull of larger circumference absorb more radiation than smaller ones. In same mAs, a same amount of radiation doses was delivered to the subject, the larger skulls absorb more radiation doses and result a lower radiation doses for the brain. If this is true, the organ protected by the skull or craniofacial bones should show a similar correlation with HC and the organ outside of the skull might not fell a negative liner correlation with HC. To test this, we exam the radiation dose in salivary glands (protected by mandible) and eye lens (not protected by bone), respectively. Our data show that there is a negative correlation between brain radiation doses and head circumference in the conventional group. Similarly, the salivary glands are protected by the mandible, and their radiation absorption is negatively correlated with the head diameter, similar to that of the brain. However, there was no significant linear relationship between radiation dose received by eye lens without skull or craniofacial bones protection and head circumference. It is essential that this results have provided theoretical support for the application of different mAs based on different HC in low-dose group.

We then investigate how the low dose head CT scan can benefit the pediatric patients. In our study, low-dose groups were divided into 3 subgroups according to HC,tube current were respectively 200mAs, 150mAs, 100mAs for group A, B, C. Conventional group carried out fixed 250 mAs not basing HC. We then test if we can use lower dose head CT scan in patients with small HC and still keep the image quality. Subjective image quality scores in low-dose and conventional group were greater than or equal to 3 scores to meet image diagnosis. There was no significant difference between the 250mAs and the 200mAs, 150mAs scans in subjective image quality score, but there was a significant difference in the image quality score between the 250mAs and the 100mAs scans. In the group C，the image score of the four patient was 3, which was the lowest acceptable quality of the clinical diagnosis, which indicated that quality of image under tube current below the 100mAs was unacceptable.

We found that personalized brain CT scan in low-dose group can significantly reduce the organ-specific-radiation dose levels than conventional group but keep image quality. HC can be used as an indicator for selecting mAs in head CT examination. Personalized head CT scan can reduce the radiation dose efficiently. Therefore, it is more objective and appropriate to select mAs using this method during head CT scans in pediatric patients.

But, no specific rules are found to further refine the relationship between HC and tube current and radiation dose. As for the HC and the specific mAs value should be set, further study is needed.

Conclusions

Selection of mAs according to different HC can be more rational and personalized design, so our research indicates that mAs basing on HC at head CT examination can effectively reduce organ-specific-radiation doses without compromise of image quality. The HC could be an effective index factor to guide personalized head CT scan.

Declarations

Acknowledgements

Not applicable.

Author’s contribution

BBY is in charge of result analysis and thesis writing; ZQC is in charge of image evaluation; ZBX in charge of scanning; WG in charge of children's head circumference survey; XSJ is in charge of original data collection; LD is in charge of guiding scheme design and paper revision. All authors have read and approved the manuscript”, and ensure that this is the case.

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Availability of data and materials

The datasets generated and analysed during the current study are not publicly available due it involves the privacy of patients but are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Ethical approval was provided by the first hospital of Jilin University (Ethical approval reference number: 2017-359). Informed consent was written obtained when patients were admitted to hospital. Written informed consent was obtained from a parent or guardian for participants under 16 years old.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Abbreviations

HC: head circumference; SD: standard deviation; SNR: signal to noise ratio; THL: thalamus; CO : centrum ovale

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Tables

Table1. Demographic characteristics of subjects

Sex (male: female)	47:36
Mean Age (SD)	8.5(4.7)
Symptoms*	
headache	41
dizzy	21
nausea	26
vomiting	12
trauma	10

*Multiple symptoms were reported by some patients

Table2. General information and scan parameters of convention and low-dose group

Group	Number	Gender		HC(cm)	Age(years old)	mAs
		M	F			
Convention	15	10	5	54.30±0.82	10.60±1.33	250
Low-dose						
A	22	11	11	56.00±0.24	13.14±0.60	200
B	24	14	10	52.98±0.20	8.17±0.65	150
C	22	12	10	49.54±0.23	3.55±0.38	100

Table 3. Grading scale for subjective image quality

Reader Score	Noise	Artefacts	Anatomical details and lesion
5	no image noise	no artefacts	clearly
4	minimum image noise	minimum	owed clear details and lesion
3	less average noise	artefacts	owed clear details, lesion appeared well
		artefacts are	identification of anatomical details was difficult, lesions
2	above average noise	obvious	shown were not clear
		but acceptable	unable to identify detail and lesions
1	unacceptable image noise	artefacts	
		affecting	
		diagnostic	
		information	
		no applicable	

Table 4. Comparison of radiation doses of sensitive organs of pediatrics with brain CT in convention and low-dose group

Group	Number	Brain	Eye lens	Salivary glands
Convention	15	34.37±3.62	41.54±1.04	35.04±4.94
Low-dose				
A	22	25.91±0.99*	33.03±0.35*	25.92±0.99*
B	24	23.18±6.11*	26.18±2.72*	22.93±6.54*
C	22	17.38±3.23*	20.88±4.45*	14.96±2.67*

*: Compare with convention group; All P<0.05

Table 5. Subjective image quality score of patient with head CT between convention and low-dose group

Group	Number	Reader Score					Mean Score	*P* value
		5	4	3	2	1		
Convention	15	15	0	0	0	0	5.00±0.00	□
Low-dose								
A	22	20	2	0	0	0	4.90±0.49	0.389*
B	24	17	7	0	0	0	4.67±0.49	0.097*
C	22	7	11	4	0	0	4.13±0.61	□0.001*

*□Compare with convention group

Table 6. Comparison of mean CT density, SD and SNR of thalamus and centrum ovale in convention and low-dose group

Group	Number	CT density(HU)		SD		SNR	
		THAL	CO	THAL	CO	THAL	CO
Convention	15	37.61±3.50	26.76±2.21	2.09±0.42	1.58±0.28	18.68±3.56	17.47±3.73
Low-dose							
A	22	37.84±3.43	26.87±2.20	2.33±0.46	1.98±0.29	16.77±2.88	15.55±2.82
B	24	37.47±3.67	26.29±2.11	2.58±0.51	2.02±0.31	15.06±2.81	13.72±2.43
C	22	38.17±3.23	26.97±2.15	2.89±0.57	2.34±0.37	13.66±2.54	11.78±2.19
P value		0.43	0.02	0.11	0.07	0.54	0.19

Note: THL indicates thalamus; CO indicates centrum ovale

Figures

Figure 1

ROI was selected in bilateral thalamus and centrum ovale

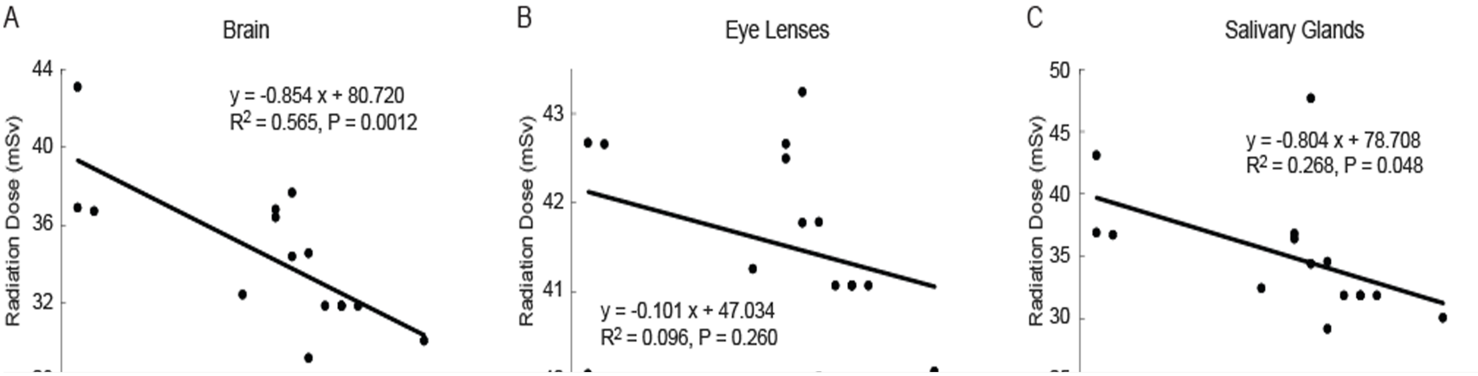

Figure 2

Relationship between head circumference and radiation doses of sensitive-organ in convention group. A brain B eye lens C salivary glands

Supplementary Files

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- formula1.JPG