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ORIGINAL ARTICLE

Multicentre Audit of Paediatric Brain Computed Tomography Dosage in Hong Kong: the Common Mistakes We Make

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ABSTRACT

Objective: *By auditing paediatric brain computed tomography (CT) performed in four Hong Kong centres, dosage values were obtained to address local practice and suggest improvements.*

Methods: *This was a retrospective review of plain CT brain studies on patients aged 16 years or below performed in four Hong Kong hospitals. During the 3-month audit periods in 2010 to 2011, patient demographic data and CT dosage using CT dose index volume ($CTDI_{vol}$) and dose-length product (DLP) as measures were recorded for each paediatric brain CT case in each participating centre. Subgroup analyses (age of <1, 1-5, 6-10, 11-16 years) with mean, standard deviation, and third quartile were performed.*

Results: *Altogether 463 CTs from the four centres were studied. Overall mean and third quartile results for $CTDI_{vol}$ and DLP in each age-group were generally comparable to international standards. However, excessive dosages were occasionally noted in individual age-groups or centres. In all, 47 (10.2%) of the CTs entailed excessive dosages, with repeated scanning due to motion artefact being the commonest reason. Incorrect use of adult (instead of paediatric) CT protocols, and excessive scan ranges (outside the region of interest) were also frequent mistakes. In one centre, significantly increased dosages were detected immediately after the installation of a new CT machine.*

Conclusions: *Our results highlight the importance of adequate sedation in the paediatric age-group. Strict adherence to paediatric protocols and narrowing the scan range should also be emphasised. Departmental imaging protocols should be regularly reviewed to monitor dosage, especially after installation of a new CT scanner.*

Key Words: *Child; Radiation dosage; Risk assessment; Tomography, X-ray computed*

中文摘要

於香港多個中心進行有關兒童腦部計算機斷層掃描劑量的審核：常見錯誤

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目的：於香港四所小兒腦部計算機斷層掃描（CT）中心進行劑量審計，以了解本地醫院的表現，並提出改善的建議。

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方法：回顧研究於四家香港醫院接受腦部CT平掃的16歲或以下的兒童。從2010到2011年的三個月審計期限，於每所中心找出有關病人人口數據的資料，記錄容積CT劑量指數（$CTDI_{vol}$）和劑量長度乘積（DLP）以作為輻射劑量的評估參數。然後進行亞組分析（即年齡為<1、1-5、6-10、11-16歲）找出平均值、標準偏差和第三四分位數。

結果：研究了四所中心共463個腦CT掃描。$CTDI_{vol}$和DLP在各年齡組別的總平均值和第三四分位數值均與國際標準大致相若。可是偶爾會發現在個別中心或年齡組別中有超劑量的情況。共47（10.2%）個病例牽涉超劑量，最普遍的原因是由於運動偽影而需重複掃描。此外，錯誤使用成人方案（而非小兒方案）以及掃描範圍過大（超出感興趣區），也是常見的錯誤。亦有一所中心在安裝新CT機後出現輻射劑量明顯加大的例子。

結論：研究結果顯示在兒童組別中使用足夠的鎮靜劑很重要。並應強調嚴格遵守使用小兒模式及縮小掃描範圍。應定期審視部門的CT掃描方案以監測輻射劑量，特別是在安裝新CT掃描儀器後。

INTRODUCTION

The use of computed tomography (CT) for clinical diagnosis and follow-up in paediatric patients has increased rapidly over recent years.[1] At the same time radiation doses associated with CT have also raised health concerns,[2-7] in particular there had been much publicity about the potential risk of developing cancer in the future. Paediatric CT dosage monitoring and regulations are therefore critical to safeguarding the health and safety of such patients. Previous international studies had identified reference values for CT radiation doses.[8-11] There is, however, a lack of local reference data for comparison. In this study, we therefore compared radiation dosages used for paediatric CT brain examinations in four Hong Kong centres. Our study aimed to (1) calculate corresponding mean dosage values, (2) compare dosage values used in the different centres, and (3) formulate recommendations to minimise unnecessary radiation.

METHODS

The radiology departments in four Hong Kong hospitals took part in this audit. The four centres were named: A, B, C, and D. For each centre, a 3-month period during the years 2010 to 2011 was randomly chosen for audit. For centres A and B, the audit period was conducted in May to July 2011, for centre C, the period was October to December 2010, and for centre D it was September to November 2011. Only non-contrast brain CT was audited in our study.

Inclusion Criteria

From the Radiology Information System and picture archiving and communication system of each centre, all patients aged ≤16 years having a plain brain CT performed within the audit period were included.

Exclusion Criteria

CT scans with more than one region being imaged in the same study were excluded, as were studies with incomplete dosage information.

Methodology

Patient demographic data, CT dosage using a CT dose index volume ($CTDI_{vol}$) and dose-length product (DLP) as measured were recorded for each case. Subgroup analysis (aged <1, 1-5, 6-10, 11-16 years) with mean, standard deviation of and third quartile values were performed for each centre. Data from all four centres were then combined for overall analysis. Overall results together with results from individual centres were compared to international standards. $CTDI_{vol}$ and DLP values from individual cases were also compared with the diagnostic reference level (DRL). A value higher than the DRL was considered as excessive dosage for

Table 1. Various computed tomography (CT) scanning parameters used by different centres in this study.

Centre / age-group (years)	kV	mA	Noise index
A			
0-1	120	100	N/A
>1	120	<220	N/A
B			
0-2	100	150	N/A
3-5	100	250	N/A
6-12	120	250	N/A
>12	120	250	N/A
C			
0-5	120	Smart mA	5.0
>5	120	Smart mA	6.0
D			
0-12	100	Smart mA	4.0
>12	120	Smart mA	3.5

Abbreviations: N/A = noise index was not applicable since dose modulation was not used; Smart mA = mA value auto-adjusted by CT machine.

that patient.

All the studies in centre A were performed using a 16-slice Philips Brilliance CT machine (Philips, Cleveland, USA), while a 64-slice Toshiba Aquilion CT (Toshiba, Nasu, Japan) was utilised in centre B. Centres C and D used 64-slice GE LightSpeed VCT machines (GE; Milwaukee, USA). The step-and-shoot technique was used as a scanning protocol in most of the studies in every centre, following paediatric CT protocols set up by individual centres. Major CT scanning parameters used in different centres are summarised in Table 1.

RESULTS

Altogether 463 patients were the subjects of our audit from the four centres; 88 were aged <1 year, 122 were aged 1 to 5 years, 100 were aged 6 to 10 years, and 153 were aged 11 to 16 years old. The mean age of the patients was 7 years.

Table 2. Dosage statistics for paediatric plain brain computed tomography (CT) studies, including CT dose index volume ($CTDI_{vol}$ in mGy) and dose-length product (DLP in mGycm) values in different age-groups for individual and all centres.

Age-group		Mean	Standard deviation	3rd Quartile	Range
<1 year					
Centre A	$CTDI_{vol}$	19.8	5.3	22.8	5.6 - 27.7
	DLP	247.7*	101.3	273.5	53.8 - 574.4
Centre B	$CTDI_{vol}$	21.3	10.5	17.1	17.1 - 42.7
	DLP	322.6†	179.5	268.8	241 - 688
Centre C	$CTDI_{vol}$	17.0	1.2	17.8	15.0 - 19.2
	DLP	220.1*	69.5	229.6	151.6 - 428.3
Centre D	$CTDI_{vol}$	22.2	6.4	25.6	14.3 - 42.5
	DLP	277.1†	68.8	309.9*	142.8 - 433.9
All centres	$CTDI_{vol}$	19.7	5.6	22.8	5.6 - 42.7
	DLP	253.0*	95.9	273.5	53.8 - 688
1-5 years					
Centre A	$CTDI_{vol}$	19.5	5.3	22.8	6.9 - 27.7
	DLP	264.8	83.2	299.5	79.5 - 398.3
Centre B	$CTDI_{vol}$	35.7*	12	42.7	17.1 - 42.7
	DLP	556.4†	194.9	677.3†	232.5 - 709.4
Centre C	$CTDI_{vol}$	21.6	3.5	24.1	15.2 - 19.2
	DLP	341.3	158.5	360.0	217.9 - 1158.7
Centre D	$CTDI_{vol}$	20.5	1.9	21.3	17.9 - 24.0
	DLP	294.7	23.0	302.1	270.6 - 342.5
All centres	$CTDI_{vol}$	21.9	7.0	24.0	6.9 - 42.7
	DLP	323.2	150.6	355.8	79.5 - 1158.7
6-10 years					
Centre A	$CTDI_{vol}$	22.5	4.5	27.6	12.5 - 27.7
	DLP	308.4	78.0	398	89.8 - 398.6
Centre B	$CTDI_{vol}$	60.1†	0	60.1†	60.1 - 60.1
	DLP	980.9†	54.2	1013.3†	908 - 1088.4
Centre C	$CTDI_{vol}$	20.4	3.9	22.2	13.5 - 30.0
	DLP	330.0	156.7	340.4	188.7 - 828.2
Centre D	$CTDI_{vol}$	34.2	15.4	48.4	18.1 - 57.7
	DLP	533.0*	247.8	779.1†	274.3 - 923.6
All centres	$CTDI_{vol}$	27.6	13.9	27.7	12.5 - 60.1
	DLP	417.7	249.6	398.4	89.8 - 1088.4
11-16 years					
Centre A	$CTDI_{vol}$	27.1	1.7	27.7	20.8 - 27.7
	DLP	382.6	45.3	398.4	249.2 - 537.8
Centre B	$CTDI_{vol}$	50.8†	5.9	56*	34.2 - 56
	DLP	918.6†	147.9	1020.5†	550.4 - 1209.6
Centre C	$CTDI_{vol}$	24.2	6.6	26.8	10.9 - 29.3
	DLP	360.1	120.1	398.2	153.1 - 776.6
Centre D	$CTDI_{vol}$	58.3†	3.5	59.8*	51.5 - 64.2
	DLP	954.1†	239.5	948.9†	753.6 - 1635.3
All centres	$CTDI_{vol}$	31.0	11.6	27.7	10.9 - 64.2
	DLP	473.1*	238.7	402.4	153.1 - 1635.3

* Mean/3rd quartile value greater than that in Belgium study but the difference was <20%.

† Mean/3rd quartile value greater than that in Belgium study by >20%.

All 463 cases from the four centres were first analysed together for combined results and values. Their respective mean, standard deviation, and third quartile results for the $CTDI_{vol}$ and DLP for each age-group (<1, 1-5, 6-10, and 11-16 years), and the respective values in each centre are summarised in Table 2.

According to the individual centre analysis, there were 217 cases in centre A, 44 in centre B, 148 in centre C, and 54 in centre D. The mean ages of the patients in the respective centres were 7.6, 7.9, 6.0, and 5.3 years. The composition of cases at each centre according to age are summarised in Table 3.

DISCUSSION

In daily practice, CTDI and DLP are convenient and easily obtained measures of CT radiation dose. CTDI represents the dose of a single CT slice and is determined using acrylic phantoms, while the weighted CTDI ($CTDI_w$) reflects the weighted sum of 2/3 peripheral dose and 1/3 central dose in a 100-mm range acrylic phantom. $CTDI_{vol}$ is the ultimate dose descriptor of CT from one tube rotation, since it represents the average value of the $CTDI_w$ throughout the volume scanned in a particular sequence.[12] It quantifies the relative intensity of the radiation that is incident on the patient.[13] Additionally, it takes into account gaps or overlaps between the radiation beams from contiguous rotations of the X-ray source.[14]

The product of $CTDI_{vol}$ and scan length is the DLP, which can be used to quantify the total amount of radiation patients receive during a given scan.[13] DLP is independent of what is actually scanned, if scanning parameters are unchanged. Monitoring of the DLP provides control over the volume of irradiation and the overall exposure from an examination.

Using conversion factors, the dose may be estimated from the DLP. However, conversion factors are problematic as they are only estimates and do not represent the full range of patient body size especially paediatric sizes. More accurate determination of the effective dose requires individual organ doses, which is obviously not practical for daily CT. As a result, $CTDI_{vol}$ and DLP are still currently the most widely used parameters to monitor radiation dosage. The $CTDI_{vol}$ represents the average dose from one tube rotation and is an excellent parameter for assessment of differences in technique parameters between centres such as tube current, beam collimation, and tube voltage. It is particularly useful for comparison between different scan protocols and different scanners.[15] The DLP is derived from the $CTDI_{vol}$ and takes into account the scan length and number of sequences made.

From our study, overall dosage values and those from individual centres were calculated and categorised for different age-subgroups. These dosage values were compared to international standards. A multicentre study done in Belgium was used as reference (Table 4[10,15,16]). It was found that for the combined (all four centre) dosage values, $CTDI_{vol}$ values were lower than international standards in all age-groups, including average and third quartile values. For DLP values, the mean value for the <1-year group was 17% higher, and for the 11-16-year-old age-group it was 6% higher than the Belgium figures, but for both groups they were within one standard deviation. The DLP mean values for the 1-5-year-old and 6-10-year-old groups, and DLP third quartile values for all groups, were lower than the international standard. Thus, our combined figures appeared generally comparable with international figures.

Table 3. Case composition in this audit divided by different age-groups in each centre.

Centre	Age-group (years)					Mean age (years)
	<1	1-5	6-10	11-16	Total	
All centres	88	122	100	153	463	7.0
Centre A	33	55	48	81	217	7.6
Centre B	6	11	11	16	44	7.9
Centre C	27	48	28	45	148	6.0
Centre D	22	8	13	11	54	5.3

Table 4. Mean and third quartile values of paediatric brain computed tomography (CT) dosages from a Belgium multicentre study,[10] compared with local data in this study in Hong Kong (combined mean value from all four centres). Dose reference levels on paediatric brain CT dosages from a UK study in 2000[15,16] are also shown.

Age-group (years)	Belgium[10] (Median/3Q)		Hong Kong (Median)		UK (2000)[15,16]	
	$CTDI_{vol}$	DLP	$CTDI_{vol}$	DLP	$CTDI_{vol}$	DLP
<1	27 / 35	216 / 280	19.7	253.0*	40	300
1-5	32 / 43	352 / 473	21.9	323.2	60	600
6-10	36 / 49	468 / 637	27.6	417.7	70	750
>10	34 / 50	442 / 650	31.0	473.1*	60	1050

Abbreviations: $CTDI_{vol}$ = volume CT dose index; DLP = dose-length product; 3Q = third quartile.
* Mean value greater than that in the Belgium study.

When separate analyses were undertaken for individual centres, performance and dosage in different units varied quite significantly. Notably, Table 2 shows that in centre B, both the $CTDI_{vol}$ and DLP mean values consistently exceeded international standards in most of the subgroups. For centre D, excessive mean dosage was occasionally evident in individual age-groups, while for centres A and C they were generally comparable to international standards.

Individual cases with dosages exceeding the DRLs were identified, and the reasons investigated. The general trend and major reasons for excessive dosages in different centres were also compared. In our study, DRLs from a UK study published in 2000[16] were employed for reference purposes (Table 4). It is noted that in this UK study, DRLs for children aged 11 or above were referred to the European Guidelines published in 2000.[15]

Firstly, in centre A, six (2.8%) out of 217 studies entailed excessive dosage, all of whom belonged to <1 year age-group. Excessive DLPs were detected in all of them, while their corresponding $CTDI_{vol}$ values were all within normal limits. Five of these six patients had repeated scanning due to excessive motion in the first sequence causing non-interpretable images. The adult scanning protocol was incorrectly employed in the remaining one case.

In centre C, seven (4.7%) of the 148 studies entailed excessive dosages, of which four belonged to the <1 year age-group, two to the 1-5 years age-group, and one to the 6-10 years age-group. All of them had excessive DLP but normal $CTDI_{vol}$ values. All seven of these cases were associated with repeated scanning performed to overcome motion artefacts. Five of them had two sets of images scanned, one had three sets, and one even had four sets.

Regarding the 54 CT brain studies performed in centre D, the DLP values in 11 (20%) exceeded the DRL, in one (1.9%) study the $CTDI_{vol}$ value exceeded the DRL. In no instance did both the $CTDI_{vol}$ and DLP values exceed the DRL. When divided according to different age-groups, percentages entailing dosage values exceeding the DRL were 27%, 0%, 31%, and 18% for age-groups of <1, 1-5, 6-10 and 11-16 years, respectively. In the age-group of <1 year, the DLP value exceeded the DRL in six out of 22 patients. The two examinations with highest DLP values were performed for a clinical diagnosis of craniosynostosis, therefore a helical scanning technique instead of the step-and-shoot technique was deployed. In the other four studies, the setting of the scan range was excessive (outside the region of interest). In the age-group of 6-10 years, DLP values exceeded the DRL in four instances. Not only the adult brain CT protocol was used incorrectly in all four cases, but also one of the patients underwent a repeat scan because of motion artefacts, whilst the scan range for the other three studies were also excessive (outside the region of interest). In the age-group of 11-16 years, the DLP value was above the DRL in one study; this scan was repeated due to motion artefact. In the single case in which the $CTDI_{vol}$ exceeded the DRL, the scan range included the region below skull base and was therefore deemed excessive.

Notably, the general dosage values from centre D, including those for subgroups not exceeding the DRL, were consistently on the high side, and yielded statistically significant differences when compared to those from centres A and C and the overall values. One reason was that centre D used a lower noise index value (set as 3.5 to 4.0) for their paediatric brain CT studies, while it was set as 5.0 or 6.0 in centre C. Reducing the noise-to-signal ratio improves image quality and diagnostic power, but the higher dosage involved is a drawback. Notably, although the number of paediatric beds in hospital D was higher than that in hospital C, the number of paediatric CT brain studies it performed were significantly fewer than in centre C. There was great awareness about the risks of radiation among the paediatricians in hospital D, hence only patients with specific indications were referred for CT. On the contrary, CT was regarded as a more general screening tool in hospital C, which also had a higher case load and higher negative scan rate. This illustrates the importance of cooperation and negotiations between clinicians and radiologists so as to obtain an appropriate balance of the number of referred cases, image quality, and radiation dosage. Sometimes limiting the number of CTs by careful selection of cases may even justify higher individual radiation dosages whilst sparing many others from indiscriminate exposure.

Among the four centres included in this study, centre B undertook the greatest number of CTs involving excessive dosages. Among these, 22 (50%) exceeded the reference levels, including 8 (73%) of 11 of the studies in the 1-5 years age-group and all 11 in the 6-10 years age-group. The overall dosage was consistently

Table 5. Number of studies with different reasons causing excessive dosage in different centres. It was noted that two contributing factors to the excessive dosage were identified in four studies in centre D.

Reason	Centre A	Centre B	Centre C	Centre D
Excessive scan range	0	0	0	8*
Adult protocol employed	1	0	0	4
Repeat scan due to motion artefact	5	0	7	2
Helical protocol employed for craniosynostosis	0	0	0	2
Suboptimal departmental scanning protocol	0	22	0	0

* Of these eight studies, dose-length product was elevated in seven studies, while computed tomography dose index volume was elevated in one study.

high. During the evaluating period, a new CT machine had just been installed, and initially the unit used imaging protocols recommended by the vendor, which might not have been optimal in terms of radiation safety. As radiologists, we have a responsibility to keep radiation exposure as low as reasonably achievable, and not rely on the vender's recommendations only. This requires regular monitoring and the conduct of audits. If the dosage appears excessive, the protocol should be reviewed and adjusted accordingly. Following the current audit, centre B made adjustments to tail down CT dosages, thus rectifying the problem at an early stage. A re-audit could be conducted after protocol adjustments.

Table 5 summarises the various reasons for individual CT studies resulting in excessive dosages in the different units. Motion artefacts were the major problem in centres A and C, which highlights the importance of adequate sedation to eliminate the need for repeat scans. Excessive scan ranges (outside the region of interest) were the major reason in centre D. This too was partly related to inadequate sedation, since one of the ways to overcome the problem of scanning unsettled children moving in the scanner was to set a larger scan range. Besides administering adequate sedation, staff should also try to limit the scan range to the minimum that is appropriate. Incorrect employment of adult protocols in paediatric patients, and recourse to helical scanning for the diagnosis of craniosynostosis were the second and third most common problems in centre D. Strict adherence to paediatric brain CT parameter should be repeatedly emphasised to every on-duty radiographer. For the assessment of craniosynostosis, the region of interest should be the calvarium rather than intracranial structures. Reducing the dose by increasing the noise index and decreasing the kV could be applied.

A major limitation of this study was the relatively small sample of patients; only 463 scans from four centres were included. Some centres had relatively small paediatric case loads. Moreover, with a small total patient number, abnormally high exposure values from a single centre may distort overall average values. To obtain a more comprehensive assessment of trends and patterns of paediatric CT dosing in Hong Kong, a larger study with greater numbers of cases and radiological units, and a longer evaluation period appears necessary.

CONCLUSION

This audit of paediatric plain brain CT imaging in four Hong Kong centres showed that the dosage values used were generally comparable to international standards. Excessive radiation dosage was observed in individual centres and individual examinations, most of which appeared avoidable. To safeguard public health and implement strict radiation protection, additional measures should include staff education and regular radiation monitoring in order to ensure that ionising radiation exposure remains as low as reasonably achievable.

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