Dose monitoring in pediatric and young adult head and cervical spine CT studies at two emergency duty departments

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Abstract

Purpose

As the number of pediatric computed tomography (CT) imaging is increasing, there is a need for real-time radiation dose monitoring and evaluation of the imaging protocols. The aim of this study was to present the imaging data, patient doses, and observations of pediatric and young adult trauma—and routine head CT and cervical spine CT collected by a dose monitoring software.

Methods

Patient age, study date, imaging parameters, and patient dose as volume CT dose index ($\mathrm{CTDI}_{\mathrm{vol}}$) and dose length product (DLP) were collected from two emergency departments' CT scanners for 2-year period. The patients were divided into four age groups (0–5, 6–10, 11–15, and 16–20 years) for statistical analysis and effective dose determination. The 75th percentile doses were evaluated to be used as local diagnostic reference levels (DRLs).

Results

Six hundred fifteen trauma head, 318 routine head, and 592 trauma cervical spine CT studies were assessed. All mean $\mathrm{CTDI}_{\mathrm{vol}}$ values were statistically lower in hospital B (40.3 ± 12.3, 30.03 ± 11.1, and 6.9 ± 3.1 mGy, respectively) than in hospital A (53.0 ± 12.9, 43.2 ± 8.7, and 18.3 ± 7.3 mGy, respectively). Statistically significant differences were observed on scanning length between hospitals and between $\mathrm{CTDI}_{\mathrm{vol}}$ values when protocol was updated. The 75th percentiles of trauma cervical spine in hospital B can be used as local DRL. Non-optimized protocols were also revealed in hospital A.

Conclusion

Dose monitoring software offers a valuable tool for evaluating the imaging practices and finding non-optimized protocols.

Keywords

Non-optimized protocols
Computed tomography
Diagnostic reference levels
Dose monitoring software

Electronic supplementary material

The online version of this article (https://doi.org/10.1007/s10140-017-1571-x) contains supplementary material, which is available to authorized users.

Introduction

The lifetime cancer mortality risk attributable to radiation from a computed tomography (CT) examination is estimated to be considerably higher for children than for adults [1]. With increasing patient exposure, an increase in cancer incidence has been reported. Cancer incidence rate was reported as 24% higher for the exposed patients when compared to a non-exposed control group [2]. Further, Pearce et al. reported pediatric head CT scanning to be associated with an increased risk of developing brain cancer and leukemia [3]. Yet, the use of CT in pediatric population has increased during the last decades [4, 5].

Because of the detrimental effects of radiation and the increased use of CT, there is a need for optimization, which is also known as ALARA (as low as reasonable achievable) principle. Diagnostic reference levels (DRLs) are one such optimization tools, as they assist to recognize too high doses that do not contribute to the clinical purpose of a medical imaging task [6]. The DRLs are defined as dose levels in diagnostic medical imaging for groups of standard-sized patients or standard phantoms for broadly defined types of equipment [7]. The DRLs are usually set on 75th percentile [8, 9, 10] on a national or local level [11]. The local DRLs are set by collecting dose data for a specific CT scanner, and local DRLs are used as they can be more effective to recognize the unusually high doses with that specific scanner than the national DRLs [12]. Indeed, there has been observed substantial deviation in doses with different CT scanners even within same indication and patient group although the doses are lower than the DRLs [13, 14, 15]. This large scale of doses implies the need for local DRLs.

The use of national or local DRLs in pediatric patients is challenging for many reasons. The DRLs for pediatrics are not widely used, although the use and the establishment of DRLs are endorsed by many professional and regulatory organizations, or even obligated like in European Union [7, 16]. Further, the DRLs are usually not indication based [17]; they are set only to special body region, and they are dependent on patient size. As the pediatric examinations are uncommon compared to the adult CT examinations, there might also be difficulties in collecting enough patients for each age or size group during the clinical follow-up of DRLs.

Thus, to fulfill the ALARA principle, there is a need for repeated quality assurance including the use of DRLs and large-scale dose analysis with respect to CT scanners and indications for a specific patient group. Recently, the vendors have introduced their own software tools for automatic dose tracking systems, which offer a possibility to collect and process large amounts of data and export it for further statistical analyzing. However, there is only little experience of their use in pediatric imaging.

The purpose of the present study was to assess and compare the doses of pediatric head and cervical spine CT at two different emergency departments and introduce the data collected by a dose monitoring software. The radiation doses of routine and trauma head CT were collected, because trauma is a common indication for CT study and head CT is the most frequently used for pediatric imaging [18]. If extension-flexion trauma is suspected and magnetic resonance imaging is not possible, the cervical spine CT is exploited. Thus, the trauma cervical spine CTs were assessed along head CTs [19, 20]. In addition, we determined 75th percentiles for different studies and age groups to be considered as local DRLs and compared our 75th percentiles to other established pediatric DRLs.

Materials and methods

The data on consecutively scanned patients was collected retrospectively at 23 June 2016 from two emergency departments on the same hospital district for 2-year period from 1 June 2014 to 1 June 2016 by using the DoseWatch software (GE, WI, USA). The scanners used were Definition Dual Flash (Siemens, Erlangen, Germany) and Aquilion One (Toshiba, Otawara, Japan), and the corresponding emergency departments are later referred as hospital A and hospital B. The scanners send the dose data including the volume computed tomography dose index ($CTDI_{vol}$) and dose length product (DLP) together with imaging parameters and protocol names automatically to DoseWatch. The data was exported further to Excel (Microsoft Office, WA, USA) by selecting specific scanner and time period from DoseWatch.

The data from pediatric and adolescent trauma head CT, routine head CT, and trauma cervical spine CT was collected and categorized to age groups of 0–5, 6–10, 11–15, and 16–20 years. The data consisted of patient age, study date, protocol name, series description, scanning length, $CTDI_{vol}$, and DLP. The effective dose was calculated from DLP by using age-specific conversion factors (see Table 1) presented by Shrimpton et al. [21]. The minimum, maximum, mean, and the DRL as a third quartile [17] for doses were determined for each age group for the chosen studies. As the doses of head and cervical spine CT studies are not dependent on the weight or height of the patient, the DRLs were set for the different age groups [22]. According to the legislation in Finland, approval from local ethical committee was not required [23] and the permission from Institutional Review Board sufficed, as the data was analyzed without identification information. For this type of study, formal consent is not required.

Table 1

Conversion factors (mSv/mGycm) for head and neck region to calculate effective doses for different age groups [21]. Conversion factors are for $\mathrm{CTDI}_{\mathrm{vol}}$ values determined with a 16 diameter phantom. Conversion factors for adults were used for age 15 and older

	0 year	1 year	5 years	10 years	Adult
Head	0.011	0.0067	0.0040	0.0032	0.0021
Neck	0.017	0.012	0.011	0.0079	0.0059

Association between $\mathrm{CTDI}_{\mathrm{vol}}$, independent variables, and study date (a variable which indicated whether study was made before or after a parameter change at 12 May 2015) was studied with descriptive statistics, two independent sample *t* tests, analysis of variance, and mixed linear models. Independent variables were defined as a device, age group, indication, and scanning type (volume or spiral). The normality of the distribution of variables was evaluated visually and tested with Shapiro-Wilk test. Differences in $\mathrm{CTDI}_{\mathrm{vol}}$ values between the two groups in categorical variables were tested with two independent sample *t* tests. Categorical independent variables with more than two groups were examined with analysis of variance. Main statistical analyses for $\mathrm{CTDI}_{\mathrm{vol}}$ were performed using mixed linear model. Age class and age class variable’s interaction with other independent variables were included as factors in all models. Other independent variables were used in models separately. Interactions examined whether mean change in age groups was different between other independent variable groups. Also scanning length was used as dependent variable to study difference between devices and age groups. Statistical significance level was set at 0.05 in all tests (two-tailed). The analyses were performed using SAS system, version 9.4

for Windows (SAS Institute Inc., Cary, NC, USA).

Results

Data of 1526 pediatric CT studies including 615 trauma head, 319 routine head, and 592 cervical spine CT studies was collected. The imaging parameters are shown in Table 2 (Supplementary Material) together with the mean $\mathrm{CTDI}_{\mathrm{vol}}$ values. The dose distributions are presented as a bar graph in Fig. 1, and Fig. 2 shows the $\mathrm{CTDI}_{\mathrm{vol}}$ as a function of patient age and study date.

Fig. 1

The $\mathrm{CTDI}_{\mathrm{vol}}$ dose distributions of trauma head (**a**), routine head (**b**), and cervical spine (**c**) CT studies at both hospitals

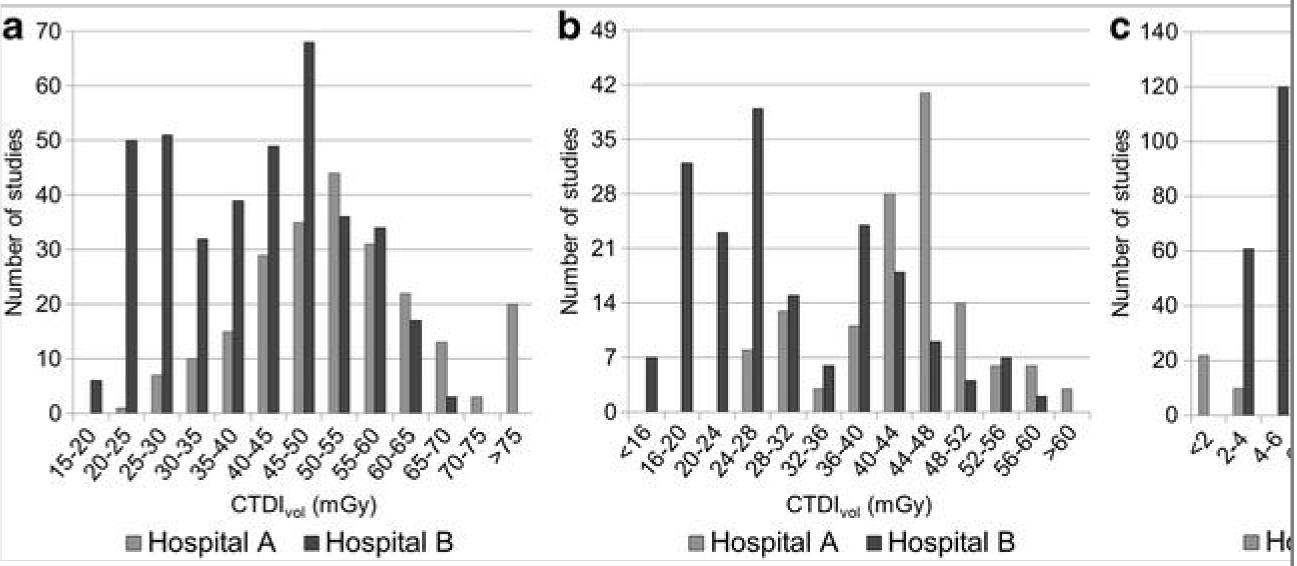
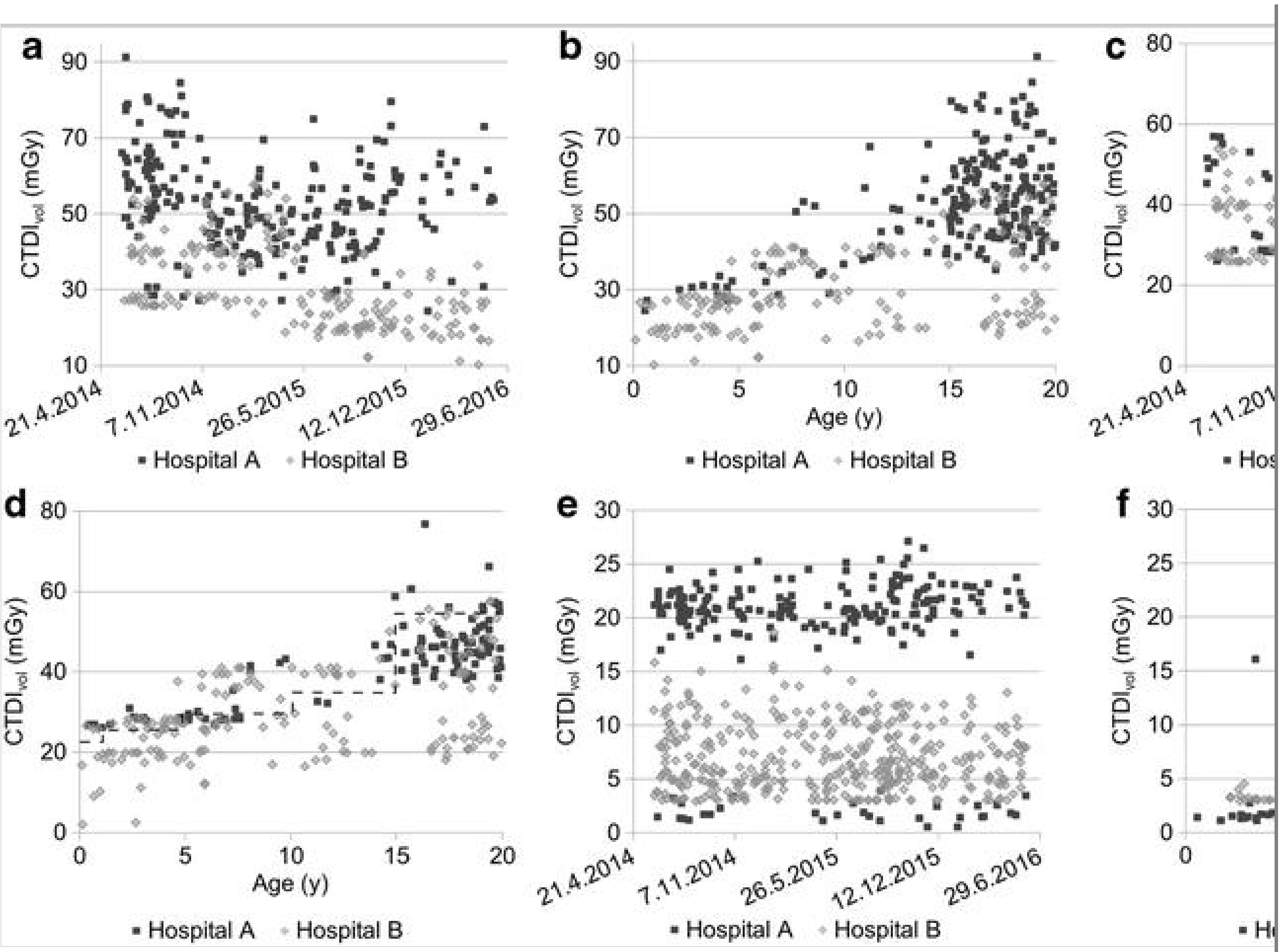


Fig. 2

Scatter plots of trauma head (**a**, **b**), routine head (**c**, **d**), and cervical spine (**e**, **f**) CTs as function of examination date and patient age. The national DRLs are marked as a function of age with dashed line [24, 25]



AQ1

Figure 1a shows CTDI$_{vol}$ values of the trauma head CT, where mean CTDI$_{vol}$ (± standard deviation, SD) was statistically significantly ($p < 0.001$) lower in hospital B (40.3 ± 12.3 mGy) than in hospital A (53.0 ± 12.9 mGy). The doses increased with age ($p < 0.001$), and the increase was similar between the age groups at both hospitals ($p > 0.05$). The mean doses from youngest to oldest age groups can be seen in Table 2 (Supplementary Material).

The trauma head CT doses were statistically higher ($p < 0.001$) than routine head CTs in both hospitals. The mean routine head CT doses were 30% higher in hospital A (43.2 ± 8.7 mGy) than in hospital B (30.0 ± 11.1 mGy) ($p < 0.001$). The routine head CT doses increased significantly with age ($p < 0.001$) like trauma head CTs, but there was significantly ($p = 0.003$) higher increase in patient doses by age in hospital A (see Table 2 in Supplementary Material). The mean routine head CTDI$_{vol}$ values exceeded the national DRLs (25, 29, 35, and 55 mGy for age groups 1–5, 5–10, 10–15, and > 16 years, respectively [24, 25]) among patients younger than 16 years in hospital A. The same protocols were mainly used for routine head CT as with trauma head, but for the three youngest age groups, a volume scanning was also adopted together with spiral scanning. With same age group, the CTDI$_{vol}$ doses were higher ($p < 0.001$) with volume scanning than spiral (see Table 2 in Supplementary Material).

The distribution of trauma and routine head CT doses was uneven (Fig. 1a, b). As shown in Fig. 2a, c, the doses decreased in hospital B. There was a change in trauma head CT protocol parameters in May 2015, where the iterative reconstruction level was changed from standard to strong and the input value of the tube current modulation (SD) was increased from value 2.3 to 3.0 in order to decrease the doses. After the protocol change, the mean dose was significantly lower ($p < 0.001$, 30.0 ± 7.8 mGy) compared to dose before the change (50.4 ± 7.2 mGy). The SD value was later (November 2015) decreased from value 3.0 to 2.8, when the CTDI$_{vol}$ was 32.5 ± 7.5 mGy ($p = 0.04$). The total reduction of the mean CTDI$_{vol}$ in the trauma head protocol from was no less than 35.5%.

The mean CTDI$_{vol}$ of trauma cervical spine CT was 62% lower in hospital B (6.9 ± 3.1 mGy) than in hospital A (18.3 ± 7.3 mGy) ($p < 0.001$). The dose increased with age ($p < 0.001$), and the increase ($p < 0.001$) was stronger in hospital A (see Table 2 in Supplementary Material). There was a threefold increase in trauma cervical spine CT doses associated with the age of 10 in hospital A (Fig. 2f). The wide range and deviation of doses are shown in Figs. 1c and 2e.

The 75th percentiles (CTDI$_{vol}$) for each age group are presented in Table 2 together with the DRLs found in the literature. The determined 75th percentiles of both hospitals exceeded the national DRLs of routine head CT.

Table 2

Our 75th percentiles of CTDI$_{vol}$ in hospitals A and B compared to the DRLs foun
literature. The percentile is presented, if there were more than 10 patients for analysis.
the updated protocols of hospital B are considered, and the age group of 16–20 yea
considered as adults

		< 1 year	1–5 years	6–10 years	11–15 years	16–20 yea
Trauma head CT	Hospital A		30.8	50.4	57.0	62.9
	Hospital B				39.5	39.6

[a]The ages below 16 years are scanned with volume scanning and ages above 16 with spiral scanning

		< 1 year	1–5 years	6–10 years	11–15 years	16–20 yea
	Australia, New Zealand [26]	28.7	32.7	35.9	42.2	
	Switzerland [27]	20	30	40	60	
	Belgium [28]	25	40	60		
	UK [29]	35	43	49	50	
Routine head CT	Hospital A		28.8	40.9	46.6	48.6
	Hospital B[a]		27.1	39.5	40.6	26.9
	Finland [24, 25]	23.0	25.0	29.0	35.0	55.0
	Portugal [30]	48.31	50	70	72.3	75
	Australia [31]	30	30	35	35	60
	French [32]	30	40	50	65	65
	Italy [33]		30.6	56.4	58.2	
Cervical spine CT	Hospital A		1.6	17.3	20.8	22.8
	Hospital B		3.3	3.8	7.9	10.5
	Portugal [30]					39
	UK [29]					28
	Ireland [34]					19

[a] The ages below 16 years are scanned with volume scanning and ages above 16 with spiral scanning

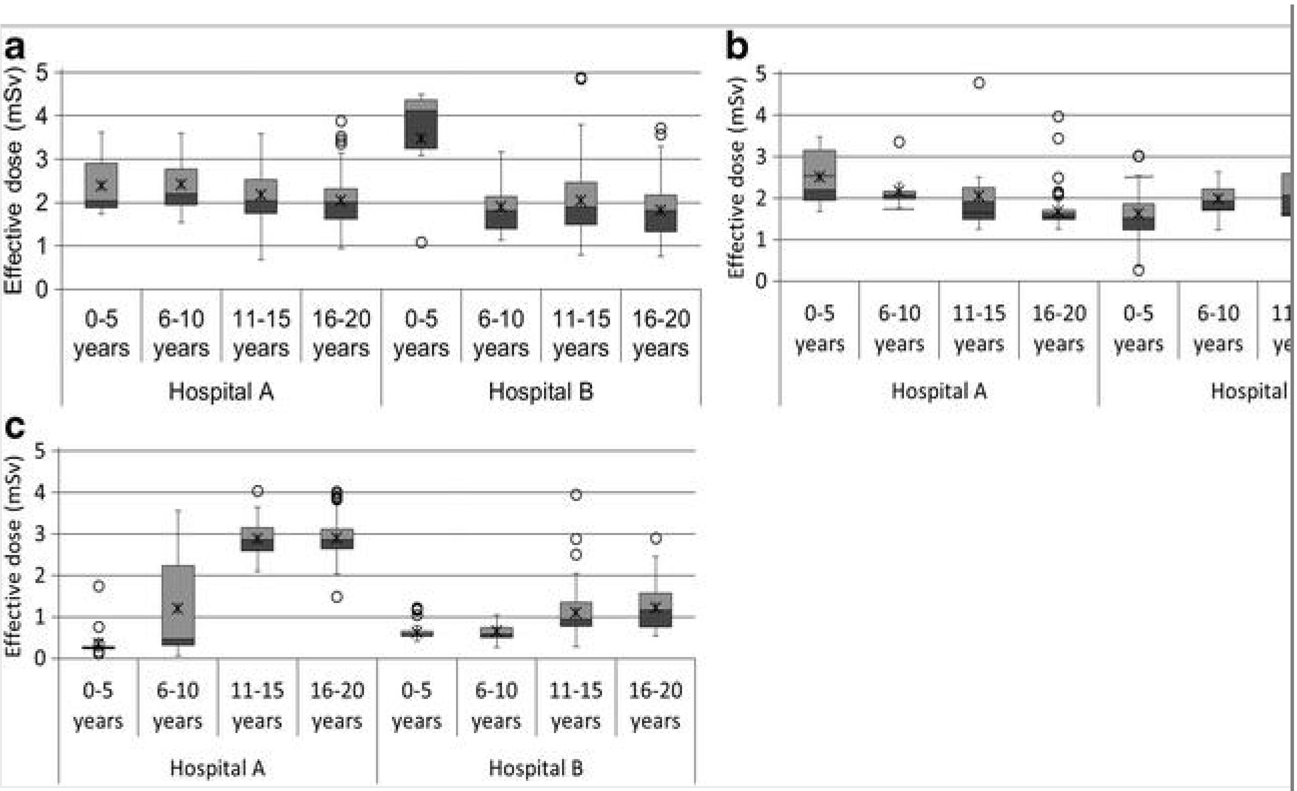
AQ2

The mean scanning lengths were significantly shorter ($p < 0.001$) in trauma head CT studies done in hospital B (175.0 ± 38.2 mm) than in hospital A (187.7 ± 22.3 mm). The age had significant impact on scanning length ($p = 0.012$), but the scanning lengths did not solely increase with age, as the youngest groups have longer scanning length than the older ones (see Table 2 in Supplementary Material). Similarly with trauma head CTs, the scanning lengths of routine head CT were longer ($p < 0.001$) in the hospital A (190.7 ± 21.2 mm) than hospital B (146.4 ± 17.9 mm). However, the age was not affecting the scanning length ($p = 0.52$) in routine head CTs. The scanning lengths of cervical spine CTs increased with age ($p < 0.001$) (Table 2 in Supplementary Material), and hospital A had longer scanning lengths than hospital B ($p < 0.001$).

The effective doses of whole study period are presented as a box plot in Fig. 3. The wide deviation of cervical spine CT doses in hospital A can be observed with effective doses. The mean effective doses of trauma head were similar (maximum difference 0.6 mSv) for all age groups on head CT studies except for the youngest group in hospital B. The high conversion factors of the youngest patients together with high-dose exposure resulted in high effective doses for patients in age group 0–5 years in hospital B. However, there was no significant association between age and effective dose.

Fig. 3

The effective doses presented as a box plot for **a** trauma head CT, **b** routine head CT, and **c** cervical spine CT for both hospitals and different age groups. The effective dose calculated from national DRLs is marked as a function of age with dotted line [21, 24, 25]. The mean values are presented with asterisk; the median is the line inside the box, and the upper and lower hinges of the box show the 75th and 25th percentile, respectively. The whiskers show minimum and maximum values, and circles express outliers. The point is an outlier, if the value is three halves times higher or lower than the hinges



Discussion

In this study, we reviewed dose register data, including pediatric head and cervical spine CT studies, and compared our patient doses to established pediatric DRLs. The dose data of over 1500 pediatric and young adult CT studies were assessed. The results revealed significant differences in doses between two emergency departments and imaging indications. Although pediatric patients are imaged relatively seldom, the reliable amount of data can be collected with dose monitoring software making also benchmarking possible.

The comparison of doses showed significantly lower doses in hospital B than in hospital A with all reviewed studies, and trauma head CT doses were higher than routine head doses. The reason for higher doses in trauma head CT scans is that radiologist prefers better image quality in trauma cases. After the head protocol adjustment in hospital B, the maximum difference in mean $\mathrm{CTDI}_{\mathrm{vol}}$ was 23 mGy between the hospitals. The probable reason for the dose differences between the scanners is the use of an iterative reconstruction in hospital B. The iterative reconstruction has shown to decrease the doses in head CT studies [35, 36], and indeed, the change of iterative reconstruction level together with moderate increase of tube current modulation input value decreased the doses significantly in hospital B. An alternative explanation might be the use of higher than necessary level of the tube current modulation in hospital A [37].

The volume scans have shown smaller doses on pediatric patients when used instead of spiral scanning [38, 39]. However, in this study, volume scans offered higher dose in hospital B due to the lower level of iterative reconstruction. Because volume scanning is used with younger patients, the level of iterative reconstruction should be set to strong level so that volume scan doses of pediatric patients are lower than spiral scan doses for adolescents. Another unexpected result was that the scanning length did not increase with age and the younger patients had longer scanning length than older ones. This may be caused by a scanning practice, where head and cervical spine are scanned in one scan with the smallest patients. The number of studies was too high to go all studies through and sort out the cases, where head and cervical spine have been scanned together. If this is the case, the protocol nomenclature should be reviewed and the protocol should be named according to the indicated study. Also, the scan lengths were longer in hospital A, which indicates that the practice needs to be updated to avoid unnecessary long scan lengths.

The determined 75th percentiles of both hospitals exceeded the national DRLs of routine head CT. Thus, those percentiles cannot be used as local DRLs, although the percentiles were comparable to the DRLs of other publications (see Table 2). This suggests that the current DRLs in Finland reflect contemporary practice well. Also, the 75th percentiles of trauma head CT were comparable to other published values, but as there were not enough patients of age groups 0–5 and 6–10 years in hospital B and the 75th percentiles of hospital A were relatively high, the 75th percentiles are not optimal for local DRLs.

The 75th percentiles of trauma cervical spine in hospital B can be used as local DRLs. A non-optimized practice of using an adult protocol in pediatric patients was revealed in hospital A, where the dose increased abruptly after the age of 10 years. The lack of DRLs together with relatively low number of patients may lead to situation, where the doses are not routinely assessed. In this case, it led to situation, where the ALARA principle was not fulfilled for patients older than 10 years. The use of adult protocol in pediatrics should be avoided, because pediatrics need own practices to achieve optimized CT study [34, 40]. Thus, there is a clear need for a dose monitoring system, which can reveal these incidences. De Bondt et al. have also reported similar results, where dose monitoring software showed several pediatric head CT studies performed erroneously with an adult protocol [41].

The low number of young patients is a challenge when reviewing radiation doses. Although the data collection period was 2 years, there were only a few patients in the youngest age group. As there were distinct protocols used in hospital B, the low number of patients affected the mean $\mathrm{CTDI}_{\mathrm{vol}}$ values. The mean $\mathrm{CTDI}_{\mathrm{vol}}$ of the age group 0–5 years was higher than the dose of age group 6–10 years, because there were no scans with the updated protocol using strong level of iterative reconstruction in the youngest age group. This can also be seen in effective doses in Fig. 3, where the effective doses are higher with the youngest age group in hospital B. There was no significant association between age and effective dose, because the DLPs of routine head increased with age, while the conversion factors correspondingly decreased.

The 75th percentiles of trauma head or routine head CT cannot be considered as local DRLs because of too high dose levels or a lack of youngest patients. The percentiles of hospital B can be considered as local DRLs for trauma cervical spine CTs. To our knowledge, there are no reported DRLs for trauma cervical spine CTs for pediatric patients. There is also a question on which studies the DRLs should be set. Our study shows that the 75th percentiles are dependent on patient age, device, and indication. We conclude that it is not reasonable to set local DRLs for all studies because of the wide range of different indications and age groups.

Conclusion

Dose monitoring solutions, such as DoseWatch, can offer valuable tools in collecting, analyzing, and benchmarking the CT data in imaging of children and young adults. The use of dose monitoring system also facilitates the evaluation of own practices and finding non-optimized protocols for radiation-sensitive patient groups.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Electronic supplementary material

ESM 1

(PDF 251 kb)

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AQ3

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