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PAPER

Optimising whole body computed tomography doses for paediatric trauma patients: a Swiss retrospective analysis

Leopold Simma[1,2,*], **Juergen Fornaro**[3], **Nikolai Stahr**[3,4], **Markus Lehner**[5], **Justus E Roos**[3] and **Thiago Viana Miranda Lima**[3,6]

[1] Emergency Department, Children's Hospital Lucerne, Spitalstrasse, CH-6000 Lucerne, Switzerland
[2] Emergency Department, University Children's Hospital Zurich, University of Zurich, Steinwiessstrasse 75, Zurich, CH 8032, Switzerland
[3] Institute of Radiology and Nuclear Medicine, Cantonal Hospital Lucerne, Spitalstrasse, CH-6000 Lucerne, Switzerland
[4] Pediatric Radiology Department, Children's Hospital Lucerne, Spitalstrasse, CH-6000 Lucerne, Switzerland
[5] Pediatric Surgery Department, Children's Hospital Lucerne, Spitalstrasse, CH-6000 Lucerne, Switzerland
[6] Institute of Radiation Physics, Lausanne University Hospital, University of Lausanne, Lausanne, Switzerland
[*] Author to whom any correspondence should be addressed.

E-mail: leopold.simma@kispi.uzh.ch

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Abstract

We aimed to evaluate the impact of a low-dose whole-body computed tomography (WBCT) protocol on radiation doses in paediatric major trauma patients. Retrospective cohort study of paediatric trauma patients (<16 years) at a national level 1 paediatric trauma centre (PTC) over a 6 year period prior and post introduction of a low-dose WBCT protocol (2014–2019). Demographic data, patient characteristics, CT device, and exposure information including scan range, dose-length product, and volume CT dose index were collected. Effective dose (ED) and exposure parameters were compared before and after protocol introduction. Forty-eight patients underwent WBCT during the study period. Prior to introduction of the low-dose protocol ($n = 18$), the ED was 20.6 mSv (median 20.1 ± 5.3 mSv [range 12.5–30.7]). After introduction of the low-dose WBCT protocol ($n = 30$), mean ED was 4.8 mSv (median 2.6 ± 5.0 [range: 0.8–19.1]). This resulted in a reduction of 77% in mean ED (p value <0.001). Significant radiation dose reduction of 77% can be achieved with low-dose WBCT protocols in PTCs.

1. Introduction

Computed tomography (CT) is a major source of ionising radiation for patients undergoing medical imaging. CT is increasingly used with children despite persistent concerns about the risks of medical radiation exposure [1]. Over the last 20 years, constant efforts have been made to reduce doses with the introduction of the ALARA (as low as reasonably achievable) concept, but CT remains the major source of radiation exposure [2]. Modern CT scanners are capable of modulating the tube current to the target region's density and acquiring images with lower patient exposure and more harmonised image quality. Additionally, scan parameters can be adjusted to children's variable body sizes with specific paediatric scan protocols [3]. Nonetheless, indications for CT use should be stringent, and risks and benefits must be carefully weighed against each other [4]. Whole-body CT (WBCT) for adult major trauma has become the standard of care in many settings [5–7]. Its use and utility in paediatric major trauma are hotly debated [8–12]. Although the classic approach to major trauma with conventional imaging and selective scanning is still advocated in children [13, 14], WBCT is increasingly used [12]. Various studies report reduction of radiation while maintaining adequate image quality in adult patients undergoing CT examinations [15–17]. Following the ALARA concept, continuous efforts to achieve the lowest radiation exposure possible is essential for any paediatric centre [18, 19].

The aim of this study was to retrospectively evaluate the impact on patients' radiation exposure of a new low-dose WBCT protocol for paediatric major trauma patients at a single paediatric major trauma centre (PTC) in central Switzerland.

2. Material and methods

We performed a retrospective study with a cohort of paediatric trauma patients who underwent WBCT at our centre over a 6 year period prior to and following introduction of a paediatric low-dose WBCT protocol (2014–2019). This article was written in accordance with the STROBE guidelines [20].

2.1. Department setting

The setting was a tertiary paediatric emergency department (PED) with an annual census of 21 000 presentations and designated national level-1 PTC in central Switzerland.

Major trauma patients are treated in a trauma bay shared with the cantonal hospital on the same campus as CT and magnetic resonance imaging, which are shared in the organisation.

Prior to March 2016, emergency presentations were classified as either surgical or paediatric and were managed exclusively by paediatric surgeons or paediatricians, respectively. In this period, adolescents under 16 years were occasionally managed by adult trauma surgeons. In 2016, an interdisciplinary PED was established. The PED is staffed by paediatricians trained in paediatric emergency medicine who are on site from 08:00 to 23:00. Paediatric surgeons remain on call. During the period described in this study, the hospital's Institute of Radiology and Nuclear Medicine operated two CT scanners (Somatom Definition Edge and Somatom Definition Flash; Siemens Healthineers, Erlangen, Germany). Both 128-row devices were equipped with CARE Dose 4D, CARE kV and CARE Child Pediatric protocols in addition to SAFIRE iterative reconstruction.

2.2. Participant selection and data collection

Patients under 16 years of age who received a WBCT within 2 h of arrival in the trauma bay between 2014 and 2019 were included in the cohort. We excluded patients receiving only selective scans of head, spine, or body. Patients were identified via data collected prospectively from our PED registry (2016–2019), and the picture archiving system (PACS) was searched for WBCTs performed in the study period by two investigators independently (LS and JF).

We collected patient age, gender, weight, time of presentation (categories 08:00–16:00, 16:00–23:00, and 23:00–08:00), diagnosis, mechanism, CT reports, CT device, phantom size, series description, scan range, head and body dose-length product (DLP), and volume computed tomography dose index ($CTDI_{vol}$). WBCT reports were read and interpreted by senior radiologists. To assess injury severity, we calculated the injury severity scores (ISSs) [21] using the 2008 abbreviated injury scale [22].

Data were extracted from the electronic medical record, PACS, the emergency department information system, and the PED registry. Data were collated in an Excel (Microsoft, Redmond, USA) spreadsheet and used for further calculation.

2.3. Effective dose calculations

The National Cancer Institute dosimetry system for CT (NCICT) was used to estimate individual patients' effective doses (EDs). The NCICT is an organ dose calculator that combines the Monte Carlo radiation transport technique with a series of computational human phantoms [23]. ED estimation required the input of the height and weight of each patient so the software could match each to one of the predefined ICRP paediatric phantoms, which correspond to reference ages of newborn, 1, 5, 10, and 15 years old; tube potential (kV); $CTDI_{vol}$; and a CTDI calibration phantom for either head or body. The scanning length obtained from the reported DLP and $CTDI_{vol}$ and the starting position of the scan was defined by the individual series. The total ED was the sum of the ED calculated for each acquired series.

2.4. Standard whole body CT protocol

Prior to the introduction of the low-dose WBCT protocol, a standard trauma WBCT protocol was the default. The protocol consisted of three phases: a cranial CT (CCT) without contrast (phase one), a CT angiography of the neck with the injection of a contrast medium bolus (phase two) and a scan of the trunk from the upper thorax to the groin (phase three). Phases one and two were selected from a lateral scout view and phase three from an anterior posterior scout view (figure 1). In patients with additional injury to the lower limbs, the scan was expanded to a more caudal region as needed. This third phase required the injection of a second bolus of contrast medium.

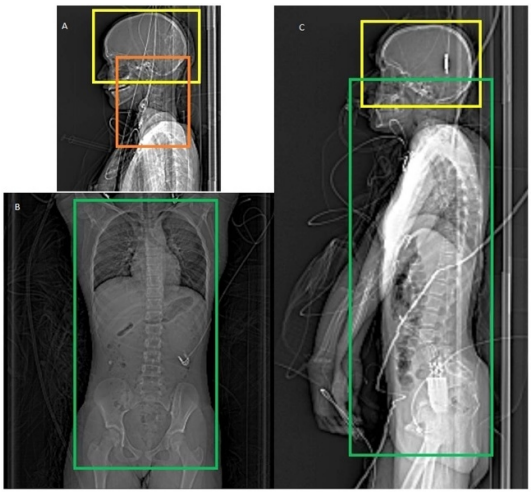

Figure 1. Scout view and scan ranges for the standard (A), (B) and low-dose whole body CT (C) protocols. (A) Lateral scout view including head acquisition (yellow) and neck acquisitions (orange). (B) Anterior posterior scout view and thorax–abdominal–pelvis (green) scan range. (C) Lateral scout view including both head (yellow) and neck and trunk (green) scan ranges.

2.5. Low-dose whole body CT protocol

The low-dose WBCT protocol ranged from head to the greater trochanter. Caudal extension was possible depending on clinical requirements, as in the standard WBCT protocol. An unenhanced CCT was performed first. After application of a first contrast medium bolus to allow detection of arterial bleeding, the neck and trunk were scanned (phase two). A second angiographic bolus was given 90 s after initiation of the second phase (split bolus principle) to allow venous evaluation of the thorax and abdomen, especially when diagnosing organ injuries. Figure 1(C) shows our use of a single lateral scout view in the low dose WBCT protocol.

2.6. Outcome measures

Radiation dose exposure in children receiving a WBCT at a designated national PTC in Switzerland. Other variables included demographic data, time and date of visits, and the ISS.

2.7. Analysis

Python's scientific module (Scipy version 1.4.1) was used to analyse the results. Descriptive statistics were provided of all baseline characteristics and study endpoints. Continuous variables were described as means with standard deviation (SD) or medians with interquartile ranges. Differences were analysed with an independent *t* test. Counts and percentages were calculated for categorical variables. Differences were analysed with the Fisher exact test.

2.8. Ethics

Use of the data for this study was approved by the ethics committee responsible (EKNZ 2020-00155). Informed consent for publication of anonymised patient data was waived for this study by the ethics committee.

3. Results

3.1. Participants and demographics

During the 6 year study period, there were 116 336 presentations to the PED (2014–2019). We identified 15 patients with a WBCT from start of 2014 to February 2016 via parameter search in the PACS. From March 2016 to end of 2019, we identified 98 major trauma patients in the prospective PED registry, of whom 33 underwent a WBCT. Of the 48 paediatric patients undergoing a WBCT, 18 (38%) were scanned with the standard WBCT protocol and 30 (63%) with the low-dose WBCT protocol. The demographic characteristics are shown in table 1. There were more females in the first cohort and more males in the second, low-dose cohort (*p* value 0.03). The mean ISS was higher in the low-dose protocol cohort (17.0 vs. 9.5).

Table 1. Basic demographic data and patient characteristics ($n = 48$).

Male		31 (65%)	
Female		17 (35%)	
Presentation in business hours		11/48 (23%)	
Standard protocol ($n = 18$)		*Low-dose protocol* ($n = 30$)	
Median age, y, [q1,q3]	14.2 [13.7;15.2]	Median age, y, [q1,q3]	12.2 [5.8;14.5]
Gender m:f	8:10	Gender m:f	23:7
ISS mean (range)	9.5 (1–35)	ISS mean (range)	17.0 (4–34)
ISS SD	8.3	ISS SD	8.9
Weight categories			
>56 kg	6 (33%)	>56 kg	8 (27%)
32–56 kg	10 (56%)	32–56 kg	8 (27%)
19–32 kg	2 (11%)	19–32 kg	7 (23%)
		10–19 kg	7 (23%)
Age categories			
>10.5 y	15 (83%)	>10.5 y	16 (53%)
5.5–10 y	3 (17%)	5.5–10 y	7 (23%)
		1.5–5.5 y	7 (23%)
Effective doses			
Median ± SD (min–max) [mSv]	20.1 ± 5.3 (12.5–30.7)	Median ± SD (min–max) [mSv]	2.6 ± 5.0 (0.8–19.1)
Mean [mSv]	20.6	Mean [mSv]	4.8

Table 2. Variation of DLP between standard and low-dose protocols ($n = 48$).

	Standard protocol ($n = 18$)	Low-dose protocol ($n = 30$)	Swiss Diagnostic Reference Level [a] [46]	European Diagnostic Reference Level [b] [47]
Scan Region				
CT Head/Brain				
No. Scans	17	27		
Median $CTDI_{vol}$ ± SD [mGy]	36.7 ± 1.8	13 ± 12	40	50
p value	<0.01			
Median DLP + SD [mGycm]	676 ± 90	266 ± 250	670	650
p value	<0.01			
CT Thorax/Abd/Pelvis				
No. Scans	35	34		
Median $CTDI_{vol}$ ± SD	13 ± 2.8	1.1 ± 3.6	7.0	13.0
p value	<0.01			
Median DLP ± SD	413 ± 310	86 ± 250	310	480
p value	<0.01			

[a] To compare with Swiss DRLs, the largest age and weight group was used (10.5 years old for the head protocol and more than 32 kg for the abdomen protocol). For the thorax–abdomen–pelvis, we compared with the abdomen values from this publication.
[b] To compare with European DRLs, the larger age and weight categories were used (>6 years old and above 50 kg). For the thorax–abdomen–pelvis, we compared with the abdomen values from this publication.

3.2. Main results

The median DLP fell from 676 mGycm in the standard protocol ($CTDI_{vol}$ 37 mGy) to 266 mGycm ($CTDI_{vol}$ 13 mGy) in the low-dose protocol for the head region (p value <0.01 for both $CTDI_{vol}$ and DLP). For the body region, it fell from 413 mGycm in the standard protocol to 86 mGycm in the low-dose protocol (p value <0.001). A similar reduction (p value <0.001) was observed for the $CTDI_{vol}$: from 13 mGy in the standard protocol to 1.1 mGy in the low-dose protocol. Table 2 and figure 3 show the $CTDI_{vol}$ and DLP before and after optimisation. The mean ED of the standard protocol was 20.6 mSv (median 20.1 ± 5.3 [range 12.5–30.7]). The mean ED with the low dose WBCT protocol was 4.8 mSv (median 2.6 ± 5.0 [range: 0.8–19.1]). This equates to a reduction of 77% in mean ED (p value <0.001). EDs and age groups are shown in figure 4.

Prior to the introduction of the low-dose protocol, an average of 2.9 acquisitions were performed per patient, in contrast to 2 acquisitions following optimisation. Additionally, we found that the average tube voltage for the acquisitions was around 118 kVp before the optimisation in comparison to approximately 98 kVp afterwards, as shown in figure 2.

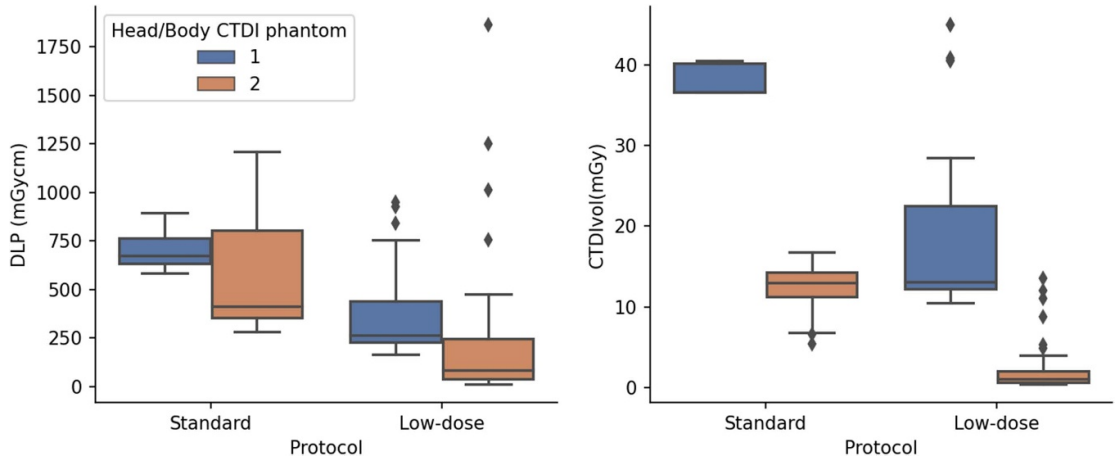

Figure 2. Comparison between DLP (left) and $CTDI_{vol}$ (right) for standard and low-dose protocols for both head (CTDI phantom 1) and body (CTDI phantom 2).

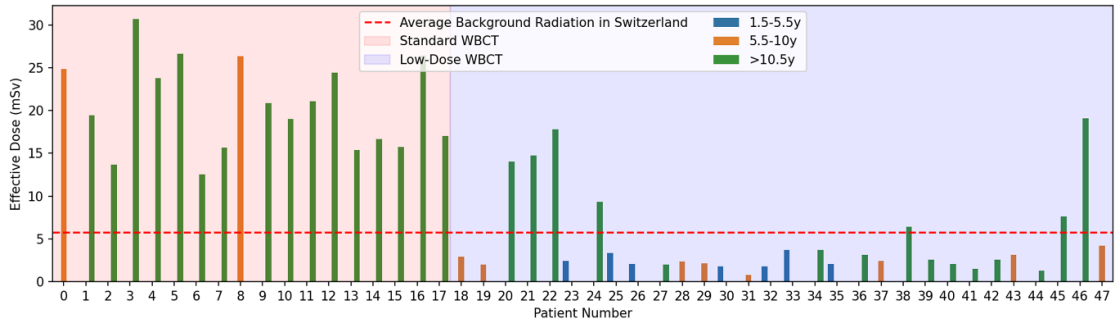

Figure 3. Calculated total EDs for each patient subdivided by patient age group, as per Swiss DRL, and protocol groups: standard and low-dose WBCT. The dashed line represents the average background radiation in Switzerland [28].

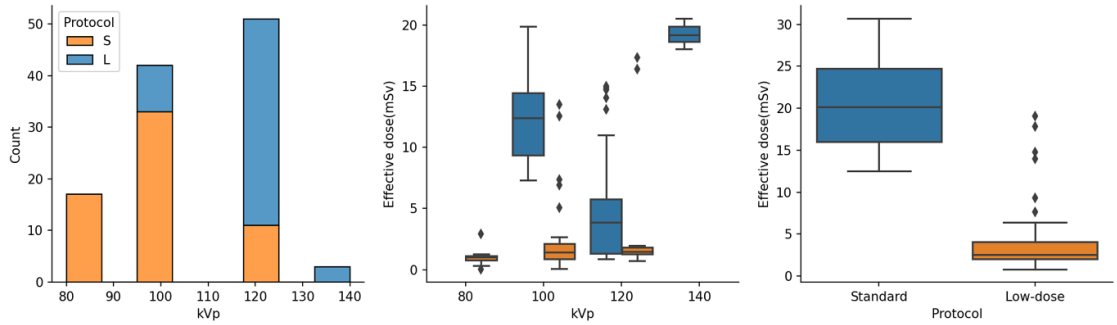

Figure 4. Comparison of tube current used for low-dose (L) and standard (S) protocols (left plot) and its effect on patient EDs (middle plot). Right plot: the overall EDs before and after protocol optimisation.

ED and weight correlations of the two protocols are shown in figure 5. A tendency to higher EDs can be seen for scans out of business hours in the low-dose group, which appears to be unrelated to the CT device used (p value 0.02). This tendency is particularly visible in patients over 50 kg (p value 0.01).

4. Discussion

In this study, the low-dose WBCT protocol significantly reduced patients' radiation doses in comparison to the standard CT protocol (p value <0.001). One of the study's strengths is the analysis of actual patient data to report and compare the introduction of the low-dose protocol.

Additionally, the low-dose protocol showed the influence of tube voltage modulation and consequently reduced patient exposure. The impact of the low-dose protocol on the ED was also seen in the individual age categories presented in figure 6. All differences were statistically significant (p value <0.001).

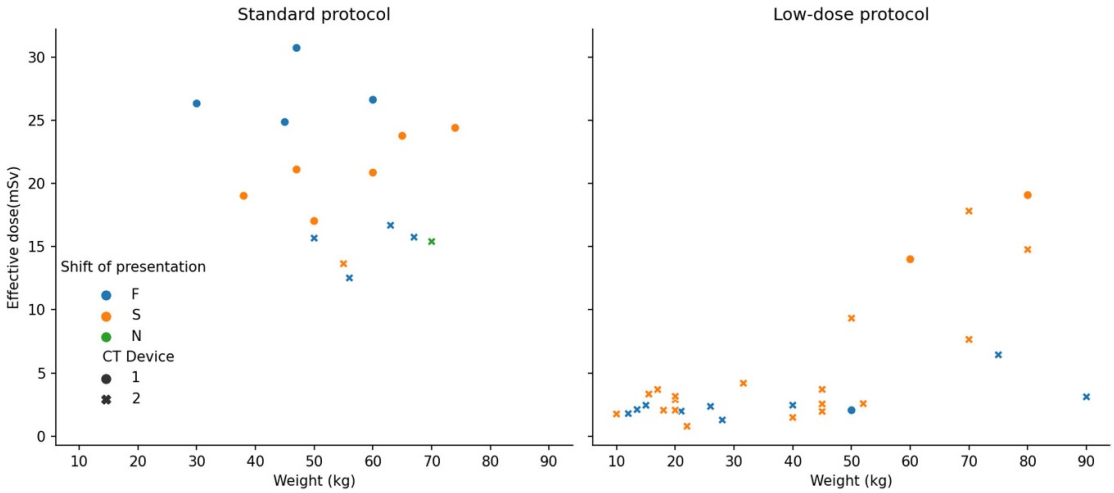

Figure 5. Dose and weight correlation with the standard protocol on the left; low-dose protocol on the right. Presentation time is coded by colour (F—morning, S—evening, N—night shift), CT device by symbol.

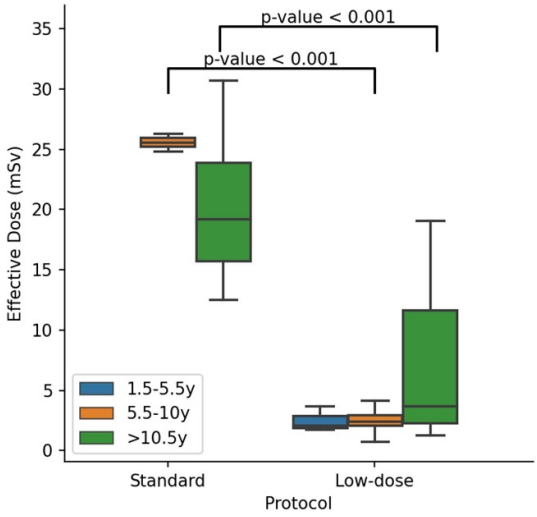

Figure 6. EDs for standard and low-dose protocols by age group.

Exposure of the paediatric population to ionising radiation is a sensitive topic, and studies have shown evidence of increased cancer risk [24, 25]. Munk *et al* reported EDs for WBCT ranging around 20.8 mSv (range 8.6–48.9 mSv, SD ± 7.9 mSv) with data from 2006 [26]. This is broadly equivalent to our results in the standard protocol group. Our most recent protocol, a dedicated low-dose WBCT, shows that a nearly 10-fold dose reduction is possible (median 20.1 mSv standard protocol versus 2.6 mSv low-dose protocol), close to the average medical exposure per inhabitant in Switzerland (1.5 mSv) [27] but lower than average Swiss background radiation exposure (5.8 mSv) [28]. Similar levels of ED have also been also reported by other groups. A French study reported EDs of 1.4 mSv and around 9–10 mSv in children under five years of age for head and abdomen CT respectively [29]. A review by Goodman *et al* provides an overview of EDs for CT scans reported in the literature, including experimental studies reporting doses as low as 1 mSv for CCTs and less than 1 mSv for abdominal CT [30]. The impact of the low-dose protocol was more pronounced in our hospital than reported in a recent publication comparing CT doses of PTCs with referral facilities in the United States [18]. The mean DLPs for the PTCs included were 444 for CT head and 181 for abdomen–pelvis scans; the corresponding medians for our sample were 266 for CT head and 86 for thorax–abdomen–pelvis scans in our sample (table 2 and figure 3). The head components of both standard and low-dose protocols were below the Swiss and European Diagnostic Reference Levels (DRLs) for paediatric CT examinations. The thorax–abdomen–pelvis component for the standard protocol was above the Swiss DRL, but the mean weight of our cohort was above the weight range for the published DRL. The impact of the low-dose protocol is clearly evident in this DRL comparison for both $CTDI_{vol}$ and DLP. However, although doses were lowered

significantly, the biological effects of a dose administered within seconds differs significantly from exposure over one year. Therefore, WBCT should be used cautiously, and even lower WBCT doses would be desirable.

The technique of split-bolus single pass protocols was reported to result in lower radiation doses without losses in image quality [31]. In adult cohorts, low-dose protocols have been shown to yield similar results to standard protocols [32].

We also analysed radiation the doses of individual patients in the low-dose cohort. Five patients in the low-dose group received high EDs >10 mSv. These high doses were associated with increased body mass and weight in adolescent patients. We also observed some WBCT scans with higher doses in patients over 50 kg during out-of-business hours (p value 0.01). Striking examples of this disparity include Patient 46 (ED $\sim$ 20 mSv with 80 kg; 16:00–23:00 h) and Patient 36 (ED $\sim$ 3 mSv with 90 kg and admitted between 8:00 and 16:00 h). The precise causes are hard to elucidate in retrospect. Possible explanations include reduced staffing out of hours, lower familiarity of the radiology technician on duty with the protocol, and time constraints. However, this highlights the importance of appropriate training and staffing to ensure the lowest radiation exposure possible.

The low-dose cohort was larger and had higher ISS than the pre-low dose cohort. The low-dose protocol was introduced 33 months into the 60 month observation period. The reasons for the significantly higher number of scans following introduction are unknown. Missing data is unlikely to be the cause, as the PACS database was searched independently by two investigators. Clinicians could have been biased towards ordering WBCT more liberally than previously once a low-dose protocol was in place. However, we believe that the low-dose protocol itself would not have lowered the threshold for using WBCT. the low-dose protocol group suffered substantially more severe injuries, with a mean ISS of 17.0 compared to 9.5 in the standard group. The reason for this increase in injury severity is unknown.

The usefulness of CT in paediatric trauma is an ongoing debate. Nellensteijn *et al* have questioned the use of abdominal CT scanning for hemodynamically stable children [33]. Large studies have analysed the difference in mortality among paediatric trauma patients and found no advantage in mortality for using WBCT versus selective CT scanning [8, 9]. However, recent guidelines endorse the use of WBCT for diagnostic work-up in paediatric major trauma [34]. In clinical scenarios with inconclusive clinical exams, ultrasound, or x-rays, decision making may require additional information. In such cases, CT protocols with the lowest possible dose must be available to expedite management.

Mortality is an important endpoint, but low-dose WBCT may offer advantages that are not easy to measure.

Even though WBCT is controversial and data show that outcome may not differ, it may expedite management in certain environments [35]. Conventional imaging of chest and pelvis may be difficult to obtain, when radiology staff are unfamiliar with mobile x-rays in a trauma bay that is geared to trauma management with WBCT. Acquiring plain films in a busy trauma bay is a challenge, even for very skilled radiology technicians. This could translate into a higher probability in the use of CT at non-level-1 PTCs and adult trauma centres [13, 36–38]. In addition to higher EDs at adult facilities [18, 39, 40], this combination may increase the risk of exposing children to unnecessary radiation. Our standard protocol group had a lower mean ISS, which could be due to injury mechanisms leading clinicians to opt for WBCT. Although reports about adult cohorts suggest that the mechanism of injury alone should not be an indication for using WBCT [7, 33, 41]. Judicious use of CT is of high importance and as with any test, the possibility of a false positive result must be considered [38].

Communicating the risks and benefits of tests to patients can be challenging. The literature provides ample evidence that physicians' knowledge and communication of radiation risks offers room for improvement [42, 43]. As a consequence, barriers arise in conversations with patients about the risks and benefits of imaging studies with ionising radiation [43, 44]. Commonly used communication strategies in these conversations include comparison with annual background radiation [42, 44, 45], which is why we use this term to convey part of our results.

4.1. Limitations

Limitations of this study include a small sample size recruited at a single centre and a retrospective design. We did not assess image quality or injuries missed by WBCT scans. However, literature reports low rates of missed injuries [32] and acceptable image quality with low-dose protocols [15–17]. We detected no clinically relevant findings missed in the low-dose protocol group, and all patients were followed in the prospective database (PED registry). In summary, although no quantitative image quality assessment was performed, the low-dose protocol images were reviewed by experienced board-certified radiologists prior to clinical implementation and were deemed adequate for answering clinical questions while adhering to the ALARA principle (see example in figure 7).

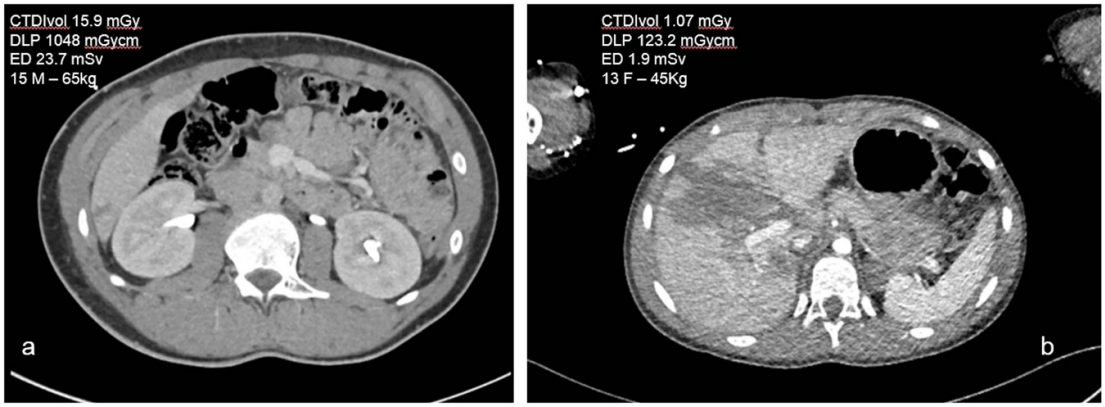

Figure 7. Abdominal axial view of a patient that underwent the standard protocol (A) and of another patient that underwent the low-dose WBCT protocol (B). The apparent reduced image quality on the low-dose protocol (B) was sufficient to report the relevant clinical findings with a 92% lower radiation dose to the patient.

Another limitation of the work was that the phantoms used for dosimetry rely on matching patient attributes to available phantom characteristics by either age or weight.

5. Conclusions

Significant radiation dose reduction can be achieved with low-dose WBCT protocols in PTC. Institutional efforts must be made to apply low-dose protocols at all times.

Data availability statement

Availability of data and material all available data is included in the publication.

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Conflict of interest

All authors have no conflict of interest to declare.

Authors' contributions

Conceptualization: L S, T L; Ethics approval: L S; Methodology: L S, T L; Formal analysis and investigation: L S, T L; Low-dose protocol development: J F; Writing—original draft preparation: L S T L; Writing—review and editing: L S T L, J F, N S, J R, M L.

Ethics approval

This research study was conducted retrospectively from data obtained for clinical purposes. An ethics approval for use of this data was granted from the IRB: ethics committee Central and Northeastern Switzerland (EKNZ 2020-00155).

Consent to participate waived by IRB.

Consent for publication waived by IRB.

ORCID iDs

Leopold Simma https://orcid.org/0000-0003-3032-2759
Thiago Viana Miranda Lima https://orcid.org/0000-0002-3105-9270

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