PAEDIATRIC DOSES DURING SOME COMMON X-RAY PROCEDURES AT SELECTED REFERRAL HOSPITALS IN TANZANIA

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The aim of this study was to determine the radiation doses to paediatric patients of different age groups at three large hospitals for optimisation purposes. The entrance surface air kerma (ESAK) values were determined from the measured X-ray output values using calibrated ionisation chamber, TW 233612 and clinical patient parameters. The air kerma-area product (KAP) values were measured using a calibrated Diametor E2 system. The volume computed tomography dose index (CTDI_{vol}) and dose length product (DLP) values were obtained from the computed tomography (CT) equipment verified by a calibrated CT chamber, Unifors Xi CT. Irrespective of age groups, the results show that the median ESAK values ranged from 62.6 to 248.1 μGy . The median KAP values ranged from 135.6 to 1612 $\mu\text{Gy cm}^2$, while the median DLP values ranged from 119.1 to 600 mGy cm. Analysis of the results indicates that optimisation can be achieved through good practice awareness and patient dose and image quality evaluations.

INTRODUCTION

There is a worldwide concern on the radiation dose levels imparted to paediatric patients during X-ray procedures and possible associated risks⁽¹⁾. This is motivated by the fact that children are more radiosensitive and their expected life expectancy gives a higher probability of incurring cancer during their childhood than adults. Despite this fact, the use of X-rays has continued to play an important role in the diagnosis of pathologies and injuries to paediatric patients when appropriate. For countries with limited resources, such appropriateness is highly influenced by the availability of and affordability to alternative imaging modalities. Because of these reasons, the application of the appropriateness criteria for particular diagnosis method tends to vary from country to country. Despite these variations, protection of children from the radiation during X-ray examinations remains an important aspect common to all countries.

For this reason, many international and national radiation protection communities have continued to create awareness on the need to justify radiological procedures involving children as a primary step in eliminating some of them that are not necessary^(2, 3). Determination of dose levels in paediatric radiology has also continued to attract many studies to establish paediatric dose levels as an input to optimisation^(4–9). At present, there is a good body of knowledge demonstrating that paediatric doses can be reduced without compromising the image quality required for diagnosis^(10–13). In Tanzania, there is high workload of

paediatric patients estimated at 5000–10 000 per year at large referral hospitals. These hospitals attract many patients as they form the last line of health-care level in the country such as in handling emergencies, diagnosis and treatment of congenital abnormalities and other medical complications.

Despite such high frequencies of patients, there are limited awareness campaigns on justification as well as optimisation of X-ray procedures involving children to achieve good imaging. This situation is due to the fact that the health-care level of the country is still developing. Moreover, paediatric examinations are performed under busy environments, with inadequate protective gears and immobilisation devices as well as with limited patient cooperation. As a result of these practical constraints, there is scarce information on the status of actual clinical practice during paediatric radiological examinations as well as on the status of image quality and patient radiation exposure. Therefore, the need to investigate typical practices and dose levels imparted to children during radiography, fluoroscopy and computed tomography (CT) procedures is imperative. The objective of this study was to determine typical radiation doses in paediatrics for different patient sizes as an input to optimisation.

MATERIALS AND METHODS

General

This study was approved by all hospital authorities, and it commenced in April 2011. Data collection in

radiography ended in the same year, while CT studies started in late 2012 and ended in early 2013. Fluoroscopy studies commenced in late 2013 and ended in June 2014 due to the delay of the arrival of calibrated dosimeter. Because the inflow of paediatric patients could not easily be predicted and the absence of all imaging modalities at all hospitals, three referral hospitals each with different modalities were selected to participate in this study. The selection of few hospitals had additional merit to assure adequate quality of the results to be obtained. Projection radiography procedures were studied at Muhimbili National Hospital (MNH), while fluoroscopy procedures were investigated at Kilimanjaro Christian Medical Centre (KCMC). Studies on CT procedures were performed at Regency Medical Centre (RMC).

Materials

X-ray facilities

The X-ray equipment used during this study at MNH was Philips Practix 300 (Philips, Germany). At this hospital, the film processor utilised was Optimax 2010 film processor (Fumingwei, China). The film–screen combination in use was Model 400 Lumax, which is a 400 speed class. At KCMC, the fluoroscopy used was Philips Duodiagnost, model 989601022011 (Philips). During screening, the image intensifier was always used together with automatic dose rate control (ADRC). In CT procedures, the CT scanner in use at RMC was 64-slice Philips Brilliance and was always used with tube current modulation mode. In the studied facilities, all images for which radiation doses are reported herein were used for diagnosis.

Dosimetry equipment

In projection radiography, output measurements were performed using ionisation chamber model TW 233612 (serial number 394) connected to electrometer model PTW UNIDOS model 10002 (serial number 20359) both manufactured by PTW, Germany. The ionisation chamber was calibrated by PTW in November 2010. Fluoroscopy measurements were performed using kerma-area product (KAP) metre model Diamantor E2 (serial number 35150 and Diamantor chamber with serial number 12799). This KAP system was calibrated by PTW in December 2012. Dosimetry in CT was performed by recording console values. The accuracy of console volume CT dose index (CTDI_{vol}) was verified by a 10-cm pencil-type chamber model Unifors Xi CT (serial number 176919) (IBA Dosimetry, Germany) calibrated in 2012. This ionisation chamber was connected to MagicMax Universal (serial number G 13-0133 Version 01) and HP laptop computer. The 16-cm standard polymethylmethacrylate phantom for typical

clinical protocols during paediatric head and abdomen CT was used. The respective protocols for head CT were 120 kVp, 500 mAs and 2 mm slice thickness while for abdomen CT were 120 kVp, 345 mAs and 0.9 mm slice thickness. Both protocols utilised standard filter. By dividing the weighted CT dose index by a pitch factor of 0.75 to get the CTDI_{vol} , the ratio of calculated CTDI_{vol} to console CTDI_{vol} was 13 % (72/63.8) for typical head CT and 9.4 % (24.4/22.3) for typical abdomen CT.

Methods

The international code of practice in diagnostic radiology dosimetry for adult patients⁽¹⁴⁾ was applied during this study to determine paediatric doses. The results were compared with the most recent published data. The estimation of uncertainties for each imaging modality was performed in accordance to the method recommended in the international code of practice⁽¹⁴⁾.

Radiography

The X-ray output and half-value layer (HVL) were performed at 851-mm focus to chamber distance (FCD) for 45, 50, 60 and 70 kVp settings. The respective HVL data were 1.96, 2.18, 2.58 and 2.91 mm Al. For other tube potentials, HVL values were obtained by interpolation from the measured values. Some demographic and exposure data during chest *posteroanterior* (PA) and abdomen *anteroposterior* (AP) X-ray examinations were collected. These included the age, gender, height, weight, tube potential, tube current–time product, focus skin distance (FSD) and the field size. Four age groups, i.e. ‘0–1 month’ (0–1 m), ‘>1 month–1 y’ (1 m–1 y), ‘>1 y–5 y’ (1–5 y) and ‘>5–10 y’ (5–10 y), were considered during this study. The exposure parameters for children indicated on the exposure chart were used. Clinical data were collected for 25 patients for each age band and X-ray examination type giving a total of 100 studied. The incident air kerma values were determined from the product of each output measurement as corrected to the inverse square effects and the tube current–time product. The entrance surface air kerma (ESAK) values were finally determined from the product of incident air kerma and the appropriate published backscatter factors⁽¹⁴⁾.

Fluoroscopy

Three types of paediatric procedures were considered during this study *Micturating Cysto-urethrography* (MCU), contrast enema and barium meal. KAP metre was used to measure KAP reading for each paediatric fluoroscopy for the age group of ‘>1–5 y’, which from experience was likely to have an adequate

number of patients. Data on age, gender, height, weight, tube potential, tube current–time product, protocol used, KAP metre reading and the fluoroscopy time were recorded for each child's procedure. In all cases, paediatric protocols marked 'small patient' on the equipment console were used. The KAP readings were corrected for average temperature and pressure conditions as well as the calibration of KAP metre. The clinical data were collected for 15 patients for each fluoroscopy examination type giving a total of 45 children studied.

CT scanning

Three types of paediatric CT procedures were considered during this study: head, chest and abdomen CT for two different age groups, i.e. '>1–5 y' and '>5–10 y'. The clinical indications were trauma or tumours for head CT, infection or tumours for chest CT and tumours for abdomen CT. CTDI_{vol} and dose length product (DLP) values for each child undergoing CT procedure were obtained from the console readings of the CT scanner. In all cases, paediatric protocols marked on the CT scanner console were used. In addition to dose values, some demographic data were also recorded for each child in each type of CT procedures. These included gender, height, weight, tube potential, effective tube current–time product, rotation time and total scan time. Others were scan length, filter used (always standard), tube current modulation (always used), acquisition slice setting and pitch. The clinical data were collected for 15 patients for each type of CT procedure and each age group giving a total of 90 children studied.

RESULTS

Present study

Table 1 shows the median ESAK values to paediatric patients during chest PA X-ray examinations. Also shown in the results are ESAK variations expressed as the ratio of maximum to minimum (max/min) ESAK.

As it can be seen, the median ESAK values ranged from 62.6 to 119.8 μGy with a maximum intra-age band variation of 12.5 being to '0–1 m' age group. The results indicate that similar exposure parameters (kVp, mAs) were utilised as characterised by low variations of these parameters. A possible cause for lower dose to '>1 m–1 y' patients than to '0–1 m' patients is the use of slightly higher tube potentials (44–64 kVp) and higher lower tube current–time product (4–12.6 mAs) for the earlier patient age group, with consequences in relatively increased incident dose to patients. For '0–1 m' age group, the respective tube potentials and tube current–time product varied from 45 to 48 kVp and 5.2 to 6.4 mAs. The values of

ESAK during abdomen AP X-ray examinations are shown in Table 2. The median ESAK values ranged from 96.2 to 248 μGy for studied children population with maximum intra-age group variation being 13.4 for '>5–10 y' age group. The selected tube potentials were similar to the values during chest X-ray examinations, but this time pronounced differences in the values of tube current–time product are visible. The selection of such exposure parameters is likely to have been influenced by the experiences of radiographers on the type of image quality that is preferred by radiologists or the thickness of the X-rayed body part.

Table 3 shows the median KAP values to the paediatric patients of '>1–5 y' age group. The KAP values were 135.6, 1612, and 318.7 $\mu\text{Gy cm}^2$ for barium meal, contrast enema and MCU, respectively. Contrast enema procedures had the highest mean KAP value likely due to relatively longer fluoroscopy times than the other two procedures. The hospital was informed of this situation and acknowledged the feedback and promised to be more careful in future situations.

Tables 4–6 show the results of median CTDI_{vol} and DLP values to the children of '>1–5 y' and '5–10 y' age groups for head, chest and abdomen CT. As expected, due to the use of similar exposure parameters, the values of CTDI_{vol} were nearly constant, which implies constant average beam intensity characteristics. Such constancy for different age group children provides another demonstration that tube current modulation may be less effective for children or small-size adult patients. The median CTDI_{vol} values ranged from 20 to 36.5 mGy (Tables 4–6) and was the highest for CT head to '>1–5 y' and '5–10 y' age groups. The median DLP values ranged from 119.1 to 825 mGy cm, with the highest value being to the '1–5 y' age group in abdomen CT (Tables 4–6).

Comparison with published data

The comparisons of ESAK values obtained during this study with published data are presented in Tables 7 and 8 for chest PA and abdomen AP, respectively. It can be seen that some ESAK values (Table 7) for chest PA were comparable, while others were lower or higher than the values obtained elsewhere^(4–8). For abdomen PA, the median ESAK values obtained in this study were all lower than the published values except for one situation of '0–1 m' age group (Table 8). The dose differences can probably be attributed to the variations in the applied techniques as a result of varying equipment and image receptor characteristics as well as radiographers' preferences. The dose differences can also be caused by the type of diagnostic modality difference used in other studies especially in situation where the cited diagnostic reference levels do not clearly indicate whether screen

Table 1. Entrance surface air kerma (ESAK) to paediatric patients for chest PA. The ratio of maximum to minimum ESAK is shown as max/min.

Age group	Median				ESAK	
	Height (cm)	Weight (kg)	Tube potential (kVp)	Tube current–time product (mAs)	Median (μGy)	Max/min
0–1 m	46	3.6	46	5.4	105.5	12.5
>1 m–1 y	65	7.4	46	5.4	62.6	1.9
>1–5 y	80	11.6	48	6.5	86.2	6.9
>5–10 y	114	17	65	7.3	119.8	9.3

Table 2. Entrance surface air kerma (ESAK) to paediatric patients for abdomen AP. The ratio of maximum to minimum ESAK is shown as max/min.

Age group	Median				ESAK	
	Height (cm)	Weight (kg)	Tube potential (kVp)	Tube current–time product (mAs)	Median (μGy)	Max/min
0–1 m	47	5	48	6	96.2	4.9
>1 m–1 y	60	7	48	6.4	146.9	2.0
>1–5 y	99	15	57	9	233.7	3.2
>5–10 y	111	16.5	57	8	248.1	13.4

Table 3. Kerma-area product (KAP) to pediatric patients of '>15' y age band for three fluoroscopy procedures. Paediatric protocol and automatic brightness stabilization was used in all cases. The ratio of maximum to minimum KAP is shown as max/min.

Procedure	Median					KAP	
	Height (cm)	Weight (kg)	Tube potential (kVp)	Tube current–time product (mAs)	Fluoroscopy time (s)	Median ($\mu\text{Gy cm}^2$)	Max/min
Barium meal	74	6	52	0.6	64	135.6	3.66
Contrast enema	92	12.8	59	0.9	268	1612	1.79
MCU	94	14.5	58	0.9	69.5	318.7	3.67

Table 4. CTDI_{vol} DLP values for head CT at 120 kVp for given parameters ranges.

Age group	H (cm)	W (kg)	mA	r (s)	t (s)	sa	l (mm)	p	Median CTDI _{vol} (mGy)	Median DLP (mGy cm)
>1–5 y	56–83	7.5–30	200–500	0.5–1	5–7.5	4 × 3	300–350	0.452–0.482	42.5	119.1
>5–10 y	120–148	25–40	315–500	0.75–1.1	5–11	4 × 5	300–500	0.452–0.797	36.5	600

H, height; W, weight; mA, tube current–time product; r, rotation time; t, scan time; sa, slice acquisition; l, scan length; p, pitch.

film, computed radiography or digital radiography was in use.

There is limited information of most recent literature data on paediatric fluoroscopy doses obtained

using KAP metre on the age groups and procedures like in this study. Hart *et al.*⁽⁹⁾ suggested UK's national diagnostic reference level of 1300 $\mu\text{Gy cm}^2$ for both the barium meal and MCU. In the present study,

Table 5. Computed tomography dose index (CTDI_{vol}) dose length product (DLP) values for chest CT for given parameters ranges. The corresponding ratio of maximum to minimum value is shown as max/min.

Age group	H (cm)	W (kg)	mA	r (s)	t (s)	sa	l (mm)	p	Median CTDI _{vol} (mGy)	Median DLP (mGy cm)
>1–5 y	52–94	12–28	315	0.75	7.5–11.3	4 × 4	252	0.797	21.4	555
>5–10 y	100–162	22–45	315	0.75	8.1–11.7	4 × 5	252	0.797	21.4	555

H, height; W, weight; mA, tube current–time product; r, rotation time; t, scan time; sa, slice acquisition; l, scan length; p, pitch.

Table 6. Computed tomography dose index (CTDI_{vol}) dose length product (DLP) values for abdomen CT for given parameters ranges. The corresponding ratio of maximum to minimum.

Age group	H (cm)	W (kg)	mA	r (s)	t (s)	sa	l (mm)	p	Median CTDI _{vol} (mGy)	Mean DLP (mGy cm)
>1–5 y	70–135	13–28	200–340	0.75–1	4–11	4 × 5	300–500	0.671	20	825
>5–10 y	125–150	25–48	200	1	4	2 × 5	400	0.671	20	500

H, height; W, weight; mA, tube current–time product; r, rotation time; t, scan time; sa, slice acquisition; l, scan length; p, pitch.

Table 7. Comparison of ESAK values in chest PA with other studies.

Age group	This study (μGy)	Wambani <i>et al.</i> ⁽⁴⁾ (μGy)	Billinger <i>et al.</i> ⁽⁵⁾ (μGy)	Hart <i>et al.</i> ^(6, 7) (μGy)	Suliman <i>et al.</i> ⁽⁸⁾ (μGy)
0–1 m	105.5	–	55 ^a	50 ^a	45 ^a
>1 m–1 y	62.6	–	69 ^b	50 ^b	57 ^b
1 y					
>1–5 y	87.2	180 ^c	82 ^d	70 ^d	63 ^d
>5–10 y	119.8	190 ^e	108 ^f	120 ^f	–

Dash (–) indicates data not available.

^a0 y.

^b1 y.

^c13–60 m.

^d5 y.

^e61–120 m.

^f10 y.

Table 8. Comparison of ESAK values in abdomen AP with other studies.

Age group	This study (μGy)	Wambani <i>et al.</i> ⁽⁴⁾ (μGy)	Billinger <i>et al.</i> ⁽⁵⁾ (μGy)	Hart <i>et al.</i> ^(6, 7) (μGy)
0–1 m	96.2	250 ^a	100 ^b	–
>1 m–1 y	146.9	270 ^c	172 ^d	400 ^d
>1–5 y	233.7	350 ^e	511 ^f	500 ^f
>5–10 y	248.1	460 ^g	966 ^h	800 ^h

Dash (–) indicates data not available.

^a<1 m.

^b0 y.

^c1–12 m.

^d1 y.

^e13–60 m.

^f5 y.

^g121–180 m.

^h10 y.

relative higher KAP value was obtained during contrast enema due to higher fluoroscopy times (Table 3).

Tables 9–11 show the comparisons of CTDI_{vol} and DLP values for head CT, chest CT and abdomen CT with published values taking into account the indicated limitations in the comparisons. In head CT (Table 9), both CTDI_{vol} and DLP values are comparable with the published data with few exceptions. The results in Table 10 (chest CT) indicate the values in the present study to be higher than the corresponding values from the other studies^(10, 15). The differences in

the protocols in use and the radiographer's preferences are one of the possible explanations. Similar situation can be observed for abdomen CT (Table 11).

DISCUSSION

Technology barrier is responsible to unnecessary radiation exposure to children in countries with limited resources. In this country, the same situation applies since the access of many children to alternative

Table 9. Comparison of CTDI_{vol} and DLP values of head CT with other studies.

Studies	CTDI _{vol} (mGy)		DLP (mGy cm)	
	>1–5 y	>5–10 y	>1–5 y	>5–10 y
This study	42.5	36.5	119.1	600
Brady <i>et al.</i> ⁽¹⁰⁾	30 ^a	40 ^b	450 ^a	650 ^b
UK ⁽¹¹⁾	40 ^c	60 ^d	650 ^c	850 ^d
Vassileva <i>et al.</i> ⁽¹⁵⁾	29.7 ^e	36 ^f	–	–

Dash (–) indicates data not available.

^a3–6 y.

^b6–10 y.

^c1 y.

^d5 y.

^e1–5 y.

^f5–10 y.

Table 10. Comparison of CTDI_{vol} and DLP values of chest CT with other studies.

Studies	CTDI _{vol} (mGy)		DLP (mGy cm)	
	>1–5 y	>5–10 y	>1–5 y	>5–10 y
This study	21.7	23.5	514	523
Brady <i>et al.</i> ⁽¹⁰⁾	3 ^a	11 ^b	100 ^a	300 ^b
Vassileva <i>et al.</i> ⁽¹⁵⁾	4.9 ^c	5.5 ^d	–	–

Dash (–) indicates data not available.

^a<5 y.

^b6–10 y.

^c1–5 y.

^d5–10 y.

imaging modalities such as magnetic resonance imaging (MRI) and ultra sound is limited due to insufficient or absence of these facilities, low affordability or low awareness. Because of these reasons, the use of X-rays remains the main diagnosis to pathologies and injury in the country. In addition, the practice, i.e. the choice of technique and optimisation level, is another cause of deteriorated image quality and/or unnecessary paediatric doses. Both the technology barrier and the practice in use were the motivation to carry out this study as an input to optimisation.

The recommended good practices in procedures involving projection radiography of paediatrics are known⁽¹⁶⁾. Three-phase X-ray equipment that allows short exposure times for applied high tube potentials but low tube potentials with longer exposure times was largely preferred. An example of non-optimised tube potential or tube current–time product values has been explained as a possible reason for higher patient dose for the patients of ‘0–1 m’ age group than the dose to ‘>1 m–1 y’ age group. Non-use of

Table 11. Comparison of CTDI_{vol} and DLP values of abdomen CT with other studies.

Studies	CTDI _{vol} (mGy)		DLP (mGy cm)	
	>1–5 y	>5–10 y	>1–5 y	>5–10 y
This study	20	20	825	500
Brady <i>et al.</i> ⁽¹⁰⁾	4 ^a	10 ^b	150 ^a	400 ^b
Vassileva <i>et al.</i> ⁽¹⁵⁾	13 ^c	12 ^d	–	–

Dash (–) indicates data not available.

^a<5 y age group.

^b6–10 y age group.

^c1–5 y.

^d5–10 y.

anti-scatter grid was observed, and this was one of the observed good practices at the hospital. However, due to the urgency of the diagnosis in emergency situations, the use of protective gears, immobilisation devices and proper collimation was rarely in place. In addition, the selection of appropriate children exposure parameters was not always assured despite the availability of exposure chart for similar reasons. Change of practice might be one of the potential areas for optimisation. This includes use of higher tube potential, use of immobilisation devices and appropriate selection of exposure parameters. Applying these measures can reduce the dose levels but maintaining images of diagnostic quality and hence reducing the observed ESAK variations (Tables 1 and 2).

The results of fluoroscopy procedures (Table 3) also shed light on possible optimisation strategies. Despite that the equipment was fitted with ADRC device and all procedures were being performed using paediatric protocols, training the imaging personnel to plan the diagnosis can result in shorter fluoroscopy times and hence lower doses⁽¹⁷⁾. This strategy applies also to contrast enema procedures, which inadvertently requires relative longer fluoroscopy times to follow up the movement of the contrast media. However, such potential optimisation may not apply in ‘obstruction’ environments where even longer screening times can results. The CT procedures were always performed using tube current modulation and paediatric protocols, practices that can reduce dose without compromising with image quality^(10, 15). However, further adjusting user-selectable scan parameters such as the use of appropriate scan length, increasing pitch factor and lowering of tube potential can lead to some dose savings. The potential for such optimisation strategies is based on the observed high CTDI_{vol} and DLP variations (Tables 4–6).

The challenges faced in the comparison of patient doses under different situations are known. These include the applied methodology, dosimetry uncertainty, equipment characteristics, clinical indications

and the preferences of radiographers and radiologists. The variations in age group classifications is another challenge as some studies used age groups that are dictated in equipment protocols⁽¹⁰⁾. Despite these differences, relative comparisons can be useful to create the related awareness to the imaging professionals. Under this assumption and acknowledging possible limitations in the comparisons, the majority of the results in this study are generally comparable with the results from other studies with some exceptions (Tables 7–11).

The results of this study were obtained using dosimetry equipment compatible to the requirements of the International Electro-technical Commission (IEC) standard, 61674⁽¹⁸⁾. Therefore, the results can be considered to be of adequate accuracy. In addition to this compliance, all ionisation chambers were calibrated and hence reducing the uncertainty in the results. The estimated relative expanded uncertainty (coverage factor = 2) using standard method⁽¹⁴⁾ for ESAK, KAP and DLP values are 23, 15 and 18 %, respectively. Therefore, the results provide a reliable basis for creating awareness on good practice, implementing optimisation measures and performing comparisons between different studies.

CONCLUSION

The challenges in the countries with limited resource to achieve good optimisation during paediatric imaging are well known. A study conducted under typical challenges has been presented. Irrespective of age groups, the results show that the median ESAK values ranged from 62.6 to 248.1 μGy . Median KAP values ranged from 135.6 to 1612 $\mu\text{Gy cm}^2$, while mean DLP ranged from 119.1 to 825 mGy cm. The results should, therefore, be useful to form a good basis for optimisation as well as in enhancing awareness to the imaging professionals. The usefulness of performing regular patient dose assessments and performing comparisons with other similar studies has been demonstrated.

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REFERENCES

1. Brenner, D. J. *What we know and what we don't know about cancer risks associated with radiation doses from radiological imaging*. Br. J. Radiol. **87**(1035), 20130629 (2014).
2. Vassileva, J. et al. *IAEA survey of pediatric computed tomography practice in 40 countries in Asia, Europe, Latin America and Africa: frequency and appropriateness*. A. J. Roentgenol. **198**, 1021–1031 (2012).
3. Frush, D. P. *Justification and optimization of CT in children: how are we performing?* Pediatr. Radiol. **41**(Suppl 2), S467–S471 (2011).
4. Wambani, J. S., Korrir, G. K., Korrir, I. K. and Kilaha, S. *Establishment of local diagnostic reference levels in pediatric screen-film radiography at a children's hospital*. Radiat. Prot. Dosim. **154**(4), 465–475 (2013).
5. Billinger, J., Nowotny, R. and Homolka, P. *Diagnostic reference levels in pediatric radiology in Austria*. Eur. Radiol. **20**, 1572–1579 (2010).
6. Hart, D., Wall, B. F., Shrimpton, P. C. and Dance, D. R. *The establishment of reference doses in paediatric radiology as a function of patient size*. Radiat. Prot. Dosim. **90**(1/2), 735–738 (2000).
7. Hart, D., Wall, B. F., Shrimpton, P. C., Bungay, D. R. and Dance, D. R. *Reference doses and patient size in paediatric radiology*, NRPB-R 318, NRPB, Chilton (2000).
8. Suleiman, A., Vlychou, M., Tsougs, I. and Theodorou, K. *Radiation doses to pediatric patients and comforters undergoing chest x rays*. Radiat. Prot. Dosim. **147**(1–3), 171–175 (2011).
9. Hart, D., Hillier, M. C. and Wall, B. F. *National reference doses for common radiographic fluoroscopic and dental X-ray examinations in the UK*. Br. J. Radiol. **82**, 1–12 (2009).
10. Brady, Z., Ramanauskas, F., Cain, T. M. and Johnston, P. N. *Assessment of pediatric CT dose indicators for purpose of optimization*. Br. J. Radiol. **85**, 1488–1498 (2012).
11. Public Health England. *Doses from computed tomography (CT) examinations in the UK-2011 Review*. PHE publications, Chilton (2014).
12. Singh, S., Kalra, M. K., Moore, M. A., Shailam, R., Liu, B., Toth, T. L., Grant, E. and Westra, S. J. *Dose reduction and compliance with pediatric CT protocols adapted to patient size, clinical indication and number of prior studies*. Radiology, **252**(1), 200–208 (2009).
13. Tsapaki, V. et al. *Dose reduction in CT while maintaining diagnostic confidence: diagnostic reference levels at routine head, chest and abdominal CT-IAEA coordinated research project*. Radiology, **24**, 828–834 (2006).
14. International Atomic Energy Agency. *Dosimetry in diagnostic radiology: an International Code of Practice*, Technical Reports Series No. 457, IAEA (2007).
15. Vassileva, J., Rehani, M. M., Applegate, K., Ahmed, N. A., Al-Dhuhli, H. and Al-Naemi, H. M. *IAEA survey of pediatric computed tomography practice in 40 countries in Asia, Europe, Latin America and Africa: procedures and protocols*. Eur. Radiol. **23**(3), 623–631 (2013).
16. European Commission. *European guidelines on quality criteria for diagnostic radiographic images in paediatrics*. Off. J. Eur. Comm. 16261EN (1996).

17. Hernanz-Schulman, M., Goske, M. J., Bercha, I. H. and Strauss, K. J. *Pause and pulse: ten steps that help manage radiation dose during pediatric fluoroscopy*. Am. J. Roentgenol. **197**, 475–481 (2011).
18. International Electrical Committee. *Medical electrical equipment: dosimeters with ionization chambers and/or semi conductor detectors as used in X-ray diagnostic imaging*. Rep. IEC-61674, IEC, Geneva (1997).