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CT radiation dose in children: a survey to establish age-based diagnostic reference levels in Switzerland

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Abstract This work aimed at assessing the doses delivered in Switzerland to paediatric patients during computed tomography (CT) examinations of the brain, chest and abdomen, and at establishing diagnostic reference levels (DRLs) for various age groups. Forms were sent to the ten centres performing CT on children, addressing the demographics, the indication and the scanning parameters: number of series, kilovoltage, tube

current, rotation time, reconstruction slice thickness and pitch, volume CT dose index ($CTDI_{vol}$) and dose length product (DLP). Per age group, the proposed DRLs for brain, chest and abdomen are, respectively, in terms of $CTDI_{vol}$: 20, 30, 40, 60 mGy; 5, 8, 10, 12 mGy; 7, 9, 13, 16 mGy; and in terms of DLP: 270, 420, 560, 1,000 mGy cm; 110, 200, 220, 460 mGy cm; 130, 300, 380, 500 mGy cm. An optimisation process should be initiated to reduce the spread in dose recorded in this study. A major element of this process should be the use of DRLs.

Keywords Computed tomography · Paediatrics · Radiation dosimetry · Radiation protection · Diagnostic reference levels

Introduction

Since its first applications in the early 1970s the use of computed tomography (CT) has been continuously growing. According to the 2000 report [1] of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the frequency of CT examinations in countries of high healthcare level increased on average from 6.1 per year per 1,000 population in the 1970s to 48 per year per 1,000 population in the period 1991–1996, while the average effective dose per CT examination increased from 1.3 mSv in the 1970s to 8.8 mSv in the period 1991–1996. This increase went on steadily during the last decade. In Switzerland, the results of the 2003 survey on the exposure of the population by

medical X-ray imaging [2] indicated a 70% increase of CT examinations in a 5-year period (1998–2003), which, combined with a 20% increase in the average effective dose per CT procedure, led to an increase by a factor of two in the CT contribution to the collective dose due to medical X-rays reaching 47%. The same trend was registered in other European countries. In Norway, the frequency of CT examinations increased by a factor of 2.2 in a decade and CT contribution to collective effective dose was estimated to account for 59% of the total, as opposed to 30% in the previous survey [3]. In Germany, the increase in the collective dose due to CT rose by about 50% between 1996 and 2002, and in the UK the frequency of CT examinations increased by 39% between 1998 and 2002.

The proportion of all CT examinations which are performed in children does not exceed a few per cent. In Switzerland, the most recent nationwide survey on the exposure of the population by diagnostic and interventional radiology that provided patient age data indicated a CT paediatric fraction of 1% in 1998 [4, 5]. The same figure was reported in Germany for the period 2005-2006 [6]. Other countries reported higher values. Recent surveys covering the year 2000 revealed a paediatric fraction of 2.7% in Japan [7], and of 6.5% in the USA [8]. The latter figure is comparable with that given by UNSCEAR for the period 1991-1996 [1]. Only general guidelines are available for the use of CT in the paediatric population [9-13] and the need for size-based CT protocols has only recently been emphasised [6, 14-18]. Given the recent attention to radiation risks and CT in children [19-24] there is an urgent need for optimisation of the present practice by means of the introduction of the Diagnostic Reference Level (DRL) by the International Commission on Radiological Protection (ICRP) in 1997 [25]. For these reasons, we sought to assess the practice of paediatric CT in Switzerland using forms sent to the ten main centres (including regional and university hospitals) that perform CT examinations in children. The results of this survey allow the development of a set of DRL values for the most common paediatric CT examinations.

Materials and method

The survey conducted between January and December 2005 consisted of a questionnaire addressed to the ten centres dealing with paediatric CT in Switzerland (Aarau, Bellinzona, Bern, Fribourg, Geneva, Lausanne, St Gallen, Sion, Winterthur, and Zurich). The data were treated in an anonymous way, with the ten centres being coded by alphabetical letters from A to J.

In this survey, the paediatric population was separated into four age/weight groups (<1 year or <10 kg; 1-5 years or 10-20 kg; 5-10 years or 20-35 kg; 10-15 years or >35 kg). Each centre was asked to give the total number per age group of children undergoing CT of the brain, chest and abdomen during the year 2005. The generic indications of the examinations were chosen to be compatible with a previous survey conducted in the UK in 2003 [26]: trauma for brain and detection of malignancy for chest. The indication for the CT of the abdomen, which was not considered in the UK survey, was detection of malignancy.

For each type of examination and each age group, the type of CT machine and the CT parameters—including the number of series, the use of a contrast medium, the tube kilovoltage and current, the rotation time, the reconstruction slice thickness, the pitch, the displayed volume CT dose index (CTDI_{vol}) and the dose length product (DLP) as defined according to [27]—were requested. No dose measurements were carried out in the participating centres, but the readings of all the CT systems operating in Switzerland are periodically checked by the inspectors of the Federal Office of Public Health and the tolerated uncertainty according to the law is $\pm 30\%$. A consistency check of the CTDI_{vol} and DLPs collected was performed using the dosimetric characteristics of the CT machines used by means of the data published on the Impact Scan website [28]. At the end of the survey each centre received a final report to verify if the data recorded was correct and if some comment needed to be added.

Since no data related to CT examination performed on specific patients was collected, the DRL for a type of examination (and the associated indication) and for an age group is not established directly by taking the 75-percentile of a dose distribution, but indirectly based on the mean value of the dosimetric quantity (CTDI_{vol} or DLP). In this alternative method, already used in the past in situations where no dose distributions were available [29, 30], the

Table 1 Characteristics of the CT units used

Centre	Manufacturer	Model	Type
A ^a	Siemens	Sensation 16 (Body examinations)	MSCT (16-slice system)
	GE	LightSpeed 16 (Brain examinations)	MSCT (16-slice system)
B	Philips	Tomoscan SR 7000 SSCT	SSCT
C	Philips	Mx 8000 IDT (16 slices)	MSCT (16-slice system)
D ^a	Philips	Mx 8000 IDT (16 slices)	MSCT (16-slice system)
E	GE	LightSpeed 8	MSCT (8-slice system)
F	Siemens	Sensation 64	MSCT (64-slice system)
G ^a	GE	LightSpeed 16	MSCT (16-slice system)
H	Toshiba	Aquilion 16	MSCT (16-slice system)
I ^a	Picker	PQ 5000	SSCT
J	GE	CT/i PRO	SSCT

^aUniversity or paediatric hospital

Table 2 Number of examinations performed in the various centres

Centre	0–5 years (0–20 kg)	5–10 years (20–35 kg)	10–15 years (>35 kg)	Total
A ^a	208	126	186	520
B	10 ^b	7 ^b	8 ^b	25
D ^a	304	219	290	813
E	29	35	33	97
F	69	76	145	290
G ^a	261	212	217	690
I ^a	563	273	203	1039
J	26	38	86	150
All	1,470	986	1,168	3,624

^aUniversity or paediatric hospital

^bBased on the total number and using the average distribution of all the other centres

DRL is obtained by multiplying the mean value, obtained by averaging the typical values provided by the participating centres, by an appropriate factor (1.25 in the present work). Due to the typical shape of the dose distributions, this method provides a figure comparable with the third quartile. Each centre provided for each anatomical region and clinical indication typical values for the various age groups, taking into account the variability due to differences in the protocols used (number of sequences, technical parameters, etc.). Therefore, the average values over the participating centres expressed the national variability for a given examination/indication.

Results

Information was obtained from eight out of the ten centres. Two centres (C and H), which are small regional hospitals, could not provide it due to the limitation of their accounting systems. Three centres were not able to provide detailed information and gave either the number of all examinations ventilated by age, but merging the first two age categories (<1 year and 1–5 years) into a single one (0–5 years), (centres D and F), or the total number of examinations

(centre B). The CT systems involved in the survey are presented in Table 1.

The total frequencies of all types of examinations are given in Table 2. The data obtained from centres A, G and J specific to the two age categories (<1 year and 1–5 years) were summed up into a single one (0–5 years), in order to allow the comparison with the other centres. Moreover, in the case of centre B, the data presented for the three age groups was calculated based on the total number of examinations and using the average distribution of all the other centres. Table 3 presents the frequency data ventilated by type of examination, associated with the five centres that provided such detailed information (A, E, G, I and J).

Table 4 displays the dose results of the survey concerning the CT examinations of the brain, the chest and the abdomen and for the four age groups. Mean values averaged over the participating centres and ranges of the $CTDI_{vol}$ (mGy) and the DLP (mGy cm) values are given. Table 5 gives the DRL values, in terms of the $CTDI_{vol}$ (mGy) and the DLP (mGy cm), established as described above for the three types of CT examinations and the four age groups, as well as the corresponding DRLs reported in the literature for Germany and the UK.

Table 3 Number of examinations per type of examination. (Only the five centres, A, E, G, I and J, which gave detailed information, are considered)

Examination	0–5 years (0–20 kg)	5–10 years (20–35 kg)	10–15 years (>35 kg)	Total
Brain	793	407	351	1,551
Chest	173	146	198	517
Abdomen	121	131	176	428
Total	1,087	684	725	2,496

Table 4 Means values averaged over participating centres and ranges of CTDI_{vol} (mGy) and the DLP (mGy cm) values

Age group	Quantity	Brain			Chest			Abdomen		
		<i>n</i>	Mean	Range	<i>n</i>	Mean	Range	<i>n</i>	Mean	Range
<1 year	CTDI _{vol}	9	17	8.3-41	9	4.2	0.8-11	8	5.9	1.4-16
	DLP	9	213	66-414	9	85	12-198	8	107	29-258
1-5 years	CTDI _{vol}	10	25	13-41	10	6.5	0.8-20	10	7.2	1.4-16
	DLP	10	332	144-538	10	161	12-617	10	238	29-650
5-10 years	CTDI _{vol}	10	32	13-50	10	7.6	2.1-20	10	10	1.4-17
	DLP	10	451	173-621	10	178	32-352	10	308	29-627
10-15 years	CTDI _{vol}	10	45	14-85	10	9.6	2.1-26	10	13	4.5-18
	DLP	10	805	216-1'485	10	366	32-1'298	10	398	90-738

As an example of the dose distribution involved, Fig. 1 summarises the data obtained for children in the age group 1–5 years. It displays graphically the relation between the DLP and the CTDI_{vol}. The slope of the distribution of points expresses the anatomical length since, by definition, the DLP is the product of the CTDI_{vol} and the length of the volume examined. This information is of particular importance as the actual length exposed to primary radiation tends to increase when switching from a SSCT to a MDCT as shown by [26]. Moreover, one needs to control the over-ranging of the examination which tends to increase with the size of the beam collimation of the CT unit.

Discussion

The participating centres that carry out paediatric CT in Switzerland use a wide range of CT technologies. Table 1 shows that most centres are using multiple-slice CT (MSCT): one eight-slice, five 16-slice and one 64-slice systems from the four main CT manufacturers (General

Electric, Philips, Siemens and Toshiba). However, three centres, one of which is a University centre (I) are still using single slice CT (SSCT) units. There is a general trend in Switzerland to replace SSCT by MSCT systems and this hold for the total number of 216 CT in the country.

The eight centres that provided frequency data performed a total of 3,624 CT examinations in 2005 (Table 2), with an average of 453 per centre and a variability from 25 in a small centre (B) to 1,039 for a big centre (I). Forty-one per cent of the examinations are performed on newborns and children before the age of 5, 27% on children between 5 and 10, and 32% on children between 10 and 15. Table 3 shows that brain examinations represent on average 62% of the total, whereas chest and abdomen account for 21% and 17%, respectively. For the age category 0-5 brain examination accounts for as high as 73%. Three centres only (A, G and J) provided data separately for the two age groups <1 and 1-5, revealing that 16% of the examinations are performed on newborns and 84% on children between 1 and 5.

Large variations in dose appear between the different centres (Table 4). These variations are reflected in Fig. 1

Table 5 DRL values in terms of CTDI_{vol} (mGy) and the DLP (mGy cm) established in the present work compared with the data reported in Germany (D) and the UK

Age group	Quantity	Brain			Chest			Abdomen		
		This work	D [6]	UK [26]	This work	D [6]	UK [26]	This work	D [6]	UK [26]
<1 year	CTDI _{vol}	20	33	30	5	3.5	12	7	5	20 ^a
	DLP	270	390	270	110	55	200	130	145	170 ^a
1-5 years	CTDI _{vol}	30	40	45	8	5.5	13	9	8	20 ^a
	DLP	420	520	470	200	110	230	300	255	250 ^a
5-10 years	CTDI _{vol}	40	50	50	10	8.5	20	13	13	30 ^a
	DLP	560	710	620	220	210	370	380	475	500 ^a
10-15 years	CTDI _{vol}	60	60	65	12	6.8	14	16	10	14
	DLP	1'000	920	930	460	205	580	500	500	560

^aThese values recommended in the EU are taken from reference [31]. For the UK, adult values were taken for age group 10–15 years since they were not available in the report

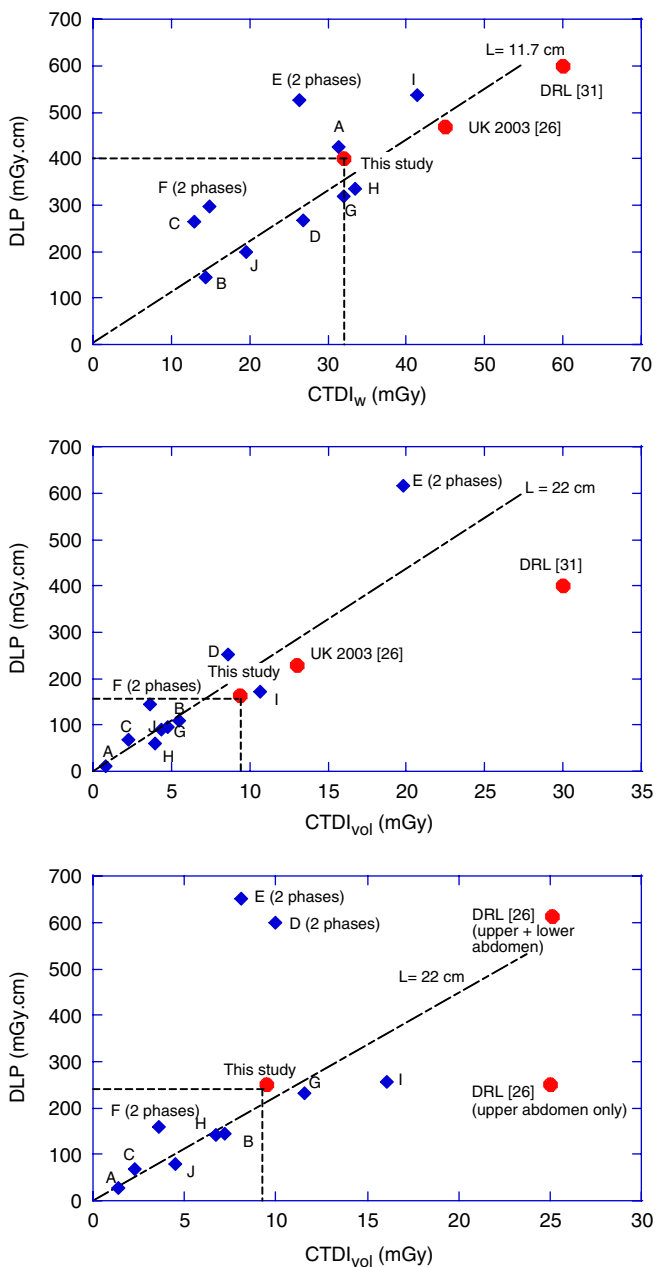


Fig. 1 Brain (*top*), chest (*middle*) and abdominal (*bottom*) examination for children in age group 1 to 5 years

that displays the plot of the DLP as a function of the CTDI_{vol} and the DLP. For brain examination, almost all data points can be aligned along a straight line that has a slope of 11.7 ($R^2=0.86$), meaning that the average length of coverage is 11.7 cm for this particular examination and age category. This examination length is fully compatible with the data obtained in the UK in 2003 (10.9–11.7 cm) [26]. For both chest and abdomen examinations, the slope is 22 ($R^2=0.94$ and $R^2=0.97$, respectively), i.e. an average scan length of 22 cm. It is of note that the value obtained for the

chest in this survey for a similar age category is slightly higher than the UK data (16.5–18.6 cm) [26]. Table 4 shows that the inter-centre variation for brain examination and for the different age groups ranges from a factor of 3.2–6.2 for the CTDI_{vol} (3.6–6.9 for the DLP) the highest variation being for age group 10–15 years where the CTDI_{vol} delivered varies from 14 to 85 mGy and the DLP varies from 216 to 1,485 mGy cm. For chest examination the inter-centre variations for the different age groups range from a factor of 9.5–25 for the CTDI_{vol} (11–51.4 for the DLP), the highest variation being for age group 1–5 years where the CTDI_{vol} delivered varies from 0.8 to 20 mGy and the DLP varies from 12 to 617 mGy cm. For abdomen examination, the inter-centre variations for the different age groups ranges from a factor of 4.0–12.1 for the CTDI_{vol} (8.2–22.4 for the DLP), the highest variation being for age group 1–5 years where the CTDI_{vol} delivered varies from 1.4 to 16 mGy and the DLP varies from 29 to 650 mGy cm.

It is worth mentioning that only one centre (I) that performs more than 1,000 CT examinations with a SSCT system does not adapt the protocols to the age of the patient. Thus, there is great potential for optimisation. The small centres (E and F) recourse systematically to a bi-phase acquisition. This practice is not adopted by the other centres for brain and chest examinations. Centre D (large) performs also a bi-phase acquisition during abdomen examinations, which leads to high dose values. Here again there is a potential for optimisation by specifying accurately the instances for which bi-phase acquisition is indicated.

The great dispersion of the CTDI_{vol} reflects a great dispersion of the associated image quality. The majority of the big centres produce images of homogeneous quality since they are well grouped. Centre I only, where no adaptation of protocols is used, the images produced are of excellent quality for a very young population of patients. On the other hand, in certain centres, where only a few examinations are carried out, such low CTDI values are used (0.8 mGy for chest and patients between 0 and 5 years; 1.4 mGy for abdomen and patients from 0 and 10 years) that the diagnostic quality of the image may be questioned.

As shown in Table 5, the DRLs in terms of CTDI_{vol} and DRLs are compatible with the values reported in Germany and the UK. In most cases they are lower than the UK data. Compared with the German data, the values established in this work are lower for the brain examination, but higher for chest and abdomen for some age groups.

The DRLs obtained in this investigation were established by considering typical dose values associated with standard protocols used in a given centre for the various types of examinations and age groups, and then averaging over the ten participating centres and multiplying by an appropriate factor. These DRLs should be considered as provisional only, to be replaced in the future by more robust data established through surveys of measured doses

on a big sample of patients leading to empirical dose distributions. The collection of such data is time and resource consuming, but the new Swiss legislation concerning the implementation of DRLs and the setting-up of a national dose database, as well as the standardisation of the way the dose descriptors (CTDI_{vol} and DLP parameters) will be stored in the DICOM header, which is under discussion, will all facilitate such an endeavour.

Conclusion

The frequency of paediatric CT examinations and the typical values of the related dose quantities (CTDI_{vol} and DRLs) were surveyed in the ten Swiss centres performing paediatric CT. Mean values averaged over the participating centres were calculated and the corresponding DRLs were established by multiplying the mean values by 1.25. This investigation revealed that 4,000–5,000 CT examinations are carried out on children in Switzerland, with an average of 453 per centre performing paediatric CT. Significant variations of the radiation dose delivered to the paediatric popu-

lation were found. An optimisation process should be initiated in order to reduce this spread in dose (appropriate image quality requirements for a given indication, number of acquisition phases that are clinically relevant, etc.). A major element of the optimisation process is a consensus on the DRLs that need to be used. This becomes a priority in the light of contributions such as described in a recent article published in the *Lancet* [32]. A set of DRL values for CT examinations of the brain, the chest and the abdomen and for the various age groups are proposed here for temporary use in paediatrics until a more extensive survey is organised to collect dose data on a large sample of patients and to establish empirical dose distributions.

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