Derivation of new diagnostic reference levels for neuro-paediatric computed tomography examinations in Switzerland

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Abstract

Purpose. Definition of new national diagnostic reference levels (DRLs) for volume computed tomography dose index (CTDIvol) and dose length product (DLP) for neuro-paediatric CT examinations depending on the medical indication.

Methods. Paediatric cranial CT data sets acquired between January 2013 and December 2016 were retrospectively collected between July 2016 and March 2017 from eight of the largest university and cantonal hospitals that perform most of the neuro-paediatric CTs in Switzerland. A consensus review of CTDIvol and DLP was undertaken for three defined anatomical regions: brain, facial bone, and petrous bone, each with and without contrast medium application. All indications for cranial CT imaging in paediatrics were assigned to one of these three regions. Descriptive statistical analysis of the distribution of the median values for CTDIvol and DLP yielded values in the minimum, maximum, 25th percentile (1st quartile), median (2nd quartile), and 75th percentile (3rd quartile). New DRLs for neuro-paediatric CT examinations in Switzerland were based on the 75th percentiles of the distributions of the median values of all eight centres. Where appropriate, values were rounded.
such that the DRLs increase or at least remain constant as the age of the patient increases. **Results.** Our results revealed DRLs for CTDI\textsubscript{vol} and DLP up to 20% lower than the DRLs used so far in Switzerland and elsewhere in Europe. **Conclusions.** This study provides Swiss neuro-paediatric CT DRL values to establish optimum conditions for paediatric cranial CT examinations. Periodic national updates of DRLs, following international comparisons, are essential.

Keywords: radiation protection, radiation monitoring, CT, neuro-paediatrics, DRL, CTDI\textsubscript{vol}, DLP

(Some figures may appear in colour only in the online journal)

**Abbreviations**

| Abbreviation | Description |
|--------------|-------------|
| CM           | contrast medium |
| CT           | computed tomography |
| CTDI\textsubscript{vol} | volume computed tomography dose index |
| DLP          | dose length product |
| DRL          | diagnostic reference level |
| FOPH         | Federal Office of Public Health |
| MRI          | magnetic resonance imaging |
| SL           | scan length |

**1. Introduction**

Exposure of children to ionising radiation during computed tomography (CT) examinations is a cause for concern. Most neuro-paediatric CT examinations take place in emergency situations, and a five-fold increase in frequency in the United States was documented from 1995–2008 [1]. This corresponds to a compound annual growth rate of 13.2% of paediatric emergency department visits that included a CT and a doubling time of approximately 5.6 years [1]. In 2008, CT was performed in 1.7 million of a total of 27.9 million paediatric visits to the emergency department [1]. Owing to its widespread availability, paediatric CT imaging is frequently used to enable correct diagnosis in the outpatient setting, e.g. for trauma and craniofacial surgery patients, who may undergo multiple head CTs during preoperative treatment and follow-up. Craniofacial paediatric CT imaging is commonly used for diagnostic evaluation, operative planning, and outcome analysis, despite increasing controversy regarding radiation exposure [2, 3]. The general increase of paediatric CT can be attributed to the availability of fast helical and multi-detector scanning, reducing the need for sedation and allowing the examination of younger, sicker, and uncooperative children.

Many university and regional hospitals in Switzerland use low-dose CT protocols, which partly limit the diagnostic value in regard to the clinical indication and necessity of repetition [4]. Low-dose CT protocols reduce the amount of ionising radiation exposure for paediatric patients but image quality and diagnostic utility are often significantly compromised.
Particularly in neurosurgical practice, children often require multiple brain CTs for some conditions e.g. hydrocephalus, intracranial haemorrhage, postoperative evaluation, and intracranial infectious fluid collections. Neurosurgeons are looking for very specific information on the CT images, in terms of the pathology and anatomical position; a decreased image quality may not be adequate. MRI—the imaging method of choice for children in most clinical circumstances—is not available in every hospital at all times.

In 2012, Pearce et al published a retrospective epidemiological study on the relationship between paediatric head CTs and increased risk of developing brain cancer and leukaemia. The authors reported that CT scans in children resulting in cumulative doses of about 50 mGy, could almost triple the risk of leukaemia, whereas doses of about 60 mGy might triple the risk of brain cancer [5]. Mathews et al reviewed a large cohort study of 680,000 children in Australia who underwent a CT examination between 1985 and 2005; a 24% higher cancer incidence in exposed than in non-exposed children was observed [6]. In 2013, the United Nations Scientific Committee on the Effects of Atomic Radiation considered the effects of radiation exposure on children and concluded that for a given radiation dose, children are generally at more risk of tumour induction than adults [7]. This emphasises that the estimates of lifetime cancer risk for those exposed as children might be a factor of two to three times higher than estimates for a population exposed at all ages [7].

These studies, together with the ‘as low as reasonably achievable’ (ALARA) concept in radiation protection, triggered worldwide awareness of the need for justification of paediatric CT examinations and optimisation of doses [8]. This led the International Commission on Radiological Protection (ICRP) to introduce the concept of diagnostic reference levels (DRLs) [9]. The objective was to suggest radiation dose levels for CTs under defined conditions in standard patients [10]. DRLs are not dose limits for individual patient examinations, rather they are used to identify those situations in which, for a specific radiological procedure, unusually high or low doses necessitate optimisation actions [10–13]. In recent years, DRLs have proved to be a valuable tool to reduce large differences in CT radiation doses between different radiological facilities. However, since the DRL is defined as the 75th percentile of the dose distribution, there is still a large potential to achieve further dose optimisation [10].

Paediatric CTs in small- and medium-sized hospitals are obviously performed much less often than adult CTs. The medical staff lack relevant experience and the use of the paediatric CT protocols is not optimised [14–19]. It is important to pay particular attention to paediatric CTs, because children are much more sensitive to ionising radiation than adults [16, 17]. Reliable CT scanning in a safe and effective manner is challenging in children because body size must be more carefully considered, patient cooperation and understanding is often limited or absent, and there is a lower tolerance for CT protocol errors in paediatrics [16, 17].

The purpose of our retrospective multicentre study was to define new national DRLs for volume computed tomography dose index (CTDIvol) and dose length product (DLP) of the most frequently performed neuro-paediatric CT examinations in Switzerland. These new DRLs are aimed to serve as an initial benchmark and provide guidance for the optimised application of CT protocols in neuroradiology departments in Swiss hospitals performing paediatric CTs. The strength, value, and originality of our study is that we propose DRLs for medical indications. The DRLs of other European countries were used for comparison.

2. Materials and methods

According to the Swiss radiation protection legislation (Radiological Protection Ordinance, Article 34, paragraph 2 [20]), the radiation protection authority is allowed to collect and
2.1. Data collection

Paediatric cranial CT data sets acquired between January 2013 and December 2016 were retrospectively collected during a 9-month period (July 2016 to March 2017) from the eight largest university and cantonal hospitals in Switzerland performing most of the neuro-paediatric CTs nationwide. The participating hospitals were the university hospitals of Geneva, Lausanne, Bern, Basel, and Zurich and the cantonal hospitals of Chur, Aarau, and Lucerne.

Anonymised dose data were collected from four Siemens CT scanners (Somatom Definition Edge), four GE CT scanners (Brightspeed 8, Discovery 750 HD, Lightspeed VCT, Revolution), three Toshiba CT scanners (Aquilion CXL, Aquilion One, Aquilion RXL), and one Philips CT scanner (Brilliance CT 64). The cantonal hospital of Aarau and the university hospital of Lausanne each provided dose data from three CT scanners; the other hospitals provided dose data from one CT scanner. In four hospitals, data were collected using commercial dose management software; in two hospitals, data were collected using data collection software developed in-house; and in two hospitals, data were manually registered in specific spreadsheets. The collected dose data were summarised in an Excel spreadsheet and sent to the project coordinator for analysis. Throughout the period of data collection, the project coordinator maintained close contact with the participating centres to provide support and clarification and give feedback when potential for increased efficiency was seen.

2.2. Patient data

The study population of children aged 0–16 years was classified into four age groups: <1.5 years, 1.5–5.5 years, 5.5–10.5 years, and 10.5–16 years. This age classification allowed the comparison of the actual Swiss practice in neuro-paediatric CT to the earlier practice in Switzerland and in other countries.

For each child, we gathered the following data: 1. age; 2. date of the CT; 3. indication for the CT; 4. exposure data, CTDI\textsubscript{vol}, and DLP, as well as approximated scan length (SL) calculated by dividing the DLP by the CTDI\textsubscript{vol}; 5. number of scans (if scans were repeated; e.g. because of lack of patient cooperation or excessive motion). The values used for the CTDI\textsubscript{vol} and DLP were the displayed values. Differences between the displayed and measured CTDI\textsubscript{vol} were in conformity with Swiss legal requirements (limit of \( \pm 20\% \)).

2.3. CT indications

A consensus review between the study coordinator, the local physicists collecting the data sets and the responsible person of the radiation protection authority of the CTDI\textsubscript{vol} and DLP was undertaken for the following three anatomical regions: brain, facial bone, and petrous bone; each with and without contrast medium (CM) application. All indications for cranial CT imaging were assigned to one of these regions. The medical indications for these defined anatomical regions, each with and without CM, are summarised in table 1.

All paediatric neuro CTs analysed were indicated after explicit consultation with the clinician and were of sufficient diagnostic image quality with regard to the clinical question. None of the scans were acquired only for study purposes.
**Table 1.** Indications for cranial CT imaging in paediatrics assigned to the three anatomic subgroups: brain, facial bone, and petrous bone, with and without CM.

| Anatomical region | Medical indication |
|-------------------|--------------------|
| **Brain without CM application** | • brain trauma |• child abuse |
|                    |• evaluation of ventricular width (e.g. in patients with suspected shunt dysfunction) |• localisation of brain pressure probes |
|                    |• preoperative determination of extent of craniosynostosis |• dysmorphia of the skull |
|                    |• detection and evaluation of calcifications (e.g. in syndromes such as Sturge–Weber) | |
| **Brain with CM application** |• in complicated mastoiditis to rule out intracranial complications like sinus vein thrombosis, intracranial abscess, or Bezold’s abscess |• central and anterior skull base tumours (e.g. fibrous dysplasia, ossifying fibroma, eccordis physalliphora) |
|                    |• for staging of systemic diseases like Langerhans histiocytosis or mastocytosis with multifocal brain manifestations | |
| **Facial bone without CM application** |• midface trauma (fracture evaluation) including the paranasal sinus, nose, and orbit |• choanal atresia and stenosis of piriform aperture |
|                    |• polyposis nasi, Morbus Widal, and evaluation of uncomplicated sinusitis |• dentogenic pathologies (e.g. periradicular cysts) |
|                    |• for foreign body localisation after midface trauma or in case of ingestion |• juvenile temporomandibular arthropathy |
| **Facial bone with CM application** |• complicated sinusitis |• acute and chronic osteomyelitis of midface and anterior skull, as well as recurrent infections (e.g. recurrent multifocal osteomyelitis in children) |
|                    |• osteonecrosis (e.g. radiogenic induced) |• suspected nasal, paranasal, or orbital tumours |
|                    |• tumour-like lesions and temporomandibular joint tumours (e.g. chondromatosis) | |
| **Petrous bone without CM application** |• congenital anomalies of the temporal bone, middle ear cavity, and inner ear | |
2.4. Patient data analysis

The data acquired were analysed per centre, and stratified according to age group and anatomical region; with and without CM. If more than one CT scan had to be acquired for a patient, e.g. if the patient had moved or needed several follow-up CT scans; each was evaluated separately.

For each age group, anatomic region, and hospital, median values for CTDIvol and DLP were calculated. Descriptive statistical analysis of the resulting distributions of the median values yielded values for minimum, maximum, 25th percentile (1st quartile), median (2nd quartile), and 75th percentile (3rd quartile). In accordance with the recommendations of the ICRP [9], national DRLs were defined as the 75th percentiles of the dose distributions.

The results for brain CTs were compared with the currently valid DRLs in Switzerland [11], from L’Institut de Radioprotection et de Sûreté Nucléaire (IRSN) France 2009 [21], the American Association of Physicists in Medicine (AAPM) [22], and the European Guidelines on DRLs for Paediatric Imaging [23]. For the international comparison of the anatomic region of facial bone we used the available valid DRLs from Switzerland [11] and the IRSN France [21] and, for petrous bone, DRLs from the IRSN France [21], which were the only ones available. Our literature search did not yield other comparable DRLs for the anatomic regions of facial bone and petrous bone; in our experience the second and third most frequently CT-examined anatomic regions in children. Note that the survey from L’Institut de Radioprotection et de Sûreté Nucléaire (IRSN) France 2009 does not document DRLs for children older than 10 years [21].

Data were reviewed and processed by an experienced medical physicist, and an independent quality assurance check of the processed data was performed. If necessary, clarification from the project coordinator was requested. At the end of our study each of the participating centres received a copy of their recorded data to verify whether the data were correct and if any comments needed to be added.

2.5. Statistical analysis

The statistical analysis was performed using R software version 3.3.3 (R: a language and environment for statistical computing, R Foundation for Statistical Computing, Vienna,
Austria). The statistical significance of differences between the different age groups for each anatomical localisation was tested with Kruskal–Wallis (significance level $p = 0.05$).

3. Results

In total, 1645 (100%) paediatric neuro CTs were recorded and retrospectively analysed: 1172 (71.2%) brain CTs without CM application; 127 (7.7%) brain CTs with CM application; 206 (12.5%) facial bone CTs without CM application; 14 (0.9%) facial bone CTs with CM application, 125 (7.6%) petrous bone CTs without CM application, and 1 (0.1%) petrous bone CT with CM application. The total frequencies of all types of examinations are given in table 2.

The number of CTs with CM application was very low; dose data for CTs with and without CM application for the three anatomic regions (results in the appendix) were pooled for further analysis. For most of the studies with CM application the same CT protocol with the same scanning parameters were used as for native CT studies. In table 3, the 75th percentiles of the distribution of the median values of all eight centres for CTDI$_{vol}$ and DLP are presented for the three anatomic regions. The values for CTDI$_{vol}$ and DLP recorded for each centre separately are documented in the appendix.

The comparison of the 75th percentiles of the distribution of the median values of all eight centres for CTDI$_{vol}$ and DLP for brain CTs to the currently valid DRLs in Switzerland [11], from IRSN France [21], the AAPM [22], and the European Guidelines on DRLs for Paediatric Imaging [23] revealed from 10% up to 40% lower values; compare figures 1(a) and (b). The international comparison of the anatomic regions, facial bone, and petrous bone, with the available valid DRLs for facial bone from Switzerland [11] and the IRSN France [21] and with the available DRLs from the IRSN France [21] for petrous bone, also revealed decreases in the 75th percentiles from 5%–70% in comparison to the currently valid values as shown in figures 2(a) and (b) and 3(a) and (b).

For CTDI$_{vol}$, there was a significant difference between the age classes for the brain ($p < 0.001$) and the facial bone ($p < 0.05$), but not for the petrous bone ($p = 0.24$). Concerning the DLP value, significant differences between age classes were found for the brain ($p < 0.001$), the facial bone ($p = 0.01$), and the petrous bone ($p = 0.02$).

In contrast, the SL for the three anatomical regions was higher than the currently valid values in Switzerland [11], as well as those from IRSN France [21], the AAPM [22], and the European Guidelines on DRLs for Paediatric Imaging [23] (see appendix).

In our large cohort of CTs, no wide variations in dose were found between the participating hospitals (compare appendix).

New DRLs for neuro-paediatric CT examinations in Switzerland were based on the 75th percentiles of the distributions of the median values of all eight centres. Where appropriate, values were rounded such that the DRLs increase, or at least remain constant, as the age of the patient increases. From our point of view such rounding of the values is practical for hospitals acquiring paediatric CTs. Table 3 shows the rounded values that were obtained taking the standard deviations into consideration. The new proposed DRLs for the three anatomic regions—brain, facial bone, and petrous bone—are presented in table 3 and figures 4(a) and (b).
| Centres | Brain without CM | Brain with CM | Facial bone without CM | Facial bone with CM | Petrous bone without CM | Petrous bone with CM | Total number of CTs | Total % of CTs |
|---------|------------------|---------------|------------------------|--------------------|-------------------------|---------------------|---------------------|------------------|
| A       | 149              | 16            | 34                     | 4                  | 23                      | 1                   | 227                 | 14               |
| B       | 130              | 31            | 18                     | 2                  | 17                      | 0                   | 198                 | 12               |
| C       | 17               | 0             | 5                      | 1                  | 3                       | 0                   | 26                  | 2                |
| D       | 38               | 0             | 4                      | 1                  | 9                       | 0                   | 52                  | 3                |
| E       | 28               | 11            | 2                      | 1                  | 9                       | 0                   | 51                  | 3                |
| F       | 39               | 10            | 29                     | 3                  | 21                      | 0                   | 102                 | 6                |
| H       | 309              | 25            | 47                     | 0                  | 0                       | 0                   | 381                 | 23               |
| I       | 462              | 34            | 67                     | 3                  | 43                      | 0                   | 609                 | 37               |
| Total number of CTs | 1172 | 127 | 206 | 14 | 125 | 1 | 1645 | — |

| Total % of CTs | 71.2% | 7.7% | 12.5% | 0.9% | 7.6% | 0.1% | — | 100 |

Table 2. Total frequencies of all types of examinations at all eight participating centres.
4. Discussion

Following our study, we established new age-related DRLs for CTDI$_{vol}$ and DLP for the most frequently performed neuro-paediatric CT examinations in Switzerland. Our results with new DRLs for CTDI$_{vol}$ and DLP were up to 20% lower than the DRLs so far used in Switzerland, as well as in other European countries (figures 1–3), confirm the importance of regular re-assessment of the radiological practice; at least every 3 to (maximum) 5 years. As a consequence of our study, new national DRLs were established in Switzerland for CTDI$_{vol}$ and DLP for paediatric patients in four defined age groups (<1.5 years, 1.5–5.5 years, 5.5–10.5 years, and 10.5–16 years) for the three main anatomic regions—brain, facial bone, and petrous bone.

DRLs are considered to be dynamic values that are reviewed periodically [24]. DRLs for indication-based CTs in Switzerland were established for adults in 2010 [25]. The results showed large variations in doses between different radiology departments in Switzerland, especially for examinations of the petrous bone, pelvis, lower limbs, and heart, indicating that the concept of DRLs was not being correctly applied for CTs in clinical routine in Switzerland.

A dose optimisation process should be triggered resulting in a lower radiation dose, especially in children. By repeatedly implementing such reviews, the global radiation dose is expected to decrease over a (short) period of time [15, 25–29].

As our study demonstrated, a multidisciplinary collaboration between different centres is essential when developing and implementing dose-optimised CT protocols beyond institutional single-centre boundaries. As shown, each participating centre provided a different amount of CT data depending on the hospital’s size.

### Table 3. New proposed rounded DRLs (75th percentiles) as well as target values (median values) for CTDI$_{vol}$ and DLP for neuro-paediatric CT examinations, age-related and separated according to the three anatomic regions: brain, facial bone, and petrous bone. For CTDI$_{vol}$ compare figure 4(a) and for DLP compare figure 4(b).

| Anatomical region | Patient’s age [years] | DRLs (75th percentile) | Target value (median) |
|-------------------|-----------------------|------------------------|-----------------------|
|                   |                       | CTDI$_{vol}$ [mGy]     | DLP [mGy.cm]         |
| Brain with CM     | <1.5                  | 25                     | 20                    |
|                   | 1.5–5.5               | 30                     | 24                    |
|                   | 5.5–10.5              | 35                     | 30                    |
|                   | >10.5                 | 40                     | 36                    |
| Brain without CM  | <1.5                  | 10                     | 7                     |
|                   | 1.5–5.5               | 15                     | 7                     |
|                   | 5.5–10.5              | 15                     | 7                     |
|                   | >10.5                 | 15                     | 10                    |
| Facial bone with CM | <1.5                 | 20                     | 17                    |
|                   | 1.5–5.5               | 30                     | 20                    |
|                   | 5.5–10.5              | 30                     | 20                    |
|                   | >10.5                 | 30                     | 20                    |
| Facial bone without CM | <1.5              | 10                     | 7                     |
|                   | 1.5–5.5               | 15                     | 7                     |
|                   | 5.5–10.5              | 15                     | 7                     |
|                   | >10.5                 | 15                     | 10                    |
| Petrous bone with CM | <1.5                  | 20                     | 17                    |
|                   | 1.5–5.5               | 30                     | 20                    |
|                   | 5.5–10.5              | 30                     | 20                    |
|                   | >10.5                 | 30                     | 20                    |
| Petrous bone without CM | <1.5              | 10                     | 7                     |
|                   | 1.5–5.5               | 15                     | 7                     |
|                   | 5.5–10.5              | 15                     | 7                     |
|                   | >10.5                 | 15                     | 10                    |
Since there was no statistically significant difference between dose data with and without CM application for the three defined anatomic regions and the number of CTs with CM was very low, the dose data were pooled for analysis. This decision was supported by the data evaluation, which revealed that for most of the studies with CM the same CT protocol was used with the same scanning parameters as for native CT studies. The pooling increased the statistical power and led to more reliable results.

The routine use of dose management software during CT scanning might also have an influence on the results. Centres using commercial or in-house developed dose management

![Figure 1](attachment:figure1.png)

**Figure 1.** Comparison of the 75th percentiles for CTDI\textsubscript{vol} (figure 1(a)) and DLP (figure 1(b)) for brain CT scans (black bars) compared to the currently valid DRLs in Switzerland from 2010 and in France from 2009 as well as to the DRLs published by the AAPM in 2014 and by the European Commission in 2015.
software provided more data than centres collecting dose data manually. The new Swiss DRLs for CTDIvol and DLP are much lower than the current Swiss DRLs and the DRLs of other European countries, indicating the use of dose-optimised CT protocols. Nevertheless, SLs were slightly higher than current values and the DRLs of other European countries suggesting a non-optimised radiological practice. The scan range chosen was too conservative and emphasises the need for continuation of efforts towards the optimisation of CT protocols.

Radiation dose must not be the only criterion considered when choosing the appropriate imaging modality for children. Some of the indications listed in table 1 could be examined

![Figure 2](image.png)  
**Figure 2.** Comparison of the 75th percentiles for CTDIvol (figure 2(a)) and DLP (figure 2(b)) for facial bone CT scans (black bars) compared to the currently valid DRLs in Switzerland from 2010 and in France from 2009.
adequately with MRI. But MRI is not always practical or preferable; particularly in acute trauma patients needing rapid treatment, CT is the preferred modality. Therefore, it is important to have CT protocols in place that minimise radiation dose without sacrificing diagnostic accuracy. Unfortunately, in practice, DRLs have not changed significantly over time [24]. Even though DRLs are currently the best tools for dose optimisation, the concept of DRLs only seems to work slowly. The DRL values set by different countries for brain CT examinations in children have changed little in recent years; several countries published
The proposed new rounded DRLs (grey bars) based on the 75th percentiles (in brackets) for CTDI\textsubscript{vol} (figure 4(a)) and DLP (figure 4(b)) for neuro-paediatric CT examinations; age-related and separated according to the three anatomic regions: brain, facial bone, and petrous bone.

current DRLs (2010–2014) that are equal to or even higher than the initial paediatric DRLs [24]. Although the ALARA principle is now more than 35 years old [30], and was introduced in paediatric imaging more than 10 years ago [8], it seems that there is still work to be done on dose optimisation in paediatric brain CT scans. This is highlighted by our current results with DRLs for CTDI\textsubscript{vol} and DLP up to 20% lower than the DRLs so far used in Switzerland as in other European countries.
There is no doubt that such regular data collection and re-evaluation is time and resource consuming, but since the Swiss legislation demands the implementation of DRLs and since dose management systems are increasingly installed in radiology departments allowing automatic data collection, this will facilitate such an endeavour.

A major element of that process of optimisation is a national and international consensus on the DRLs to avoid wide variations and minimise radiation risk and long-term complications in children. We recommend a time frame of 3 to a maximum of 5 years. In the future, it would be worthwhile to suggest DRLs for sub-specific cranial CT indications that might have different image quality requirements.

5. Limitations

The number of paediatric cranial CTs performed in Switzerland is limited. There are relatively few paediatric patients owing the small population and low number of university, cantonal, and regional hospitals compared to other European countries. The small amount of dose data inevitably results in decreased statistical accuracy. However, since one of the aims of this study was to harmonise the CT practice across Switzerland, all available data was included for analysis.

We are also aware that the different methods of data collection in the eight hospitals—using commercial dose management software; in-house developed data collection or manual data registration in specific spreadsheets—might have an influence on the amount and correctness of collected data. Commercial dose management software accesses all dose data from the DICOM header whereas manual data collection might be biased in terms of number and accuracy.

To improve statistical accuracy, the calculation of the 75th percentile of a dose distribution should be based on at least 20 data sets, as recommended by the ICRP in publication 135 on DRLs in medical imaging \[9\]. However, since the number of neuro-paediatric CT scans in Switzerland is limited, several hospitals provided fewer than 20 data sets for specific examinations (see table 2). If these data were to be omitted from the analysis, DRLs would be based on data from only a few hospitals and would not reflect the overall CT practice across Switzerland. Therefore, in order to harmonise the CT practice across Switzerland, we decided to include all data in our analysis, being fully aware that the statistical accuracy was decreased.

Image quality of the CT scans was assessed in a qualitative manner by the clinicians depending on the clinical indication. Image quality was considered to be sufficient if it allowed an accurate diagnosis. No quantitative image quality assessment (e.g. by calculating the signal-to-noise ratio or using model observers) was performed, since this would have gone beyond the scope of this study.

6. Conclusion

This article reports results from a national dose survey of neuro-paediatric CT examinations (1645 data sets were analysed) in eight participating university and cantonal hospitals in Switzerland. The results of the DRLs for CTDI\textsubscript{vol} and DLP were up to 20% lower than the DRLs so far used in Switzerland and other European countries, indicating that regular national and international updates of DRLs are essential. With respect to the rapidly evolving technology allowing a lower exposure to radiation while maintaining a high image quality...
sufficient for a correct diagnosis, periodic updates of regional and international DRLs at least every 3 to a maximum of 5 years are indispensable to establish optimum conditions for paediatric brain CTs.

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Appendix

A. Median values for CTDI<sub>vol</sub>, DLP, and SL from all eight centres for CT of the brain with and without primary CM application separated by age group.

| Table A.1. Paediatric Patients aged <1.5 years, brain CT without CM application. |
|-------------------------------------------------|
| **Center:** | **A** | **B** | **C** | **D** | **E** | **F** | **H** | **I** | **All data** | **DRL 75** |
|----------|------|------|------|------|------|------|------|------|-------------|-----------|
| CTDI [mGy] | Min | 17 | 6 | 13 | 17 | 5 | 6 | 12 | 1 | 1 | 21 |
| 25<sup>th</sup> percentile | 18 | 16 | 13 | 20 | 10 | 8 | 14 | 1 | 13 | |
| Median | 30 | 23 | 13 | 20 | 13 | 20 | 16 | 16 | 16 | |
| 75<sup>th</sup> percentile | 31 | 26 | 13 | 22 | 13 | 24 | 19 | 16 | 19 | |
| Max | 32 | 30 | 13 | 26 | 21 | 26 | 27 | 29 | 32 | |
| DLP [mGy.cm] | Min | 241 | 18 | 207 | 255 | 108 | 66 | 51 | 25 | 18 |
| 25<sup>th</sup> percentile | 292 | 202 | 209 | 307 | 307 | 151 | 134 | 205 | 30 | 163 |
| Median | 474 | 314 | 211 | 321 | 186 | 299 | 245 | 182 | 229 | 316 |
| 75<sup>th</sup> percentile | 530 | 361 | 212 | 339 | 201 | 365 | 273 | 231 | 290 | |
| Max | 723 | 416 | 214 | 395 | 417 | 483 | 390 | 628 | 723 | |
| Scan length [cm] | Median | 16 | 14 | 16 | 15 | 16 | 15 | 15 | 14 | 15 |
| number of exams | 26 | 38 | 2 | 10 | 5 | 11 | 64 | 107 | 263 | |

| Table A.2. Paediatric patients aged <1.5 years, brain CT with CM application. |
|-------------------------------------------------|
| **Center:** | **A** | **B** | **C** | **D** | **E** | **F** | **H** | **I** | **All data** | **DRL 75** |
|----------|------|------|------|------|------|------|------|------|-------------|-----------|
| CTDI [mGy] | Min | 32 | 22 | n | n | n | 22 | 14 | 16 | 12 |
| 25<sup>th</sup> percentile | 32 | 25 | n | n | n | 22 | 14 | 16 | 16 | |
| Median | 32 | 26 | n | n | n | 22 | 14 | 16 | 20 | 26 |
| 75<sup>th</sup> percentile | 32 | 26 | n | n | n | 22 | 14 | 16 | 26 | |
| Max | 32 | 27 | n | n | n | 22 | 14 | 16 | 32 | |
| DLP [mGy.cm] | Min | 321 | 120 | n | n | n | 347 | 181 | 136 | 22 |
| 25<sup>th</sup> percentile | 366 | 630 | n | n | n | 347 | 190 | 189 | 197 | |
| Median | 410 | 679 | n | n | n | 347 | 199 | 197 | 236 | |
| 75<sup>th</sup> percentile | 455 | 816 | n | n | n | 347 | 208 | 221 | 320 | |
| Max | 500 | 943 | n | n | n | 347 | 217 | 251 | 500 | |
| Scan length [cm] | Median | 13 | 13 | n | n | n | 16 | 14 | 12 | 13 |
| number of exams | 2 | 8 | 0 | 0 | 0 | 1 | 2 | 7 | 20 | |
### Table A.3. Paediatric patients aged 1.5–5.5 years, brain CT without CM application.

| Center | A | B | C | D | E | F | H | I | All data | DRL 75 |
|--------|---|---|---|---|---|---|---|---|----------|--------|
| CTDI [mGy] |   |   |   |   |   |   |   |   |          |        |
| Min    | 18 | 12 | 16 | 15 | 6  | 24 | 16 | 1  | 1        |        |
| 25th percentile | 31 | 28 | 16 | 20 | 11 | 25 | 19 | 19 | 19       |        |
| Median | 32 | 30 | 16 | 22 | 17 | 26 | 25 | 19 | 19       | 27     |
| 75th percentile | 32 | 30 | 21 | 24 | 17 | 27 | 35 | 19 | 30       |        |
| Max    | 32 | 44 | 26 | 27 | 17 | 30 | 39 | 40 | 44       |        |
| DLP [mGy.cm] |   |   |   |   |   |   |   |   |          |        |
| Min    | 189| 22 | 276| 246| 77 | 391| 159| 13 | 13       |        |
| 25th percentile | 530| 390| 276| 339| 188| 396| 301| 252| 271      |        |
| Median | 577| 416| 276| 366| 300| 401| 435| 271| 312      | 420    |
| 75th percentile | 630| 472| 360| 426| 307| 436| 515| 290| 472      |        |
| Max    | 803| 870| 443| 521| 314| 528| 392| 577| 932      |        |
| Scan length [cm] | Median | 18 | 14 | 18 | 18 | 16 | 16 | 14 | 15       | 18     |
| number of exams | 31  | 44 | 3  | 19 | 3  | 4  | 69 | 118| 291      |        |

### Table A.4. Paediatric patients aged 1.5–5.5 years, brain CT with CM application.

| Center | A | B | C | D | E | F | H | I | All data | DRL 75 |
|--------|---|---|---|---|---|---|---|---|----------|--------|
| CTDI [mGy] |   |   |   |   |   |   |   |   |          |        |
| Min    | 31 | 16 | n | n | 5  | 25 | 19 | 14 | 5        |        |
| 25th percentile | 31 | 29 | n | n | 11 | 26 | 19 | 18 | 19       |        |
| Median | 31 | 30 | n | n | 17 | 26 | 19 | 19 | 19       | 29     |
| 75th percentile | 32 | 32 | n | n | 18 | 26 | 31 | 19 | 31       |        |
| Max    | 32 | 43 | n | n | 18 | 31 | 36 | 19 | 43       |        |
| DLP [mGy.cm] |   |   |   |   |   |   |   |   |          |        |
| Min    | 499| 43 | n | n | 89 | 331| 263| 252| 43       |        |
| 25th percentile | 551| 345| n | n | 210| 401| 277| 266| 293      |        |
| Median | 596| 418| n | n | 331| 402| 313| 271| 405      | 414    |
| 75th percentile | 666| 454| n | n | 356| 410| 480| 298| 454      |        |
| Max    | 791| 529| n | n | 381| 446| 556| 382| 791      |        |
| Scan length [cm] | Median | 19 | 14 | n | n | 20 | 16 | 15 | 16       | 18     |
| number of exams | 4  | 8  | 0 | 0 | 3  | 5  | 6  | 4  | 30       |        |

### Table A.5. Paediatric patients aged 5.5–10.5 years, brain CT without CM application.

| Center | A | B | C | D | E | F | H | I | All data | DRL 75 |
|--------|---|---|---|---|---|---|---|---|----------|--------|
| CTDI [mGy] |   |   |   |   |   |   |   |   |          |        |
| Min    | 29 | 28 | 4 | 16 | 6  | 11 | 4  | 1  | 1        |        |
| 25th percentile | 31 | 30 | 11 | 21 | 14 | 26 | 28 | 33 | 28       |        |
| Median | 32 | 31 | 18 | 21 | 17 | 28 | 36 | 35 | 32       | 33     |
| 75th percentile | 32 | 35 | 20 | 23 | 18 | 31 | 46 | 36 | 36       |        |
| Max    | 32 | 39 | 30 | 28 | 21 | 33 | 50 | 41 | 50       |        |
| DLP [mGy.cm] |   |   |   |   |   |   |   |   |          |        |
| Min    | 861| 390| 51 | 297| 54 | 254| 36 | 16 | 16       |        |
| 25th percentile | 522| 416| 186| 349| 193| 429| 468| 473| 452      |        |
| Median | 594| 500| 285| 365| 262| 462| 550| 510| 511      | 520    |
| 75th percentile | 683| 543| 329| 392| 309| 553| 719| 547| 583      |        |
| Max    | 923| 621| 533| 504| 385| 614| 983| 838| 983      |        |
| Scan length [cm] | Median | 19 | 15 | 16 | 17 | 16 | 17 | 16 | 15       | 17     |
| number of exams | 32  | 12 | 5  | 7  | 4  | 17 | 73 | 114| 264      |        |
Table A.6. Paediatric patients aged 5.5–10.5 years, brain CT with CM application.

| Center: | A | B | C | D | E | F | H | I | All data | DRL 75 |
|---------|---|---|---|---|---|---|---|---|----------|--------|
| CTDI [mGy] | Min | 30 | 29 | n | n | 19 | 27 | 28 | 19 | 15         |
|          | 25<sup>th</sup> percentile | 31 | 29 | n | n | 20 | 28 | 28 | 35 | 28         |
|          | Median | 32 | 29 | n | n | 22 | 29 | 36 | 36 | 32         |
|          | 75<sup>th</sup> percentile | 32 | 29 | n | n | 27 | 29 | 48 | 36 | 36         |
|          | Max | 32 | 29 | n | n | 37 | 30 | 48 | 40 | 48         |
| DLP [mGy.cm] | Min | 261 | 472 | n | n | 326 | 460 | 418 | 271 | 216       |
|          | 25<sup>th</sup> percentile | 503 | 472 | n | n | 378 | 468 | 482 | 510 | 473       |
|          | Median | 560 | 472 | n | n | 431 | 476 | 515 | 546 | 511       |
|          | 75<sup>th</sup> percentile | 721 | 472 | n | n | 538 | 484 | 707 | 583 | 613       |
|          | Max | 778 | 472 | n | n | 755 | 491 | 815 | 659 | 815       |
| Scan length [cm] | Median | 18 | 16 | n | n | 19 | 17 | 15 | 15 | 16         |
| number of exams | 8 | 1 | 0 | 0 | 4 | 2 | 7 | 17 | 39 | 39        |

Table A.7. Paediatric patients aged 10.5–16 years, brain CT without CM application.

| Center: | A | B | C | D | E | F | H | I | All data | DRL 75 |
|---------|---|---|---|---|---|---|---|---|----------|--------|
| CTDI [mGy] | Min | 29 | 23 | 26 | 19 | 4 | 23 | 23 | 1 | 1       |
|          | 25<sup>th</sup> percentile | 31 | 39 | 26 | 22 | 8 | 30 | 36 | 39 | 31       |
|          | Median | 32 | 45 | 39 | 24 | 17 | 32 | 46 | 40 | 41       |
|          | 75<sup>th</sup> percentile | 32 | 45 | 39 | 26 | 20 | 34 | 50 | 40 | 41       |
|          | Max | 46 | 53 | 40 | 29 | 27 | 41 | 174 | 41 | 174      |
| DLP [mGy.cm] | Min | 357 | 451 | 416 | 363 | 77 | 402 | 296 | 22 | 22       |
|          | 25<sup>th</sup> percentile | 567 | 631 | 500 | 417 | 151 | 512 | 600 | 576 | 569      |
|          | Median | 602 | 676 | 647 | 471 | 340 | 541 | 730 | 617 | 618      |
|          | 75<sup>th</sup> percentile | 719 | 721 | 665 | 525 | 374 | 593 | 873 | 618 | 721      |
|          | Max | 1008 | 808 | 766 | 579 | 492 | 873 | 1222 | 970 | 1222     |
| Scan length [cm] | Median | 20 | 16 | 17 | 19 | 19 | 17 | 17 | 15 | 16       |
| number of exams | 60 | 36 | 7 | 2 | 16 | 7 | 103 | 123 | 354 | 354     |

Table A.8. Paediatric patients aged 10.5–16 years, brain CT with CM application.

| Center: | A | B | C | D | E | F | H | I | All data | DRL 75 |
|---------|---|---|---|---|---|---|---|---|----------|--------|
| CTDI [mGy] | Min | 30 | 22 | n | n | 17 | 30 | 15 | 40 | 19       |
|          | 25<sup>th</sup> percentile | 30 | 41 | n | n | 17 | 30 | 28 | 40 | 29       |
|          | Median | 31 | 45 | n | n | 18 | 30 | 41 | 40 | 40       |
|          | 75<sup>th</sup> percentile | 31 | 50 | n | n | 20 | 30 | 49 | 40 | 48       |
|          | Max | 31 | 58 | n | n | 21 | 30 | 52 | 41 | 58       |
| DLP [mGy.cm] | Min | 536 | 58 | n | n | 270 | 471 | 306 | 576 | 58       |
|          | 25<sup>th</sup> percentile | 544 | 570 | n | n | 342 | 475 | 357 | 586 | 517      |
|          | Median | 551 | 699 | n | n | 508 | 479 | 737 | 617 | 617      |
|          | 75<sup>th</sup> percentile | 559 | 721 | n | n | 1049 | 484 | 844 | 617 | 730      |
|          | Max | 566 | 808 | n | n | 2396 | 488 | 989 | 618 | 989      |
| Scan length [cm] | Median | 18 | 16 | n | n | 19 | 16 | 17 | 15 | 16       |
| number of exams | 2 | 14 | 0 | 0 | 4 | 2 | 10 | 6 | 38       |
B. The median value for CTDI\textsubscript{vol}, DLP, and scan length of all eight centres for CT of the facial bone with and without primary CM application separated by age group.

**Table B.1.** Paediatric patients aged <1.5 years, facial bone CT without CM application.

| Center | A | B | C | D | E | F | H | I | All data | DRL 75 |
|--------|---|---|---|---|---|---|---|---|----------|--------|
| CTDI [mGy] | | | | | | | | | | |
| Min | 7 | 6 | n | n | 13 | 3 | n | 3 | 3 | |
| 25\textsuperscript{th} percentile | 7 | 6 | n | n | 13 | 4 | n | 3 | 3 | |
| Median | 7 | 7 | n | n | 13 | 6 | n | 6 | 7 | |
| 75\textsuperscript{th} percentile | 7 | 9 | n | n | 13 | 8 | n | 8 | 8 | |
| Max | 7 | 11 | n | n | 13 | 8 | n | 8 | 13 | |
| DLP [mGy.cm] | | | | | | | | | | |
| Min | 139 | 71 | n | n | 200 | 31 | n | 41 | 31 | |
| 25\textsuperscript{th} percentile | 139 | 79 | n | n | 200 | 36 | n | 55 | 52 | |
| Median | 139 | 87 | n | n | 200 | 41 | n | 75 | 87 | 139 |
| 75\textsuperscript{th} percentile | 139 | 95 | n | n | 200 | 56 | n | 108 | 121 | |
| Max | 139 | 102 | n | n | 200 | 92 | n | 159 | 200 | |
| Scan length [cm] | | | | | | | | | | |
| Median | 19 | 19 | n | n | 16 | 10 | n | 15 | 12 | 19 |
| number of exams | 1 | 3 | 0 | 0 | 1 | 4 | 0 | 4 | 13 | |

**Table B.2.** Paediatric patients aged <1.5 years, facial bone CT with CM application.

| Center | A | B | C | D | E | F | H | I | All data | DRL 75 |
|--------|---|---|---|---|---|---|---|---|----------|--------|
| CTDI [mGy] | | | | | | | | | | |
| Min | 11 | n | n | 2 | n | 3 | n | 8 | 2 | |
| 25\textsuperscript{th} percentile | 11 | n | n | 2 | n | 3 | n | 8 | 3 | |
| Median | 11 | n | n | 2 | n | 3 | n | 8 | 6 | 9 |
| 75\textsuperscript{th} percentile | 11 | n | n | 2 | n | 3 | n | 8 | 9 | 15 |
| Max | 11 | n | n | 2 | n | 3 | n | 8 | 11 | |
| DLP [mGy.cm] | | | | | | | | | | |
| Min | 122 | n | n | 19 | n | 39 | n | 99 | 19 | |
| 25\textsuperscript{th} percentile | 122 | n | n | 19 | n | 39 | n | 99 | 34 | |
| Median | 122 | n | n | 19 | n | 39 | n | 99 | 69 | 105 |
| 75\textsuperscript{th} percentile | 122 | n | n | 19 | n | 39 | n | 99 | 105 | |
| Max | 122 | n | n | 19 | n | 39 | n | 99 | 122 | |
| Scan length [cm] | | | | | | | | | | |
| Median | 11 | n | n | 10 | n | 12 | n | 15 | 11 | 12 |
| number of exams | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 4 | |

**Table B.3.** Paediatric patients aged 1.5–5.5 years, facial bone CT without CM application.

| Center | A | B | C | D | E | F | H | I | All data | DRL 75 |
|--------|---|---|---|---|---|---|---|---|----------|--------|
| CTDI [mGy] | | | | | | | | | | |
| Min | 1 | 5 | n | 2 | 5 | 4 | 4 | 6 | 1 | |
| 25\textsuperscript{th} percentile | 7 | 6 | n | 2 | 5 | 4 | 4 | 6 | 4 | |
| Median | 16 | 9 | n | 2 | 5 | 4 | 5 | 6 | 6 | 7 |
| 75\textsuperscript{th} percentile | 16 | 12 | n | 2 | 5 | 4 | 10 | 8 | 11 | |
| Max | 18 | 13 | n | 2 | 5 | 4 | 36 | 11 | 36 | |
| DLP [mGy.cm] | | | | | | | | | | |
| Min | 15 | 78 | n | 16 | 85 | 34 | 38 | 86 | 15 | |
| 25\textsuperscript{th} percentile | 95 | 81 | n | 17 | 85 | 34 | 45 | 90 | 71 | |
| Median | 176 | 119 | n | 18 | 85 | 34 | 69 | 106 | 86 | 113 |
| 75\textsuperscript{th} percentile | 210 | 162 | n | 19 | 85 | 34 | 150 | 108 | 164 | |
| Max | 258 | 176 | n | 20 | 85 | 34 | 809 | 138 | 809 | |
| Scan length [cm] | | | | | | | | | | |
| Median | 13 | 14 | n | 9 | 16 | 9 | 15 | 14 | 15 | 14 |
| number of exams | 7 | 4 | 0 | 2 | 1 | 1 | 7 | 9 | 31 | |
Table B.4. Paediatric patients aged 1.5–5.5 years, facial bone CT with CM application.

| Center: | A | B | C | D | E | F | H | I | All data | DRL 75 |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| CTDI [mGy] | | | | | | | | | | |
| Min | 14 | n | n | n | 5 | n | n | n | 5 | 9 |
| 25th percentile | 14 | n | n | n | 5 | n | n | n | 9 | 5 |
| Median | 14 | n | n | n | 5 | n | n | n | 5 | 12 |
| 75th percentile | 14 | n | n | n | 5 | n | n | n | 22 | 22 |
| Max | 14 | n | n | n | 5 | n | n | n | 29 | 29 |
| DLP [mGy.cm] | | | | | | | | | | |
| Min | 205 | n | n | n | 68 | n | n | n | 68 | 68 |
| 25th percentile | 205 | n | n | n | 68 | n | n | n | 68 | 68 |
| Median | 205 | n | n | n | 68 | n | n | n | 70 | 136 |
| 75th percentile | 205 | n | n | n | 68 | n | n | n | 68 | 205 |
| Max | 205 | n | n | n | 68 | n | n | n | 736 | 736 |
| Scan length [cm] | Median | 15 | n | n | n | 14 | n | n | n | 15 |
| number of exams | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 2 |

Table B.5. Paediatric patients aged 5.5–10.5 years, facial bone CT without CM application.

| Center: | A | B | C | D | E | F | H | I | All data | DRL 75 |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| CTDI [mGy] | | | | | | | | | | |
| Min | 1 | 11 | 1 | 2 | n | 4 | 4 | 6 | 3 | 2 |
| 25th percentile | 11 | 17 | 2 | 2 | n | 4 | 4 | 6 | 11 | 11 |
| Median | 15 | 23 | 2 | 2 | n | 4 | 4 | 5 | 11 | 11 |
| 75th percentile | 17 | 28 | 2 | 2 | n | 5 | 5 | 8 | 14 | 14 |
| Max | 27 | 34 | 2 | 2 | n | 12 | 12 | 16 | 48 | 48 |
| DLP [mGy.cm] | | | | | | | | | | |
| Min | 13 | 134 | 22 | 32 | n | 48 | 36 | 75 | 13 | 13 |
| 25th percentile | 118 | 273 | 25 | 32 | n | 56 | 51 | 109 | 58 | 58 |
| Median | 172 | 412 | 29 | 32 | n | 60 | 62 | 138 | 123 | 123 |
| 75th percentile | 230 | 551 | 32 | 32 | n | 66 | 184 | 155 | 163 | 163 |
| Max | 274 | 690 | 35 | 32 | n | 96 | 983 | 300 | 983 | 983 |
| Scan length [cm] | Median | 11 | 16 | 16 | 14 | n | 14 | 12 | 16 | 14 |
| number of exams | 12 | 2 | 2 | 1 | 0 | 8 | 15 | 17 | 14 | 57 |

Table B.6. Paediatric patients aged 5.5–10.5 years, facial bone CT with CM application.

| Center: | A | B | C | D | E | F | H | I | All data | DRL 75 |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| CTDI [mGy] | | | | | | | | | | |
| Min | 13 | n | n | n | n | 3 | n | 10 | 3 |
| 25th percentile | 13 | n | n | n | n | 4 | n | 10 | 5 |
| Median | 13 | n | n | n | n | 4 | n | 10 | 10 |
| 75th percentile | 13 | n | n | n | n | 4 | n | 10 | 13 |
| Max | 13 | n | n | n | n | 5 | n | 10 | 16 |
| DLP [mGy.cm] | | | | | | | | | | |
| Min | 170 | n | n | n | n | 65 | n | 182 | 65 |
| 25th percentile | 170 | n | n | n | n | 70 | n | 182 | 86 |
| Median | 170 | n | n | n | n | 76 | n | 182 | 170 |
| 75th percentile | 170 | n | n | n | n | 81 | n | 182 | 182 |
| Max | 170 | n | n | n | n | 86 | n | 182 | 247 |
| Scan length [cm] | Median | 13 | n | n | n | 20 | n | 18 | 15 |
| number of exams | 1 | 1 | 0 | 0 | 0 | 2 | 0 | 1 | 5 | 5 |
Table B.7. Paediatric patients aged 10.5–16 years, facial bone CT without CM application.

| Center | A | B | C | D | E | F | H | I | All data | DRL 75 |
|--------|---|---|---|---|---|---|---|---|----------|--------|
| **CTDI [mGy]** | | | | | | | | | | |
| Min    | 1 | 1 | 2 | 2 | n | 4 | 4 | 6 | 1 | 1      |
| 25th percentile | 1 | 1 | 2 | 2 | n | 5 | 7 | 8 | 5 | 5      |
| Median | 14 | 11 | 2 | 2 | n | 5 | 27 | 8 | 8 | 13     |
| 75th percentile | 19 | 14 | 2 | 2 | n | 5 | 28 | 8 | 12 | 12    |
| Max    | 28 | 15 | 2 | 2 | n | 12 | 38 | 16 | 16 | 38     |
| **DLP [mGy.cm]** | | | | | | | | | | |
| Min    | 18 | 75 | 30 | 24 | n | 56 | 56 | 77 | 18 |        |
| 25th percentile | 21 | 153 | 35 | 24 | n | 66 | 135 | 117 | 76 |        |
| Median | 155 | 195 | 40 | 24 | n | 74 | 268 | 128 | 129 | 175    |
| 75th percentile | 225 | 216 | 40 | 24 | n | 81 | 452 | 138 | 209 |          |
| Max    | 329 | 302 | 41 | 24 | n | 309 | 763 | 270 | 763 |        |
| **Scan length [cm]** | | | | | | | | | | |
| Median | 13 | 17 | 17 | 12 | n | 15 | 16 | 16 | 15 | 17     |
| **number of exams** | 14 | 9 | 3 | 1 | 0 | 16 | 25 | 37 | 105 |        |

Table B.8. Paediatric patients aged 10.5–16 years, facial bone CT with CM application.

| Center | A | B | C | D | E | F | H | I | All data | DRL 75 |
|--------|---|---|---|---|---|---|---|---|----------|--------|
| **CTDI [mGy]** | | | | | | | | | | |
| Min    | 17 | n | 5 | n | n | n | n | 40 | 9 | 4      |
| 25th percentile | 17 | n | 5 | n | n | n | n | 40 | 10 |        |
| Median | 17 | n | 5 | n | n | n | n | 40 | 18 | 28     |
| 75th percentile | 17 | n | 5 | n | n | n | n | 40 | 19 |        |
| Max    | 17 | n | 5 | n | n | n | n | 40 | 40 |        |
| **DLP [mGy.cm]** | | | | | | | | | | |
| Min    | 197 | n | 70 | n | n | n | n | 617 | 79 |        |
| 25th percentile | 197 | n | 70 | n | n | n | n | 617 | 262 |        |
| Median | 197 | n | 70 | n | n | n | n | 617 | 332 | 407    |
| 75th percentile | 197 | n | 70 | n | n | n | n | 617 | 404 |          |
| Max    | 197 | n | 70 | n | n | n | n | 617 | 810 |        |
| **Scan length [cm]** | | | | | | | | | | |
| Median | 12 | n | 15 | n | n | n | n | 16 | 18 | 15     |
| **number of exams** | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 3 |        |
C. The median value for CTDIvol, DLP, and scan length of all eight centres for CT of the petrous bone with and without primary CM application separated by age group.

**Table C.1.** Paediatric patients aged <1.5 years, petrous bone CT without CM application.

| Center: | A | B | C | D | E | F | H | I | All data | DRL 75 |
|---------|---|---|---|---|---|---|---|---|----------|--------|
| CTDI [mGy] | | | | | | | | | | |
| Min | 17 | 26 | n | n | 13 | 17 | n | 11 | 11 | |
| 25th percentile | 17 | 28 | n | n | 13 | 18 | n | 11 | 13 | |
| Median | 17 | 29 | n | n | 13 | 19 | n | 11 | 17 | 19 |
| 75th percentile | 17 | 31 | n | n | 13 | 20 | n | 11 | 26 | |
| Max | 17 | 32 | n | n | 13 | 21 | n | 13 | 35 | |
| DLP [mGy.cm] | | | | | | | | | | |
| Min | 105 | 163 | n | n | 70 | 76 | n | 62 | 62 | |
| 25th percentile | 105 | 170 | n | n | 70 | 86 | n | 84 | 85 | |
| Median | 105 | 177 | n | n | 70 | 95 | n | 85 | 114 | 105 |
| 75th percentile | 114 | 184 | n | n | 70 | 105 | n | 102 | 179 | |
| Max | 122 | 191 | n | n | 70 | 114 | n | 179 | 240 | |
| Scan length [cm] | Median | 6 | 6 | n | n | 5 | 5 | n | 8 | 6 |
| number of exams | 3 | 2 | 0 | 0 | 1 | 2 | 0 | 5 | 13 | |

Paediatric patients aged <1.5 years, petrous bone CT with CM application: No such examinations were recorded at any of the participating centres.

**Table C.2.** Paediatric patients aged 1.5–5.5 years, petrous bone CT without CM application.

| Center: | A | B | C | D | E | F | H | I | All data | DRL 75 |
|---------|---|---|---|---|---|---|---|---|----------|--------|
| CTDI [mGy] | | | | | | | | | | |
| Min | 17 | 27 | 1 | 44 | 17 | 14 | n | 3 | 1 | |
| 25th percentile | 17 | 35 | 1 | 44 | 17 | 18 | n | 11 | 11 | |
| Median | 17 | 36 | 1 | 44 | 17 | 21 | n | 11 | 18 | 29 |
| 75th percentile | 19 | 40 | 1 | 44 | 17 | 23 | n | 11 | 35 | |
| Max | 21 | 54 | 1 | 44 | 17 | 24 | n | 16 | 54 | |
| DLP [mGy.cm] | | | | | | | | | | |
| Min | 118 | 162 | 12 | 186 | 88 | 98 | n | 43 | 12 | |
| 25th percentile | 133 | 218 | 12 | 260 | 88 | 104 | n | 67 | 88 | |
| Median | 147 | 260 | 12 | 352 | 88 | 110 | n | 79 | 114 | 204 |
| 75th percentile | 165 | 265 | 12 | 393 | 88 | 142 | n | 89 | 222 | |
| Max | 182 | 378 | 12 | 435 | 88 | 228 | n | 106 | 435 | |
| Scan length [cm] | Median | 7 | 7 | 9 | 8 | 5 | 7 | n | 7 | 7 |
| number of exams | 3 | 6 | 1 | 3 | 1 | 7 | 0 | 11 | 32 | |

Paediatric patients aged 1.5–5.5 years, petrous bone CT with CM application: No such examinations were recorded at any of the participating centres.
### Table C.3. Paediatric patients aged 5.5–10.5 years, petrous bone CT without CM application.

| Center:                      | A  | B  | C  | D  | E  | F  | H  | I  | All data | DRL 75 |
|------------------------------|----|----|----|----|----|----|----|----|----------|--------|
| **CTDI [mGy]**               |    |    |    |    |    |    |    |    |          |        |
| Min                          | 17 | 43 | 1  | 44 | 16 | 16 | n  | 15 | 3        |        |
| 25<sup>th</sup> percentile   | 21 | 43 | 1  | 44 | 17 | 18 | n  | 15 | 15       |        |
| Median                       | 21 | 43 | 1  | 44 | 17 | 22 | n  | 15 | 18 32    |        |
| 75<sup>th</sup> percentile   | 21 | 43 | 1  | 44 | 17 | 23 | n  | 15 | 40       |        |
| Max                          | 21 | 43 | 1  | 44 | 18 | 26 | n  | 16 | 54       |        |
| **DLP [mGy.cm]**             |    |    |    |    |    |    |    |    |          |        |
| Min                          | 131| 291| 10 | 261| 74 | 106| n  | 93 | 10       |        |
| 25<sup>th</sup> percentile   | 163| 291| 10 | 274| 101|121 | n  |106 |107       |        |
| Median                       | 171| 291| 10 | 293| 102|125 | n  |115 |131 231   |        |
| 75<sup>th</sup> percentile   | 188| 291| 11 | 300| 106|141 | n  |124 |264       |        |
| Max                          | 201| 291| 11 | 386| 112|170 | n  |209 |397       |        |
| **Scan length [cm]**         |    |    |    |    |    |    |    |    |          |        |
| Median                       | 8  | 7  | 7  | 6  | 7  | n  | 8  | 7  | 7        |        |
| **number of exams**          |    |    |    |    |    |    |    |    |          |        |
|                              | 6  | 1  | 2  | 6  | 6  | 7  | 0  | 16 | 44       |        |

### Table C.4. Paediatric patients aged 5.5–10.5 years, petrous bone with CM application.

| Center:                      | A  | B  | C  | D  | E  | F  | H  | I  | All data | DRL 75 |
|------------------------------|----|----|----|----|----|----|----|----|----------|--------|
| **CTDI [mGy]**               |    |    |    |    |    |    |    |    |          |        |
| Min                          | 21 | n  | n  | n  | n  | n  | n  | n  | 21       |        |
| 25<sup>th</sup> percentile   | 21 | n  | n  | n  | n  | n  | n  | n  | 21       |        |
| Median                       | 21 | n  | n  | n  | n  | n  | n  | n  | 21       |        |
| 75<sup>th</sup> percentile   | 21 | n  | n  | n  | n  | n  | n  | n  | 21       |        |
| Max                          | 21 | n  | n  | n  | n  | n  | n  | n  | 21       |        |
| **DLP [mGy.cm]**             |    |    |    |    |    |    |    |    |          |        |
| Min                          | 212| n  | n  | n  | n  | n  | n  | n  | 212      |        |
| 25<sup>th</sup> percentile   | 212| n  | n  | n  | n  | n  | n  | n  | 212      |        |
| Median                       | 212| n  | n  | n  | n  | n  | n  | n  | 212      |        |
| 75<sup>th</sup> percentile   | 212| n  | n  | n  | n  | n  | n  | n  | 212      |        |
| Max                          | 212| n  | n  | n  | n  | n  | n  | n  | 212      |        |
| **Scan length [cm]**         |    |    |    |    |    |    |    |    |          |        |
| Median                       | 10 | n  | n  | n  | n  | n  | n  | n  | 10       |        |
| **number of exams**          |    |    |    |    |    |    |    |    |          |        |
|                              | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 1  | 1        |        |

### Table C.5. Paediatric patients aged 10.5–16 years, petrous bone CT without CM application.

| Center:                      | A  | B  | C  | D  | E  | F  | H  | I  | All data | DRL 75 |
|------------------------------|----|----|----|----|----|----|----|----|----------|--------|
| **CTDI [mGy]**               |    |    |    |    |    |    |    |    |          |        |
| Min                          | 21 | 35 | n  | n  | 20 | 16 | n  | 8  | 8        |        |
| 25<sup>th</sup> percentile   | 21 | 51 | n  | n  | 20 | 18 | n  | 15 | 15       |        |
| Median                       | 21 | 54 | n  | n  | 20 | 27 | n  | 15 | 21 27    |        |
| 75<sup>th</sup> percentile   | 21 | 54 | n  | n  | 20 | 27 | n  | 15 | 28       |        |
| Max                          | 21 | 54 | n  | n  | 20 | 28 | n  | 16 | 54       |        |
| **DLP [mGy.cm]**             |    |    |    |    |    |    |    |    |          |        |
| Min                          | 131| 162| n  | n  | 123| 116| n  | 70 | 70       |        |
| 25<sup>th</sup> percentile   | 185| 325| n  | n  | 123| 134| n  |102 |131 131   |        |
| Median                       | 201| 365| n  | n  | 123| 147| n  |117 |180 201   |        |
| 75<sup>th</sup> percentile   | 212| 430| n  | n  | 123| 172| n  |132 |228       |        |
| Max                          | 238| 450| n  | n  | 123| 196| n  |184 |450       |        |
| **Scan length [cm]**         |    |    |    |    |    |    |    |    |          |        |
| Median                       | 9  | 8  | n  | n  | 6  | 7  | n  | 8  | 8        |        |
| **number of exams**          |    |    |    |    |    |    |    |    |          |        |
|                              | 11 | 8  | 0  | 0  | 1  | 5  | 0  | 11 | 36       |        |

Paediatric patients aged 10.5–16 years, petrous bone with CM application: No such examinations were recorded at any of the participating centres.
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