CT exposure from pediatric MDCT: results from the 2007-2008 SFIPP/IRSN survey

HJ Brisse (1) and B Aubert (2)

Résumé
Niveaux d’exposition en tomodensitométrie multicoupées pédiatrique : résultats de l’enquête dosimétrique SFIPP/IRSN 2007-2008
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Objectif. Évaluer les niveaux actuels d’exposition en scanner multicoupées pédiatrique et en déduire des recommandations pour la pratique pouvant servir de base à l’élaboration de futurs niveaux de référence diagnostiques (NRD).

Matériels et méthodes. Une enquête de pratique a été réalisée auprès des sites hospitaliers correspondants de la SFIPP (Société Francophone d’Imagerie Pédiatrique et Prénatale). Les valeurs protocolaires de haute tension et de dose théorique absorbée (IDSV) ont été relevées pour trois âges types (1, 5 et 10 ans) et des indications types sur huit régions anatomiques.

Résultats. Vingt des 29 sites contactés ont transmis leurs protocoles. Tous âges confondus, 97% des protocoles comportaient un niveau de haute tension ≤ 120 kV. Pour les âges de 1, 5 et 10 ans respectivement, les 75e centiles des distributions de dose étaient : 31, 39,5 et 49,5 mGy pour le protocole « crâne » ; 24, 22 et 24 mGy pour le « massif facial » ; 11, 11 et 11 mGy pour les « sinus » ; 46, 71 et 87 mGy pour les « rochers » ; 3, 3,5 et 5,5 mGy pour le « thorax standard » ; 2, 3 et 4 mGy pour le « poumon basse dose » ; 4, 4,5 et 7 mGy pour « l’abdomen-pelvis » ; 7, 11 et 12 mGy pour l’« os ». Les écarts dosimétriques inter-centres restaient élevés.

Conclusion. L’étude a permis d’évaluer les pratiques actuelles au sein de centres radiopédiatriques de référence et de réajuster les recommandations dosimétriques. Elle pourrait servir de base pour l’établissement de NRD en scanographie pédiatrique.


Abstract
Purpose. To evaluate current exposure levels from pediatric MDCT examinations in order to issue recommendations for the routine clinical practice that may be used for establishing future diagnostic reference levels (DRL).

Materials and methods. A survey was conducted at hospital sites affiliated with the SFIPP (Société Francophone d’Imagerie Pédia- trique et Prénatale). Tube potential and volume computed tomography dose index (CTDII) vol. values were obtained for three age groups (1, 5 and 10 years) for typical scanning indications of eight anatomical regions.

Results. Twenty of 29 sites provided us with a copy of their protocols. All ages groups combined, 97% of protocols used a tension level ≤120 kVp. For age groups 1, 5 and 10 years respectively, the 75th percentiles of dose distributions were : 31, 39.5 and 49.5 mGy for the “head” protocol; 24, 22 and 24 mGy for “head and neck”; 11, 11, and 11 mGy for “paranasal sinuses”; 46, 71 and 87 mGy for “petrous bone”; 3, 3.5 and 5.5 mGy for “chest”; 2, 3 and 4 mGy for “low dose lung”; 4, 4.5 and 7 mGy for “abdomen-pelvis”; 7, 11 and 12 mGy for “bone”. The inter-center discrepancy for doses were still high.

Conclusion. This study provided an evaluation of current practices in reference centers for pediatric imaging and allowed readjustment of MDCT dose recommendations. It could help in the development of DRLs for pediatric MDCT.

Key words: CT. MDCT. Child. Radiation protection. Dosimetry. Data collection. Diagnostic reference levels.


French regulation concerning radiation protection in patients subjected to ionizing radiation for medical purposes (Decree n° 2002-460 of 24 March 2003) is a legal application of the 97/43/Euratom European Directive (Order 2001-270 of 28 March 2001). In the French Public Health Code, it introduced principles for justifying and optimising procedures (article L. 1333-1). This regulation applies to all patients but it is especially pertinent to pediatrics since children are much more sensitive to ionizing radiation than adults (1). The International Commission on Radiological Protection (ICRP) estimated the risk (life) of cancer deaths and sievert (for a single exposure) to be 14% at birth as compared to 1% at 75 years-old (2). The long-term effects of low ionizing radiation doses are still very controversial (3, 4), but radiation protection of patients continues (for precautionary reasons) to be based on a non-threshold linear relation model. An excessive risk of radiation-induced cancer can therefore theoretically be extrapolated to doses used in diagnostic radiology (5-9).

Surveys of practices provide an overview of procedures for a given period, while also highlighting the range of doses used by physicians. Diagnostic reference levels (DRLs) can then be established through statistical analysis of the findings of these surveys. In agreement with European recommendations, these DRLs correspond to the 75th percentile of the observed dose distribution. These indicators are neither legal limits nor optimal values, but rather “safeguards” to avoid obviously excessive doses.
This concept was initially introduced by ICRP in 1996 (10), and then included in the 97/43/Euratom Directive, which defines them as follows: "dose levels [...], for typical examinations for groups of standard-sized patients or standard phantoms for broadly defined types of equipment. These levels are expected not to be exceeded for standard procedures when good and normal practice regarding diagnostic and technical performance is applied." (Article 2) (11). In adults, prescribed DRLs for conventional radiology and CT were published in France in 2004 (12) on the basis of levels proposed by the European Commission in 1996-1999 (13, 14), and a national multicentre survey conducted between 2001 and 2003 at 24 French sites (15).

In children, so far DRLs have only been published for conventional radiology (12) on the basis of a survey of the Lake Starnberg Group (14). Very little CT data is available, and what is available is mainly from British sources (16, 17). There are currently no pediatric regulatory DRLs in USA. However, in 2003 (18) and 2008 (19), the Society for Pediatric Radiology (SPR) published two surveys describing scanning practices used by its members, but only for screening the trunk (chest, abdomen) and without providing dose levels corresponding to the procedures used, thus hampering comparison with practices in other countries.

The aim of this study was thus to record MDCT dose levels in a large sample of pediatric imaging services, for typical protocols and age groups, representing the bulk of tests performed in routine clinical practice.

### Materials and Methods

In November 2007, through the Société Francophone d’Imagerie Pédiatrique et Prénatale (SFIPP) listing, a data report form was sent out to the directors of 29 sites where pediatric imaging is regularly or exclusively performed. This form included an information page outlining the study objectives and dose indices to be provided. A protocol form was proposed for each predefined typical age group: 1 year-old (or 10 kg and 75 cm), 5 years-old (or 19 kg and 110 cm) and 10 years-old (or 32 kg and 140 cm). For each typical age group, eight protocols were requested, with each including a typical clinical indication (table I). For each protocol, the requested information was the tension used (in kV) and the theoretical volumetric computed tomographic dose index (CTDIvol; in mGy; while specifying the field of view used for acquisition), and other parameters (intensity, turnaround time, collimation, number of passes) could be optionally reported. Participants were not asked to report individual doses for the series of examinations performed, but rather to provide information associated with the protocol that they generally used for each specific age group and indication and available on their CT console. The reported CTDI values were not measured at the site or recalculated from the acquisition parameters. This information was provided by the manufacturer and displayed on the CT console (mean CTDI when automatic load modulation software was used). The theoretical CTDI values reported were rounded to the half mGy. DLPS were calculated by multiplying the CTDI and the scan length, i.e. previously estimated mean scan length for a sample of patients of comparable ages and weights (Institut Curie, unpublished data).

These calculated DLPS values were rounded to mGy/cm.

In this study, our results are expressed in CTDI₀/₁₆ and DLP₀/₁₆ (CTDI and DLP were standardised for a head PMMA phantom of 16 cm dia.) for head and neck examinations, and in CTDI₁₂ and DLP₁₂ (CTDI and DLP were standardised for an adult body PMMA phantom of 32 cm) for trunk (chest, abdomen, pelvis) and limb examinations. When the manufacturer’s CTDI values were associated with an unsuitable phantom (CTDI₁₂ for a head and neck examination or CTDI₁₆ for a trunk examination), and for comparison with British study findings, we assumed that the CTDI₁₂ and CTDI₁₆ differed by a factor of 2 (CTDI₁₂ = 2xCTDI₁₆).

### Results

20 (69%) of the 29 sites contacted responded completely or partially to the questionnaire between November 2007 and March 2008 depending on their recruitment. 18 of these 20 sites were French (16 university hospitals, two institutions affiliated with public sector hospitals) and two were foreign university hospitals (one Belgian, one Dutch).

The scanners used at these sites were trademarks of Siemens (n=7), General Electric (n=7), Philips (n=5) and Toshiba (n=1), that had been installed between 2001 and 2008, including devices with 4 (n=2), 16 (n=10) or 64 detector channels (n=8). Table II shows the distribution of tension values used according to patient ages and protocols. Regardless of the age, 97% of the reported protocols had a tension of ≤ 120 kV. The maximum value (140 kV) was only used for "temporal bone" protocols, and by only 31% of sites for the 10 year age group. For the other head examinations ("head", "facial bones" and "sinus" protocols combined), 76% of the sites used the 120 kV value, while the rest used 100 kV, except for sinus scans at one site where 80 kV was used. For chest screening ("routine" and "low dose" combined), 61% of the sites used minimum values of 80 or 90 kV for the 1 year age group, as compared to only 28% for the 5 year group and 19% for the 10 year group. For abdomen and pelvis screening, 47% of the sites used these minimum values for the 1 year group, as compared to 24% for the
Table II

Tension levels recorded in the SFIPP/IRSN 2007-2008 survey of pediatric CT practices.

<table>
<thead>
<tr>
<th>Regions / protocols</th>
<th>Age (years)</th>
<th>80/90 kV</th>
<th>100 kV</th>
<th>120 kV</th>
<th>140 kV</th>
<th>Total</th>
</tr>
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<tbody>
<tr>
<td>Head</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>15</td>
<td>0</td>
<td>19</td>
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<td>0</td>
<td>3</td>
<td>13</td>
<td>0</td>
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</tr>
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<td>5</td>
<td>7</td>
<td>0</td>
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<td>7</td>
<td>10</td>
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<td>1</td>
<td>14</td>
<td>1</td>
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<td>17</td>
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<td>0</td>
<td>0</td>
<td>11</td>
<td>5</td>
<td>16</td>
</tr>
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<td>11</td>
<td>5</td>
<td>3</td>
<td>0</td>
<td>19</td>
</tr>
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<td>2</td>
<td>9</td>
<td>8</td>
<td>0</td>
<td>19</td>
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<tr>
<td>Low dose chest</td>
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<td>9</td>
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<td>2</td>
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<td>0</td>
<td>13</td>
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<td>8</td>
<td>7</td>
<td>2</td>
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<td>17</td>
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<td>0</td>
<td>4</td>
<td>10</td>
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<tr>
<td>Total</td>
<td></td>
<td>51</td>
<td>103</td>
<td>224</td>
<td>10</td>
<td>338</td>
</tr>
<tr>
<td>%</td>
<td></td>
<td>13</td>
<td>27</td>
<td>58</td>
<td>3</td>
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</tr>
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</table>

5 year group and 5% for the 10 year group. The other sites generally used 100 kV for the chest and abdomen examinations for patients up to 5 years-old, and usually 120 kV for the abdomen when screening 10 year-old patients. When scanning bone, 68% of the sites used the 120 kV value, regardless of the age group. Table III gives the survey results for each protocol and age group in terms of the theoretical absorbed dose and compares the observed CTDI values with those recommended in the 2006 SFR Guide to Radiological Procedures. The observed CTDI values were quite dispersed. The ratios between extremity doses were as high as 10 for “sinus” and “temporal bones” protocols, 15 for three other protocols (“low dose chest at 5 years”, “bone at 1 year” and “sinus at 10 years”) and 22 for the “chest at 1 year” protocol. Ratios of around 5 were obtained for the “head”, “facial bones”, “abdomen” and “low dose chest” protocols. The lowest dispersion was noted for the “chest at 10 years” and “low dose chest at 10 years” protocols, while the other ratios ranged from 3.3 to 4. When comparing the mean standard deviations, the greatest dispersions were noted for “routine chest at 1 year” (87%) and “bone at 1 year” (93%) protocols, with the lowest noted for the “head” (34-40%) and “abdomen” (33-47%) protocols.

When the 75th percentiles for the observed dose distributions were compared with those recommended in SFIPP 2006, differences were noted for a few protocols: the observed doses were actually higher than the recommended doses for the “sinus” (+100% at 1 and 5 years, +37% at 10 years), “temporal bones” (+15% to +75% depending on the age), and “head” (+25% at 10 years) protocols.

Only one of the 10 centres for which information was available used the sequential scanning mode for head scans (with a 16 channel scanner).

Table IV gives the mean theoretical absorbed doses per scanner type for each protocol after pooling the three age groups. This table does not show any marked dose variations, except for the “head” protocols, which had the highest doses for the 64 channels at 1 year and 10 years (mean doses of 20, 23.5 and 27.5 mGy for 4, 16 and 64 channels, respectively, at 1 year; 35, 30 and 36 mGy at 5 years; 35, 35.5 and 48 mGy at 10 years).

Discussion

MDCT is currently the diagnostic radiological technique that is likely to generate the most radiation. It is therefore essential to ensure that such procedures are absolutely necessary, especially in pediatric applications. It is important to note that a scan examination request can only be placed if there has been a preliminary written exchange of information between the requesting physician and the scan operator who shares, along with the radiologist, the responsibility of making the final decision. All requests should refer to the Guide for Proper Use of Medical Imaging Examinations. The patient’s history should also be checked to avoid over frequent or even unnecessary examinations, and nonradiological techniques such as ultrasound or MRI should be prescribed when possible.

In France, MDCT accounts for only 8% of all radiological procedures, but it is reported to be responsible for 39% of the collective radiation exposure (20), and around 11% of all examinations concern children (0-15 years-old) (21). Several studies have confirmed that pediatric doses could be optimised, especially for screening the brain (22-24), sinuses (25), chest (26-29), abdomen (30, 31) and pelvis (32). Despite these findings, there are still relatively few exposure parameters used for imaging children as compared adult procedures (18, 33).

The absence of DRL regulations for pediatric MDCT is unfortunate, and it is also a limiting factor since only procedures associated with a DRL are subject to annual mandatory control. Very few data have been published on this topic, and what has been published is no longer applicable to current practices and scanners. SFIPP and the French Institut de Protection et Sûreté Nucléaire (IRSN) consider that it is now quite urgent to...
CT exposure from pediatric MDCT: results from the 2007-2008 SFIPP/ISRN survey

HJ Brisse, B Aubert

Table III
Pediatric CT exposure levels: results of the SFIPP/IRSN 2007-2008 survey of pediatric CT practices and comparison with the 2006 SFIPP in the SFR Guide to Radiological Procedures.

<table>
<thead>
<tr>
<th>Regions / protocols</th>
<th>Age (years)</th>
<th>N²</th>
<th>75 th perc.</th>
<th>50 th perc.</th>
<th>SD</th>
<th>min-max</th>
<th>CTDI 160°°² (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>1</td>
<td>19</td>
<td>31</td>
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<td>39.5</td>
<td>35.5</td>
<td>11.5</td>
<td>11.5 – 55.5</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>18</td>
<td>49.5</td>
<td>38.5</td>
<td>16</td>
<td>14.5 – 83</td>
<td>40</td>
</tr>
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<td>16</td>
<td>24</td>
<td>14.5</td>
<td>9.5</td>
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<td>16.5</td>
<td>13.5</td>
<td>8.5 – 55</td>
<td>25</td>
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<tr>
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<td>13</td>
<td>11</td>
<td>8.5</td>
<td>4.5</td>
<td>1.5 – 13.5</td>
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</tr>
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<td>5</td>
<td>16</td>
<td>11</td>
<td>8.5</td>
<td>4</td>
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<td>18</td>
<td>11</td>
<td>8.5</td>
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<td>1.5 – 25</td>
<td>8</td>
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<td>16</td>
<td>46</td>
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<td>16</td>
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<td>63</td>
<td>27.5</td>
<td>10.5 – 112.5</td>
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<td>19</td>
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<td>2 – 7.5</td>
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<td>1.5</td>
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<td>1.5 – 6</td>
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<td>3</td>
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<td>1 – 4.5</td>
<td>4</td>
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<td>19</td>
<td>7</td>
<td>5.5</td>
<td>2.5</td>
<td>2.5 – 13</td>
<td>7</td>
</tr>
<tr>
<td>Bone</td>
<td>1</td>
<td>11</td>
<td>7</td>
<td>5.5</td>
<td>6.5</td>
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<td>14</td>
<td>12</td>
<td>8.5</td>
<td>4</td>
<td>2.5 – 14.5</td>
<td>13</td>
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</tbody>
</table>

(1) CTDI 16 index for head and neck examinations and CTDI 32 index for trunk and bone examinations; (2) N: number of sites that provided data on this protocol; (3) Review of CTDI values recommended by SFIPP in the 2006 Guide to Radiological Procedures.

Table IV
Comparison of mean doses (CTDI) per protocol for each type of scanner according to the number of detection channels.

<table>
<thead>
<tr>
<th>Regions/protocols</th>
<th>CTDI (mGy)</th>
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</thead>
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<td></td>
<td>4 channel (n = 2)</td>
</tr>
<tr>
<td>Head</td>
<td>30</td>
</tr>
<tr>
<td>Facial bones</td>
<td>14</td>
</tr>
<tr>
<td>Sinus</td>
<td>9</td>
</tr>
<tr>
<td>Temporal bones</td>
<td>59</td>
</tr>
<tr>
<td>Routine chest</td>
<td>4</td>
</tr>
<tr>
<td>Low dose chest</td>
<td>3</td>
</tr>
<tr>
<td>Abdomen/Pelvis</td>
<td>4</td>
</tr>
<tr>
<td>Bone</td>
<td>9</td>
</tr>
</tbody>
</table>

CTDI 16 index for head and neck examinations and CTDI 32 index for trunk and bone. Mean values for the three typical ages and the same group of scanners.

draw up specific pediatric radiology recommendations to fulfil the obligation of EC Member States to promote the development and implementation of DRLs with the aim of optimising such imaging procedures.

The first baseline doses for pediatric CT established through a European survey of 40 sites in seven countries were published by British authors in 2000 (16), and some of these doses were subsequently lowered on the basis of a survey conducted in the UK in 2003 (17). These doses still seem relatively high with respect to current practices.

SFIPP published its first recommendations in the SFR (Société Française de Radiologie) Guide to Radiological Procedures. These recommendations were based on the results of a preliminary clinical survey of SFIPP members carried out in late 2005 (SFIPP, unpublished data).

This new survey assessed current practices in some 20 pediatric radiology services, or 69% of all sites queried. This percentage participation is quite high, especially in comparison to the participation in a recent North American survey, i.e. 25% (61 sites) (19).

The overall picture highlighted substantial variability in practices, which is usual for such surveys.

Our survey showed that 100 and 120 kV were the most common tensions used for imaging children (table II), whereas 140 kV was used only for screening compact temporal bones, but this choice is de-
The most common examinations. Concern-
fants, but the values are more uniform for
chest and bone imaging of nursing in-
concern and for which specific CT re-
that current practices are still very hetero-
120 kV, with 43% of the values
said that they used maximum tensions of
chest and abdomen scans, 100% of the
used. This is in line with the results of a
ray), thus also enabling lower doses to be
X-ray spectrum closer to the iodine K-
puted contrast media (effective energy of the
enhancement of soft tissues or iodina-
be selected because this does not increase
literature on pediatric CT tension levels.
There is currently no consensus in the li-
100 kV, or even 120 kV, for imaging the
children up to 10 years-old. The factor li-
mining these low values is the risk of atte-
uation artefacts around compact bones
(shoulders, pelvis) (34), which is why
most sites preferred to use a tension of
100 kV, or even 120 kV, for imaging the
abdomen at 10 years-old.
There is currently no consensus in the li-
terature on pediatric CT tension levels.
However, relatively low tensions should be
selected because this does not increase the
enhancement of soft tissues or iodina-
ted contrast media (effective energy of the
X-ray spectrum closer to the iodine K-
ray), thus also enabling lower doses to be
used. This is in line with the results of a
recent North American survey (19): for chest and abdomen scans, 100% of the
SPR pediatric radiologists interviewed
said that they used maximum tensions of
120 kV, with 45% of the values ≤ 100 kV
for chest imaging. However, only 20% of
them claimed that they used ≤ 100 kV
tensions for the abdomen. The pediatric
CT rationale should differ from that ap-
plicated for imaging adults whereby, for a
constant intensity, a tension of 120-140 kV
is generally required to achieve effective
dose levels. The pediatric CT rationale
also differs from that applied in conven-
tional radiology where, with automatic
exposure, a quite substantial dose savings
can be achieved by scanning at maximum
tension (in line with the desired contrast
enhancement).
In terms of absorbed dose, the reported
theoretical CTDI values (table III) were
quite dispersed. These findings indicate that
current practices are still very hetero-
genous, even within a specialised field for
which radiation protection is a prime
concern and for which specific CT rec-
ommendations have been available since
2006. This mixture of practices prevails in
chest and bone imaging of nursing in-
ants, but the values are more uniform for
head and abdomen protocols, which are
the most common examinations. Concen-
ting the “bone” protocol, the heteroge-
enity noted was likely also associated with
the fact that this indication is relatively
uncommon in children and to the fact
that the protocol must be tailored to the
screened region (e.g. the dose used for
imaging the hips has to be higher than
that used for limb scanning).
The number of scanning channels used in
this study did not seem to modify the de-
ivered doses (table IV), except for “head”
protocols for which the doses were higher
for 64-channel scans, especially within
the 1-10 age range (+37%). This differen-
ce could possibly be explained by the fact
that 64-channel helical acquisition was
more often used for screening the head,
whereas sequential scans are still possible
with 4- and 16-channel scanners. Adult
DRL readings for the 2006-2008 period
with the “brain” protocol also showed a
75th percentile increase, which prompted
IRSN to propose an increase from 58 to
75 mGy in the “adult brain” DRL (35). In
their 2003 survey, Schrümpt et al. (17)
had also noted an increase of around 55%
for the head between doses delivered by
mono-versus multislice scanners, a diffe-
rence that was related to the technique
(high penumbral shadow and lower
geometrical efficacy with multislice
scanners).
Overall, the recorded 75th percentiles for
dose distributions seemed to be consistent
with the SFIPP 2006 Guide to Radiologi-
Procedures, especially for trunk scans.
A few differences (increases) were still
noted for the “sinus”, “temporal bones”
and “head at 10 years old” protocols. The
findings of this new survey should be
considered more relevant since they are
more recent and concerned a greater
number of sites, so they are more repre-
sentative of the results obtained with
current practices and scanners.
The 75th percentiles for CTDI values
noted in our survey were lower than the
baseline levels reported by British re-
searchers in 2000 (16) and 2006 (17). Table V
compares CTDI values according to sur-
vay years. Between 2000 and 2008, these
values were 6- to 7-fold lower for “high
resolution” lung (equivalent to “low dose”
chest in this study, 2.5- to 4-fold lower for
“routine chest”, and 2- to 3-fold lower for
“abdomen”). As compared to 2003, the
2008 values obtained in our study for the
“chest” protocol were 2-fold lower. The
dosage reduction for “head” protocols
was less marked, i.e. ranging from 22 to
34% between 2000 and 2008, and only
minor differences were noted between
2003 and 2008. This reduction in doses
used since early 2000 was likely due to se-
veral different factors. first, there was a
methodological bias – the British surveys
covered a broader imaging site sample, so
they thus included nonspecialised sites
where less optimal protocols were used.
Technological advances in multislice CT
subsequently improved the scanner
detector efficacy and geometry, thus
making it possible to obtain equivalent
quality images at lower exposure levels.
Finally, due to the legal application of the
Euratom Directive in 2001 and the commu-
nication campaign on this topic in learned
societies and in the literature, the boosted
user awareness likely helped to further
optimise the protocols. This dose reduc-
tion has also been noted in adult imaging,
i.e. in its last report (35), concerning the
2006-2008 records, IRSN thus recom-
ended a 25% DRL reduction for the
“chest” protocol (15 instead of 20 mGy)
and a 15% reduction for the “abdomen-
pelvis” protocol (17 instead of 25 mGy).
A significant reduction in exposure para-
eters, especially marked for the 0-4 age
category, was also noted between 2001
and 2006 in North American pediatric
surveys (19), thus indicating a reduction in
absorbed doses.
There are currently no pediatric DRL
regulations in USA. The Food & Drug
Administration published a special noti-
fication on pediatric scanner optimisation
in 2001 (http://www.fda.gov/cdrh/safety/
110201-ct.html), which simply referred to
a pediatric protocol proposal (weight ad-
justed) that had just been published by
one team (36). As part of its accreditation
programme, the American College of Ra-
diology published, for three typical exa-
minations, baseline values and threshold
values (i.e. requiring special attention and
quality control) (http://www.acr.org/ac-
creditation/computed/ct_reqs.aspx).
These values only apply to three typical
examinations: adult head (baseline
CTDIvol 75 mGy, and threshold 80 mGy,
respectively), adult abdomen (25 and
30 mGy) and pediatric abdomen at
5 years olds (20 and 25 mGy). More re-
cently, the Alliance for Radiation Safety
in Pediatric Imaging working group (37)
was launched by North American insti-
tutions in the fields of radiology (ACR),
medical physics (American Association of
Physicists in Medicine), pediatric radiology
considered that it would be more reasonable to draw up recommendations by consulting only institutions (mainly associated with hospitals) that frequently, or exclusively, implement pediatric radiological procedures. This recruitment bias has also been noted in other studies such as that conducted by SPR, in which 100% of the members who had responded to the survey practiced in a hospital establishment, including 49% in a university hospital centre and 34% in a pediatric hospital (19). This is actually representative of this specialisation which, contrary to adult imaging, is mainly practiced in hospitals. The results obtained in this survey could be transformed into baseline dosimetric values (table VI). As a first approximation, it could be assumed that the 75th percentile dosages of these optimised practices are reasonable for standard morphotypes and routine indications. In practice, these values should still be tailored to the case at hand, to the type of scanner used, to the specific morphotype of the child patient and to the clinical indications. These values should not be considered as DRLs from a regulatory standpoint. DRLs can only be formally established on the basis of data subsequently collected through a larger sampling of services, but these data could already serve as a useful working basis to supplement current regulations.

In clinical practice, a simple effective method for optimising paediatric parameters could involve:

- setting the tension according to the examined region and the child’s morphotype (range 80 to 120 kV, table VI);
- setting the temporal resolution (rotation time and pitch) according to the examined region and the child’s potential cooperation (e.g. pitch 1.5-2 and minimum rotation time for a non-breath-hold infant lung scan; pitch < 1 and mean rotation time for screening a bone segment in a large child);
- and optimising by adjusting mAs to obtain a CTDI in compliance with current SFIPP recommendations (table VI).

Radiologists using scanners running at constant load should be cautious when there is a pitch modification, since the mAs are automatically adjusted by the device (they should be subsequently readjusted to obtain the desired CTDI).

The range of CT dose indices is still debatable. Regulatory DRLs are currently expressed in CTDIw and DLP (38). According to the order of 22 September 2006 (12), for scanning procedures, the dosimetric information that has to be provided in the procedure report is the dose-length product (DLP), as CTDIh is only essential for pelvic exposures in women of child-bearing age and for warranted abdominal-pelvic exposures in pregnant

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(SPR) and imaging technology (American Society of Radiologic Technologists). This group conducted an awareness campaign to promote the optimisation of pediatric radiological imaging and, rather than absolute baseline levels, currently proposes guidelines for reducing mAs in reference to the “abdomen” protocol used for average adults (http://www.pedrad.org/associations/5364/files/Protocols.pdf). The mAs level suggested for an abdominal scan (with all other parameters constant) of an adult with a “small” morphotype is thus equal to 90% of that of an “average” adult, equal to 76% at 15 years-old, 66% at 10 years-old, 59% at 5 years-old, 51% at 1 year-old and 43% for newborn infants. For the chest, the recommended levels are 82, 73, 64, 57, 49 and 42%, respectively. Table V compares the 75th percentiles obtained in our study with these recommended levels, with the calculation based on the future “adult abdomen” DRLs proposed by IRSN. The North American calculations still seem relatively high, i.e. 60-178% higher than the 75th percentiles noted in our survey.

### Table V
Comparison of 75th percentile doses from the SFIPP/IRSN 2007-2008 survey of pediatric CT practices with French adult DRLs, UK pediatric DRLs and North American recommendations.

<table>
<thead>
<tr>
<th>Region / protocol</th>
<th>DRL2004 Adults³ CTDI (mGy)</th>
<th>SFIPP / IRSN 2007-2008 study 75th percentile</th>
<th>UK pediatric DRLs</th>
<th>US recommendations⁵</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>CTDI2000 ²⁶ (mGy)</td>
<td>CTDI2000 ²² (mGy)</td>
<td>CTDI2003 ²⁴ (mGy)</td>
</tr>
<tr>
<td>Head</td>
<td>58/75</td>
<td>31</td>
<td>40</td>
<td>35/30 ⁷</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>39.5</td>
<td>60</td>
<td>50/45</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>49.5</td>
<td>70</td>
<td>65/50</td>
</tr>
<tr>
<td>Routine chest</td>
<td>20/15</td>
<td>3</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>3.5</td>
<td>15</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>5.5</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>Low dose chest⁶</td>
<td>–</td>
<td>2</td>
<td>15</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>3</td>
<td>20</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>4</td>
<td>25</td>
<td>–</td>
</tr>
<tr>
<td>Abdomen-pelvis</td>
<td>25/17</td>
<td>4</td>
<td>10</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>4.5</td>
<td>12.5</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>7</td>
<td>15</td>
<td>–</td>
</tr>
</tbody>
</table>

(1) Review of current French adult CT DRLs (38) and adjustments recently proposed by IRSN (15); (2) CTDI₁₆ index for head and neck examinations and CTDI₁₂ index for trunk examinations (CTDI₁₂ values were recalculated by dividing the CTDI₁₆ values by 2); (3) according to Shrimpton and Wall (16); (4) from Shrimpton et al. (17); (5) Values calculated according to recommendations of the Alliance for Radiation Safety in Pediatric Imaging, based on the future French DRL values for adult abdominal CT recommended by IRSN in 2008; (6) 75th percentile values from the SFIPP/IRSN 2007-2008 survey; (7) Values for the subtentorial and supratentorial regions, respectively; (8) The studies of Schrimpton et al. (16) assessed a high resolution chest imaging protocol, equivalent to the “low dose chest” protocol of our study.

women. In its recent 2008 report (35), IRSN recommended that DRLs now be defined on the basis of dosage ranges corresponding to operational ranges accessible to professional radiologists, especially in terms of CTDI_{vol} and no longer CTDI_{w}. Our recommendations are provided in CTDI_{vol} and DLP (per pass). DLP clearly reflects the individual cumulated dose and enables, if necessary, assessment of the effective dose, whereas CTDI_{vol} is the most relevant index in terms of optimisation. DLP is actually a function of the scan length (which depends on the patient’s height), the scan area and the number of passes required. This index is in some ways “imposed” by the patient’s morphological features and the diagnostic imperatives of the examination (mono- or multiphase scans). However, the CTDI_{vol} selected by the operator is the baseline dose index, which can be optimised by adapting the acquisition parameters (tension, load, collimation). CTDI_{vol} is the index that can be used to readily compare practices to regulatory DRLs or those of other teams.

In this study, we differentiated phantom 16 and 32 cm values. By convention, CTDI_{16} and DLP_{16} indices are used for “head and neck” examinations and CTDI_{32} and DLP_{32} indices are used for trunk examinations (chest, abdomen, pelvis), even though these latter indices underestimate the dose for small morphotype patients. British pediatric DRLs are still expressed in CTDI_{vol_{16}}, even for trunk examinations. Manufacturers’ index displays can be a source of confusion. For some manufacturers (Philips, Siemens), these indices are selected according to the examined anatomical region (protocol name), whereas for others (GEH, Toshiba) it depends on the acquisition field of view. It is recommended that all manufacturers agree on a clear uniform index to display, while specifying in the dose ratio to which phantom the CTDI is standardised, as some manufacturers have already done (GEH, Siemens). Meanwhile, it is important to note that an adjustment could be required before applying our recommendations – if a pediatric trunk examination is performed with a small field of view and the console displays a CTDI_{16}, the mAs should be corrected so that the first line displayed dose (in CTDI_{16}) is equal to twice the recommended dose in CTDI_{32}. For instance, a user programmes a sequence for an abdominal scan of a 5 year-old child while targeting a CTDI_{32} value of 4.5 mGy; if the index displayed on the console is that which has been standardised for a 32 cm phantom, then the mAs have to be adjusted to obtain this 4.5 mGy value; if, on the other hand, the index displayed on the console is calculated for a 16 cm phantom – as is sometimes the case when a small field of view is used with scanners of some manufacturers – then the mAs have to be adjusted to obtain twice the value, i.e. 9 mGy, otherwise too low a dose will be used and the images will be too noisy and thus of poor quality).

### Table VI

<table>
<thead>
<tr>
<th>SFIPP/IRSN 2008 multislice pediatric CT (tension, CTDI, PDL) dose recommendations.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1 year Height 75 cm Weight 10 kg</strong></td>
</tr>
<tr>
<td><strong>Tension (kV)</strong></td>
</tr>
<tr>
<td>Head</td>
</tr>
<tr>
<td>Facial bones</td>
</tr>
<tr>
<td>Sinus</td>
</tr>
<tr>
<td>Temporal bones</td>
</tr>
<tr>
<td>Routine chest</td>
</tr>
<tr>
<td>Low dose chest</td>
</tr>
<tr>
<td>Abdomen-pelvis</td>
</tr>
<tr>
<td>Bone</td>
</tr>
</tbody>
</table>

(1) CTDI_{16} index for “head and neck” examinations and CTDI_{32} index for trunk and bone; (2) index DLP_{16} index for “head and neck” examinations and DLP_{32} index for trunk and bone, for one pass; (3) Data not shown, function of the studied bone segment.

### Conclusion

This survey was carried out within the framework of SFIPP in collaboration with IRSN to assess current practices in around 20 pediatric radiology services. The findings revealed that the practices used are relatively heterogeneous. However, a statistical analysis of the data enabled an update of French pediatric CT recommendations. These recommended doses were found to be lower than international baseline and recommended doses. These figures could also serve as a basis for an IRSN database and used to establish specific pediatric CT DRLs.

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Conflict of interest declaration

The authors declare that there are no conflicts of interest.

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