Diagnostic Reference Levels From the ACR CT Accreditation Program

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\begin{abstract}
\textbf{Purpose:} The aim of this study was to assess the distribution of CT dose index (CTDI) values reported by sites undergoing ACR CT accreditation between 2002 and 2004.

\textbf{Methods:} Weighted CTDI (CTDI\textsubscript{w}) values were measured and reported by sites applying for ACR CT accreditation, and the percentage of scanners with values above the 2002 ACR diagnostic reference levels (DRLs) was determined. Acquisition parameters for a site’s adult head, adult abdominal, and pediatric abdominal examinations were used to calculate volume CTDI (CTDI\textsubscript{vol}), and the average and standard deviation were calculated by year. Histogram analysis was performed to determine 75th and 90th percentiles of CTDI\textsubscript{vol}.

\textbf{Results:} Between September 2002 and December 2004, 829 scanners underwent the accreditation process. Volume CTDI values (average $\pm$ SD) for 2002, 2003, 2004, and 2002 to 2004, respectively, were 66.7 $\pm$ 23.5, 58.5 $\pm$ 17.5, 55.8 $\pm$ 15.7, and 59.1 $\pm$ 18.6 mGy for adult head examinations; 18.7 $\pm$ 8.0, 19.2 $\pm$ 8.6, 17.0 $\pm$ 7.6, and 18.4 $\pm$ 8.3 for adult abdominal examinations; and 17.2 $\pm$ 9.7, 15.9 $\pm$ 8.6, 14.0 $\pm$ 7.0, and 15.5 $\pm$ 8.4 for pediatric abdominal examinations. For 2004 data, 23.8%, 2.3%, and 6.9% of sites reported doses above the 2002 CTDI\textsubscript{w} reference levels, compared with 49.6%, 4.7%, and 15% for 2002 data for adult head, adult abdominal, and pediatric abdominal examinations, respectively. Seventy-fifth percentiles of CTDI\textsubscript{vol} were 76.8 mGy (adult head, 2002 only), 22.2 mGy (adult abdominal), and 20.0 mGy (pediatric abdominal).

\textbf{Conclusions:} From 2002 to 2004, average CTDI\textsubscript{vol} values decreased by 10.9, 1.7, and 3.2 mGy for adult head, adult abdominal, and pediatric abdominal examinations. Effective January 1, 2008, the ACR program implemented United States-specific diagnostic reference levels of 75, 25, and 20 mGy, respectively, for the CTDI\textsubscript{vol} of routine adult head, adult abdominal, and pediatric abdominal CT scans.

\textbf{Key Words:} CT dose, diagnostic reference levels, ACR accreditation

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\end{abstract}

\section*{INTRODUCTION}

The use of diagnostic reference levels (DRLs) is endorsed by many professional and regulatory organizations, including the International Commission on Radiological Protection [1,2], the ACR [3,4], the American Association of Physicists in Medicine [5], the UK Health Protection Agency [6,7], the International Atomic Energy Agency [8,9], and the European Commission [10-12], as an important dose optimization tool. DRLs are generally set at the upper third or quartile of doses sampled from actual practice data [2]. They do not represent ideal dose levels but rather an upper limit of dose levels that should be used under typical conditions for a standard patient size. As such, when these levels are routinely exceeded, sites should initiate investigation of the appropriateness...
of their examination protocols to more appropriately optimize examination quality and safety [2].

The use of DRLs has been shown to reduce the overall dose and the range of doses observed in clinical practice. For example, UK national dose surveys demonstrated a 30% decrease in typical radiographic doses from 1984 to 1995 and an average drop of about 50% between 1985 and 2000 [13,14]. These reductions are attributed to at least 2 factors: improvements in equipment dose efficiency and the internal investigations triggered when a DRL was consistently exceeded. Working as a team, the radiologist, radiologic technologist, and diagnostic medical physicist can often find dose reduction strategies that do not negatively affect the overall quality of the specific diagnostic examination, allowing the required level of image quality to be attained at lower dose levels. These and other activities resulted in dose levels that started above the 75th percentile to move, over time, below the 75th percentile, with the net effect of achieving an overall narrower dose distribution and a lower mean dose.

Diagnostic reference levels must be defined in terms of an easily and reproducibly measured dose metric, using technique parameters that reflect those used in a site’s clinical practice [2,4]. In radiographic and fluoroscopic imaging, typically measured quantities are entrance skin dose for radiography and dose-area product for fluoroscopy. Dose can be measured directly with thermoluminescent dosimeters or derived from exposure measurements. In CT, published DRLs use CT dose index (CTDI)-based metrics such as weighted CTDI (CTDIw), volume CTDI (CTDIvol), and dose-length product [10-12,15-19]. Published, normalized (eg, per 100 mAs) CTDI values for different scanners may be used with typical technique factors (eg, tube current-time product, pitch), or CTDI values can be directly measured at typical technique factors to determine a site’s typical scanner output. At the inception of the ACR program, initial CT DRLs for the United States were set using CTDIw DRLs from the United Kingdom’s national dose survey as guidance [7,13,14], with a longer term objective to use the collected United States data as a basis for determining United States CT DRLs (as reported here). Specifically, DRLs for adult head, adult abdominal, and pediatric abdominal CT examinations were set at 60, 35, and 25 mGy, respectively [10]. The DRL for head CT was consistent with data published from the United States Nationwide Evaluation of X-Ray Trends surveys of head CT doses, which reported mean CTDIw values of 45.9 ± 18.1 and 50.3 ± 19.4 mGy, respectively, for 1990 and 2000 [20,21]. At the inception of the ACR CT Accreditation Program in 2002, the reported CTDIw values were not used as pass/fail criteria in the program. Exceeding the 2002 DRLs did not preclude a site from becoming accredited, but it did require the site to provide documentation as to why its practice used CTDIw values above the DRL. The purpose of this work was to analyze the first three years of data from the ACR CT Accreditation Program and determine United States-specific CT DRL values for routine adult head, adult abdominal, and pediatric abdominal CT examinations.

METHODS

Since 2002, the ACR CT Accreditation Program [22] has required sites undergoing the accreditation process to measure and report CTDIw and CTDIvol using the sites’ typical acquisition parameters for several routine examinations: (1) routine adult head (such as the technique used for the cerebral portion of a scan for headaches or to exclude neoplasms), (2) routine adult abdominal (such as for detection of possible liver metastases or lymphoma), and (3) routine pediatric abdominal (such as for blunt trauma, acute abdominal pain, or infection; sites were instructed to report their techniques assuming a 5-year-old patient). For adult head examinations, sites were to calculate CTDIw and CTDIvol, using the standard 16-cm-diameter poly-methyl-methacrylate (PMMA) phantom placed in a head holder [18,19,23]. For adult abdominal scans, CTDIw and CTDIvol were determined using the standard 32-cm-diameter PMMA phantom placed on the tabletop [18,19,23]. For pediatric abdominal scans, CTDIw and CTDIvol were determined using the standard 16-cm-diameter PMMA phantom placed on the tabletop [18,19,23].

For a single axial scan at the center of the phantom, exposure or air kerma measurements were recorded using a calibrated 100-mm ionization chamber and electrometer. Total nominal beam width and chamber correction factors were recorded by a qualified medical physicist performing the phantom tests in a provided Excel spreadsheet (Microsoft Corporation, Redmond, Washington). The CTDI100 at isocenter, in milligrams, was calculated for both the center and edge positions using previously described techniques [15,18,19,24-26].

The CTDIw [10,18,25,27] was calculated in the spreadsheet using the equation

$$\text{CTDI}_w = \frac{1}{3}(\text{CTDI}_{100,\text{center}}) + \frac{2}{3}(\text{CTDI}_{100,\text{edge}})$$  \hspace{1cm} (1)

Although CTDIw is an easily measured dose metric, it does not account for pitch, ie, “gaps or overlaps” in a helical scan). Volume CTDIvol quantifies scanner output for a specific scan protocol, taking into account pitch, which quantifies the table increment per consecutive rotation of the x-ray source. Volume CTDI was calculated in the spreadsheet using the equation

$$\text{CTDI}_{\text{vol}} = \text{CTDI}_w / \text{pitch},$$  \hspace{1cm} (2)

where pitch is the ratio of the table increment per gantry rotation to the total nominal beam width [18,25].

Between September 2002 and December 2004, a total of 829 scanners underwent the accreditation process.
(178 in 2002, 396 in 2003, and 255 in 2004). A manual review of all data reported between 2002 and 2004 was performed. Additionally, as part of their review for the accreditation program, any data deemed by the ACR CT Accreditation Program physics reviewers to have been incorrectly measured were removed from the Excel-based database. The average and standard deviation of CTDI values were calculated by year for each examination type, and the statistical significance of the changes in average CTDI values by year was tested using a two-tailed t-test. P values < .05 were considered statistically significant. Finally, the percentage of all scanners that reported CTDI values above the ACR 2002 DRLs was determined.

Histogram analysis was performed for each examination type and year. Reported CTDI values were grouped into bins of 5-mGy width. The frequency was normalized to a total of 100 scans per year and cumulative percentage frequency plotted. Normalization to 100 scans per year was performed to allow plotting of the data from each year on the same y-axis scale (ie, on the same plot). The 75th and 90th percentiles of CTDI for each examination from 2002 to 2004 were determined from the histograms. All data were carefully reviewed by the ACR CT Accreditation Committee, its CT Physics Subcommittee, and ACR staff members, and CTDI DRLs (75th percentile) and maximum accreditable CTDI values (90th percentile) were selected. The percentage of scanners exceeding the proposed DRLs was also calculated.

**RESULTS**

Between September 2002 and December 2004, 829 scanners underwent the accreditation process, and after excluding incorrect CTDI measurements, a total of 630 adult head, 600 adult abdominal, and 466 pediatric abdominal CTDI values were analyzed. Weighted CTDI values (average ± SD) in 2002, 2003, 2004, and 2002 to 2004, respectively, were 66.7 ± 23.5, 58.5 ± 17.5, 55.8 ± 15.7, and 59.1 ± 15.7 mGy for adult head examinations; 18.7 ± 8.0, 19.2 ± 8.6, 17.0 ± 7.6, and 18.4 ± 8.3 mGy for adult abdominal examinations; and 17.2 ± 9.7, 15.9 ± 8.6, 14.0 ± 7.0, and 15.5 ± 8.4 mGy for pediatric abdominal examinations (Tables 1-3, Figure 1). With the exception of adult abdominal examinations in 2003, the average and standard deviation of CTDI values and the percentage of scanners reporting CTDI values above the 2002 DRLs, fell for each consecutive year. The decreases in average CTDI values were 10.9, 1.7, and 3.2 mGy (18.2%, 4.9%, and 12.8% of the 2002 ACR DRLs) for adult head, adult abdominal, and pediatric abdominal examinations, respectively (Figure 1).

The histograms for adult head scans (CTDI) for 2002, 2003, and 2004 (Figure 2) demonstrate an increasingly abrupt transition at 60 mGy. In 2002, 50.79% of CTDI values were ≤60 mGy. This increased to 66.67% in 2003 and 76.17% in 2004. This trend paralleled feedback received by the ACR that sites were reluctant to submit head CTDI values >60 mGy because of the requirement to submit additional documentation explaining why their practices operated above the head CTDI DRL of 60 mGy. Simultaneously, the ACR received complaints that head examination image quality at a CTDI value of <60 mGy was inadequate. Therefore, it seemed that sites were altering their scan protocols to reduce head CTDI to ≤60 mGy, even if they were unhappy with the resulting image quality. The data from the first year of the program (2002) were the least likely to have been influenced by this effect, because early on in the program, sites were not aware that they would be required to document their rationales for exceeding the initial program DRLs. Hence, the committee was reluctant to use the 2003 and 2004 data as representative of the actual practice of head CT in the United States, and only the 2002 dose data for adult head were used for selecting new DRLs. Specifically, the 2002 head data and the cumulative data from 2002 to 2004 for adult abdominal and pediatric abdominal examinations were used to determine the 75th percentile of scanner radiation output in terms of CTDI vol, and these values were used to select new DRLs (Figure 3). Ninetieth percentile data from all three years were used for all three examinations to select pass/fail limits (Figure 3).

In 2002, 49.6%, 4.7%, and 15% of sites reported CTDI values above DRLs compared with 23.8%,

| Table 1. Adult head weighted CT dose index (mGy) data |
|----------------|----------------|----------------|----------------|----------------|
|                | 2002           | 2003           | 2004           | 2002-2004      |
| Mean ± SD      | 66.7 ± 23.5    | 58.5 ± 17.5    | 55.8 ± 15.7    | 59.1 ± 15.7    |
| 75th percentile| 76.8           | 63.9           | 60.0           | 64.3           |
| 90th percentile| 99.0           | 82.2           | 74.0           | 81.3           |

| Table 2. Adult abdominal weighted CT dose index (mGy) data |
|----------------|----------------|----------------|----------------|----------------|
|                | 2002           | 2003           | 2004           | 2002-2004      |
| Mean ± SD      | 18.7 ± 8.0     | 19.2 ± 8.7     | 17.0 ± 7.6     | 18.4 ± 8.3     |
| 75th percentile| 22.6           | 23.4           | 21.1           | 22.2           |
| 90th percentile| 29.4           | 30.6           | 25.8           | 29.5           |
2.3%, and 6.9% in 2004 for adult head, adult abdominal, and pediatric abdominal examinations, respectively (Table 4, Figure 4). On the basis of the 75th percentile, new ACR CTDI_{vol} DRLs were established at 75 mGy for adult head, 25 mGy for adult abdominal, and 20 mGy for pediatric abdominal studies. Upper dose limits (ie, pass/fail values) for receiving ACR CT accreditation were set at 80 mGy for adult head, 30 mGy for adult abdomen, and 25 mGy for pediatric abdomen on the basis of the 90th percentile values. The percentages of scanners exceeding the 2008 ACR CTDI_{vol} DRLs would have been 25.6%, 15.9%, and 26.4% for 2002 and 9.1%, 12.7%, and 19.2% in 2004 for the adult head, adult abdominal, and pediatric abdominal examinations, respectively (Table 5).

### DISCUSSION

On the basis of this study, new CT DRLs were adopted by the ACR CT Accreditation Program, effective January 1, 2008. The 2008 CTDI_{vol} DRLs were set at 75 mGy for adult head, 25 mGy for adult abdominal, and 20 mGy for pediatric abdominal examinations [4]. These values were comparable with the range of DRLs from other countries (Tables 6 and 7 [28-33]). Additionally, the 90th percentile data points from 2002 to 2004 were used to establish maximum CTDI_{vol} levels for sites wishing to receive ACR accreditation; CTDI_{vol} values above the 90th percentile were not considered consistent with the program goals of ensuring overall quality and safety for CT practices in the United States. The introduction of maximum CTDI_{vol} values for CT accreditation (80 mGy for adult head, 30 mGy for adult abdominal, and 25 mGy for pediatric abdominal examinations) reflects a change in ACR policy, in that sites having CTDI_{vol} values above these limits would not be granted ACR CT accreditation. Before 2008, CTDI_{w} values were not included in pass/fail criteria.

The delay between the data survey (2002-2004) and the adoption of new DRL values (January 1, 2008) was due to several factors. First, as a new accreditation program, software needed to be developed during 2005 to allow retrieval and analysis of the needed scan and dose parameters. Second, the existing database did not flag dose values for which the physics reviewers had noted errors in some aspect of the dose measurement process. Thus, manual review of all physics applications was performed to remove data points for which errors had been documented. Data analysis was completed by April 2006, and results reported at the annual meeting of RSNA in November 2006 [34]. Formal approval of the

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**Table 3. Pediatric abdomen weighted CT dose index (mGy) data**

<table>
<thead>
<tr>
<th></th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2002-2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ± SD</td>
<td>17.2 ± 9.7</td>
<td>15.9 ± 8.6</td>
<td>14.0 ± 7.0</td>
<td>15.5 ± 8.4</td>
</tr>
<tr>
<td>75th percentile</td>
<td>20.6</td>
<td>20.5</td>
<td>18.4</td>
<td>20.0</td>
</tr>
<tr>
<td>90th percentile</td>
<td>26.6</td>
<td>25.6</td>
<td>23.4</td>
<td>24.9</td>
</tr>
</tbody>
</table>

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![Fig 1. Average ± SD volume CT dose index (CTDI_{vol}) values for adult head, adult abdominal, and pediatric abdominal CT examinations for 2002, 2003, 2004, and 2002 to 2004. P values < .05 are shown.](image)
CT Accreditation Program Committee’s recommendation for new DRLs was then obtained using established ACR processes, and an announcement of the intended changes made during 2007. Thus, official adoption of the new ACR CT DRL values did not occur until January 1, 2008.

CT dose index values do not represent the dose for any given patient [35]. For a given phantom size, they represent a monotonic indication of the amount of radiation being produced by the scanner. It is essential to note that current international safety standards [36] require that the CTDI<sub>vol</sub> values reported on a scanner console be measured with the 16-cm-diameter (“head”) CTDI phantom for head examinations and the 32-cm-diameter (“body”) CTDI phantom for body examinations [25]. This is true regardless of patient size, gender, or age. This is important, for example, in allowing users to better understand how much the scanner’s radiation output was adjusted between larger and smaller patients (eg, how much the tube current was decreased for a pediatric patient). With all other parameters held constant, the tube current can be reduced by a factor of 5 for body CT imaging of a neonate relative to the value used in a typical adult [37]. Using the same (32-cm-diameter) “body” CTDI phantom, the CTDI values would also decrease by a factor of 5, indicating to the site how much it had “dialed down.” However, if the smaller (16-cm-diameter) “head” phantom was used to determine and display the CTDI values for pediatric body examinations, the displayed CTDI values for the neonate would be only a

![Fig 2. Histogram analysis of adult head CT data illustrating frequency and cumulative percentage for 2002, 2003, and 2004. CTDI<sub>w</sub> = weighted CT dose index.](image)

![Fig 3. Seventy-fifth and ninetieth percentile values for adult head, adult abdominal, and pediatric abdominal routine CT examinations. CTDI<sub>vol</sub> = volume CT dose index.](image)
factor of approximately 2 lower than for the adult, which does not accurately convey to the user the amount by which the tube current had been decreased.

The ACR CT Accreditation Program’s use of the 16-cm “head” phantom for assessment of the pediatric body CTDI values followed the example of the United Kingdom’s National Dose Surveys [7,38]. Unfortunately, both are examples of how changing the phantom size creates confusion as to the appropriate CTDI value for a pediatric patient. When measured in the “head” phantom, the 2008 ACR pediatric abdominal DRL is 20 mGy, which gives the impression that nearly the same technique is acceptable for a 5-year-old child as for an adult (the 2008 ACR adult abdominal DRL is 25 mGy). However, the adult abdominal DRL is assessed using the “body” (32-cm-diameter) phantom, so the two values are not directly comparable. To account for this difference, the pediatric DRL measured in a “head” phantom must by reduced by a factor of approximately 2.4 to be directly compared with the adult DRLs. Thus, a CTDIvol of 20 mGy in the “head” phantom translates to approximately 8.3 mGy if measured with a “body” phantom (the precise ratio is somewhat dependent on scanner model), which seems more appropriate for a 5-year-old relative to the use of 25 mGy in an adult. To complicate this issue, several manufacturers currently display on the scanner console pediatric body CTDI values based on the “head” phantom, which is different than what is specified in current international safety standards [36] and what is used by other manufacturers. Hence, great care must be taken to identify the phantom size used when comparing pediatric CTDIvol values between sites and scanner models or against adult values. National and international discussions are under way to address this confusing situation and standardize the phantom size used for pediatric body CTDI values.

Although dose reduction was observed for adult head CT examinations, feedback from sites undergoing accreditation indicated that sites were altering their scan protocols to reduce head CTDIw to ≤60 mGy, although complaints with regard to head image quality at this CTDI level were received. Histogram analysis of the adult head scans showed abrupt transitions at 60 mGy during 2003 and 2004 (this was also seen in 2002 data, but to a lesser extent; Figure 2). Thus, the reference value of 75 mGy was recommended on the basis of the more Gaussian-like dose distribution from 2002, which we believe represented a more accurate picture of United States routine head protocols before the growing influence of the 60 mGy ACR head DRL.

The 2008 head CTDIvol DRL value adopted by the ACR is 75 mGy, an increase compared with the 2002 head CTDIw DRL of 60 mGy. Increased head CT DRLs

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**Table 4. Percentages of scanners above 2002 weighted CT dose index diagnostic reference levels**

<table>
<thead>
<tr>
<th>Examination</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2002-2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adult head</td>
<td>49.6</td>
<td>33.3</td>
<td>23.8</td>
<td>33.4</td>
</tr>
<tr>
<td>Adult abdominal</td>
<td>4.7</td>
<td>5.2</td>
<td>2.3</td>
<td>4.2</td>
</tr>
<tr>
<td>Pediatric abdom</td>
<td>15.0</td>
<td>11.7</td>
<td>6.9</td>
<td>10.8</td>
</tr>
</tbody>
</table>

**Table 5. Percentages of scanners above 2008 volume CT dose index diagnostic reference levels**

<table>
<thead>
<tr>
<th>Examination</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2002-2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adult head</td>
<td>25.6</td>
<td>12.8</td>
<td>9.1</td>
<td>14.0</td>
</tr>
<tr>
<td>Adult abdominal</td>
<td>15.9</td>
<td>20.3</td>
<td>12.7</td>
<td>17.0</td>
</tr>
<tr>
<td>Pediatric abdom</td>
<td>26.4</td>
<td>27.2</td>
<td>19.2</td>
<td>24.5</td>
</tr>
</tbody>
</table>

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**Fig 4.** Percentage of scanners exceeding 2002 weighted CT dose index (CTDIw) diagnostic reference levels (DRLs) and 2008 volume CT dose index (CTDIvol) DRLs. Because DRLs typically reflect the 75th percentile of the dose distribution, the number of scanners above the DRL should fall at the horizontal line (25%).
are also seen in the United Kingdom, where current CTDI\textsubscript{vol} DRLs range from 65 mGy for scans of the cerebrum to 100 mGy for scans of the posterior fossa (Table 7) [12]. This is in comparison with the CTDI\textsubscript{vol} of 60 mGy for either portion of the head recommended by the European Commission in 1999 [11,39]. Current CTDI\textsubscript{vol} DRLs for head CT examinations range from 60 mGy (European Commission) to 100 mGy (United Kingdom), with a median DRL of 75 mGy [4,12]. We believe that the transition from 10-mm image width in the cerebrum, which was quite standard in the 1980s and early to mid-1990s, to the ubiquitous 5-mm image widths used today explains the need for the 15% to 25% increase in dose that radiologists deem necessary for today’s level of expected image quality. In contrast, doses for body CT examinations have dropped remarkably since the 1980s and early 1990s, even though image widths have also decreased for body CT [40]. The difference is likely related to differences in lesion conspicuity in the head compared with the body; the differences in CT numbers between gray and white matter in the brain are only a few Hounsfield units, whereas most pathologies in the torso have higher inherent contrast.

The percentages of scanners exceeding the 2002 CTDI\textsubscript{w} DRLs were evaluated to determine if initial DRLs had been appropriately chosen (Figure 4). By definition, approximately 25% of scanners should fall above an appropriately set DRL that is based on the 75th percentile of clinically used values. For adult head examinations in 2002, nearly 50% of scanners fell above the 2002 DRL, while the percentages of scanners exceeding the adult abdomen and pediatric abdomen DRLs were well below 25% (Figure 4). This demonstrates that the DRL for adult head scans was too low and that the DRLs for both adult and pediatric abdomen scans were too high for the United States in 2002. That is, the initial program values taken from the 1999 European Commission Guidelines on Quality Criteria for CT [10] were not reflective of the technology and practice of CT in the United States from 2002 to 2004.

After selection of the 2008 DRLs, we compared the 2002 to 2004 cumulative CTDI\textsubscript{vol} data with the 2008

### Table 6. Published adult DRLs for CTDI\textsubscript{w} (mGy) and DLP (mGy · cm)

<table>
<thead>
<tr>
<th></th>
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<th>Abdomen</th>
<th>Pelvis</th>
<th>Abdomen and Pelvis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CTDI\textsubscript{w}</td>
<td>DLP</td>
<td>CTDI\textsubscript{w}</td>
<td>DLP</td>
</tr>
<tr>
<td>European Commission 1999 [10]</td>
<td>60</td>
<td>1,050</td>
<td>35</td>
<td>780</td>
</tr>
<tr>
<td>United Kingdom 2003 [7]</td>
<td>65†, 110‡</td>
<td>930</td>
<td>20</td>
<td>470</td>
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<tr>
<td>Germany 2003 [28]</td>
<td>60</td>
<td>1,050</td>
<td>25</td>
<td>770</td>
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<tr>
<td>Switzerland 2004 [29]</td>
<td>60</td>
<td>800</td>
<td>20</td>
<td>710</td>
</tr>
</tbody>
</table>

Note: CTDI\textsubscript{w} = weighted CT dose index; DLP = dose-length product; DRL = diagnostic reference level.
†Cerebrum.
‡Posterior fossa.

### Table 7. Published adult DRLs for CTDI\textsubscript{vol} (mGy) and DLP (mGy · cm)

<table>
<thead>
<tr>
<th></th>
<th>Head</th>
<th>Abdomen</th>
<th>Pelvis</th>
<th>Abdomen and Pelvis</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>CTDI\textsubscript{vol}</td>
<td>DLP</td>
<td>CTDI\textsubscript{vol}</td>
<td>DLP</td>
</tr>
<tr>
<td>Sweden 2002 [31]</td>
<td>75</td>
<td>1,200</td>
<td>25</td>
<td>—</td>
</tr>
<tr>
<td>United Kingdom 2003 [7]</td>
<td>65†, 100‡</td>
<td>930</td>
<td>14</td>
<td>470</td>
</tr>
<tr>
<td>The Netherlands 2008 [32]</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Switzerland 2010 [33]</td>
<td>65</td>
<td>1,000</td>
<td>15‡</td>
<td>400</td>
</tr>
</tbody>
</table>

Note: CTDI\textsubscript{vol} = volume CT dose index; DLP = dose-length product; DRL = diagnostic reference level.
†Cerebrum.
‡Posterior fossa.
‡Acute pain, renal stones, abscesses.
§Liver, pancreas, adrenal glands.
ACR DRLs. The percentages of scanners reporting CTDI values above the respective DRLs became much closer to the target value of 25%: 14.0%, 17.0%, and 24.5% above the 75th percentile for adult head, adult abdominal, and pediatric abdominal examinations, respectively (Figure 4). The value equals 25% for the head in 2002 but not for 2003 or 2004 because of the previously discussed effect of the perceived 60-mGy “dose limit.” In the case of adult abdominal examinations, the 75th percentile of CTDIvol was 22.2 mGy, but the committee elected to round up to 25 mGy, in part to make the value more easily remembered, but also because the dose distribution was very narrow for adult abdominal examinations, implying that a small shift in the selected DRL value could cause a large change in the number of sites falling above the DRL. To be sure not to force an arbitrary change in adult abdominal CT scanning in the United States because of the selection of a potentially inappropriate DRL (as observed with the 2002 CTDIw head DRL of 60 mGy), the physics subcommittee elected to recommend 25 mGy. Ongoing evaluation of program data will allow continued refinement of the ACR CT DRLs, reflecting the increased numbers of sites participating in the program, the evolving levels of scanner technology, and changes in the United States practice.

Because the practice of CT encompasses many more examination types than routine head and body examinations, DRLs for many other common CT examinations are needed to broaden the dose optimization efforts in CT. To this end, several national surveys have begun to assess a broader range of examination types. The ACR has initiated the Dose Index Registry to automatically collect CTDIvol data directly from the Digital Imaging and Communications in Medicine (DICOM) header, thus allowing considerably faster accumulation of the data required to establish DRLs for additional examination types [41]. This is being accomplished through collaboration with multiple institutions and manufacturers that have modified their DICOM headers to include CTDIvol values. New elements have been officially added to the CT DICOM standards to allow more accurate and rapid dose data surveys on a broad scale. The newest scanner models and software versions have begun including these data elements, although the implementation time frame for older scanners remains unclear. Finally, individual practices and investigators, some representing multicenter trials, have begun to collect and report CTDIvol data for a variety of examination types [42,43]. Publication of additional studies is anticipated over the coming years for a variety of patient populations, countries, and practice types. Such information will extend the value of the concept of DRLs to the majority of CT applications, enabling individual CT users and the community at large to answer the question, “What doses are typical, and what doses are too much?”

CONCLUSIONS
In every case except adult abdominal examinations in 2003, both the average and the standard deviation of observed scanner output levels (in terms of CTDIw and CTDIvol) fell for each consecutive year between 2002 and 2004. Over the same time period, average CTDIw values decreased by 10.9, 1.7, and 3.2 mGy for routine adult head, adult abdominal, and pediatric abdominal examinations. These absolute reductions represent percentage reductions of 18.2%, 4.9%, and 12.8% of the 2002 CTDIw DRLs for the respective examinations. Similarly, the 75th and 90th percentile values and the percentage of scanners with CTDI values over the DRLs fell for almost every year. Thus, along with continuing improvements in CT equipment and increased user education regarding CT dose optimization, the establishment of CT DRLs in the United States may have played a role in reducing both the average and the standard deviation of scanner output levels for three common CT examinations. Effective January 1, 2008, the ACR CT Accreditation Program adopted CTDIvol DRLs of 75, 25, and 20 mGy, respectively, for routine adult head, adult abdominal, and pediatric abdominal CT scans [4]. These DRLs reflect typical clinical protocols in the United States and take into account the effect of pitch.

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