Radiology

U.S. Diagnostic Reference Levels and Achievable Doses for 10 Adult CT Examinations[1]

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Purpose: To develop diagnostic reference levels (DRLs) and achievable doses (ADs) for the 10 most common adult computed tomographic (CT) examinations in the United States as a function of patient size by using the CT Dose Index Registry.

Materials and Methods: Data from the 10 most commonly performed adult CT head, neck, and body examinations from 583 facilities were analyzed. For head examinations, the lateral thickness was used as an indicator of patient size; for neck and body examinations, water-equivalent diameter was used. Data from 1 310 727 examinations (analyzed by using SAS 9.3) provided median values, as well as means and 25th and 75th (DRL) percentiles for volume CT dose index ($CTDI_{vol}$), dose-length product (DLP), and size-specific dose estimate (SSDE). Applicable results were compared with DRLs from eight countries.

Results: More than 46% of the facilities were community hospitals; 13% were academic facilities. More than 48% were in metropolitan areas, 39% were suburban, and 13% were rural. More than 50% of the facilities performed fewer than 500 examinations per month. The abdomen and pelvis was the most frequently performed examination in the study (45%). For body examinations, DRLs (75th percentile) and ADs (median) for $CTDI_{vol}$, SSDE, and DLP increased consistently with the patient's size (water-equivalent diameter). The relationships between patient size and DRLs and ADs were not as strong for head and neck examinations. These results agree well with the data from other countries.

Conclusion: DRLs and ADs as a function of patient size were developed for the 10 most common adult CT examinations performed in the United States.

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Computed tomography (CT) is critical for screening, diagnosis, therapy, and the management of patient care. In emergency departments alone, CT significantly impacts leading diagnosis, diagnostic confidence, and admission decisions (1). However, with these benefits come increased utilization and an increase in population exposure to ionizing radiation.

Americans were exposed to more than seven times as much ionizing radiation from medical procedures in 2006 than in the early 1980s. Although CT scans represented only 12% of imaging procedures, they contributed almost 50% of the total radiation dose to the U.S. population from medical imaging (2). This increase in population dose is of concern because of the potential for radiation-induced malignancies.

Until recently, a national collection of patient-based dose estimates was not available in the United States. The Nationwide Evaluation of X-Ray Trends (3) program surveyed a representative sample of U.S. CT facilities, but reported only radiation exposure to a phantom, not radiation exposure estimated from individual patient scans.

Doses are routinely estimated by using standard 16- or 32-cm diameter polymethylmethacrylate cylinder phantoms representing "average" patients. For CT, this parameter, the volume CT dose index ($CTDI_{vol}$), approximates the average dose to a cross section of the phantom (4). Dose-length product (DLP) is based on $CTDI_{vol}$ factors in the length of the scan. Presently, $CTDI_{vol}$ and/or DLP are displayed on CT units for each scan. Although these parameters are tagged to individual examinations, they do not represent the patient's dose but rather the dose to one of the standard phantoms. Depending on the size of the patient relative to the size of the phantom used to report $CTDI_{vol}$, the actual dose to the patient may be considerably different (4,5). $CTDI_{vol}$ is primarily useful as a quality assurance tool to compare doses from different protocols and to compare scanner outputs from different manufacturers.

More recently, the American Association of Physicists in Medicine (AAPM) developed a new CT parameter, the size-specific dose estimate (SSDE), to more accurately estimate dose at the center of the scanned region of an individual patient by factoring in the patient's size (6). SSDE is determined by applying a conversion factor based on linear dimensions of the transverse cross section of the patient to the $CTDI_{vol}$. Although SSDE is not yet automatically reported by CT manufacturers, discussions are underway by the medical profession and manufacturers to automatically acquire the patient dimensions, apply them to the $CTDI_{vol}$, and report SSDE for each patient.

Diagnostic reference levels (DRLs) are benchmarks for radiation protection

Advances in Knowledge

- National diagnostic reference levels (DRLs) and achievable doses (ADs) as a function of patient size are provided for the 10 most common adult CT examinations (head and brain without contrast material; neck with contrast material; cervical spine without contrast material; chest without contrast material; chest with contrast material; chest and pulmonary arteries with contrast material; abdomen and pelvis without contrast material; abdomen and pelvis with contrast material; abdomen and pelvis for nephrolithiasis without contrast material; and chest, abdomen, and pelvis with contrast material) by using 2014 data.
- For the most common examination, abdomen and pelvis with contrast material (25.8% of all examinations in this study), the DRLs for patients with water-equivalent diameters between 29 and 33 cm were 15 mGy (volume CT dose index [$CTDI_{vol}$]), 18 mGy (size-specific dose estimate), and 755 mGy-cm (dose-length product [DLP]).
- For head and brain without contrast material examinations (17.1% of all examinations in this study), the DRLs for patients with lateral head thicknesses between 14 and 16 cm were 56 mGy ($CTDI_{vol}$) and 962 mGy-cm (DLP).
- The new DRLs show that examination exposures to the U.S. adult population are generally not higher than those in other countries.

Implications for Patient Care

- The results of this study will enable facilities to compare their patient doses with national benchmarks.
- Because smaller patients require lower doses than larger ones to yield adequate image quality, the new size-specific DRLs and ADs will enable facilities to more effectively optimize their CT protocols for the wide range of sizes of the patients they examine and thus to appropriately reduce dose to patients.

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Abbreviations:
AAPM = American Association of Physicists in Medicine
ACR = American College of Radiology
AD = achievable dose
$CTDI_{vol}$ = volume CT dose index
DIR = Dose Index Registry
DLP = dose-length product
DRL = diagnostic reference level
ICRP = International Commission on Radiological Protection
SSDE = size-specific dose estimate

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Conflicts of interest are listed at the end of this article.

and optimization of patient imaging. They were first mentioned by the International Commission on Radiological Protection (ICRP) in 1990 (7) and were clarified further in 1996 (8). The ICRP defines two key elements in medicine: justification and optimization of radiology examinations. Justification implies that the examination is indicated and the patient's benefit exceeds any potential detriments. Optimization implies that the radiation exposure is optimized for the clinical purpose of the examination.

An important optimization tool, DRL is defined as an investigational level that applies to an easily measured quantity using a standard phantom or representative patient. It is intended for use as a simple test for identifying situations where the levels of patient dose are unusually high (8). The ICRP emphasizes that DRLs "are not for regulatory or commercial purposes, not a dose restraint and not linked to limits or constraints" (9). The use of DRLs is endorsed by professional, advisory, and regulatory organizations, including the ICRP, American College of Radiology (ACR), AAPM, United Kingdom Health Protection Agency, International Atomic Energy Agency, and European Commission. DRLs are typically set at the 75th percentile of the dose distribution from a survey conducted across a broad user base (ie, large, small, public, private, hospital, and outpatient facilities) using a specified dose-measurement protocol. They are established both regionally and nationally, and considerable variations have been seen across both regions and countries (9,10).

The concept of achievable dose (AD) was introduced in 1999 by the United Kingdom National Radiation Protection Board to further optimize practice. In 2012, the National Council on Radiation Protection and Measurements, or NCRP, proposed that ADs be set at the median (50th percentile) of a dose survey, on the basis that 50% of the facilities have already achieved doses at or below this value (11).

There are few current US recommendations for DRLs and ADs. For example, the ACR-AAPM Practice Parameter for Diagnostic Reference Levels and Achievable Doses in Medical X-Ray Imaging (12) developed DRLs and ADs from data prior to 2005 for only three adult examinations (head, abdomen and pelvis, and chest). These DRLs and ADs are based on phantom data and apply only to a patient size that corresponds to the size of the phantom. However, radiation dose must increase with patient size (13) to maintain acceptable image quality. Although some work developing size-specific DRLs for pediatric patients has been done (14), guidance is not available for small- and large-sized adult patient populations.

The National Radiology Data Registry (NRDR) is a data warehouse for diagnostic imaging registries run by the ACR to collect examination data and results. The primary purpose of the NRDR is to provide national and regional data to aid facilities in improving patient care. The CT Dose Index Registry (DIR) continuously collects, de-identifies, and transmits dose indexes and patient size information to the NRDR for storage and analysis (15), enabling the development of benchmarks.

The purpose of this study was to use the power of the CT DIR to develop DRLs and ADs for the 10 most common adult CT examinations as a function of patient size.

Materials and Methods

The 10 most common examinations in the United States performed between January and December 2014 in patients aged 19 years and older were included in the study. These are head and brain without contrast material; neck with contrast material; cervical spine without contrast material; chest without contrast material; chest with contrast material; chest and pulmonary arteries with contrast material; abdomen and pelvis without contrast material; abdomen and pelvis with contrast material; abdomen and pelvis for nephrolithiasis without contrast material; and chest, abdomen, and pelvis with contrast material. Only examinations with complete patient information (age, study date), dose indexes, and study descriptions were included. Examinations from facilities outside the United States, multiscan examinations, and body examinations with missing water-equivalent diameters and head examinations with missing lateral thicknesses were excluded. Multiscan examinations were identified as examinations with and without contrast material studies or those in which more than one body part was included in the examination. These were excluded to prevent overestimation of the radiation dose.

Anteroposterior diameters and lateral thicknesses were determined from the localizer images (16) to determine patient size. For head examinations, only the lateral thickness was used as the indicator of head size. Analysis of the anteroposterior diameters showed an unexplained bimodal data distribution, so they were considered to be unreliable indicators of head size. The median lateral dimension (15 cm) was consistent with the mean published by Huda et al (14.7 cm) (17).

Water-equivalent diameter (18) was used for neck and body examinations and was calculated from the automatically determined anteroposterior diameter and lateral thickness (16), following the AAPM method. For body examinations, the water-equivalent diameter was used to determine the appropriate conversion factor to estimate SSDE from $CTDI_{vol}$ normalized to a 32-cm phantom. SSDE conversion factors for head and neck examinations are not available at this time from the AAPM (18) and will be integrated into the program at a later date.

Results from the analysis were tabulated alongside corresponding data from other countries derived from the literature. Descriptive comparisons were made; no statistical comparisons were made because of the current variability in methods among countries and regions and inadequate data for statistical comparisons.

Statistical Analysis

A sensitivity analysis was performed to determine whether examinations excluded from the study because of

Table 1

Numbers of CT Examinations Included in Study

Body Part and Examination	No. of Examinations	Percentage
Head		
CT of head and brain without contrast material	223 908	17.1
Total	223 908	17.1
Neck or cervical spine		
CT of neck with contrast material	33 740	2.6
CT of cervical spine without contrast material	97 586	7.4
Total	131 326	10.0
Chest		
CT of chest without contrast material	159 909	12.2
CT of chest with contrast material	111 898	8.5
CT of chest pulmonary arteries with contrast material	58 986	4.5
Total	330 793	25.2
Abdomen and pelvis		
CT of abdomen and pelvis without contrast material	201 754	15.4
CT of abdomen and pelvis with contrast material	338 056	25.8
CT of abdomen, pelvis, and kidney without contrast material	47 748	3.6
Total	587 558	44.8
Chest, abdomen, and pelvis		
CT of chest, abdomen, and pelvis with contrast material	37 142	2.8
Total	37 142	2.8
Grand total	1 310 727	

Table 2

Characteristics of Facilities and Examinations Included in the Study

Characteristic	No. of Facilities in DIR	Percentage	No. of Examinations in Study	Percentage
Facility category				
Academic	78	13.4	372 746	28.4
Community hospital	271	46.5	794 839	60.6
Multispecialty clinic	27	4.6	40 594	3.1
Freestanding center	176	30.2	95 293	7.3
Children's hospital	22	3.8	1278	0.1
Other	9	1.5	5977	0.5
Facility location				
Metropolitan	280	48.0	708 965	54.1
Suburban	227	38.9	514 047	39.2
Rural	76	13.0	87 715	6.7
Census region				
Northeast	168	28.8	555 612	42.4
Midwest	152	26.1	297 155	22.7
South	159	27.3	304 633	23.2
West	104	17.8	153 327	11.7
Trauma center level				
I	87	14.9	351 883	26.9
II	63	10.8	318 043	24.3
III	37	6.4	115 513	8.8
IV	12	2.1	18 007	1.4
Not a trauma center	384	65.9	507 281	38.7
Average no. of examinations per month				
0–500	330	56.6	181 656	13.9
501–1000	92	15.8	218 872	16.7
1001–2000	105	18.0	424 557	32.4
>2000	56	9.6	485 642	37.1
Total in DIR	583	100	1 310 727	100

missing water-equivalent diameter or lateral thickness were inherently different from those with non-missing values.

Distributions of lateral thickness for head examinations and water-equivalent diameter for body examinations were obtained by using univariate procedures. Head examinations were categorized into 2-cm lateral thickness bins because of the small range of thicknesses. Neck and body examinations were categorized into 4-cm water-equivalent–diameter bins because of the larger ranges of water-equivalent diameters.

Descriptive statistics were calculated for facility category, location, census region, and average volume of examinations per month. One-way frequency tables were generated for demographic distributions of the study population.

Median values of $CTDI_{vol}$, DLP, and SSDE were calculated for each facility. Twenty-fifth percentiles, medians, and 75th percentiles for these median values were calculated for each of the examinations. Median values were used for consistency with proposed international recommendations to enable comparison of our results with those of other countries following these recommendations. In early 2016, the ICRP published a draft of "Diagnostic Reference Levels in Medical Imaging" for public comment. In that document, they say, "The Commission now recommends that the median value (not the mean

Table 3

Demographic Distribution of Study Population

Characteristic	No. of Examinations in Study	Percentage
Sex		
Female	726 485	55.4
Male	582 510	44.4
Other/unknown	1732	0.1
Age group (y)		
19–44	346 272	26.4
45–64	443 889	33.9
≥65	520 566	39.7
Total	1 310 727	100

Table 4

Size-based ADs and DRLs for Head and Neck CT Examinations

Examination and Median Size (Thickness or Diameter)	Size (cm)	No. of Facilities	No. of Patients	$CTDI_{vol}$ (mGy)		DLP (mGy-cm)	
				AD (50th Percentile)	DRL (75th Percentile)	AD (50th Percentile)	DRL (75th Percentile)
Head and brain without contrast material*	12–14	227	19933	47	56	767	936
	14–16	290	137755	49	56	811	962
	16–18	256	57292	52	60	902	1020
	18–20	160	5390	51	60	926	1069
	All†	347†	223908	49	57	849	1011
Neck with contrast material‡	14–18	352	9458	14	18	377	509
	18–22	350	8723	15	19	429	563
	22–26	334	5717	15	19	423	560
	26–30	307	5012	16	20	457	572
	30–34	259	2655	17	23	494	656
	All†	417†	33740	15	20	431	572
Cervical spine without contrast material§	13–17	350	22739	18	24	362	495
	17–21	375	36711	20	28	421	562
	21–25	346	18600	21	28	438	575
	25–29	326	11640	22	29	450	609
	29–33	265	5477	25	33	551	703
	All†	434†	97586	21	28	432	602

Note.—The AD is the 50th percentile of the distribution of median values (the 50th percentile) of all participating facilities; the DRL is the 75th percentile of the distribution of median values of all participating facilities.

* Only lateral thickness (cm) was used. The median lateral thickness was 15 cm.

† "All" includes data beyond lowest- and highest-size bins; "No. of facilities" is the total number of facilities submitting data for any size patient.

‡ Water-equivalent diameter (cm) was used. The median diameter was 20 cm.

§ Water-equivalent diameter (cm) was used. The median diameter was 19 cm.

value) for the DRL quantity from each of the facilities in the survey should be used. National DRLs should be set as the 75th percentile of the median values obtained in a sample of representative centers" (ICRP, unpublished document, 2016).

A multivariable mixed regression analysis was performed to determine whether dose indexes varied significantly by water-equivalent diameter and lateral thickness. Facility was included as a random effect, and fixed effects included facility characteristics, age, and sex. An analysis was performed for multiple comparisons among size bins for each body part to determine if the means of the dose indexes were significantly different from each other.

Size bins were constructed not by relying on statistical significance but by using the distribution of the data—that is, the number of data points in each of the bins—and by keeping the clinical perspective and practical usefulness in mind. We considered collapsing the non–statistically significant bins into one but realized that the resulting bins would be confusing and lose their usability.

All analyses were performed by using SAS software, version 9.3, of the SAS System for Windows (2015, SAS Institute, Chicago, Ill).

Results

The DIR collected 5701421 adult examinations between January and December 2014; 3417992 were in the top 10 most frequently performed examinations. After the exclusion of multiphase examinations, neck and body examinations with missing water-equivalent diameters, and head examinations with missing lateral thicknesses, 1310727 examinations were analyzed from 583 facilities (Tables 1, 2). The sensitivity analysis indicated no difference between the examinations included in the study and the examinations that were excluded from the study (0%–0.13% difference in mean values of $CTDI_{vol}$ and DLPs). We did not test for statistical significance because the differences were too small to be clinically meaningful.

Abdomen and pelvis was the most common examination (45%), followed by chest (25%); head (17%); neck/cervical spine (10%); and chest, abdomen, and pelvis (2.8%). More than 46% of participating facilities were community hospitals; 13% were academic facilities; 280 facilities (48%) were in metropolitan areas; 227 (39%) were in suburban areas; and 76 (13%) were in rural areas. Fewer than 500 examinations per month were performed at 56.6% of facilities.

More than 55% of the examinations were in female patients, and 60% were in patients between 19 and 64 years of age (Table 3).

Figure 1

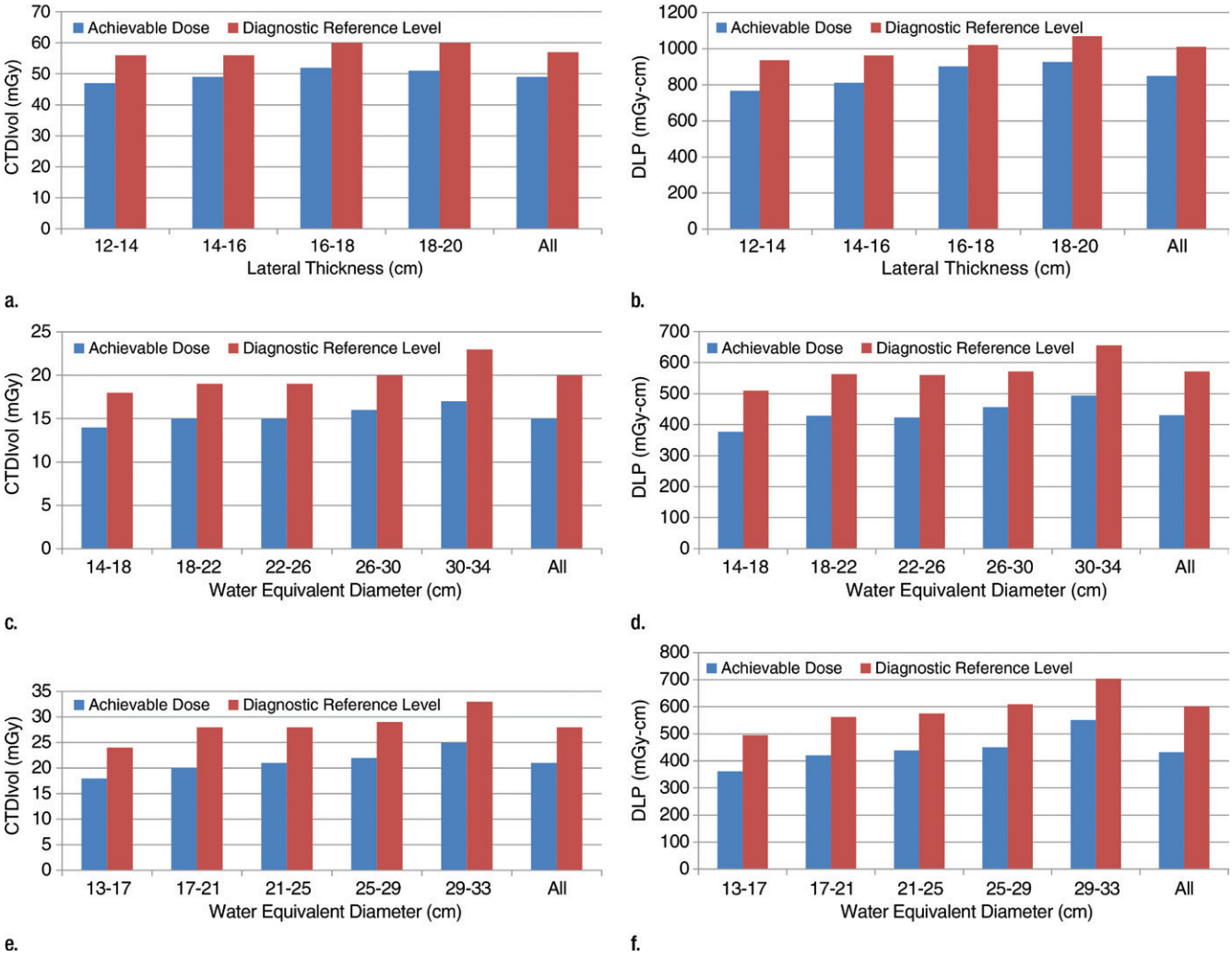

Figure 1: Graphs show head, neck, and cervical spine ADs and DRLs. **(a)** AD and DRL for head and brain without contrast material–$CTDI_{vol}$. **(b)** AD and DRL for head and brain without contrast material–DLP. **(c)** AD and DRL for neck with contrast material–$CTDI_{vol}$. **(d)** AD and DRL for neck with contrast material–DLP. **(e)** AD and DRL for cervical spine without contrast material–$CTDI_{vol}$. **(f)** AD and DRL for cervical spine without contrast material–DLP.

Multivariate regression analysis showed that water-equivalent diameter and lateral thickness were significant predictors of dose indexes (after controlling for facility as random effect and facility characteristics, age, and sex as fixed effects). The analysis for body examinations showed that all bins were significantly different from each other for $CTDI_{vol}$. For chest examinations, all but 21–25 cm and 25–29 cm were different from each other for DLP. For head and neck examinations, most bins were not statistically significantly different from the next bin.

Table 4 and Figure 1 show the variation of dose indexes with lateral thickness (head examinations) and water-equivalent diameter (neck and cervical spine examinations). The median lateral thickness for examinations of the head and brain without contrast material was 15 cm. Among 223 908 head examinations, 137 755 (62%) fell in the 14–16-cm bin that included the median thickness. The median water-equivalent diameter for neck with contrast examinations was 20 cm. There were 33 740 neck examinations, of which 8723 (26%) fell in the 18–22-cm bin. The median water-equivalent diameter for examinations of the cervical spine without contrast material was 19 cm. There were 97 586 cervical spine examinations, of which 36 711 (38%) fell in the 17–21-cm bin.

Tables 5–7 show the variation of the dose indexes for chest, abdomen and pelvis, and chest, abdomen, and pelvis examinations with water-equivalent diameter. Figures 2–4 show graphic

Table 5

Size-based ADs and DRLs for Chest CT Examinations

Examination and Median Size (Diameter)	Size (cm)	No. of Facilities	No. of Patients	$CTDI_{vol}$ (mGy)		SSDE (mGy)		DLP (mGy-cm)	
				AD (50th Percentile)	DRL (75th Percentile)	AD (50th Percentile)	DRL (75th Percentile)	AD (50th Percentile)	DRL (75th Percentile)
Chest without contrast material*	21–25	389	10863	5	7	8	12	186	270
	25–29	445	35204	6	9	9	12	231	317
	29–33	454	58650	9	12	11	15	334	443
	33–37	431	39375	13	17	14	18	477	610
	37–41	394	10539	17	21	15	19	595	760
	All†	485†	159909	10	15	11	16	347	545
Chest with contrast material*	21–25	367	7507	5	8	9	12	205	299
	25–29	437	25021	7	10	9	13	238	366
	29–33	447	41044	10	13	11	15	353	469
	33–37	428	27097	14	18	15	18	516	660
	37–41	373	7581	18	23	16	20	663	855
	All†	476†	111898	10	16	12	17	374	596
Chest pulmonary arteries with contrast material*	21–25	112	2578	6	9	9	14	203	282
	25–29	147	10930	8	11	10	15	250	350
	29–33	146	20224	11	14	13	17	357	445
	33–37	141	17244	15	19	15	20	477	631
	37–41	118	6683	19	25	18	23	611	838
	All†	183†	58986	11	18	13	19	357	557

Note.—The AD is the 50th percentile of the distribution of median values (the 50th percentile) of all participating facilities; the DRL is the 75th percentile of the distribution of median values of all participating facilities.

* Water-equivalent diameter (cm) was used. The median diameter was 31 cm for all examinations.

† "All" includes data beyond lowest- and highest-size bins; "No. of facilities" is the total no. of facilities submitting data for any size patient.

representations of the same data. The median water-equivalent diameter for all examinations was 31 cm. There were 330793 chest examinations, of which 119918 (36%) fell in the 29–33-cm bin. There were 587558 abdomen examinations, of which 187860 (32%) fell in the 29–33-cm bin. There were 37142 chest, abdomen, and pelvis examinations, of which 12117 (33%) fell in the 29–33 cm bin. The median (50th percentile) and 75th percentile $CTDI_{vol}$ and SSDE for these examinations increased with patient size, especially with the very large sizes. The median DLPs also increased consistently from smaller to larger sizes.

Table 8 and Figure 5 summarize the results for the trunk (chest; abdomen and pelvis; chest, abdomen, and pelvis) examinations for median-size patients.

Table 9 shows that the U.S. DRLs are not markedly different from those in other countries (11–13,19–25).

Discussion

This work establishes DRLs and ADs using data from the largest source in the world of CT dose information from actual patient examinations. The DIR was launched in 2011 (26) and, as of July 2016, has data on 30.3 million examinations from 1524 facilities. This extensive participation and totally automated complete capture of all patient examinations enable the development of robust, clinically based national DRLs and ADs. DRLs and ADs are provided for $CTDI_{vol}$, SSDE, and DLP for the 10 most common CT examinations.

One of the unique contributions of this work is the development of size-based DRLs and ADs. Although the impact of patient size on radiation dose is well established (13,27), national DRLs have previously provided only one value for each examination. These are based on a standard-size phantom representing an "average" patient (11,12), a single patient size (19,20), or data averaged across all patient sizes (13,22). Size-based DRLs will allow facilities to optimize protocols so that the resultant dose is commensurate with the size of the patient, thus avoiding unnecessary radiation exposure to the patient.

SSDE (for body examinations) adjusts the phantom-based $CTDI_{vol}$ for the size of the patient and gives a more realistic estimation of patient dose. For all body examinations, SSDE ADs and DRLs were higher than $CTDI_{vol}$ values for smaller patients; SSDE ADs and

Table 6

Size-based ADs and DRLs for Abdomen and Pelvis CT Examinations

Examination and Median Size (Diameter)	Size (cm)	No. of Facilities	No. of Patients	$CTDI_{vol}$ (mGy)		SSDE (mGy)		DLP (mGy-cm)	
				AD (50th Percentile)	DRL (75th Percentile)	AD (50th Percentile)	DRL (75th Percentile)	AD (50th Percentile)	DRL (75th Percentile)
Abdomen and pelvis without contrast material*	21–25	353	14667	7	9	11	14	318	422
	25–29	390	43185	9	12	13	16	443	545
	29–33	415	64317	13	16	15	19	639	781
	33–37	403	51133	17	21	18	22	865	1048
	37–41	365	21901	21	25	19	22	1071	1306
	All†	446†	201754	13	20	15	19	657	1004
Abdomen and pelvis with contrast material*	21–25	397	29691	7	9	10	13	300	394
	25–29	443	82822	9	11	12	15	409	524
	29–33	448	108921	12	15	15	18	608	755
	33–37	434	76681	17	21	18	21	887	1056
	37–41	392	30640	21	24	19	22	1072	1266
	All†	492†	338056	13	19	15	19	615	995
Abdomen, pelvis, and kidney without contrast material*	21–25	137	4173	7	9	10	15	291	408
	25–29	165	10640	8	12	12	16	380	526
	29–33	170	14622	12	15	14	19	576	705
	33–37	164	11440	16	20	17	20	788	943
	37–41	148	5111	19	22	17	20	901	1092
	All†	202†	47748	12	18	14	19	586	877

Note.—The AD is the 50th percentile of the distribution of median values (the 50th percentile) of all participating facilities; the DRL is the 75th percentile of the distribution of median values of all participating facilities.

* Water-equivalent diameter (cm) was used. The median diameter was 31 cm for all examinations.

† All" includes data beyond lowest- and highest-size bins; "No. of facilities" is the total no. of facilities submitting data for any size patient.

Table 7

Size-based ADs and DRLs for Chest, Abdomen, and Pelvis CT Examinations

Examination and Median Size (Diameter)	Size (cm)	No. of Facilities	No. of Patients	$CTDI_{vol}$ (mGy)		SSDE (mGy)		DLP (mGy-cm)	
				AD (50th Percentile)	DRL (75th Percentile)	AD (50th Percentile)	DRL (75th Percentile)	AD (50th Percentile)	DRL (75th Percentile)
Chest, abdomen, and pelvis with contrast material*	21–25	162	3465	7	10	11	15	407	591
	25–29	197	9363	9	11	12	15	536	705
	29–33	202	12117	12	15	14	18	779	947
	33–37	187	7817	17	21	17	21	1076	1348
	37–41	147	3089	21	25	18	22	1328	1647
	All†	250†	37142	12	19	15	19	774	1193

Note.—The AD is the 50th percentile of the distribution of median values (the 50th percentile) of all participating facilities; the DRL is the 75th percentile of the distribution of median values of all participating facilities.

* Water-equivalent diameter (cm) was used. The median diameter was 31 cm.

† "All" includes data beyond lowest- and highest-size bins; "No. of facilities" is the total no. of facilities submitting data for any size patient.

Figure 2

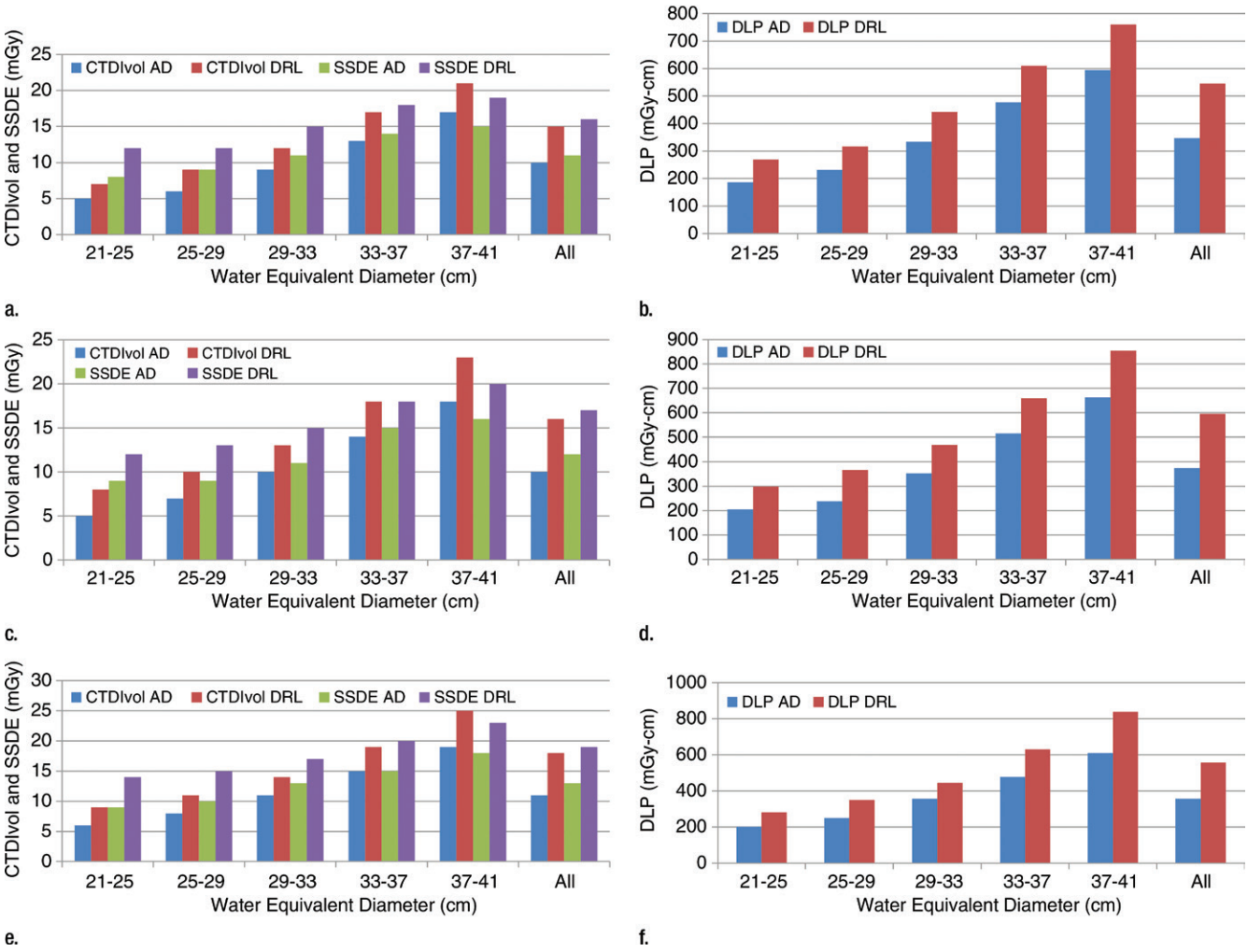

Figure 2: Graphs show chest ADs and DRLs. **(a)** AD and DRL for chest without contrast material—$CTDI_{vol}$ and SSDE. **(b)** AD and DRL for chest without contrast material–DLP. **(c)** AD and DRL for chest with contrast material—$CTDI_{vol}$ and SSDE. **(d)** AD and DRL for chest with contrast material–DLP. **(e)** AD and DRL for chest pulmonary arteries with contrast material—$CTDI_{vol}$ and SSDE. **(f)** AD and DRL for chest pulmonary arteries with contrast material–DLP.

DRLs were lower than $CTDI_{vol}$ values for the largest patient sizes.

DRLs for the size bin containing median-size patients were similar to those in other countries. As more modern CT scanners with more dose-reduction options become available, we anticipate a further reduction in radiation dose used for clinical examinations. The DIR will continue to monitor this trend and will revise the U.S. ADs and DRLs as necessary.

The use of DRLs has been shown to reduce the overall dose and the range of doses observed in clinical practice. For example, in the United Kingdom, the 2005 DRLs for radiography, fluoroscopy, and dental x-rays were approximately 16% lower than those in 2000 and were approximately half of those in the mid-1980s (28). While improvements in equipment dose efficiency may be reflected in these dose reductions, investigations triggered when DRLs are exceeded can often result in new, lower-dose protocols that provide sufficient image quality for the diagnostic task. Thus, data points above the 75th percentile are, over time, moved below the 75th percentile—with the net effect of a narrower dose distribution and a lower median dose.

DRLs should be used to determine if a facility's dose indexes are unusually high; they should not be used as target doses. Both ADs and DRLs are provided to encourage facilities to optimize dose to a lower level than that indicated by the DRL. Image quality must be taken into consideration when using DRLs and ADs to evaluate CT protocols on each scanner to determine if protocols are optimized. Ideally, facilities should analyze and compare their median, size-grouped dose indexes

Figure 3

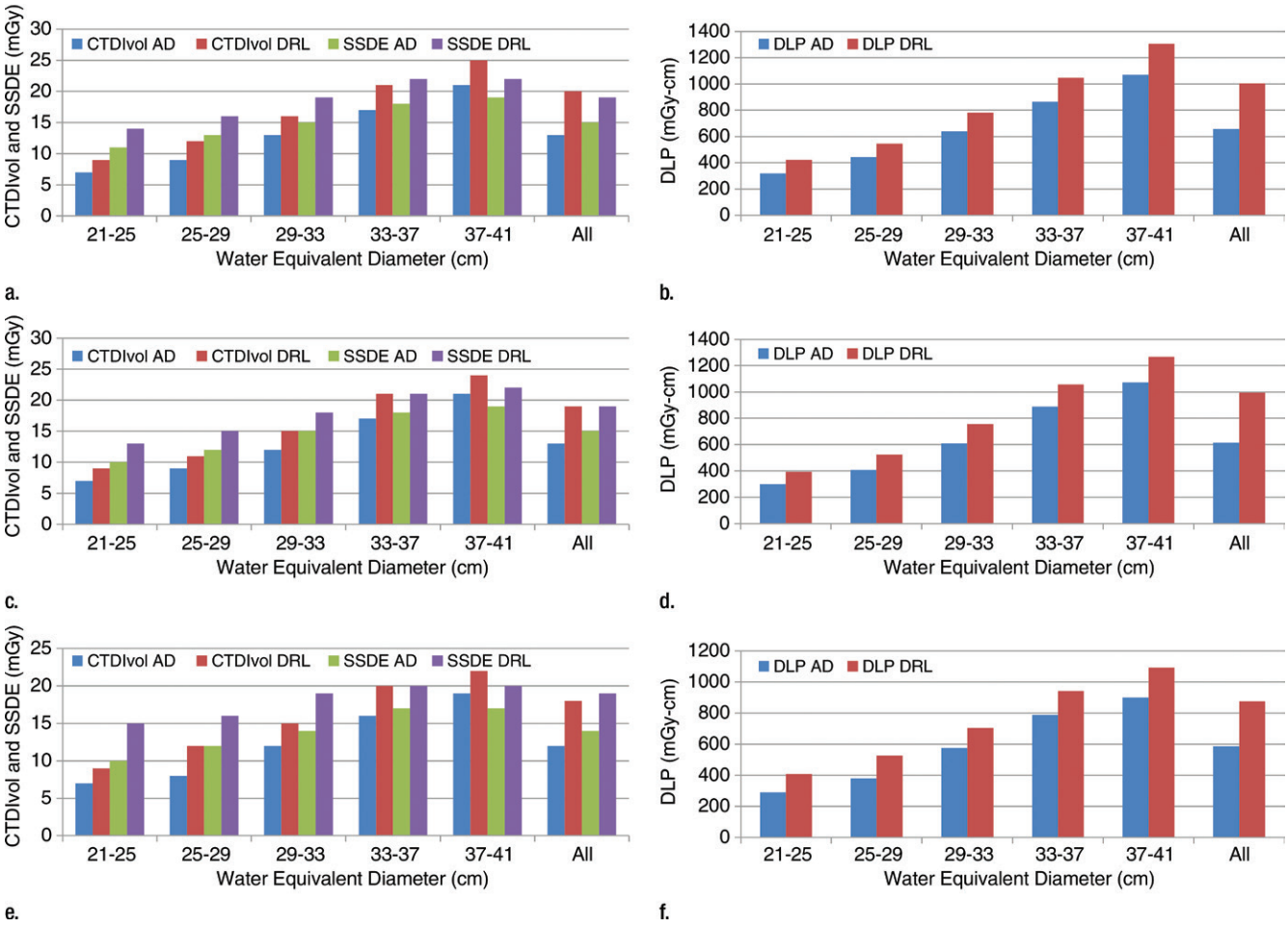

Figure 3: Graphs show abdomen and pelvis ADs and DRLs. **(a)** AD and DRL for abdomen and pelvis without contrast material—$CTDI_{vol}$ and SSDE. **(b)** AD and DRL for abdomen and pelvis without contrast material—DLP. **(c)** AD and DRL for abdomen and pelvis with contrast material—$CTDI_{vol}$ and SSDE. **(d)** AD and DRL for abdomen and pelvis with contrast material—DLP. **(e)** AD and DRL for abdomen, pelvis, and kidney without contrast material—$CTDI_{vol}$ and SSDE. **(f)** AD and DRL for abdomen, pelvis, and kidney without contrast material—DLP.

Figure 4

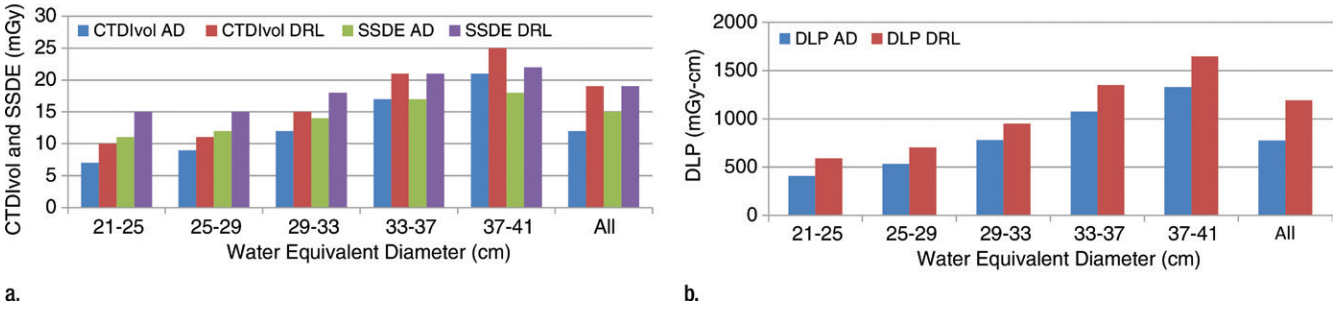

Figure 4: Graphs show chest, abdomen, and pelvis ADs and DRLs. **(a)** AD and DRL for chest, abdomen, and pelvis with contrast material—$CTDI_{vol}$ and SSDE. **(b)** AD and DRL for chest, abdomen, and pelvis with contrast material—DLP.

Table 8

AD and DRL Comparisons for Trunk Examinations

Examination	$CTDI_{vol}$ (mGy)		SSDE (mGy)		DLP (mGy-cm)	
	AD	DRL	AD	DRL	AD	DRL
Chest without contrast material	9	12	11	15	334	443
Chest with contrast material	10	13	11	15	353	469
Chest and pulmonary arteries with contrast material	11	14	13	17	357	445
Abdomen and pelvis without contrast material	13	16	15	19	639	781
Abdomen and pelvis with contrast material	12	15	15	18	608	755
Abdomen, pelvis, and kidney without contrast material	12	15	14	19	576	705
Chest, abdomen, and pelvis with contrast material	12	15	14	18	779	947

Note.—ADs and DRLs are based on the size bin containing median-size patients.

Figure 5

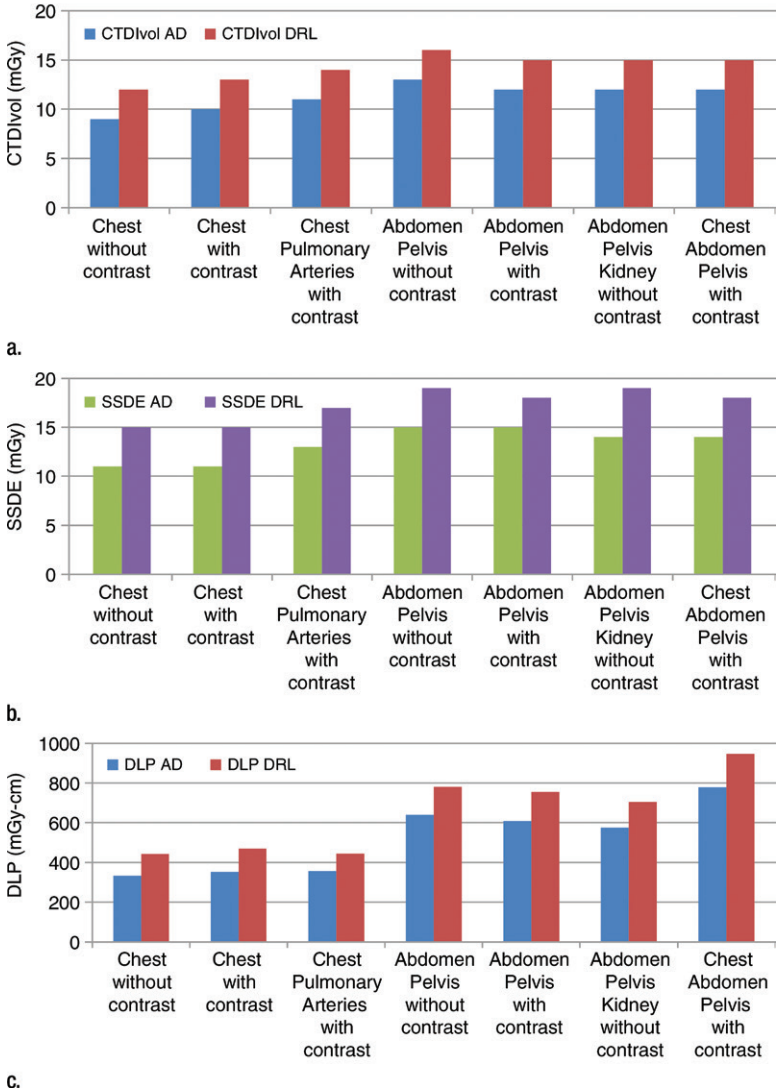

Figure 5: Graphs show AD and DRL comparisons for trunk examinations.

with the respective size-based ADs and DRLs. If size-grouped dose indexes are not available, facilities should compare their overall median indexes with the "all" DRLs and ADs. Also, if the $CTDI_{vol}$ or SSDE for a protocol is below its DRL but the DLP exceeds its DRL, the scan length should be reviewed. DRLs and ADs are not intended to be used for comparisons with dose indexes for individual patients. Implementation of DRLs and ADs is most effective if the facility has a system to automatically monitor patient dose indexes so that aggregate results may be evaluated.

One of the advantages of using a dose index registry to determine national ADs and DRLs is eliminating the need to manually collect data from a small sample of facilities and patients. Data from an enormous patient population and an all-inclusive set of examinations are automatically collected, resulting in fewer errors and enabling frequent updates. Transparency of DIR data encourages ongoing data quality improvement at participating facilities.

There were some limitations inherent to any automated data-collection process. The DIR is a voluntary registry and is not a random sample of facilities, examinations, or patients. However, the DIR demographics show it has broad participation from all types of facilities. Participants in the DIR do not submit clinical indication information, so ADs and DRLs can be developed only based on examination type. Also, the reported values reflect the doses that are currently used in practice rather than the lowest doses that would provide clinically adequate images (or are optimal in any other sense). In addition, facilities do not submit clinical images with their dose information, so image quality at the participating sites is not assessed. We have to assume that the majority of the examinations submitted to the DIR met the facilities' image quality standards because we assume the vast majority were interpreted. An independent assessment of image quality is addressed by other processes, such as accreditation (29). Another limitation was the manual process for

Table 9

Domestic and International DRL Comparisons

Body Part, Examination, and Parameter	DRLs										
	ACR DIR (2016)*	ACR-AAPM (2013)†	NCRP (2012)‡	Japan (2015)§	EU (2014)‖	UK (2014)#	Ireland (2012)**	Australia (2011)††	Canada (2016)‡‡	The Netherlands (2012)§§	Greece (2014)‖‖
Head											
CT of head and brain without contrast material											
$CTDI_{vol}$ (mGy)	56	75	75	85	60	60	58	60	79		67
DLP (mGy-cm)	962			1350	1000	970	940	1000	1302		1055
Neck/cervical spine											
CT of neck with contrast material											
$CTDI_{vol}$ (mGy)	19							30			
DLP (mGy-cm)	563				500			600			
CT of cervical spine with contrast material											
$CTDI_{vol}$ (mGy)	28					28	19				
DLP (mGy-cm)	562				400–600	600	420				
Chest											
CT of chest without contrast material											
$CTDI_{vol}$ (mGy)	12	21	21	15	10	12	9	15	14		14
DLP (mGy-cm)	443			550	400	610	390	450	521		480
CT of chest with contrast material											
$CTDI_{vol}$ (mGy)	13	21	21	15	10	12	9	15	14		14
DLP (mGy-cm)	469			550	400	610	390	450	521		480
CT of chest pulmonary arteries with contrast material											
$CTDI_{vol}$ (mGy)	14					13	13			10	
DLP (mGy-cm)	445					440	430			350	
Abdomen and pelvis											
CT of abdomen and pelvis without contrast material											
$CTDI_{vol}$ (mGy)	16	25	25	20	25	15	12	15	18	15	16
DLP (mGy-cm)	781			1000	800	745	600	700	874	700	760
CT of abdomen and pelvis with contrast material											
$CTDI_{vol}$ (mGy)	15	25	25	20	25	15	12	15	18	15	16
DLP (mGy-cm)	755			1000	800	745	600	700	874	700	760
CT of abdomen, pelvis, and kidney without contrast material											
$CTDI_{vol}$ (mGy)	15					10					
DLP (mGy-cm)	705					460					

Table 9 (*continues*)

Table 9 (continued)

Domestic and International DRL Comparisons

Body Part, Examination, and Parameter	DRLs										
	ACR DIR (2016)*	ACR-AAPM (2013)†	NCRP (2012)‡	Japan (2015)§	EU (2014)‖	UK (2014)#	Ireland (2012)**	Australia (2011)††	Canada (2016)‡‡	The Netherlands (2012)§§	Greece (2014)‖‖
Chest, abdomen, and pelvis											
CT of chest, abdomen, and pelvis with contrast material											
$CTDI_{vol}$ (mGy)	15			18			13	30	17		17
DLP (mGy-cm)	947			1300		1000	12	1200	1269		1020

* ACR registry DRLs are based on the size bin containing median-size patients.

† ACR-AAPM Practice Parameter for Diagnostic Reference Levels and Achievable Doses in Medical X-Ray Imaging (12)—based on phantom of average-size patient.

‡ National Council on Radiation Protection and Measurements (11)—based on phantom of average-size patient.

§ Japan (19)—based on standard-sized (50–60-kg) patients.

‖ European Union (20)—derived from "most common value" from surveyed countries.

United Kingdom (13)—no condition specified for patient size.

** Ireland (21)—based on average-sized (60–80 kg) patients.

†† Australia (22)—no condition specified for patient size.

‡‡ Canada (23)—based on average-sized (50–90-kg) patients.

§§ The Netherlands (24)—based on standard-sized patients.

‖‖ Greece (25)—based on a "typical" acquisition.

examination code mapping, with its inherent and unavoidable inconsistencies. Examinations not tagged accurately by the facility may cause problems both by skewing the benchmark data and by being compared with inappropriate benchmark data. The DIR drives facilities to standardize procedure names through the use of mapping tools and RadLex terminology (30). The use of dose-reduction techniques, such as iterative reconstruction, is not collected in the DIR. The study did not assess CT scanner type and detector configuration.

Another limitation was the use of facility median dose indexes to develop the DRL. This gives equal weight to each facility, irrespective of its size and volume. To address this concern, we also analyzed the data so that each patient examination was given equal weight and noted that the different methods created only slight differences in the resulting DRLs. This is probably because of the large number of examinations submitted by all facilities. Irrespective of the limitations noted above, the study's enormous patient volume provides robust benchmarks for DRLs and ADs.

This work provides DRLs and ADs for the 10 most common CT adult examinations performed in the United States using 2014 data from the DIR and represents the first time, to our knowledge, that national adult DRLs and ADs have been developed as a function of patient size. This will enable facilities to effectively compare their patient doses with national benchmarks and to optimize their CT protocols, resulting in lower doses at the appropriate image quality.

The DIR will update its ADs and DRLs on a routine basis to capture future trends in CT scanners and radiation dose. Future work will include expanding the analysis to include high-dose studies and various scanner configurations.

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