Anatomical and Clinical Diagnostic Reference Levels- An Update – The North American Perspective

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Learning Objectives

1. *To learn the concept of DRLs and clinical DRLs*
2. *Use DRLs to compare patient doses with national benchmarks*
3. *Use DRLs to optimize CT protocols*
4. *To learn how the patient repositories can facilitate the establishment of DRLs*

Outline

- Definition of diagnostic reference level (DRL)
- DRL Resources
- ACR study on adult CT DRLs
- How to use DRLs
- Key take home points

Definition of DRL

- A DRL is an investigational level used to identify unusually high radiation doses for common diagnostic medical X-ray imaging procedures.
- DRLs are suggested action levels above which a facility should review its methods and determine if acceptable image quality can be achieved at lower doses.
- The International Commission on Radiological Protection (ICRP) emphasizes that DRLs “are not for regulatory or commercial purposes, not a dose restraint and not linked to limits or constraints.
- DRLs are a practical tool to promote optimization and were first successfully implemented for conventional radiography in the 1980s and subsequently developed for other modalities in the 1990s.

Definition of DRL

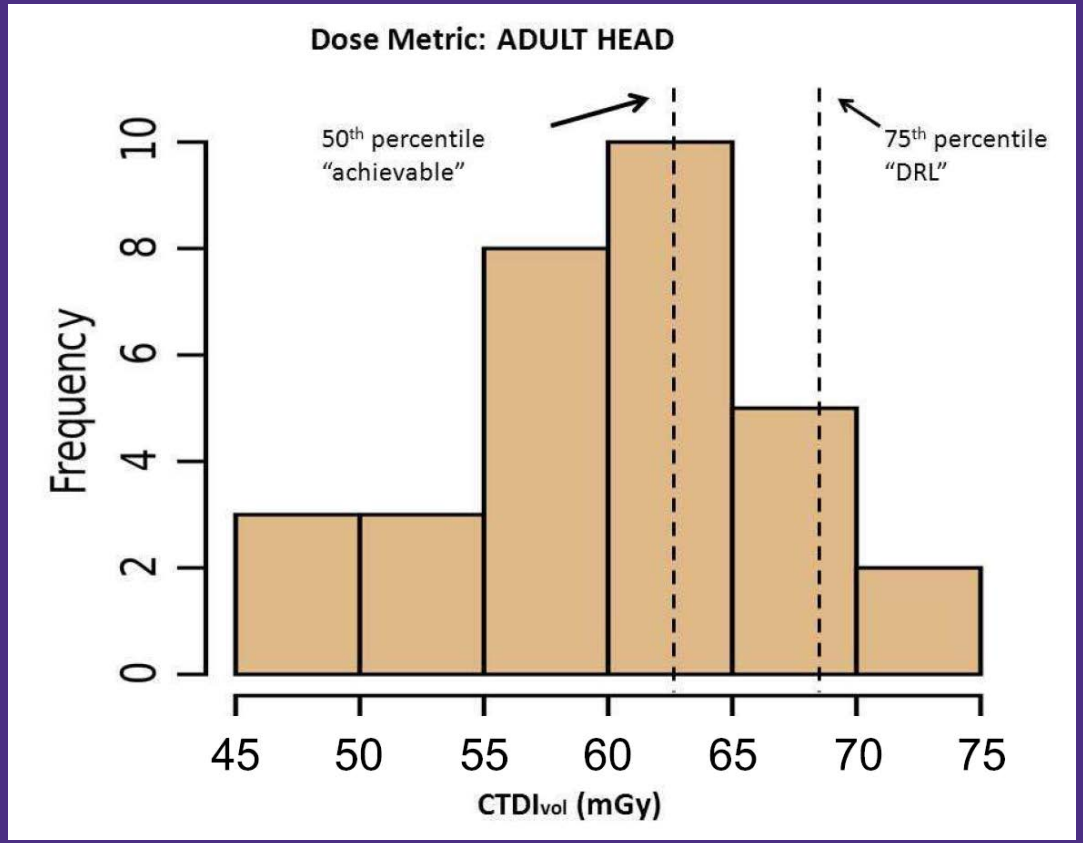
- DRLs are based on standard phantom or patient measurements under specific conditions at a number of representative clinical facilities.
- DRLs have been set at approximately the 75th percentile of measured patient or phantom data. This means that procedures performed at 75% of the institutions surveyed have exposure levels at or below the DRL.
- The ICRP also emphasizes that DRLs should not be applied to individual patients.
- To make meaningful comparisons, aggregate facility data collected in the same manner that the benchmark DRLs were developed should be compared against the DRL.

Achievable Dose (AD)

- ADs can be used with DRLs to assist in optimizing image quality and dose.
- ADs are set at approximately the median (50th percentile) of the study dose distribution, i.e., half of the facilities are producing images at lower doses and half are using higher doses.
- Further information on ADs is available in the National Council on Radiation Protection and Measurements (NCRP) Report 172.

Definition of AD and DRL

- DRLs and ADs are part of the optimization process.
- It is essential to ensure that image quality appropriate for the diagnostic purpose is achieved when changing patient doses.
- Optimization must balance image quality and patient dose.



Quantities used to set DRLs

Vassileva and Rehani: AJR 2015; 204:W1–W3

TABLE 1: Dose Quantities and Units Commonly Used to Set Diagnostic Reference Levels

Type of Procedure	Dose Quantity and Units
Radiography (including dental radiography)	Incident air kerma K_i (in air, without backscatter) or entrance surface air kerma (or dose) K_e (in air, with backscatter), in mGy, for a given radiographic projection; air kerma (or dose)–area product, in mGy·cm^2
Mammography	Incident air kerma (K_i), in mGy; mean glandular dose (D_G), in mGy
Complex procedures (including fluoroscopy-guided procedures)	Air kerma (or dose)–area product (P_{KA}), in Gy·cm^2; cumulative air kerma at the reference point ($K_{a,r}$) in Gy
CT	CT air kerma (or dose) index, in mGy; CT air kerma (or dose)–length product, in mGy·cm
Diagnostic nuclear medicine	Administered activity (A), in MBq

Note—Air kerma represents the kinetic energy released per unit mass when an x-ray beam is traveling through air.

American College of Radiology Practice Parameters

Revised 2018 (Resolution 40)*

ACR–AAPM–SPR PRACTICE PARAMETER FOR DIAGNOSTIC REFERENCE LEVELS AND ACHIEVABLE DOSES IN MEDICAL X-RAY IMAGING

ACR–AAPM–ACNM–SNMMI PRACTICE PARAMETER FOR REFERENCE LEVELS AND ACHIEVABLE ADMINISTERED ACTIVITY FOR NUCLEAR MEDICINE AND MOLECULAR IMAGING

Council-approved 2020

X-Ray

Table 1

DRLs and ADs for Adult and Pediatric X-Ray Examinations (incident air kerma, free-in-air)

Examination (patient thickness)	DRL (mGy)	AD (mGy)
Adult PA chest (23 cm), with grid	0.15	0.11
Pediatric PA chest (12.5 cm), with grid	0.12	0.07
Pediatric PA chest (12.5 cm), without grid	0.06	0.04
Examination (patient thickness)	**DRL (mGy)**	**AD (mGy)**
Adult AP abdomen (22 cm)	3.4	2.4
Adult AP lumbosacral spine (22 cm)	4.2	2.8

Fluoroscopy

Table 2
DRLs and ADs for Under Table Adult (22-cm PA Abdomen) Fluoroscopic Imaging (incident air kerma rate, with backscatter)

Phantom: Adult PA Abdomen with grid	**DRL**	**AD**
Upper GI fluoroscopy, without oral contrast media	54 mGy min^{-1}	40 mGy min^{-1}
Upper GI fluoroscopy, with oral contrast media	80 mGy min^{-1}	72 mGy min^{-1}
Fluorographic image, without contrast (incident air kerma, with backscatter)		
Film	3.9 mGy	2.5 mGy
Digital	1.5 mGy	0.9 mGy
Fluorographic image, with contrast (incident air kerma, with backscatter)		
Film	27.5 mGy	18.7 mGy
Digital	9.9 mGy	5.3 mGy

CT

Table 3

Phantom-Based DRLs and ADs for Adult and Pediatric CT ($CTDI_{vol}$)

Examination	Patient Lateral Dimension (cm)	CTDI Phantom Diameter (cm)	$CTDI_{vol}$	
			DRL (mGy)	AD (mGy)
Adult head [4,17]	16	16	75	57
Adult abdomen-pelvis [4,17]	38	32	25	17
Adult chest [4]	35	32	21	14
Pediatric 1-year-old head [19]	15	16	35	*
Pediatric 5-year-old abdomen-pelvis [19]	20	16	15	*
		32	7.5	*

**ADs are not available for pediatric studies from source reference* [19]

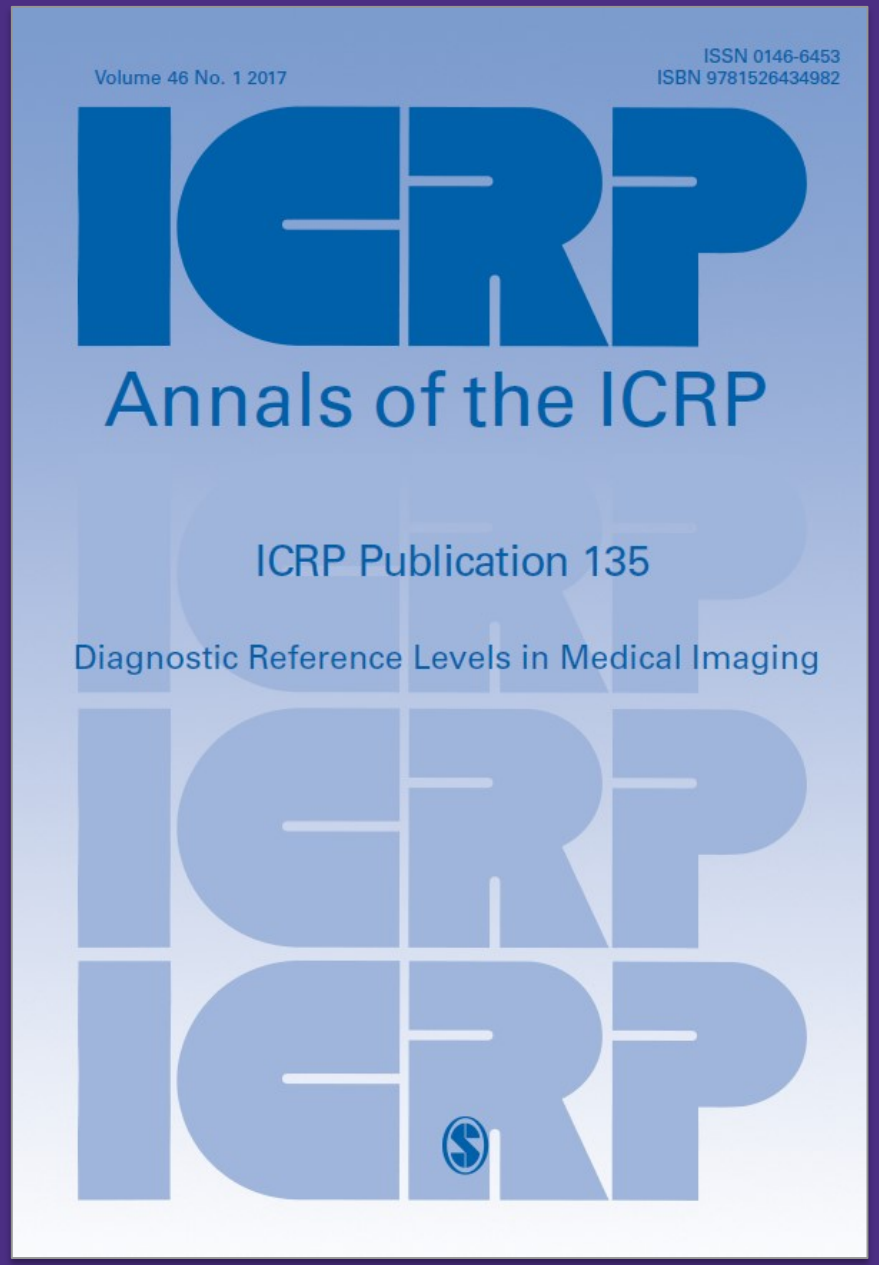
CT

Table 4
Patient-Based DRLs and ADs for Adult CT [24]

Examination	Patient Size (cm)	$CTDI_{vol}$ (mGy)		SSDE (mGy)		DLP (mGy-cm)	
		DRL	AD	DRL	AD	DRL	AD
Head and brain without contrast	14 to 16 (lat thickness)	56	49			962	811
Neck with contrast	18 to 22 (water-eq dia)	19	15			563	429
Cervical spine without contrast	18 to 22 (water-eq dia)	28	20			562	421
Chest without contrast	29 to 33 (water-eq dia)	12	9	15	11	443	334
Chest with contrast	29 to 33 (water-eq dia)	13	10	15	11	469	353
Chest pulmonary arteries with contrast	29 to 33 (water-eq dia)	14	11	17	13	445	357
Abdomen and pelvis witl contrast							
Abdomen and pelvis witl contrast							
Abdomen, pelvis, and ki without contrast							
Chest, abdomen, and pel with contrast material							

Table 5
Patient-Based DRLs and ADs for Pediatric CT

Examination	Effective Diameter (cm)	Lateral Body Width (cm)	$CTDI_{vol}$ (mGy)		SSDE (mGy)		DLP (mGy-cm)	
			DRL	AD	DRL	AD	DRL	AD
Chest [28]	<15	<18	1.8		3.9	2.1	28	
	15 to 19	18 to 23	2.0		4.5	3.0	52	
	20 to 24	24 to 30	3.2		5.1	3.4	80	
	25 to 29	31 to 35	4.8		6.6	4.7	148	
	≥30	…	7.8		8.4	6.3	253	
Abdomen [29]		<15	5.0	3.4	12.0	8.0	106	88.0
		15 to 19	5.6	4.1	12.2	8.7	162	124
		20 to 24	7.1	5.4	13.4	9.8	245	186
		25 to 29	9.8	8.0	16.4	13.0	418	328
		≥30	14.0	10.8	19.0	15.6	651	518



Annals of the ICRP

ICRP PUBLICATION 135

Diagnostic Reference Levels in Medical Imaging

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PUBLISHED FOR

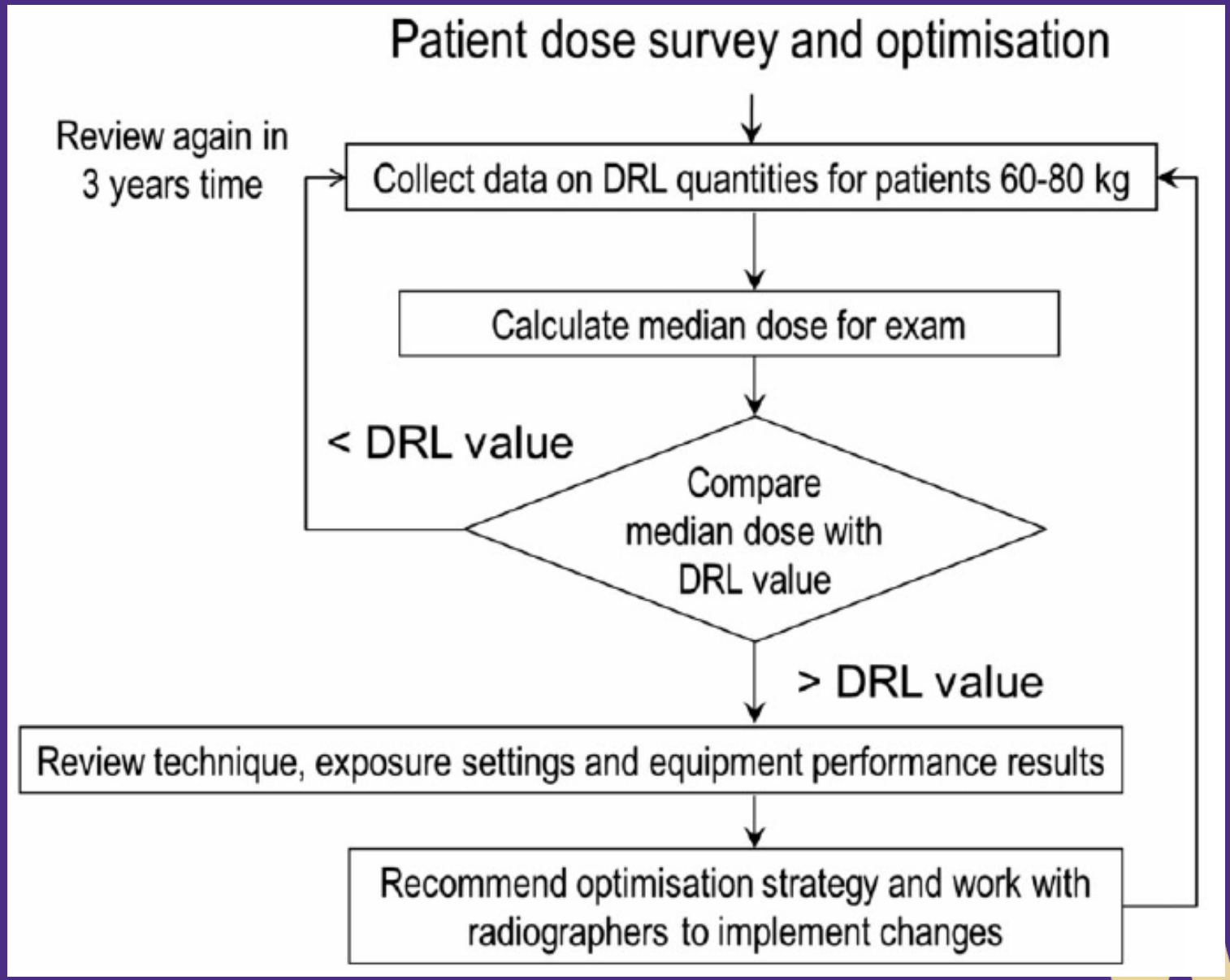
The International Commission on Radiological Protection

by

SAGE

Please cite this issue as 'ICRP, 2017. Diagnostic reference levels in medical imaging. ICRP Publication 135. Ann. ICRP 46(1).'

Process of determining DRL



Example of audit cycle and optimisation flow chart (fig. from ICRP-135)

Dose Monitoring software is helpful!

Dose Index Registry

The DIR lets facilities compare their CT dose indices to regional and national values. The information collected is masked, transmitted to the ACR and stored in a database. Facilities receive quarterly feedback reports comparing their results to aggregate results by body part and exam type.

The DIR offers participants additional ways to fulfill reporting requirements for the Merit-based Incentive Payment System (MIPS). Participation also allows credit for

NRDR DIR® DOSE INDEX REGISTRY
AMERICAN COLLEGE OF RADIOLOGY

IMALOGIX

GE, DOSEWATCH

PACSHealth, DOSE MONITOR

Bayer, RADIMETRICS

Dose Monitoring software is helpful!

- https://www.dicardiology.com/content/radiation-dose-monitoring

Radiation Dose Monitoring

Last updated on May 27, 2020

Company	Product
Agfa Healthcare	Enterprise Dose Management (powered by DoseMonitor)
Bayer Healthcare LLC	Radimetrics Enterprise Platform
Bracco Diagnostics	NEXO[DOSE]
Canon Medical	Dose Tracking System
Canon Medical	Spot Fluoroscopy
Fujifilm Medical Systems U.S.A. Inc.	FDX Console (common acquisition workstation for all Fujifilm DR portable and room solutions)
Fujifilm Medical Systems U.S.A. Inc.	Aspire AWS Console (common acquisition workstation for all Fujifilm mammography solutions)
GE Healthcare	DoseWatch
GE Healthcare	DoseWatch Explore

Dose Monitoring software is helpful!

COMPANY NAME	Bayer Healthcare LLC	GE Healthcare	Imalogix	Infin
Product name	Radimetrics Enterprise Platform	DoseWatch	Imalogix	
FDA cleared year	Registered as a Class 1 medical device under FDA 2013	Compliant w/ FDA regulations	Registered as a Class 1 medical device under FDA 2014	FDA
CE mark approval year	Yes, 2013	Yes, 2012	Yes, 2014	
Briefly explain what the software monitors, reports	Radimetrics Enterprise Platform is a solution for integrated radiation and contrast dose management; integrating seamlessly with radiology workflow and hospital IT infrastructure; tracking examination dose across patients, supporting automated alerting for incidences where customized DRLs are exceeded, population level performance analysis through customizable dashboards, and integrated protocol management; the software's tools help the hospital meet compliance needs, increase quality, improve workflow and	DoseWatch is an enterprise-wide dose management solution that captures, tracks, alerts and reports on patient radiation dose; analytics assist in quality control and dose optimization; data is automatically collected directly from imaging devices or PACS, supporting multiple vendors in CT, IR, mammo and rad, and fluoro; DoseWatch displays detailed information on the patient (e.g. name, age, BMI, effective diameter), the exam (e.g. protocol, acquisition parameters) and the dose (series, study and cumulative	Imalogix is an innovative cloud-based performance management and dose monitoring solution for imaging. We take the complexity out of the process to achieve compliance. There is virtually no IT involvement - we automate the process to map your protocols and provide advanced analytics that go beyond dose monitoring. In a concise dashboard you can compare dose trends, identify outliers and trend performance across your enterprise with ease. Imalogix is simple, powerful, smart, sophisticated.	DoseM Do extrac infor imag them systen can v ra infor frienc Co intern suc DI integr infor (HIS, auto ra i Furth car radia com

	MRI			image)
Does the system support diagnostic reference levels (DRLs) set locally, by registries or by regulatory bodies	Yes, customizable patient cumulative, exam, and acquisition DRLs, based on a percentile of local performance, or standards from registries and regulatory bodies	Yes, ACR, national, and custom DRLs are supported; segment by age, weight, height, study and series type	DRLs are set by age, sex and size and evaluated at acquisition, exam and patient cumulative dose	Yes, provision of DRL range set-up and separate display
Does software offer pediatric DRL's	Offers DRLs filtered to patient age, gender, weight, height, BMI, diameter and/or WED	ACR DRLs are provided as well as DRLs for many EU nations. Custom DRLs as a function of patient age and / or size can also be set	DRLs are set by age, sex and size and evaluated at acquisition, exam and patient cumulative dose	Yes, set up DRL values by age
How does the software help providers comply with Joint Commission requirements	Web-based protocol management system including RadLex Master Protocol names, assists with DRLs, dose analysis, benchmarks, and automated reporting to speech-recognition, RIS, and PACS	Yes, documents radiation dose index on every examination produced during CT exam; captures exam specific dose index and summarizes by series or anatomic region; documents dose in a retrievable format, displays performed and scheduled studies; documents incidents where dose indices	Imalogix provides protocol review, threshold, DRLs, alerts and documented follow up	Collect and record dose and notify when exceed DRL. Provide the examination and patient reports

DRLs using ACR Dose Index Registry (DIR)

- The ACR DIR is a tool for quality improvement so facilities can review dose indices and optimize protocols
  - Collects and compares dose index information across facilities
  - Fully automated; uses standard methods of data collection and processing
- CT DIR launched in May 2011
- We developed diagnostic reference levels (DRLs) and achievable doses (ADs) for the 10 most common adult CT examinations in the United States as a function of patient size using the ACR CT Dose Index Registry

ORIGINAL RESEARCH ■ MEDICAL PHYSICS

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

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Priscilla F. Butler, MS
Debapriya Sengupta, MBBS, MPH
Mythreyi Bhargavan-Chatfield, PhD
Laura P. Coombs, PhD
Richard L. Morin, PhD

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

Radiology

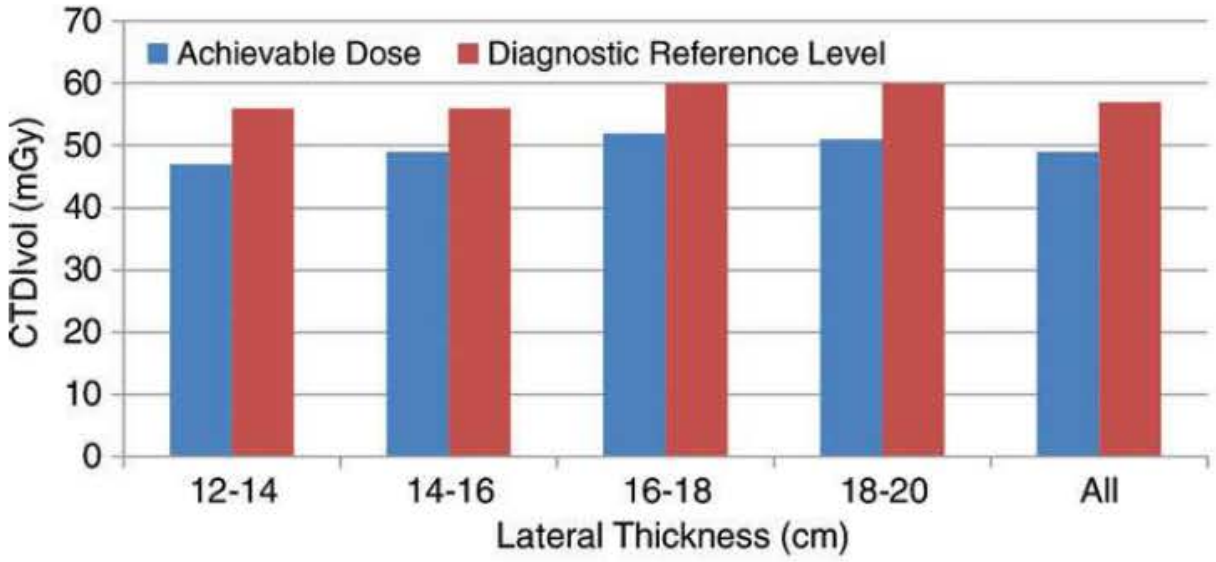
radiology.rsna.org ■ ***Radiology:*** Volume 284: Number 1—July 2017

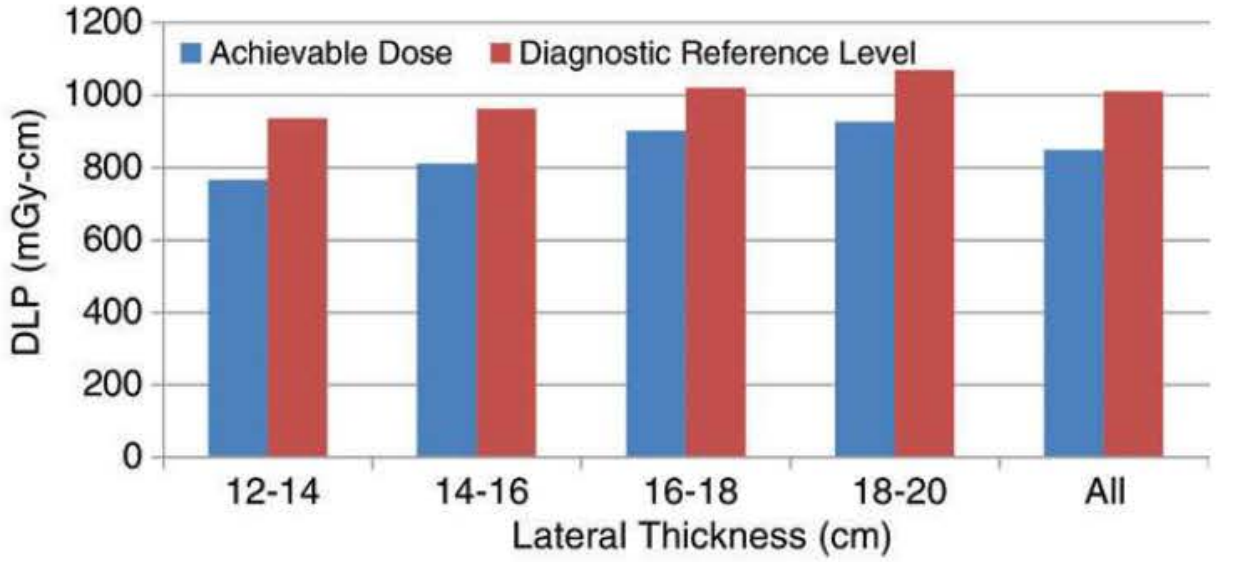
Develop diagnostic reference levels (DRLs) and achievable doses (ADs) for the 10 most common adult CT examinations in the United States as a function of patient size using the ACR CT Dose Index Registry

DRLs using ACR Dose Index Registry (DIR)

- 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 provided median (AD) values, mean, 25^{th} and 75^{th} (DRL) percentiles for $CTDI_{vol}$, DLP and SSDE

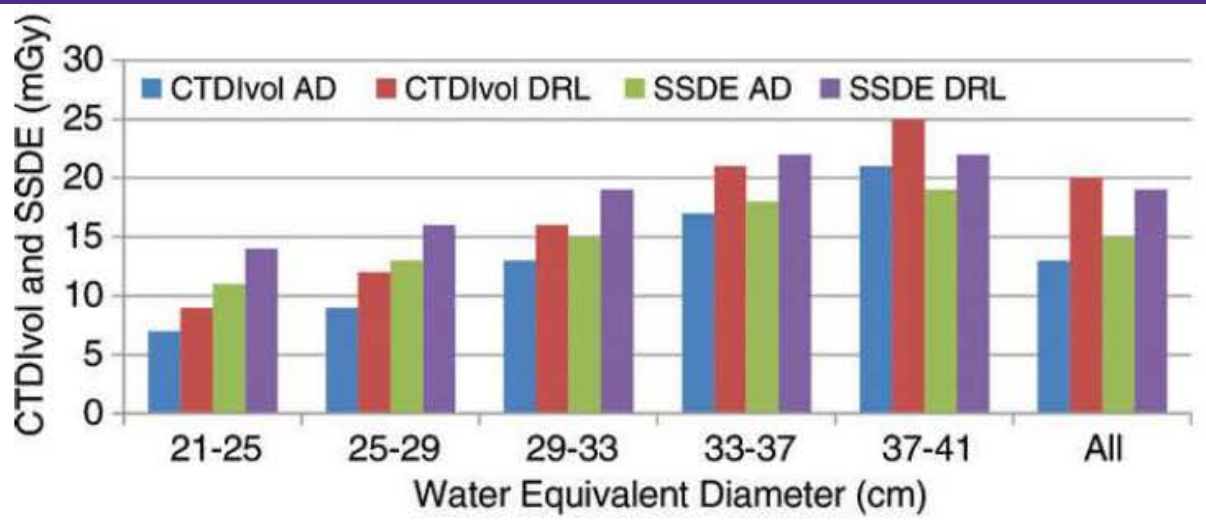
Results – HEAD

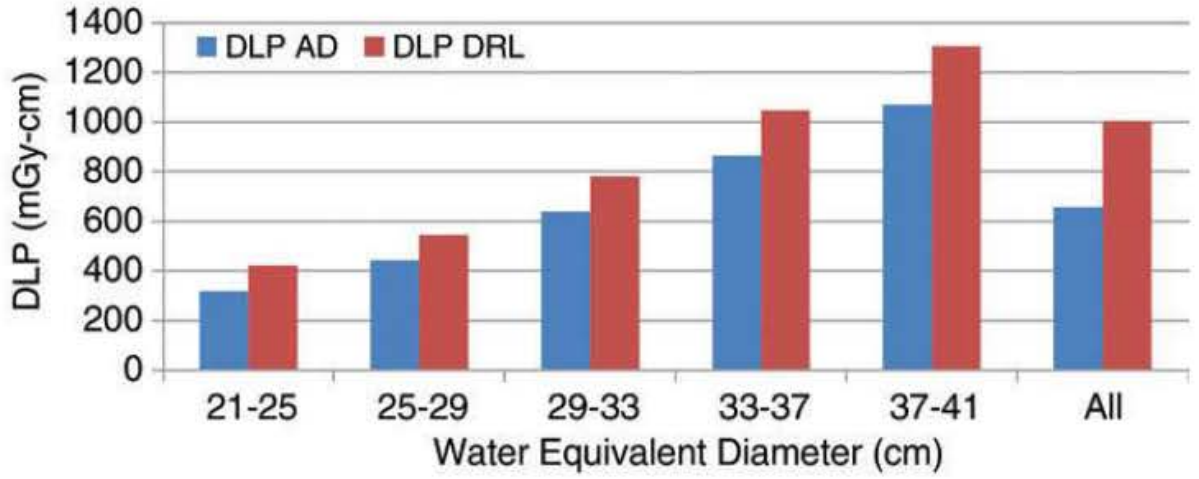




Examination and Median Size (Thickness or Diameter)	Size (cm)	No. of Facilities	No. of Patients	$CTDI_{vol}$ (mGy)		DLP (mGy-cm)	
				AD (50th Percentile)	DRL (75th Percentile)	AD (50th Percentile)	DRL (75th Percentile)
Head and brain without contrast material*	12–14	227	19 933	47	56	767	936
	14–16	290	137 755	49	56	811	962
	16–18	256	57 292	52	60	902	1020
	18–20	160	5390	51	60	926	1069
	All†	347†	223 908	49	57	849	1011

Results – Abdomen/Pelvis without Contrast





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	14 667	7	9	11	14	318	422
	25–29	390	43 185	9	12	13	16	443	545
	29–33	415	64 317	13	16	15	19	639	781
	33–37	403	51 133	17	21	18	22	865	1048
	37–41	365	21 901	21	25	19	22	1071	1306
	All†	446†	201 754	13	20	15	19	657	1004

DRLs using ACR Dose Index Registry (DIR)

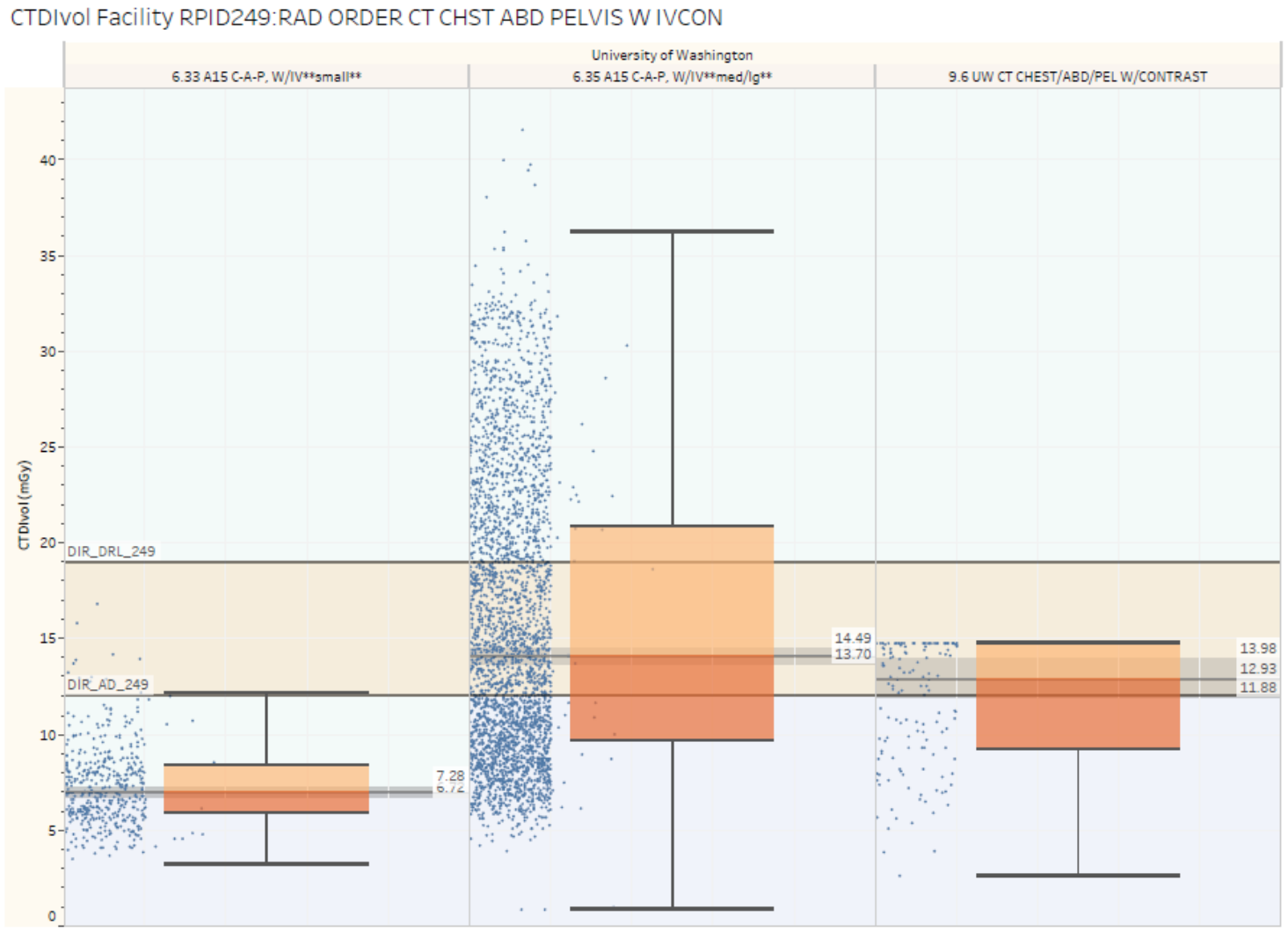
Body Part	Procedure	Parameter	Diagnostic Reference Levels - $CTDI_{vol}$ (mGy) and DLP (mGy-cm)										
			ACR DIR (2016)[a]	ACR-AAPM (2013)[b]	NCRP (2012)[c]	Japan (2015)[d]	EU (2014)[e]	UK (2014)[f]	Ireland (2012)[g]	Australia (2011)[h]	Canada (2016)[i]	Netherlands (2012)[j]	Greece (2014)[k]
Head	Head Brain without contrast	$CTDI_{vol}$	56	75	75	85	60	60	58	60	79		67
		DLP	962			1350	1000	970	940	1000	1302		1055
Neck/C-Spine	Neck with contrast	$CTDI_{vol}$	19							30			
		DLP	563				500			600			
	Cervical Spine with contrast	$CTDI_{vol}$	28					28	19				
		DLP	562				400-600	600	420				
Chest	Chest without contrast	$CTDI_{vol}$	12	21	21	15	10	12	9	15	14		14
		DLP	443			550	400	610	390	450	521		480
	Chest with contrast	$CTDI_{vol}$	13	21	21	15	10	12	9	15	14		14
		DLP	469			550	400	610	390	450	521		480
	Chest Pulmonary Arteries with contrast	$CTDI_{vol}$	14					13	13			10	
		DLP	445					440	430			350	
Abdomen Pelvis	Abdomen Pelvis without contrast	$CTDI_{vol}$	16	25	25	20	25	15	12	15	18	15	16
		DLP	781			1000	800	745	600	700	874	700	760
	Abdomen Pelvis with contrast	$CTDI_{vol}$	15	25	25	20	25	15	12	15	18	15	16
		DLP	755			1000	800	745	600	700	874	700	760
	Abdomen Pelvis Kidney without contrast	$CTDI_{vol}$	15					10					
		DLP	705					460					
Chest Abdomen Pelvis	Chest Abdomen Pelvis with contrast	$CTDI_{vol}$	15			18			13	30	17		17
		DLP	947			1300		1000	12	1200	1269		1020

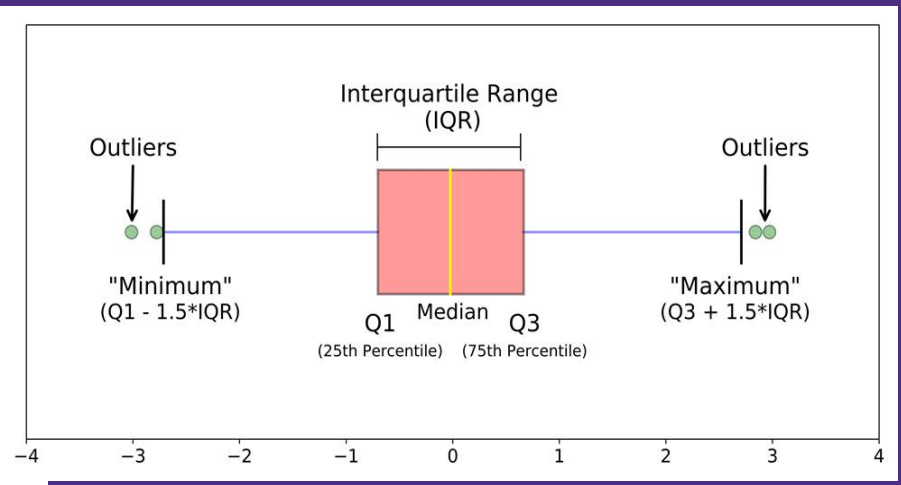
How to use this information?

CT HEAD BRAIN WO IVCON
CT CHEST WO IVCON
CT ABDOMEN PELVIS W IVCON
CT CHEST ABDOMEN PELVIS W IVCON
CT ABDOMEN LIVER MULTIPHASE WO THEN W
CT NECK W IVCON
CT CHEST HIGH RESOLUTION
CT C SPINE WO IVCON
CT ABDOMEN PELVIS WO IVCON
CT CHEST PULMONARY ARTERIES W IVCON
CT CHEST W IVCON

CTDIvol	AD	DIR
Exam	ACR	
CT Head Brain without contrast	49	
CT Neck with contrast	15	
CT C Spine without contrast	21	
CT Chest without contrast	10	
CT Chest with contrast	10	
CT Chest Pulmonary Arteries with contrast	11	
CT Abdomen Pelvis without contrast	13	
CT Abdomen Pelvis with contrast	13	
CT Abdomen Pelvis Kidney without contrast	12	
CT Chest Abdomen Pelvis with contrast	12	

How to use this information?





The lower level of the diagnostic reference range is chosen as the 25th percentile of the estimated patient radiation dose, below which reduced image quality may not be diagnostic; the upper level is set at the 75th percentile of estimated patient dose, above which the dose may be in excess

What about Pediatric DRLs using DIR data?

- We have just started working on this data
- We will be analyzing 2016-2019 peds CT data from ACR DIR (approximately a million exams)
- Will analyze by size and age
- Hope to have this published early in 2021

Take home points

- Understand the definition of DRL and AD
- Be familiar with DRL resources
- Understand the process of determining DRL
- Dose monitoring software is a useful tool in determining DRL
- Using ACR DIR, CT DRLs have been developed in the USA for adults.
- Development of DRLs will enable facilities to effectively compare their patient doses to national benchmarks and more effectively optimize their CT protocols for the wide range of patient habitus they examine and thus, appropriately reduce dose to patients.
- PED CT DRL are in the process of being developed from the ACR DIR data.

Thank You

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