Establishment of Pediatric CT Diagnostic Reference Levels in the United States

Kalpana Kanal, PhD, DABR, FAAPM, FACR, FSABI
Professor and Section Chief
Diagnostic Physics Section

DEPARTMENT OF RADIOLOGY
UNIVERSITY of WASHINGTON

Acknowledge my colleagues

- Priscilla Butler*, Mythreyi Chatfield*, Jered Wells+, Ehsan Samei+, Michael Simanowith*, Dan Golden*, Dustin Gress*, Judy Burleson*, William Sensakovic^, Keith Strauss#, Donald Frush+

* American College of Radiology, Reston, VA, USA

+ Duke University Medical Center, Durham, NC, USA

^ Mayo Clinic, Phoenix, AZ, USA

Children's Hospital Medical Center, Cincinnati, OH, USA

Learning objectives

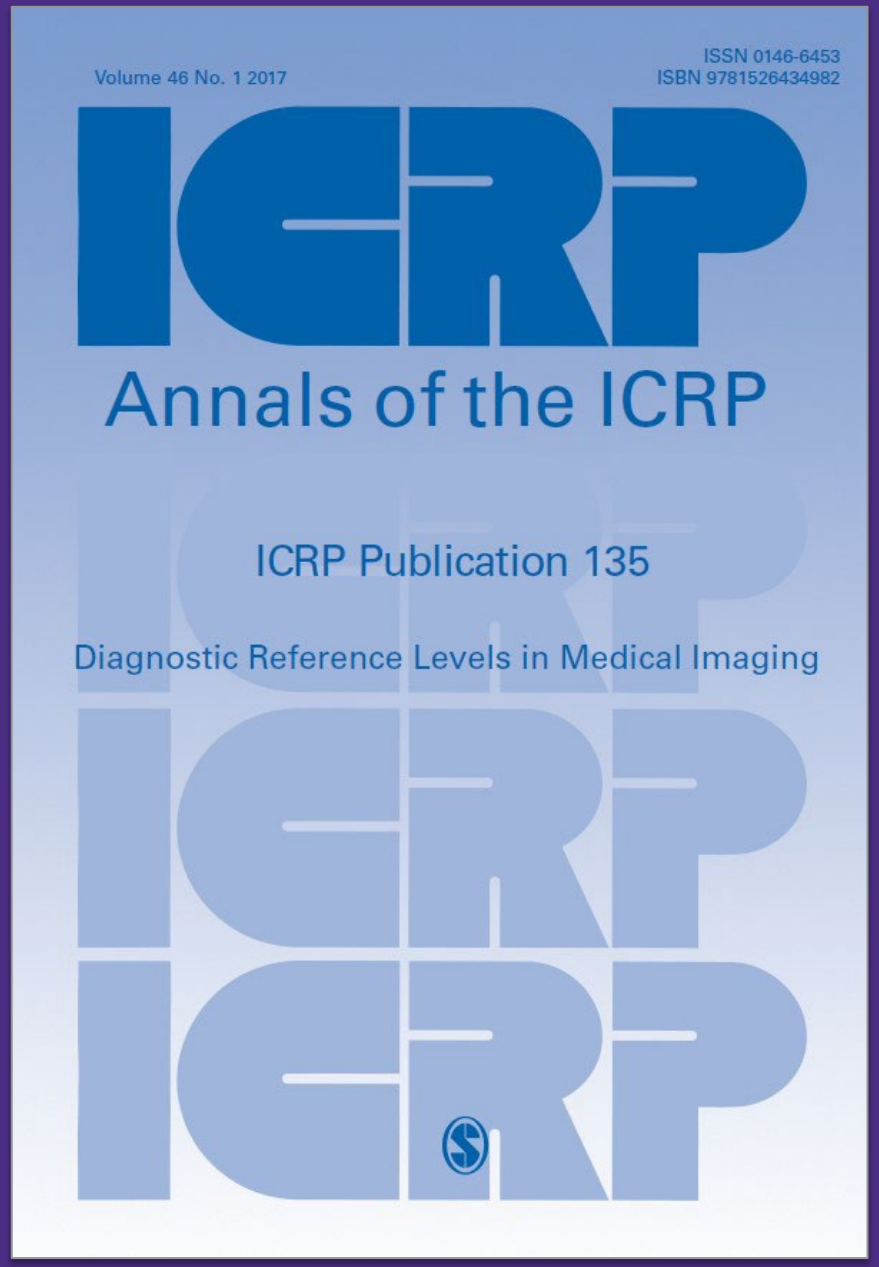
- To understand the concept of DRLs and ADs
- To be aware of DRLs and ADs for the 10 most common pediatric CT exams in the USA
- To learn how to use published DRLs to help optimize dose at local level

Outline

- Concept of DRLs and ADs
- ACR CT Dose Index Registry
- Adult DRLs
- Ped DRLs
- How to use?

DRL CONCEPTS

- Diagnostic Reference Level (DRL) – first proposed in 1990 by ICRP, typically set at the 75th percentile of the dose distribution from a survey conducted across a wide user base
- DRLs are investigation levels
  - Not regulations
  - Not legal standards of care
  - Do not apply to individual patients
- DRLs identify exams where levels of patient dose are unusually high
  - If DRLs consistently exceeded, conduct review of procedures and equipment for optimization
  - If not optimized, take action to reduce dose
- Overriding clinical objective - achieving acceptable image quality or adequate diagnostic information, consistent with the medical imaging task



Annals of the ICRP

ICRP PUBLICATION 135

Diagnostic Reference Levels in Medical Imaging

Editor-in-Chief
C.H. CLEMENT

Associate Editor
H. OGINO

Authors on behalf of ICRP
E. Vañó, D.L. Miller, C.J. Martin, M.M. Rehani, K. Kang, M. Rosenstein, P. Ortiz-López, S. Mattsson, R. Padovani, A. Rogers

PUBLISHED FOR

The International Commission on Radiological Protection

by

SAGE

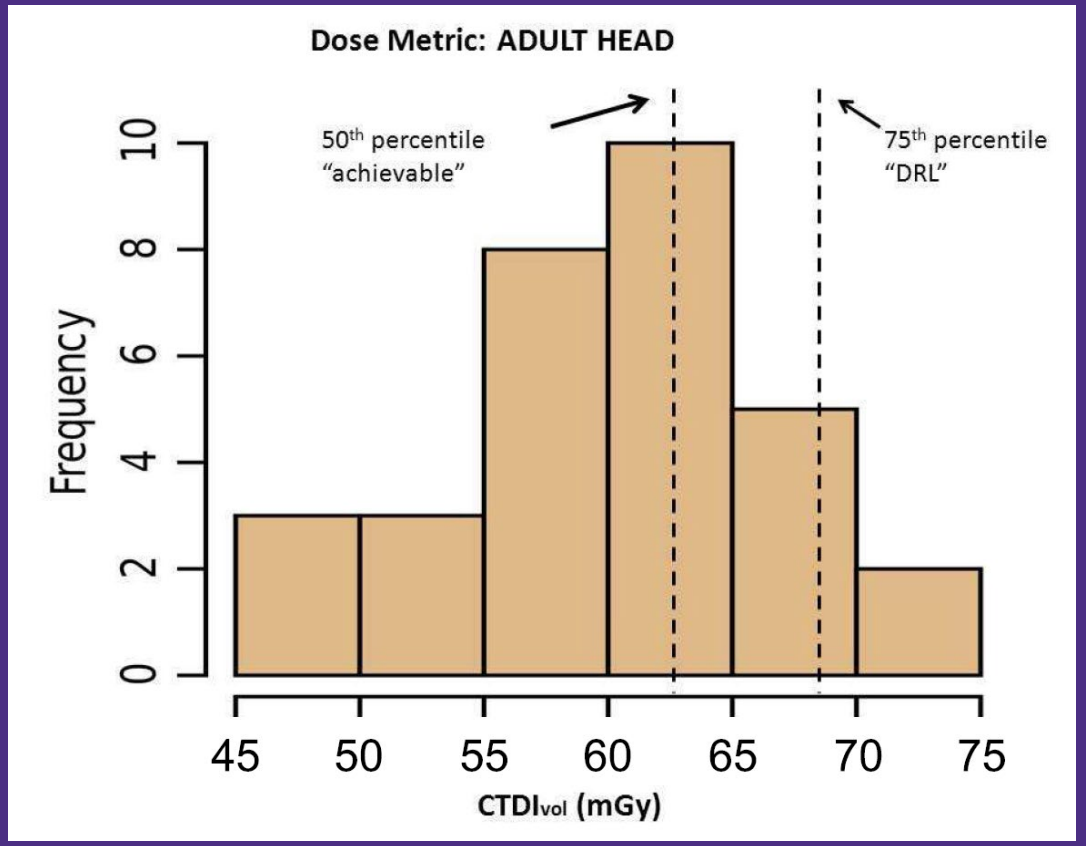
Please cite this issue as 'ICRP, 2017. Diagnostic reference levels in medical imaging. ICRP Publication 135. Ann. ICRP 46(1).'

Achievable Dose (AD)

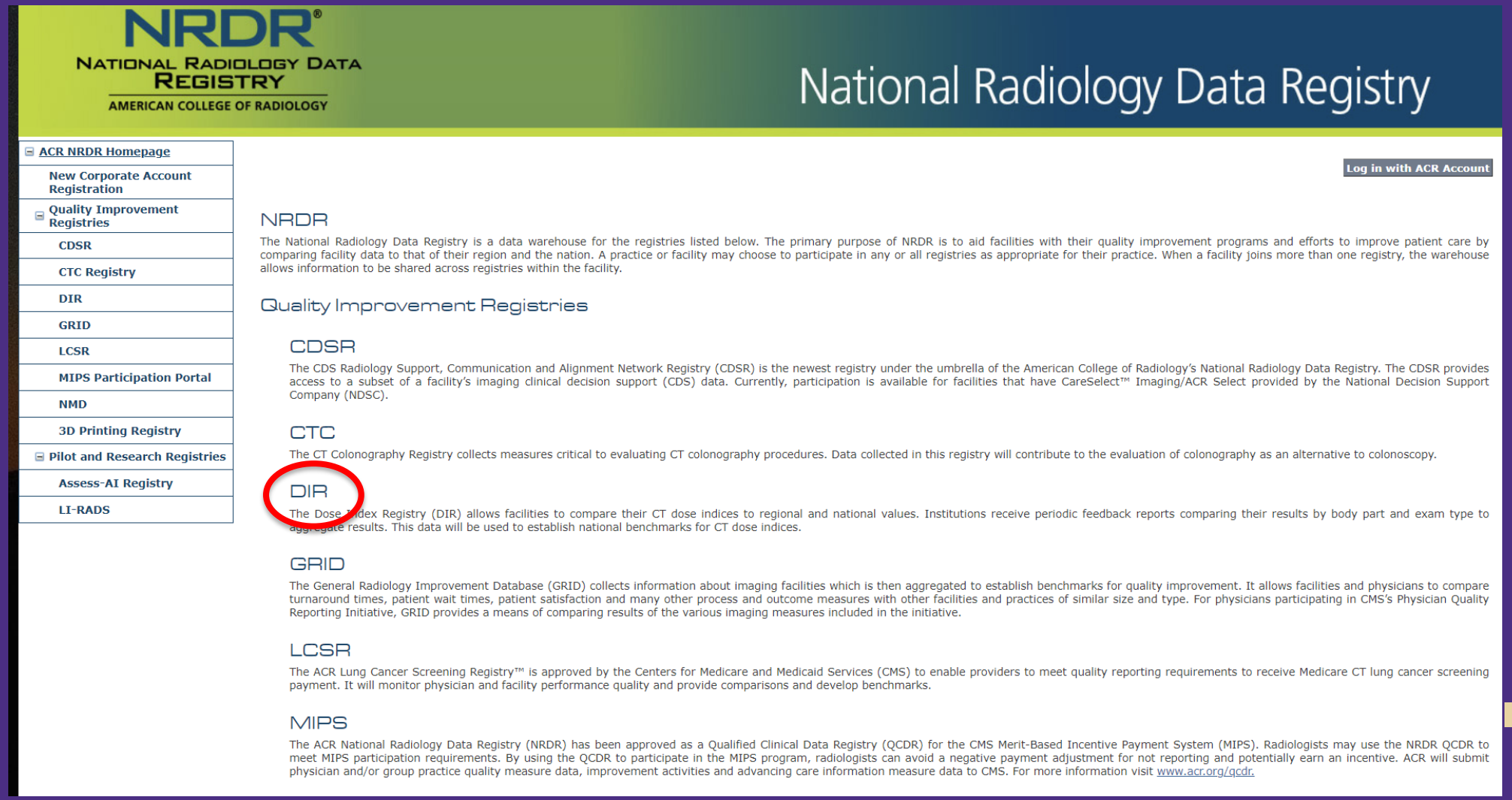
- ADs can be used with DRLs to assist in optimizing image quality and dose.
- ADs are set at approximately the median (50th percentile) of the study dose distribution, i.e., half of the facilities are producing images at lower doses and half are using higher doses.
- Further information on ADs is available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



American College of Radiology – National Radiology Data Registry



https://nrdr.acr.org/Portal/Nrdr/Main/page.aspx

American College of Radiology (ACR) – CT Dose Index Registry (DIR)

NRDR® National Radiology Data Registry
American College of Radiology

Log in with ACR Acc

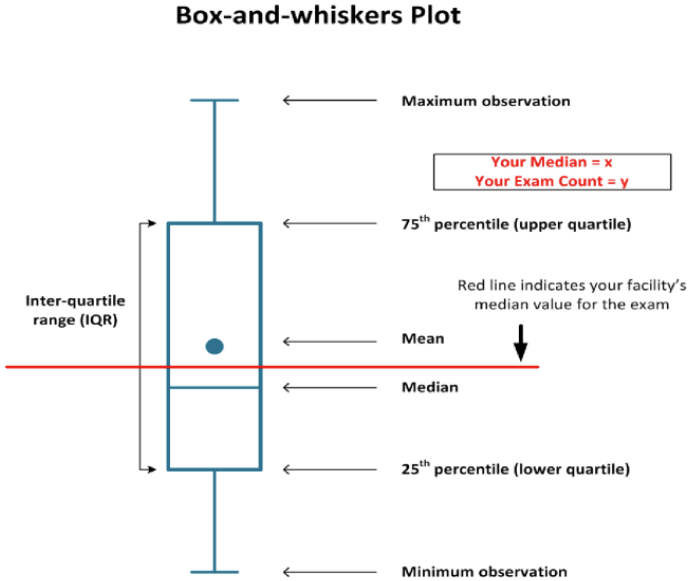
DIR

- DIR
- ACR NRDR Homepage
- Resources
  - About the DIR
  - DIR Data Dictionary
  - DIR Data Submission Overview
  - DIR Available Reports
  - DIR Sample Executive Summary Report
  - Exam Name Mapping Tool User Guide

The DIR enables participants to benchmark dose indices performance data against regional and national values using interactive reports. The report's extensive filters facilitate pinpointing outlier exams and identifying performance patterns for further investigation to ensure high-quality exam performance and patient care.

DIR-CT dose indices reports have been available since 2011 and registry expansion is underway to include a full slate of fluoroscopy, digital radiography and nuclear medicine reports. The DIR automatically de-identifies exam data sent directly to the registry with modality-specific dose information.

Check the DIR Available Reports page in the NRDR Knowledge Base for ongoing updates. The DIR offers opportunities to both fulfill reporting requirements for the Merit-based Incentive Payment System (MIPS) and earn credit for Maintenance of Certification (MOC) Part IV requirements of the American Board of Radiology (ABR).

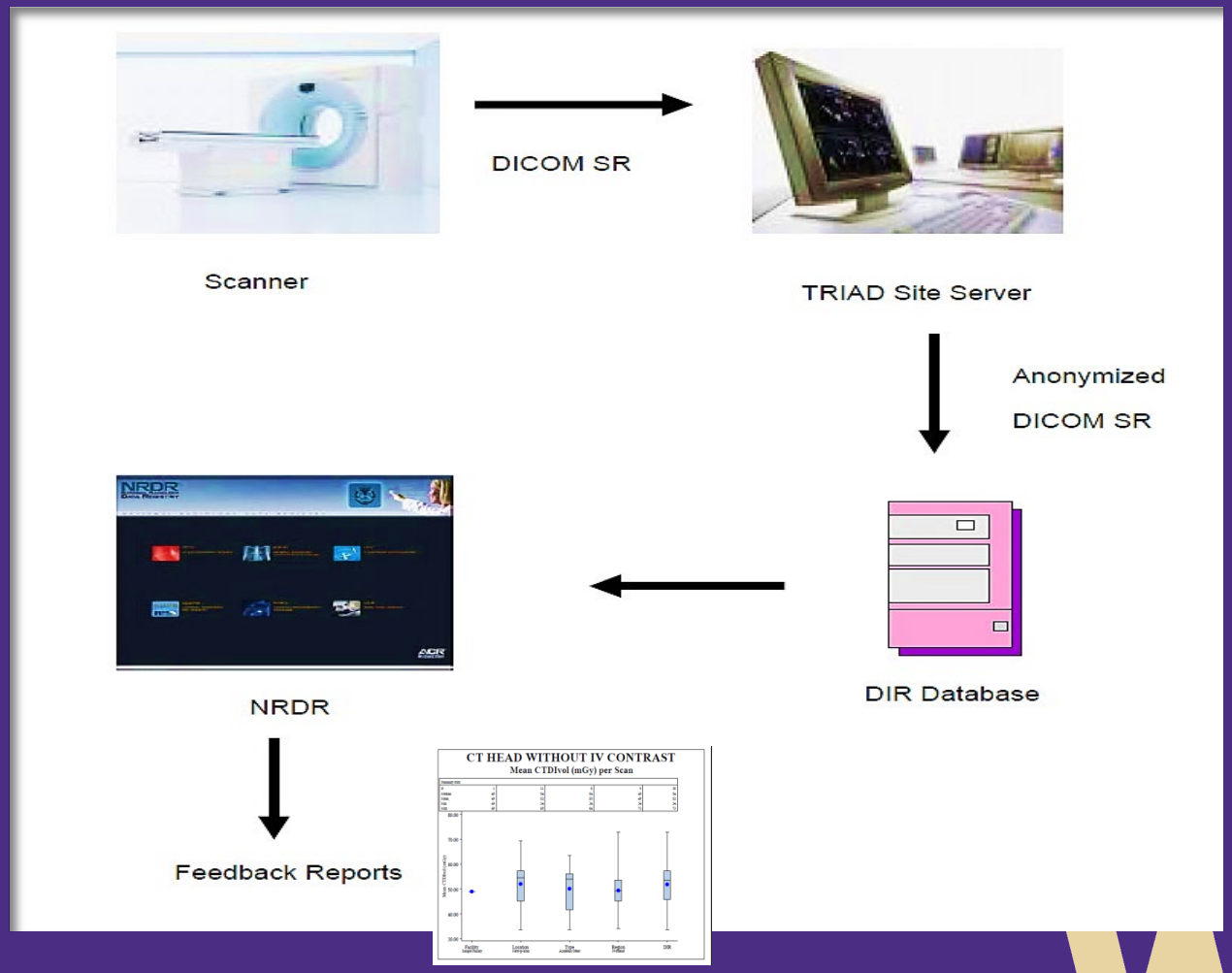


https://nrdr.acr.org/Portal/Nrdr/Main/page.aspx

ACR CT Dose Index Registry

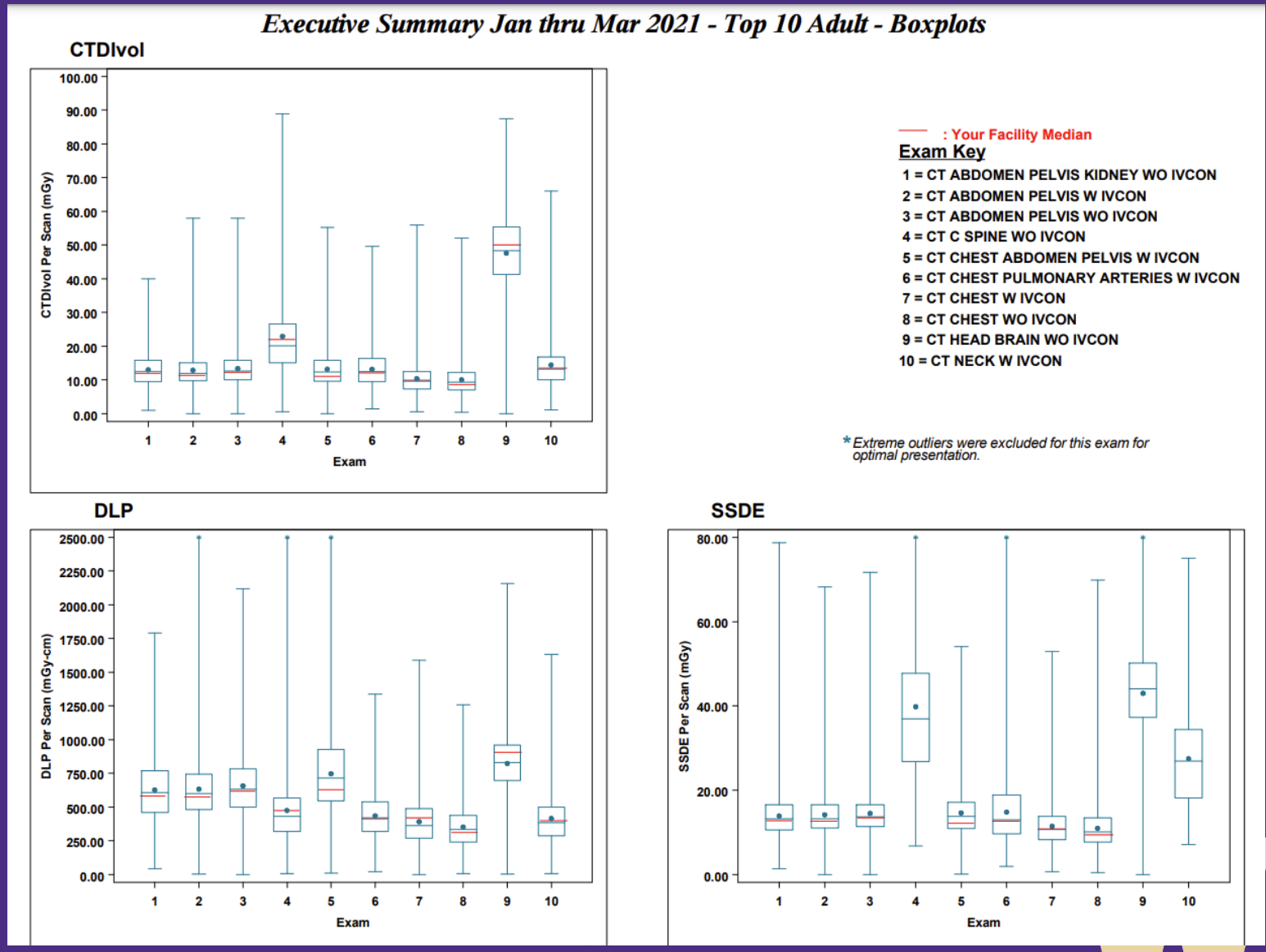
- A tool for quality improvement so facilities can review dose indices and optimize protocols
  - Collects and compares dose index information across facilities
  - Fully automated; uses standard methods of data collection and processing

CT DIR launched in May 2011



ACR CT Dose Index Registry – REPORT SNAPSHOT

https://nrdrsupport.acr.org/support/solutions/articles/11000044333-dir-executive-summary-and-qcdr-preview



ORIGINAL RESEARCH ■ MEDICAL PHYSICS

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

Kalpana M. Kanal, PhD
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

What about PED DRLs?

- We started working on analyzing DIR Data from the 10 commonly performed examinations in the US performed between January 2016 and December 2020 on patients younger than 18 years
- Median values - CTDIvol, DLP, and SSDE - for each facility by size and by age
- The 50th and 75th percentiles for these median values were then determined
- Head exams were grouped by age only
  - Uncertainly in the size estimation due to the inconsistent presence of shoulders in the field of view
  - SSDE not calculated
- Body examinations were grouped by age and size (effective diameter)
- All analyses were done using SAS software, Version 9.4 (SAS Institute Inc., Cary, NC, USA).

PED DRLs - 2021

Radiology

ORIGINAL RESEARCH • PEDIATRIC IMAGING

U.S. Diagnostic Reference Levels and Achievable Doses for 10 Pediatric CT Examinations

Kalpana M. Kanal, PhD • Priscilla F. Butler, MS • Mythreyi B. Chatfield, PhD • Jered Wells, PhD • Ehsan Samei, PhD • Michael Simanowith, MD • Dan Golden, BA • Dustin A. Gress, MS • Judy Burleson, MHSA • William F. Sensakovic, PhD • Keith J. Strauss, MSc • Donald Frush, MD

From the Department of Radiology (K.M.K), University of Washington, 1959 NE Pacific St, Box 357987, Seattle, WA 98195-7987; Department of Quality and Safety (P.F.B., M.B.C., M.S., D. Golden, D. Gress, J.B.), American College of Radiology, Reston, Va; Department of Radiology (J.W., E.S., D.F.), Duke University Medical Center, Durham, NC; Department of Radiology (W.S.), Mayo Clinic, Phoenix, Ariz; and Department of Radiology (K.S.), Cincinnati Children's Hospital Medical Center, Cincinnati, Ohio. Received May 14, 2021; revision requested June 2; revision received August 5; accepted August 10. **Address correspondence to** K.M.K. (e-mail: *kkanal@uw.edu*).

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

Radiology 2021; 000:1–11 • https://doi.org/10.1148/radiol.2021211241 • Content codes: CT PD

Background: Diagnostic reference levels (DRLs) and achievable doses (ADs) were developed for the 10 most commonly performed pediatric CT examinations in the United States using the American College of Radiology Dose Index Registry.

Purpose: To develop robust, current, national DRLs and ADs for the 10 most commonly performed pediatric CT examinations as a function of patient age and size.

Materials and Methods: Data on 10 pediatric (ie, patients aged 18 years and younger) CT examinations performed between 2016 and 2020 at 1625 facilities were analyzed. For head and neck examinations, dose indexes were analyzed based on patient age; for body examinations, dose indexes were analyzed for patient age and effective diameter. Data from 1 543 535 examinations provided medians for AD and 75th percentiles for DRLs for volume CT dose index ($CTDI_{vol}$), dose-length product (DLP), and size-specific dose estimate (SSDE).

Results: Of all facilities analyzed, 66% of the facilities (1068 of 1625) were community hospitals, 16% (264 of 1625) were free-standing centers, 9.5% (154 of 1625) were academic facilities, and 3.5% (57 of 1625) were dedicated children's hospitals. Fifty-two percent of the patients (798 577 of 1 543 535) were boys, and 48% (744 958 of 1 543 535) were girls. The median age of patients was 14 years (boys, 13 years; girls, 15 years). The head was the most frequent anatomy examined with CT (876 655 of 1 543 535 examinations [57%]). For head without contrast material CT examinations, the age-based $CTDI_{vol}$ AD ranged from 19 to 46 mGy, and DRL ranged from 23 to 55 mGy, with both AD and DRL increasing with age. For body examinations, DRLs and ADs for size-based $CTDI_{vol}$, SSDE, and DLP increased consistently with the patient's effective diameter.

Table 1: Types of CT Examinations Included in Study

Body Part and Examination Type	RPID Code	No. of Examinations* (*n* = 1 543 535)
Head		
Head without contrast material	1850, 266, 22, 1825, and 1803	811 150 (53)
Sinuses without contrast material	62 and 371	27 944 (1.8)
Maxillofacial area without contrast material	34 and 365	37 561 (2.4)
Total		876 655 (57)
Neck		
Neck soft tissue with contrast material	39	38 128 (2.5)
Cervical spine without contrast material	21 and 1892	91 219 (5.9)
Total		129 347 (8.4)
Chest		
Chest without contrast material	16 and 1886	24 682 (1.6)
Chest with contrast material	18 and 1904	47 546 (3.1)
Total		72 228 (4.7)
Abdomen and pelvis		
Abdomen and pelvis without contrast material	144, 1842, and 1905	62 205 (4)
Abdomen and pelvis with contrast material	145 and 1841	376 323 (24)
Total		438 528 (28)
Chest, abdomen and pelvis with contrast material	249	26 777 (1.7)

Characteristic	No. of Facilities (*n* = 1625)	No. of Examinations (*n* = 1 543 535)
Facility category		
Academic	154 (9.5)	198 239 (13)
Community hospital	1068 (66)	874 501 (57)
Multispecialty clinic	53 (3.3)	17 960 (1.2)
Freestanding center	264 (16)	36 299 (2.4)
Children's hospital	57 (3.5)	407 288 (26)
Other	29 (1.8)	9248 (0.6)

Age group (y)		
0 to <1	NA	173 087 (11)
1 to <5	NA	158 069 (10)
5 to <10	NA	191 269 (12)
10 to <15	NA	305 069 (20)
15–18	NA	716 041 (46)

Examination volume†		
1 to <10	810 (50)	124 474 (8.1)
10 to <20	305 (19)	170 839 (11)
20 to <30	187 (12)	199 162 (13)
30 to <40	107 (6.6)	159 364 (10)
40 to <50	59 (3.6)	107 689 (7)
50 to <60	43 (2.6)	109 162 (7.1)
60 to <70	22 (1.4)	59 135 (3.8)
70 to <80	19 (1.2)	60 174 (3.9)
80 to <90	8 (0.5)	16 803 (1.1)
90 to <100	9 (0.6)	33 936 (2.2)
≥100	56 (3.4)	502 797 (33)

Table 3: Age-based Achievable Doses and Diagnostic Reference Levels

Examination Type and Age (y)	No. of Examinations*	$CTDI_{vol}$ (mGy)		SSDE (mGy)		DLP (mGy · cm)	
		AD	DRL	AD	DRL	AD	DRL
Head without contrast material							
0 to <1	66 307	19	23	NA	NA	267	344
1 to <2	42 462	22	27	NA	NA	350	440
2 to <6	108 808	25	31	NA	NA	409	518
6–18	593 573	46	55	NA	NA	748	910
Sinuses without contrast material							
0 to <1	…	…	…	NA	NA	…	…
1 to <2	…	…	…	NA	NA	…	…
2 to <6	2234	6.7	12	NA	NA	94	219
6–18	25 606	14	22	NA	NA	209	377
Maxillofacial area without contrast material							
0 to <1	917	6.3	12	NA	NA	103	155
1 to <2	413	7.0	15	NA	NA	127	286
2 to <6	2488	11	23	NA	NA	196	472
6–18	33 743	24	34	NA	NA	480	647
Neck soft tissue with contrast material							
0 to <1	743	2.5	3.8	NA	NA	41	58
1 to <5	7502	3.4	4.4	NA	NA	65	88
5 to <10	6971	4.6	6.3	NA	NA	98	137
10 to <15	6491	7.8	11	NA	NA	198	270
15–18	16 421	10	14	NA	NA	300	385

Adult Head	49	57
Neck	15	20

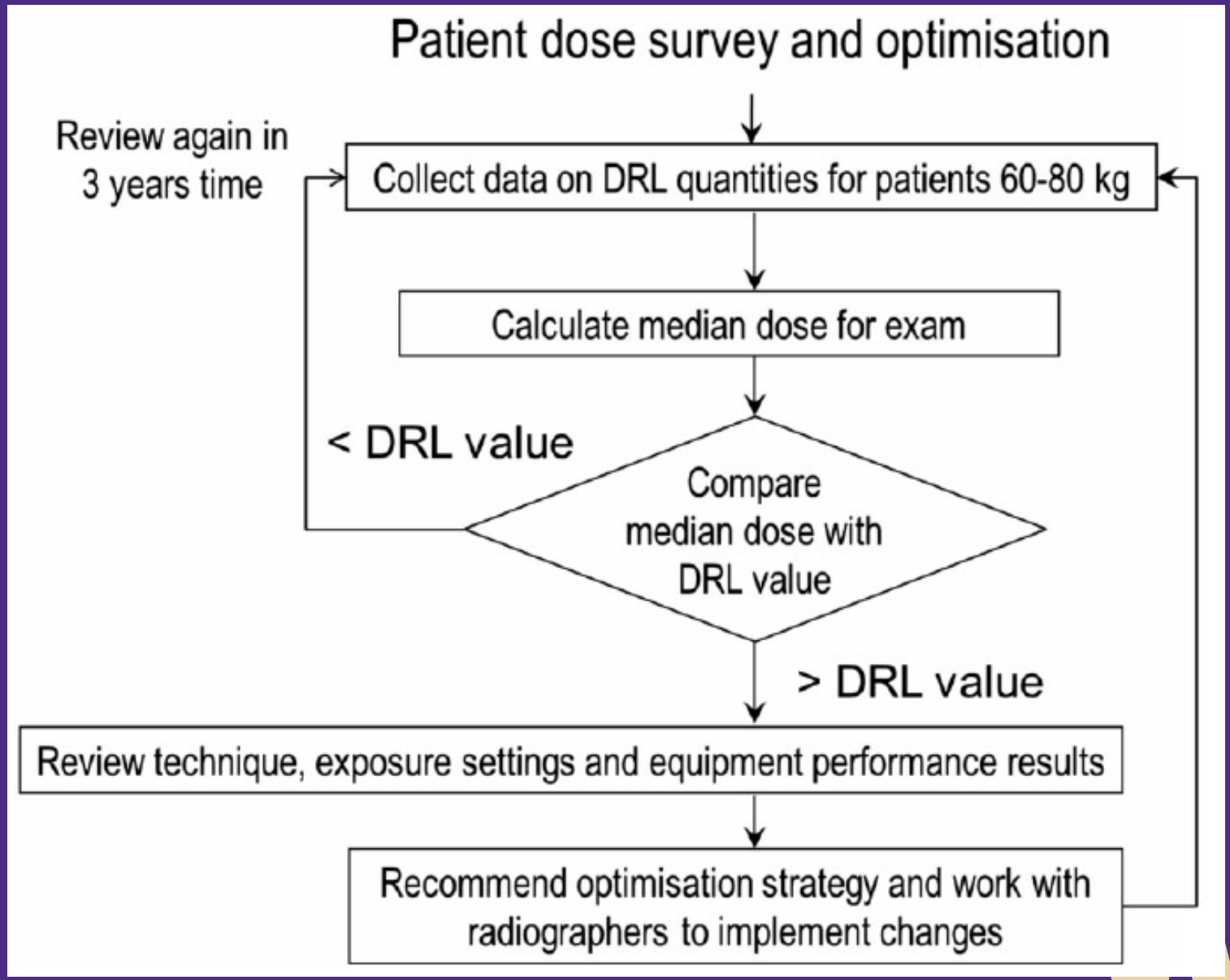
Examination Type and Age (y)	No. of Examinations*	$CTDI_{vol}$ (mGy)		SSDE (mGy)		DLP (mGy · cm)	
		AD	DRL	AD	DRL	AD	DRL
Abdomen and pelvis without contrast material							
0 to <1	…	…	…	…	…	…	…
1 to <5	1278	2.2	2.6	4.5	5.4	69	95
5 to <10	5058	3.4	4.8	5.9	7.9	124	171
10 to <15	11048	6.2	8.1	8.9	11	277	367
15–18	43747	8.4	11	11	14	408	510
Abdomen and pelvis with contrast material							
0 to <1	1886	1.8	2.4	4.2	5.3	49	60
1 to <5	14470	2.4	2.9	4.6	5.9	79	100
5 to <10	49323	3.3	4.6	5.8	8.0	126	170
10 to <15	99433	6.2	7.9	8.9	11	276	358
15–18	208728	8.3	11	11	14	402	511
Chest, abdomen, and pelvis with contrast material							
0 to <1	505	2.0	2.7	4.4	6.4	62	89
1 to <5	3804	2.2	3.0	4.4	5.3	87	109
5 to <10	3770	2.9	4.3	4.7	7.0	142	204
10 to <15	4305	5.9	9.1	8.0	12	321	437
15–18	14071	12	17	14	21	691	964

Adult Abd/pel w/o	13	20
Adult Abd/pel w	13	19

Examination Type and Effective Diameter (cm)	No. of Examinations*	$CTDI_{vol}$ (mGy)		SSDE (mGy)		DLP (mGy • cm)	
		AD	DRL	AD	DRL	AD	DRL
Chest without contrast material							
12 to <16	1471	1.7	1.9	3.7	4.2	29	41
16 to <20	1875	1.9	2.5	3.7	4.7	50	63
20 to <24	2572	2.5	3.2	4.0	5.1	81	106
24 to <28	3556	3.5	4.5	4.8	6.5	122	154
28 to <32	1894	4.5	6.0	5.7	7.5	160	186
32 to <36	390	5.7	7.4	6.0	7.9	213	249
36 to <40	…	…	…	…	…	…	…
>40	…	…	…	…	…	…	…
Chest with contrast material							
12 to <16	3636	1.5	2.0	3.3	4.4	30	42
16 to <20	3979	2.0	2.6	3.9	5.0	53	67
20 to <24	4139	2.5	3.4	4.2	5.5	78	107
24 to <28	5331	4.7	6.1	6.6	8.5	159	260
28 to <32	3325	7.2	12	8.9	15	268	480
32 to <36	1238	9.2	13	10	15	392	592
36 to <40	273	8.1	15	7.8	13	295	538
>40	425	12	13	8.9	9.3	417	568

	ACR DIR		Australia, 2018 (27)		Belgium, 2020 (31)		Canada, 2016 (28)		Germany, 2019 (32)		Japan, 2020 (30)		Korea, 2017 (29)		Europe, 2018 (16)*	
Parameter	Age (y)	DRL	Age (y)	DRL	Age (y)	DRL	Age (y)	DRL	Age (y)	DRL	Age (y)	DRL	Age (y)	DRL	Age (y)	DRL
Head without contrast material																
$CTDI_{vol}$ (mGy)	0 to <1	23	0–4	30	<1	22	0–3	37	3 m to <1	30	<1	30	0	18	<3 m	24
$CTDI_{vol}$ (mGy)	1 to <2	27	NA	NA	1 to <5	30	NA	NA	1 to <5	35	1 to <5	40	1	23	3 m to <1	28
$CTDI_{vol}$ (mGy)	2 to <6	31	NA	NA	5 to <10	40	3–7	49	5 to <10	50	5 to <10	55	2–5	26	1 to <6	40
$CTDI_{vol}$ (mGy)	6–18	55	5–14	35	10 to <15	45	7–13	57	>10	55	10 to <15	60	6–10, 11–17	31, 36	≥6	50
Head without contrast material																
DLP (mGy • cm)	0 to <1	344	0–4	470	<1	420	0–3	578	3 m to <1	300	<1	480	0	260	<3 m	300
DLP (mGy • cm)	1 to <2	440	NA	NA	1 to <5	540	NA	NA	1 to <5	450	1 to <5	660	1	350	3 m to <1	385
DLP (mGy • cm)	2 to <6	518	NA	NA	5 to <10	660	3–7	843	5 to <10	650	5 to <10	850	2–5	420	1 to <6	505
DLP (mGy • cm)	6–18	910	5–14	600	10 to <15	780	7–13	888	>10	800	10 to <15	1000	6–10, 11–17	500, 620	≥6	650

Process of determining DRL

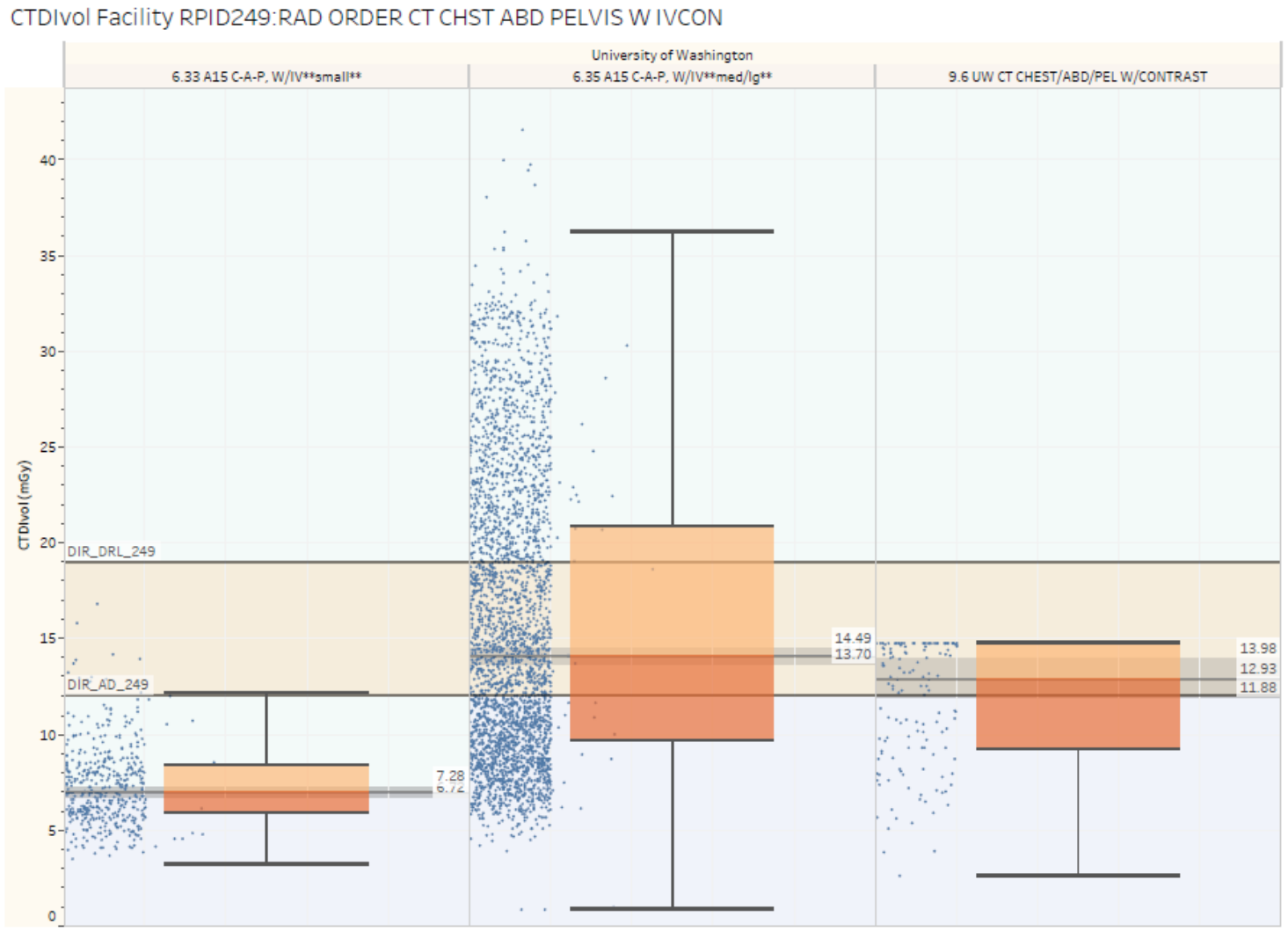


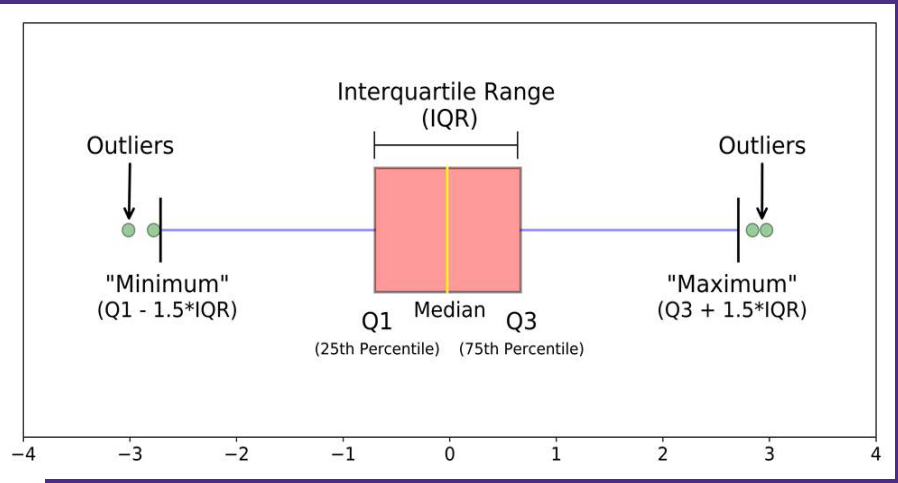
Example of audit cycle and optimisation flow chart (fig. from ICRP-135)

How to use this information?

Examination	Age (y)	# Exams*	$CTDI_{vol}$ (mGy)		Your facility	
			AD	DRL	AD	DRL
Head without contrast material	0 - <1	66,307	19	23	15	20
	1 - <2	42,462	22	27	20	25
	2 - <6	108,808	25	31	28	35
	6 - 18	593,573	46	55	55	75
Chest without contrast material	0 - <1	884	1.2	1.7	0.9	2.0
	1 - <5	3,110	1.7	2.2	1.5	2.0
	5 - <10	3,862	2.1	2.5	2.0	2.5
	10 - <15	6,639	3.4	4.1	4.0	6.0
	15 - 18	9,980	5.9	7.4	8.0	10
Abdomen and pelvis without contrast material	0 - <1	-	-	-	-	-
	1 - <5	1,278	2.2	2.6	1.9	2.6
	5 - <10	5,058	3.4	4.8	5.0	7.0
	10 - <15	11,048	6.2	8.1	6.0	8.0
	15 - 18	43,747	8.4	11	8.0	11

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

Limitations

- DIR uses automated data collection process
- Clinical images or indication information not submitted
- Exam code mapping is manual process
- Use of dose reduction techniques not collected in the DIR.
- ICRP 135 methodology using facility median dose indices to develop DRLs. This gives equal weight to each facility irrespective of size and volume.

Advantages

- This work provides DRLs and ADs for the 10 commonly performed CT pediatric examinations performed in the US from the DIR representing a broad representation of geography and practice types.
- This is the first time national pediatric DRLs and ADs have been developed as a function of both patient age and size.
- This will enable facilities to effectively compare their patient dose indices to national benchmarks and work to optimize their CT protocols resulting in an appropriate dose for diagnostic purposes.

THANK YOU

- As of 10/27/2021, this work has been published online in Radiology
- https://pubs.rsna.org/doi/10.1148/radiol.2021211241

- ACR press release
- https://www.acr.org/Media-Center/ACR-News-Releases/2021/New-Radiation-Diagnostic-Reference-Levels-for-Top-10-Pediatric-CT-Exams

- kkanal@uw.edu – my email