IAEA
International Atomic Energy Agency

DRLs in paediatric radiology

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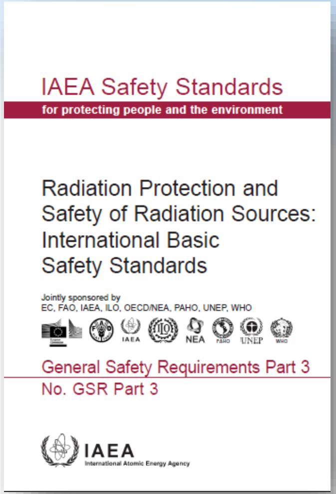
International BSS: Optimization

Particular aspects of medical exposures to be considered in the optimization process for:

- Paediatric patients subject to medical exposure;

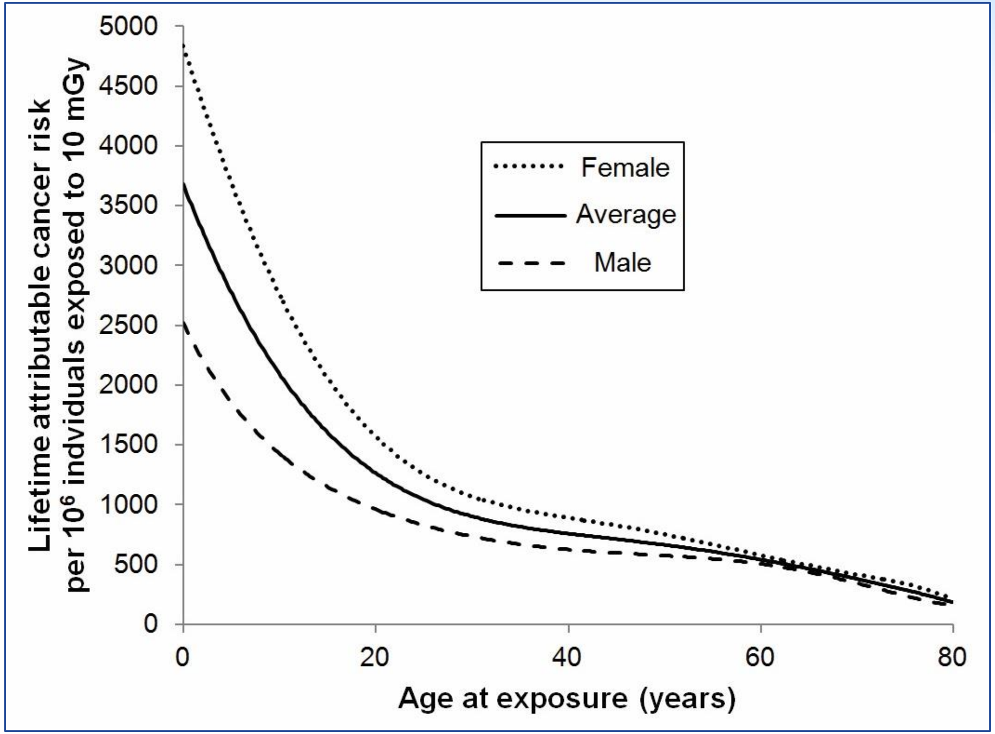
- Exposure of the embryo or fetus, in particular for radiological procedures in which the abdomen or pelvis of the pregnant female patient is exposed to the useful radiation beam or could otherwise receive a significant dose;

- Exposure of a breastfed infant as a result of a female patient having undergone a radiological procedure with radiopharmaceuticals.



Radiosensitivity of children

Children are generally at higher risk for radiation induced cancer than adults

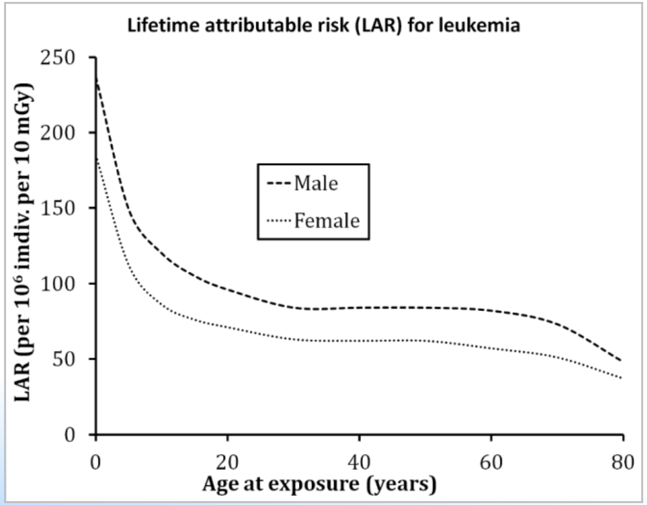


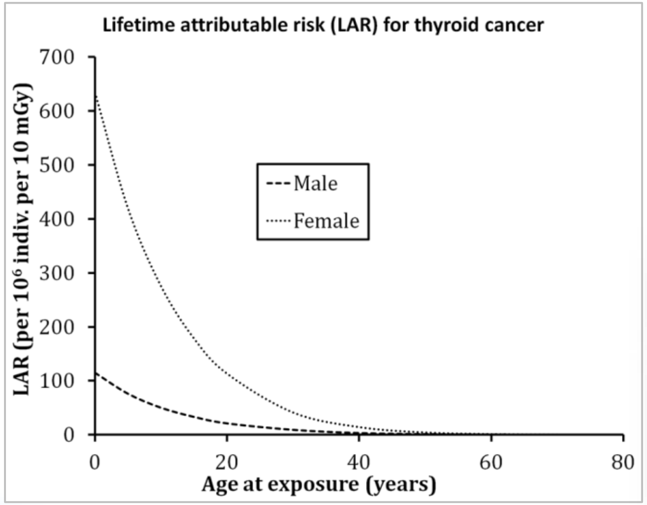
Source: BEIR VII report

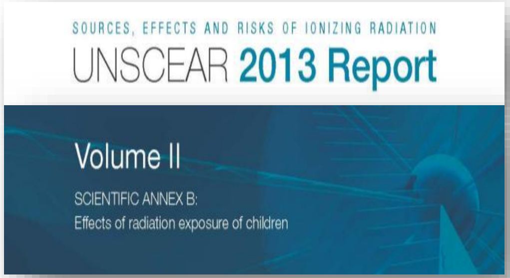
Radiosensitivity of children

Scientific data: radiogenic tumor incidence in children is more variable than in adults and depends on tumor type, age and gender.

- For about 25% of cancers children are more radiosensitive (leukemia and thyroid, skin, breast and brain cancer)







Radiosensitivity of children

Scientific data: radiogenic tumor incidence in children is more variable than in adults and depends on tumor type, age and gender.

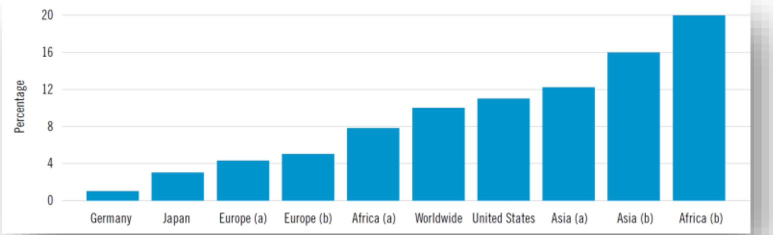
- For about 25% of cancers children are more radiosensitive (leukemia and thyroid, skin, breast and brain cancer)
- For 15% sensitivity is the same (colon cancer)
- For 10% children are less radiosensitive than adults (lung cancer)
- For others week relationship

Radiological procedures in children

- Approximately 3-10 % of all X ray procedures are performed on children
- Percentage of the all procedures in health-care level I countries:

Radiography	
Head/ skull	19%
Extremities	15%
Abdomen	13%
Spine AP	7-12%
Chest PA and Lat	9-12%
Pelvis/ hips	9%
Other radiographic	3-9%

Computed tomography	
Head	8%
Abdomen	4%
Thorax	5%
Spine	3%



UNSCEAR (2013). UNSCEAR 2013 Report. Sources, effects and risks of ionizing radiation. Volume II: Scientific Annex B: Effects of radiation exposure of children.

WHO (2016). Communicating radiation risks in paediatric imaging: information to support health care discussions about benefit and risk.

Increased individual doses

- Increased individual doses for children

Johnson JN et al. Circulation 2014. 130:161-7

337 children with heart disease exposed to 13 932 radiation examinations:

CED 0.1 - 76.9 mSv

(median 2.7 mSv):

92% of all exams radiography

81% of ED from CT and cardiac catheterisations

Glatz AC et al, J Pediatr. 2014 Apr;164(4):789-794

4132 children with congenital heart disease subjected to 134 715 radiation exams

Median 14 exams (majority radiographs) at ED of 0.96 mSv (majority from cardiac catheterization)

5.3% had >20 mSv/year

Seal A.et al. PLoS One. 2017 Jan 12;12(1):e0167922

54 paediatric transplant recipients had 6215 imaging studies

CED ranged 4.1–400 mSv (median 78 mSv)

19 (35%) had >100 mSv

*CED = cumulative effective dose

Increased individual doses

- Increased individual doses for children

Fuchs Y et al, J Pediatr Gastroenterol Nutr. 2011 Mar;52(3):280-5

257 children with IBD
(171 with Crohn disease and 86 ulcerative colitis).
Mean CED 17.6 mSv

15 (5.8%) had CED ≥50 mSv
14 of them with Crohn disease

Huang JS et al. J Pediatr Gastroenterol Nutr. 2011 Nov;53(5):502-6

105 paediatric patients with IBD
Mean CED 15 mSv
42% ≥ 10 mSv
6% ≥ 50 mSv

Sauer CG et al. Inflamm Bowel Dis. 2011 Nov;17(11):2326-32

117 children with IBD
(86 Crohn's disease and 31 ulcerative colitis)
Median CED 15.1 mSv in CD and 7.2 mSv in UC (43% from CT)
47 out of 78 (60%) children would exceed 50 mSv by 35 years of age.

*CED = cumulative effective IBD = inflammatory bowel disease

Use of non-optimized protocols

- The same exposure parameters are often used for children as for adults, resulting in higher than necessary doses to children

AJR:176, February 2001 **From the Editor's Notebook**

Taking Care of Children: Check Out the Parameters Used for Helical CT

Anne Paterson[1]
Donald P. Frush[2]
Lane F. Donnelly[3]

Helical CT of the Body: Are Settings Adjusted for Pediatric Patients?

National Conference on Dose Reduction in CT, with an Emphasis on Pediatric Patients

Otha W. Linton[1] and Fred A. Mettler, Jr.[2]

Minimizing Radiation Dose for Pediatric Body Applications of Single-Detector Helical CT: Strategies at a Large Children's Hospital

Lane F. Donnelly[1,2], Kathleen H. Emery[1,2], Alan S. Brody[1,2], Tal Laor[1,2], Victoria M. Gylys-Morin[1,2], Christopher G. Anton[1,2], Stephen R. Thomas[2], Donald P. Frush[3]

Helical CT of the Body: A Survey of Techniques Used for Pediatric Patients

Caroline Hollingsworth[1]
Donald P. Frush[1]
Mark Cross[2]
Javier Lucaya[3]

Paediatric CT examinations in 19 developing countries: frequency and radiation dose

W. E. Muhogora, N. A. Ahmed, J. S. AlSuwaidi, A. Beganovic, O. Ciraj-Bjelac, V. Gershan, E. Gershkevitsh, E. Grupetta, M. H. Kharita, N. Manatrakul, B. Maroufi, M. Milakovic, K. Ohno, L. Ben Omrane, J. Ptacek, C. Schandorf, M. S. Shaaban, N. Toutaoui, D. Sakkas, J. S. Wambani, M. M. Rehani ✉

Radiation Protection Dosimetry, Volume 140, Issue 1, June 2010, Pages 49–58, https://doi.org/10.1093/rpd/ncq015

Estimation of effective dose and radiation risk in pediatric barium studies procedures

A. Sulieman[a,*], B. Elhag[b], M. Alkhorayef[c,d], E. Babikir[c], K. Theodorou[e], C. Kappas[e], D. Bradley[d,f]

Paediatric CT Exposure Practice in the Federal Republic of Germany

Results of a Nation-wide Survey in 2005/06

M. Galanski, H.D. Nagel, G. Stamm

Francis R. Verdun
Daniel Gutierrez
John Paul Vader
Abbas Aroua
Leonor Trinidad Alamo-Maestre
François Bochud
François Gudinchet

CT radiation dose in children: a survey to establish age-based diagnostic reference levels in Switzerland

https://www.imagegently.org/

IAEA survey of practice in paediatric radiology

IAEA

- Three phases (2009 – 2013)
- 40 countries, 126 hospitals, 146 CT facilities
  - Questionnaires for radiologists and for radiographers
  - Data collection: standard protocols and patient exams

IAEA Survey of Pediatric CT Practice in 40 Countries in Asia, Europe, Latin America, and Africa: Part I, Frequency and Appropriateness

AJR FOCUS ON:

AJR 2012; 198:1021–1031

Jenia Vassileva[1]
Madan M. Rehani[2]
Humoud Al-Dhuhli[3]
Huda M. Al-Naemi[4]
Jamila Salem Al-Suwaidi[5]
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Danijela Arandjic[7]
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Adnan Beganovic[9]
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Tadeusz Bieganski[11]
Simone Dias[12]
Leila El-Nachef[13]
Dario Faj[14]
Mirtha E. Gamarra-Sánchez[15]
Juan Garcia-Aguilar[16]
Vesna Gershan[18]
Eduard Gershkevitsh[19]
Edward Gruppetta[20]
Alexandru Hustuc[21]
Sonja Ivanovic[22]
Arif Jauhari[23]
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Leos Novak[35]
Aruna S. Pallewatte[36]
Mohamed Shaaban[37]
Esti Shelly[38]

Eur Radiol
DOI 10.1007/s00330-012-2639-3

COMPUTED TOMOGRAPHY

IAEA survey of paediatric computed tomography practice in 40 countries in Asia, Europe, Latin America and Africa: procedures and protocols

Jenia Vassileva · Madan M. Rehani · Kimberly Applegate · Nada A. Ahmed ·

Radiation Protection Dosimetry Advance Access published April 1, 2015

Radiation Protection Dosimetry (2015), pp. 1–5 doi:10.1093/rpd/ncv113

PATIENT GROUPING FOR DOSE SURVEYS AND ESTABLISHMENT OF DIAGNOSTIC REFERENCE LEVELS IN PAEDIATRIC COMPUTED TOMOGRAPHY

J. Vassileva[1,*] and M. Rehani[2]

Radiation Protection Dosimetry Advance Access published April 1, 2015

Radiation Protection Dosimetry (2015), pp. 1–11 doi:10.1093/rpd/ncv116

A STUDY TO ESTABLISH INTERNATIONAL DIAGNOSTIC REFERENCE LEVELS FOR PAEDIATRIC COMPUTED TOMOGRAPHY

J. Vassileva[1,*], M. Rehani[2], D. Kostova-Lefterova[3], H. M. Al-Naemi[4], J. S. Al Suwaidi[5], D. Arandjic[6], E. H. O. Bashier[7], S. Kodlulovich Renha[8], L. El-Nachef[9], J. G. Aguilar[10], V. Gershan[11], E. Gershkevitsh[12], E. Gruppetta[13], A. Hustuc[14], A. Jauhari[15], Mohammad Hassan Kharita[16], N. Khelassi-Toutaoui[17], H. R. Khosravi[18], H. Khoury[19], I. Kralik[20], S. Mahere[21], J. Mazuoliene[22], P. Mora[23], W. Muhogora[24], P. Muthuvelu[25], D. Nikodemova[26], L. Novak[27], A. Pallewatte[28], D. Pekarovič[29], M. Shaaban[30], E. Shelly[31], K. Stepanyan[32], N. Thelsy[33], P. Visrutaratna[34] and A. Zaman[35]

40 countries, 126 hospitals, 146 CT facilities

IAEA

73 (50%) in Asia

- China (3)
- Indonesia (1)
- Iran (10)
- Israel (7)
- Kuwait (5)
- Lebanon (6)
- Malaysia (1)
- Myanmar (1)
- Oman (1)
- Pakistan (5)
- Qatar (1)
- Singapore (1)
- Sri Lanka (2)
- Syria (8)
- Thailand (1)
- UAE (15)

51 (35%) in Europe

Armenia (1)
Belarus (1)
Bosnia and Herzegovina (3)
Bulgaria (12)
Croatia (3)
Czech Republic (6)
Estonia (2)
Lithuania (3)
FYR Macedonia (5)
Malta (1)
Moldova (5)
Montenegro (1)
Poland (1)
Serbia (3)
Slovakia (4)
Slovenia (1)

10 (7%) in Africa

Algeria (4)
Sudan (3)
Tanzania (3)

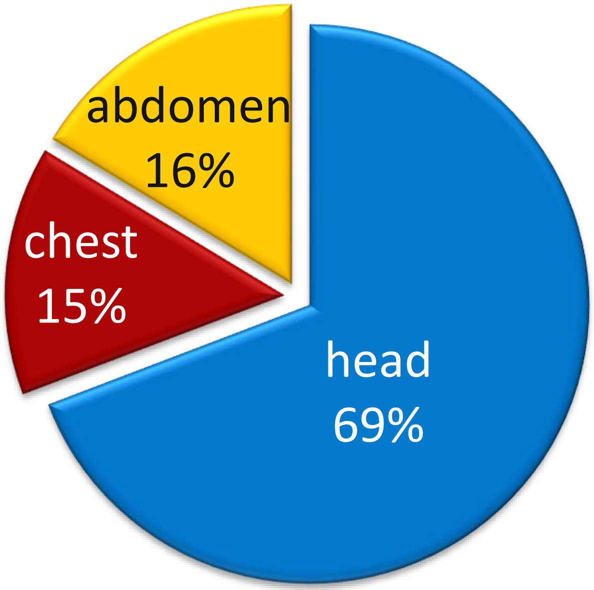
12 (8%) in Latin America

- Brazil (5)
- Costa Rica (1)
- Mexico (1)
- Paraguay (3)

IAEA survey of practice in paediatric radiology

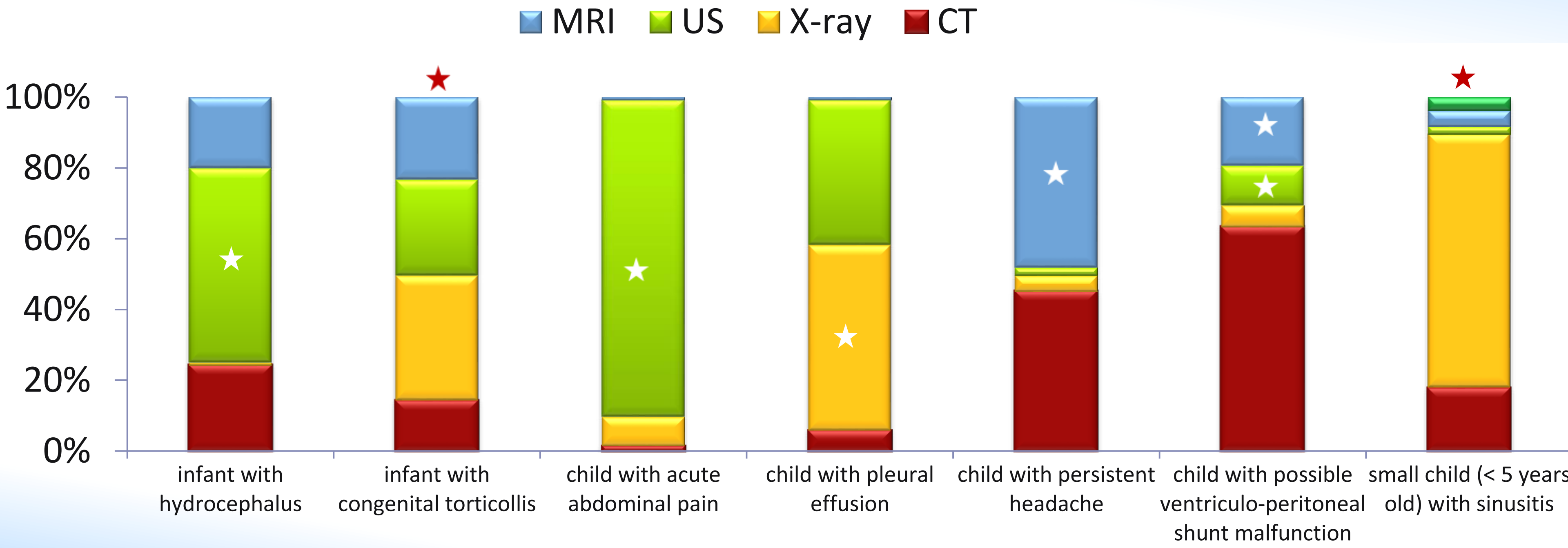
Frequency of paediatric exams: 95 CT facilities in 28 countries

- The frequency of paediatric CT examinations ranged from less than 1% to 49.4%.
- Head was the most frequently scanned body part (69%)
- No significant difference between regions



IAEA survey of practice in paediatric radiology

Which examination is " the first choice examination" in case of:



IAEA survey of practice in paediatric radiology

Review of standard protocols

- Up to 22-fold variation of CTDI values:
  - Head CT: between 3.3 (>5-10 y) and 18 (<10-15 y)
  - Chest CT: between 6.4 (>5-10y) and **22.3** (>10-15y)
  - Abdomen CT: between 6.4 (>10-15y) and 13.4 (>5-10y)
- In **40%** facilities the scanning protocols were not adapted to the body size.
- In **13%** of facilities the same protocol was used for all age groups.
- In **8.2%** of the scanners CTDI values for paediatric patients were higher than for adults in at least one age group and one examination.
- In **> 50 %** of facilities, manufacturers' pre-programmed protocols were used without any change, or, were modified mostly by the manufacturer's representative.

IAEA survey of practice in paediatric radiology

IAEA

Protocols for **chest examination** of infant (<1 y) in 8 CT facilities with the same 64-detector scanner model (Light Speed VCT, GE)

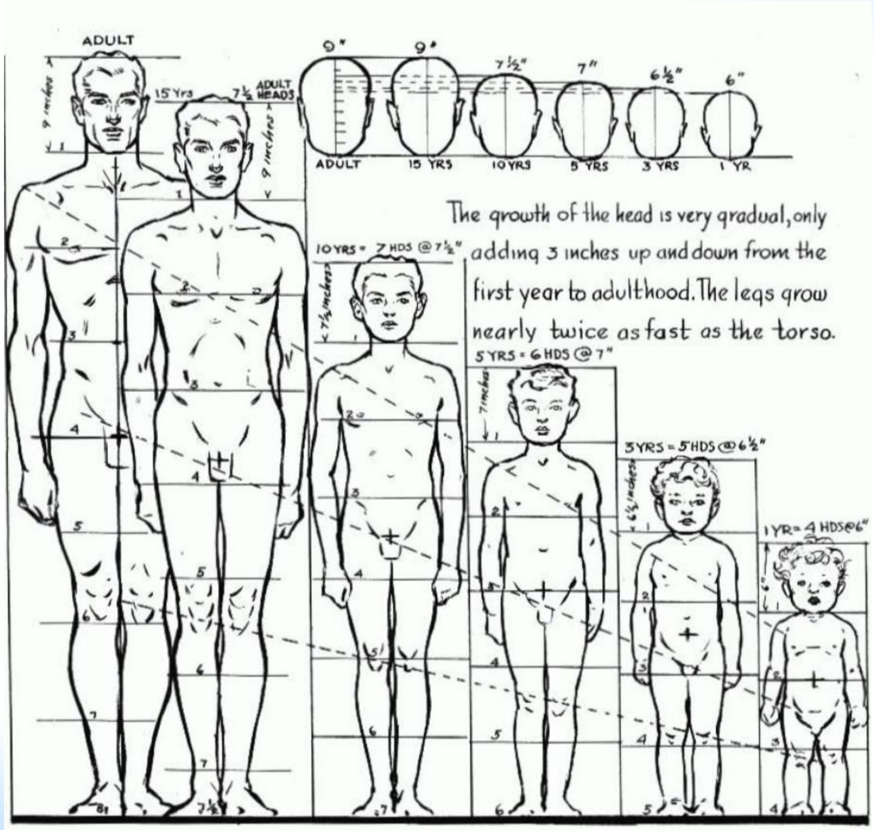
Scanner number	mode	Tube voltage, kV	Tube current, mA	t rot, s	Pitch value	$CTDI_{vol}$, mGy
39	helical	80	129	0.5	1.3	1.89
40	helical	120	120	0.5	0.984	10.21
102	helical	80	240	0.5	0.984	2.64
26	helical	80	100-250	0.5	0.96	4.26
29	helical	100	180	0.4	0.98	3.2
8	helical	120	80	0.4	1.375	4.5
124	helical	80	25	0.5	0.9	0.71
119	helical	120	80	0.6	0.9	10

Variation in CTDI dose values across scanners:

- 14-fold for chest
- 6-fold for abdomen
- 4-fold for head

What to consider in dose surveys for children?

Children are not small adults



Different body size

Different proportions:

- The head grows very gradual (~7 cm)
- Body height ≈ 4 heads for infant
  5 heads for 3 years old
  6 heads for 5 years old
  7 heads for 10 years old
  71/2 heads for 15 years old
  8 heads for adult

- Body mass (weight) in children can vary by a factor of more than 100,
  while in adults – a factor of ~4 approximately

Children are not small adults

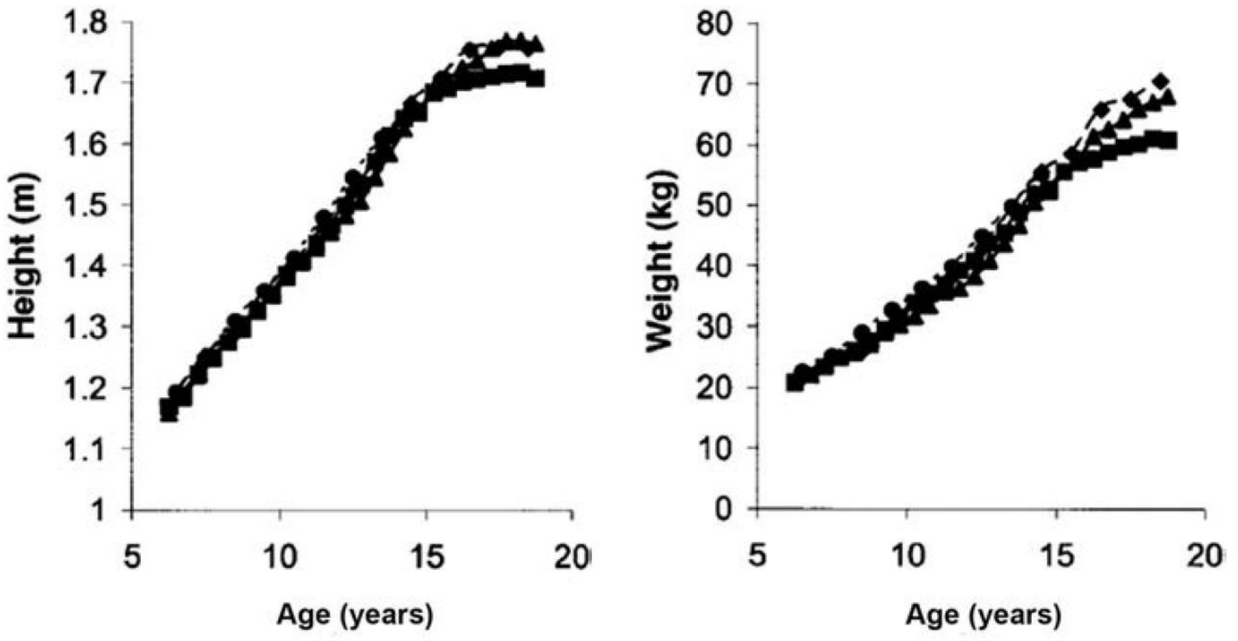
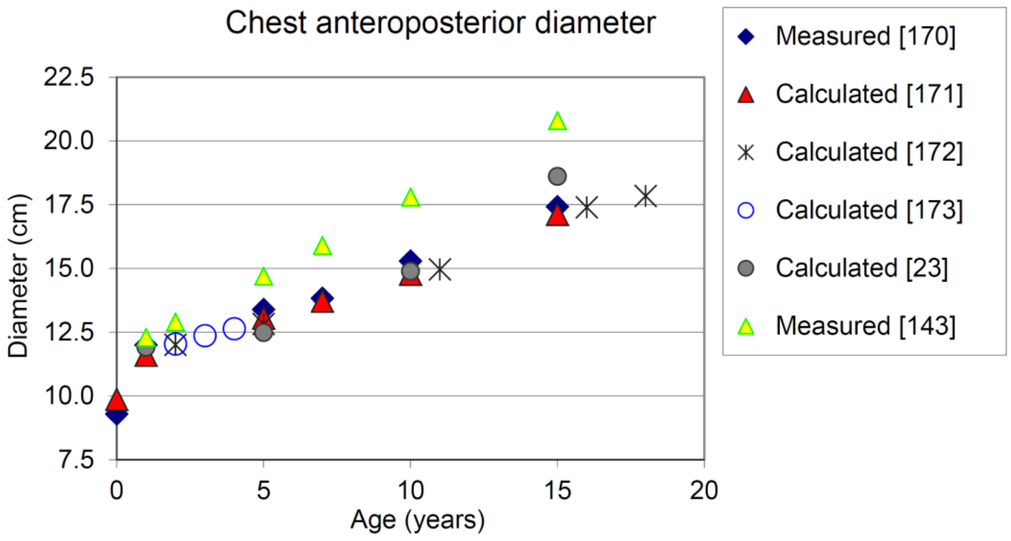
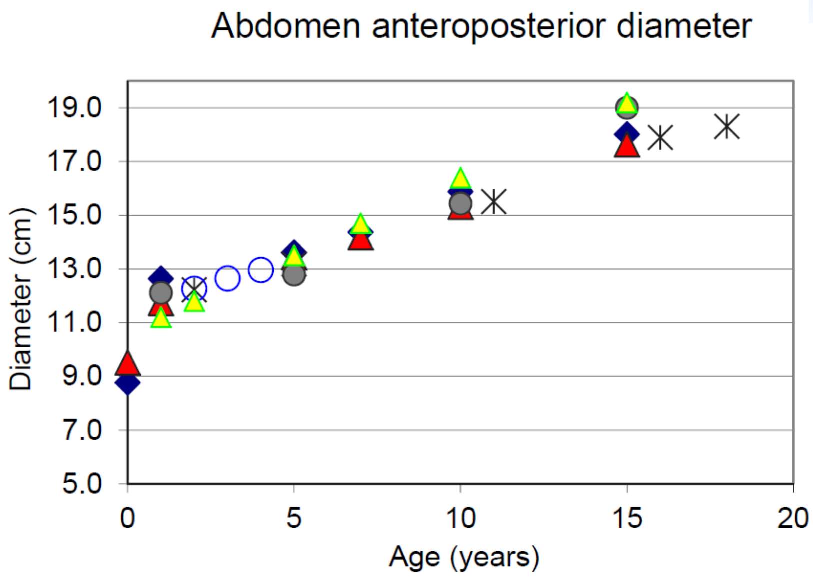


FIG. 6. Mean height and weight for each class for boys from Japan (●), Singapore (■), the United Kingdom (▲) and the United States of America (♦) [168].

IAEA. Dosimetry in diagnostic radiology for paediatric patients.Vienna, 2013.

Children are not small adults





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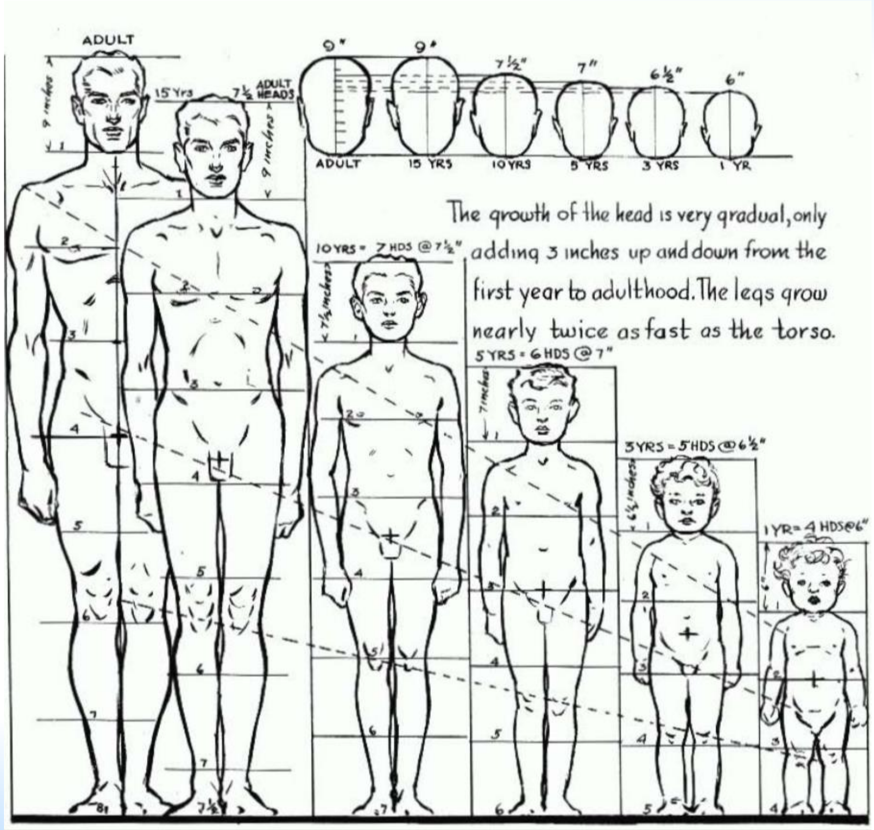


A single "standard" paediatric patient should not be used

Patient grouping is needed

Patient grouping

Age

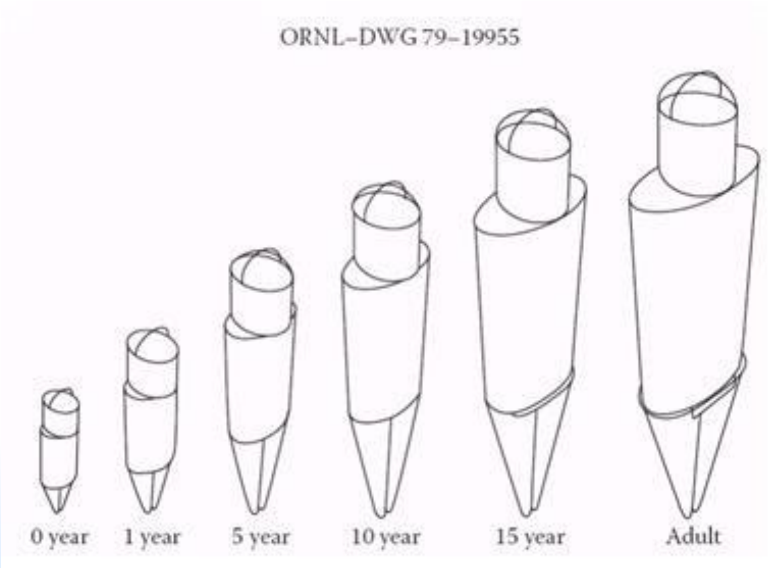
- Easily obtained
- Easily comparable
- Poorly reflects
  - Anatomical variability
  - Relatively independent of clinical presentation
  - Relatively independent of CT acquisition parameters

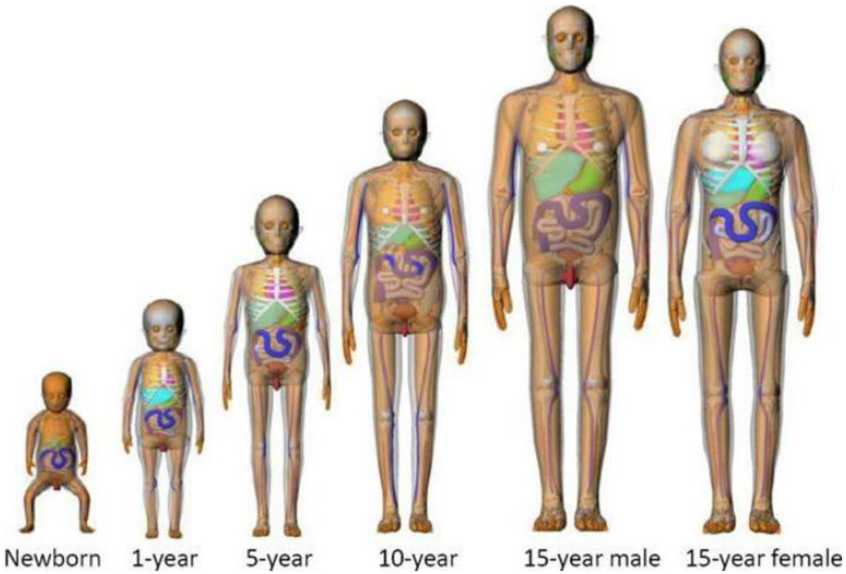
Weight

- Easily obtained (?)
- Better reflects
  - CT acquisition parameters
  - Anatomical variability
  - Clinical presentation
- Level of granularity inversely proportional to statistical error for small data cohorts

Pediatric categorization by age

- Rare publications quoting patient age and weight
- Majority used patient age
- Four or five age groups



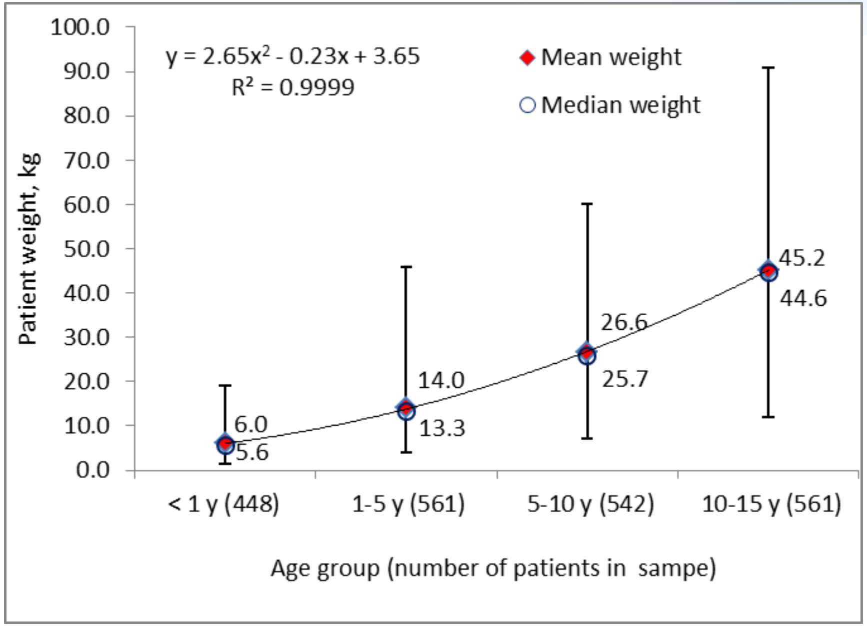


Patient grouping by weight

In general, individual patient size does not correlate well with patient age, even though **fitted average patient sizes are age-dependent.**

IAEA survey:

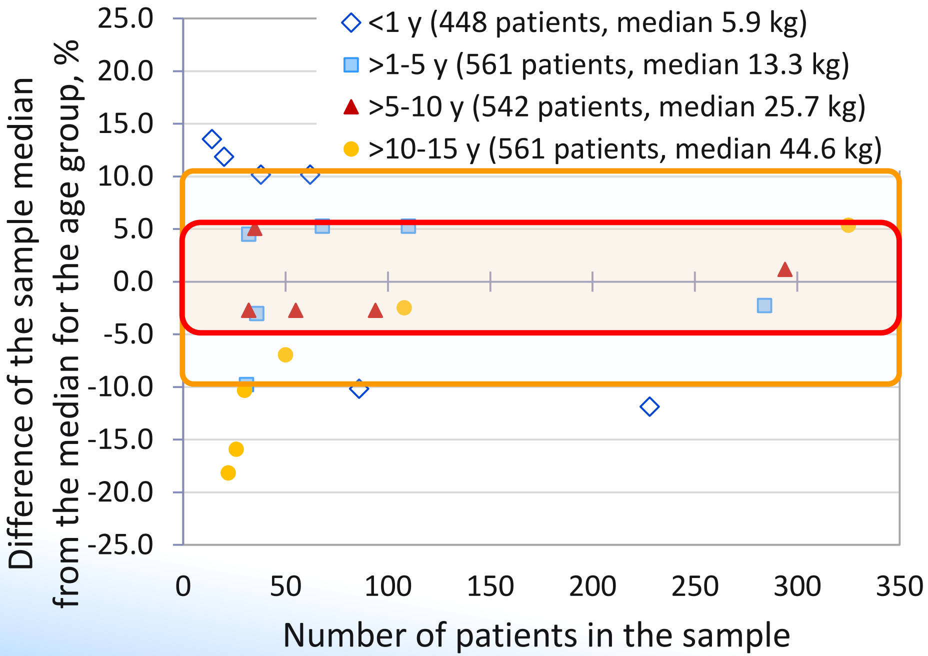
- For 2012 out of 6115 patient (43.5%) both age and weight were known
- Grouped in 4 age groups
- A smooth increasing trend found for the mean and median weight as a function of the age group (for large samples).



Vassileva J, Rehani M. Patient grouping for dose surveys and establishment of diagnostic reference levels in paediatric computed tomography. Radiat Prot Dosimetry. 2015 Jul;165(1-4):81-5

Patient grouping

Relative difference of the median weight for samples of different size from the median weight for the corresponding age group, defined from the whole patient cohort



Within ±10% if > 35 patients in the sample (19 samples)

Within ±5% if > 90 patients in the sample (7 samples)

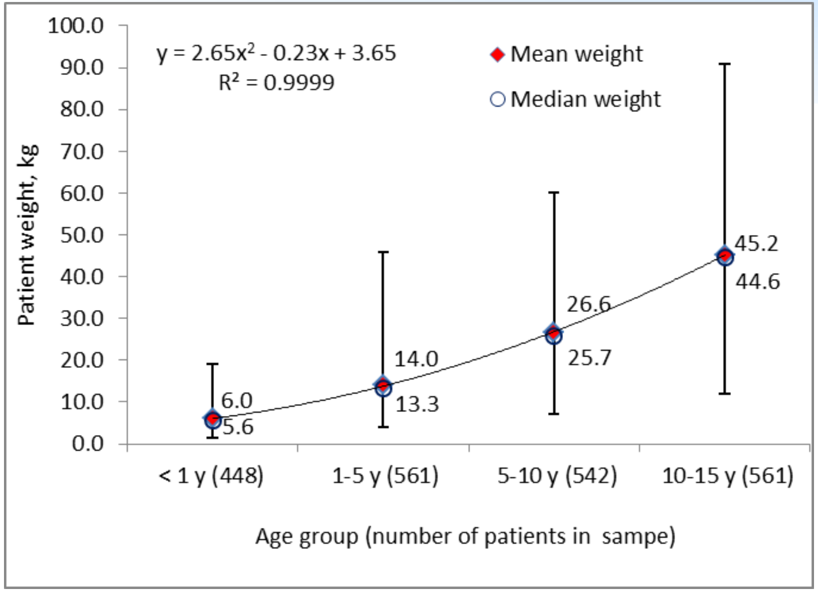
Largest variation in the age group <1y ⇨
Relevant to split this group: --

- new-born (< 1 month)
- infant (>1 month to 1 y)

Vassileva J, Rehani M. Patient grouping for dose surveys and establishment of diagnostic reference levels in paediatric computed tomography. Radiat Prot Dosimetry. 2015 Jul;165(1-4):81-5

Patient grouping by weight

- Large sample
  - Use of four age groups, <1, >1–5, >5–10 and >10–15 y, is realistic and pragmatic for dose surveys in less resourced countries
  - Data for >30 patients in a particular age group should be collected
- Small sample
  - Need to record weight
  - Median weight within 5–10 % from the median weight of the sample for which the DRLs are established



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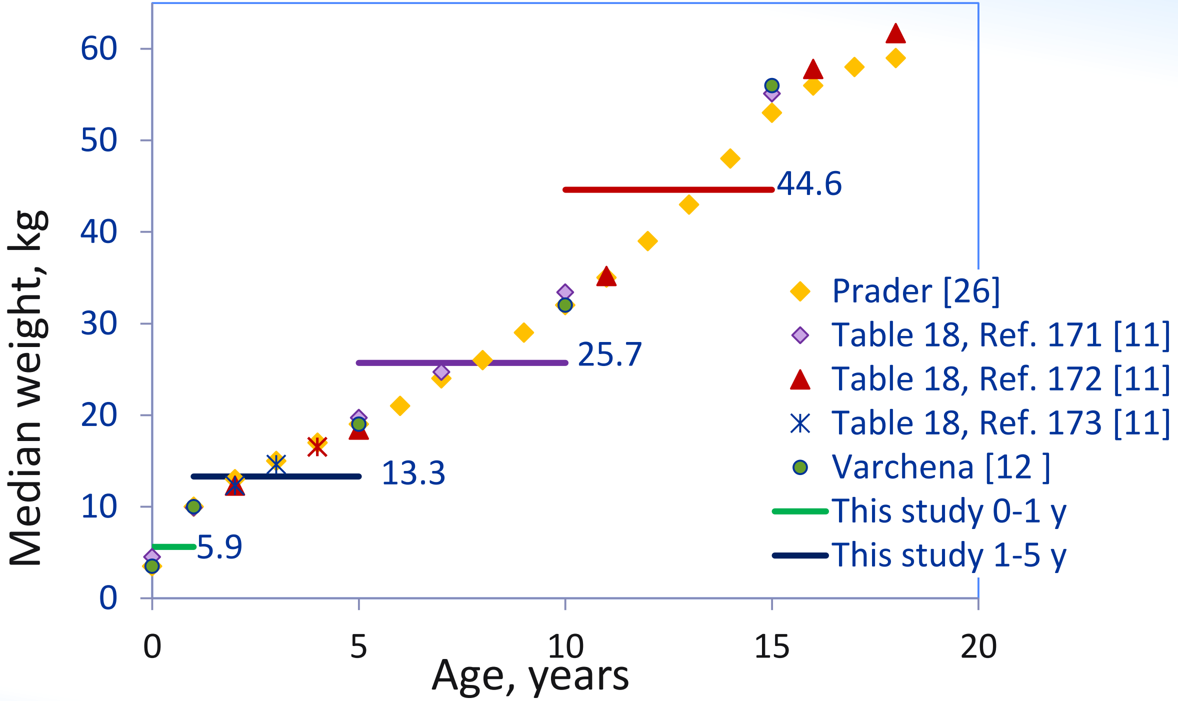
Patient grouping



Comparison of results from different surveys should be performed with caution, taking into consideration the grouping of paediatric patients

Vassileva J, Rehani M. Patient grouping for dose surveys and establishment of diagnostic reference levels in paediatric computed tomography. Radiat Prot Dosimetry. 2015 Jul;165(1-4):81-5

Weight grouping for paediatric DRLs

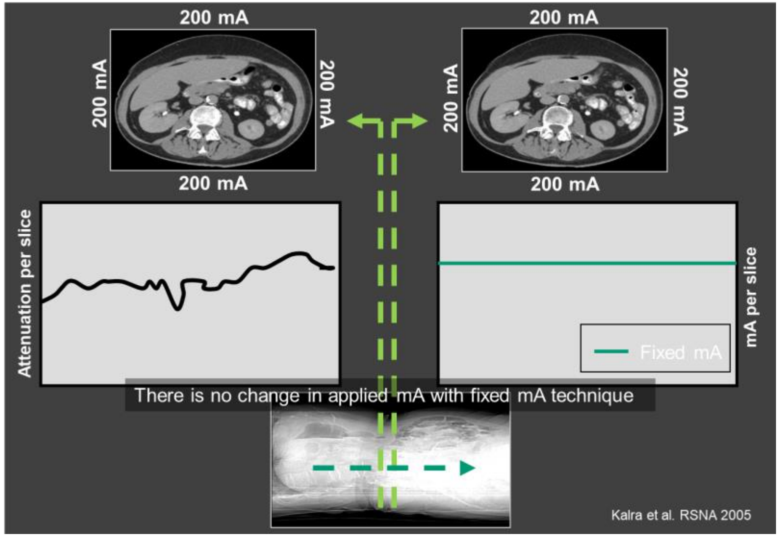
Description	Weight group	Age group based on weight-for-age charts	Most common age groups used for the NDRLs (or equivalent)
Neonate	< 5 kg	< 1 m	0 y
Infant, toddler and early childhood	5 - < 15 kg	1 m - < 4 y	1 y
Middle childhood	15 - < 30 kg	4 - < 10 y	5 y
Early adolescence	30 - < 50 kg	10 – < 14 y	10 y
Late adolescence	50 - < 80 kg	14 - < 18 y	15 y

Recommended weight groups (intervals) for *body* examinations	Recommended age groups (intervals) for *head* examinations
< 5 kg 5 - < 15 kg 15 - < 30 kg 30 - < 50 kg 50 - < 80 kg	0 - < 3 months 3 months - < 1 y 1- < 6 y ≥ 6 y

European Guidelines on Diagnostic Reference Levels for Paediatric Imaging. Radiation Protection 185. European Union, Luxembourg.
http://www.eurosafeimaging.org/wp/wp-content/uploads/2018/09/rp_185.pdf

Attenuation-based bands

- Modern systems have AEC and TCM
- In order to develop useful values for paediatric DRLs, consideration should be given in the future to grouping survey data into attenuation-based bands

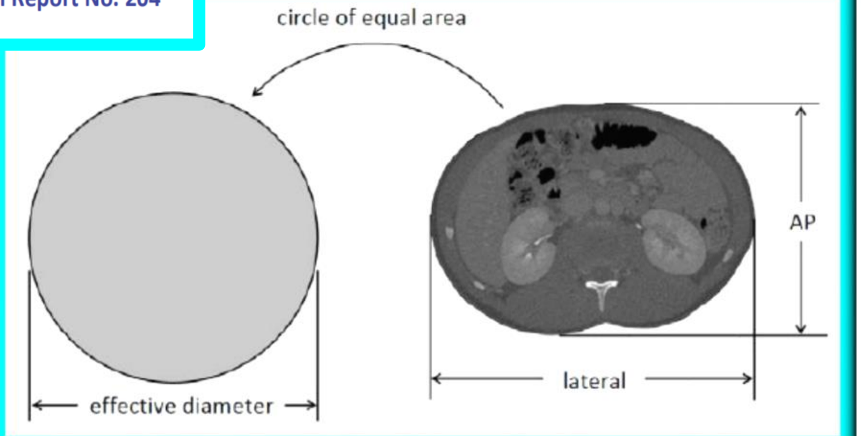


Paediatric DRL values for CT

- $CTDI_{vol}$ and DLP, based on 32-cm-diameter phantom for body examinations and a 16-cm-diameter phantom for head examinations
- Values for these quantities should be obtained from patient examinations
- SSDE may be used in addition to the recommended DRL quantities

Size Specific Dose Estimates (SSDE)

AAPM Report No. 204



$$effective\ diameter = \sqrt{AP \times LAT}$$

Effective Dia (cm)	Conversion Factor
35	1.02
36	0.99
37	0.95
38	0.92
39	0.88
40	0.85
41	082
42	0.79
43	0.76
44	0.74
45	0.71

$$size\ specific\ dose\ estimate = SSDE = f^{16X}_{size} \times CTDI^{16}_{vol}$$

Values of SSDE are derived from displayed values of $CTDI_{vol}$, though application of tabulated correction factors specific to patient age or effective diameter (AP and LAT dimensions)

Issue with phantom diameter

- To compare $CTDI_{vol}$ or DLP:
  - Phantom diameter used for the specific scanner model
  - Software version
- Phantom diameter:
  - Displayed on the user console
  - DICOM report
  - Consult manufacturer for older scanners

What examination should be included?

- On the basis of collective dose to the paediatric population
- Examinations resulting in high collective doses:
  - Low dose examinations
  - Less common high dose examinations

Radiography and fluoroscopy

Anatomical region	Projection(s) or procedure
Radiography	
Head (skull)	AP/PA
	LAT
Thorax (chest)	AP/PA
Abdomen	Abdomen-pelvis AP
Pelvis	Pelvis/hip AP
Cervical spine	AP/PA
	LAT
Thoracic spine	AP/PA
	LAT
Lumbar spine	AP/PA
	LAT
Whole spine/Scoliosis	AP/PA
	LAT
Fluoroscopy	
Urinary tract	Micturating/Voiding cystourethrography (MCU/VCU)
Gastro-intestinal tract	Upper GE-examinations
	Contrast enema

European Guidelines on Diagnostic Reference Levels for Paediatric Imaging. Radiation Protection 185. European Union, Luxembourg. http://www.eurosafeimaging.org/wp/wp-content/uploads/2018/09/rp_185.pdf

Computed tomography

Anatomical region	Procedure
Head	Routine Paranasal sinuses Inner ear/internal auditory meatus Ventricular size (shunt)
Neck	Neck
Chest	Chest
	Cardiovascular CT angiography
Abdomen	Abdomen (upper abdomen)
	Abdomen+pelvis
Trunk	Whole body CT in trauma
Spine	Cervical spine
	Thoracic spine
	Lumbar spine

Indication based DRL

European Guidelines on Diagnostic Reference Levels for Paediatric Imaging. Radiation Protection 185. European Union, Luxemb
http://www.eurosafeimaging.org/wp/wp-content/uploads/2018/09/rp_185.pdf

Interventional procedures

- Few available data
- Development of LDRLs should be encouraged
- Limited experiences for determination of the complexity levels
- Procedure to be considered:

Cardiac procedures

- Patent Ductus Arteriosus (PDA) occlusion
- Atrial Septal Defect (ASD) occlusion
- Pulmonary valve dilatation
- Diagnostic cardiac catheterization

Non-cardiac procedures

- Peripherally inserted central catheter (PICC)

DRLs for adults vs DRLs for children

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Common for adults and children

- Choice of DRL quantity
- Statistical analysis
- Phantom and patient issues

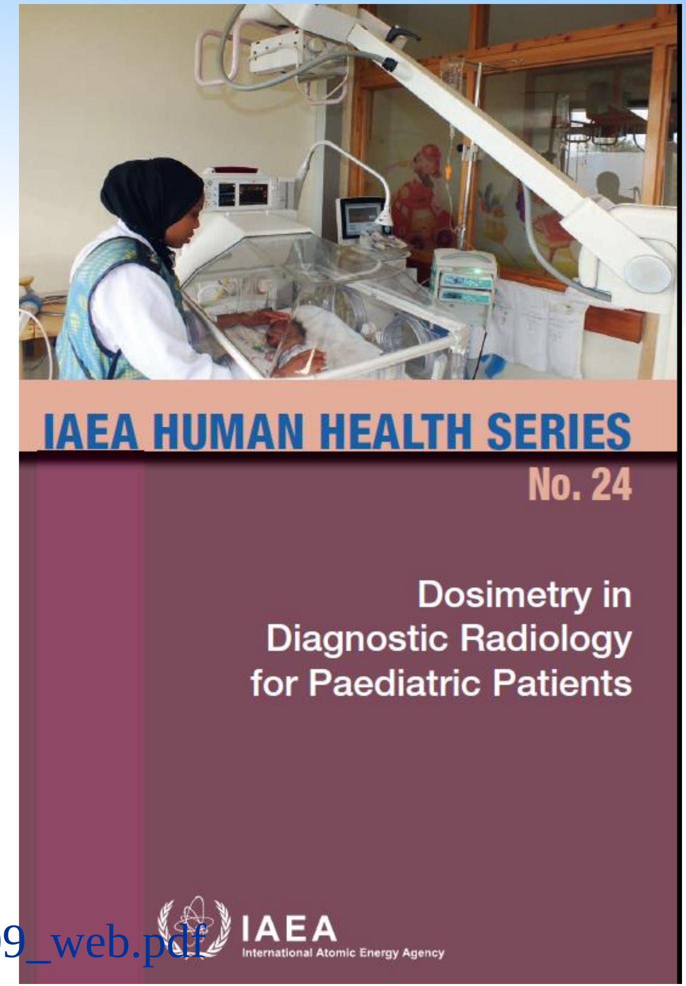
Specific for children

- Patient weight and size
- Patient procedures

DRL values for adults are defined for a patient of standard size, whereas for children, there cannot be a single standard patient due to the large size range of paediatric patients.

DRL quantities for paediatric patients

Modality	Quantity	Recommended symbols	Recommended unit
Radiography	Entrance surface air kerma	$K_{a,e}$	mGy
	Air kerma-area product	P_{KA}	$mGy.cm^2$
Fluoroscopy and interventional radiology	Air kerma-area product	P_{KA}	$Gy.cm^2$
	Fluoroscopy time and number of images	-	-
	Air kerma at the patient entrance reference point (interventional procedures)	$K_{a,r}$	mGy
Computed tomography	Volume computed tomography dose index	$CTDI_{vol}$	mGy
	Dose-length product	DLP	mGy.cm
	Size specific dose estimate	SSDE	mGy
Diagnostic nuclear medicine	Administered activity or activity per body weighty	A	MBq or MBq kg^{-1}



https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1609_web.pdf

Additional parameters to be recorded

Radiography	Fluoroscopy	Interventional procedures
Equipment: manufacturer and type	Equipment: manufacturer and type	Equipment: manufacturer and type
Detector system: SF, CR, DR	Type of detector (DR)	Type of detector (DR)
Source detector distance (SDD)	Source detector distance (SDD)	Source detector distance (SDD)
Added filtration	Added filtration	Added filtration
Grid (used/not used/removable)	Grid (used/not used/removable)	Grid (used/not used/removable)
Exposure parameters: kV, mA, mAs	Exposure parameters: kV, mA, mAs	Exposure parameters: kV, mA, mAs
Automatic exposure control, AEC (active/deactivated)	AEC mode	AEC mode

European Guidelines on Diagnostic Reference Levels for Paediatric Imaging. Radiation Protection 185. European Union, Luxembourg.
http://www.eurosafeimaging.org/wp/wp-content/uploads/2018/09/rp_185.pdf

Additional parameters to be recorded

CT	
Equipment: manufacturer and type	Image quality level: Quality Reference mAs/noise index/reference image
Detector configuration (number of detector rows)	Standard deviation of CT numbers or equivalent
Exposure parameters: kV, mA, mAs	Image handling: reconstruction slice thickness, iterative reconstruction
Automatic tube voltage selection tool used/not used	Number of phases and scan sequences
Rotation time, mode (sequential/helical), pitch (helical) or table Increment (sequential), Field of View (FOV), collimation thickness, beam shaping filters, scanning length	Size of the calibration phantom
Tube –current modulation	

Towards DRLs in paediatric radiology

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- Coordinator appointment
- Identification of examinations
- Selection X ray facilities
- Data collection method
- Data collection and analysis
- Typical doses in each room
- Data from different rooms
- Establish DRLs for the selected examinations
- Use of DRLs for the optimization of practice

Image quality

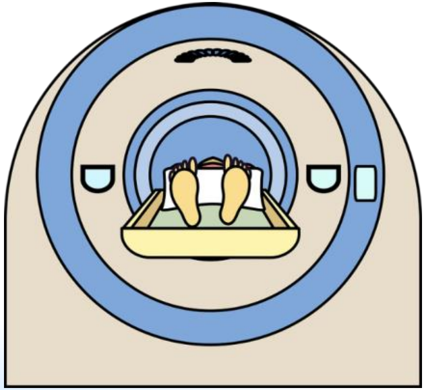
- The image quality should be adequate for the diagnosis according to the indication of the examination
- Patient doses associated with rejected images should not be included in the sample for setting DRLs
- No limit or warning level for low image quality based solely on the dose level is recommended

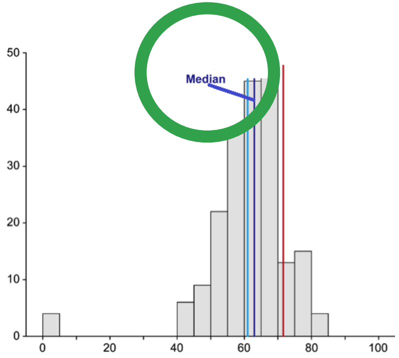
Sample for national DRLs

- Dedicated paediatric healthcare facilities and departments (i.e. children hospitals or departments/units specializing in paediatric imaging)
- General healthcare facilities and departments where paediatric practices are part of the overall radiology services

Data analysis for a given facility and patient group

- Statistical description: Minimum, Maximum, Average, Standard deviation, Median of patient sample
- **Typical value: Median**



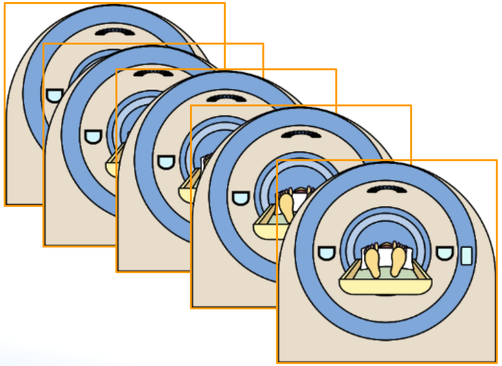


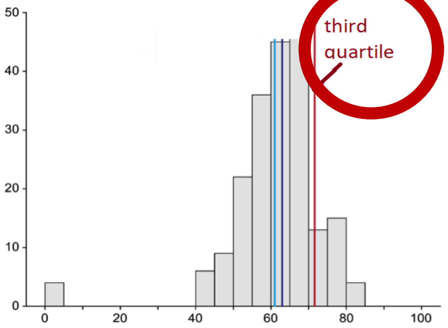
MEDIAN VALUE

TYPICAL VALUE

Local DRLs

- Collection of data from different X ray rooms (10-20 rooms), performing the same procedure or X ray rooms from a few facilities in local area
- Statistical description: Minimum, Maximum, Average, Standard deviation, Median of typical doses from different rooms
- **Local DRL: Third quartile of median values for each patient group**



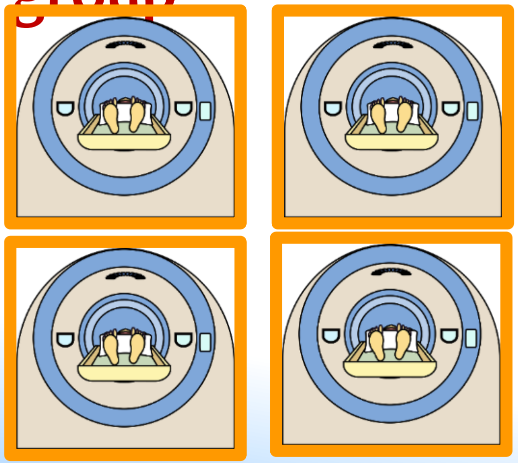


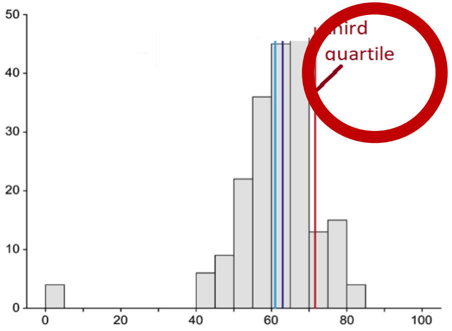
THIRD QUARTILE OF MEDIAN VALUES

LOCAL DRL

National DRLs

- Collection of data from representative sample of facilities covering an entire country
- Statistical description: Min, Max, Average, Standard deviation, Median of typical doses from different hospital for each patient group
- **National DRL: Third quartile of median values for each patient group**

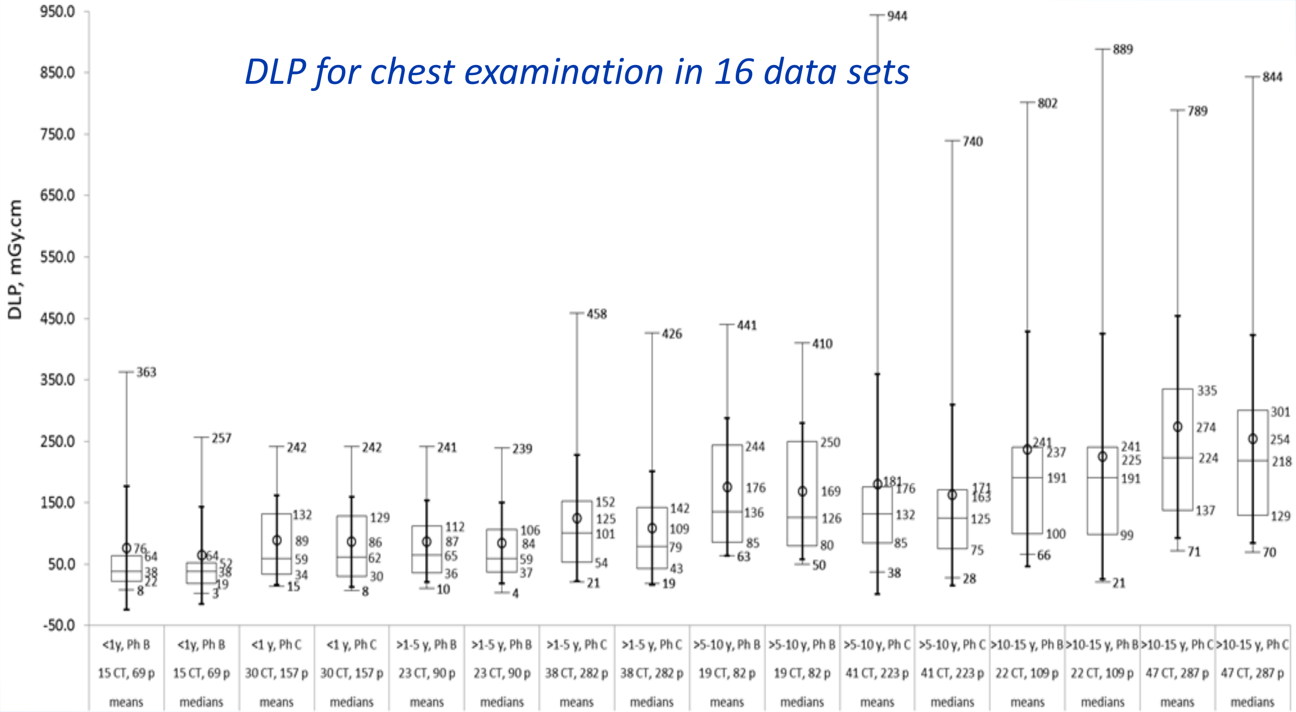




THIRD QUARTILE OF MEDIAN VALUES

NATIONAL DRL

Difference between samples based on facilities mean and median values

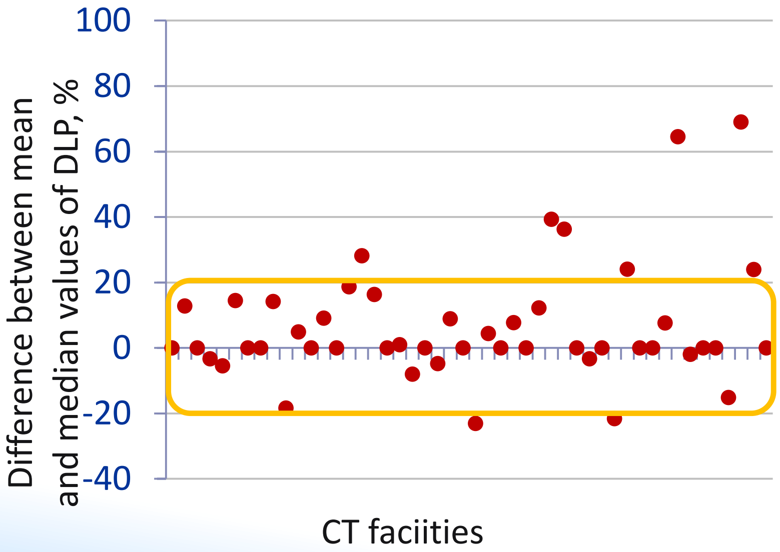


Vassileva J, et al. A study to establish international diagnostic reference levels for paediatric computed tomography. Radiat Prot Dosimetry. 2015 Jul;165(1-4):70-80.

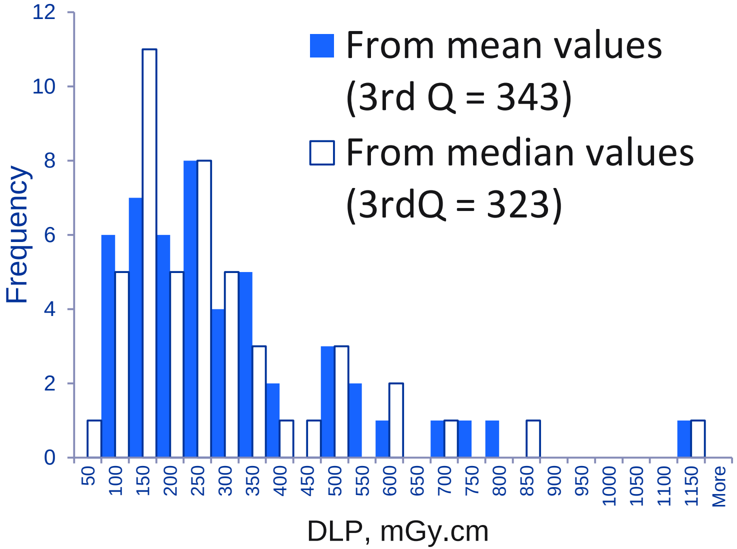
Difference between samples based on facilities mean and median values

Mean and median values of DLP for chest for 48 CT facilities (287 patients in the sample) in the age group >10-15 y, phase C.

a) differences between mean and median values



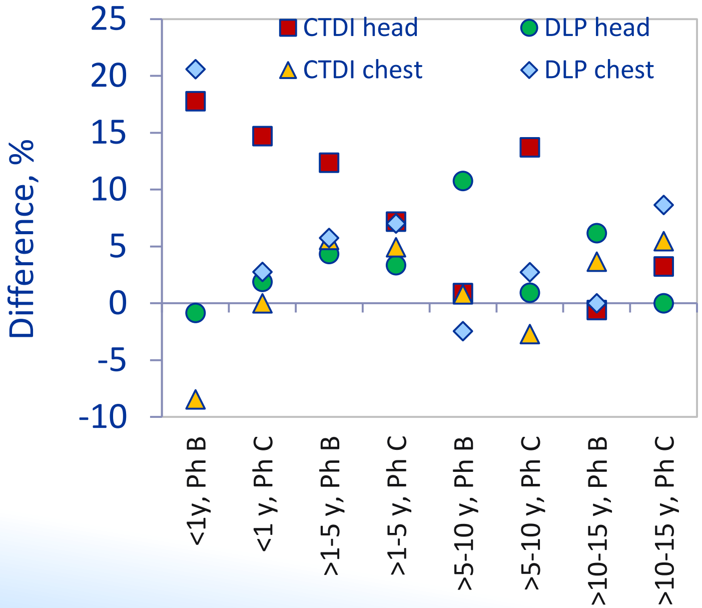
b) histogram of distribution



Vassileva J, et al. A study to establish international diagnostic reference levels for paediatric computed tomography. Radiat Prot Dosimetry. 2015 Jul;165(1-4):70-80.

Difference between samples based on facilities mean and median values

Difference between 75th percentiles of the two paired samples: based on mean values and based on median values of individual patient dose indexes in each facility



- The difference between mean and median values can result in up to 20–25% difference in set DRL.
- The median is better estimate of typical dose, both in small and large samples with symmetrically or non-symmetrically distributed data and in the presence of extreme values.

Vassileva J, et al. A study to establish international diagnostic reference levels for paediatric computed tomography. Radiat Prot Dosimetry. 2015 Jul;165(1-4):70-80.

If national DRL are not available?

- When regional or national DRL values are not available, local practice may be compared with appropriate available published data

International DRLs for paediatric CT

Table 1. Third-quartile values from three study phases and proposed international DRLs for $CTDI_{vol}$ and DLP for head, chest and abdomen CT, and for all age groups.

Examination	Age group	$CTDI_{vol}$, mGy					DLP, mGy cm			
		Phase A	Phase B	Phase C	DRL $CTDI_{16}$	DRL $CTDI_{32}$	Phase B	Phase C	DRL DLP_{16}	DRL DLP_{32}
Head CT	<1 y	29.0	25.1	25.8	26.0	—	486	439	440	—
	>1–5 y	37.7	38.3	36.1	36.0	—	584	536	540	—
	>5–10 y	46.1	55.6	43.3	43.0	—	738	692	690	—
	>10–15 y	58.1	59.7	53.0	53.0	—	987	835	840	—
Chest CT	<1 y	7.0	3.0	5.2		5.2	52	129		130
	>1–5 y	8.5	4.4	6.0		6.0	106	142		140
	>5–10 y	10.0	5.5	6.8		6.8	250	171		170
	>10–15 y	13.2	7.0	7.3		7.3	241	301		300
Abdomen CT	<1 y	10.7	3.4	5.2		5.2	130	129		130
	>1–5 y	13.0	4.3	7.0		7.0	190	245		250
	>5–10 y	12.0	7.3	7.8		7.8	315	308		310
	>10–15 y	14.3	7.1	9.8		9.8	402	456		460

International DRLs can be used by the clinical staff in countries without sufficient medical physics support, to identify non-optimised practice.

Vassileva J, et al. A study to establish international diagnostic reference levels for paediatric computed tomography. Radiat Prot Dosimetry. 2015 Jul;165(1-4):70-80.

Example: Trends in national reference doses for common CT examinations on children

TABLE 13 Trends in national reference doses for common CT examinations on children

Examination (clinical indication)	Region/ technique	National reference doses for the UK[a]					
		CTDI$_{vol}$ per sequence (mGy)			DLP per exam (mGy cm)		
		2000[b]	2003[c]	2011[d]	2000[b]	2003[c]	2011[d]
Paediatric head: 0–1 y[e] (trauma)	Post fossa	–	35	–	–	–	–
	Cerebrum	–	30	–	–	–	–
	Whole exam	40	–	25	300	270	350
Paediatric head: >1–5 y[e] (trauma)	Post fossa	–	50	–	–	–	–
	Cerebrum	–	45	–	–	–	–
	Whole exam	60	–	40	600	470	650
Paediatric head: >5 y[e] (trauma)	Post fossa	–	65	–	–	–	–
	Cerebrum	–	50	–	–	–	–
	Whole exam	70	–	60	750	620	860

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/349188/PHE_CRCE_013.pdf

European DRLs for paediatric radiology

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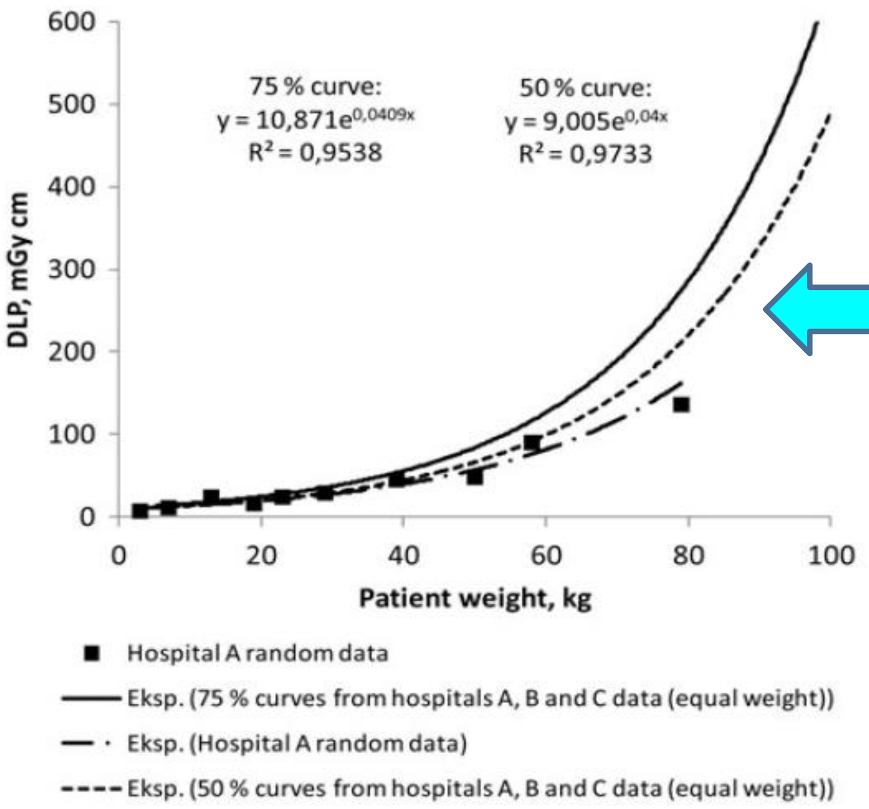
Radiography and fluoroscopy			
Examination	Age or weight group	EDRL	
		$K_{a,e}$, mGy	P_{KA}, mGy cm^2
Head AP/PA	3 months-<1 y		215
	1-<6 y		295
	≥6 y		350
Head LAT	3 months-<1 y		200
	1-<6 y		250
Thorax AP/PA**	<5 kg		15
	5-<15 kg	0,06	22
	15-<30 kg	0,08	50
	30-<50 kg	0,11	70
	50-<80 kg		87
Abdomen AP	<5 kg		45
	5-<15 kg		150
	15-<30 kg	0,40	250
	30-<50 kg	0,75	475
	50-<80 kg		700
Pelvis AP	15-<30 kg		180
	30-<50 kg		310
MCU	<5 kg		300
	5-<15 kg		700
	15-<30 kg		800
	30-<50 kg		750*

*Based on 4 NDRLs, range 400-2000 mGy cm^2; **AP/PA: DRL applies to both AP and PA projections

Computed tomography			
Exam	Age or weight group	EDRL	
		$CTDI_{vol}$, mGy	DLP, mGy cm
Head	0-<3 months	24	300
	3 months-<1 y	28	385
	1-<6 y	40	505
	≥6 y	50	650
Thorax	<5 kg	1,4	35
	5-<15 kg	1,8	50
	15-<30 kg	2,7	70
	30-<50 kg	3,7	115
	50-<80 kg	5,4	200
Abdomen	<5 kg		45
	5-<15 kg	3,5	120
	15-<30 kg	5,4	150
	30-<50 kg	7,3	210
	50-<80 kg	13	480

European Guidelines on Diagnostic Reference Levels for Paediatric Imaging. Radiation Protection 185. European Union, Luxembourg. http://www.eurosafeimaging.org/wp/wp-content/uploads/2018/09/rp_185.pdf

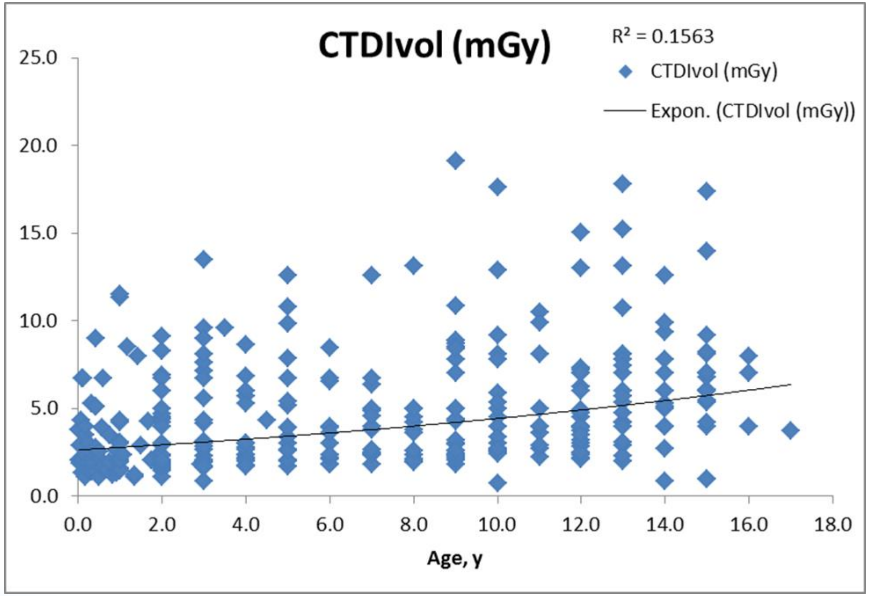
DLR quantity-weight curve

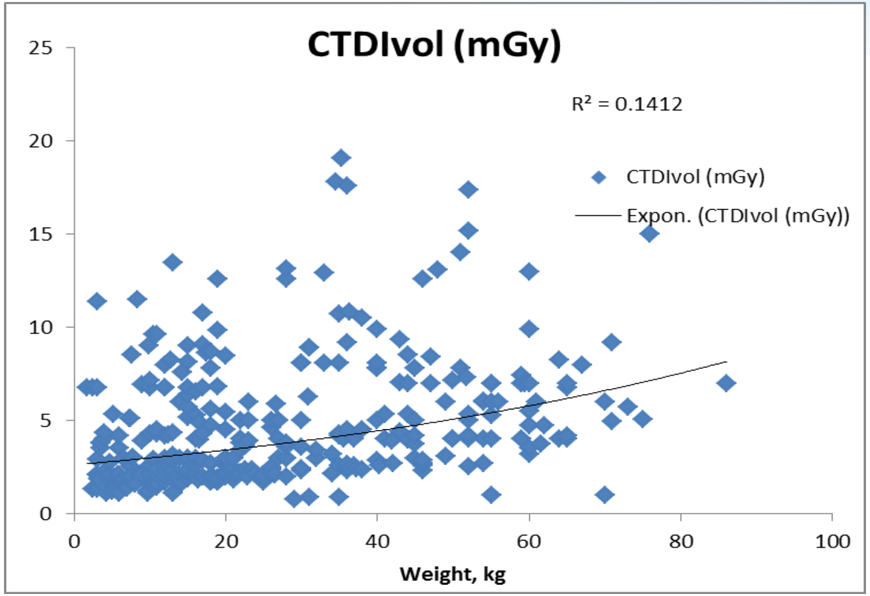


DRL-curves for CT chest, 32 cm diameter CT dosimetry phantom

Järvinen H, et al. Indication-based national diagnostic reference levels for paediatric CT: a new approach with proposed values. Radiat Prot Dosimetry. 2015 , 165(1-4):86-90.

Chest CT, all ages (332 patients)





Diagnostic reference range (DRR)

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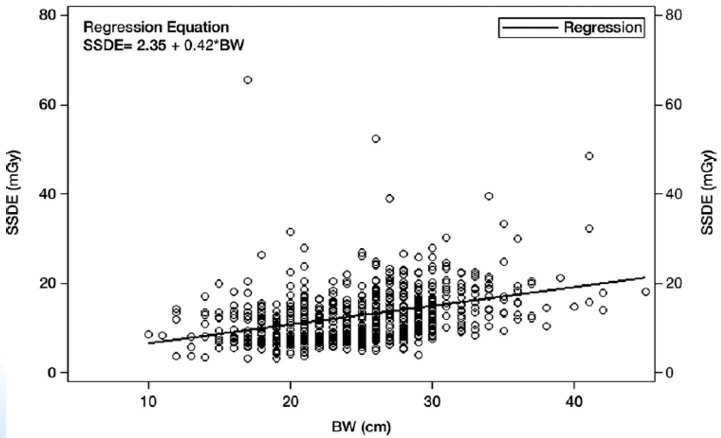
Table 3

Distribution of SSDE

BW Group	No. of Scans	Mean	Standard Error	Lower DRR, 25th Percentile	Median, 50th Percentile	Upper DRR, 75th Percentile	$SSDE/SSDE_{adult}$ Ratio
<15 cm	21	8.6	0.9	5.8	8.0	12.0	0.52
15–19 cm	153	10.0	0.5	7.3	8.7	12.2	0.61
20–24 cm	286	11.4	0.7	7.6	9.8	13.4	0.69
25–29 cm	326	13.5	0.3	9.8	13.0	16.4	0.82
⩾30 cm	168	16.5	0.4	13.1	15.6	19.0	1.00



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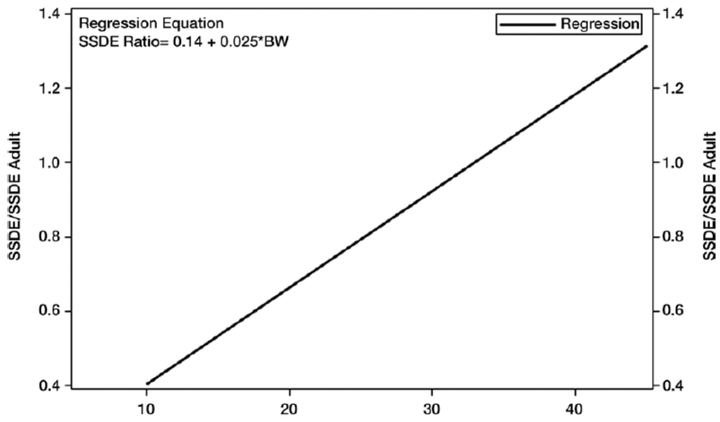

Goske MJ, et al. Diagnostic reference ranges for pediatric abdominal CT. Radiology. 2013 Jul;268(1):208-18.