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Diagnostic Reference Levels in Medical Imaging (smr3333)
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Establishing and using DRLs for optimization in dental radiology

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Objectives

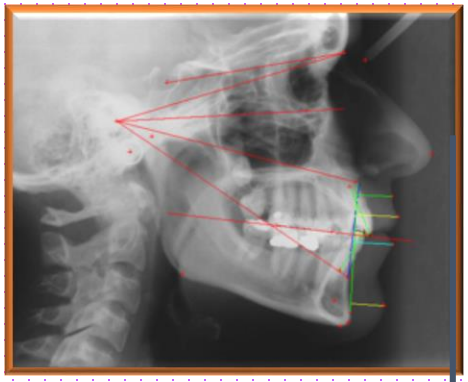
To understand

- Why the DRLs are needed in dental radiology
- What dose metrics should be used for DRLs in dental radiology
- How to collects data and establish and use DRLs in dental radiology

Dental radiography

INTRAORAL RADIOGRAPHY

CEPHALOMETRIC RADIOGRAPHY



PANORAMIC RADIOGRAPHY

CONE BEAM CT

Dental radiography examinations, their relative frequencies and contribution to collective effective dose

Examination	Percentage of total frequency of all radiography examinations (%)	Percentage contribution to collective dose (%)
Dental radiography	13	< 1

520 millions X rays procedures/year

74 per 1000 population average world

UNSCEAR, 2008

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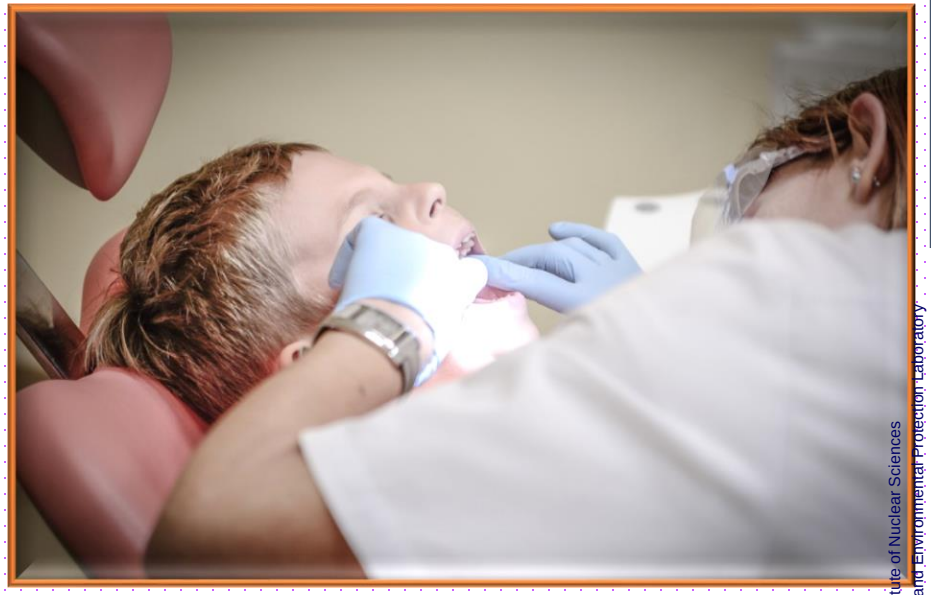
Dental imaging in children

High frequency of dental radiography examinations of children



DRL quantity for dental radiography

Modality	DRL quantity	Unit
Intraoral radiography	$K_{a,i}$	mGy
Panoramic radiography	P_{KA}	mGy cm²
Dental cone beam CT (depending on availability of the quantity)	P_{KA}	mGy cm²

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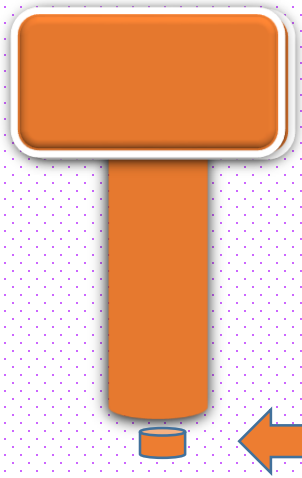
Intraoral radiography: incident air kerma

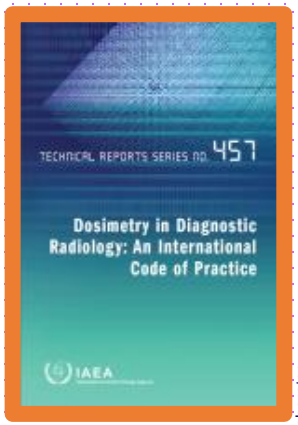
- Calibrated detector at the centre of the exit of the cone
- Sensitive volume of the detector is completely covered by the primary X ray beam
- Record the dosimeter readings and machine parameters (tube voltage and tube loading)
- Repeat for all settings used in clinical practice

$$K_{a,i}(FDD) = M \cdot N_K \cdot k_Q$$

Incident air kerma



dosimeter



For detailed information, please refer to IAEA TRS 457, https://www-pub.iaea.org/MTCD/publications/PDF/TRS457_web.pdf

Panoramic radiography: kerma area product

- P_{KA} can be measured with an ionization chamber that is attached to the X ray tube housing and intercepts the entire beam

- Pencil type chamber in front of the secondary collimator (slit)
- Exposure using standard settings of tube voltage, tube load and exposure time
- Kerma area product is obtained from the measured air kerma–length product, multiplied by the height of the X ray.

Kerma-length product

$$P_{KA} = P_{KL}\, H$$

H: height of X ray beam, as measured by the film

For detailed information, please refer to IAEA TRS 457, https://www-pub.iaea.org/MTCD/publications/PDF/TRS457_web.pdf

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Cone-beam CT: kerma-area product

- P_{KA} can be measured using an ionization chamber that is attached to the X ray tube housing and intercepts the entire beam
- P_{KA} provided by machine
- Verification/calibration is needed

Output, phantom or patients?

- Same standard exposure settings linked to the teeth being imaged are used for the majority of adults
- Measurement of output at the cone tip with the appropriate settings can be considered as the median incident air kerma or patient dose for each intra-oral dental unit
- DRL values can then be set based on the distribution of the measurements for different dental unit

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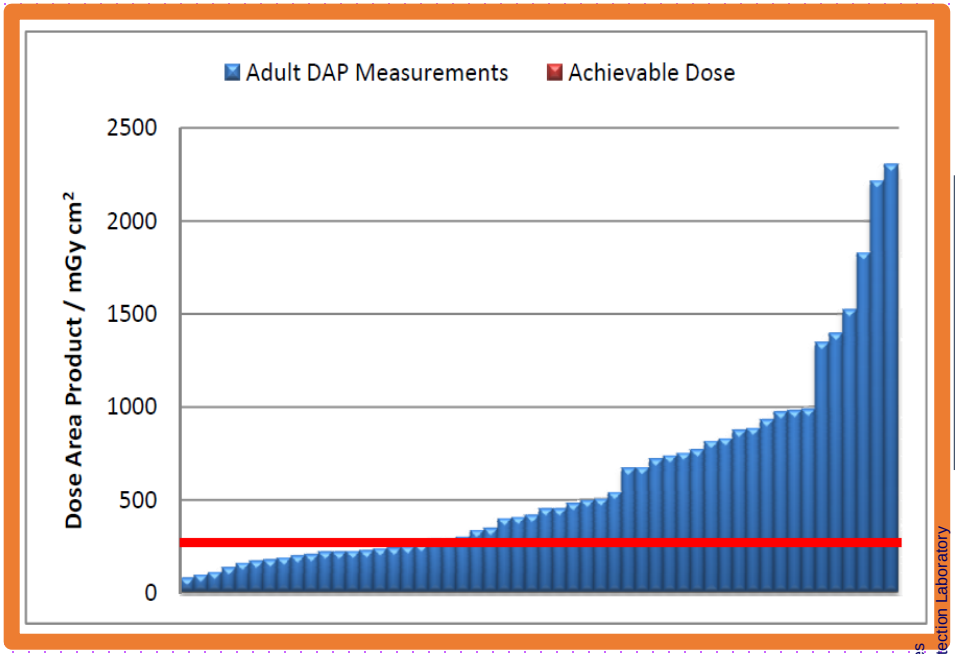
Cone-beam computed tomography in dentistry

- Intended to display high contrast objects, bone and air, with low radiation exposure compared with conventional CT
- Little progress has been made towards setting DRLs for cone beam CT



Based on a preliminary audit of KAP values on 41 dental and maxillofacial cone-beam CT units in UK proposed a tentative DRL of 250 mGy cm^2

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/348022/HPA-RPD-065_for_website.pdf

Steps to establish DRLs

Collect data in a particular X ray room

Collect only dose data for procedures where the image quality was confirmed as adequate for the clinical purpose.

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Data collection

Examination parameters

- Modality (dental radiography)
- Procedure (intra oral radiography, bitewing X rays)
- Clinical indication targeted for the examination (interdental caries)

Data collection

Examination parameters

Patient parameters

- Patient type (adult, child, emergency patients, etc.)
- Patient characteristics (gender, age, weight, etc.)

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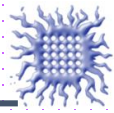
Data collection

Examination parameters

Patient parameters

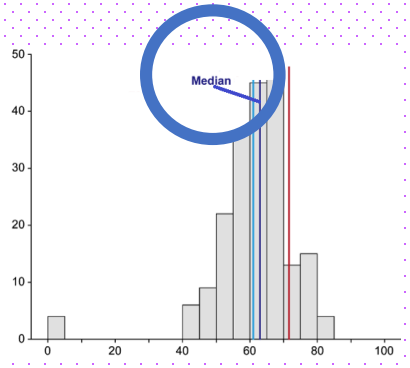
Acquisition parameters

- Specific imaging system (manufacturer and model, software version)
- Dental imaging room
- Timing of the examination (e.g. shift, period of year, etc)
- Radiographer/ technologist
- Specific imaging protocol applied in the data acquisition
- Dose indices/DRL quantity (depending on the type of the imaging procedures)



Data analysis for a given dental room or facility

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



MEDIAN VALUE

TYPICAL DOSE

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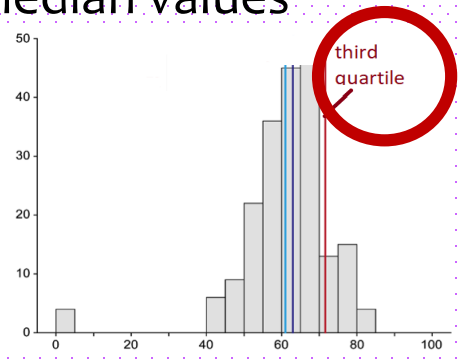
Local DRLs

- Collection of data from different 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



THIRD QUARTILE OF MEDIAN VALUES

LOCAL DRL

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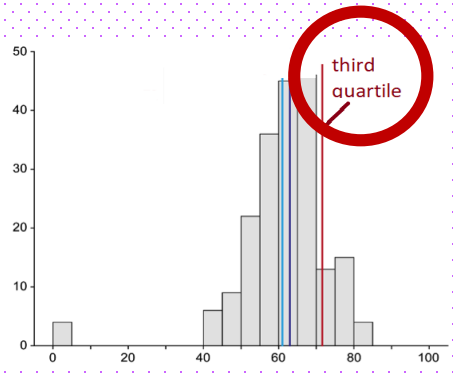
National DRLs

- Collection of data from representative sample of facilities covering an entire country
- Statistical description: Minimum, Maximum, Average, Standard deviation, Median
  of typical doses from different hospital
- National DRL: Third quartile of median values



THIRD QUARTILE OF MEDIAN VALUES

NATIONAL DRL

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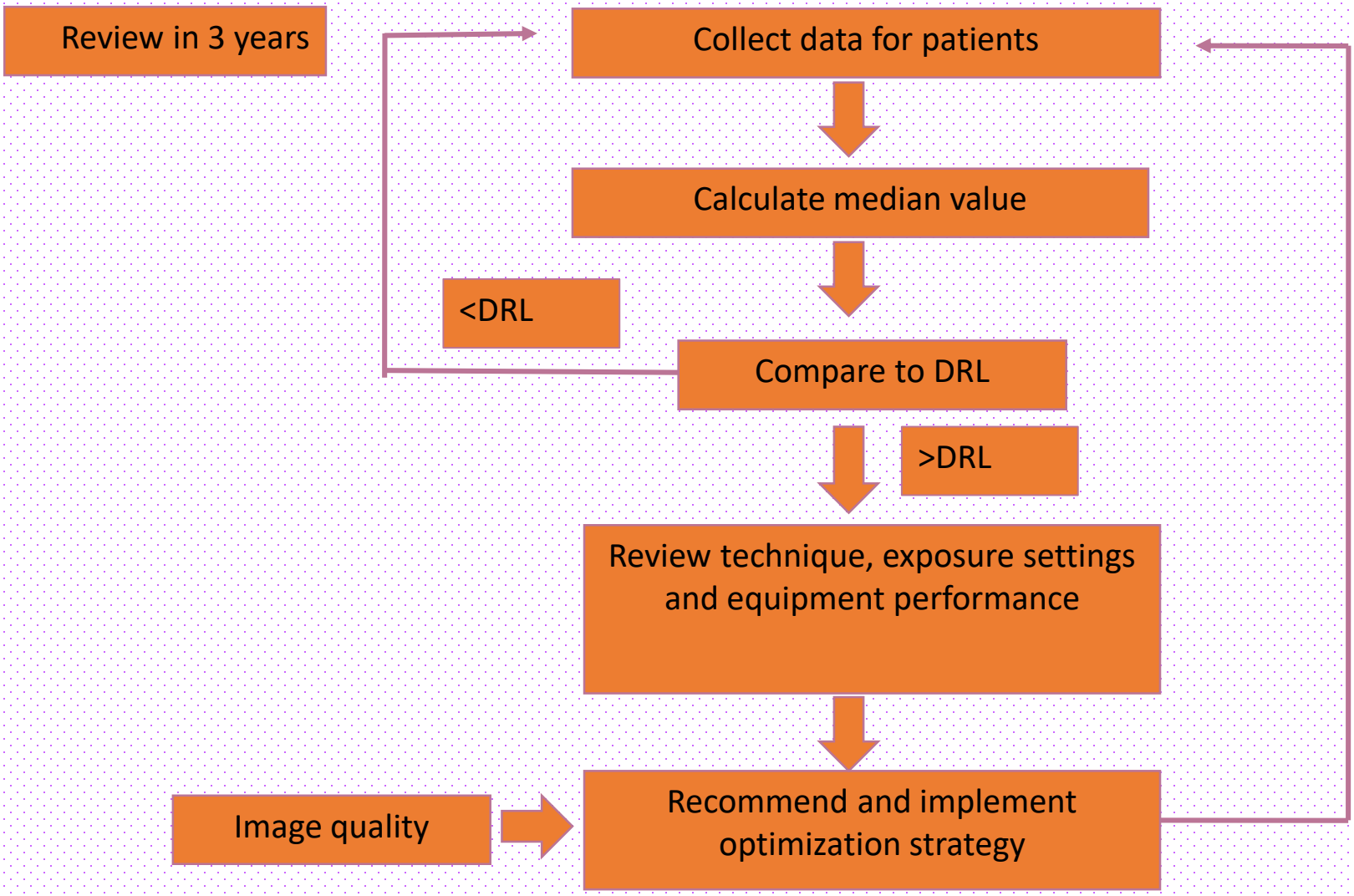
Patient doses in different dental modalities

Table 2. The values of DAP in dental radiography (mGy·cm^2).

	Molar	Premolar	Incisor	Panoramic	Cephalometric	CBCT
Mean	49.2	42.0	33.6	98.2	144.5	1972 (15 × 15.2 cm)
Maximum	281.0	244.0	211.0	206.0	550.0	3960.0
Minimum	6.0	3.0	3.0	40.0	23.0	476.0
Third quartile	55.5	46.0	36.5	120.3	146	3203 (18 × 16.2 cm)
Standard deviation	57.3	51.2	42.9	38.0	118.0	1182.0
Number of units	49	49	49	42	24	14

Han S, et al. Dose area product measurement for diagnostic reference levels and analysis of patient dose in dental radiography. Radiat Prot Dosimetry. 2012 Jul;150(4):523-31.

Use of DRLs in dental radiology



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Example: DRLs for dental imaging

Table 7. Comparative results of research for DRLs in dental radiography (previous literature and this study).

No.	Researcher (country, year)	Radiography	Dose quantity	
1	Teunen *et al.* (Denmark, 1995)[21]	Mandibula incisor	3.5 mGy	CED
2	Gonzalez *et al.* (Spain, 2001)[22]	—	3.5 mGy	ESD
3	IPEM (UK, 2002)[23]	Mandibula molar	2.1 mGy	ESD
4	CRCPD (2003)[24]	—	2.2 mGy	ESAK
5	Gulson *et al.* (HPA, 2005)[13]	—	2.3 mGy	PED
6	Looe *et al.* (Germany 2005)[8]	Maxillary molar	48.8 mGy cm^2	DAP
7	Poppe *et al.* (Germany, 2007)[6]	Maxillary molar	61.5 mGy cm^2	DAP
8	Brendan *et al.* (Irish, 2008)[25]	Maxillary molar	2.3 mGy	ESD
9	Han *et al.* (Korea, 2009)[11]	Mandibula molar	3.2 mGy	ESD
10	KFDA report (Korea, 2009)[10]	Mandibula molar	59.4 mGy cm^2	DAP
11	Tierris *et al.* (Greece, 2004)[9]	Panoramic	117 mGy cm^2	DAP
12	Gulson *et al.* (HPA, 2005) [13]	Panoramic	89 mGy cm^2	DAP
13	Gulson *et al.* (HPA, 2005)[13]	Panoramic	60 mGy mm	DWP
14	Poppe *et al.* (Germany, 2006)[7]	Panoramic	87 mGy cm^2	DAP
15	KFDA report (Korea, 2009)[10]	Panoramic	110.9 mGy cm^2	DAP
16	Kim *et al.* (Korea, 2009)[12]	Panoramic	106.7 mGy mm	DWP
17	CRCPD (2003)[24]	Cephalometric	0.2 mGy	ESAK
18	KFDA report (Korea, 2009)[6]	Cephalometric	161.1 mGy cm^2	DAP
	This study (Korea, 2011)	Maxillary molar	55.5 mGy cm^2	DAP
		Maxillary premolar	46 mGy cm^2	DAP
		Maxillary incisor	36.5 mGy cm^2	DAP
		Panoramic	120.3 mGy cm^2	DAP
		Cephalometric	146 mGy cm^2	DAP
		CBCT	3203 mGy cm^2 (16 × 18 cm)	DAP

IPEM, Institute of Physics and Engineering in Medicine; CRCPD, conferences of radiations control program directors; CED, cone and dose; ESD, entrance surface dose; DWP, dose with product.

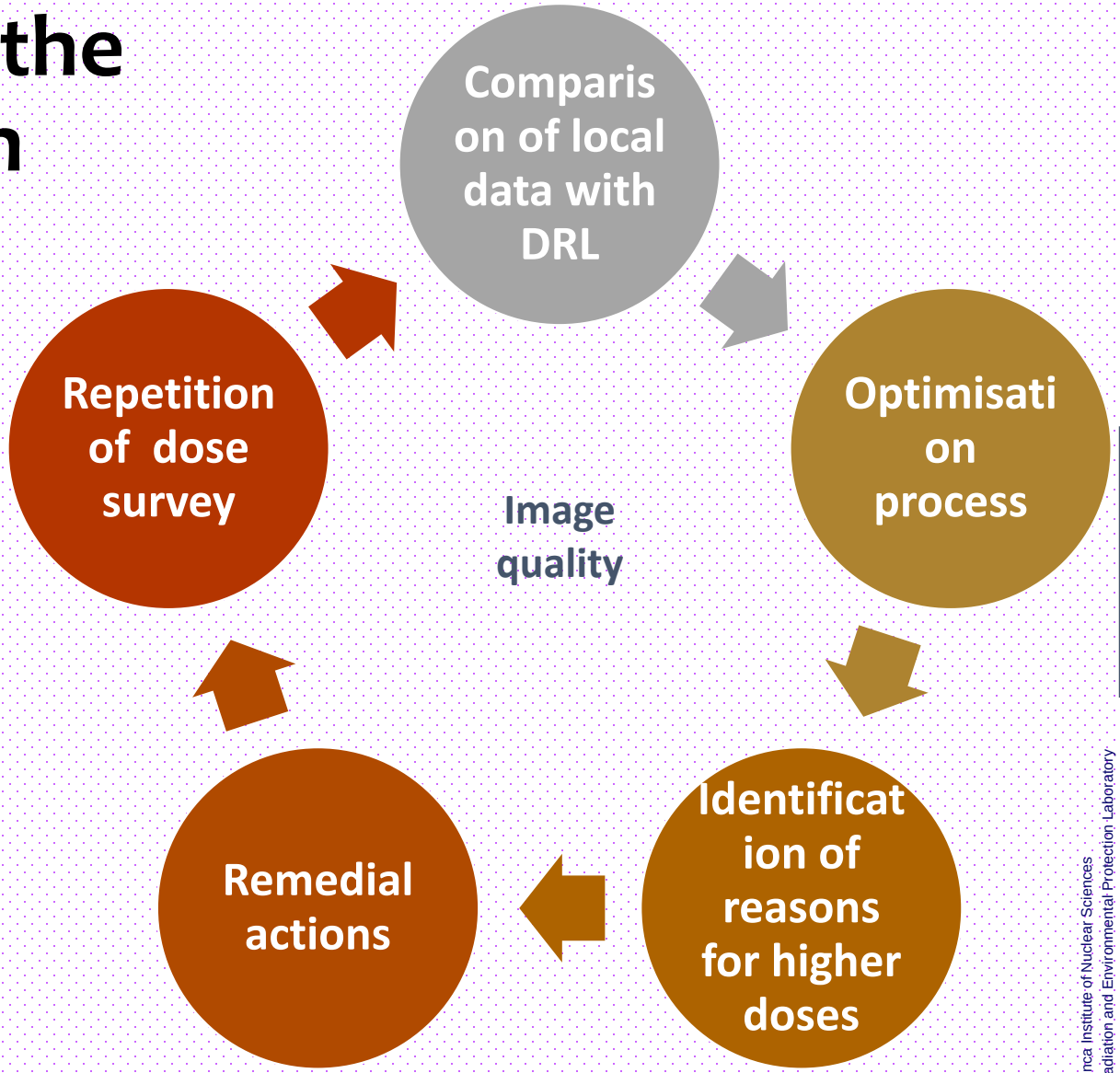
Han S, et al. Dose area product measurement for diagnostic reference levels and analysis of patient dose in dental radiography. Radiat Prot Dosimetry. 2012 Jul;150(4):523-31

DRLs in dental radiology

Modality	Entrance surface dose (mGy)	Dose-area product (mGy cm^2)
Intraoral	0.65-3.7	26.2-87.4
Panoramic	0.66-4.2	67-120.3
Cephalometric	-	33-146

European Commission. Radiation Protection Report 136, Luxembourg 2004
Manousaridis G, et al. Radiat Prot Dosim 2013;156(4):455–7.
Manousaridis G, et al. Radiat Prot Dosim 2015;165(1–4):111–4.

Outcome of the investigation



Use of DRLs in dental radiography

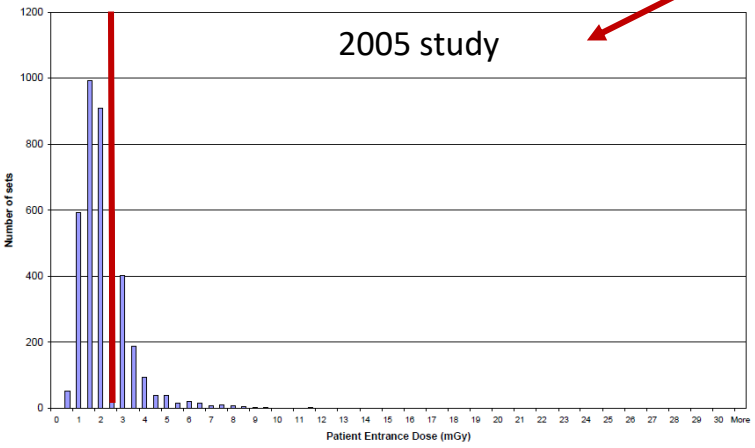
- Dentists should be aware how their average doses
- Requirement of the medical physics expert
- These assessments should be
  - Carried out on a regular basis, at least every 3 years or as required by national legislation
  - Seen to be a part of QA programme

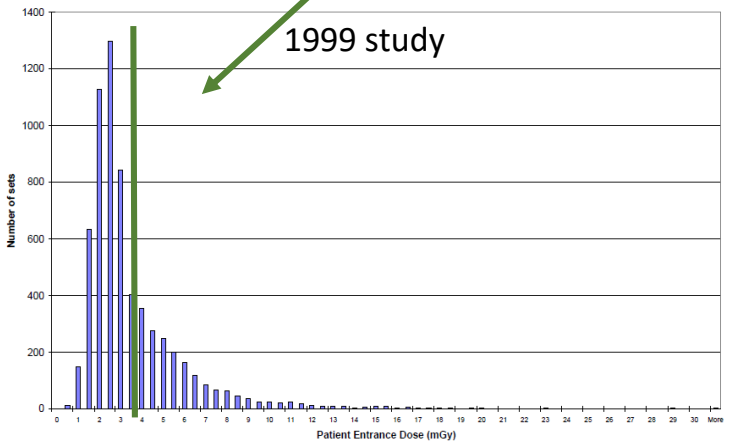
Example: DRLs in dental radiography

TABLE 1 Comparison of intra oral dose data

Parameter	Assessed Value	
	2005 study	1999 study
Highest dose, mGy	30.0	45.7
Lowest dose, mGy	0.05	0.14
Third quartile dose, mGy	2.4	3.9
Mean dose, mGy	1.9	3.3
Sample size	4006	6344

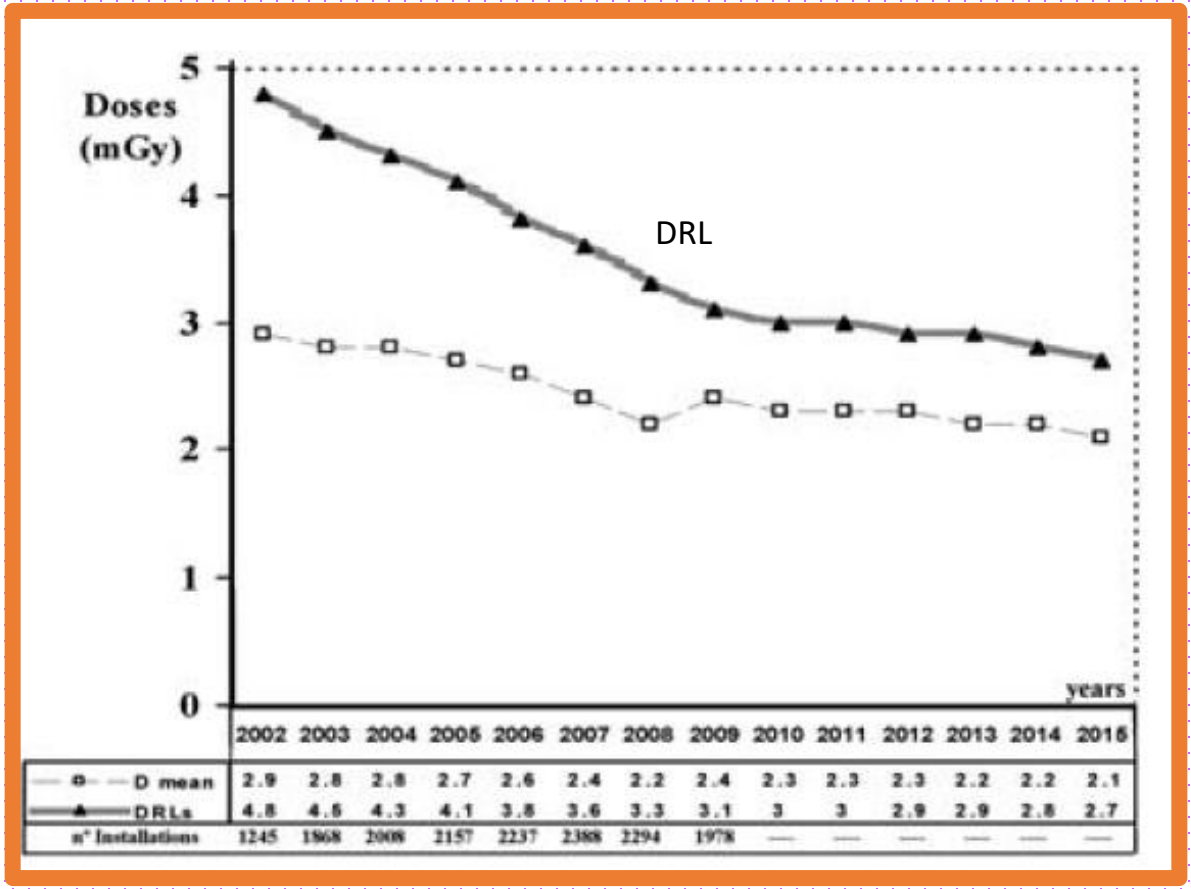
Note: the difference in sample sizes is due to variations in workload over the two periods of study.





Gulson, A.D., Knapp, T.A., Ramsden, P.G., 2007. Doses to Patients Arising from Dental Xray Examinations in the UK 2002–2004. A Review of X-ray Protection Service Data. HPARPD-022. Health Protection Agency, Chilton.

Evolution of DRLs



Alcaraz, M., et al. Evolution of diagnostic reference levels in Spanish intraoral radiology. Radiation Protection Dosimetry (2012), Vol. 151, No. 1, pp. 166–171

Intraoral dental radiography

Indonesia, 71 healthcare institutions involving a total of 92 dental X ray devices

Low dose: pediatric, small or incisor
High dose: large adult, premolar or molar

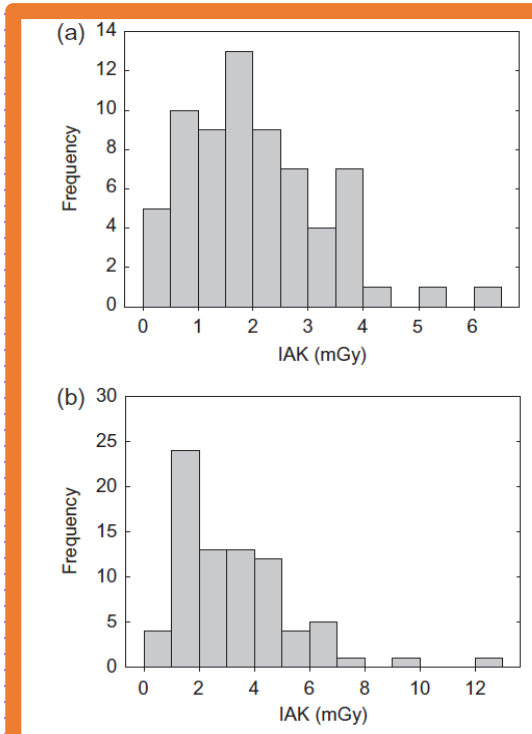


Figure 3. Measurement result as IAK in intraoral dental radiography devices under (**a**) low dose modes and (**b**) high dose modes.

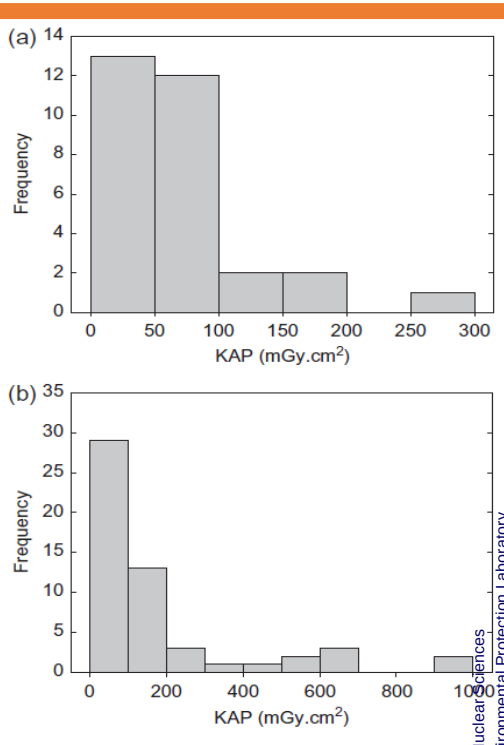


Figure 4. Measurement result as KAP in panoramic dental radiography devices under (**a**) low dose modes and (**b**) high dose modes.

Lubis LE, et al. Radiation dose from dental radiography in Indonesia: a five-year survey. Radiat Prot Dosimetry. 2018

Example: Radiation dose in intraoral radiography

Table 2 Exposure times and patient entrance doses (PEDs) for the periapical bisecting technique

Site	Sex	Patient (*n*)	Exposure time (s)[a]		Current-exposure time product (mAs)	PED (mGy)[b]
Maxillary incisors	Male	71	0.27 ± 0.05	0.26 ± 0.04 (0.32)	1.80	1.56 ± 0.2 (1.93)
	Female	98	0.25 ± 0.04			
Maxillary premolars	Male	38	0.34 ± 0.07	0.32 ± 0.06 (0.40)	2.23	1.92 ± 0.3 (2.42)
	Female	66	0.31 ± 0.06			
Maxillary molars	Male	80	0.41 ± 0.07	0.40 ± 0.06 (0.40)	2.80	2.42 ± 0.3 (2.42)
	Female	103	0.39 ± 0.04			
Mandibular incisors	Male	12	0.17 ± 0.02	0.18 ± 0.05 (0.20)	1.26	1.09 ± 0.3 (1.21)
	Female	18	0.19 ± 0.06			
Mandibular premolars	Male	43	0.21 ± 0.04	0.21 ± 0.04 (0.25)	1.47	1.27 ± 0.2 (1.51)
	Female	70	0.21 ± 0.04			
Mandibular molars	Male	99	0.27 ± 0.04	0.26 ± 0.03 (0.25)	1.84	1.59 ± 0.2 (1.51)
	Female	122	0.25 ± 0.02			

No significant difference between male and female.

[a] Mean exposure time ± standard deviation with 75th percentile in parentheses.

[b] Mean patient entrance dose ± standard deviation with 75th percentile in parentheses. The 75th percentile is the initial value of the local diagnostic reference level

Izawa M. Establishment of local diagnostic reference levels for quality control in intraoral radiography. Oral Radiol. 2017;33(1):38-44

Example: Greek DRLs for intraoral radiography

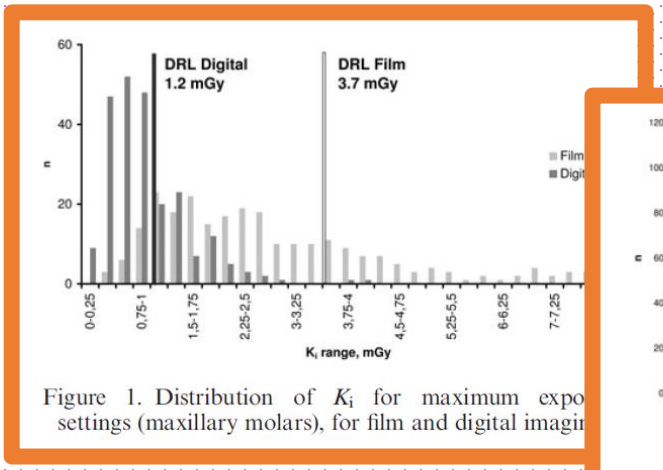


Figure 1. Distribution of K_i for maximum expo
settings (maxillary molars), for film and digital imagi

maxillary molars

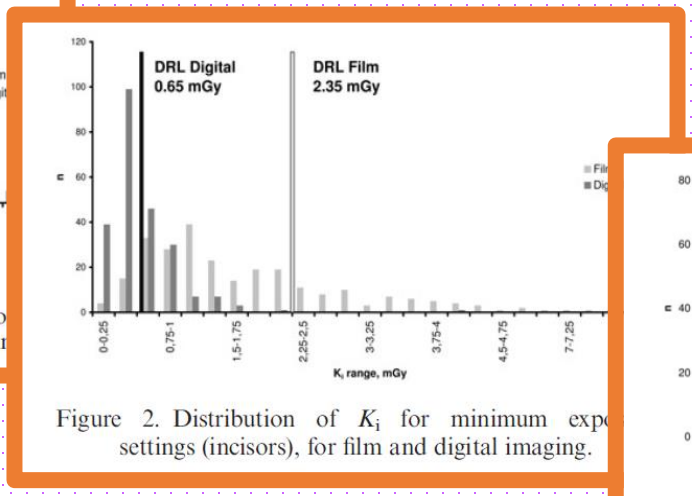


Figure 2. Distribution of K_i for minimum exp
settings (incisors), for film and digital imaging.

incisors

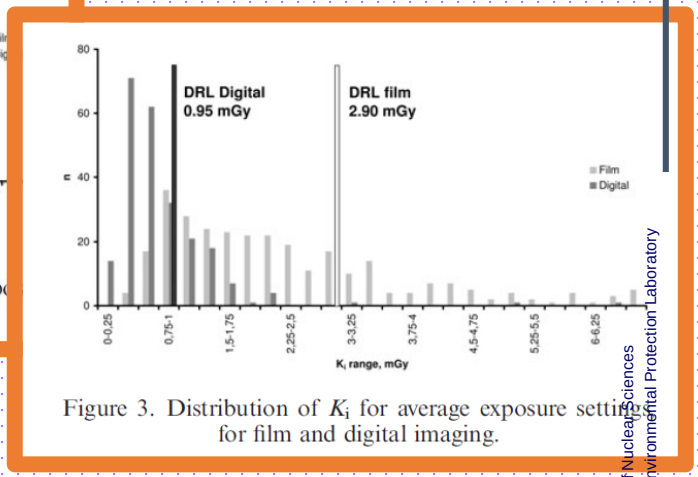


Figure 3. Distribution of K_i for average exposure setti
for film and digital imaging.

all the exposure settings

Manousaridis G, et al. Establishment of diagnostic reference levels for dental intraoral radiography. Radiat Prot Dosimetry. 2013 Oct;156(4):455-7

Example: DRLs for intraoral radiography, adults vs children

52 intraoral X ray units at
45 dentists in Germany

Table 1. Third quartiles and means of the DAP values for only child exposure settings and DAP values including adult exposure settings along with the percentage difference between both.

Examinations	3rd quartile[a] (mGy cm^2)	3rd quartile[b] (mGy cm^2)	Difference in 3rd quartile (%)	Mean[a] (mGy cm^2)	Mean[b] (mGy cm^2)	Difference in mean (%)
Maxillary molar	40.9	48.8	19.3	29.7	39.1	31.6
Maxillary premolar	27.7	37.6	35.7	19.7	27.1	37.6
Maxillary canine	23.6	33.6	42.4	18.3	23.6	29.0
Maxillary incisor	22.0	32.0	45.5	17.1	24.3	42.1
Mandibular molar	27.8	35.0	25.9	19.9	25.9	30.2
Mandibular premolar	18.9	24.4	29.1	14.6	19.8	35.6
Mandibular canine	18.9	24.4	29.1	14.6	19.6	34.2
Mandibular incisor	14.4	20.6	43.1	12.0	18.1	50.8
BTW: front	39.8	41.6	4.5	28.0	29.1	3.9
BTW: back	41.7	41.9	0.5	29.9	30.4	1.7
OCC: maxilla	56.9	56.9	0	51.9	47.8	−7.9
OCC: mandible	44.2	44.2	0	40.8	37.1	−9.1

[a]Only child exposure
[b]Included adult exp
BTW, bitewing; OCC, oc

Looe HK, et al. Radiation exposure to children in intraoral dental radiology. Radiat Prot Dosimetry. 2006;121(4):461-5.

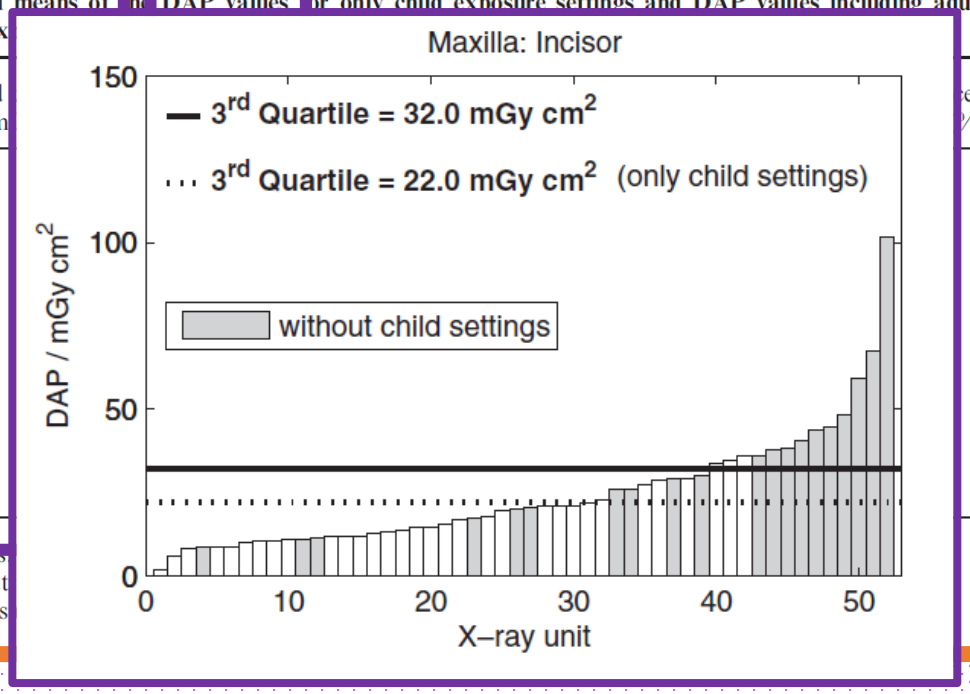
Example: DRLs for intraoral radiography, adults vs children

52 intraoral X ray units at
45 dentists in Germany

Table 1. Third quartiles and means of the DAP values for only child exposure settings and DAP values including adult ex

Examinations	3rd (m
Maxillary molar	
Maxillary premolar	
Maxillary canine	
Maxillary incisor	
Mandibular molar	
Mandibular premolar	
Mandibular canine	
Mandibular incisor	
BTW: front	
BTW: back	
OCC	
OCC	

[a]Only child exposure settings
[b]Included adult exposure sett
BTW, bitewing; OCC, occlus



Looe HK, et al. Radiation exposure to children in intraoral dental radiology. Radiat Prot Dosimetry. 2006;121(4):461-5.

Different image receptors

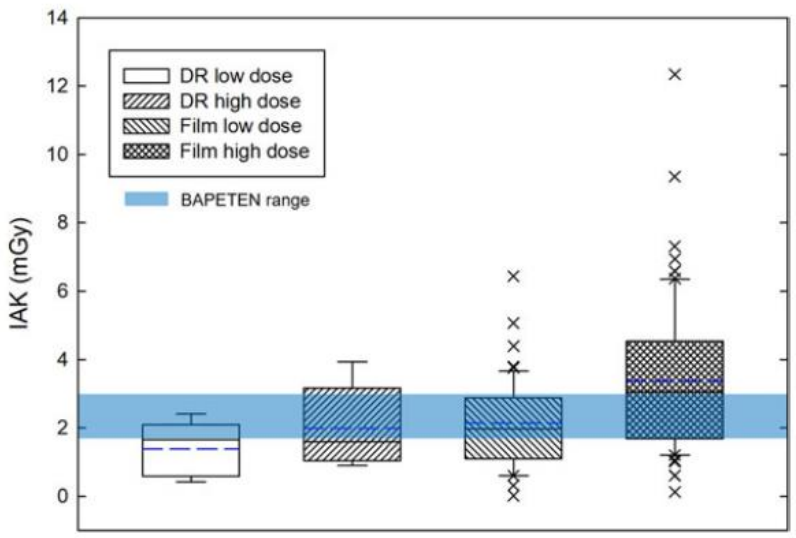


Figure 5. Incident air kerma (IAK) of intraoral devices by modes and image receptors used.

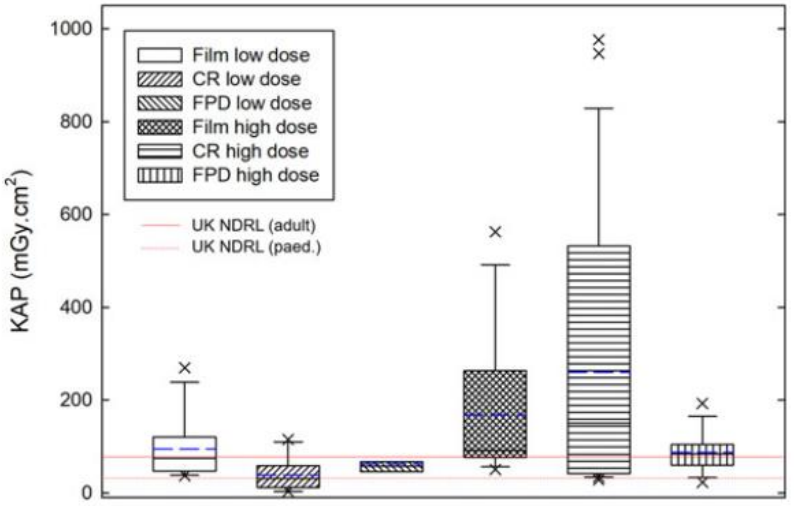


Figure 6. Air kerma area product (KAP) of the panoramic devices by modes and image receptors used.

Low dose: pediatric, small or incisor
High dose: large adult, premolar or molar

Lubis LE, et al. Radiation dose from dental radiography in Indonesia: a five-year survey. Radiat Prot Dosimetry. 2018

Example: national DRLs for panoramic radiography

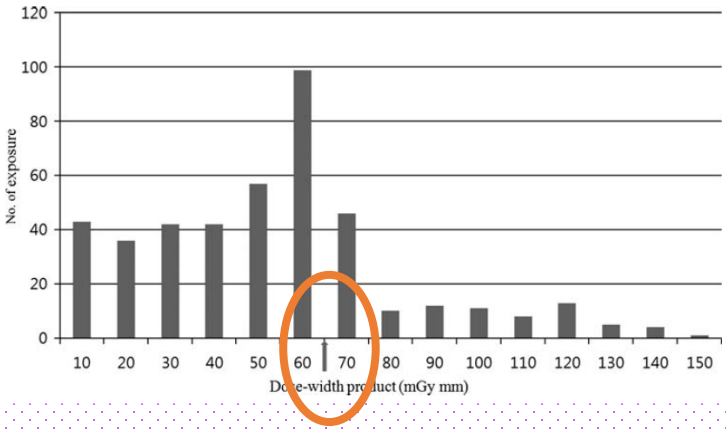
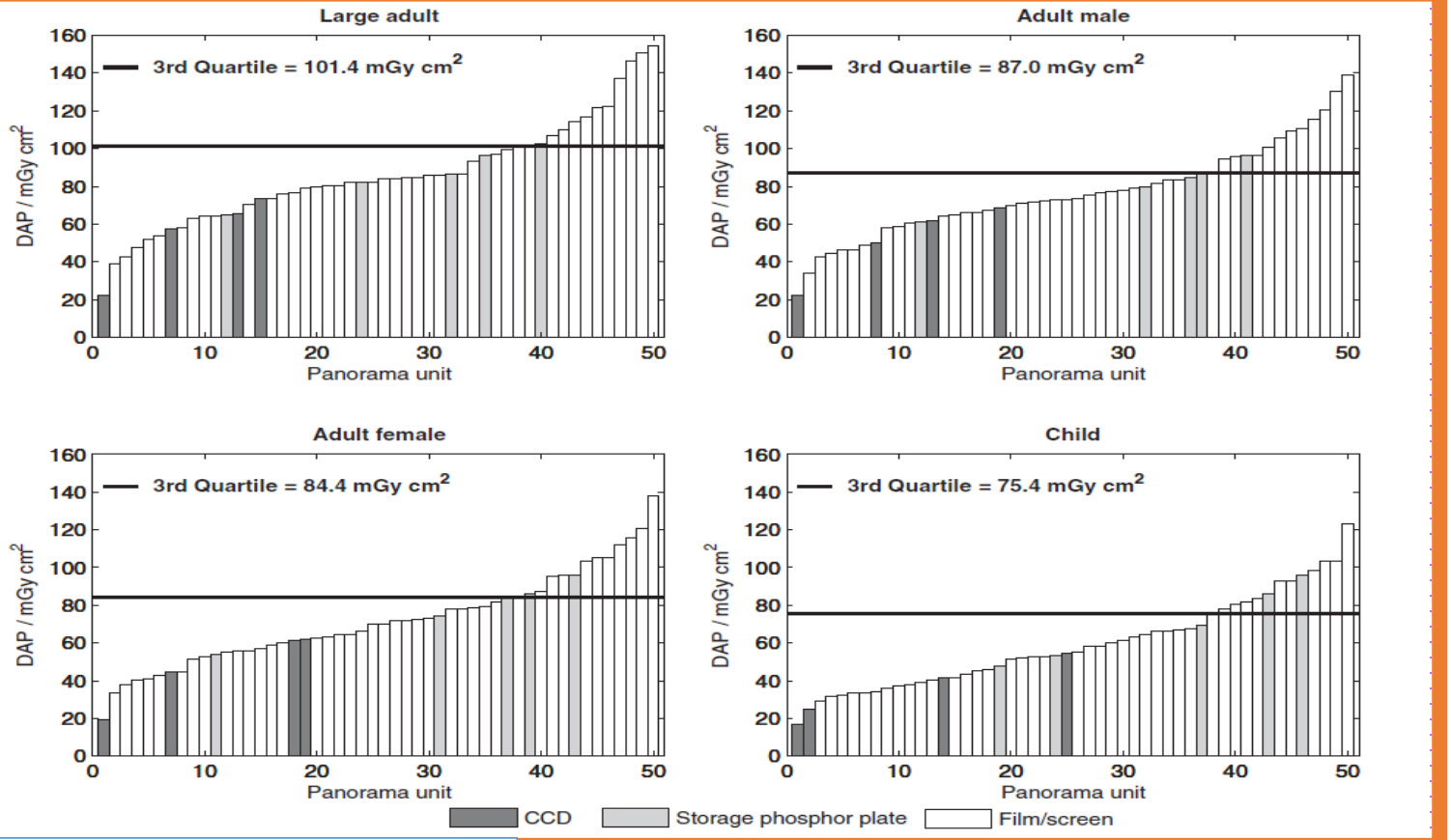


Table 3. DWP of the 429 patients for panoramic radiography.

Panoramic units/gender	Number of measurement	Mean (mGy mm)	Lowest (mGy mm)	Highest (mGy mm)	Third quartile (mGy mm)
Digital/male	180	49.5	1.3	148.9	60.5
Digital/female	199	41.7	0.8	130.1	54.9
Analogue/male	21	82.3	55.8	118.8	100
Analogue/female	29	58.4	27.1	118.6	64.4
Overall	429	47.7	0.8	148.9	60.1

Lee, JS, et al. Reference dose levels for dental panoramic radiography in Gwangju, South Korea. Radiat Prot Dosimetry. 2010, 142(2-4):184-90

Example: DRLs in panoramic radiography for different patient categories



50 panoramic units of different vendors in North German dental facilities

Poppe B, at al. Dose-area product measurements in panoramic dental radiology. Radiat Prot Dosimetry. 2007;123(1):131-4.

Radiation dose in CBCT

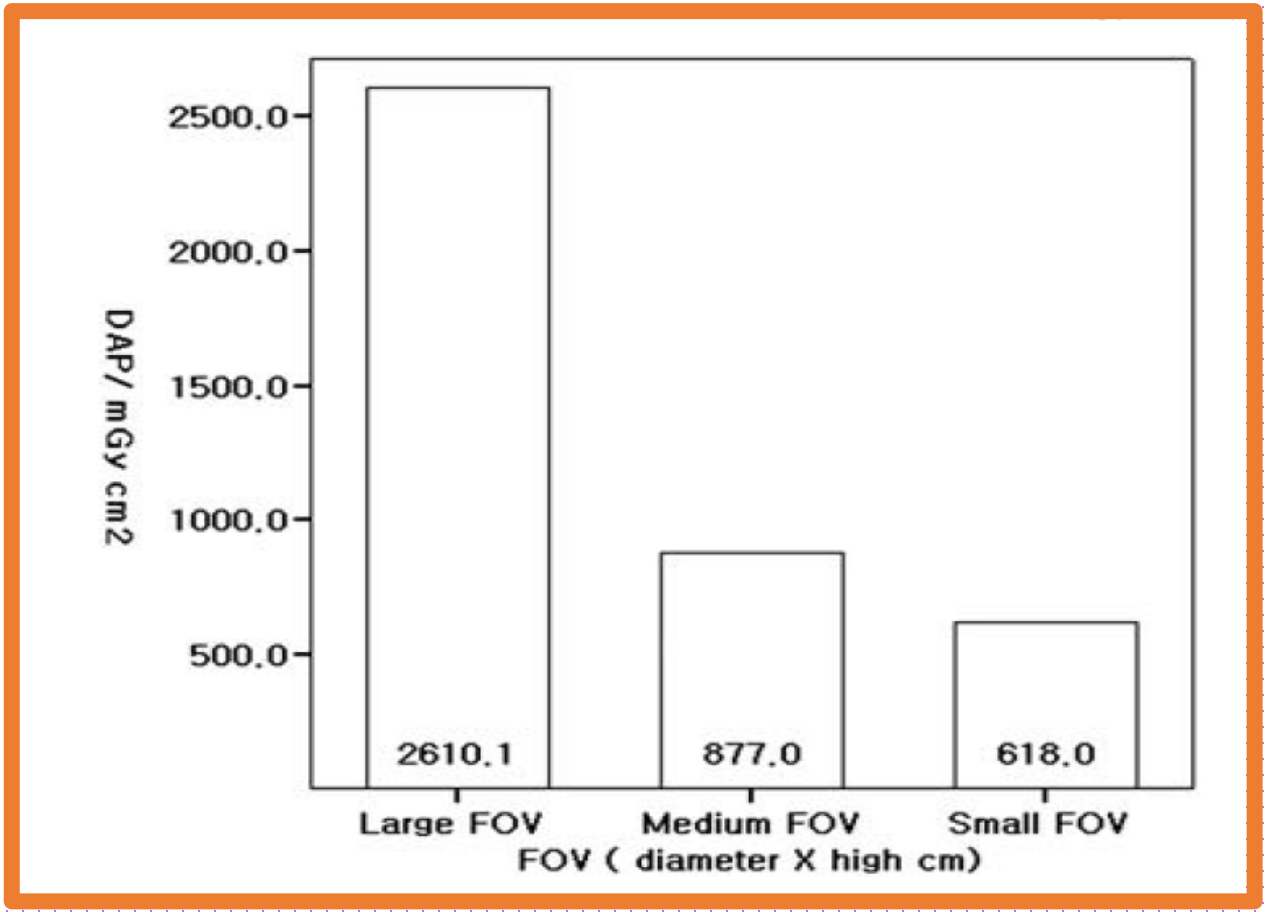
Table 2 Air dose values and DAP values from different cone beam CT units

Dental office	Model	Tube potential (kV)	Current (mA)	Exposure time(s)	Measured length (cm)	Area (cm^2)	Air dose (mGy)		DAP (mGy cm^2)
							Mean	Standard deviation	
1	A	90	5	9	6.7 × 6.8	45.6	2.78	0.10	126.7
2	A	90	4	17.5	6.9 × 6.5	44.9	3.58	0.27	160.6
3	A	90	5	9	6.9 × 6.8	46.9	4.79	0.45	224.7
4	A	90	5	17.5	6.8 × 6.8	46.2	5.87	0.32	271.4
5	A	90	5	17.5	7.0 × 6.8	47.6	7.55	0.31	359.4
6	B	70	10	10.8	6.0 × 4.9	29.4	10.08	0.28	296.4
7	B	74	10	10.8	5.9 × 4.8	28.3	9.19	0.67	260.3
8	B	70	10	10.8	6.2 × 5.0	31.0	9.11	0.43	282.4
9	C	80	5	9.4	6.8 × 6.5	44.2	6.63	0.33	293.0
10	C	80	5	9.4	7.0 × 6.6	46.2	6.43	0.99	297.1
11	C	80	5	9.4	6.9 × 6.5	44.9	7.28	0.89	326.5
12	C	80	5	9.4	6.9 × 6.6	45.5	7.17	0.88	326.5
13	C	80	5	9.4	7.0 × 6.6	46.2	7.61	0.20	351.6
14	D	84	12	12	8.1 × 8.1	65.6	6.14	0.36	402.8
15	D	84	12	12	8.4 × 8.7	73.1	5.67	0.65	414.4
16	D	84	12	12	8.0 × 8.3	66.4	6.46	1.04	428.9
17	D	84	12	12	8.1 × 8.2	66.4	6.64	0.46	441.0
18	D	84	12	12	8.2 × 9.4	77.1	6.49	0.54	500.2
19	E	85	4	17	9.7 × 9.6	93.1	10.33	0.56	961.9
20	E	85	6	17	9.5 × 9.8	93.1	13.11	0.99	1220.5
21	E	85	6	17	9.7 × 9.8	95.1	15.53	0.56	1476.9

DAP, dose–area product.
Models: A, 3D Accuitomo (J Morita, Kyoto, Japan); B, Kodak 9000 3D (Trophy, Croissy-Beaubourg, France); C, Veraviewepocs3D (J Morita); D, ProMax 3D (Planmeca OY, Helsinki, Finland); E, AZ3000 (Asahi Roentgen Industry, Kyoto, Japan).

Endo, A, et al. A preliminary study to determine the diagnostic reference level using dose-area product for limited-area cone beam CT. Dentomaxillofac Radiol. 2013;42(4):20120097.

Why we need the Field of View (FOV) in the dental CBCT?



Han S, et al. Dose area product measurement for diagnostic reference levels and analysis of patient dose in dental radiography. Radiat Prot Dosimetry. 2012 Jul;150(4):523-31.

Field of View (FOV) and resolution in the dental CBCT?

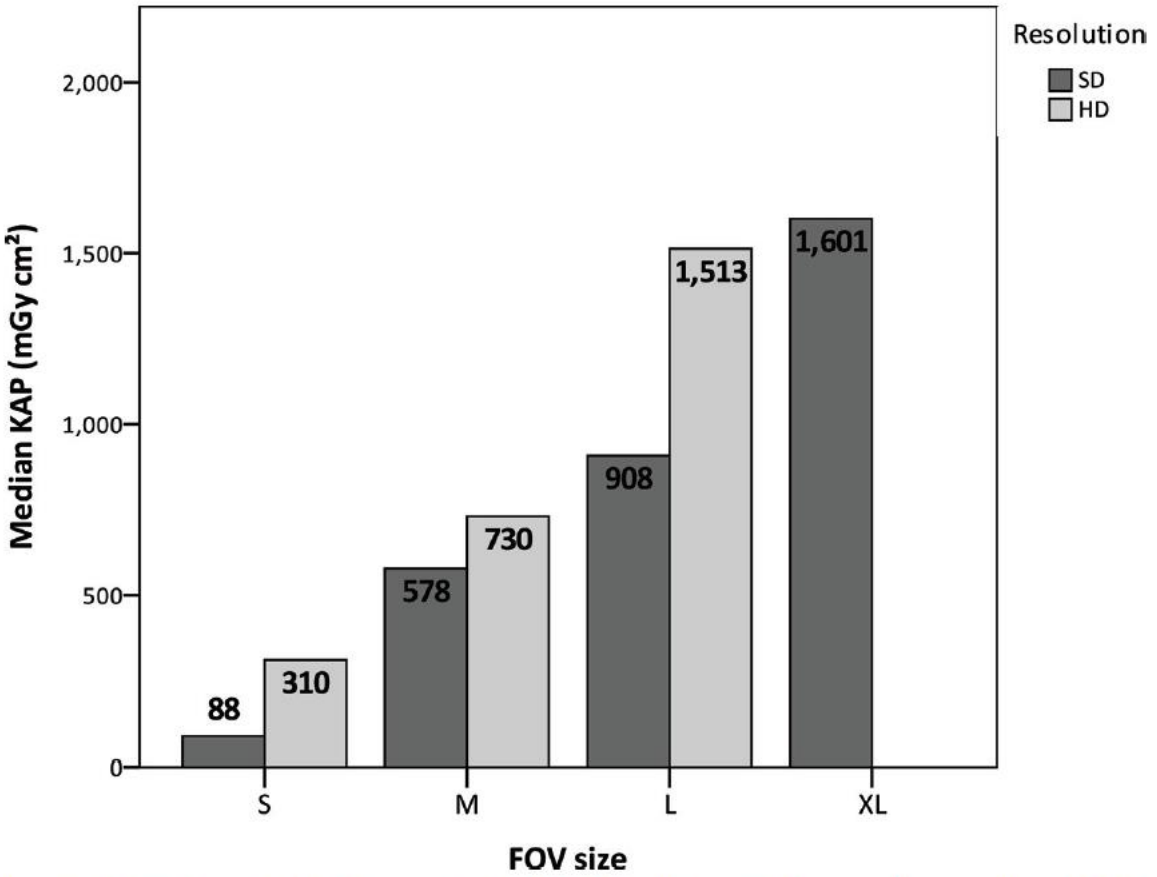


Figure 7 Median values of air kerma–area product (mGy cm²) for different FOV sizes and two resolution modes—HD (voxel size <0.2 mm) and SD (voxel size ≥0.2 mm) in 15 different institutions from four countries. FOV,field of view; HD, high definition; SD, standard definition.

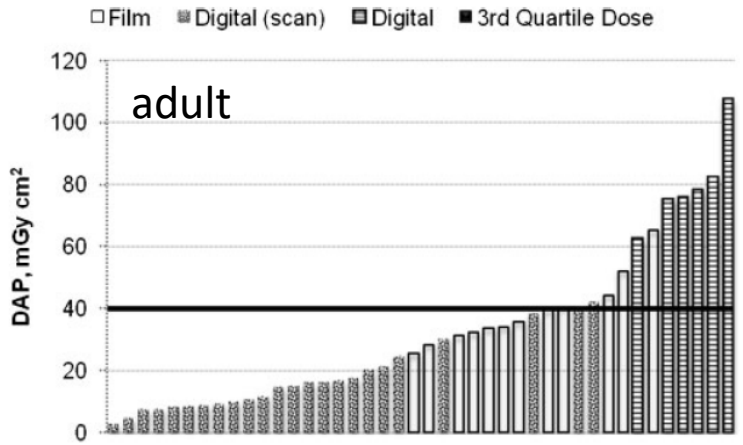
Baganovic, et al. IAEA survey of dental cone beam computed tomography practice and related patient exposure in nine Central and Eastern European countriesDentomaxillofacial Radiology (2019) 48, 20190157

Example: UK national DRLs for cephalometric radiography

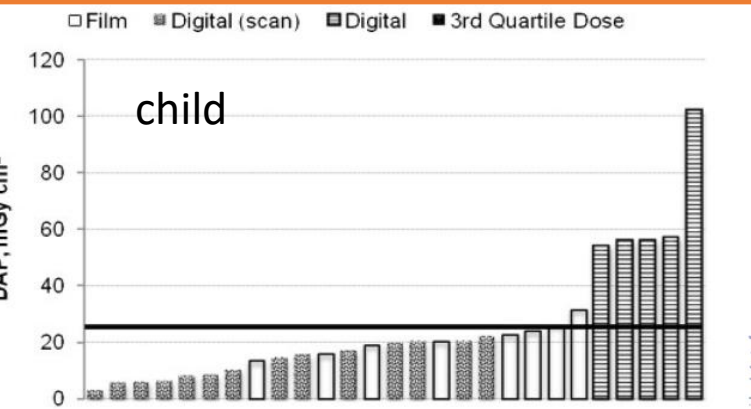
Table 2. Summary of lateral cephalometric dose data

	Adult	Child
No. of X-ray sets	42	27
Minimum dose (mGy)	0.07	0.03
Maximum dose (mGy)	2.85	2.21
Minimum beam size (cm^2)	6	6
Maximum beam size (cm^2)	832	832
Minimum DAP (mGy cm^2)	3	3
Maximum DAP (mGy cm^2)	108	102
Mean DAP	32	25
Third quartile DAP	41	25

DAP, dose–area product.



Cephalometric equipment can typically be operated in two modes: lateral and anteroposterior



Holroyd JR, National reference doses for dental cephalometric radiography. Br J Radiol. 2011 Dec;84(1008):1121-4.

Example: UK national DRLs for cephalometric radiography

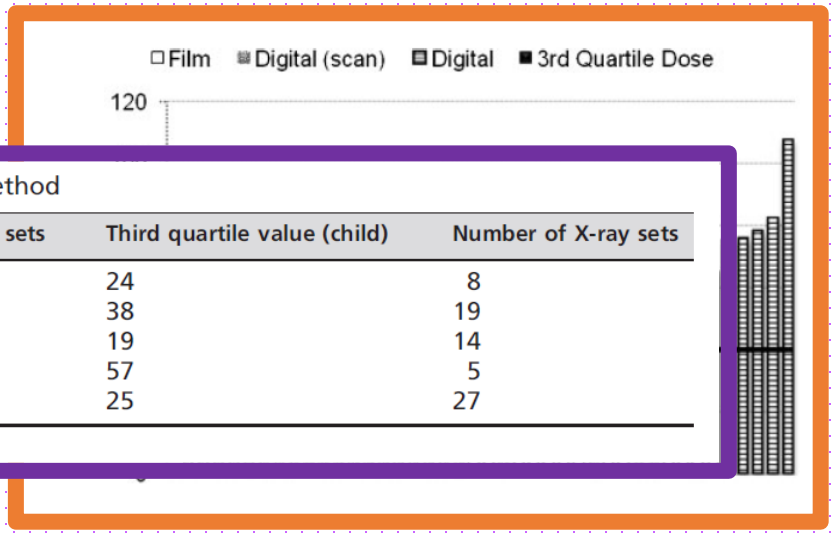
Table 2. Summary of lateral cephalometric dose data

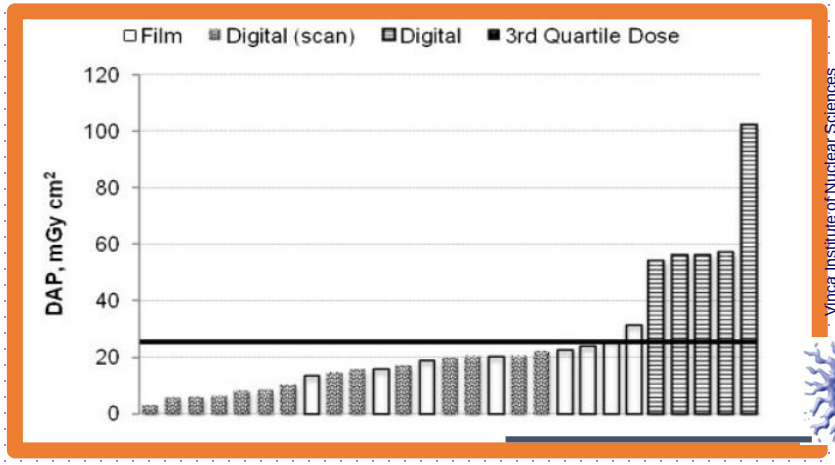
	Adult	Child
No		
Mi		
Ma		
Mi		
Ma		
Mi		
Ma		
Me		
Th		

DAP, dose–area product.

Table 3. Third quartile dose values, separated by image capture method

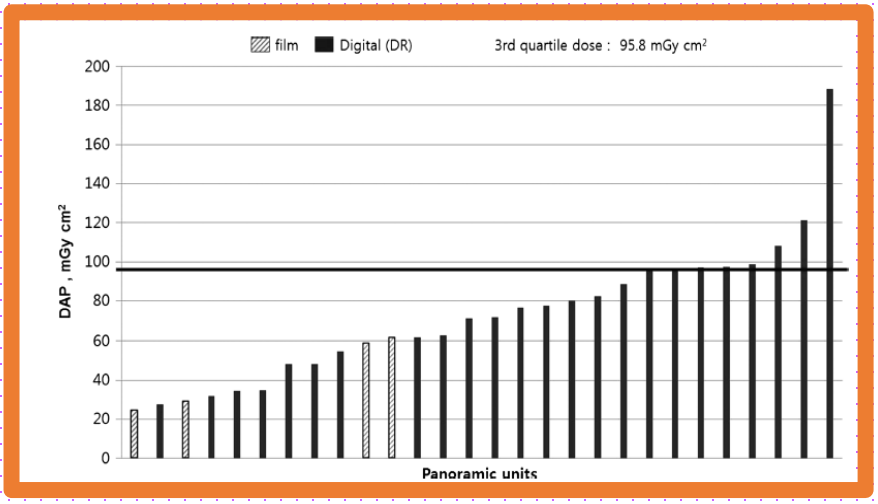
Imaging system	Third quartile value (adult)	Number of X-ray sets	Third quartile value (child)	Number of X-ray sets
Film	42	12	24	8
All digital	40	30	38	19
Digital (scanning)	20	24	19	14
Digital (static)	81	6	57	5
All	41	42	25	27

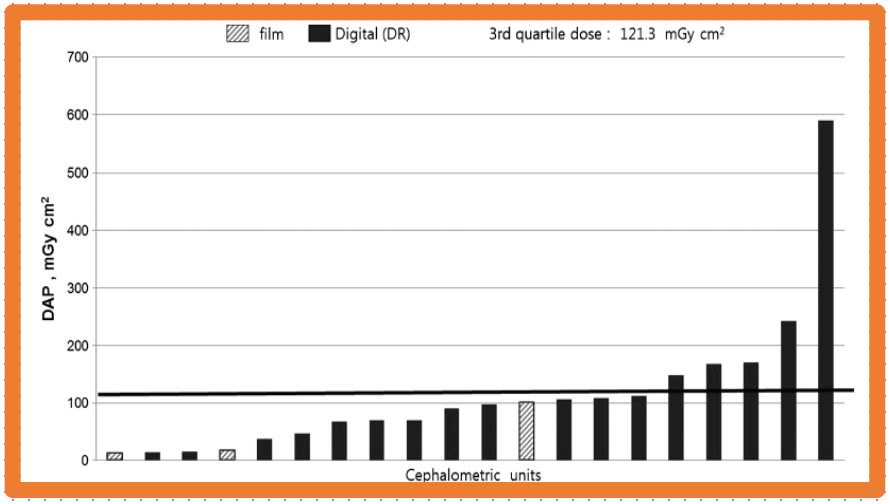




Holroyd JR, National reference doses for dental cephalometric radiography. Br J Radiol. 2011 Dec;84(1008):1121-4.

DRLs for panoramic and cephalometric radiography in children



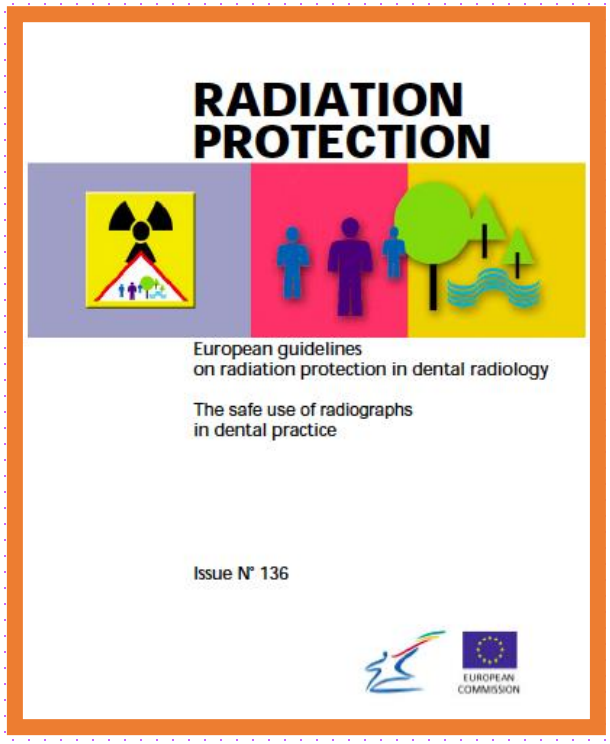


Kim YH, et al. Diagnostic reference levels for panoramic and lateral cephalometric radiography of Korean children. Health Phys. 2014, 107(2):111-6

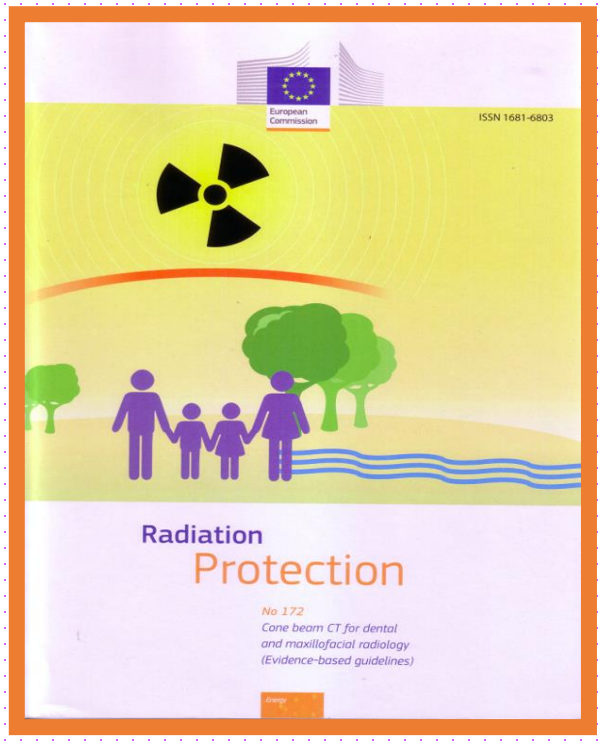
Guidelines


NRPB
Guidance Notes for
Dental Practitioners on th
Safe Use of X-Ray Equipn
DH Department of Health
Australian Government
Australian Radiation Protection and Nuclear Safety Agency
CODE OF PRACTICE & SAFETY GUIDE
Radiation Prote
in Dentistry
NCRP REPORT No. 145
RADIATION PROTECTION IN DENTISTRY
NCRP
National Council on Radiation Protection and Measurements
Health Canada Sante Canada
Radiation Protection i
Recommended Safety Pr
for the Use of
Dental X-Ray Equipment
Safety Code 30
RPII - 96/2
Code of Practice for Radiological Protection in Dentistry
Prepared by the Radiological Protection Institute of Ireland
in consultation with the Department of Health
and the Dental Council
(revised March 1996)
Radiological Protection Institute of Ireland

Guidelines



https://ec.europa.eu/energy/sites/ener/files/documents/136.pdf



http://ec.europa.eu/energy/nuclear/radiation_protection/doc/publication/172.pdf

Summary

- Dental radiography is one of the most frequent types of radiological procedure, although the exposures to individual patients are low
- Different DRL quantities have been used for surveys of dental radiography practice, depending on the modality and availability of the quantity
- The dose surveys should be repeated periodically and a part of DRL process
- These assessments should be carried out on a regular basis, at least every 3 years or as required by national legislation

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