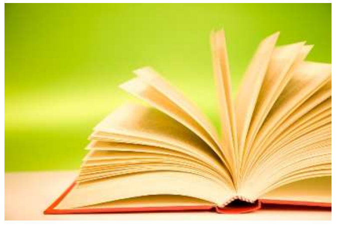
Radiation protection during X-ray examinations before and during pregnancy

Hilde Bosmans
Medical Physics Expert
in the
department of radiology

UZ Leuven

Overview



1. Reasons for extra attention
2. Doses, from adult to children
   - X-rays & CT
3. Risks
4. Dose monitoring in pediatric radiology
5. Practical hints
   - X-rays & CT
6. Imaging during pregnancy

Conclusion

Conflict of interest

- Hilde Bosmans is co-founder of Qaelum NV.
- Some graphs in this presentation have been made with DOSE by Qaelum

1. Reasons for extra attention

From the proposal of Belgian implementation of the directive 2013/59/EURATOM (basic safety standards - BSS

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Art 22 (info prior to the exam)

§2. Voor wat betreft radiotherapeutische toepassingen en interventionele radiologie en voor wat betreft CT-onderzoeken en nucleair geneeskundige onderzoeken bij kinderen, dient deze informatie bovendien schriftelijk aan de patiënt of zijn wettelijke voogd te worden overgemaakt.

§2. En ce qui concerne les applications radiothérapeutiques et la radiologie interventionnelle, et en ce qui concerne les examens de tomodensitométrie et les examens de médecine nucléaire effectués sur des enfants, ces informations doivent en outre être remises par écrit au patient ou à son tuteur légal2.

Art 36 (equipment)

Geschikte medisch-radiologische uitrustingen en praktische technieken moeten worden gebruikt voor de medische blootstellingen:

a) van kinderen;

b) van zwangere vrouwen;

Des équipements radiologiques médicaux et des techniques pratiques appropriés doivent être utilisés pour les expositions médicales :

a) d'enfants ;

b) de femmes enceintes ;

ART 51.2, 56.2, 58.2, 60.2, 61.2, 70.2

De opleiding besteedt een bijzondere aandacht aan de medische blootstelling van kinderen en zwangere vrouwen,

La formation accorde une attention particulière aux expositions médicales concernant les enfants et les femmes enceintes,

ART 75.b (practical training of the MPE)

Deze opleiding omvat bovendien een klinische stage van minstens één jaar voor radiotherapie en van minstens zes maanden voor radiologie of nucleaire geneeskunde en besteedt bijzondere aandacht aan de medische blootstelling van kinderen,

Cette formation inclut en outre un stage clinique d'un an au moins pour la radiothérapie et de six mois au moins pour la radiologie ou la médecine nucléaire et accorde une attention particulière aux expositions médicales concernant des enfants,

Art 23 limits

§2. Geen enkele persoon onder de 18 jaar mag in dit kader worden blootgesteld boven de dosislimiet voor het publiek.

§3. De bescherming van het ongeboren kind mag niet minder zijn dan deze van personen van het publiek. Hieruit volgt dat voor zwangere vrouwen, de blootstelling zo laag als redelijkerwijze mogelijk moet worden en in elk geval lager moet zijn dan 1 millisievert gedurende de totale duur van de zwangerschap.

§2. Aucune personne de moins de 18 ans ne peut, dans ce contexte, être soumise à une exposition supérieure à la limite de dose pour le public.

§3. La protection de l'enfant à naître ne peut être inférieure à celle offerte aux membres du public. Il en résulte, pour les femmes enceintes, que l'exposition doit être la plus faible que raisonnablement possible et, en tous cas, inférieure à 1 millisievert pendant toute la durée de la grossesse.

Art 28 Information, precaution

De noodzakelijke maatregelen worden getroffen, bijvoorbeeld door het uithangen van een zichtbare waarschuwing bij het onthaal van de patiënten, in de wachtzalen en in kleedhokjes, om vrouwen die een medische blootstelling moeten ondergaan, bewust te maken van het belang van het inlichten van de verwijzend persoon en de practicus over het bestaan of over de mogelijkheid van een zwangerschap of het geven van borstvoeding. Bijzondere aandacht dient besteed te worden aan de begrijpbaarheid van de informatie.

Les mesures nécessaires sont prises, par exemple par l'affichage de mises en garde à l’accueil des patients, dans les salles d'attente et dans les cabines de déshabillage, pour attirer l'attention des femmes devant être soumises à une exposition médicales, sur la nécessité d'informer la personne référente et le praticien de l'existence ou de la possibilité d'une grossesse ou d'un allaitement. Une attention particulière doit être accordée à la compréhensibilité de l’information.

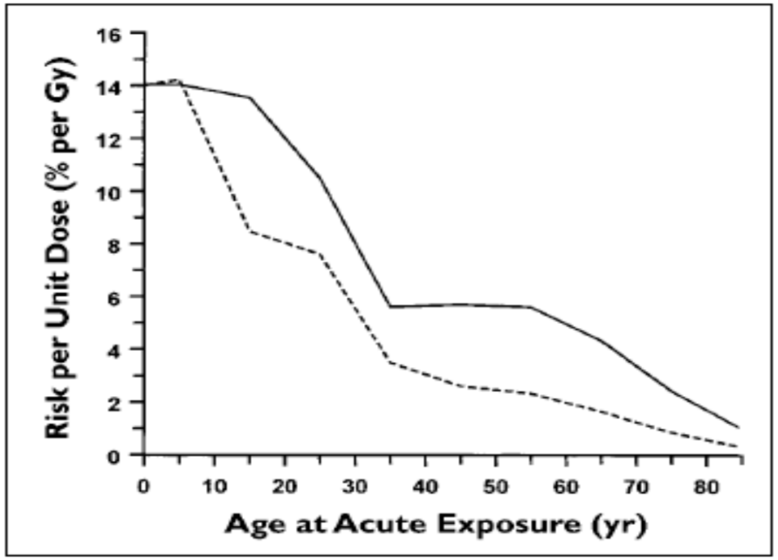
Art 49 Accidental exposure

Bij een accidentele of onbedoelde blootstelling dient, waar aangewezen en zeker indien het een kind of een zwangere vrouw betreft, een berekening van de ontvangen dosis voor respectievelijk de persoon, het kind of het ongeboren kind te worden uitgevoerd.

En cas d’exposition accidentelle ou non intentionnelle, dans les cas appropriés et certainement lorsqu’il s’agit d’un enfant ou d’une femme enceinte, la dose reçue respectivement par la personne, l’enfant ou l’enfant à naître doit être calculée.

Reasons for extra attention

All this, and of course:



2. Doses, from adult to children

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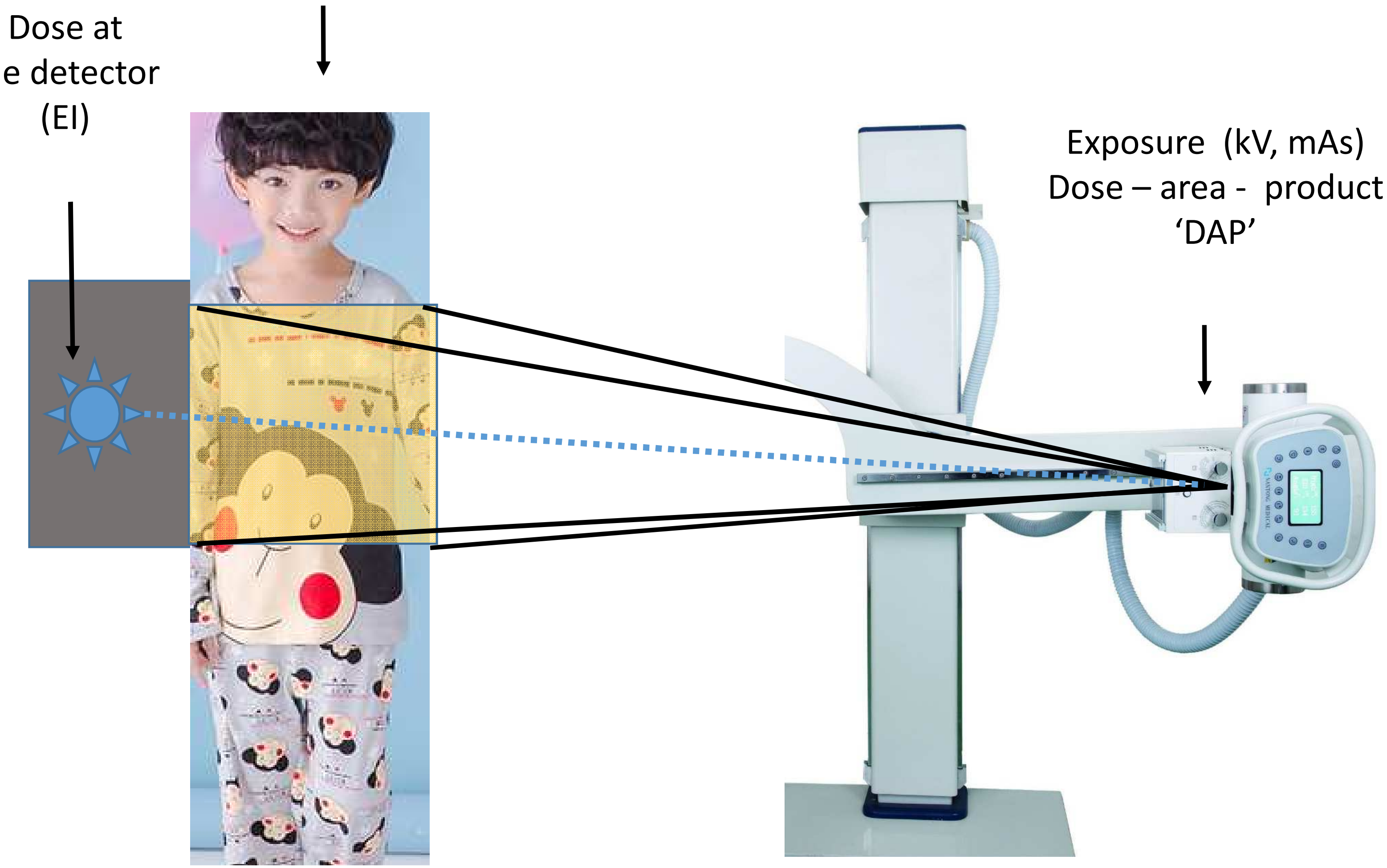

Organ doses /
effective dose
Dose at
the detector
(EI)
Exposure (kV, mAs)
Dose – area - product
'DAP'

Dose area product or DAP

measures incident dose * area ;

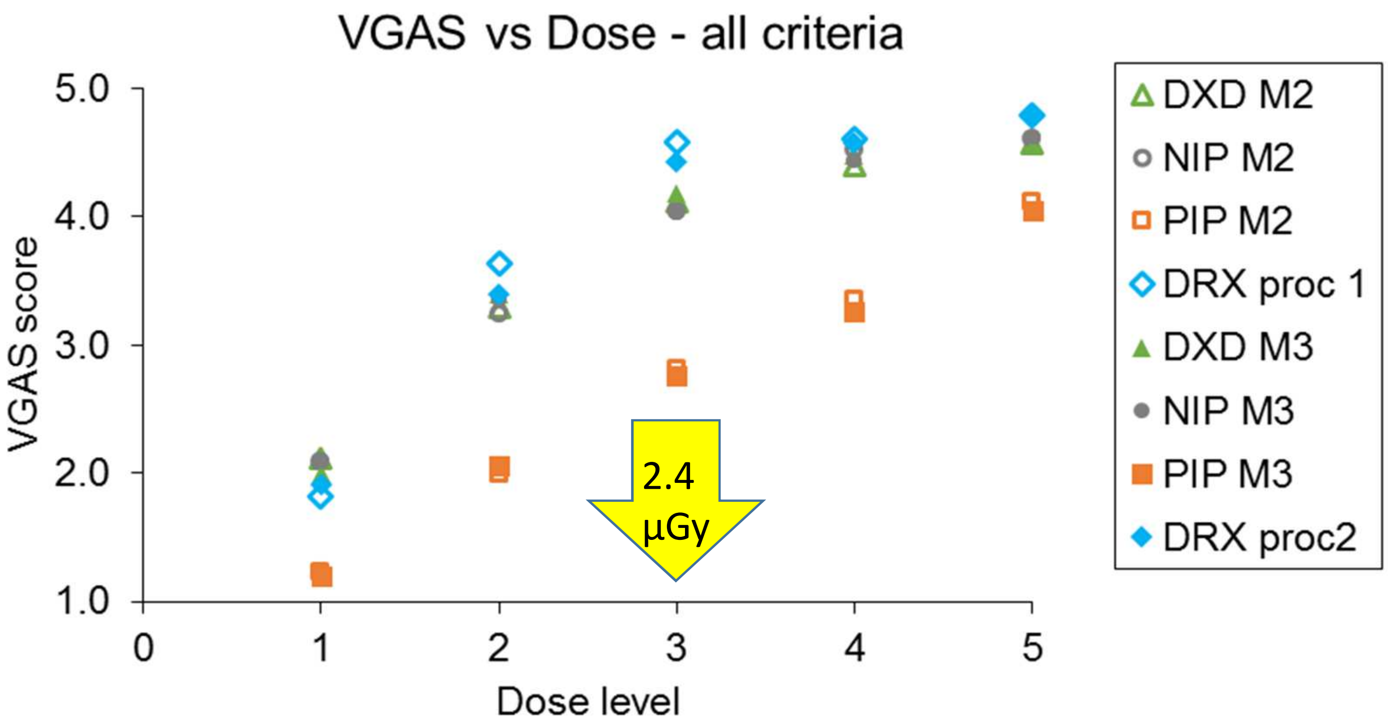
is measured at the tube (as this gives the same value as at patient entrance);

unit cGy.cm^2 or µGy.m^2 or …

Exposure indicator (EI) or Dose at the detector

- Very interesting: they determine the quality
- Can/Should (?) be independent of patient size
- Can be (dose) monitored if correctly present in DICOM header

A first reference for EI



(re-submitted for publication in Europ Rad by M. Smet)

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CT dosimetry via CTDI

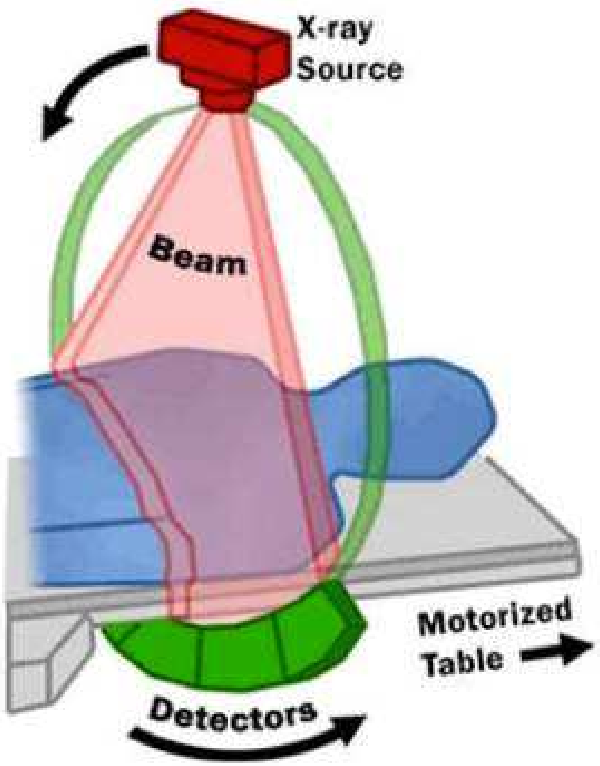

Figure 1: Drawing of CT fan beam (left) and patient in a CT imaging system

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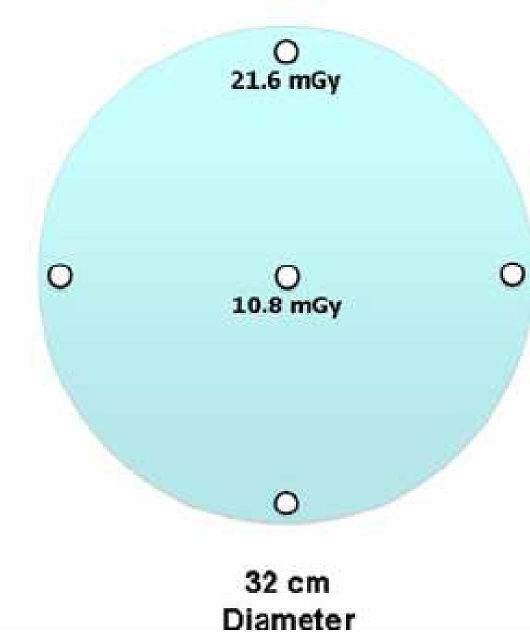
CT dosimetry via CTDI



$$CTDI_{vol} = \frac{1}{3} Dose_{central} + \frac{2}{3} Dose_{periphery}$$

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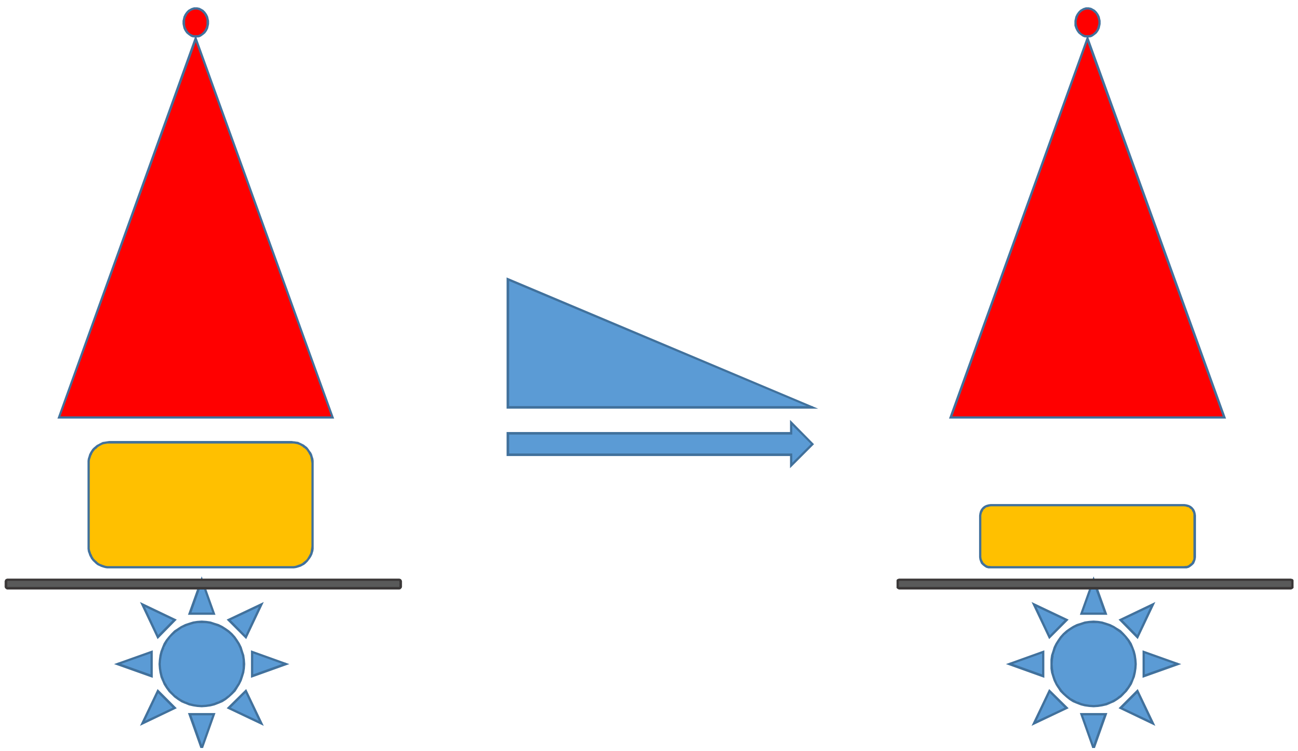
Doses, from adult to children

The lucky factor (for x-rays & CT) : incident radiation in children is lower
(deterministic effects of radiation are very rare)



Doses, from adult to children

The ‘dangerous’ factor :

(1) doses are only low if pre-programmed settings are adjusted towards children; make sure you have pediatric protocols pre-programmed

(2) dose display can be misleading

- DAP should be very low in children, as both incident dose and area go down; reference values from adults don’t work
- $CTDI_{vol}$ keeps on telling what the absorbed dose would be in a cylinder with diameter 32cm (abdomen) or 16cm (head); children can be very different from these test objects

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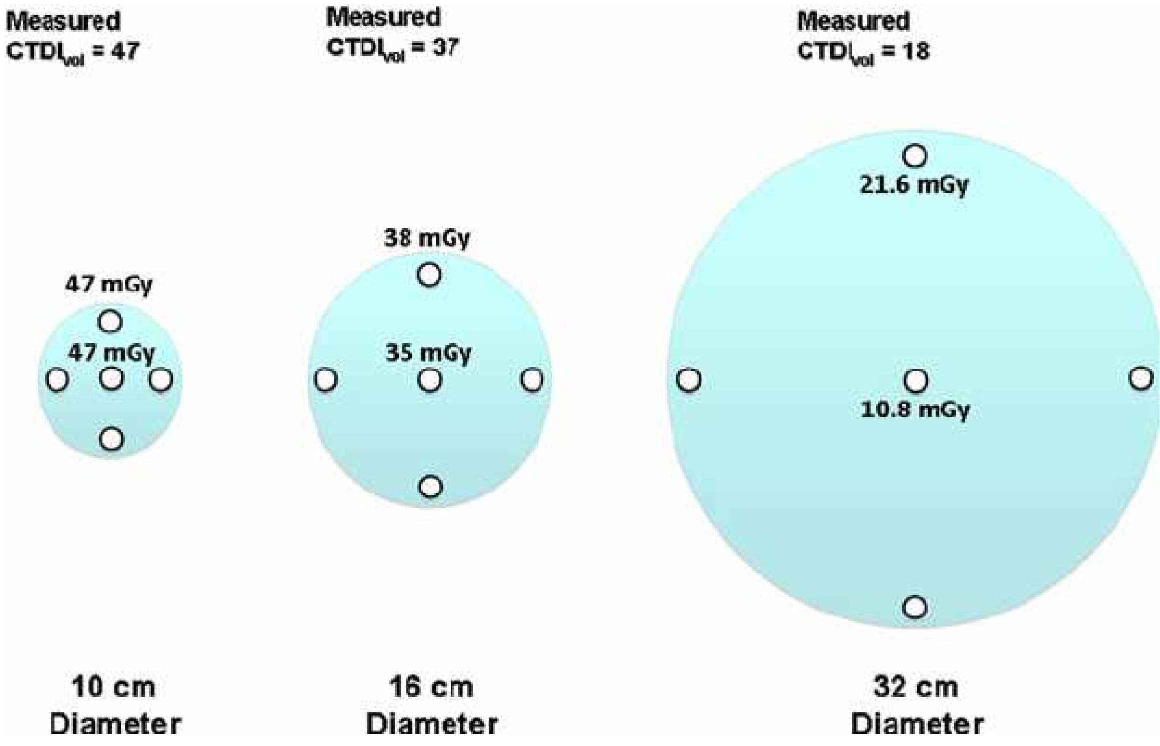
Doses, from adult to children

The ‘dangerous’ factor in CT: a CT scan with identical CTDI produces different absorbed doses in children than in adults

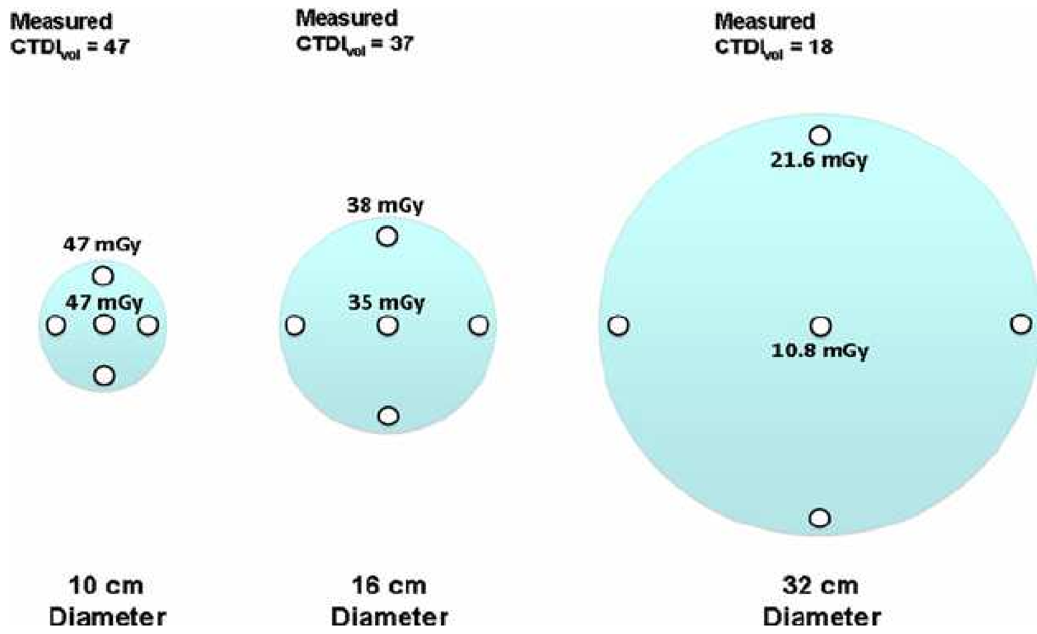


Doses, from adult to children

Consider the case of abdominal CT.

If your patient is like a 32cm phantom, then his absorbed dose will be similar to the $CTDI_{vol}$. Ex: 18mGy

If your patient is more like a 10cm phantom, the absorbed dose for the same $CTDI_{vol}$ is 47mGy.



Size Specific Dose Estimate (SSDE)

New !!!

Concept:

(1) Define which plexiglass cylinder attenuates the x-rays like your patient

(2) Calculate how much more or less the measured CTDIvol would be in this theoretical cylinder -> correction factor

(3) SSDE = correction factor * $CTDI_{vol}$

The SSDE corresponds to the dose that would be absorbed if you replaced the big CTDI phantom by a cylinder like your patient.

After the scan, a scanner or a dose monitoring program could calculate the SSDE. This value would be close to the absorbed dose in the patient

3. Risks

Risks

Risk = risk factor * dose

Different possibilities:

- Risk = risk factor1 * effective dose
  - 5/100 000 / mSv
- Risk = risk factor2 * organ doses
- Risk = (organ specific) life attributable risk * organ doses

Effective dose

ICRP Publication 103

Table A.4.3. Proposed tissue weighting factors.

Tissue	w_T	$\sum w_T$
Bone-marrow (red), Colon, Lung, Stomach, Breast, Remainder Tissues* (Nominal w_T applied to the average dose to 14 tissues)	**0.12**	0.72
Gonads	**0.08**	0.08
Bladder, Oesophagus, Liver, Thyroid	**0.04**	0.16
Bone surface, Brain, Salivary glands, Skin	**0.01**	0.04

* Remainder Tissues (14 in total): Adrenals, Extrathoracic (ET) region, Gall bladder, Heart, Kidneys, Lymphatic nodes, Muscle, Oral mucosa, Pancreas, Prostate, Small intestine, Spleen, Thymus, Uterus/cervix.

Tissue or Organ	H_T per Series [mSv]	Remainder Organs	H_T per Series [mSv]
Thyroid	0.1	Brain	0.0
Breasts	5.4	Thymus	0.8
Oesophagus	0.8	Spleen	17.2
Lungs	6.0	Pancreas	14.4
Liver	16.8	Adrenals	14.0
Stomach	17.1	Kidneys	17.5
Colon	14.1	Small intest.	15.8
Testicles	0.0	Upp. large int.	16.5
Ovaries	14.8	Uterus	13.0
Bladder	15.9		
Bone marrow	7.8	**Misc.**	**H_T per Series** [mSv]
Bone surface	11.9		
Skin	6.5	Eye lenses	0.0

LAR incidence tables of BEIR VII report

TABLE 12D-1 Lifetime Attributable Risk of Cancer Incidence[a]

	Age at Exposure (years)										
Cancer Site	0	5	10	15	20	30	40	50	60	70	80
Males											
Stomach	76	65	55	46	40	28	27	25	20	14	7
Colon	336	285	241	204	173	125	122	113	94	65	30
Liver	61	50	43	36	30	22	21	19	14	8	3
Lung	314	261	216	180	149	105	104	101	89	65	34
Prostate	93	80	67	57	48	35	35	33	26	14	5
Bladder	209	177	150	127	108	79	79	76	66	47	23
Other	1123	672	503	394	312	198	172	140	98	57	23
Thyroid	115	76	50	33	21	9	3	1	0.3	0.1	0.0
All solid	2326	1667	1325	1076	881	602	564	507	407	270	126
Leukemia	237	149	120	105	96	84	84	84	82	73	48
All cancers	2563	1816	1445	1182	977	686	648	591	489	343	174
Females											
Stomach	101	85	72	61	52	36	35	32	27	19	11
Colon	220	187	158	134	114	82	79	73	62	45	23
Liver	28	23	20	16	14	10	10	9	7	5	2
Lung	733	608	504	417	346	242	240	230	201	147	77
Breast	1171	914	712	553	429	253	141	70	31	12	4
Uterus	50	42	36	30	26	18	16	13	9	5	2
Ovary	104	87	73	60	50	34	31	25	18	11	5
Bladder	212	180	152	129	109	79	78	74	64	47	24
Other	1339	719	523	409	323	207	181	148	109	68	30
Thyroid	634	419	275	178	113	41	14	4	1	0.3	0.0
All solid	4592	3265	2525	1988	1575	1002	824	678	529	358	177
Leukemia	185	112	86	76	71	63	62	62	57	51	37
All cancers	4777	3377	2611	2064	1646	1065	886	740	586	409	214

NOTE: Number of cases per 100,000 persons exposed to a single dose of 0.1 Gy.

[a]These estimates are obtained as combined estimates based on relative and absolute risk transport and have been adjusted by a DDREF of 1.5, except for leukemia, which is based on a linear-quadratic model.

LAR mortality tables of BEIR VII report

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TABLE 12D-2 Lifetime Attributable Risk of Cancer Mortality[a]

	Age at Exposure (years)										
Cancer Site	0	5	10	15	20	30	40	50	60	70	80
Males											
Stomach	41	34	30	25	21	16	15	13	11	8	4
Colon	163	139	117	99	84	61	60	57	49	36	21
Liver	44	37	31	27	23	16	16	14	12	8	4
Lung	318	264	219	182	151	107	107	104	93	71	42
Prostate	17	15	12	10	9	7	6	7	7	7	5
Bladder	45	38	32	27	23	17	17	17	17	15	10
Other	400	255	200	162	134	94	88	77	58	36	17
All solid	1028	781	641	533	444	317	310	289	246	181	102
Leukemia	71	71	71	70	67	64	67	71	73	69	51
All cancers	1099	852	712	603	511	381	377	360	319	250	153
Females											
Stomach	57	48	41	34	29	21	20	19	16	13	8
Colon	102	86	73	62	53	38	37	35	31	25	15
Liver	24	20	17	14	12	9	8	8	7	5	3
Lung	643	534	442	367	305	213	212	204	183	140	81
Breast	274	214	167	130	101	61	35	19	9	5	2
Uterus	11	10	8	7	6	4	4	3	3	2	1
Ovary	55	47	39	34	28	20	20	18	15	10	5
Bladder	59	51	43	36	31	23	23	22	22	19	13
Other	491	287	220	179	147	103	97	86	69	47	24
All solid	1717	1295	1051	862	711	491	455	415	354	265	152
Leukemia	53	52	53	52	51	51	52	54	55	52	38
All cancers	1770	1347	1104	914	762	542	507	469	409	317	190

NOTE: Number of deaths per 100,000 persons exposed to a single dose of 0.1 Gy.

[a]These estimates are obtained as combined estimates based on relative and absolute risk transport and have been adjusted by a DDREF of 1.5, except for leukemia, which is based on a linear-quadratic model.

Trend line for every cancer

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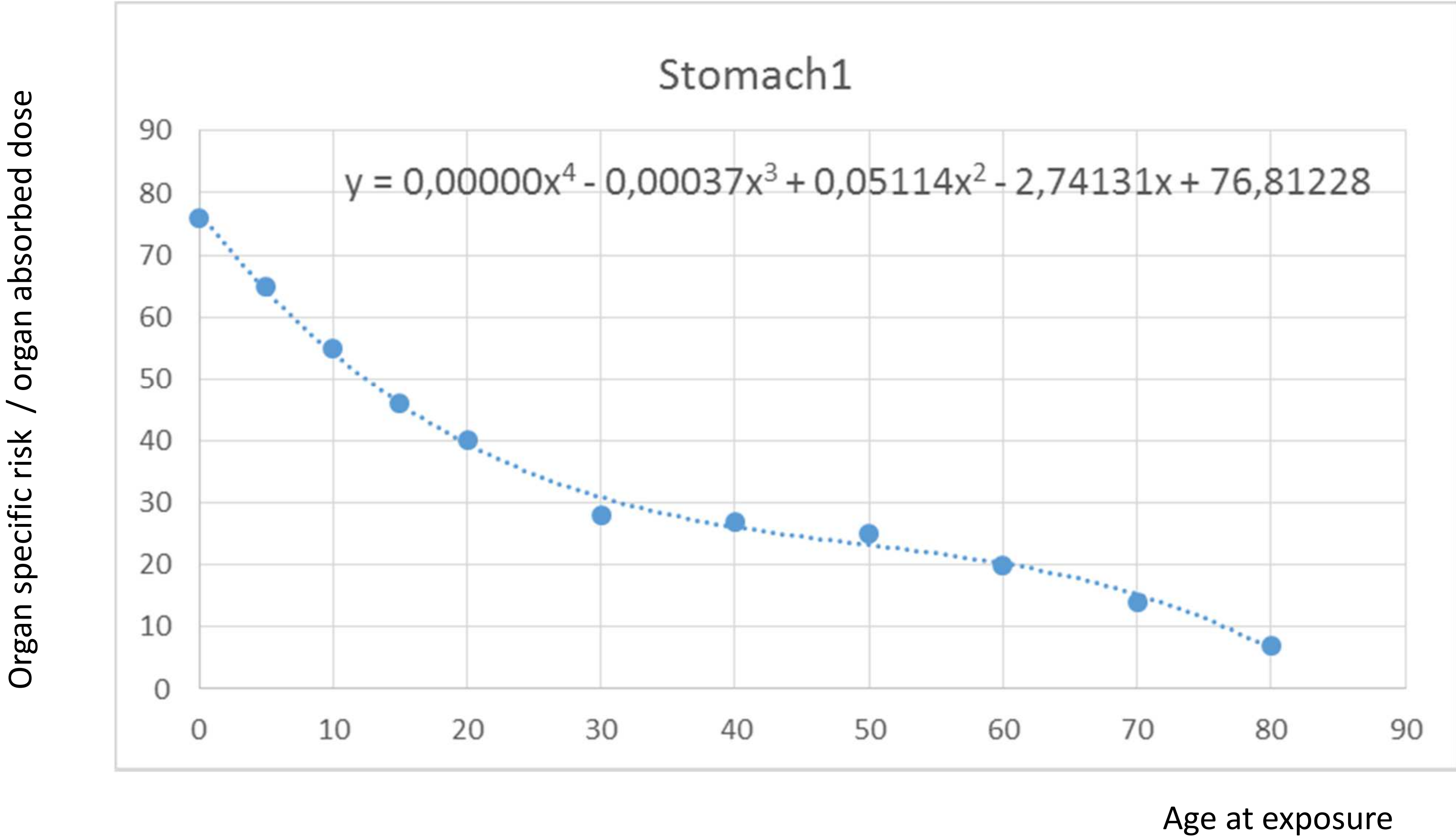

User input

	A	B	C	D	E	F	G
1		Input					
2	Incidence or mortality?						
3	Gender?						
4	Type of cancer?			Calculate LAR			
5	Age at exposure (years)?						
6							
7	LAR per 0,1 Gy						
8							
9	Organ dose (Gy)?						
10							
11		Output					
12	Calulated LAR		based on the formule on p.310 in BEIR 7				

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Example for a dental CBCT exam in 5y old

age at exposure / gender	5 years old / male											
kV	70				80				90			
mAs	16		7,4		16		7,4		60		16	
	absorbed dose (µGy)											
Brain	12		6		27		12		101		40	
Skin	16		7		27		13		89		35	
Esophagus	45		21		81		37		274		109	
Muscle	8		4		15		7		53		21	
ET	101		47		194		90		686		274	
Thyroid	73		34		134		62		460		184	
Salivary_glands	197		91		376		174		1327		531	
Oral_mucosa	508		235		1007		466		3624		1449	
RBM (Leukemia)	10		5		19		9		71		29	
bone surface	47		22		90		42		331		133	
Lymph nodes	24		11		44		20		149		59	
	incidence	mortality	incidence	mortality	incidence	mortality	incidence	mortality	incidence	mortality	incidence	mortality
Brain	0,002	0,001	0,001	0,000	0,005	0,002	0,002	0,001	0,017	0,007	0,007	0,003
Skin	0,003	0,011	0,001	0,000	0,005	0,002	0,002	0,001	0,015	0,006	0,006	0,002
Esophagus	0,031	0,011	0,014	0,005	0,056	0,019	0,025	0,009	0,188	0,065	0,075	0,026
Muscle	0,001	0,000	0,001	0,000	0,002	0,001	0,001	0,000	0,008	0,003	0,003	0,001
ET	0,016	0,006	0,007	0,003	0,031	0,012	0,014	0,005	0,109	0,041	0,043	0,017
Thyroid	0,056	0,017	0,026	0,008	0,102	0,032	0,047	0,015	0,352	0,109	0,141	0,044
Salivary_glands	0,034	0,013	0,016	0,006	0,065	0,025	0,030	0,011	0,228	0,087	0,091	0,035
Oral_mucosa	0,081	0,028	0,037	0,013	0,160	0,061	0,074	0,028	0,575	0,218	0,230	0,087
RBM (Leukemia)	0,015	0,007	0,008	0,004	0,029	0,014	0,014	0,006	0,109	0,051	0,045	0,021
bone surface	0,008	0,003	0,004	0,001	0,015	0,006	0,007	0,003	0,057	0,022	0,023	0,009
Lymph nodes	0,004	0,001	0,002	0,001	0,007	0,003	0,003	0,001	0,024	0,009	0,009	0,007
Total LAR	0,250	0,097	0,117	0,041	0,477	0,176	0,220	0,081	1,682	0,619	0,674	0,252

/100.000

Life Attributable Risk (LAR)

- Ultimate solution
- Corrects for age and gender
- Requires also detailed input on organ doses (not trivial)

Risks and doses, from adult to children

(1) Organ dose calculation

- ✓Should be specific for children;
- ✓Requires specific software tools or test objects ('specialisation')
- ✓CT: Would benefit from SSDE display

(1) Risk factors

- ✓The 'normal' effective dose uses risk factors that are an average over the whole population (including children, but largely overwhelmed by adults)
- ✓Go for LAR ? (for which the tools are not largely available)

4. Dose monitoring in pediatric radiology

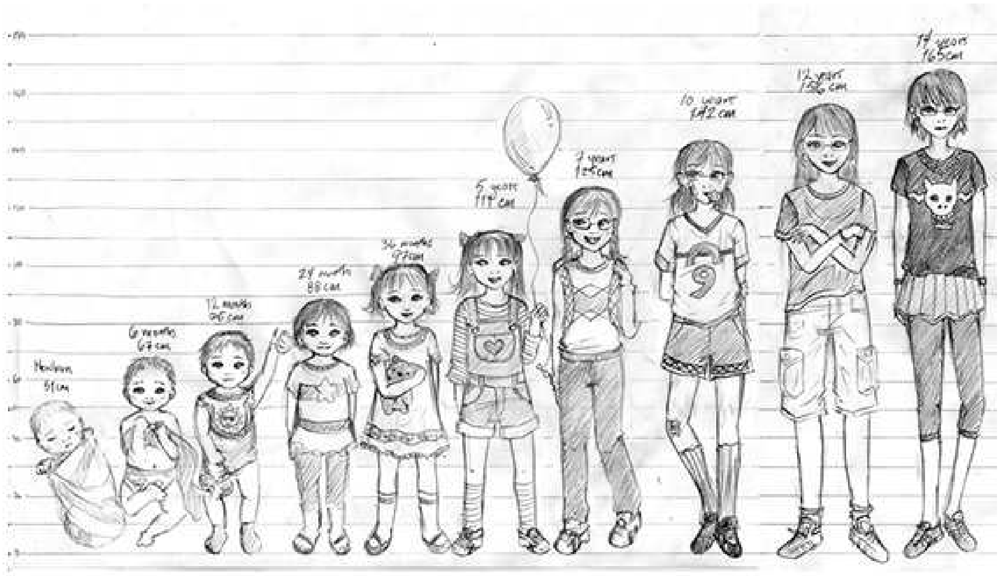
Rationale:

- a proper system for adults does not guarantee that pediatric doses are ALARA
- the legislator is asking for specific attention
- there is less experience with what is good practice, yet most radiology practices welcome children
- probably it is logical to make it a priority

Dose monitoring in pediatric radiology

The challenges:

- (most) pediatric exams are less frequent than adult exams
- in terms of dosimetry, there are large differences between children



Dose monitoring in pediatric radiology

Solutions:

- (most) pediatric exams are less frequent
  - use all data, via efficient dose data collection
  - multicenter/national/European surveys & data pooling
  - calculate multicenter/national/European diagnostic dose reference levels (DRLs) with feedback

- in terms of dosimetry, there are large differences between children
  - diagnostic dose reference curves, rather than 1 value
  - Weight or age groups

Dose monitoring in pediatric radiology

Example of a curve
(courtesy to the team
In STUK, Finland)

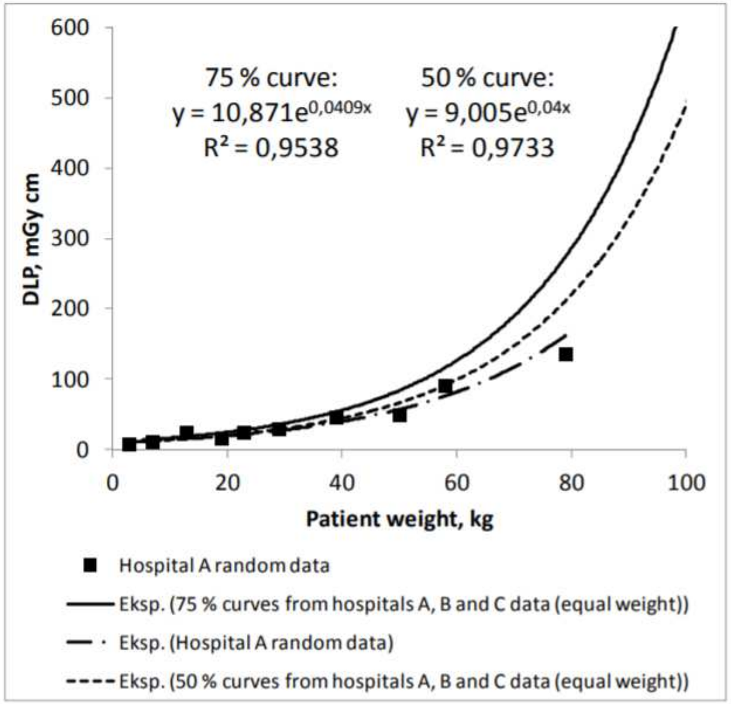


Fig. 7.1. An example of DRL-curves for DLP in chest CT.
The DLP values relate to the 32 cm diameter CT dosimetry phantom.
The lowest dotted curve shows an example of using the DRL curve.
(Järvinen et al. 2015)

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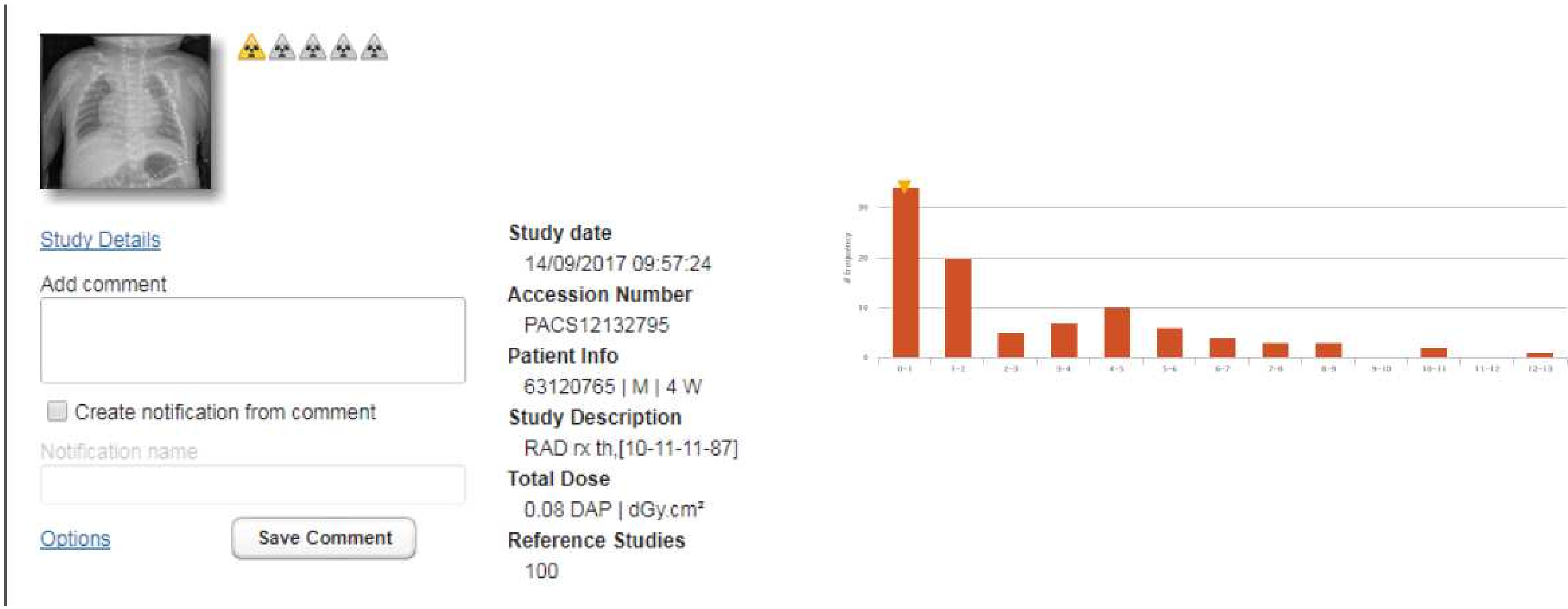
Local dose monitoring in pediatric imaging



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Multi center dose monitoring in neonatalogy

J Dabin et al, Radiation dose to premature new-borns in the Belgian noenatal intensive care units. RPD, (2014), Vol. 158, No. 1, pp. 28–35

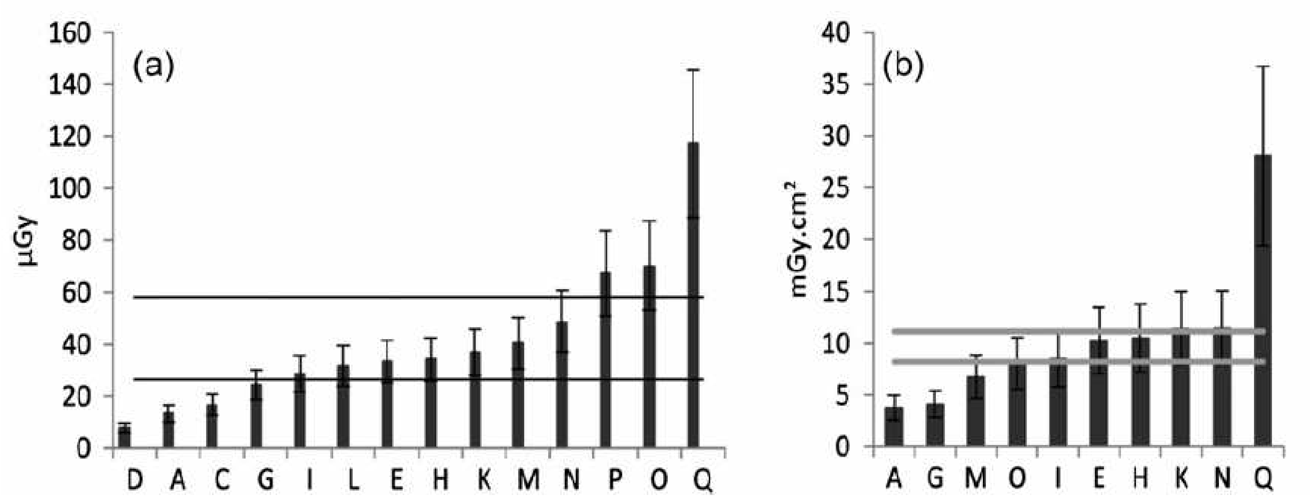

Figure 2. An overview of the median ESK (a) and KAP values (b) for combined chest–abdomen radiographs. 25th and 75th percentiles (solid lines) are reported.

National dose monitoring & national DRLs

Tabel 1. DRL's voor CT-onderzoeken bij volwassenen

VOLWASSENEN	CTDI$_{vol}$ (mGy)		DLP (mGy.cm)			
	Enkelvoudig onderzoek		Enkelvoudig onderzoek		Volledig onderzoek	
Onderzoek	P25	DRL (P75)	P25	DRL (P75)	P25	DRL (P75)
Abdomen	7,5	12	350	600	420	700
Angio CT van de thorax	6	15	180	410	220	460
Hart (CCTA)	14	35	200	490	250	530
Colon	-	-	-	-	230	530
Cervicale wervelzuil	16	30	280	490	-	-
Lumbale wervelzuil	20	30	400	650	-	-
Schedel (hersenen)	39	55	660	950	-	-
Sinussen	3	7	40	90	-	-
Thorax	5,5	9	200	320	-	-
Thorax-abdomen	-	-	-	-	550	960

Voor het bepalen van representatieve DRL's bij kinderen is het absoluut noodzakelijk om de parameters leeftijd, gewicht en grootte aan te geven, gezien de grote variatie in grootte tussen een boreling en een adolescent van 15 jaar.

Hoewel er niet veel gegevens beschikbaar waren, was een onderverdeling van de CTDIvol en de DLP op basis van leeftijd mogelijk, behalve voor het onderzoek thorax-abdomen.

Tabel 2. DRL's voor CT-onderzoeken bij kinderen op basis van leeftijd

KINDEREN	CTDI$_{vol}$ (mGy)				DLP (mGy.cm)			
	Enkelvoudig onderzoek - DRL (P75)				Volledig onderzoek - DRL (P75)			
Onderzoek / Leeft. (j)	<1	1 - <5	5 - <10	10 - <15	<1	1 - <5	5 - <10	10 - <15
Abdomen	-	-	5	7,5	-	110	220	330
Schedel (hersenen)	22	30	40	45	420	540	660	780
Sinussen	-	-	4	6	-	50	65	80
Thorax	-	1,5	2	3,5	-	35	55	130
Thorax-abdomen	-	-	-	-	-	-	-	-

Tabel 3. DRL's voor onderzoeken in de conventionele radiologie bij volwassenen

VOLWASSENEN	DAP (cGy.cm²)			
	Enkelvoudig onderzoek		Meervoudig onderzoek	
Onderzoek	P25	NRD (P75)	P25	NRD (P75)
Abdomen	85	275	175	400
Bekken	110	350	-	-
Lumbal wervelzuil	-	-	530	1800
Thorax PA	10	30	-	-
Thorax volledig	-	-	35	110

	AGD (mGy) per opname - NRD
Mammografie	2,0

Voor kinderen was een onderverdeling van de DAP op basis van leeftijd mogelijk.

Tabel 4. DRL's voor onderzoeken in de conventionele radiologie bij kinderen op basis van leeftijd

KINDEREN	DAP (cGy.cm²)			
	DRL (P75)			
Onderzoek / Leeftijd (jaar)	<1	1 - <5	5 - <10	10 - <15
Abdomen	3	10	25	45
Thorax enkelvoudig	2	3,5	5	12
Thorax meervoudig	6	10,5	15	36

See: website of the FANC

European dose monitoring in pediatric radiology

Example of weight and age groups, with age group being much more practical for dose monitoring

Table 7.2. Approximate equivalence of weight and age groups for the purpose of comparing weight-based DRLs with age-based 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

European dose monitoring in pediatric radiology

- PiDRL FP7 European Commission supported project
- Extensive literature survey of existing pediatric dose data & finding gaps

Table 11.2b. European DRLs for computed tomography.

Computed tomography				
Exam	Weight group, kg	Age group, y	EDRL	
			$CTDI_{vol}$, mGy	**DLP, mGy cm**
Head	<10	0	25	300
	10-<15	1	25	370
	15-<30	5	38	505
	30-<60	10	53	700
	>60	15	60	900
Thorax	<10	0	2,7	45
	10-<15	1	3,3	80
	15-<30	5	5,6	115
	30-<60	10	5,7	180
	>60	15	6,9	200
Abdomen	<10	0		90
	10-<15	1	5,7	160
	15-<30	5	5,7	170
	30-<60	10	7,0	290
	>60	15	14	580

Tabel 2. DRL's voor CT-onderzoeken bij kinderen op basis van leeftijd

KINDEREN	$CTDI_{vol}$ (mGy)				DLP (mGy.cm)			
	Enkelvoudig onderzoek - DRL (P75)				Volledig onderzoek - DRL (P75)			
Leeft. (j) / Onderzoek	<1	1 - <5	5 - <10	10 - <15	<1	1 - <5	5 - <10	10 - <15
Abdomen	-	-	5	7,5	-	110	220	330
Schedel (hersenen)	22	30	40	45	420	540	660	780
Sinussen	-	-	4	6	-	50	65	80
Thorax	-	1,5	2	3,5	-	35	55	130
Thorax-abdomen	-	-	-	-	-	-	-	-

European dose monitoring in pediatric radiology

Table 11.2a. European DRLs for radiography and fluorosc

Radiography and fluoroscopy				
Exam	Weight group, kg	Age group, y	EDRL	
			$K_{a,e}$, mGy	**P_{KA}, mGy cm^2**
Head	10-<15	1		230
	15-<30	5		300
Thorax PA	<10	0		14
	10<15	1		20
	15-<30	5	0,08	39
	30-<60	10	0,11	38
	>60	15	0,11	73
Thorax LAT	15-<30	5	0,14	40
	30-<60	10		60
				60
Abdomen	10-<15	1		150
	15-<30	5	0,75	250
	30-<60	10		425
Pelvis	15-<30	5	0,48	
MCU	<10	0		300
	10-<15	1		700
	15-<30	5		800
	30-<60	10		750

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Daily compliance monitoring

Compliance monitoring - Study level (DLP | mGy.cm) ×

Parameter type: DLP

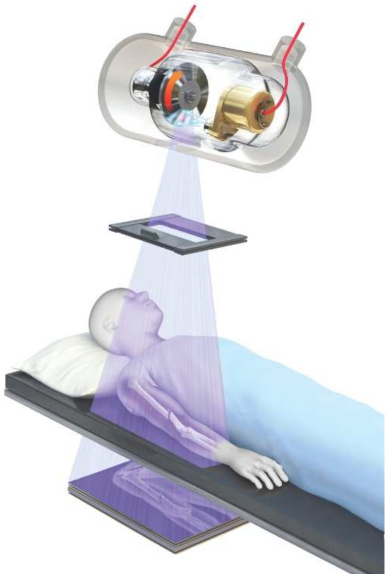
87 studies don't match a limit | 1417 studies don't have a category or limit assigned

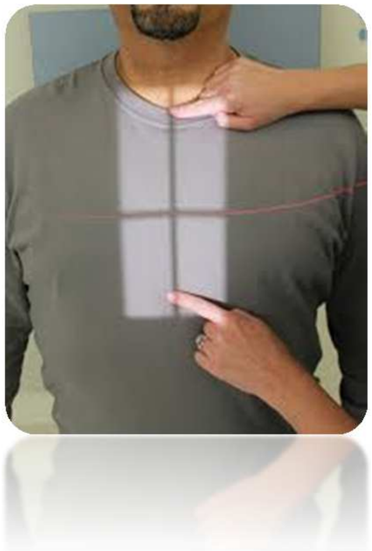
STUDY GROUP	COUNT (#)	MIN	PERC. (25)	MEAN	MEDIAN	PERC. (75)	MAX	COMPARISON
Abdomen Enkelvoudig onderzoek (Adult)	17	350	415.5	1094.797	622	1288.555	5744	
Abdomen Volledig onderzoek (5-10 jaar)	2	43.15	43.15	73.575	73.575	104	104	
Abdomen Volledig onderzoek (1-5 jaar)	1	70	70	70	70	70	70	
Abdomen Volledig onderzoek (10-15 jaar)	1	253.33	253.33	253.33	253.33	253.33	253.33	
Abdomen Volledig onderzoek (Adult)	134	209.9	458.778	870.598	599.5	872.368	4580.86	
Angio CT van de thorax Enkelvoudig onderzoek (Adult)	309	9	136.705	492.224	445	660.685	4024	
Cervicale wervelkolom Enkelvoudig onderzoek (Adult)	29	184	319	373.742	374	415.705	714.25	
Colon (Adult)	19	102.1	152	220.018	206	249	553	
Hart (CCTA) Enkelvoudig onderzoek (Adult)	69	75	165.665	445.155	467	723.825	1098	
Hart (CCTA) Volledig onderzoek (Adult)	69	75	165.665	445.155	467	723.825	1098	
Lumbale wervelkolom Enkelvoudig onderzoek (Adult)	80	150.66	368.272	687.224	502.03	869.627	3257	
Schedel (hersenen) Enkelvoudig onderzoek (Adult)	211	261	570	696.344	652	724	3791.92	
Sinussen Enkelvoudig onderzoek (Adult)	19	27	31	74.616	33	37.33	443	
Thorax Enkelvoudig onderzoek (Adult)	83	121	220	351.713	289	367.73	2483	
Thorax Volledig onderzoek (1-5 jaar)	0	0	0	0	0	0	0	
Thorax Volledig onderzoek (10-15 jaar)	0	0	0	0	0	0	0	
Thorax Volledig onderzoek (5-10 jaar)	0	0	0	0	0	0	0	
Thorax-abdomen (Adult)	44	10.79	493.632	697.922	553	813.5	1518	

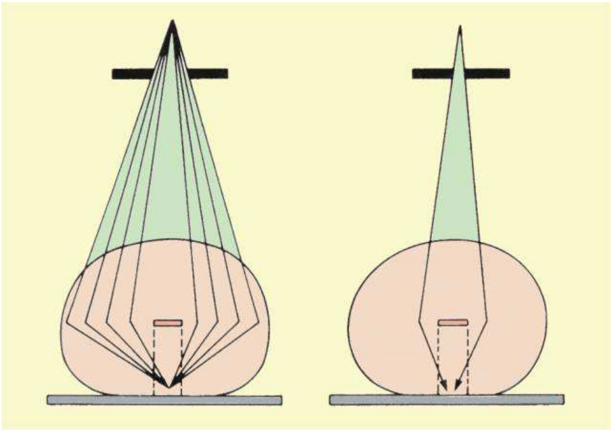
5. Practical hints to limit the doses

Limit the irradiated volume to the volume of interest

- Active collimation
- Not too much magnification







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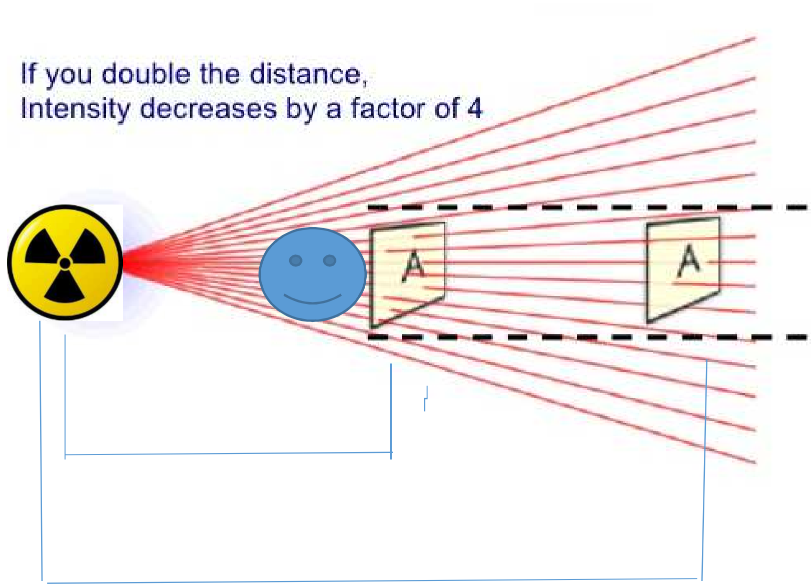
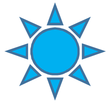
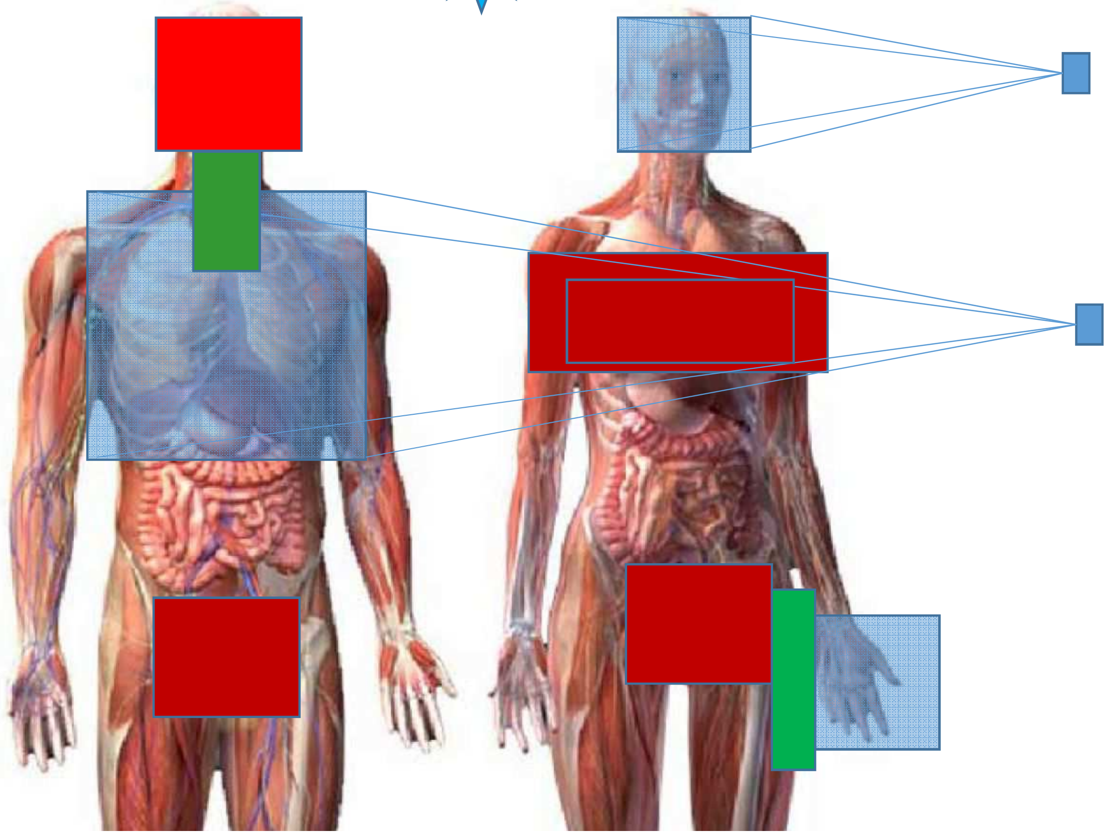
Put the detector as close as possible to the patient



The use of lead

Only useful in primary beam ('green'), otherwise nonesense ('red')

Be careful not to cover the 



Hints

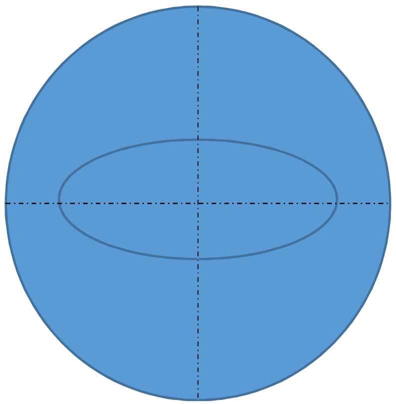
- Justification first
- Limit irradiated volume
- Use preprogrammed programs for children
  - Specific dose levels at the detector
- (Just guessing the mAs is no guarantee for optimal exposure)
- Avoid retakes: train the personnel
- ‘Immobilize’ the children
- No scopy for positioning
- pulsed fluoroscopy & last image holde

Hints on CT scanning, copied from RX

- Justification first
- Limit irradiated volume, limit scan length
- Use preprogrammed programs for children
  - ‘Specific dose levels at the detector’
  - Tube current modulation (to be verified first)
- (Just guessing the mAs is no guarantee for optimal exposure)
- Avoid retakes: train the personnel
- ‘Immobilize’ the children or scan fast enough

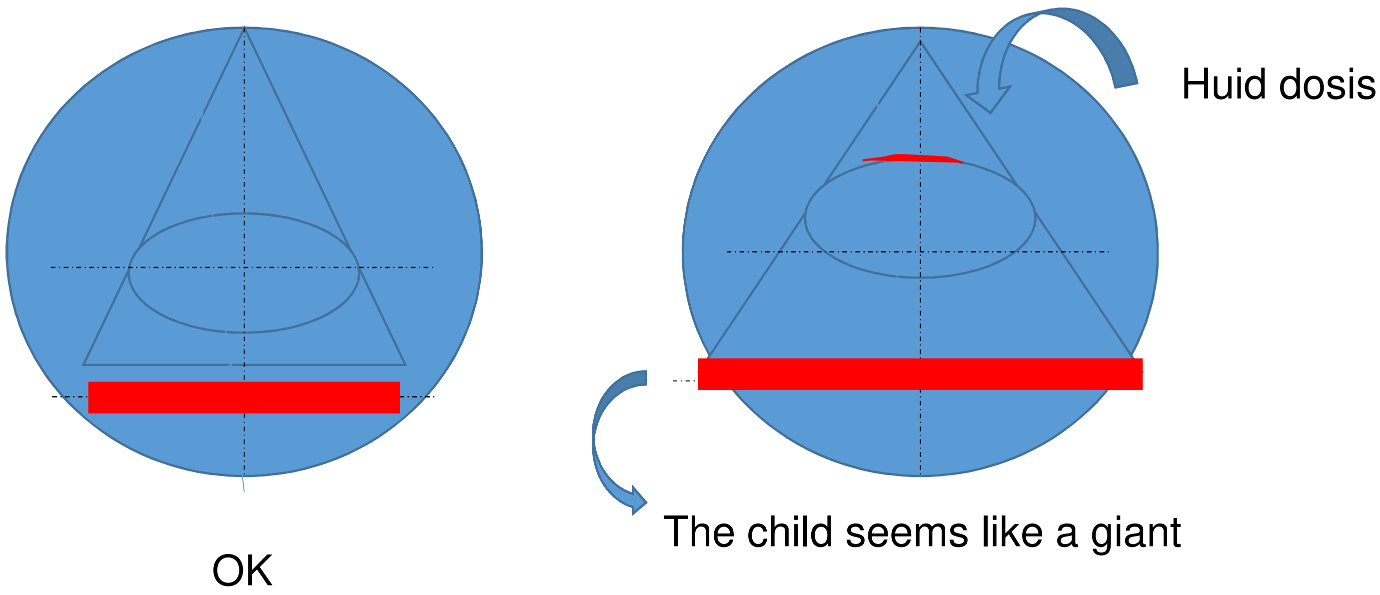
Hints on CT scanning

- Make sure your (pediatric) patient is well centered, especially if tube current modulaiton is activited



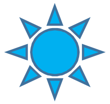
Hints on CT scanning

- On some scanners, the size of the scout view determines the tube current settings.. Your child is better not a giant !

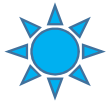


The use of lead in CT

We had (with x-rays): lead sheets are only useful in the primary beam …

But CT is today also usually used with its 

(You call this ‘tube current modulation’ and automatic exposure level)

With lead in the primary beam, you will always hit the 

Lead in the beam will create atefacts…

Don’t do !

More hints for CT scanning

- Use pre-programmed settings
  - Check quality level; involve your
  - Compare with FANC's DRLs
- Lower kV (with lower concentration of contrast agents)
- Scan correctly, and only once
- Use iterative reconstruction (after validation)

6. Imaging during pregnancy

Imaging during pregnancy

- Can be planned, for mother or foetus
  - No dose limits: justification required

- Can be accidental
  - Doses should be lower than 1mSv/y, as for the public
  - If not:
    - estimate the doses;
    - inform the FANC of your case

Dose threshold for the foetus

UZ Leuven

- *Lethal effects*: There is sensitivity to the lethal effects of irradiation in the preimplantation period of embryonic development (up to 14 d after conception). At doses below 100 mGy, these lethal effects will be very infrequent. There is no reason to believe that significant risks to health will be expressed after birth.
- *Malformations*: During the period of major organogenesis, conventionally taken to be from the third to the eighth week after conception, malformations may be caused, particularly in the organs under development at the time of exposure. These effects have a threshold of ~100 mGy.
- *Central nervous system effects*: From 8 to 25 weeks after conception, the central nervous system is particularly sensitive to radiation. A reduction in intelligence quotient cannot be identified clinically at absorbed doses to the fetus below 100 mGy. During the same time period, absorbed doses to the fetus on the order of 1 Gy result in a high probability of severe mental retardation. The sensitivity is highest from 8 to 15 weeks after conception, and lower from 16 to 25 weeks of gestational age. No mental retardation cases were detected before 8 weeks or after 25 weeks.
- *Leukemia and childhood cancer*: Radiation has been shown to increase the probability of leukemia and many types of cancer in both adults and children. Throughout most of pregnancy, the embryo and fetus are assumed to be at approximately the same risk for potential carcinogenic effects as children (*i.e.*, about three times that of the population as a whole).

- 0 - 14 days after conception; at doses below 100mGy: infrequent
- Week 3 – 8: threshold of 100mGy for malformations
- Week 8 – 25: IQ can be lower above 100mGy;
  > 1Gy: mental retardation

Copied from ICRP 2007 & NCRP 168

Dosimetry of the foetus: required info

1. Which x-ray technique?
    - CT
    - Interventional RX
    - Projection imaging
    - Dental, bone densitometry
        - Fetus in the primary beam
            - Yes
            - No

Access to the image information (image and DICOM header) is crucial

Dosimetry of the foetus: required info

2. Patient size ?

Patient habitus, foetus

- < 14d
- 14d – 8weeks
- 8 – 24 weeks

Patient habitus, mother

- BMI
- Diameter
  at the level of the fetus

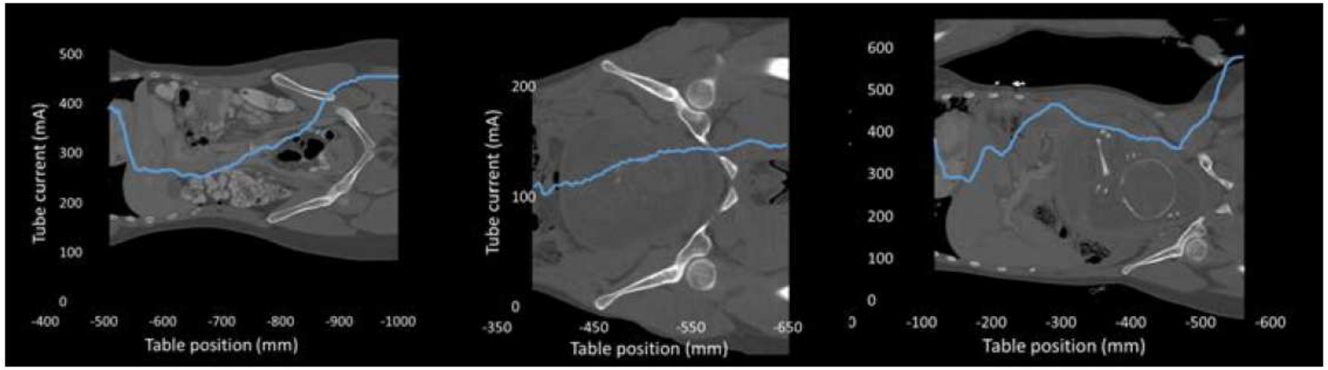


Figure 7.1: Tube current modulation as a function of the table position on coronal images of three patients, each from each trimester A: first, B: second and C: third trimester.

Dosimetry of the foetus: tools

Tools for retrospective analysis

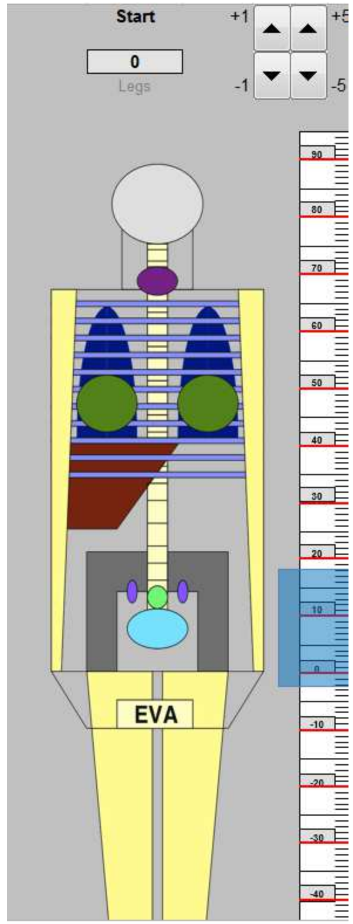
(1) ‘CT dose in the uterus’

as calculated with software tools

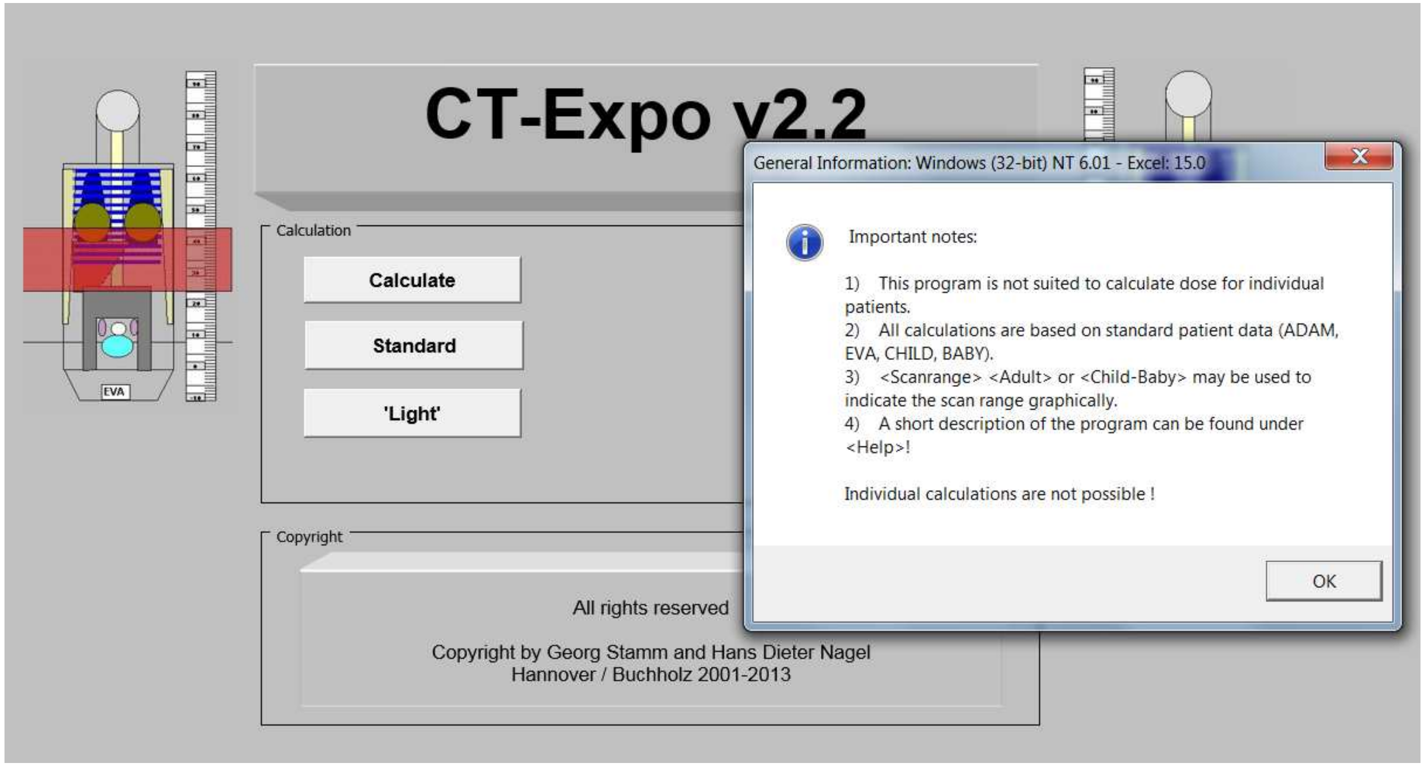
for non pregnant cases

Example: CT-Expo

(validated in several of our research projects)



Example


CT-Expo v2.2
EVA
Calculation
Calculate
Standard
'Light'
Copyright
All rights reserved
Copyright by Georg Stamm and Hans Dieter Nagel
Hannover / Buchholz 2001-2013
General Information: Windows (32-bit) NT 6.01 - Excel: 15.0
Important notes:
1) This program is not suited to calculate dose for individual patients.
2) All calculations are based on standard patient data (ADAM, EVA, CHILD, BABY).
3) <Scanrange> <Adult> or <Child-Baby> may be used to indicate the scan range graphically.
4) A short description of the program can be found under <Help>!
Individual calculations are not possible !
OK

Example

Dose Values per Scan or per Series*				
$CTDI_w$ [mGy]	$CTDI_{vol}$ [mGy]	DLP_w* [mGy*cm]	E* [mSv]	D_{uterus}* [mSv]
6.9	6.9	159	**2.8**	10.0

CTDI and DLP values refer to 32cm body phantom

Effective dose E refers to ICRP 103

7. Effective Dose

ICRP
- ○ 60
- ● 103

Dose Values per Examination		
DLP_w [mGy*cm]	E [mSv]	D_{uterus} [mSv]
159	**2.8**	10.0

Effective dose E refers to ICRP 103

Please note:
All organ doses H_T are based on conversion coefficients for <u>standard patients</u> (ADAM, EVA, CHILD, BABY) and serve for information purposes only (in particular for organs outside the scan range) !

Tissue or Organ	H_T per Series [mSv]	Tissue or Organ	H_T per Series [mSv]
Brain	0.0	Upp. large int.	8.1
Salivary glands	0.0	Thymus	0.0
Thyroid	0.0	Spleen	0.6
Breasts	0.0	Pancreas	0.6
Oesophagus	0.0	Adrenals	0.3
Lungs	0.1	Kidneys	1.6
Liver	0.9	Small intest.	8.1
Stomach	1.2	Uterus	10.0
Low. Large int.	6.8	Prostate	0.0
Testicles	0.0	Gall bladder	0.6
Ovaries	8.3	Heart	0.0
Bladder	8.4	ET tissue	0.0
Bone marrow	3.1	Oral mucosa	0.0
Bone surfaces	3.2	Lymph nodes	2.7
Skin	2.0	Muscle	2.7
		Eye lenses	0.0

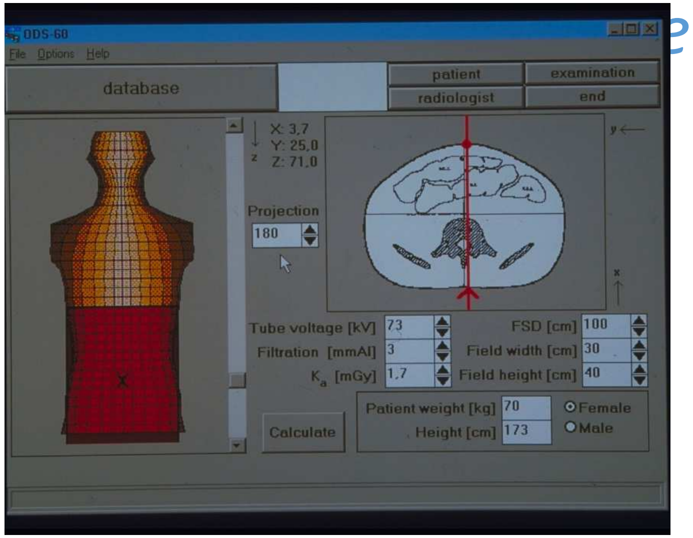
Dosimetry of the foetus: tools

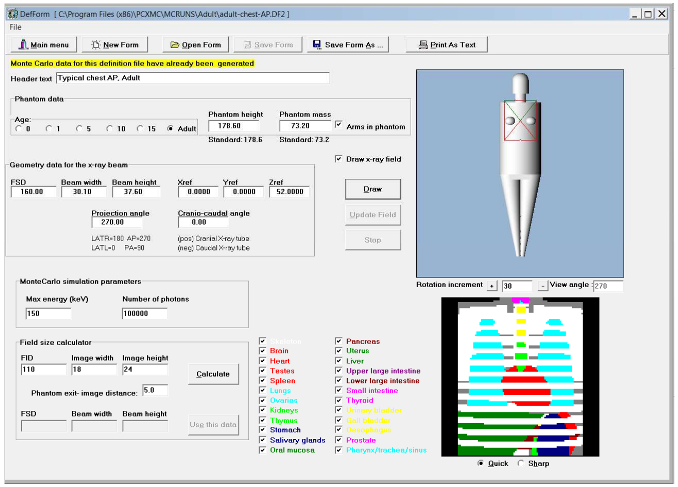
Tools for retrospective analysis

(2) ‘dose in the uterus’

as calculated with software tools

for non pregnant cases





Example: RADOS, and the newer version PCXMC

(developed and validated in extenso, by STUK, Finland)

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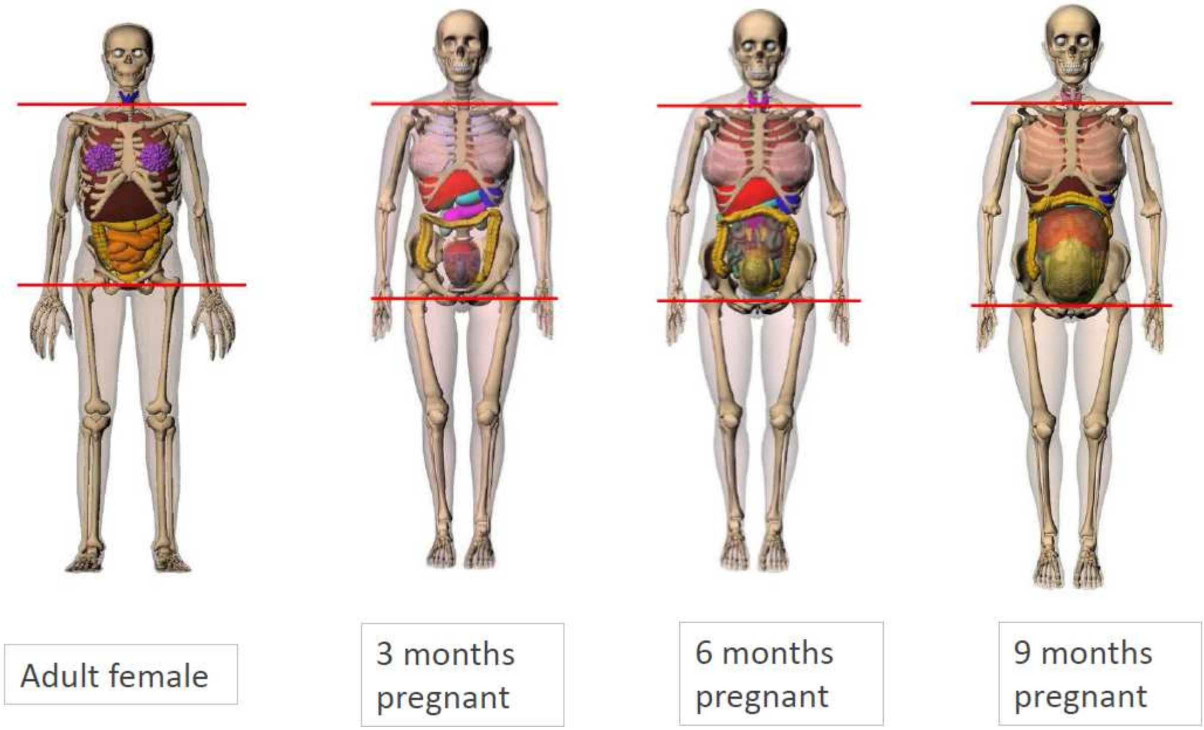
Dosimetry of the foetus: tools

Tools for retrospective analysis

(3) Specific software tools for pregnant patients

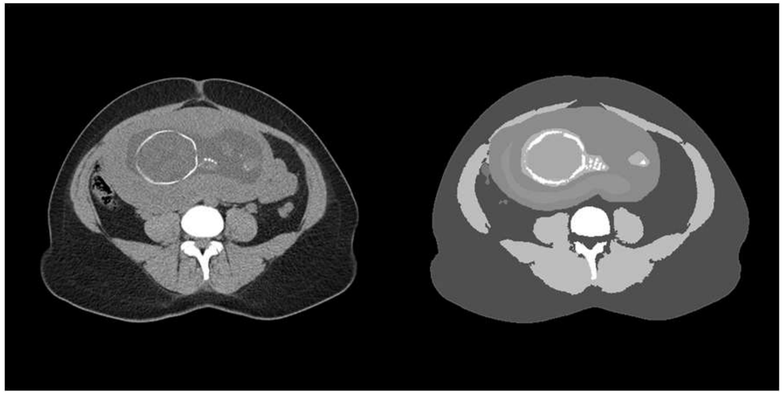


Example: VirtualDose,
as implemented in DOSE (Qaelum)

Dosimetry of the foetus: tools

Tools for retrospective analysis

(4) Individual Monte Carlo



Courtesy PhD Thesis, X. Lopez Rendon (KUL)

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Monte Carlo calculations compared to others

Model	Maternal age (y)	GA (w-d)	Trimester	Perimeter (cm)	kV	mAs/ref	Indication
1*	24	6	First	109.2	120	141/180	Crohn's disease
2*	25	12 -6	First	110.9	140	319/161	Polytrauma
3	22	17	Second	102.9	100	330/275	Fetal dysplasia
4†*	19	17-6	Second	95.1	140	188/350	Lower back pain
5	26	23-4	Second	85.6	120	65/100	Fetal dysplasia
6	31	24-1	Second	118	100	291/275	Fetal dysplasia
7	24	29-6	Third	96.2	120	171/200	Polytrauma
8	30	31-3	Third	107.9	100	241/275	Fetal Dysplasia

†Patients with fetus not fully covered,* Unknown pregnancy

Table 7.2: Radiation dose to the conceptus for the seven voxel models incl
estimated with the Monte Carlo framework, D_{uterus} was estimated with CT-Expo
in literature. The percentage error is presented consider

Model	GA (w-d)	ED (cm)	kV	$D_{conceptus}$ (mGy)	D_{uterus} (mGy)	%error D_{uterus}, $D_{conceptus}$	$D_{a,ave}$ (mGy)	%error $D_{a,ave}$, $D_{conceptus}$
1	6	29.8	120	18.6	15.7	-15.6	12.7	-31.8
2	12w 6d	29.7	140	45.1	55.1	22.2	NA	NA
3	17	28.9	100	14.2	18.8	32.4	NA	NA
5	23-4	26	120	7.9	6.7	-15.2	7	-11.1
6	24-1	34.3	100	12.5	17.5	40	NA	NA
7	29-6	27.2	120	24.9	20.6	-15.9	15.4	-37.2
8	31-3	30.4	100	12.9	18	39.5	NA	NA

A procedure in case of foetal dysplasia

Make (antropomorphic) test objects of different sizes with critical items;

Scan this object with several dose levels;

Define dose level at which the critical items are just visible and/or noise in images is at acceptable level;

Calculate SSDE for this test object.

A new patient arrives. Calculate her SSDE. Scan her with the dose level for that SSDE

(Courtey Inge Indesteege, Michael Aertsen, see you hopefully at ECR 2018)

(This could be a typical project as suggested by the FANC in their proposal of Belgian implementation of the BSS)

Summary:
Doses and risks… works in progress

- Things happen
- New concepts:
  - DRL curve
  - SSDE
  - LAR

Summary:
But this is only half of the story

- How can we balance dose and quality ?
- Is tube current modulation OK in children ?
- What do we know about image quality requirements in pediatric imaging ?

- I would love to run a specific quality project and report to you

UZ Leuven

- To the organizers
- To the physics team in Leuven
- To Walter Coudyzer
- To Michael Aertsen and prof. Marleen Smet
- To prof Oyen

- To all of you for picking this topic
  for your permanent training

THERE
COMES A TIME
WHEN YOU
HAVE TO CHOOSE
BETWEEN
TURNING THE
PAGE AND
CLOSING THE
BOOK.