Radiation risks and CT

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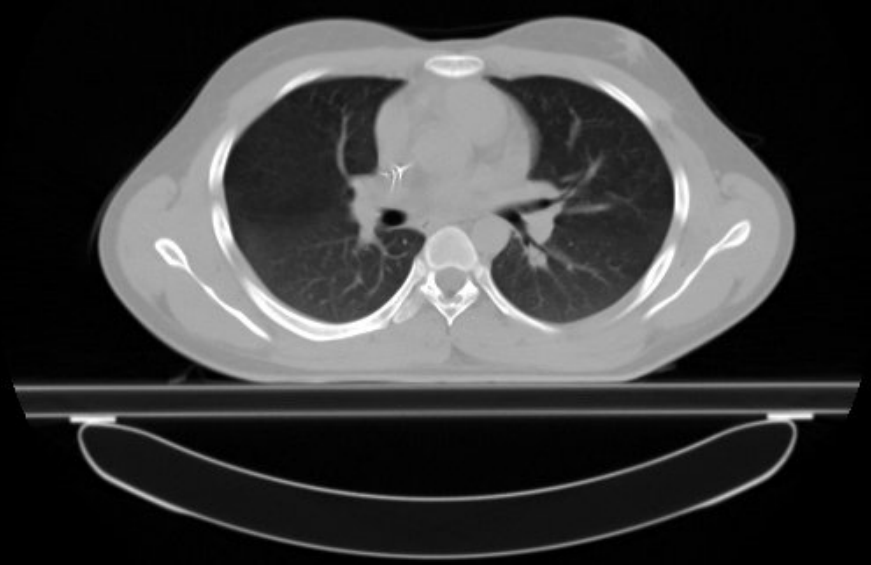
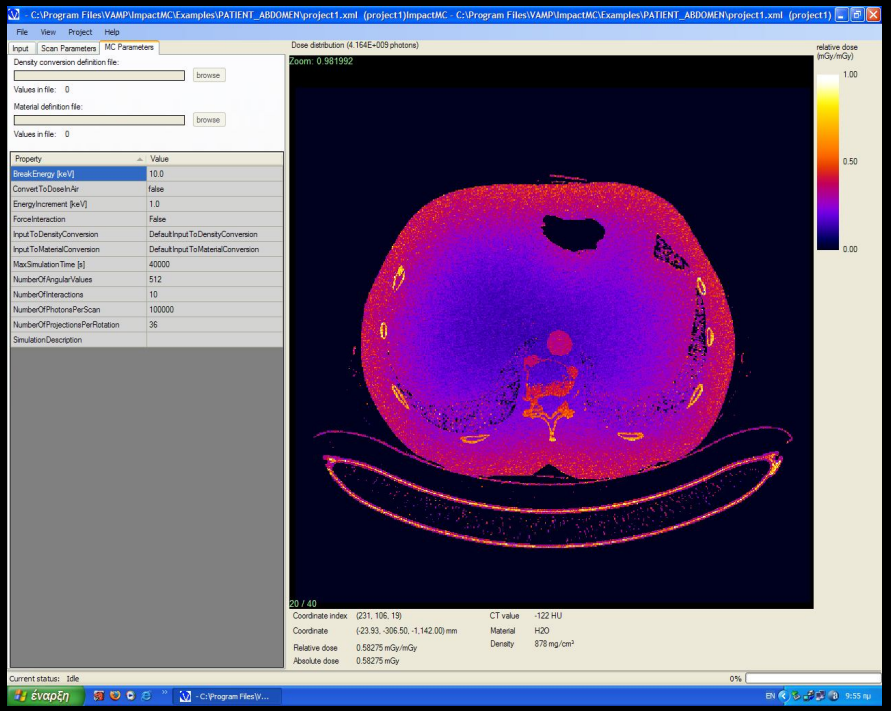
Doses from frequently-performed CT examinations





ORIGINAL RESEARCH ■ MEDICAL PHYSICS

Radiation Doses in Consecutive CT Examinations from Five University of California Medical Centers[1]

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Purpose: To summarize data on computed tomographic (CT) radiation doses collected from consecutive CT examinations performed at 12 facilities that can contribute to the creation of reference levels.

Materials and Methods: The study was approved by the institutional review boards of the collaborating institutions and was compliant with HIPAA. Radiation dose metrics were prospectively and electronically collected from 199 656 consecutive CT examinations in 83 181 adults and 3871 consecutive CT examinations in 2609 children at the five University of California medical centers during 2013. The median volume CT dose index ($CTDI_{vol}$), dose-length product (DLP), and effective dose, along with the interquartile range (IQR), were cal-

Radiology

Table 1

Radiation Dose Metrics in Adults

Area and Examination Type	No. of Examinations	$CTDI_{vol}$ (mGy)			DLP (mGy · cm)			Effective Dose (mSv)		
		25th Percentile	50th Percentile	75th Percentile	25th Percentile	50th Percentile	75th Percentile	25th Percentile	50th Percentile	75th Percentile
Head										
Single phase	25 245				640	880	1120	1	2	3
Multiphase	7418				1150	1550	2130	3	4	8
All	32 663	37	50	62	690	960	1300	2	2	3
Chest										
Single phase	16 413				260	420	610	5	9	13
Multiphase	10 444				570	880	1430	12	18	29
All*	26 857	7 (9)	12 (14)	17 (20)	320	550	830	6	11	18
Abdomen										
Single phase	22 755				360	580	860	6	10	16
Multiphase	40 412				850	1220	1790	15	22	32
All*	63 167	8 (11)	12 (15)	17 (19)	600	960	1460	11	17	26
Chest and abdomen										
Single phase	10 944				820	1260	1800	16	25	36
Multiphase	16 054				1070	1560	2160	21	31	43
All*	26 998	10 (12)	13 (16)	17 (20)	970	1450	2020	19	29	40
Sinus										
Single phase	3536				260	380	530	1	1	1
Multiphase	414				740	1210	1670	2	4	7
All	3950	16	25	29	280	400	610	1	1	2
Neck										
Single phase	2505				370	490	650	4	5	7
Multiphase	967				330	560	1150	5	7	14
All	3472	12	16	22	360	510	690	4	6	8
All other areas	42 549									

* Numbers in parentheses are SSDEs, which reflect an adjusted $CTDI_{vol}$ measurement.

Table 2

Radiation Dose Metrics in Children

Area and Examination Type	No. of Examinations	$CTDI_{vol}$ (mGy)			DLP (mGy · cm)			Effective Dose (mSv)		
		25th Percentile	50th Percentile	75th Percentile	25th Percentile	50th Percentile	75th Percentile	25th Percentile	50th Percentile	75th Percentile
Head										
Single phase	1116				290	420	570	1	2	3
Multiphase	166				540	870	1310	3	4	6
All	1282	22	30	38	310	450	650	1	2	4
Chest										
Single phase	292				50	90	130	2	3	4
Multiphase	63				70	150	210	2	6	7
All*	355	2 (3)	3 (4)	5 (6)	60	90	150	2	3	5
Abdomen										
Single phase	625				80	140	230	3	4	6
Multiphase	83				120	210	330	4	6	10
All*	708	2 (4)	4 (5)	5 (9)	90	140	230	3	4	7
Chest and abdomen										
Single phase	49				110	240	380	3	6	12
Multiphase	35				210	300	840	7	9	20
All*	84	3 (4)	4 (6)	8 (12)	130	270	510	5	9	15
Sinus										
Single phase	153				110	270	460	<0.5	1	2
Multiphase	32				270	570	850	1	2	4
All	185	9	18	28	150	310	500	1	1	2
Neck										
Single phase	103				90	140	340	2	3	6
Multiphase	16				170	270	590	4	6	9
All	119	5	6	13	100	160	340	2	4	6
All other areas	1138									

Note.—Examinations were performed in children younger than 1 year (n = 483 [12.5%]), 1–4 years (n = 949 [24.5%]), 5–9 years (n = 991 [25.6%]), and 10–14 years (n = 1448 [37.4%]).

* Numbers in parentheses are SSDEs, which reflect an adjusted $CTDI_{vol}$ measurement.

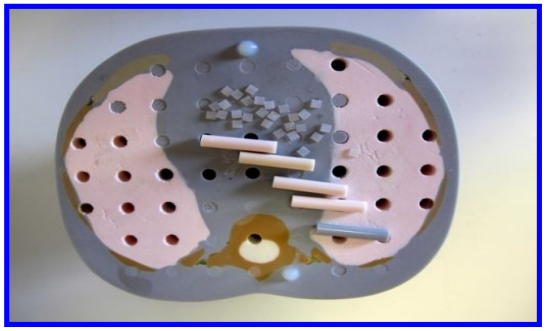
Effective dose ‘hides’ differences in the doses delivered to various organs from CT examinations

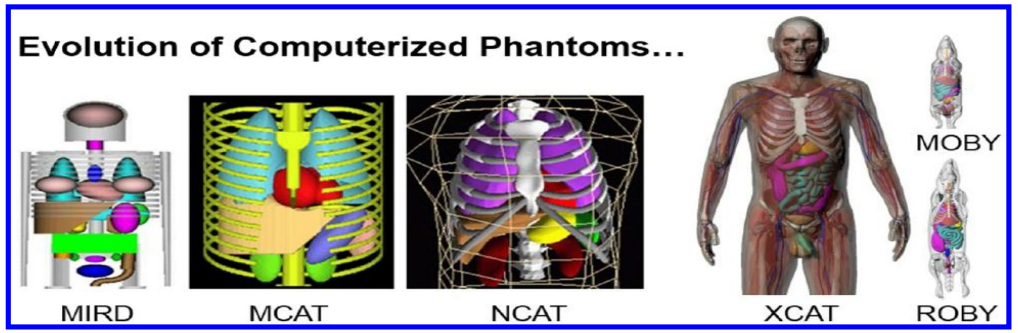
CCTA: Dose with 256-slice scanning

Effective Dose: < 2.0 mSv (Prospective mode)

Breast Dose: 14 mGy
Lung Dose: 9 mGy

It's important to focus on organ doses





Anthropomorphic phantoms represent only

standard size patients of standard ages

There are obvious differences in the anatomy and size of patients. Consequently, there may be considerable differences in the outer dimensions and organ location between phantoms and patients undergoing examinations

Patient-specific and equipment-specific dosimetry is needed

Most existing dose estimation methods don't take into consideration

- dual energy techniques

- parameters influencing dose such as contrast material

- new dose reduction tools (automatic kV selection ,

organ dose modulation etc)

Radiology

ORIGINAL RESEARCH ■ MEDICAL PHYSICS

Estimating the Patient-specific Dose to the Thyroid and Breasts and Overall Risk in Chest CT When Using Organ-based Tube Current Modulation[1]

Caro Franck, MSc
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Lore Lapeire, MD
Eric Achten, MD, PhD
Klaus Bacher, PhD

Purpose: To assess the potential dose reduction to the thyroid and breasts in chest computed tomography (CT) with organ-based tube current modulation (OBTCM).

Materials and Methods: In this retrospective study (from January 2015 to December 2016), the location of the breasts with respect to the reduced tube current zone was determined. With Monte Carlo simulations, patient-specific dose distributions of

Figure 1

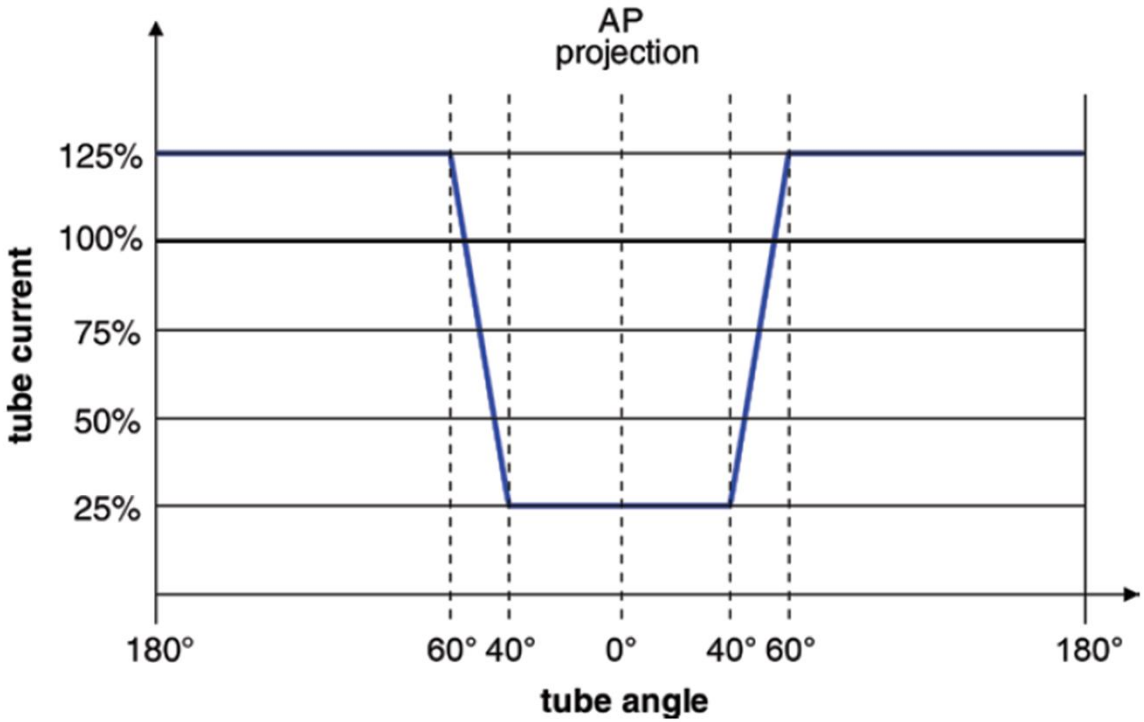


Figure 1: Graph shows that organ-based tube current modulation with X-CARE (Siemens Healthcare, Erlangen, Germany) reduces dose to anteriorly located organs by lowering tube current in axial plane within a range of 80°. To maintain image quality, tube current is higher during lateral and posterior part of body circumference. Relative milliampere values are shown, normalized to average tube current during one rotation. *AP* = anteroposterior. (Data from Siemens Healthcare.)

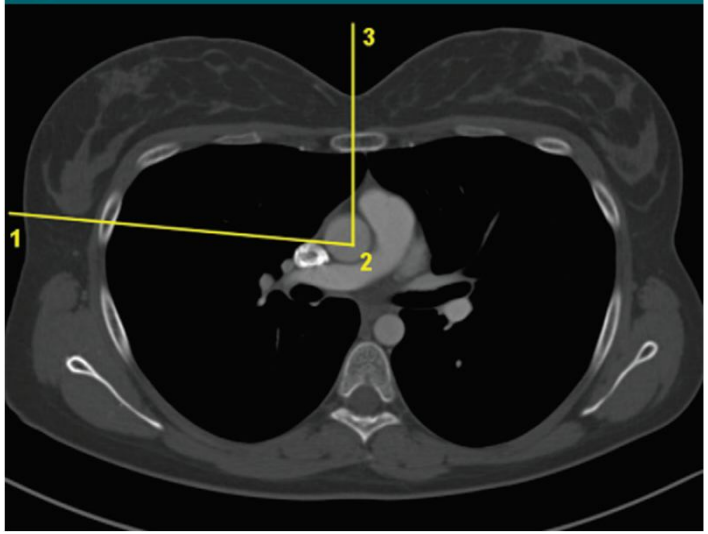
Table 3

Mean Organ Dose and Mean Percentage Dose Reduction

Organ ($n = 17$)	Organ Dose (mGy)			Potential Dose Reduction (%)	*P* Value	Clinical Dose Reduction (%)	*P* Value
	Standard Acquisition	Virtual OBTCM	OBTCM Acquisition				
Thyroid	21 ± 8	15 ± 6	17 ± 7	28 ± 5	<.001	18 ± 32	.04
Breast	17 ± 3	14 ± 3	16 ± 3	18 ± 3	<.001	9 ± 10	.003
Lung	15 ± 3	14 ± 3	17 ± 3	4 ± 2	<.001	−17 ± 19	.005
Liver	15 ± 3	13 ± 1	16 ± 2	10 ± 4	<.001	−11 ± 14	.01
Kidney	13 ± 1	14 ± 1	16 ± 2	−4 ± 3	<.001	−26 ± 18	<.001

Note.—Standard chest scans and organ-based tube current modulation simulations are compared. To compute the potential dose reduction, the same patient voxel models and scanning parameters are used as for the standard scans. The clinical dose reduction is based on the available CT data for 17 patients. Negative values indicate an increase in organ dose. Dose differences are statistically significant. OBTCM = organ-based tube current modulation.

Figure 3



Conclusion: The potential benefit of OBTCM to the female breast in chest CT is overestimated because of a limited reduced tube current zone; despite a 9% dose reduction to the female breast, posterior organs will absorb up to 26% more radiation, resulting in no reduction in radiation-induced malignancies.

Radiology

The Effect of Contrast Material on Radiation Dose at CT:

Part II. A Systematic Evaluation across 58 Patient Models[1]

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W. Paul Segars, PhD
Daniele Marin, MD
Rendon C. Nelson, MD
Ehsan Samei, PhD

Purpose: To estimate the radiation dose as a result of contrast medium administration in a typical abdominal computed tomographic (CT) examination across a library of contrast material–enhanced computational patient models.

Materials and Methods: In part II of this study, first, the technique described in part I of this study was applied to enhance the extended cardiac-torso models with patient-specific iodine-time profiles reflecting the administration of contrast material. Second, the patient models were deployed to assess the patient-specific organ dose as a function of time in a typ-

ORIGINAL RESEARCH ■ MEDICAL PHYSICS

Figure 4

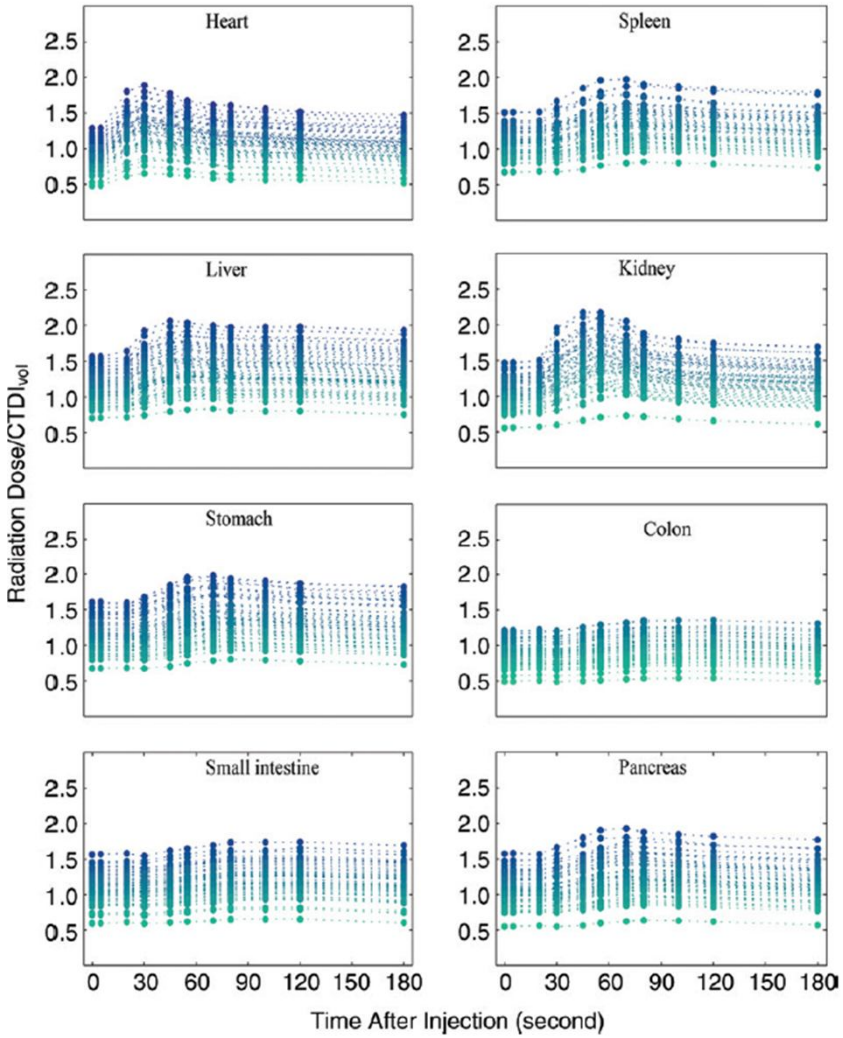

Figure 4: Graphs show results of Monte Carlo simulation of the organ dose to the heart, spleen, liver, kidneys, stomach, colon, small intestine, and pancreas as a function of time across the XCAT models for a contrast-enhanced abdominal CT examination. The organ doses are normalized by $CTDI_{vol}$.

Implication for Patient Care

- Contrast enhancement is used in more than 60% of CT imaging studies, which not only remarkably affects the CT image quality but also increases the total radiation dose.

The effect of iodine uptake on radiation dose absorbed by patient tissues in contrast enhanced CT imaging: Implications for CT dosimetry

Kostas Perisinakis[1,2] · Antonis Tzedakis[2] · Kostas Spanakis[3] · Antonios E. Papadakis[2] · Adam Hatzidakis[3,4] · John Damilakis[1,2]

European Radiology

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Abstract

Objectives To investigate the effect of iodine uptake on tissue/organ absorbed doses from CT exposure and its implications in CT dosimetry.

Methods The contrast-induced CT number increase of several radiosensitive tissues was retrospectively determined in 120 CT examinations involving both non-enhanced and contrast-enhanced CT imaging. CT images of a phantom containing aqueous solutions of varying iodine concentration were obtained. Plots of the CT number increase against iodine concentration were produced. The clinically occurring iodine tissue uptake was quantified by attributing recorded CT number increase to a certain concentration of aqueous iodine solution. Clinically occurring iodine uptake was represented in mathematical anthropomorphic phantoms. Standard 120 kV CT exposures were simulated using Monte Carlo methods and was 0.82% w/w. For the same CT exposure, iodinated tissues were found to receive higher radiation dose than non-iodinated tissues, with dose increase exceeding 100% for tissues with high iodine uptake.

Conclusions Administration of iodinated contrast medium considerably increases radiation dose to tissues from CT exposure.

Key-points

- *Radiation absorption ability of organs/tissues is considerably affected by iodine uptake*
- *Iodinated organ/tissues may absorb up to 100 % higher radiation dose*
- *Compared to non-enhanced, contrast-enhanced CT may deliver higher dose to patient tissues*
- *CT dosimetry of contrast-enhanced CT imaging should encounter tissue iodine uptake*

Eur Radiol (2018) 28:151–158

Table 4 Increase (%) of organ dose and effective dose in CECT exposures with respect to NECT exposures for female and male patients

Organ	Head and neck CT				Thoracic CT				Abdomen CT			
	CECTmean-NECT		CECTmax-NECT		CECTmean-NECT		CECTmax-NECT		CECTmean-NECT		CECTmax-NECT	
	f	m	f	m	f	m	f	m	f	m	f	m
Brain	2	3	4	4	2	4	3	4	1	2	1	5
Salivary glands	21	22	43	43	20	26	41	48	21	27	40	51
Thyroid	33	31	98	96	30	36	92	97	30	19	100	78
Breast	4	–	6	–	4	–	6	–	1	–	2	–
Muscle	6	6	11	12	6	6	11	12	5	6	10	11
Heart	19	17	33	33	22	21	37	35	16	12	28	29
Stomach	38	29	63	60	32	32	58	55	36	36	64	63
Liver	20	17	27	25	20	19	26	25	21	20	29	28
Spleen	33	31	49	48	31	30	51	49	32	30	51	49
Kidneys	45	43	62	59	46	46	64	64	52	50	74	72
Ovaries	10	–	19	–	11	–	26	–	11	–	22	–
Red bone marrow	9	9	22	20	10	11	20	18	10	12	21	24
Effective dose	22	23	64	66	7	10	15	20	12	13	23	23

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Original paper

What is the underestimation of radiation dose to the pediatric thyroid gland from contrast enhanced CT, if contrast medium uptake is not taken into account?

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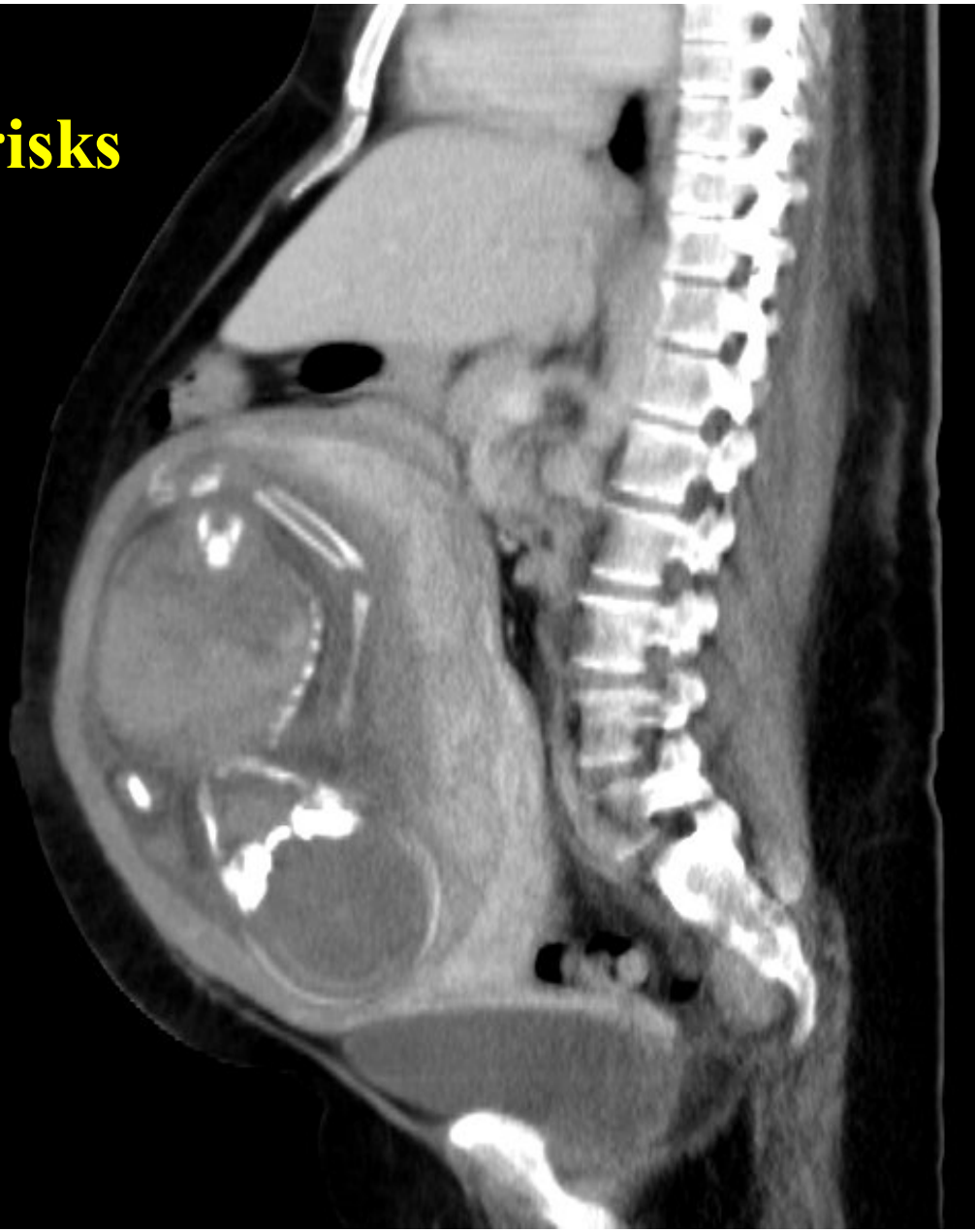
ARTICLE INFO

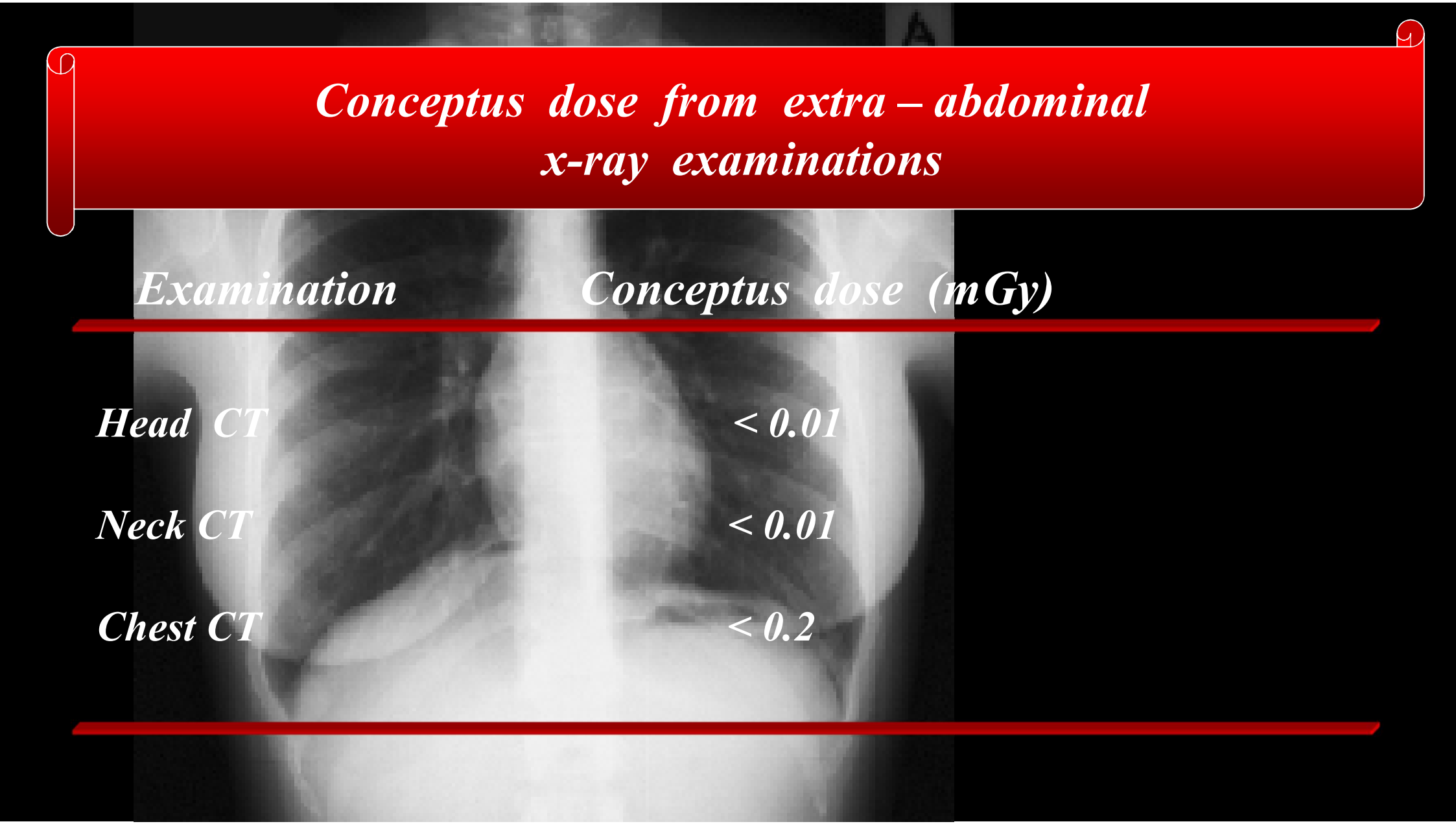
Keywords:
Thyroid
Pediatric
Iodinated contrast agent
CT
Radiation dose

Highlights

- The thyroid radiation dose from contrast-enhanced CT may be highly underestimated.
- The effect of iodinated contrast uptake should be encountered in thyroid dosimetry.
- The thyroid is frequently included in imaged volume of pediatric chest CT exams.
- Meticulous demarcation of imaged volume in pediatric chest CT exams is imperative.

Pregnancy: Conceptus doses and risks from CT examinations

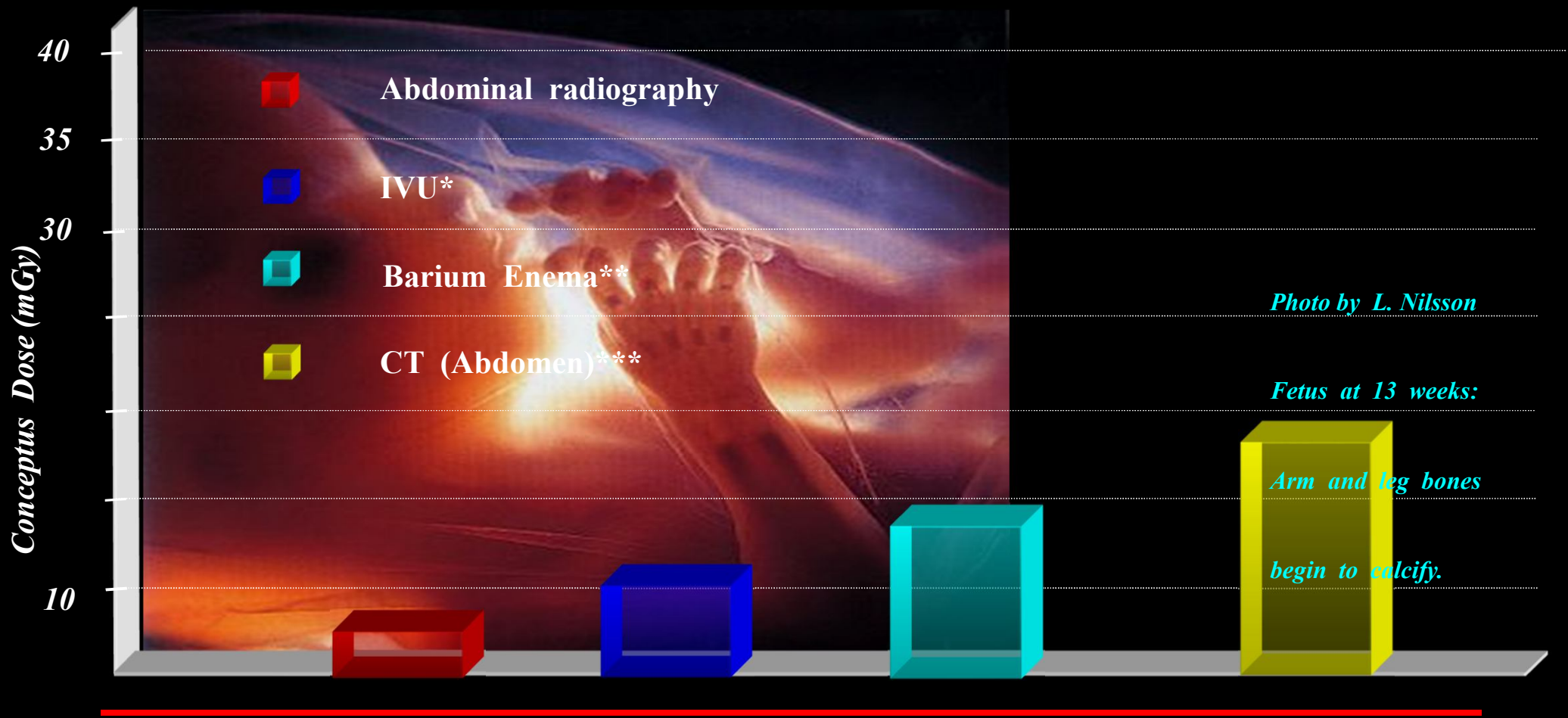




Conceptus dose from extra – abdominal x-ray examinations

Examination	*Conceptus dose (mGy)*
Head CT	*< 0.01*
Neck CT	*< 0.01*
Chest CT	*< 0.2*

Conceptus dose from abdominal X-ray examinations



** J. Damilakis et al, Radiat Prot Dosim 1997, **J. Damilakis et al, Invest Radiol 1996 ***J. Damilakis et al, Radiology 2010*

Conceptus absolute radiogenic risk

Radiation risk for fatal childhood cancer : 6% per Gy (6% per 1000 mGy)

If the conceptus dose from a diagnostic examination is 10 mGy

the risk of excess childhood fatal cancer is 0.06%

CT Screening

Cancer screening is becoming popular…..

Discov Med. 2016 Oct;22(121):181-188.

Cancer screening of asymptomatic individuals using 18F-FDG PET/CT in China: a retrospective study.

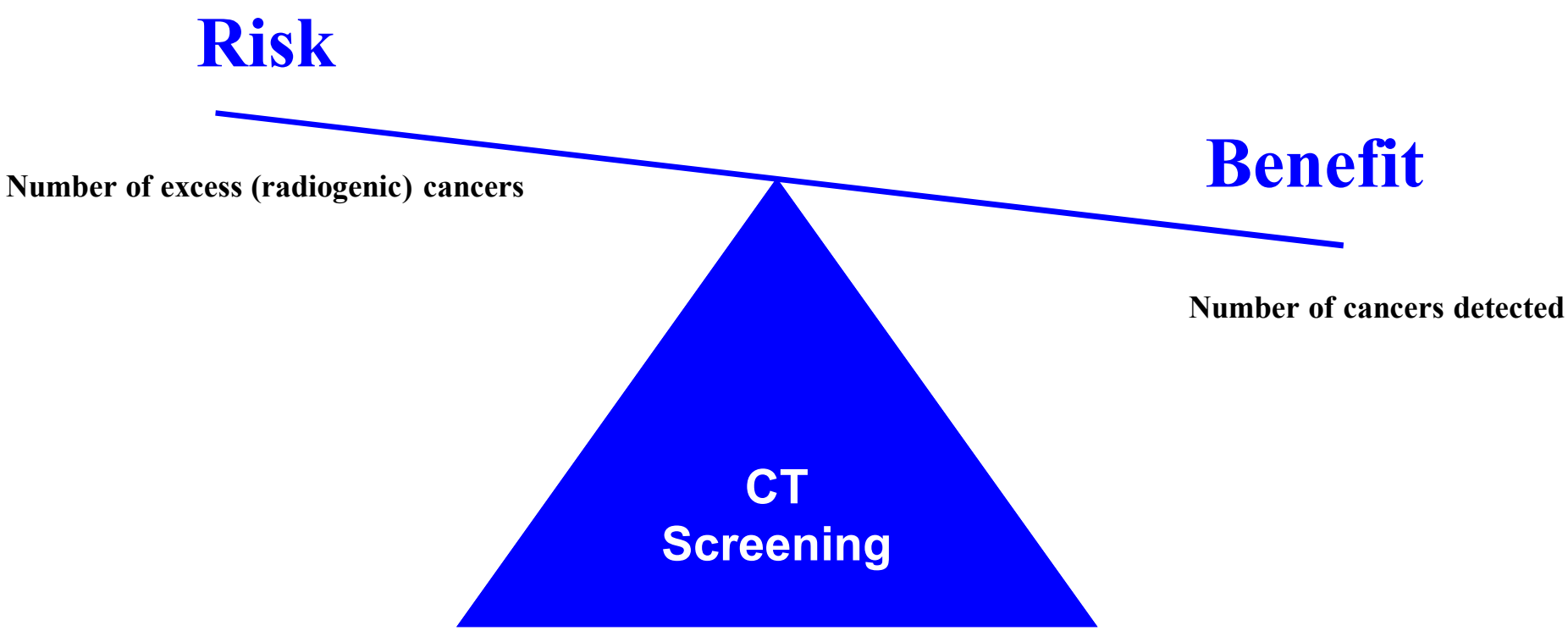
Tong J[1,2], Zou Y[3,2], Jiang J[4], Shi W[4], Tao R[4], Ye J[4], Lu Y[4], Jiang X[5,2], Wang W[6,2].

Author information

Abstract

BACKGROUND: In recent years, the application of 18F-fluorodeoxyglucose (FDG) positron emission tomography (PET)/computed tomography (CT) for voluntary cancer screening of asymptomatic individuals is becoming more and more popular in China. However, the utility of such screening is still controversial.

Benefits vs. risks

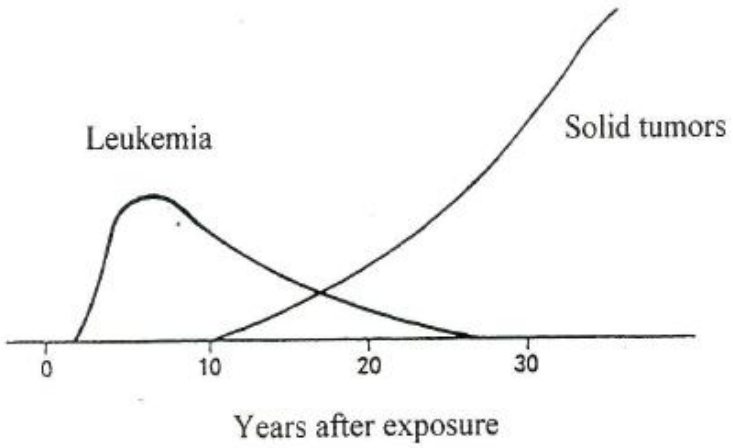


How do we estimate risk of radiation-induced cancer following CT for screening?

Epidemiological studies

It is not feasible to study the risk of radiogenic cancer from screening CT scans directly

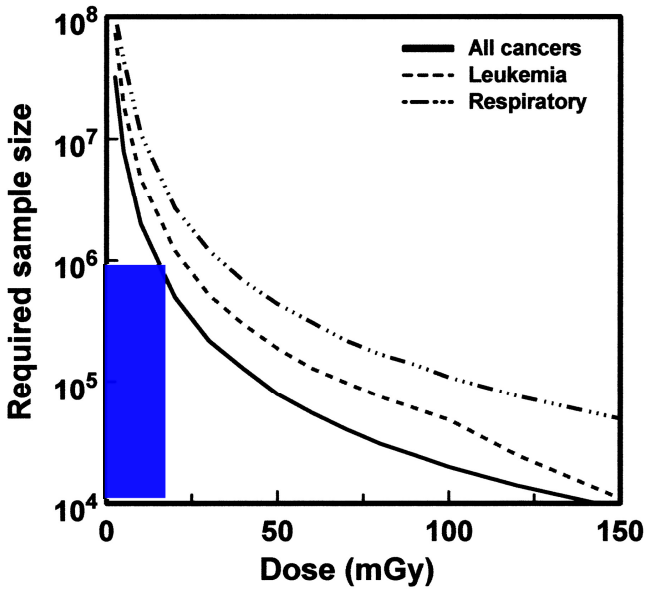
- **very long term patient follow-up due to the long latency for cancer development after exposure**



Epidemiological studies

It is not feasible to study the risk of radiogenic cancer from screening CT scans directly

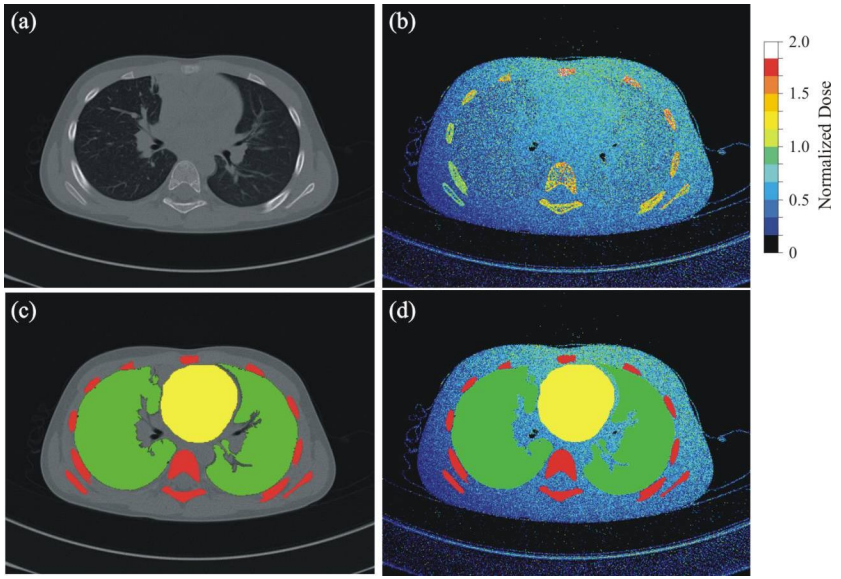
- **very large number of patients needed to perform statistical analysis**



Size of a cohort which would be required to detect a significant increase in cancer mortality in that cohort, assuming lifetime follow-up.

Brenner et al, PNAS 100:13761-13766, 2003

Accurate dosimetry + risk coefficients



LAR of cancer incidence (BEIR VII – Phase 2)

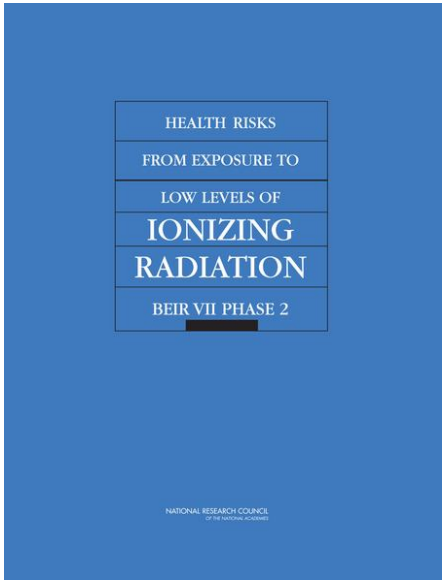


TABLE 12D-1 Lifetime Attributable Risk of Cancer Incidence[a]

	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 of cancer mortality (BEIR VII – Phase 2)

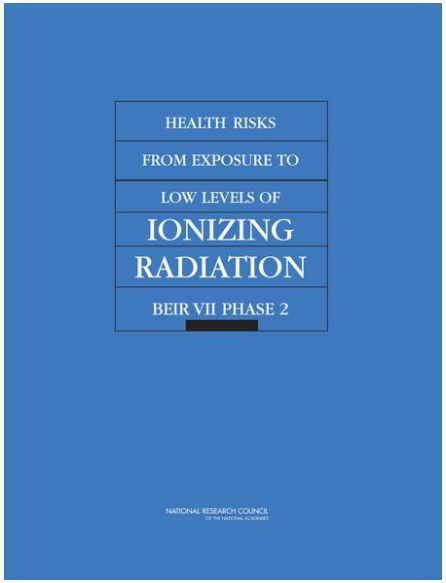


TABLE 12D-2 Lifetime Attributable Risk of Cancer Mortality[a]

	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.

CT exams that have been used for screening

- **Lung cancer CT to screen smokers of particular ages**
- **CT virtual colonoscopy to screen for colorectal cancer**
- **Whole body CT for anything that can be found**
- **CT coronary calcium scoring to screen for heart disease**

Lung cancer screening

RESEARCH

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Exposure to low dose computed tomography for lung cancer screening and risk of cancer: secondary analysis of trial data and risk-benefit analysis

Cristiano Rampinelli,[1] Paolo De Marco,[2] Daniela Origgi,[3] Patrick Maisonneuve,[4] Monica Casiraghi,[5] Giulia Veronesi,[5,6] Lorenzo Spaggiari,[5,7] Massimo Bellomi[1,7]

British Medical Journal 356:j347, 2017

Cancer screening with LDCT

Italy: COSMOS Study, 5203 participants

- MDCT in heavy smokers (20+ pack-years of cigarette smoking)
- age > 50 years
- 5,203 subjects
- Milan, 2004-2015
- Annual LDCT for 10 consecutive years
- Additional recalls for suspicious findings with LDCT and PET/CT

Table 2 | Median cumulative organ dose and effective doses for screening and recall low dose CT scans and PET CT scans at baseline, 3rd, 5th, and 10th screening round

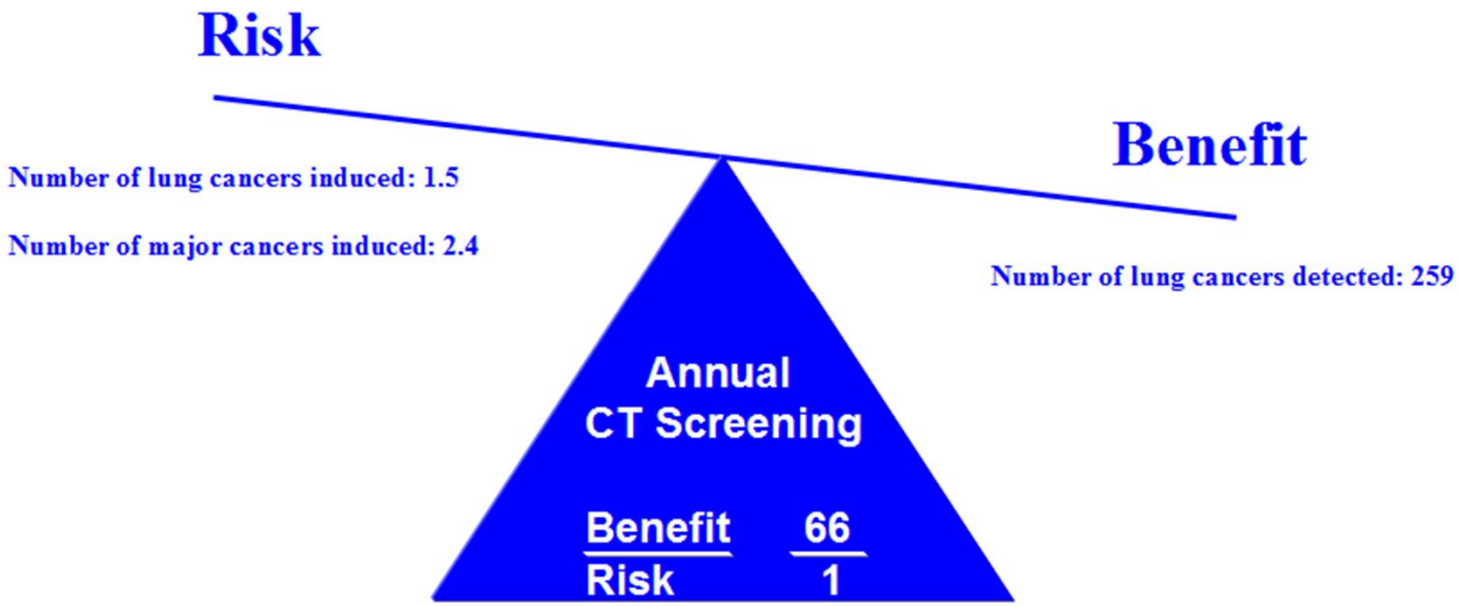
	Men				Women			
	Baseline	3rd year	5th year	10th year	Baseline	3rd year	5th year	10th year
No of participants	3439	3056	2768	1850	1764	1527	1352	884
Effective dose (mSv)	1.0	3.0	5.2	9.3	1.4	4.2	7.2	13.0
Organ dose (mGy):								
Breast	—	—	—	—	2.5	7.6	13.0	23.3
Bladder	0.0	0.1	0.1	0.2	0.0	0.1	0.1	0.2
Colon	0.2	0.7	1.2	2.2	0.2	0.6	1.1	2.0
Oesophagus	1.4	4.5	7.7	13.6	1.8	5.6	9.5	16.9
Gallbladder	1.5	4.6	7.9	14.0	1.3	4.2	7.2	12.9
Heart	2.1	6.8	11.5	20.5	2.5	7.6	13.0	23.2
Kidney	1.9	5.9	10.1	18.0	1.8	5.6	9.7	17.4
Liver	1.9	6.1	10.4	18.4	2.1	6.6	11.2	20.0
Lung	2.3	7.1	12.2	21.7	2.7	8.3	14.2	25.3
Ovaries	—	—	—	—	0.1	0.2	0.3	0.6
Marrow	0.8	2.5	4.3	7.6	0.9	2.8	4.7	8.4
Skeleton	1.4	4.3	7.4	13.3	1.7	5.3	9.1	16.5
Spleen	2.0	6.1	10.5	18.6	2.2	6.8	11.7	20.9
Stomach	1.9	5.9	10.0	17.9	2.0	6.1	10.4	18.7
Thyroid	0.2	0.6	1.1	1.9	0.5	1.6	2.8	5.2
Uterus	—	—	—	—	0.1	0.2	0.3	0.5

Table 3 | Number of lung cancers detected after 10 years of CT screening and number of estimated lung and major cancers associated with radiation exposure, according to age and sex of COSMOS trial participants

Participant age and sex at start of screening	No of participants	No of lung cancers detected	No of estimated radiation induced lung cancers (LAR/10 000)	No of estimated radiation induced major cancers* (LAR/10 000)
50-54				
Male	1153	35 (1 in 33)	0.24 (2.1)	0.43 (3.7)
Female	606	19 (1 in 32)	0.33 (5.5)	0.49 (8.1)
55-59				
Male	1114	56 (1 in 20)	0.21 (1.9)	0.38 (3.4)
Female	611	31 (1 in 20)	0.31 (5.1)	0.44 (7.2)
60-64				
Male	716	54 (1 in 13)	0.12 (1.7)	0.22 (3.0)
Female	345	13 (1 in 27)	0.16 (4.5)	0.21 (6.2)
≥65				
Male	456	41 (1 in 11)	0.07 (1.4)	0.12 (2.6)
Female	202	10 (1 in 20)	0.08 (3.8)	0.10 (5.1)
All ages, both sexes	5203	259 detected	1.5 induced	2.4 induced

LAR=lifetime attributable risk.
*Cumulative LAR for cancers of the stomach, colon, liver, lung, bladder, thyroid, breast, ovaries, uterus, or leukaemia.

Benefit vs. Radiogenic risk



MEDIRAD project

Subtask 2.1.3 Development of an innovative software tool on image quality and radiation dose (UoC, *OvGU, IPC, VGR, UPDescartes, ISGlobal)* ***M12-M48***

Data produced in ST2.1.1 and ST2.1.2 will be integrated into a freeware modular software expert system [CT Image Quality and Radiation Dose (CT-IQURAD)] that will provide a) image quality information, b) accurate estimation of patient organ doses and c) estimation of radiogenic risk associated with chest CT examinations performed for several clinical indications. This tool will be of paramount importance for the determination of the optimal chest CT protocol based on the relation between clinical indication, required image quality and lowest achievable dose. The prototype will be clinically evaluated in the university hospitals participating in ST2.1.1. The 'organ dose and risk estimation' module can be stand alone or Windows based. This tool will be available by the end of the project for chest CT optimisation. For optimisation of CT examinations on other anatomical areas, further research would be needed using the same methodology.

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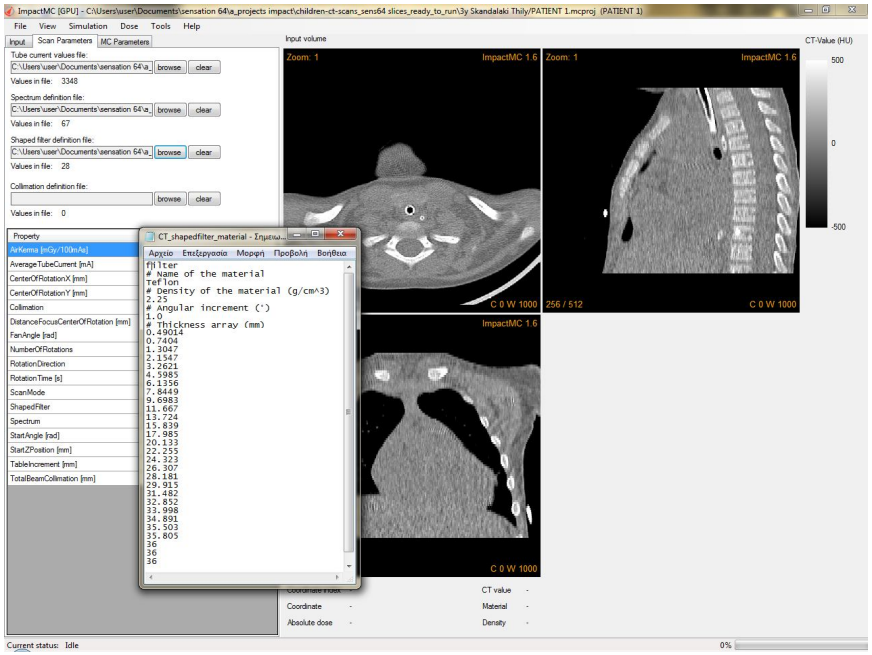
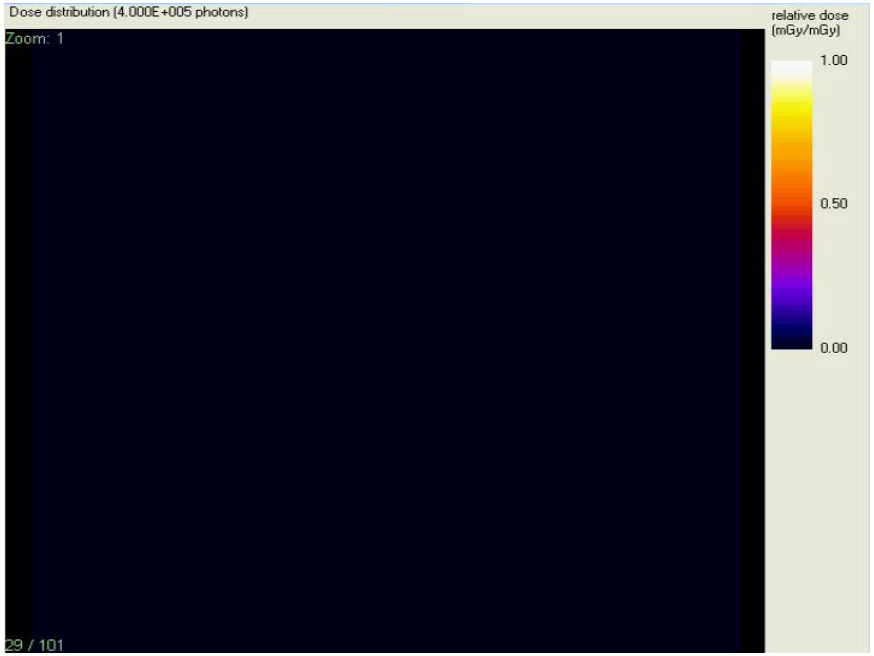
MEDIRAD project





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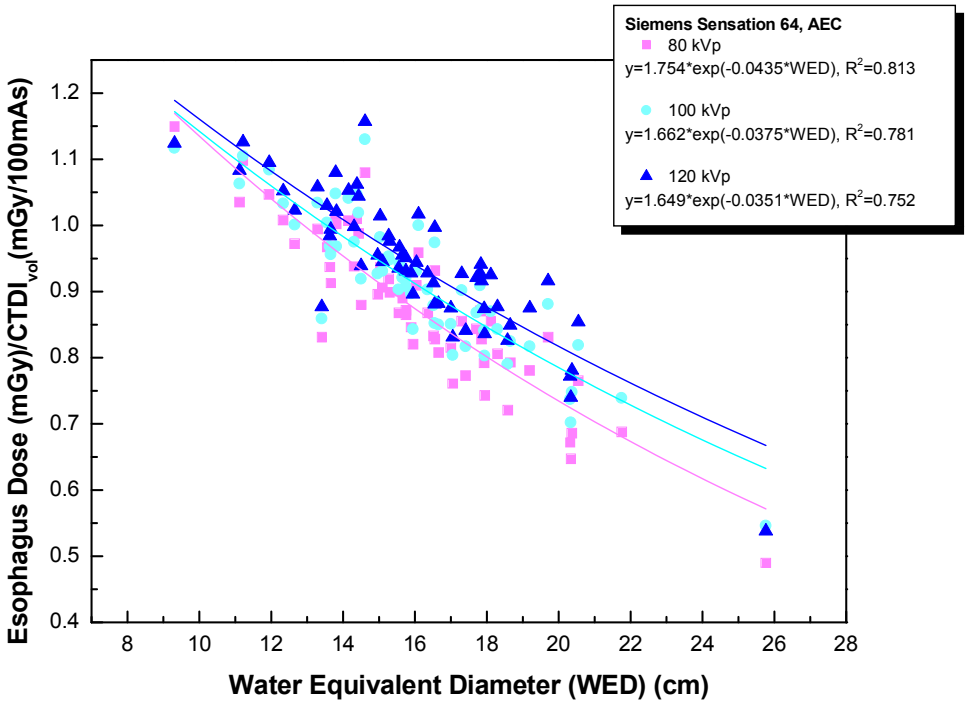

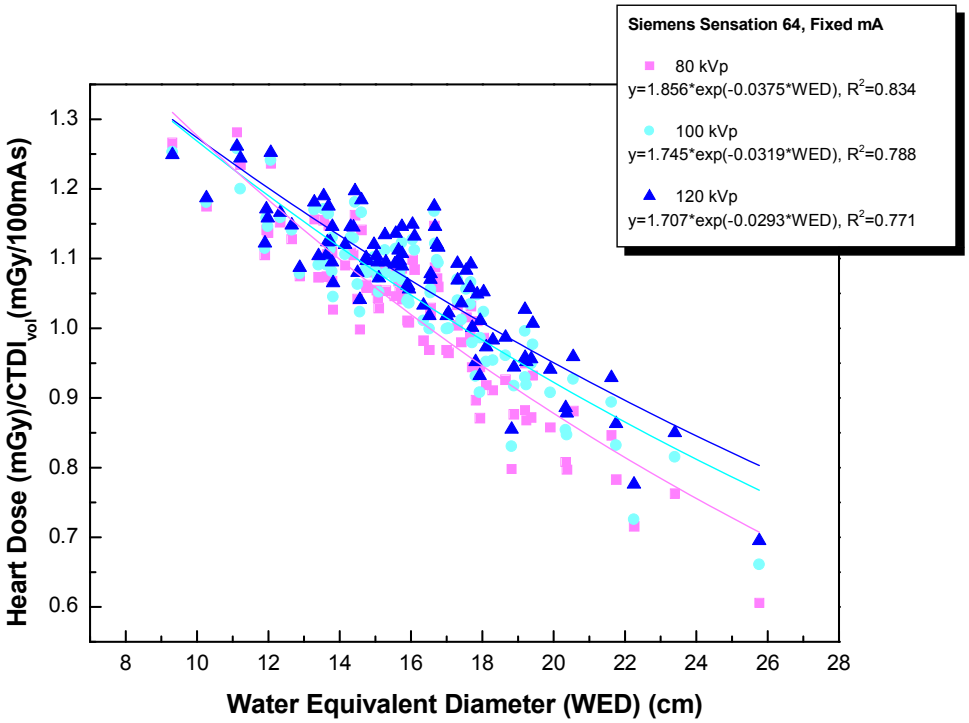

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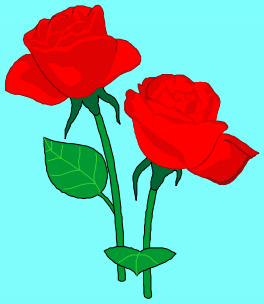

Thank you !