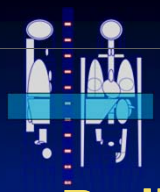


Radiation Dose and Radiation Risk

Dominik Fleischmann

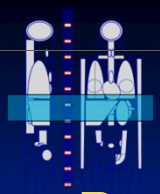
Department of Radiology
Stanford University

Radiation Dose and Radiation Risk

OBJECTIVE

Explain Radiation dose parameters (for CT) and associated risk of radiation exposure:

CT specific	• CTDIvol: milligray (mGy) • DoseLength product (mGy*cm)
general	• whole body dose (mSv) (relates to risk)



Radiation Risk (mSv)

general	• whole body dose (mSv) (relates to risk)

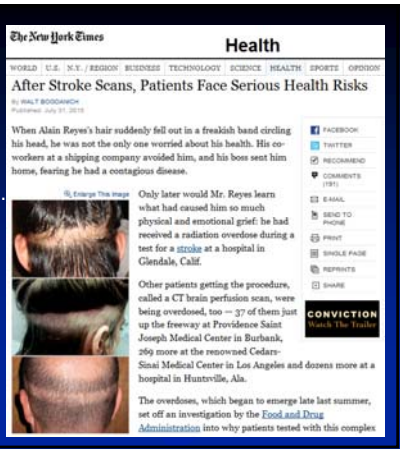
Risk of Radiation Exposure

Internatonal commision on radiological protection – IRCP estimates

- Deterministic *(high dose range)*
  - 250 – 500 mSv blood changes
  - >4000 mSv 50% probability of death
- Stochastic *(low dose range)*
  - Risk of fatal cancer (~5% per 1000mSv)
  - Risk of non-fatal cancer (1.2% per 1000mSv)

~ 0.01 % /mSv Cancer risk (incl.non-fatal)
~ 0.005 % /mSv fatal Cancer risk

Deterministic effects of high radiation dose ..



The New York Times — Health

WORLD | U.S. | N.Y. / REGION | BUSINESS | TECHNOLOGY | SCIENCE | HEALTH | SPORTS | OPINION

After Stroke Scans, Patients Face Serious Health Risks

By WALT BOGDANICH
Published: July 31, 2010

When Alain Reyes's hair suddenly fell out in a freakish band circling his head, he was not the only one worried about his health. His co-workers at a shipping company avoided him, and his boss sent him home, fearing he had a contagious disease.

Enlarge This Image

Only later would Mr. Reyes learn what had caused him so much physical and emotional grief: he had received a radiation overdose during a test for a stroke at a hospital in Glendale, Calif.

Other patients getting the procedure, called a CT brain perfusion scan, were being overdosed, too — 37 of them just up the freeway at Providence Saint Joseph Medical Center in Burbank, 269 more at the renowned Cedars-Sinai Medical Center in Los Angeles and dozens more at a hospital in Huntsville, Ala.

The overdoses, which began to emerge late last summer, set off an investigation by the Food and Drug Administration into why patients tested with this complex

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Deterministic effects of high radiation dose ..

California Bill
SB 1237
(signed Sept 2010)

SB 1237 —2—

CHAPTER _____

An act to add Sections 115111, 115112, and 115113 to the Health and Safety Code, relating to public health.

LEGISLATIVE COUNSEL'S DIGEST

SB 1237, Padilla. Radiation control: health facilities and clinics: records.

Under existing law, the State Department of Public Health licenses and regulates health facilities and clinics, as defined.

Under existing law, the Radiation Control Law, the department licenses and regulates persons that use devices or equipment utilizing radioactive materials. Under existing law the department may also require registration and inspection of sources of ionizing radiation, as defined. Violation of these provisions is a crime.

This bill would, commencing July 1, 2012, require hospitals and clinics, as specified, that use computed tomography (CT) X-ray systems for human use to record, if the CT systems are capable, the dose of radiation on every CT study produced during the administration of a CT examination, as specified. The bill would require the dose to be verified annually by a medical physicist, as specified, unless the facility is accredited.

This bill would, commencing July 1, 2013, require facilities that furnish CT X-ray services to be accredited by an organization that is approved by the federal Centers for Medicare and Medicaid Services, an accrediting agency approved by the Medical Board of California, or the State Department of Public Health. The bill would also require the facility to report certain information to the department, the affected patient, and the patient's treating physician.

Because this bill expands the definition of a crime, it would impose a state-mandated local program.

The California Constitution requires the state to reimburse local agencies and school districts for certain costs mandated by the state. Statutory provisions establish procedures for making that reimbursement.

This bill would provide that no reimbursement is required by this act for a specified reason.

Risk of Radiation Exposure

Internatonal commision on radiological protection – IRCP estimates

- Deterministic *(high dose range)*
  - 250 – 500 mSv blood changes
  - >4000 mSv 50% probability of death
- Stochastic *(low dose range)*
  - <100 mSv: definition of 'low exposure'
  - Risk of non-fatal cancer
  - Risk of fatal cancer

not well known,
linear, no threshold dose-effect relationship?

Estimated number of cancers from 100mSv exposure for 100,000 persons

Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VI report

Berrington de Gonzalez et al., Arch Intern Med. 2009

	All solid cancer		Leukemia	
	males	females	males	females
Excess cases (including non-fatal)	800 (400-1600)	1300 (600-2500)	100 (30-300)	70 (20-250)
cases in the absence of exposure	45,500	36,900	830	590
Ex… exp…				
dea… of exposure				

~1000 cancers / 100mSv / 100,000 persons =
~10 cancers / mSv / 1,000 persons =
~1 cancer / mSv / 10,000 persons = ..

~ 0.01% / mSv Cancer risk (incl. non fatal)
~ 0.005% / mSv fatal Cancer

MDCT Radiation Dose

Typical effective dose values

C. McCollough, MDCT Course 2003 San Francisco

Head CT	1-2 mSv
Chest CT	5-8 mSv
Abdomen CT	5-10 mSv
Pelvis CT	3-4 mSv
Abd-Pelv CT	8-15 mSv
Chest x-ray	0.02 mSv
Abdomen x-ray	0.07 mSv

- Average U.S background radiation ~ 3.6 mSv

~ 0.01% / mSv Cancer risk (incl. non fatal)
~ 0.005% / mSv fatal Cancer

Estimated Risks of Fatal Malignancy of Death from Radiation Exposure and Lifetime Odds of Dying as a Result of Selected Activities of Everyday Life

	(per 100 Individuals)
1 mSv (calcium score)	0.005
10mSv (coronary CT, cath, ..)	0.05
50mSv (yr radiation worker allowance)	0.25
100mSv (definition of 'low exposure')	0.5
NATURAL fatal cancer	21.2
passive smoking	0.4-1.0
radon in home (US average)	0.3
Motor vehicle accident	1.9

~ 0.005% / mSv fatal Cancer

Gerber et al. Circulation 2009

Computed Tomography (CT) in the United States in 2007

- approx. 70 million scans / year (threefold increase of CT since 1993)

ORIGINAL INVESTIGATION

Projected Cancer Risks From Computed Tomographic Scans Performed in the United States in 2007

Amy Berrington de Gonzalez, DPhil; Mahadevappa Mahesh, MS, PhD; Kwang-Pyo Kim, PhD; Mythreyi Bhargavan, PhD; Rebecca Lewis, MPH; Fred Mettler, MD; Charles Land, PhD

Background: The use of computed tomographic (CT) scans in the United States (US) has increased more than 3-fold since 1993 to approximately 70 million scans annually. Despite the great medical benefits, there is concern about the potential radiation-related cancer risk. We conducted detailed estimates of the future cancer risks from current CT scan use in the US according to age, sex, and scan type.

(95% UL, 15 000-45 000) future cancers could be related to CT scans performed in the US in 2007. The largest contributions were from scans of the abdomen and pelvis (n = 14 000) (95% UL, 6900-25 000), chest (n = 4100) (95% UL, 1900-8100), and head (n = 4000) (95% UL, 1100-8700), as well as from chest CT angiography (n = 2700) (95% UL, 1300-5000). One-third of the projected cancers were due to scans performed at the ages

Berrington de Gonzalez et al., Arch Intern Med. 2009

Computed Tomography (CT) in the United States in 2007

- approx. 70 million scans / year (threefold increase of CT since 1993)

Overall, we estimated that approx. 29 000 * (95% UL, 15 000-45 000) future cancers could be related to CT scans performed in '07 in US.

The largest contributions were from scans of
- abdomen and pelvis (n = 14 000)
- chest (n=4100),
- head (n=4000),
- chest CT angiography (n=2700).

(*2% of ~1.4 m cancers diagnosed annually in US)

Berrington de Gonzalez et al., Arch Intern Med. 2009

Number of CT Scans Performed in the U.S. in 2007
Estimated using IMV,7 Medicare, and nationalcommercial insurance database.

Scan Type	Scans (mio)	Percent
Head	21.5	30
Chest	11	15
Cervical spine	1.8	2.5
Thoracic spine	0.4	0.6
Lumbar spine	2.5	3.5
Abdomen/pelvis	24.2	34
CTA chest	2.6	3.6
CTA abdomen	0.9	1.3
CTA pelvis	0.5	0.7
CTA head	0.7	1.0
other cardiac	0.5	0.7
Whole body	0.3	0.4
Colonography	0.2	0.3
calcium scoring	0.7	1.0
Other	4	5.6
Total	71.7	100.0

Berrington de Gonzalez et al. Arch Intern Med. 2009

MDCT Radiation Dose

Typical effective dose values

C. McCollough, MDCT Course 2003 San Francisco

- Head CT 1-2 mSv
- Chest CT 5-8 mSv
- Abdomen CT 5-10 mSv
- Pelvis CT 3-4 mSv
- Abd-Pelv CT 8-15 mSv

- Chest x-ray 0.02 mSv
- Abdomen x-ray 0.07 mSv

CT dose of 15mSv
~ 750 chest x-rays
~ 4 years backgr.

~ 0.15% cancer (incl. non-fatal)

- Average U.S background radiation ~ 3.6 mSv

MDCT Radiation Dose

Typical effective dose values

C. McCollough, MDCT Course 2003 San Francisco

- Head CT 1-2 mSv
- Chest CT 5-8 mSv
- Abdomen CT 5-10 mSv
- Pelvis CT 3-4 mSv
- Abd-Pelv CT 8-15 mSv

- Chest 5-8 mSv (12-18 mGy)
- Low-dose Chest 2-5 mSv (5-12 mGy)
- HR-CT 1.2-2.5 mSv (3-5 mGy)

- Average U.S background radiation ~ 3.6 mSv

MDCT Radiation Dose

Calculated radiation-induced Risk of dying from cancer per mSv.

- Child (0-10y)
- Adolescent (10-20y)
- Adult (20-30y)
- Adult (30-40y)
- Adult (60)
- Adult (80)

Estimates, extrapolated from accidental or occupatonal whole-body exposure to high doses and dose-rates. Risk cannot yet be statistically proven for an effective dose below 20mSv.

- Average 5.0 / 100 000 0.005% / mSv
- Natural risk 30 000.0 / 100 000

~ 0.01% / mSv Cancer risk (incl. non-fatal)

IRCP publication 60

The Lancet, June 2012

Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study

Mark S Pearce, Jane A Salotti, Mark P Little, Kieran McHugh, Choonsik Lee, Kwang Pyo Kim, Nicola L Howe, Cecile M Ronckers, Preetha Rajaraman, Sir Alan W Craft, Louise Parker, Amy Berrington de Gonzalez

Summary

Background Although CT scans are very useful clinically, potential cancer risks exist from associated ionising radiation, in particular for children who are more radiosensitive than adults. We aimed to assess the excess risk of leukaemia and brain tumours after CT scans in a cohort of children and young adults.

Methods In our retrospective cohort study, we included patients without previous cancer diagnoses who were first examined with CT in National Health Service (NHS) centres in England, Wales, or Scotland (Great Britain) between 1985 and 2002, when they were younger than 22 years of age. We obtained data for cancer incidence, mortality, and loss to follow-up from the NHS Central Registry from Jan 1, 1985, to Dec 31, 2008. We estimated absorbed brain and red bone marrow doses per CT scan in mGy and assessed excess incidence of leukaemia and brain tumours cancer with Poisson relative risk models. To avoid inclusion of CT scans related to cancer diagnosis, follow-up for leukaemia began 2 years after the first CT and for brain tumours 5 years after the first CT.

Findings During follow-up, 74 of 178 604 patients were diagnosed with leukaemia and 135 of 176 587 patients were diagnosed with brain tumours. We noted a positive association between radiation dose from CT scans and leukaemia (excess relative risk [ERR] per mGy 0·036, 95% CI 0·005–0·120; p=0·0097) and brain tumours (0·023, 0·010–0·049; p<0·0001). Compared with patients who received a dose of less than 5 mGy, the relative risk of leukaemia for patients who received a cumulative dose of at least 30 mGy (mean dose 51·13 mGy) was 3·18 (95% CI 1·46–6·94) and the relative risk of brain cancer for patients who received a cumulative dose of 50–74 mGy (mean dose 60·42 mGy) was 2·82 (1·33–6·03).

Interpretation Use of CT scans in children to deliver cumulative doses of about 50 mGy might almost triple the risk of leukaemia and doses of about 60 mGy might triple the risk of brain cancer. Because these cancers are relatively rare, the cumulative absolute risks are small: in the 10 years after the first scan for patients younger than 10 years, one excess case of leukaemia and one excess case of brain tumour per 10 000 head CT scans is estimated to occur. Nevertheless, although clinical benefits should outweigh the small absolute risks, radiation doses from CT scans ought to be kept as low as possible and alternative procedures, which do not involve ionising radiation, should be considered if appropriate.

Fonding US National Cancer Institute and UK Department of Health.

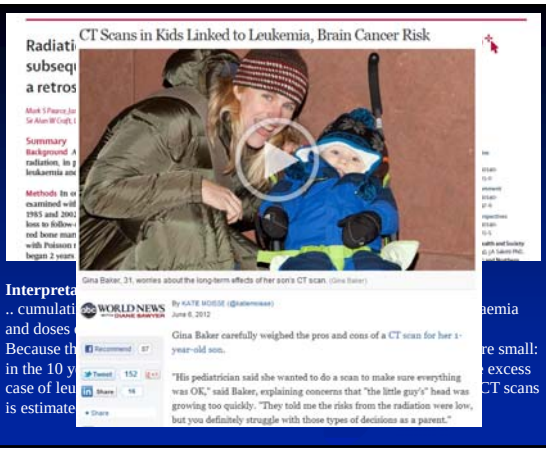
The Lancet, June 2012

Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study

Interpretation

.. cumulative doses of about 50 mGy might almost triple the risk of leukaemia and doses of about 60 mGy might triple the risk of brain cancer. Because these cancers are relatively rare, the cumulative absolute risks are small: in the 10 years after the first scan for patients younger than 10 years, one excess case of leukaemia and one excess case of brain tumour per 10 000 head CT scans is estimated to occur.

The Lancet, June 2012



MDCT Radiation Dose

Calculated radiation-induced Risk of dying from cancer per mSv.

• Child (0-10y)	14 / 100 000	
• Adolescent (10-20y)	10 / 100 000	
• Adult (20-30y)	7.5 / 100 000	
• Adult (30-40y)	3.5 / 100 000	
• Adult (60)	2.0 / 100 000	
• Adult (80)	1.0 / 100 000	
• Average	5.0 / 100 000	0.005% / mSv
• Natural risk	30 000.0 / 100 000	

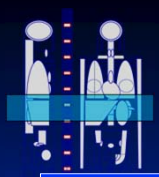
~ 0.01% / mSv Cancer risk (incl. non-fatal)

IRCP publication 60

Radiation Risk: Summary

- very difficult estimate true effective dose (mSv) from CT exposure parameters (CTDI, DPL)
- Radiation has deterministic effects at high doses (>250mSv),
- CT doses are in the low dose range (<100mSv), typically 1–50 mSv, which has stochastic effects (i.e. cancer, on population basis), with wide error margins of estimates
  - **~ 0.01% / mSv Cancer risk (incl. non fatal)**
  - **~ 0.005% / mSv fatal Cancer**
- prudent to reduce dose ALARA (as low as reasonably achievable)

RADIATION DOSE AND RISK IN CT



CT specific CTDIvol: milligray (mGy)
- DoseLength product (mGy*cm)

Radiation Dose (CT)

Radiation Dose in Computed Tomography

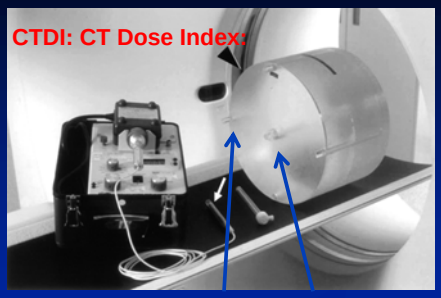
OBJECTIVE

Explain risk of radiation exposure and Radiation dose parameters:

general (whole body) • milli Sievert [mSv]

CT specific
- CTDIvol: milligray (mGy)
- DoseLength product (mGy*cm)

Instrumentation for measurement of radiation exposure in computed tomography



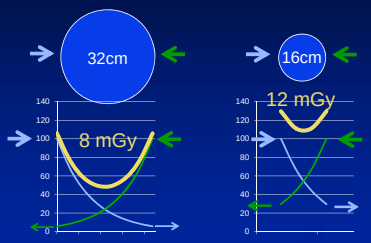
$CTDIw = (2*CTDI_{periphery} + CTDI_{center})/3$

$CTDI_{vol} = CTDIw / pitch$

Morin, R. L. et al. Circulation 2003;107:917-922

CTDI (CT Dose Index)
Not so Intuitive Concept …

- Phantom size gives different CTDI for same scanning parameters: large phantom – less dose !



- Large patients shield themselves, slim patients more dose than CTDI suggests

Dose Quantities in CT

$CTDI_{vol}$ (mGy)

CT dose index → local dose measured in head or body phantom

STANDARDIZED on all scanners, and all models …

displayed on the scanner console

… most important parameter to optimize your scan protocols!

Dose Quantities in CT

$CTDI_{vol}$ (mGy)

CT dose index → local dose measured in head or body phantom

displayed on the scanner console

- mAs
- kVp
- gantry rotation time
- pitch
- filtration

summarized completely in CT Dose index (CTDI) in milli-Gray (mGy)

Scan Protocol Optimization

start with review scanning protocols and optimizing

- patient positioning (centering)
- scanning range
- number of phases
- appropriate use of automated exposure control
- new dose reduction techniques (e.g. ASIR)
- cardiac: gating technique, low heart rate
- for each acquisition, look at the CTDI
- COMPARE TO REFERENCE VALUES

European guidelines on quality criteria for Computed Tomography – EUR 16262

Table 3: Proposed reference dose values for routine CT examinations on the basis of absorbed dose to air

Examination	Reference dose value	
	$CTDI_w$ (mGy)	DLP (mGy cm)
Routine head[a]	60	1050
Face and sinuses[a]	35	360
Vertebral trauma[b]	70	460
Routine chest[b]	30	650
HRCT of lung[b]	35	280
Routine abdomen[b]	35	780
Liver and spleen[b]	35	900
Routine pelvis[b]	35	570
Osseous pelvis[b]	25	520

Notes: a.Data relate to head phantom (PMMA, 16 cm diameter)
b.Data relate to body phantom (PMMA, 32 cm diameter)

European guidelines on quality criteria for Computed Tomography – EUR 16262

Table 3: Proposed reference dose values for routine CT examinations on the basis of absorbed dose to air

upper limits (ACR)

- Head ~ 70 mGy
- Body ~ 35 mGy
- Cardiac ~ 50 mGy
- head perfusion <500mGy

Examination Reference dose value

Osseous pelvis[b] 25 520

Notes: a.Data relate to head phantom (PMMA, 16 cm diameter)
b.Data relate to body phantom (PMMA, 32 cm diameter)

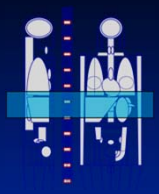
Stanford Hospital and Clinics Policy

CT Reference Exposure Values and Repeat Exposure

Stanford Reference CTDI values (per series)

Description of Series	Phantom	CTDI Threshold
Adult Neuro		
Adult Head	16cm	75 mGy
Adult Head	32cm	37.5 mGy
Head perfusion	16cm	600 mGy
Adult Body		
Adult body	16cm	70 mGy
Adult body	32cm	30 mGy
Body perfusion	32cm	300 mGy
Adult Cardiac		
Cardiac(Retrospective)	32cm	150 mGy
Cardiac(Prospective)	32cm	50 mGy
Cardiac(Flash mode)	32cm	50 mGy
Pediatric		
Pediatric head	16cm	35 mGy
Pediatric body	32cm	10 mGy
Pediatric body	16cm	20 mGy

based on ACR guidelines, and AAPM recommendations
(Jia Wang, PhD)



Thank you …