

Review of Radiation Risk from Computed Tomography and X-rays

YMA CME Update November 4-6 2011

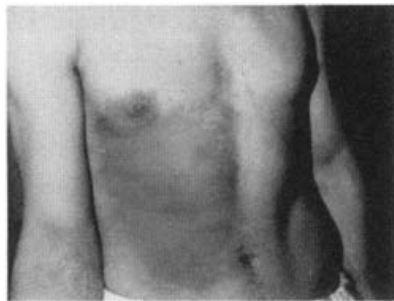
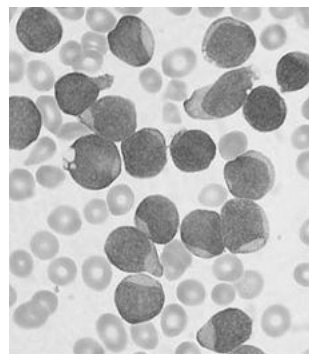
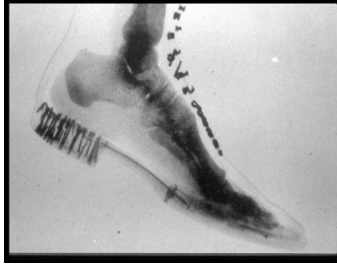
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A Historical Perspective

- X-rays first observed and documented in 1895 by Wilhelm Conrad Roentgen
- first X-ray image ever taken: his wife's hand



“...it’s unearthly, it’s downright mystical.”
~ Wilhelm Conrad Roentgen



Fast forward to today...

- CT = CANCER
- Huge media attention
 - CNN Sanjay Gupta
 - December 2009

Media attention

The New York Times
nytimes.com

November 29, 2007

Report Links Increased Cancer Risk to CT Scans

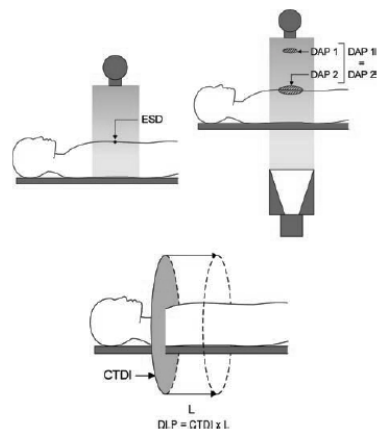
By THE ASSOCIATED PRESS

Outline

- Background – radiation principles
 - calculating radiation dose
 - biological effects of ionizing radiation
 - risk of cancer from exposure to ionizing radiation
- Illustrative cases
 - CT and radiation
 - cumulative radiation dose
 - pediatric population
 - radiation and pregnancy
- What can we do?

Estimating radiation dose

- $E = OQ \times CF$
 - E: effective dose
 - OQ: operational quantity
 - CF: conversion factor



Effective Dose

- Represents a whole-body equivalent dose that would be expected to produce the same overall cancer risk as nonuniform or partial-body irradiation
- Sets of generic conversion factors with average dose indicators applied to a standard adult patient
- Useful for comparing risks of different investigations

Table 1
Generic Entrance Skin Doses, Conversion Factors, and Effective Doses at Radiography in a Standard Adult Patient

Examination	Projection	Entrance Skin Dose (mGy)	Conversion Factor (mSv/mGy)	Effective Dose (mSv)
Chest	Posteroanterior	0.1	0.29	0.02
Abdomen	Anteroposterior	6.0	0.30	1.8
Abdomen	Posteroanterior	6.0	0.15	0.9
Lumbar spine	Posteroanterior	6.0	0.15	0.9
Lumbar spine	Lateral	20.0	0.03	0.6
Extremities	...	1.0	0.005	0.005

Source.—Adapted from reference 27.

Table 2
Generic Dose-Area Products, Conversion Factors, and Effective Doses at Angiography in a Standard Adult Patient

Examination*	Fluoroscopy time (min)	Dose-Area Product (Gy • cm ²)	Conversion Factor (mSv/Gy • cm ²)	Effective Dose (mSv)
Cerebrum	12	75	0.04	3.0
Coronary arteries	4	75	0.20	15.0
Abdomen	8	80	0.25	20.0
Lower limbs	6	50	0.10	5.0

Source.—Adapted from reference 27.
*Including image acquisition.

Table 3
Generic Dose-Length Products, Conversion Factors, and Effective Doses at CT in a Standard Adult Patient

Examination	Dose-Length Product (mGy • cm)	Conversion Factor (mSv/mGy • cm)	Effective Dose (mSv)
Head	1000	0.0023	2.3
Neck	400	0.0054	2.2
Chest	300	0.017	5.1
Abdomen-pelvis	500	0.015	8.0
Lower limbs (excluding pelvis)	500	0.0012	0.6

Sources.—References 21 and 32.

Effective dose

Table 3. Medical Imaging Procedures with Largest Contribution to Cumulative Effective Dose.^a

Procedure	Average Effective Dose (millisieverts)	Annual Effective Dose per Person	Proportion of the Total Effective Dose from All Study Procedures (%)
Myocardial perfusion imaging	15.6†	0.540	22.1
CT of the abdomen	8	0.446	18.3
CT of the pelvis	6	0.297	12.2
CT of the chest	7	0.184	7.5
Diagnostic cardiac catheterization	7	0.113	4.6
Radiography of the lumbar spine	1.5	0.080	3.3
Mammography	0.4	0.076	3.1
CT angiography of the chest (noncoronary)	15	0.075	3.1
Upper gastrointestinal series	6	0.058	2.4
CT of the head or brain	2	0.049	2.0
Percutaneous coronary intervention	15	0.043	1.8
Nuclear bone imaging	6.3	0.035	1.4
Radiograph of the abdomen	0.7	0.028	1.1
CT of the cervical spine	6	0.020	0.8
CT of the lumbar spine	6	0.018	0.7
Chest radiograph	0.02‡	0.016	0.7
Thyroid uptake	1.9	0.016	0.7
Intravenous urography	3	0.014	0.6
CT of the neck	3	0.014	0.6
Cardiac resting ventriculography	7.8	0.014	0.6

Fazel R, Krumholz HM, Wang Y et al. Exposure to low-dose ionizing radiation from medical imaging procedures. *NEJM* 2009; 361: 849-857.

Biologic effects of ionizing radiation

■ STOCHASTIC EFFECTS

- the probability but not the severity of the effect depends on the dose
- threshold dose not precisely known
- eg: induction of cancer, hereditary mutations

■ DETERMINISTIC EFFECTS

- appear above a threshold dose (high dose radiation)
- severity of effect depends on the dose
- cell killing

Biologic effects of ionizing radiation

- 1. Creation of hydroxyl radicals from x-ray interactions with water molecules
 - radicals interact with DNA causing strand breaks and base damage
- 2. Direct ionization of DNA
- Most DNA damage is repaired by the cell, but double strand DNA breaks are less easily repaired
 - induction of point mutations, chromosomal translocations, gene fusions = induction of cancer

Uncertainty regarding risk from low dose ionizing radiation

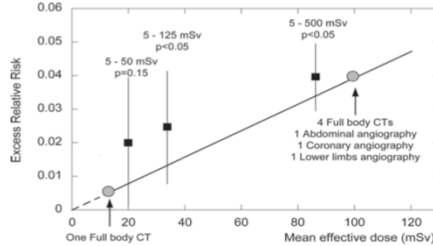
- Most dose estimates are actually overestimated
 - based on models of standard adult patient (70 kg)
- Below 10 mSv, no good epidemiologic studies
 - risk remains hypothetical
 - linear no threshold principle
- BEIR VII:
 - at doses of 100 mSv or less, statistical limitations make it difficult to evaluate cancer risk in humans

Linear-no-threshold principle

- Model of radiation risk
 - Assumption that the risk of cancer increases in a linear fashion with increase in dose
 - No threshold dose below which radiation is not carcinogenic

Risk of cancer

- Japanese atomic bomb survivors
 - low dose exposure (5-50 mSv): ERR = 0.02 (P=0.15) of mortality from solid cancers
 - 5-100 mSv exposure (mean 29 mSv): significant increase in solid cancer risk



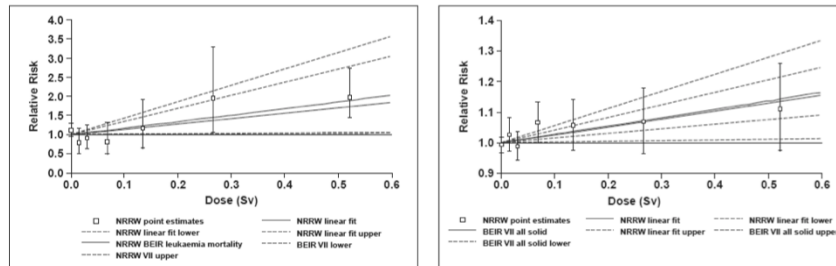
Risk of cancer

- Multinational study of >400 000 workers in the nuclear industry:
 - cumulative exposure of 100 mSv
 - 9.7% (1.4 – 19.7%) increased mortality from all cancers excluding leukemia
 - 5.9% (-2.9% to 17%) increased mortality from all cancers excluding leukemia, lung and pleura

	ERR	RR for 100 mSv dose
All cancers excluding leukemia	0.97 per Sv	1.10
Leukemia (excluding CLL)	1.93 per Sv	1.19

Risk of cancer

- Comparison of BEIR VII (Japanese bomb survivors) and NRRW (radiation workers)
 - good agreement
- Range of risk (upper/lower) – wide 90% confidence intervals



Cancer risk associated with CT

- Up to 1.5 to 2% of all cancers in the US may be attributable to radiation from CT studies
- 7th Biological Effects of Ionizing Radiation report (BEIR VII) - 2006
 - for a standardized US population, average lifetime attributable risk of one radiation-induced cancer per 1000 patients receiving a 10 mSv effective dose
 - approximately half of these cancers are expected to be fatal

Radiation induced cancers

- Cancers that are more frequently associated with radiation exposure:
 - leukemia (all forms except CLL)
 - thyroid (well-differentiated papillary adenocarcinoma)
 - breast, lung
 - gastrointestinal tract



Case 1

- Called to the ER at 11pm to see a 22 year old female with 24 hours RLQ pain
 - anorexia, nausea, temp 37.5, WBC 13
 - day 25 in her menstrual cycle
- (A) Wait until morning to get an U/S
(B) Get a CT A/P that night
(C) Take her straight to the OR

Case 2

- 55 year old male with 24 hours RLQ pain
 - anorexia, nausea, temp 38.1, wbc 17

(A) Get a CT A/P

(B) Manage expectantly and CT if pain does not resolve with bowel rest and antibiotics

(C) Take him to the OR, he has appendicitis

What is the most appropriate test?

Variant 2: Fever, leukocytosis; possible appendicitis, atypical presentation, adults and adolescents.

Radiologic Procedure	Rating	Comments	RRL*
CT abdomen and pelvis with contrast	8	Use of oral or rectal contrast depends on institutional preference.	☼☼☼☼
X-ray abdomen	6	May be useful in excluding free air or obstruction.	☼☼☼
US abdomen RLQ	6	With graded compression.	○
US pelvis	6		○
CT abdomen and pelvis without contrast	6	Use of oral or rectal contrast depends on institutional preference.	☼☼☼☼
MRI abdomen and pelvis with or without contrast	5	See statement regarding contrast in text under "Anticipated Exceptions."	○
X-ray contrast enema	3		☼☼☼
Tc-99m WBC scan abdomen and pelvis	3		☼☼☼
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			*Relative Radiation Level

What is the most appropriate test?

Variant 4: Fever, leukocytosis, possible appendicitis, atypical presentation in children (less than 14 years of age).

Radiologic Procedure	Rating	Comments	RRL*
US abdomen RLQ	8	With graded compression.	O
CT abdomen and pelvis with contrast	7	May be useful following negative or equivocal US. Use of oral or rectal contrast depends on institutional preference. Consider limited RLQ CT.	***
X-ray abdomen	6	May be useful in excluding free air or obstruction.	**
US pelvis	5		O
CT abdomen and pelvis without contrast	5	Use of oral or rectal contrast depends on institutional preference. Consider limited RLQ CT.	***
MRI abdomen and pelvis with or without contrast	5	See statement regarding contrast in text under "Anticipated Exceptions."	O
X-ray contrast enema	3		***
Tc-99m WBC scan abdomen and pelvis	2		**
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			*Relative Radiation Level

Case 3: Multiple Exposures

- 65 year old male colon cancer post curative resection.
 - He is seen in your clinic and is concerned about the multiple surveillance CT scans he will be getting in the future. He read that they increase his risk of cancer.

Cumulative risk

- A lot of literature focuses on risk from single CT studies, or <100 mSv
- What evidence is there on the risk in patients undergoing multiple radiologic examinations?

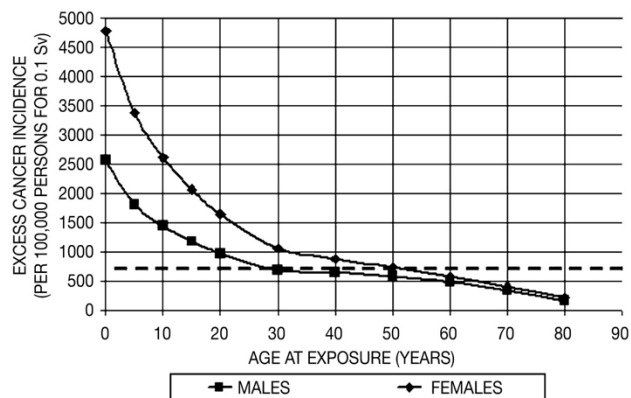
Cumulative risk

- Effects of dose fractionation or several small exposures in contrast to single acute exposures not well understood
 - relies on risks extrapolated from high dose exposure
 - can't account for DNA repair mechanisms at low dose exposure - stochastic effects NOT cumulative
- Epidemiologic challenge, many variables to consider

Case 4: Childhood Exposure

- 35 year old female with multiple CT scans in childhood for hepatoblastoma treated with right liver resection and chemotherapy.
- She now is diagnosed with breast cancer and wants to know if her past radiation exposure from CTs is the cause of this cancer

Risk of cancer – age/gender dependent



Risk vs benefit

- For most CTs, there is a favourable ratio of benefit to risk
 - small potential risk vs potential incremental survival benefit from detection/diagnosis
- Increased risk in pediatric population
 - longer life expectancy (longer period to develop cancer)
 - greater organ radiosensitivity
 - estimated lifetime cancer mortality attributable to radiation exposure from CT in a 1-year-old (single examination):
 - abdominal (0.18% or 1/550)
 - head (0.07% or 1/1500)

Risk vs benefit

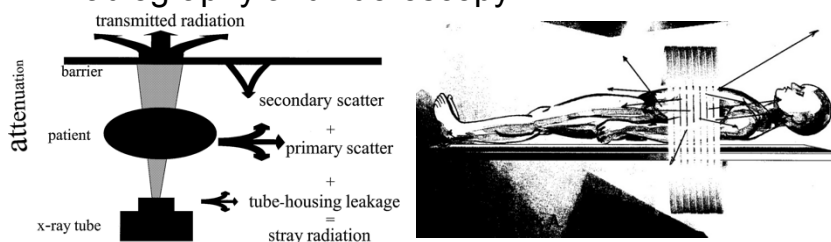
- CT for diagnosis vs screening
- Unnecessary studies?
 - CT scans requested in the practice of defensive medicine
 - CT scan repeated as the patient passes through the medical system, often due to lack of communication
 - Alternative approaches/modalities may be better suited to the patient, especially pediatric patients

Case 5 : Scatter radiation

- MVC patient in trauma bay, portable Xray unit brought in for trauma radiographs (chest, C-spine)
- Physician putting in a femoral line, realizes he/she is not wearing a lead apron
- What is the risk to the physician?

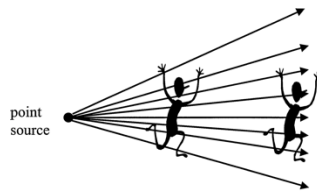
Scatter

- Primary scatter is emitted from the patient in all directions
 - major source of hazard to personnel in mobile radiography and fluoroscopy



Effects of scatter on personnel

- Inverse square law
 - intensity of Xrays inversely related to the square of the distance from the source
- At 1 metre distance from patient (source), the intensity of the X-rays is decreased by 1/1000, or 0.1% of the patient entrance dose
- 0.5 mm lead equivalent apron shields from 95% of incident Xrays



Case 6: Imaging in Pregnancy

- 29 year old pregnant female (20 wks GA) is brought in to hospital by EMS following a high speed MVC with chest and abdominal tenderness
 - GCS 14, tachycardic, normotensive +ve seat belt sign
 - CXR: Left pneumothorax - chest tube inserted
 - FAST: Negative

Case 6 cont: Imaging in Pregnancy

- As she had a high risk mechanism and sustained some injuries you want a CT scan of the chest, abdomen, and pelvis.
- The patient keeps asking you if the CT scan will harm her child and if it is absolutely necessary

Radiation effects in utero

- Pre-implantation: lethal, “all or nothing” effect
- Organogenesis: congenital malformations (most commonly CNS); microcephaly and growth retardation
- Fetal growth (most sensitive week 8 – 15): functional defects of the CNS; mental retardation and growth retardation
 - decreased risk in 3rd trimester



- Delayed effects: small risk of childhood cancers
- increase in risk with exposures >10 mGy (10 mSv)

Radiation exposure in utero

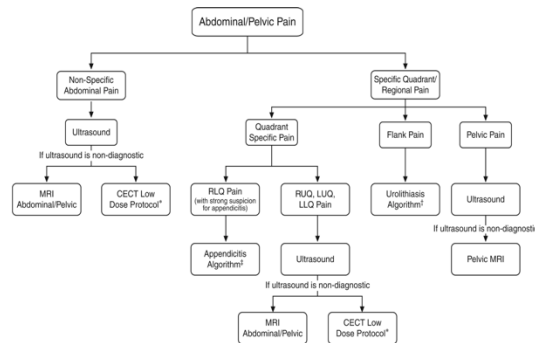
- Routine CT examination of the abdomen and pelvis
 - probability of birthing a healthy baby with no malformation and no cancer decreases by only 0.1% (95.93% to 95.83%)

TABLE II: Probability of Birthing Healthy Children*

Conceptus Dose Above Background† mrem (mSv)	Probability of Birthing Child With No Malformation	Probability Child Will Not Develop Cancer	Probability Child Will Have No Malformation and No Cancer
0 (0)	96%	99.93%	95.93%
50 (0.5)	95.999%	99.926%	95.928%
100 (1.0)	95.998%	99.921%	95.922%
250 (2.5)	95.995%	99.908%	95.91%
500 (5.0)	95.99%	99.89%	95.88%
1000 (10.0)	95.98%	99.84%	95.83%

Suggested algorithm for imaging pregnant patients with abdominal pain

- Trauma - initial workup
 - CXR, lateral C-spine XR
 - US of placenta and fetus
- CT
 - most accurate and cost-efficient diagnostic tool available for evaluation of the seriously injured pregnant patient with blunt abdominal trauma



Contrast material in pregnancy

- No well-controlled studies performed
- Oral contrast – safe
 - intraluminal barium can be used for internal shielding
- IV contrast
 - CT (iodinated contrast)
 - ACR recommendation: iodinated contrast material is likely safe in pregnancy
 - neonatal thyroid function should be checked in the first few days of life
 - MR (gadolinium)
 - theoretical risk: gadolinium chelates accumulate in amniotic fluid and dissociate over time, releasing the toxic free gadolinium ion
 - at FMC – no gadolinium contrast in pregnancy (safety in humans not proven)

Summary

- Background – radiation principles
 - calculating radiation dose
 - biological effects of ionizing radiation
 - risk of cancer from exposure to ionizing radiation
- Illustrative cases
 - CT and radiation
 - cumulative radiation dose
 - pediatric population
 - radiation and pregnancy
- What can we do?

What can we do?

1. Reduce CT-related dose in individual patients (OPTIMIZATION)
 - ALARA principle
 - AEC/tube current modulation
 - shielding (circumferential)
2. Replace CT with other modalities, when practical (ie: US, MR)
3. Decrease the number of CT studies ordered (JUSTIFICATION)
 - ACR Appropriateness Criteria

Justification

- ACR appropriateness criteria:
 - Evidence based guidelines to assist in making the most appropriate imaging decision for a specific clinical condition
 - www.acr.org
- Clinical concern
 - Effective communication between consultants is essential

Bottom line

- Controversial topic
- CT is an indispensable diagnostic tool
- Risk of cancer from a single CT scan to an individual is small
 - less than 1/1000 for a single CT A/P (assumption)
 - concern is for built-up public health risk over a long period of time
- Cumulative risk in patients undergoing multiple studies?
 - concern in pediatric population
- Education of all those involved
 - Radiologists
 - Family Physicians
 - ED, Specialists

Putting risk into perspective

- Dose from a single CT examination (~1-14 mSv) is comparable to annual dose received from naturally occurring sources of radiation
- Background dose in Canada : ~1-3 mSv/ year

TABLE 1: Estimated Lifetime Risk of Death From Various Sources

Cause of Death	Estimated No. of Deaths per 1,000 Individuals
Cancer [38]	228
Motor vehicle accident	11.9
Radon in home	
Average U.S. exposure	3
High exposure (1-3%)	21
Arsenic in drinking water	
2.5 µg/L (U.S. estimated average)	1
50 µg/L (acceptable limit before 2006)	13
Radiation-induced fatal cancer	
Routine abdominopelvic CT	0.5
Single phase, ~ 10-mSv effective dose	
Annual dose limit for a radiation worker	
10 mSv (recommended yearly average)	0.5
50 mSv (limit in a single year)	2.5
Pedestrian accident	1.6
Drowning	0.9
Bicycling	0.2
Lightning strike	0.013

Note—Adapted with permission from [97].

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