Radiation doses in nuclear cardiology and cardiac CT examinations

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Brainstorming meeting

Capri 2009

Original Papers on Radiation Risk in 2009

• **Projected Cancer Risks from CT scans performed in the United States in 2007**

Arch Intern Med. 2009

• **Radiation Dose Associated with Common CT Examinations and the Associated Lifetime Attributable Risk of Cancer**

Arch Intern Med. 2009

Editorial

• **Exposure to Low Dose Ionizing Radiation from Medical Imaging Procedures**

N Eng J Med 2009

White paper on radiation dose in Medicine
American College of Radiology, 2007

Table 1. Growth of computed tomography (CT) and nuclear medicine examinations in the United States (approximate) [5-8]

Examination	1980	2005
CT	3,000,000	60,000,000
Nuclear medicine	7,000,000	20,000,000

Aware of radiation exposure

- CT use has increased rapidly
- More than 62 millions CT scans per year
- 4 millions in children
- CT is a user friendly procedure for both the patient (1 second scan) and physician
- Screening of asymptomatic patients
- The increasing exposure to radiation in the population may be a public health issue in the future.

CT radiation dosimetry

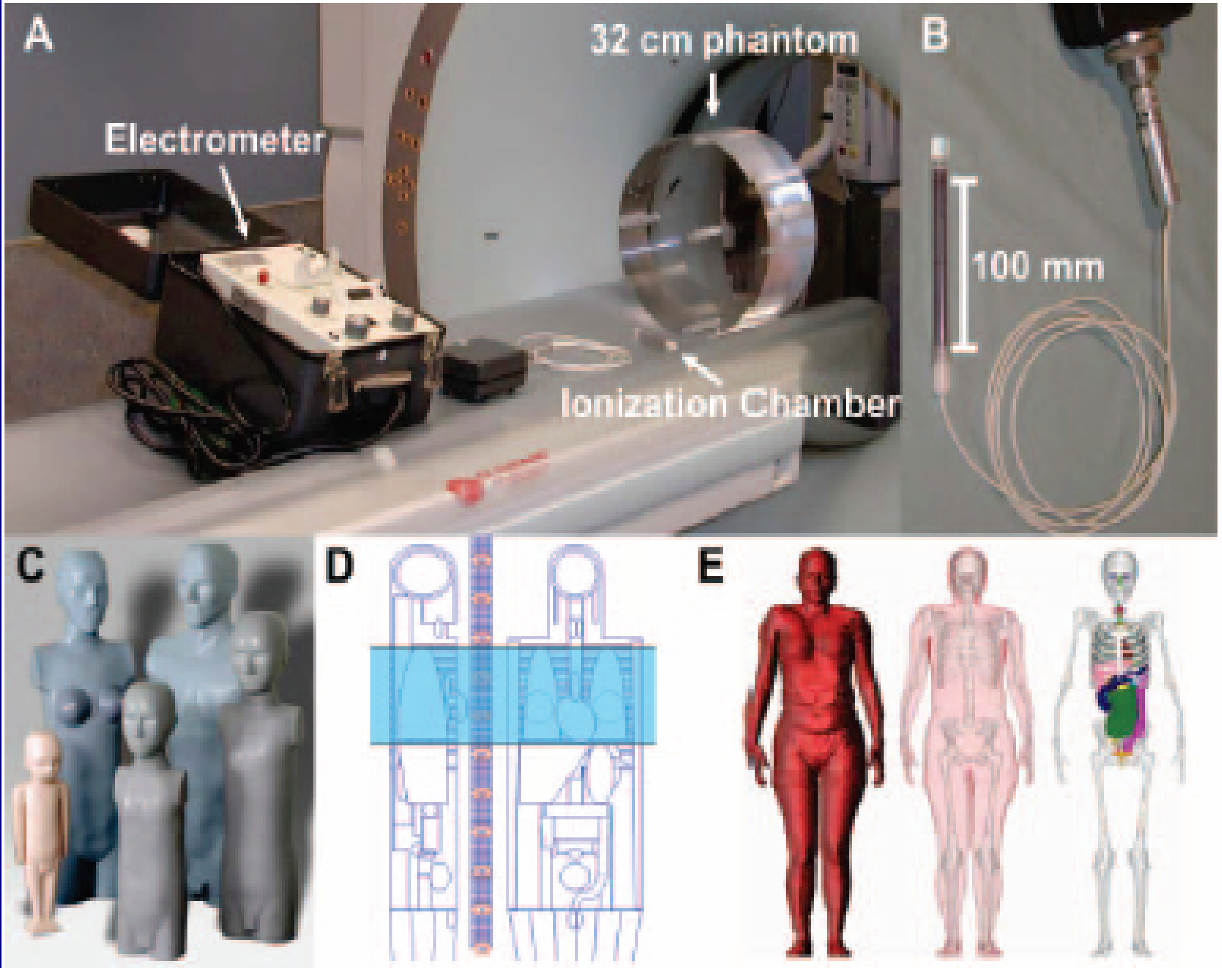


Figure 4. CT dosimetry measurement tools. A, Electrometer and ionization chamber set up to take CTDI measurements in a 32-cm polymethyl-methacrylate "body" phantom. B, Close-up of the 100-mm pencil ionization chamber. C, Physical anthropomorphic phantoms (ATOM, CIRS Inc, Norfolk, Va). Reproduced with permission from CIRS Inc. D, Geometric mathematical phantom used in Monte Carlo simulations. E, Voxel mathematical phantom used in Monte Carlo simulations. Reproduced from Dimbylow,[28] with permission from the publisher. Copyright © 2005, IOP Publishing.

Radiation quantities and units

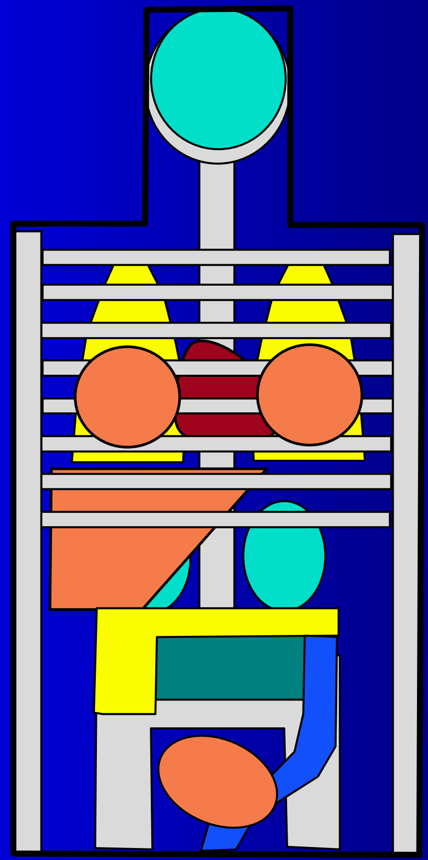
Quantity	Unit	Determination
Exposure	Coulomb per Kg, roentgen (R)	measurement
Dose	Gray (Gy), rad	multiply expose by f-factor
Equivalent dose	Sievert (Sv), rem	multiply dose by quality factor
Effective dose (radiation risk)	Sv, mSv, mrm	multiply equivalent dose by a tissue weighting factor

Radiation Risk ⇒ Biological Injury

- Biological injury includes
  - deterministic effects (skin burns, cataract formation)
  - stochastic effects (cancer induction, genetic effects)
- Risk estimates are derived from
  - atomic bomb survivor data, other exposed groups
- Risk estimates are dependent on
  - organ dose and type, age, gender, reproductive status
  - organ doses depend on patient size

ICRP 60 Weighting Values

Gonads	0.20
RBM, colon, lung, stomach	0.12
Bladder, breast, liver	0.05
Esophagus, thyroid	0.05
Skin, bone surface	0.01
Remainder	0.05
	Σ 1.00



Radiation Risk ⇒ Effective Dose

- Stochastic v. Deterministic
- Probabilities
- Assumptions
- Uncertainties
- Changing

Radiation Risk- need to know

- **LNT- Linear No Threshold**
- **LAR- Lifetime Attributed Risk *of cancer radiation***
- ***The carcinogenic effect occurs after 10-30 years.***
- **Known risk from effective dose radiation of 10 mSv**
- **Significant increase in cancer at dose estimate in access of 50 mSV**

- **Lifetime risk of a fatal malignancy 1: 5**
- **Exposure of 10 mSv (MPI, CT) is 1: 2,000**

Radiation Risk

Radiation dosage of selected exposures

Study	*effective dose (mSv)*
chest x rays (2 views)	0.08
Mammogram	0.13
Background radiation	3.0/y
Smoking cigarettes	2.8/y
Air travel	0.01 per 1000 miles

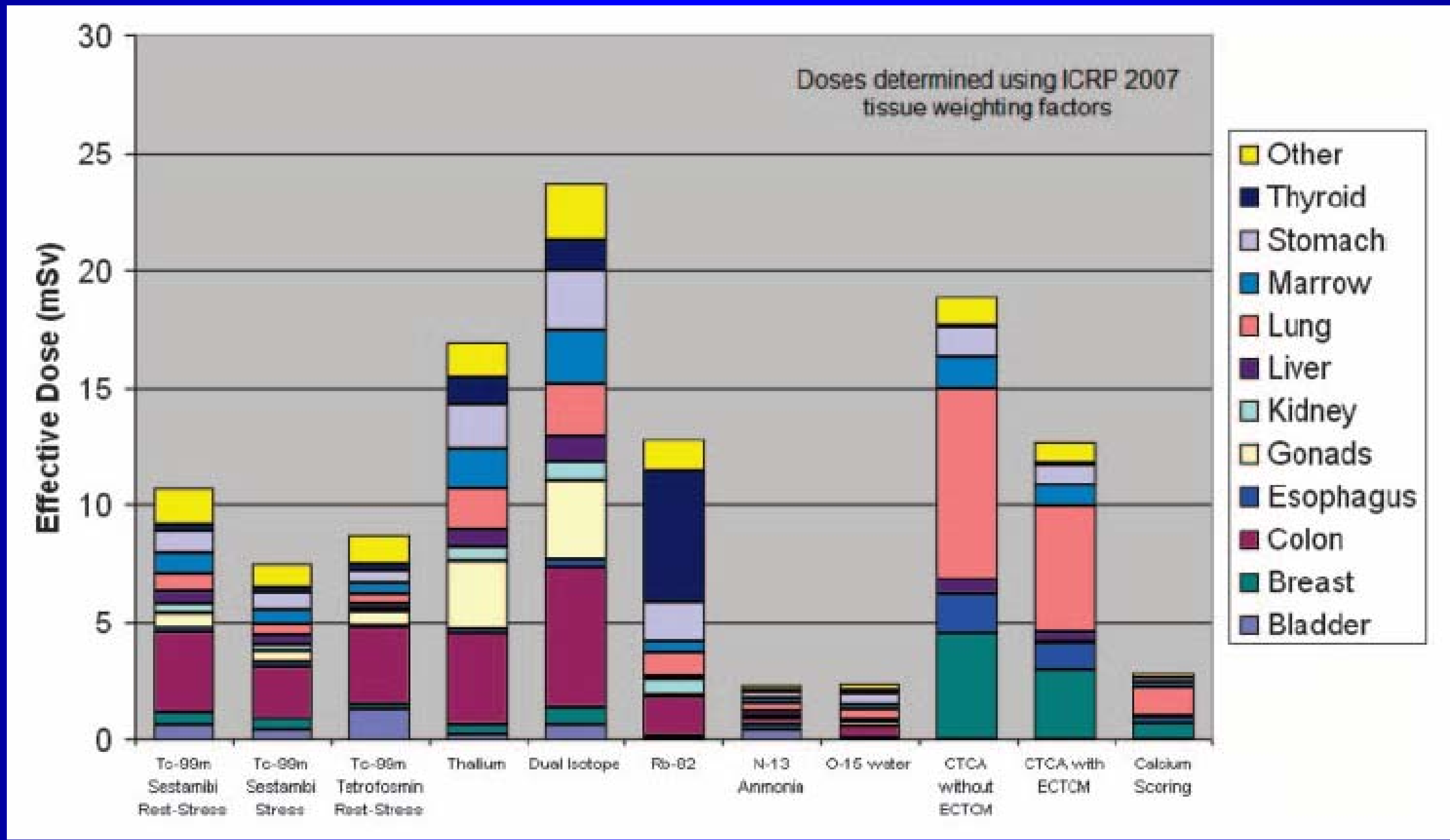
Radiation dosage in nuclear studies (AJ, Einstein, Circulation 2008)

TABLE 2. Estimates of Effective Doses of Standard Myocardial Perfusion Imaging Protocols

	Injected Activity (mCi)		Effective Doses, mSv			
			From ICRP Tables		From Manufacturers' PIs	
Protocol	Rest	Stress	E_1	E_2	E_1	E_2
^{99m}Tc *sestamibi rest-stress*	10.0	27.5	11.3	11.4	14.6	NR
^{99m}Tc *sestamibi* stress only	0.0	27.5	7.9	8.0	10.0	NR
^{99m}Tc *sestamibi* 2-day	25.0	25.0	15.7	15.6	20.6	NR
^{99m}Tc tetrofosmin rest-*stress*	10.0	27.5	9.3	9.9	9.7	12.9
^{99m}Tc tetrofosmin stress only	0.0	27.5	6.6	7.1	6.7	8.8
^{99m}Tc tetrofosmin 2-day	25.0	25.0	12.8	13.5	13.7	18.3
^{201}Tl *stress*-redistribution	0.0	3.5	22.0	22.0	28.7 (PI 1) 9.3 (PI 2) 28.4 (PI 3)	46.6 (PI 1) NR (PI 2) 46.6 (PI 3)
^{201}Tl *stress*-reinjection	1.5	3.0	31.4	31.5	43.0 (PI 1) 14.0 (PI 2) 42.6 (PI 3)	69.9 (PI 1) NR (PI 2) 69.9 (PI 3)
Dual isotope ^{201}Tl-^{99m}Tc sestamibi	3.5	25.0	29.2	29.3	37.8 (PI 1) 18.4 (PI 2) 37.5 (PI 3)	NR (PI 1) NR (PI 2) NR (PI 3)
^{99m}Tc-labeled erythrocytes	22.5	0.0	5.7	5.8	2.3	NR
^{82}Rb	50.0	50.0	13.5	12.6	3.0	NR
^{13}N-ammonia	15.0	15.0	2.4	2.2	NA	NA
^{15}O-water*	29.7	29.7	2.5	2.4	NA	NA
^{18}F-FDG	10.0	0.0	7.0	7.0	NA	NA

CT Radiation – effective dose in mSv

Study	Total-body effective dose (mSv)
EBCT coronary calcium scoring (male), retrospective ECG triggering	1.0
EBCT coronary calcium scoring (female), retrospective ECG triggering	1.3
MDCT coronary calcium scoring (male), no ECG pulsing	2.3–2.9
MDCT coronary calcium scoring (female), no ECG pulsing	3.2–3.6
MDCT coronary calcium scoring (male), with ECG pulsing	1.3–1.4
MDCT coronary calcium scoring (female), with ECG pulsing	1.9–2.0
16-Slice MDCT coronary CTA (male), no ECG pulsing	7.9–11.8
16-Slice MDCT coronary CTA (female), No ECG pulsing	11.1–16.3
16-Slice MDCT coronary CTA (male), with ECG pulsing	4.0–6.2
16-Slice MDCT coronary CTA (female), with ECG pulsing	5.6–8.7
64-Slice MDCT coronary CTA (male), no ECG pulsing	9.6–15.2
64-Slice MDCT coronary CTA (female), no ECG pulsing	13.5–21.4
64-Slice MDCT coronary CTA (male), with ECG pulsing	4.8–10
64-Slice MDCT coronary CTA (female), with ECG pulsing	6.8–14


Effective Dose (mSv)
30
25
20
15
10
5
0
Doses determined using ICRP 2007
tissue weighting factors
Other
Thyroid
Stomach
Marrow
Lung
Liver
Kidney
Gonads
Esophagus
Colon
Breast
Bladder
Tc-99m Sestamibi Rest-Stress
Tc-99m Sestamibi Stress
Tc-99m Tetrofosmin Rest-Stress
Thallium
Dual Isotope
Rb-82
N-13 Ammonia
O-15 water
CTCA without ECTCM
CTCA with ECTCM
Calcium Scoring

EFFECTIVE DOSE (E):

A flawed concept that could and should be replaced

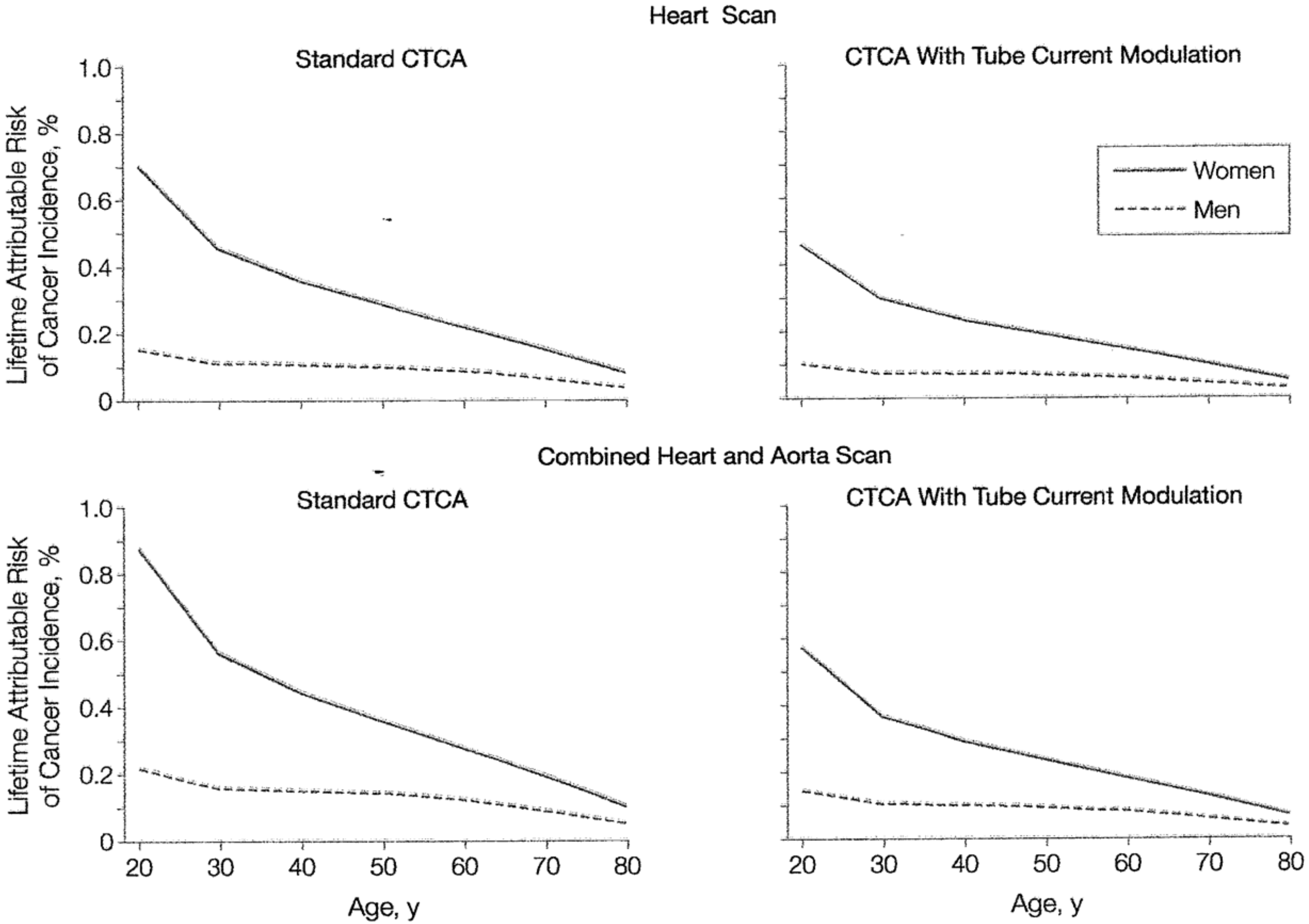
(DJ Brenner, 2008)

A single number proportional to the radiobiological ‘detriment”

- **E is often confused and misused**
- **The use of the effective dose concept inherently involves a number of problematic assumptions and issues.**
- **The uncertainty of estimated value of E for a reference patient is about ± 40%**
- **The estimated risk of cancer may be a factor of three higher or lower when applied to a reference patient**

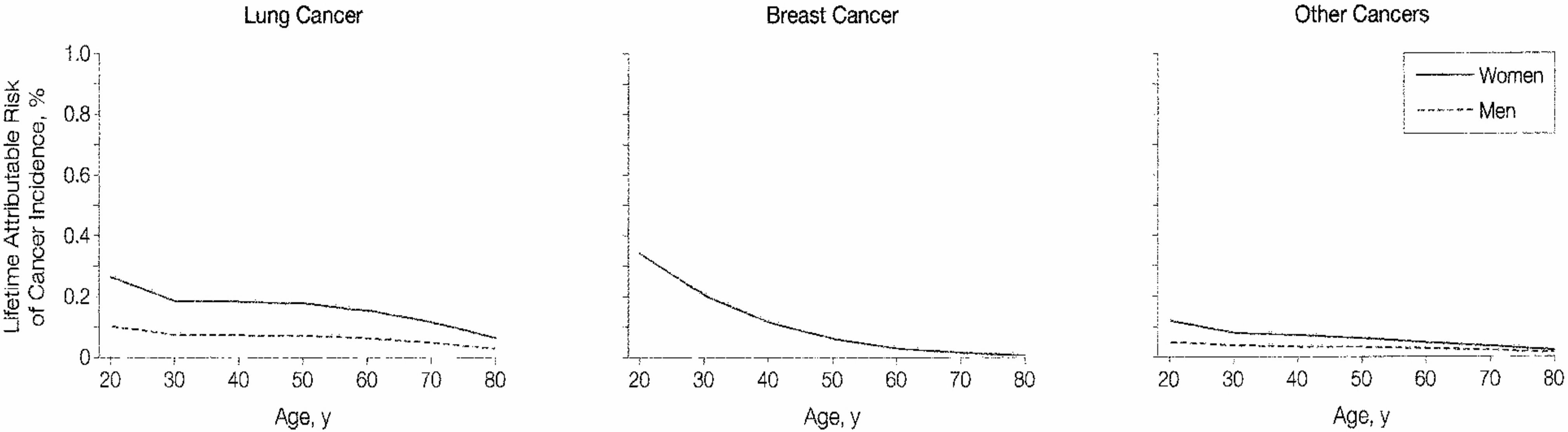
Radiation risk of CTCA scan

Figure 1. Lifetime Attributable Risk of Cancer Incidence From a Single Computed Tomography Coronary Angiography (CTCA) Scan



Radiation Risk from single dose of CTCA scan

Figure 2. Organ Contributions to Lifetime Attributable Risk of Cancer Incidence From a Single Standard Computed Tomography Coronary Angiography (CTCA) Scan



Risk – Benefit of diagnostic tests

- The majority of patients undergoing cardiac cath. procedures and nuclear stress tests are above 60 years of age.
- The lifetime risk of a radiation- related malignancy developing is much lower in older adults compared with children and fertile women.
- Thus, the risk of serious heart disease (or the risk of missing a diagnosis of serious heart disease) is much greater than the theoretic risk of radiation- related malignancy.

How to minimize radiation dose

to patients from cardiac nuclear tests

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Appropriateness Criteria for cardiac imaging

Recommendations:

Physician education should emphasize that cardiac imaging studies that expose patients to ionizing radiation should be ordered only after thoughtful consideration of the potential benefit to the patient and in keeping with established appropriateness criteria.

Class 1, Level of evidence C

Circulation Feb 2009

Effective doses of ionizing radiation from medical procedures

Subjects	Total subjects (n)	Subjects undergoing more than 1 procedure (%)	Mean annual effective dose from procedures (mSv)
All subjects	952 420	68.8	2.4
•Males	453 078	57.9	2.3
•Females	499 342	78.7	2.6
•18–34 y	233 586	49.5	1.0
•35–39 y	118 365	65.7	1.6
•40–44 y	144 728	72.1	2.0
•45–49 y	146 703	74.9	2.6
•50–54 y	131 209	78.2	3.3
•55–59 y	115 520	79.5	4.1
•60–64 y	62 309	85.9	5.2

Fazel R et al. *N Engl J Med* 2009; 361: 849-57.

Medical imaging procedures with largest contribution to cumulative effective dose

Procedure	Average effective dose (mSv)	Proportion of the total effective dose from all study procedures (%)
Myocardial perfusion imaging	15.6	22.1
CT of abdomen	8	18.3
CT of pelvis	6	12.2
CT of chest	7	7.5
Diagnostic cardiac catheterization	7	4.6
Radiography of the lumbar spine	1.5	3.3
Mammography	0.4	3.1
CT angiography of the chest (noncoronary)	15	3.1
Upper gastrointestinal series	6	2.4
CT of head or brain	2	2.0
PCI	15	1.8

Fazel R et al. *N Engl J Med* 2009; 361: 849-57.

Annual Effective doses of Radiation in study population

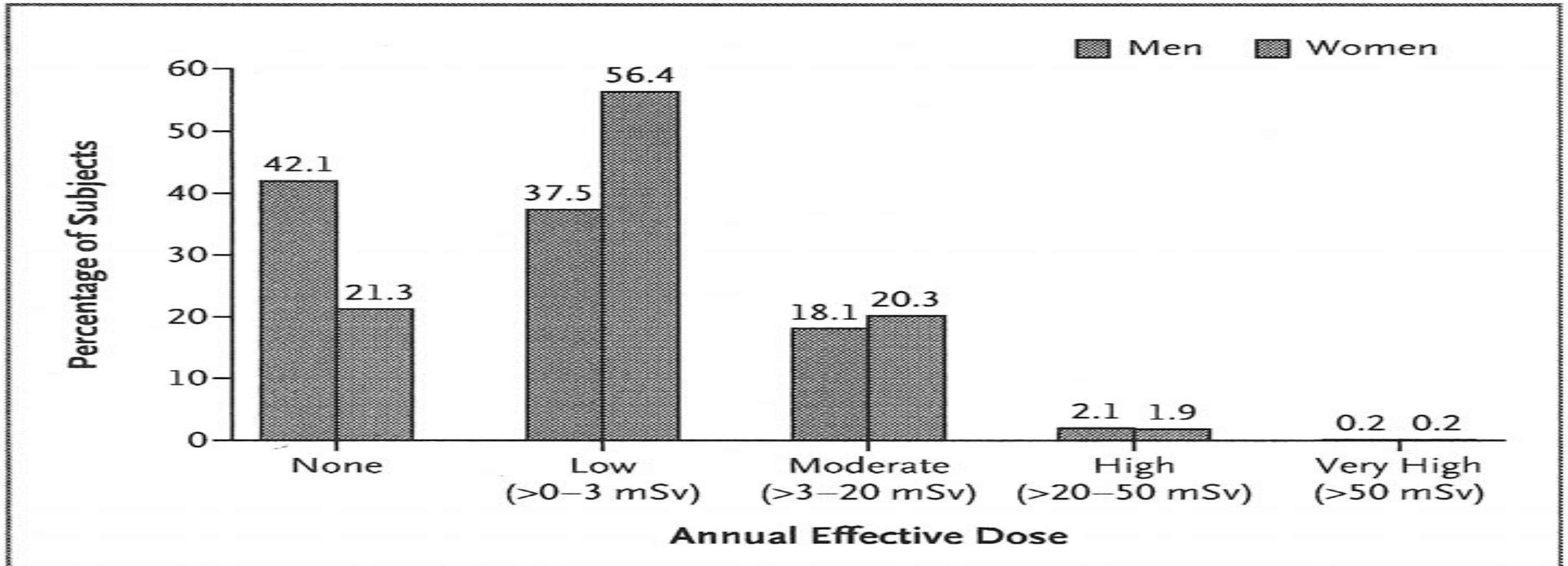

Figure 1. **Overall Distribution of Annual Effective Doses of Radiation in the Study Population, Stratified According to Sex.**
Percentages may not total 100 because of rounding.

Radiation Risk- Practical rules

- Use ALARA (as low as reasonably achievable) philosophy
- Be very familiar with the dosage of radiation of cardiac diagnostic tests
- Introduce ways to minimize radiation

Proposed new Terminology for radiation risk

Table 3. Terminology that could be used to describe risks from radiation exposure

E dose range (mSv)	Level of risk[a]	Proposed risk term	Examples of medical exposures
<0.1	1 in 1 million	Negligible	Radiographs of chest, limbs, head, neck and teeth
0.1–1	1 in 100 000	Minimal	Radiographs of spine, abdomen and pelvis
1–10	1 in 10 000	Very low	Barium meals and enemas, CT scans of head, chest and abdomen, nuclear medicine bone scans
10–100	1 in 1000	Low	Double CT scans for contrast enhancement, higher dose interventional radiology procedures

[a]The excess lifetime risk of fatal cancer to a reference adult patient resulting from radiation exposures in the dose ranges could be a factor of up to 10 higher or lower than values quoted.

CJ Martin,The British Journal of radiology, August 2007

How to avoid unnecessary excess cancers

- Radiation protocols should be improve to eliminate the 13 fold differences in radiation dose from the same CT scan
- Use the lowest dose technique
- Patients should be fully informed about the radiation risk

How to minimize radiation dose in CTA tests

- Avoid inappropriate tests
- Employ ECG-co
- Start with Ca score, and stop imaging in case of Ca zero or >1000
- Prospective dose if possible
- In future, Flash mode CTA (only 1mSv)

How to minimize radiation dose in CTA tests

- Tailor technical parameters of the examination that affect radial dosage: mAs, kVp, scan pitch
- automated x ray dose shaping algorithms and x ray tube pulsing should be applied
- Particular attention to radiation dose is needed in children, young adults and young women.
- As a rule cardiac MDCT the CTDI (dose index) should not be greater than 60mGy or effective dose not greater than 13 mSv.

How to minimize radiation dose to patients from cardiac nuclear tests

- Prefer Tc 99m agents on thallium 201, especially in obese patients and women
- Tailor activity (mCi) for each patient
- Be aware of "uni dose" system
- Hydrate after imaging and encourage early micturition

How to minimize radiation dose

to patients from cardiac nuclear tests

Protocols

- Consider stress first/ stress only protocol
- Avoid one day dual isotope rest stress tests
- Use attenuation correction tools
- Use prone imaging (7 min acquisition)
- Use half time processing in order to low dose Tc test

Radiation Risk – Take Home

- Risk is Complex – Be Wary of Dogmatic Statements
- Given All Else, Radiation Risk is the Least Problem for Cardiology Patients
- Not Every Cardiovascular Patient needs a Cardiovascular CT or nuclear study