RAMPS-GNYCHPS 2010 Spring Symposium
New York, NY, April 30, 2010

Error Prevention and Patient Safety for Radiation Treatment and Diagnosis

Radiotherapy and Radiology in the 21st Century: Risks and Benefits

Dauer et al.
Rad Protect Dosimetry
April 2010

Radiology

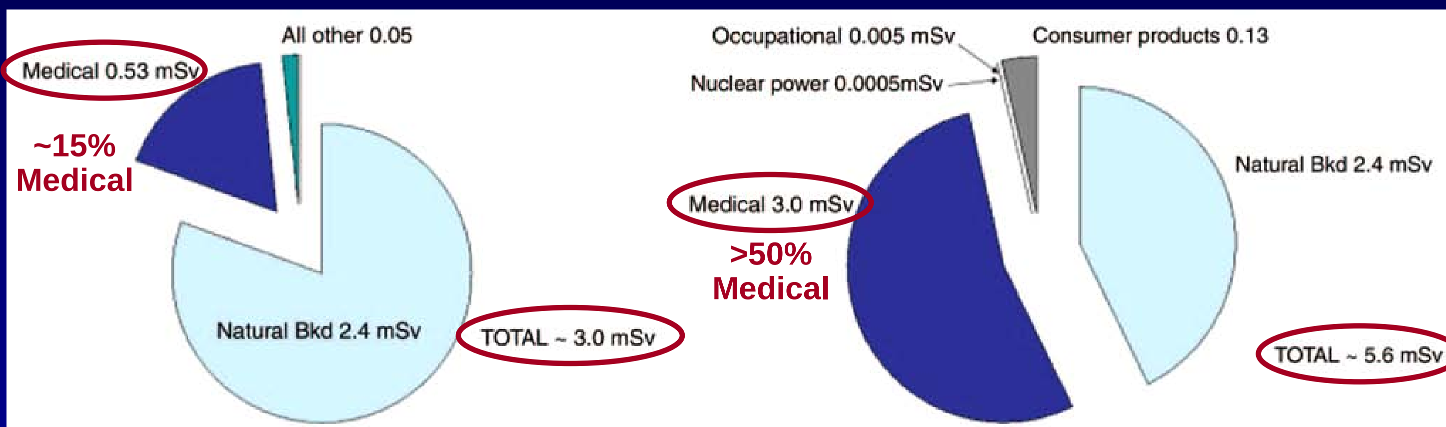
Pat Zanzonico, PhD
Member and Attending Physicist
Memorial Sloan-Kettering Cancer Center
New York, NY

For slides, reprints etc **ZanzoniP@MSKCC.ORG**

Radiologic procedures are on the rise…

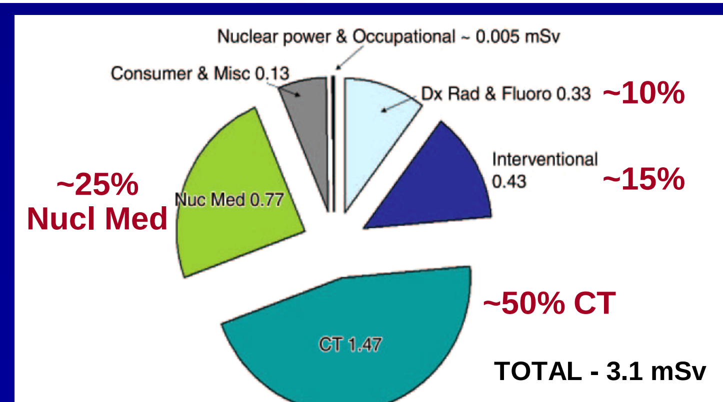
- **Between 1970and 2005 in US, annual # of**
  - **Nuclear Medicine procedures** ↑ **5X**
    from 3.5M to 17M
    - *Nuclear Cardiology*
    - *FDG PET & PET-CT*
  - **CT procedures** ↑ **20X**
    from 3M to 60M
    - *Spiral CT (2-sec scans)*

1980
Total



2006
Total

Background Radiation



Man-made

Mettler et al. Radiology 253: 520-531

Radiation Injury in Diagnostic Nuclear Medicine and Radiology

- ***Stochastic***
  - **Carcinogenesis**
  - **Germ-cell mutagenesis**

Neel et al.
Am J Hum Genet
1990

- A-Bomb survivor data (n ≈ 12,000): No effect @ mean gonadal Ds = 36 rad

An order of magnitude higher than Dx doses

  - **Teratogenesis**

Otake et al.
RERF Tech Report
16-87, 1990

- A-Bomb survivor data (n ≈ 1,600): Threshold Ds ≈ 10s of rads → No radiogenic abortions or congenital defects @ Dx doses

Stewart et al.
Lancet
1990

- Oxford Survey of Childhood Cancers: ~50% increase in incidence of childhood cancer per rad *in utero*, but total incidence (300 *vs* 200 per 10^6 births) very low

Radiation Injury in Diagnostic Nuclear Medicine and Radiology

➢ *Deterministic*

Balter et al. Radiology 2010

- ♦ **Skin injury**
  - 200 rad: Threshold → >1,500 rad: Ulceration
    Sx repair

3 yr post-coronary angiography & angioplasty

Shope. Radiographics 1996

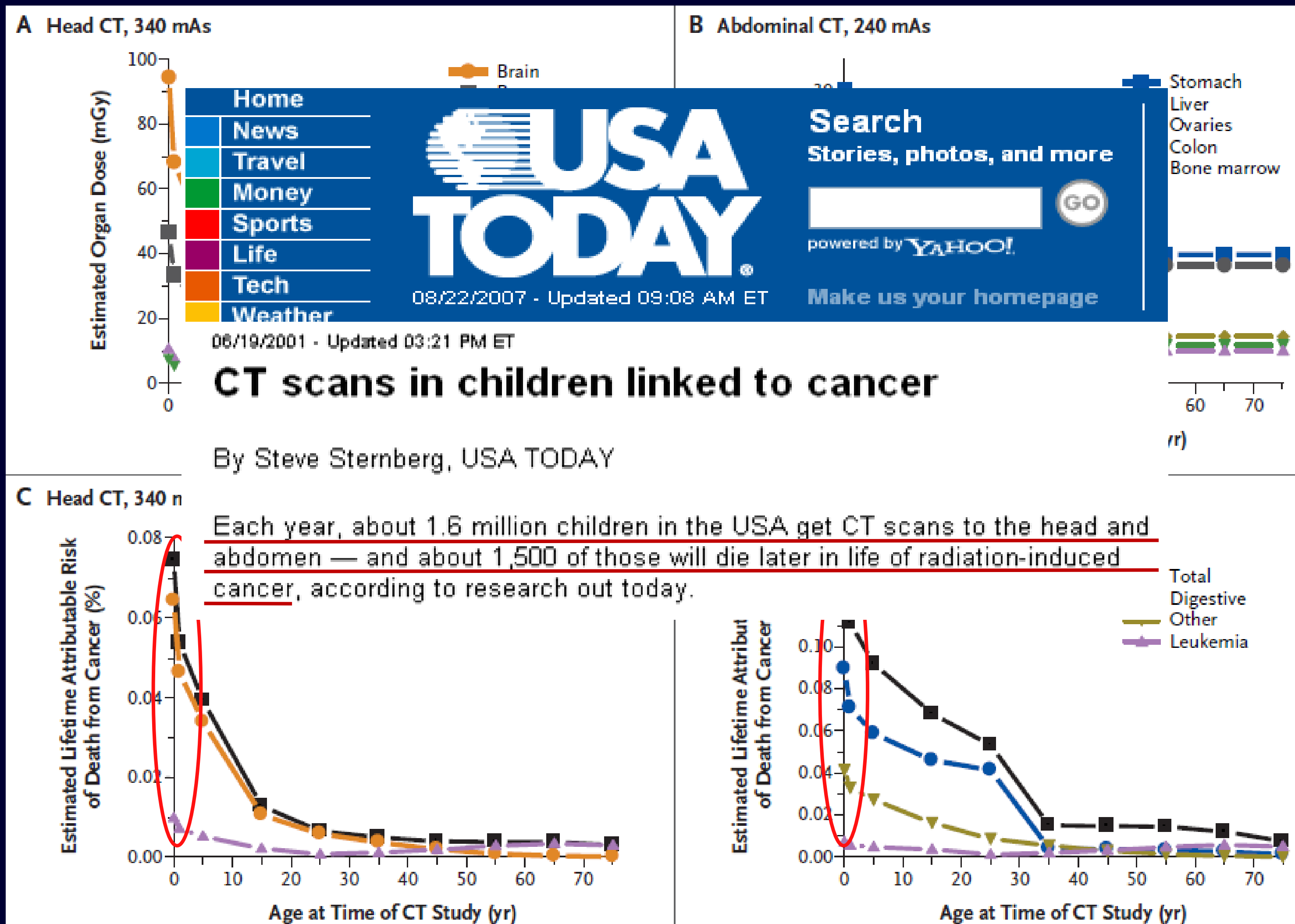
- ♦ **Fluoroscopically-guided interventions**
  - ~<u>0.1%</u> significant skin injuries (1992-95)

FDA Alert, 10/8/09

- ♦ **CT overdose**
  - Brain perfusion studies in >200 stroke pts @ Cedars-Sinai (over *18 months*, 2008-09)
  - 300-400 rad (vs 50 rad) to head → Hair loss, Erythema
  - Human error - Incorrect CT parameters
    - No check of *displayed* CTDI, DLP

Carcinogenesis remains <u>the</u> concern in diagnostic imaging.

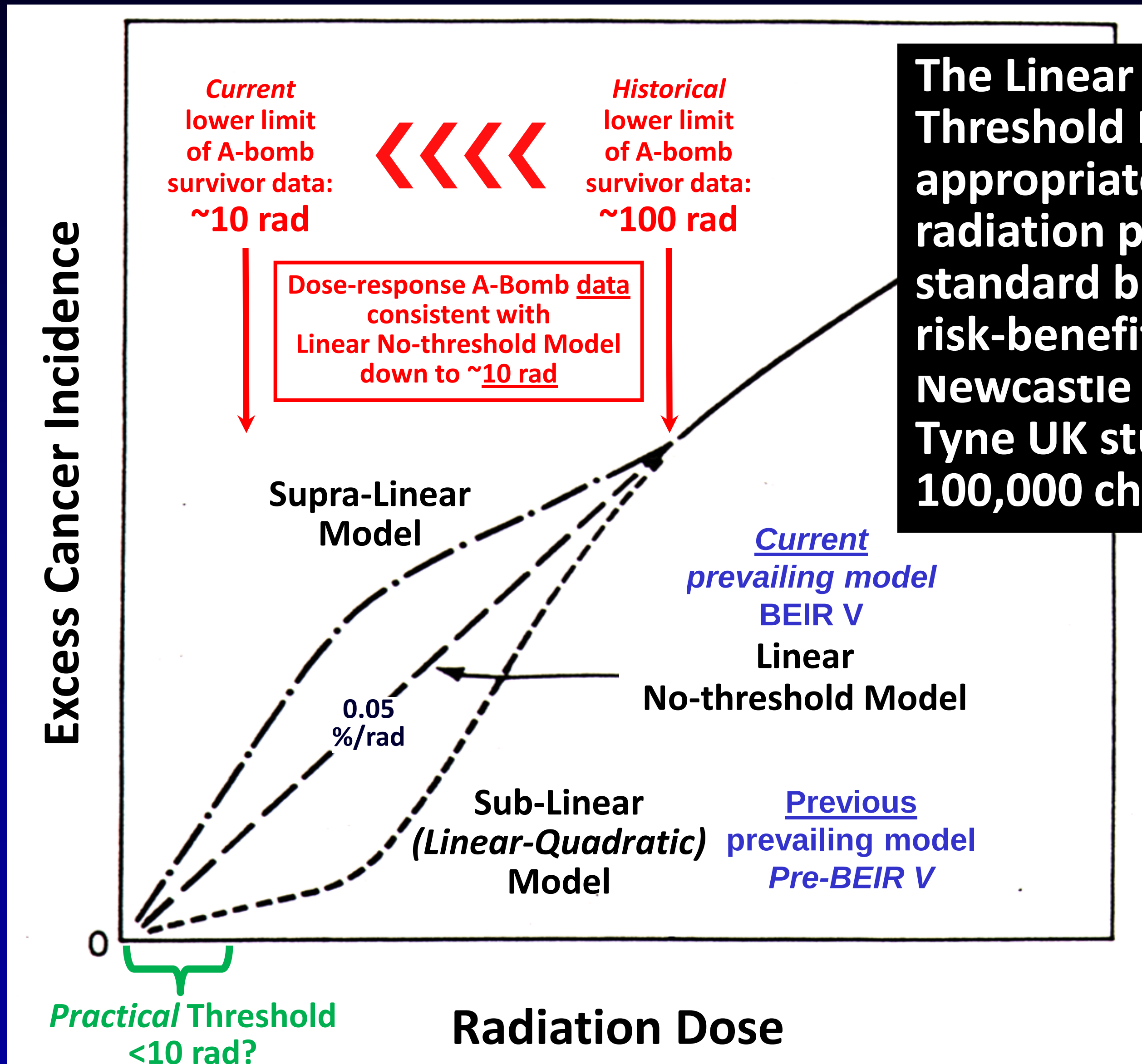
CT and Cancer Induction?



Brenner and Hall. N Engl J Med 357:2277-84, 2007

2% of all cancers in US attributable to CT!

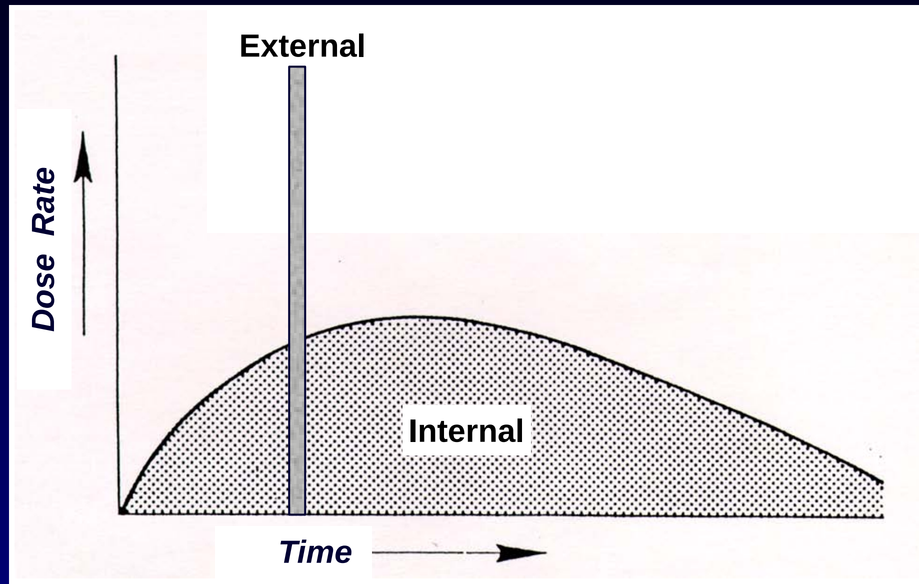
Dose-Response Models



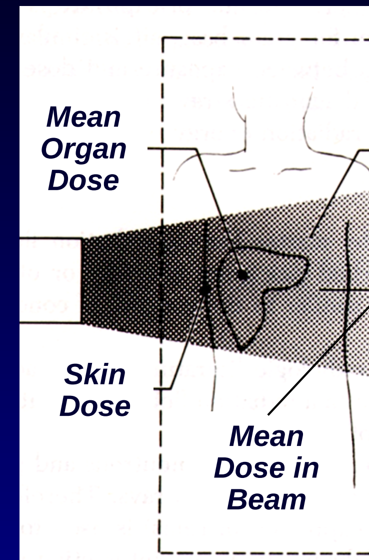
The Linear No-Threshold Model appropriate as a radiation protection standard but *not* for risk-benefit analysis? Newcastle upon Tyne UK study (n ≈ 100,000 children)

Types of Radiation Exposures

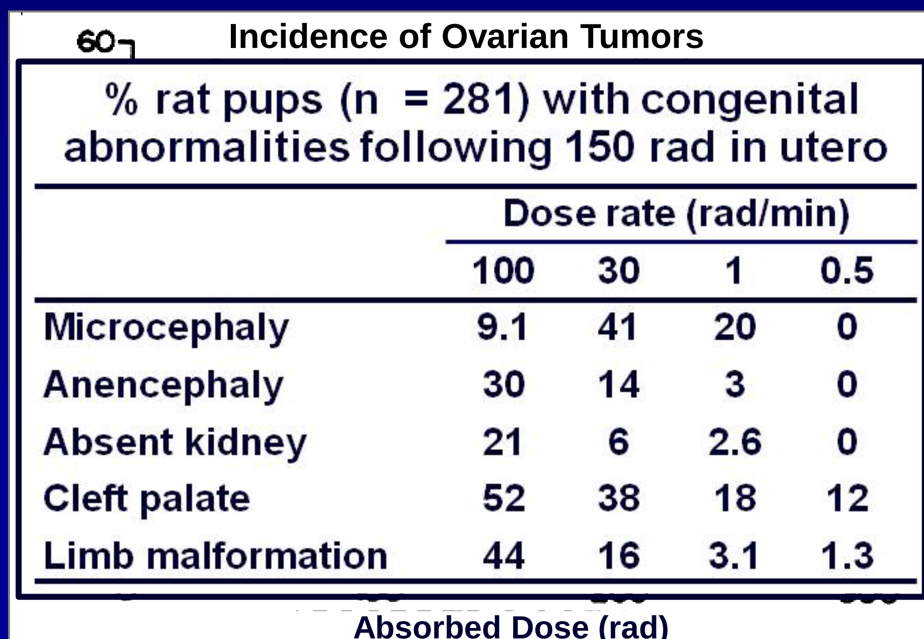
Internal



External



- Lo $\dot{D}$
- D calculated
- Whole-body
  Systemic effects?



% rat pups (n = 281) with congenital abnormalities following 150 rad in utero

	Dose rate (rad/min)			
	100	30	1	0.5
Microcephaly	9.1	41	20	0
Anencephaly	30	14	3	0
Absent kidney	21	6	2.6	0
Cleft palate	52	38	18	12
Limb malformation	44	16	3.1	1.3

- Hi $\dot{D}$
- D measured
- Partial-body
  Local effects only?

Brent et al. Rad Res 1971

Ullrich and Storer. IAEA/STI/PUB/489,1978

15-Country Collaborative Study of Cancer Risk among Radiation Workers in Nuclear Industry

Cardis et al. Rad Res 167: 396-416, 2007

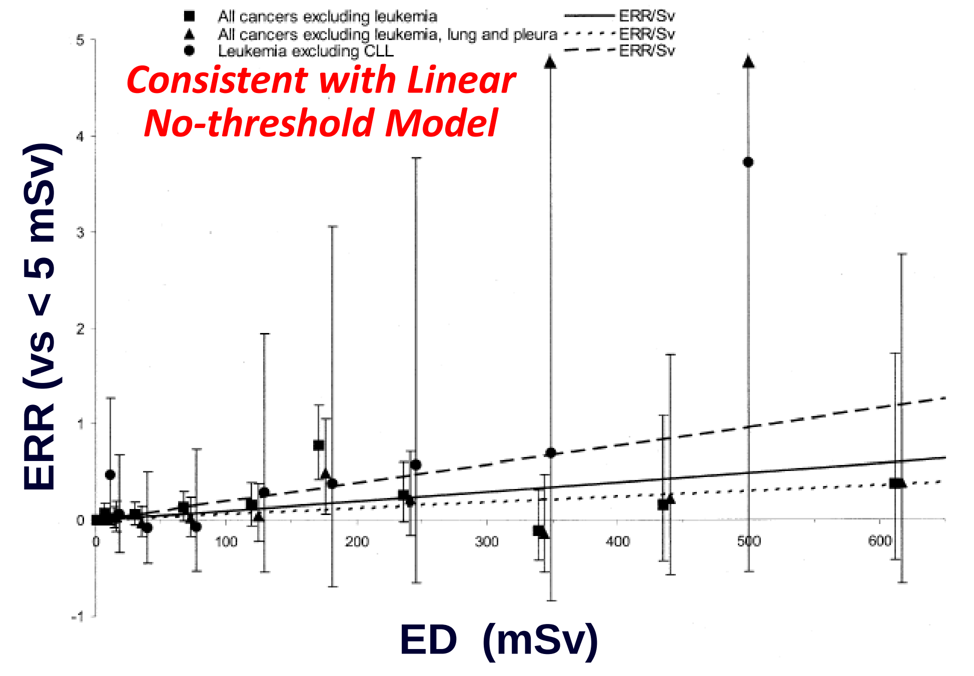
Protracted / Low-dose rate exposure

- 15-Country collaborative cohort study of cancer risk among 407,391 nuclear industry workers monitored individually for external radiation and with average follow-up > 10 year

- Dose-related increase in all cancer mortality
  - n: 5,233 deaths
  - ERR/Sv: 0.97
  - 90% CI: 0.28 - 1.77

- ED ≈ 2 mSv (2 rad)
  Significantly increased cancer risk @ < 150 mSv (15 rad)

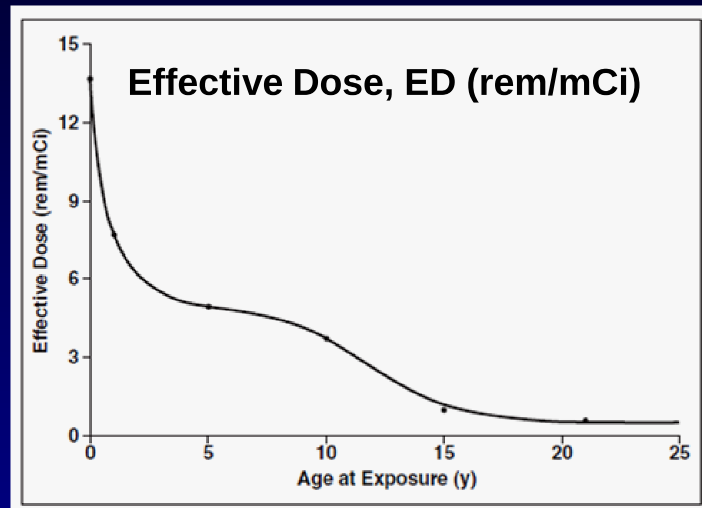
- Caveats (Dauer et al.)
  - Exclusion of workers from previous 3-country study risk showing no increased cancer risk*
  - No smoking data - More smokers among higher-D/ higher-risk workers?
  - Notably high Canadian risk estimates - Dosimetry?
  - Large error bars



Projected Excess Cancer Risk in Pediatric Osteosarcoma Patients Undergoing Tl201 Scanning

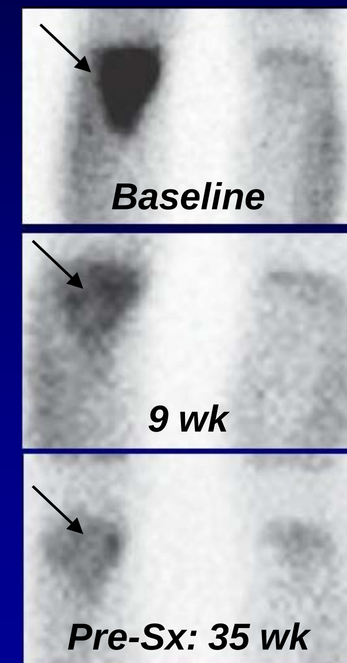
Kaste et al. AJR 194: 245-249, 2009

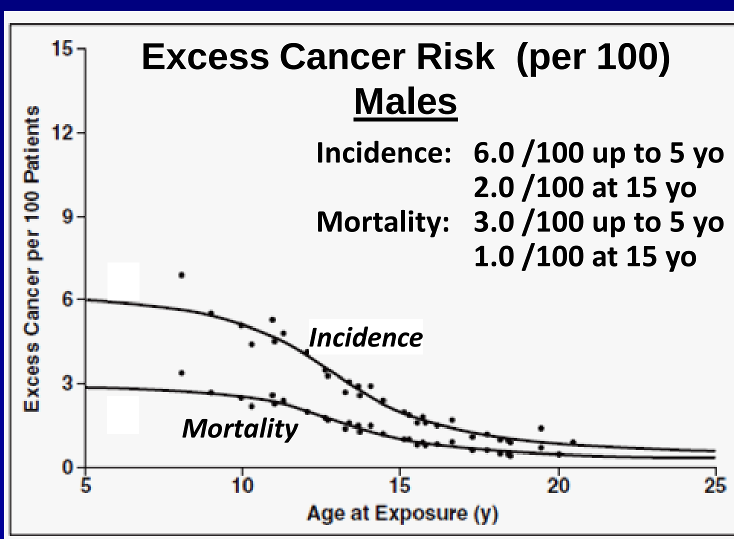
- 73 patients - 32 males, 15 yo
  - 41 females, 14 yo
- 3 studies - 4.4 mCi /study
  - BSA-adjusted
- ED - males: 19 rem
  - females: 22 rem
- BEIR VII risk ERRs

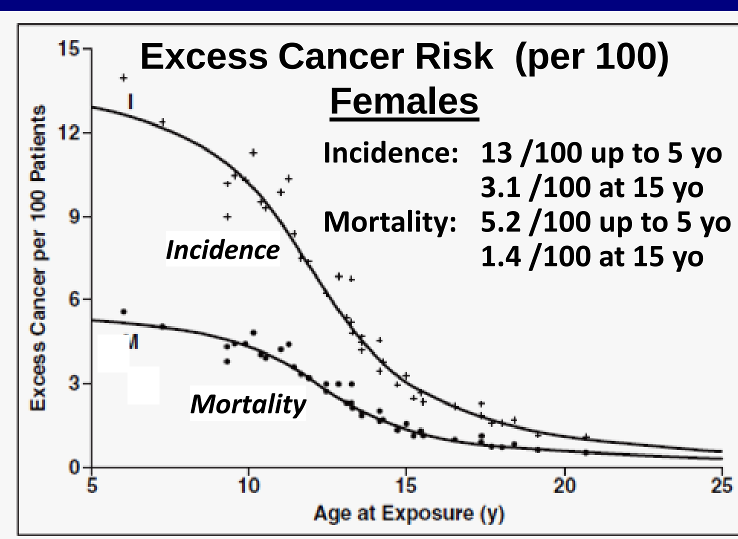


Neoadjuvant Tx

Tumor-bearing leg *Normal leg*







Measured Excess Thyroid Cancer Risk in Thyroid Patients Undergoing I131 Dx

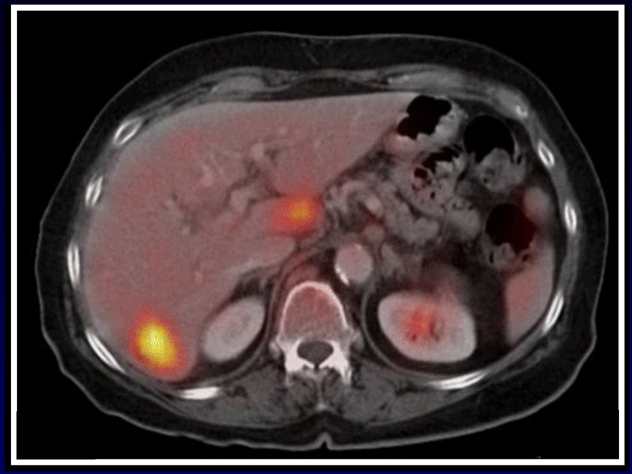
Dickman et al. Int J Cancer 106: 580–587, 2003

- Sweden
- 1952-1969
- ≥ 20-yr FU
- Individual thyroid dosimetry

			No prior neck XRT		Prior neck XRT	
Reason for I131 Dx			Thyroid cancer?	Other	Thyroid cancer?	Other
n			11,015	24,010	608	1,159
# Thyroid Cancers			69	36	12	12
Male, Female (%)			14, 86	23, 77	18, 82	25, 75
Age	-	1st Exposure (yr)	44	43	53	51
	-	% < 20 yo	6	7	0	2
Total AA (mCi)			0.068	0.043	0.095	0.084
Thyroid Uptake (%)			39	38	36	36
Total Thyroid Dose (rad)						
< 25	-	SIR *	3.7	0.45	18	6.9
	-	95% CI	1.6-7.3	0.15-1.1	0.47-103	0.84-25
25-50	-	SIR *	3.8	1.1	11	0
	-	95% CI	2.0-6.6	0.43-2.2	0.28-62	0-17
50-100	-	SIR *	2.6	0.86	11	4.1
	-	95% CI	1.3-4.8	0.37-1.7	1.3-39	0.10-23
>100	-	SIR *	3.7	1.3	15	11
	-	95% CI	2.6-5.0	0.73-2.1	6.3-29	5.0-21

Threshold > 100 rad?

** SIR, Standardized Incidence Ratio = Observed / Expected # of thyroid cancers*



$\neq$

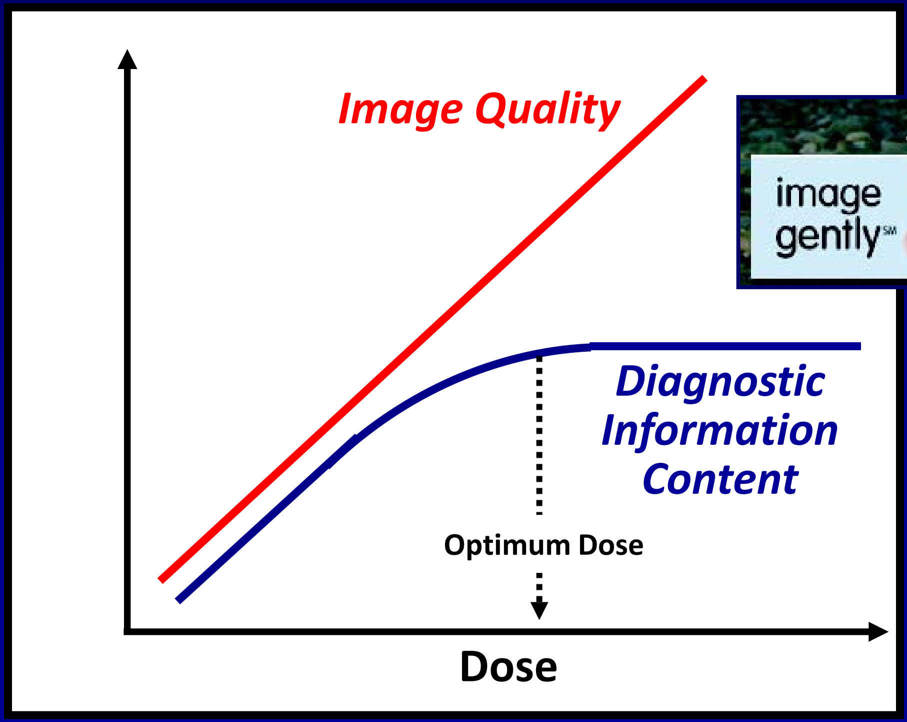


image
gently℠

Dose-Reduction Strategies in CT

- **Reduce tube voltage (kVp)**
  x-ray flux & dose $\propto$ kVp^2
- **Reduce tube current (mA)**
  x-ray flux & dose $\propto$ mA

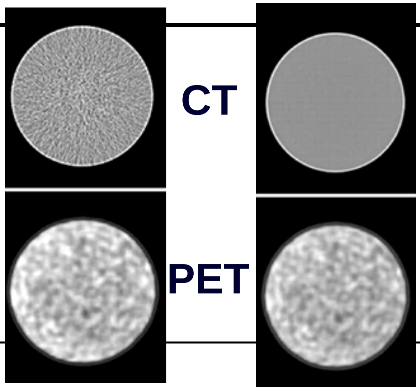
Application- and Patient-adapted CT protocols becoming the standard

- **EKG-controlled tube current modulation (ECTCM)**
  Cardiac motion *least* during diastole, greatest during systole →
  Image quality *best* during systole, worst during systole →
  EKG-triggered mA reduction during systole

Reduces ED for MSCT coronary angiography >50% - without loss of diagnostic information content

Radiation Dosimetry in PET (and SPECT)

FDG PET-CT	Dose *(rem)*			
	^{18}FDG *10 mCi*	PET w/ ^{68}Ge Transmission Scan *	PET-CT w/ "Low-Dose" CT *	PET-CT w/ "Diagnostic" CT *
Bladder	4.4	4.4	4.4	6.8
Bone Marrow	0.48	0.49	0.53	2.3
Breasts	0.34	0.35	0.38	1.8
Liver	0.58	0.60	0.66	3.2
Lungs	0.64	0.66	0.70	2.5
Ovaries	0.48	0.51	0.54	2.4
Effective Dose	1.1	1.1	2.0	3.3
Transmission Scan Contribution		*3%*	*49%*	*71%*
kVp			120	140
mAs			64	190
Pitch			1.5	1.25
			Attenuation Correction + Anatomy	***Diagnosis***



Cylinder filled with aqueous solution of F18

	ED (rem)	Critical Organ (rad)
Radiotracer	1-2	3-4
"Low-dose" CT	1	1
Total	2-3	4-5

Adapted from NUREG/CR-6345 1996.
Groves et al. Br J Radiol 77: 662, 2004.
Huda & Vance. AJR 188: 540, 2007.
Fahey. Radiology on-line/pre-print, 2007.

** No difference in SUVs*

Kamel et al. Eur J Nucl Med 29: 346, 2002.

Risk-Benefit Analyses: *Example*

^{18}FDG PET in pre-operative assessment of suspected NSCLC

Data

• Conventional pre-op work-up	→	Thoracotomy:	81% (78 / 97)
		Thoracotomy futile:	41% (39 / 78)
• Conventional pre-op work-up w/ PET	→	Thoracotomy:	65% (60 / 92)
		Thoracotomy futile:	21% (19 / 60)
• Surgey (Sx)-related mortality:			6.5%
• w/ PET	→	Avoided futile Sx:	20%

Van Tinteren *et al*. Lancet 359: 1388, 2002

Extrapolation

• New lung cancers in US (2006):			174,470	/yr
• Conventional pre-op work-up	→	Futile-Sx deaths:	3,766	/yr
• Conventional pre-op work-up + PET	→	Futile-Sx deaths:	1,547	/yr
• *Gross* benefit of pre-op PET - Lives saved w/ PET:			2,219	/yr
• ^{18}FDG ED / 10 mCi:			0.7	rem
• Excess cancer deaths (@ 0.05%/rem):			77	/yr
• *Net* benefit of pre-op PET - Lives saved w/ PET:			2,142	/yr

Summary and Conclusions

Thank You!

- **Other than for I131 (thyroid), there are *no* <u>data</u> on excess risk in <u>Dx</u>**
  - ♦ **University of Newcastle on Tyne study pending**
  - ♦ ***Caveats*: Measured *vs* Projected excess risks**
    - **– Uncertainties in dose estimates $\pm$[illegible]5-[illegible]0%**
- **Implications (eg for Dose-rate effect) of "Radiation Worker" study (Cardia et al. 2007)?**
- **For Dx & Tx I131 (thyroid):**
  - ♦ **<u>No</u> excess thyroid cancer risk @ thyroid doses up to 100 rem**
  - ♦ **<u>No</u> excess leukemia risk @ marrow doses up to 20 rem**
- ***Practical* threshold for cancer induction: <u>10s of rem</u>?**