Image Gently and Image Wisely in Nuclear Medicine

Frederic H. Fahey DSc

Boston Children's Hospital
Harvard Medical School

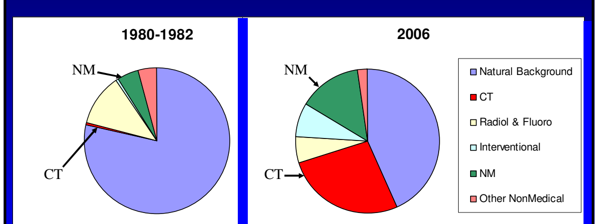
frederic.fahey@childrens.harvard.edu

Thanks to S. James Adelstein, S. Ted Treves,
Keith Strauss, Matthew Palmer,
Marilyn Goske, James Brink

Outline

- Radiation Risk
- Dosimetry and Dose Reduction
  - Radiopharmaceuticals
  - Hybrid Imaging
- Communication of Risk
- Image Gently
- Image Wisely (Works In Progress)

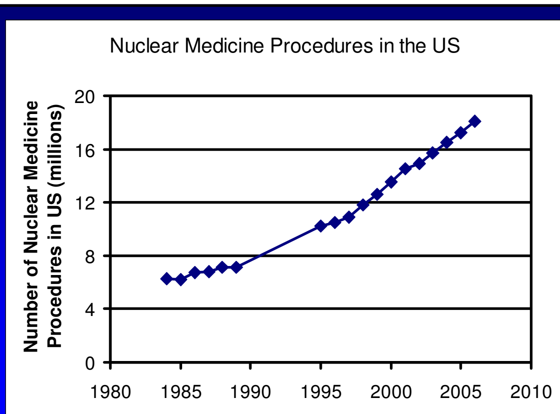
Estimated Annual Per Capita Adult Effective Dose in US



Medical 0.5 mSv
Total 3.1 mSv

Medical 3.0 mSv
Total 5.5 mSv

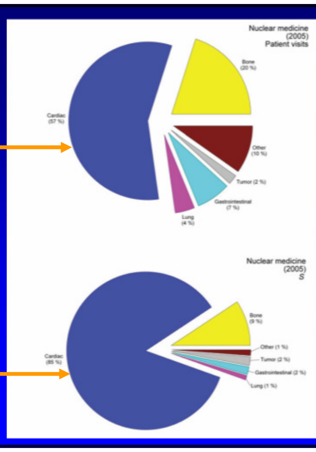
from NCRP 160



NCRP 160

Nuclear Cardiology

57% of Patient Visits



85% of Collective Dose

NCRP 160

R. Fazel et al., Exposure to Low-Dose Ionizing Radiation from Medical Imaging Procedures. NEJM 2009; 361:841-843

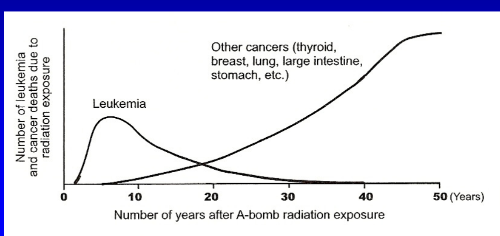
- Studied insurance records of over 900,000 patients (18-65 YO) over 3 years
- 69% had at least 1 radiologic exam
- Annual effective dose
  - Mean 2.4 ± 6.0 mSv
  - Median 0.1 mSv (inter-quartile range 0.1-1.7 mSv)
  - 78.6% < 3 mSv; 19.4% 3-20 mSv
  - 1.9% 30-50 mSv; 0.2% >50 mSv

R. Fazel et al., NEJM 2009; 361:841-843

Procedure	Ave ED (mSv)	Ann'l ED per cap	% Total ED
1. Myo Perf Img	15.6	0.540	22.1
2. CT Abdomin	8	0.446	18.3
3. CT Pelvis	6	0.297	12.2
4. CT Chest	7	0.184	7.5
5. Dx Card Cath	7	0.113	4.6
6. Rad Lumbar	1.5	0.080	3.3
7. Mammo	0.4	0.076	3.1
8. CT Ang Chest	15	0.075	3.1
12. Bone Scan	6.3	0.035	1.4
17. Thyroid Uptk	1.9	0.016	0.7

PET or PET/CT not in Top 20

From the Life Span Study (LSS) of the Radiation Effects Research Foundation atom bomb survivors we have learned about the time course of cancer appearance after a single acute dose of radiation – in the next decade we will learn more from those exposed in early childhood.



Cancer Mortality (Solid Tumors) from Lifespan Study (1950-2003)

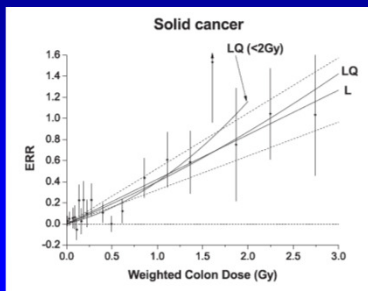
TABLE 9
Observed and Excess Deaths from Solid Cancer and Noncancer Diseases

			Solid cancer			Noncancer diseases[b]		
Colon dose (Gy)	Number of subjects	Person-years	Number of deaths	Number of excess cases[a]	Attributable fraction (%)	Number of deaths	Number of excess cases[a]	Attributable fraction (%)
<0.005	38,509	1,465,240	4,621	2	0	15,906	1	0
0.005–	29,961	1,143,900	3,653	49	1.3	12,304	36	0.3
0.1–	5,974	226,914	789	46	5.8	2,504	36	1.4
0.2–	6,356	239,273	870	109	12.5	2,736	82	3.0
0.5–	3,424	129,333	519	128	24.7	1,357	86	6.3
1–	1,763	66,602	353	123	34.8	657	76	11.6
2+	624	22,947	124	70	56.5	221	36	16.3
Total	86,611	3,294,210	10,929	527	4.8	35,685	353	1.0

[a] Based on the ERR model was defined as the linear model with effect modification: $\lambda_0(c,s,b,a)[1 + \beta_1 d \cdot \exp(\tau e + \upsilon \ln(a)) \cdot (1 + \sigma s)]$.
[b] Non-neoplastic blood diseases were excluded from noncancer diseases.

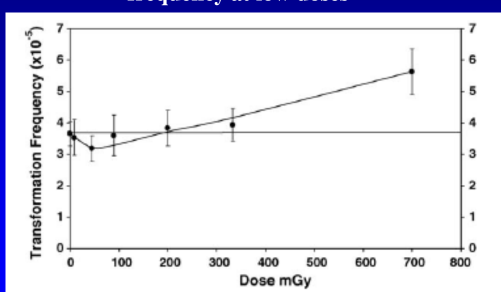
Ozasa et al., Rad Research 2012;177:229-243.

Most national and international bodies (ICRP,NCRP) have based their low dose (<100 mSv) risk estimates on linear extrapolation of the higher dose data. This report states that there is a significant trend in this range, consistent with that observed for the full dose range.



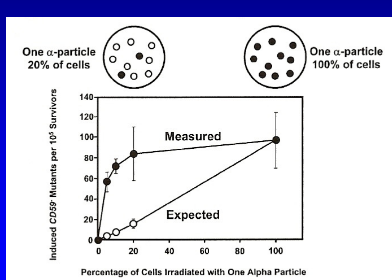
Ozasa et al., Rad Research 2012;177:229-243.

Neoplastic transformation of human fibroblasts dips below background frequency at low doses



Ko *et al* 2006

Induction of mutations in bystander cells by an alpha-particle microbeam (Bystander Effect)



Hall 2004

This, in turn, has led to the battle of the national academies:

From BEIR VII – National Academies of the USA

…current scientific evidence is consistent with the hypothesis that there is a linear, no-threshold dose-response relationship between exposure to ionizing radiation and the development of cancer in humans

From Académie des Science – Institut de France

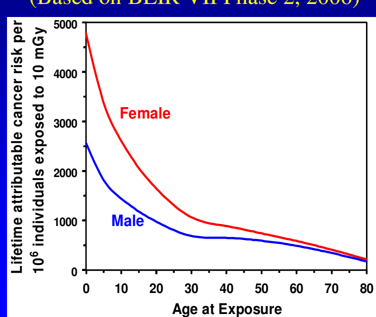
While LNT may be useful for the administrative organization of radioprotection, its use for assessing carcinogenic risks, induced by low doses, such as those delivered by diagnostic radiology or the nuclear industry, is not based on valid scientific data.

Lifetime Attributable Risk
10 mGy in 100,000 exposed persons
(BEIR VII Phase 2, 2006)

	All Solid Tumors		Leukemia	
	Male	Female	Male	Female
Excess Cases	80	130	10	7
Excess Deaths	41	61	7	5

Note: About 45% will contract cancer and 22% will die.

Lifetime Attributable Risk
10 mGy in 1,000,000 exposed persons
(Based on BEIR VII Phase 2, 2006)



Factors Affecting Dose in NM and SPECT

- Injected activity
  - Total counts and imaging time
- Choice of camera
  - Detector thickness and material
  - Number of detectors
- Choice of collimator
  - Hi Sens, Gen Purpose, Hi Res, Pinhole
- Image processing and reconstruction

Patient Effective Dose (mSv)

Summary	1 Year	5 Year	10 Year	15 Year	Adult
Mass (kg)	9.7	19.8	33.2	56.8	70
Tc-MDP (20 mCi*)	2.8	2.9	3.9	4.2	4.2
Tc-ECD (20 mCi*)	4.1	4.6	5.3	5.9	5.7
Tc-MAG3 (10 mCi*)	1.2	1.3	2.2	2.8	2.7

*max admin activ

ICRP 80 and 106

Patient Effective Dose (mSv)

Summary	1 Year	5 Year	10 Year	15 Year	Adult
Mass (kg)	9.7	19.8	33.2	56.8	70
Tc-MIBI Rest (10 mCi*)#	2.7	2.9	3.2	3.6	3.3
Tc-MIBI (30 mCi*)#	6.9	7.2	8.4	9.0	8.8
Tc-Tetrafosmin Rest (10 mCi*)#	2.2	2.3	2.3	2.9	2.8
Tc-Tetrafosmin Rest (30 mCi*)#	5.3	5.6	6.3	7.3	7.7
Tl-201 (3 mCi*)@	20.0	24.8	29.5	18	15.5

*max admin activity

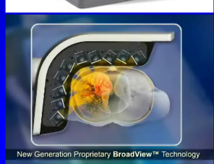
#ICRP 80, @ICRP 106

Cardiovascular Nuclear Imaging: Balancing Proven Clinical Value and Potential Radiation Risk

SNM Cardiovascular Council Board of Directors

"In summary, radionuclide MPI can provide scientifically validated, accurate, and in certain cases unique information for management of patients with known or suspected coronary artery disease at risk for major cardiovascular events. The radiation exposure risk associated with radionuclide MPI, albeit small and long term as opposed to the higher and more immediate risk for major cardiovascular events, mandates careful adherence to appropriateness criteria and guidelines developed or endorsed by [SNM, ASNC, ACC and AHA]. **With recent developments in technology, there are many opportunities to further reduce radiation exposure and further enhance the benefit-to-risk ratio of this well-established, safe imaging modality.**"

Cardiac SPECT



DSPECT (10 CZT detectors)

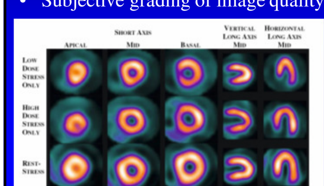
GE Discovery 530c
(Shown with 64 slice CT)

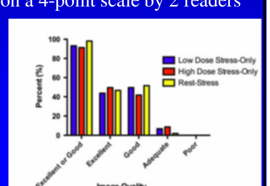
- 19 stationary CZT detectors
- 32x32 (5mm) array
- Multiple pinhole (5mm) apertures

Potential for dose reduction as well as greater throughput.

Duvall et al. Reduced isotope dose with rapid SPECT MPI imaging: Initial experience with a CZT SPECT J Nucl Cardiol 2010;17:1009-1014.

- GE Discovery NM 530c Camera
- Low-dose (12.5 mCi) stress only, high-dose (25-36 mCi) stress only, standard rest-stress (8-13 mCi for rest) => 4.2, 8.0 & 11.8 mSv ED, respectively
- Subjective grading of image quality on a 4-point scale by 2 readers





DePuey et al. A comparison of the image quality of full-time myocardial perfusion SPECT vs wide beam reconstruction half-time and half-dose. J Nucl Cardiol 2011;18:273-280.

- Acquired with conventional dual-head gamma camera
- Wide beam reconstruction (WBR): utilizes system information in reconstruction, suppresses noise, enhances signal-to-noise
  - Group A: Full-time with OSEM: 9-12 mCi rest, 32-40 mCi stress
  - Group B: Half-dose with WBR: 5.7 and 17.6 mCi for rest, stress

Table 2. Image quality of "full-time" OSEM and "half-dose" myocardial perfusion SPECT processed with Wide Beam Reconstruction

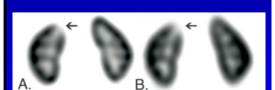
	Full-time Group A	Half-dose WBR Group B
Rest	3.6 ± 0.7	4.3 ± 0.8*
Stress	3.8 ± 0.7	4.6 ± 0.6*
Post-stress gated	3.9 ± 1.0	4.7 ± 0.6*

For grading image quality 1 = poor, 2 = fair, 3 = average, 4 = good, 5 = excellent.
* $P < .001$ vs full-time OSEM.

•Subjective image quality of 5-pt scale by 2 observers

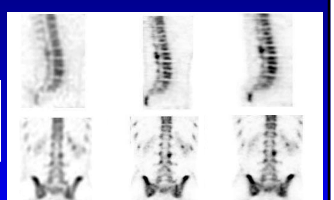
Half dose WBR: 5-6 mCi compared to Full-time OSEM ~11 mCi

Use of OSEM-3D Reconstruction In SPECT



FBP Full Cts OSEM Half Cts

Sheehy et al. Radiol 2009; 251:511-516


FBP Full Cts OSEM Full Cts OSEM Half Cts

Stansfield et al. Radiol 2010; 257:793-801

Factors Affecting Dose in PET

- Injected activity
  - Total counts and imaging time
- Choice of scanner
  - Crystal material and thickness
  - 2D vs 3D
  - Axial field of view
- Image processing

Patient Dose from FDG (mSv)

Summary	1 Year	5 Year	10 Year	15 Year	Adult
Mass (kg)	9.7	19.8	33.2	56.8	70
Act (mCi)	*1.46*	*2.97*	*4.98*	*8.52*	*10.5*
Bladder*	25.6	35.9	44.4	48.8	50.5
Eff Dose*	5.2	5.9	6.6	7.3	7.4

ICRP 106

Factors Affecting Radiation Dose in Multi-Detector CT

- Tube current or time (α mAs)
- Reduce tube voltage (α kVp^2)
- Beam collimation
- Pitch (table speed) (α 1/pitch)
- Patient size
- Region of patient imaged

CIRS Tissue Equivalent Phantoms

•Dosimetric CT phantoms

•Simulated spine

•Five 1.3 cm holes

•Five different sizes

Phantom	AP x Lat (cm)	Circum (cm)
Newborn	9 x 10.5	32
1 Year Old	11.5 x 14	42
5 Year Old	14 x 18	53
10 Year Old	16 x 20.5	61
Med Adult	25 x 32.5	96

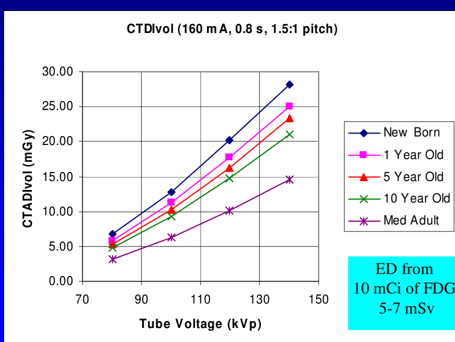
Fahey et al. *Radiology* 2007;243:96-104

Dosimetry of PET-CT and SPECT-CT

- PET/CT
  - GE Discovery LS

- SPECT/CT
  - Philips Precedent

Dose from CT of PET-CT GE Discovery LS (4-slice)

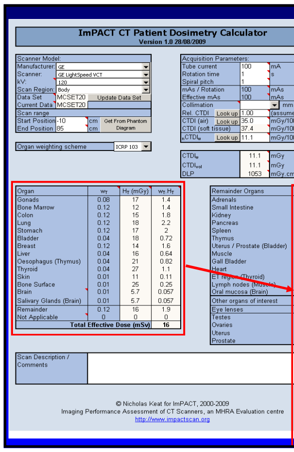


Median Effective Dose Values

Review of Published Results

Head CT	1.9 mSv (0.3-8.2)
Chest CT	7.5 mSv (0.3-26.0)
Abdomen CT	7.9 mSv (1.4-31.2)
Pelvis CT	7.6 mSv (2.5-36.5)
Abd & pelvis CT	9.3 mSv (3.7-31.5)

Pantos et al., Brit J Radiol 2011;84:293-303

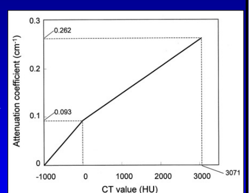


ImPACT CT Dose Calculator
120 kVp, 100 mAs, Pitch 1:1
"eyes to thighs" (95 cm)
CTDIvol = 11.1 mGy
DLP = 1053 mGy-cm
Effective Dose = 16 mSv

Organ	w_T	H_T (mGy)	$w_T.H_T$
Gonads	0.08	17	1.4
Bone Marrow	0.12	12	1.4
Colon	0.12	15	1.8
Lung	0.12	18	2.2
Stomach	0.12	17	2
Bladder	0.04	18	0.72
Breast	0.12	14	1.6
Liver	0.04	16	0.64
Oesophagus (Thymus)	0.04	21	0.82
Thyroid	0.04	27	1.1
Skin	0.01	11	0.11
Bone Surface	0.01	25	0.25
Brain	0.01	5.7	0.057
Salivary Glands (Brain)	0.01	5.7	0.057
Remainder	0.12	16	1.9
Not Applicable	0	0	0
Total Effective Dose (mSv)			16

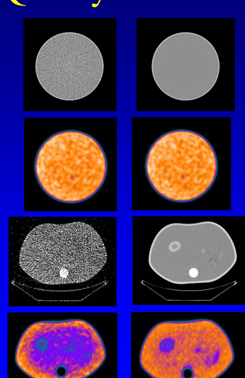
CT-Based Attenuation Correction

- Acquire CT Scan and reconstruct
- Apply energy transformation
- Reproject to generate correction matrix
- Smooth to resolution of PET/SPECT
- Apply during reconstruction



Quality of CTAC

80 kVp
10 mA
0.5 s/rot
1.5:1



140 kVp
160 mA
0.8 s/rot
1.5:1

Initial Experience with weight-based, low-dose pediatric PET/CT protocols

Alessio et al. J Nucl Med 2009;50:1570-1578

- 0.144 mCi/kg FDG (1 & 10 mCi min & max)
- 120 kVp
- Weight-based (Broselow-Luten color scale) 10-40 mAs
- 45 patients (9.2-109 kg, 1.4-23 YO)
- Dosimetry extrapolated from standard phantoms
- WB PET/CT effective dose from 5.4 to 10.0 mSv for 9 and 70 kg patient, respectively

Axial Extent of CT

- “Whole Body” PET typically acquired “Eyes to Thighs”
- Potential for SPECT acquisitions to all be extended, particularly with more efficient reconstruction
- Thus CT component can be combination of head & neck, thoracic, abdominal and pelvic CT
- Is “One size fits all” appropriate?
- Alternative paradigm suggested by George Segall of Stanford and Palo Alto VA Medical Center
- Standardization of technique

Adult Effective Doses (mSv)

Procedure	Average Effective
Radiograph of Extremity	0.001
Posterior/Anterior and Lateral Chest Radiograph	0.1
Mammography	0.4
Abdominal Radiograph	0.7
Head CT	2.0
^{99m}Tc MAG3 Renal Scan	***2.7***
Intravenous Urography	3.0
^{99m}Tc MDP Bone Scan	***4.2***
^{99m}Tc ECD Brain Scan	***5.7***
Pelvic CT	6.0
Chest CT	7.0
^{18}F FDG PET Scan	***7.4***
Abdominal CT	8.0
^{99m}Tc MIBI for Stress/Rest Cardiac Scan	***11.8***
Coronary Angiographic CT	16.0

Mettler et al. Radiol 2008;248:254-263, ICRP 80 and 106

Dose/Risk Statements

AAPM (Dec 2011)

http://www.aapm.org/org/policies/details.asp?id=318&type=PP

"Risks of medical imaging at effective doses below 50 mSv for single procedures or 100 mSv for multiple procedures over short time periods are too low to be detectable and may be nonexistent. Predictions of hypothetical cancer incidence and deaths in patient populations exposed to such low doses are highly speculative and should be discouraged. These predictions are harmful because they lead to sensationalistic articles in the public media that cause some patients and parents to refuse medical imaging procedures, placing them at substantial risk by not receiving the clinical benefits of the prescribed procedures."

Dose/Risk Statements

SNMMI (June 2012)

http://interactive.snm.org/docs/SNM_Position_Statement_on_Dose_Optimization_FINAL_June_2012.pdf

"Radiation dose for all nuclear medicine and molecular imaging procedures should be optimized so that the patient receives the smallest possible amount of radiopharmaceutical that will provide the appropriate diagnostic information. SNM and SNMTS also recognize that if an appropriate procedure—one that can provide the physician with clinical information essential to the patient's treatment—is *not* performed when necessary due to fear of radiation, it can be detrimental to the patient."

"The SNM and SNMTS believe that the right test with the right dose should be given to the right patient at the right time."

Communication of Risk

- Need to be prepared to speak to referring physicians, patients, and parents
- In general, referring physicians have very little understanding of radiation risk and may perceive NM as a "high dose" procedure.
- Teenage patients and parents may have seen discussions of medical radiation in the news.
- Reports have shown that informing patients regarding radiation risk does not adversely affect their willingness to have an appropriately ordered study.

Fahey, Treves, Adelstein. Minimizing and Communicating Radiation Risk in Pediatric Nuclear Medicine. J Nucl Med. 2011;52:1240-1251.

Regarding radiologic procedures, when patients and families ask

"What is my dose?"

they are really asking…

Regarding radiologic procedures, when patients and families ask

"What is my dose?"

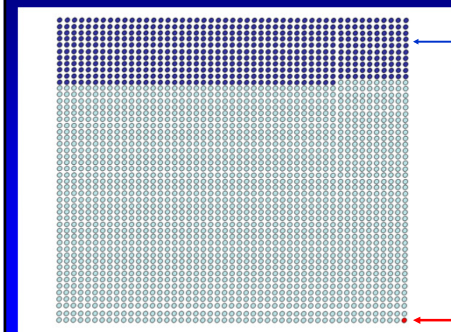
they are really asking…

"What is my risk?"

A reasonable approach is to discuss with patients and their families:

- We will be administering a small amount radioactivity in order to perform a study which emits radiation similar to that emitted by x-ray machines.
- This exposure may lead to a slight increase in the risk of contracting cancer sometime in their lifetime.
- The radiation dose from this procedure is in the range of many other radiological tests and is on the same order as that individuals get from natural background in one year.
- The dose to the parent of the patient is on the order of the radiation one would receive during a transcontinental flight.

Risk of dying of cancer as a result from a FDG PET scan (~1 in 2500)



Lifetime fatal risk from everyday activities






Activity	Lifetime Risk
Accident while riding in a car	304
Accident as a pedestrian	652
Choking	894
Accidental poisoning	1,030
Drowning	1,127
Exposure to fire or smoke	1,181
Falling down stairs	2,024
Cancer from ^{18}F PET scan	*2,700*
Accident while riding a bike	4,734
Cancer from ^{99m}Tc MDP bone scan	*4,760*
Accidental firearms discharge	6,333
Accident while riding in a plane	7,058
Hit by lightning	84,388

Decrease in Life Expectancy

Activity or risk	LLE (days)
Living in poverty	3,500
Being male (vs. female)	2,800
Cigarettes (male)	2,300
Working as a coal miner	1,100
30-lb overweight	900
Grade school dropout	800
15-lb overweight	450
Alcohol	230
Motor vehicle accidents	180
Speed limit: 65 vs. 55 miles per hour	40
Coffee: 2 cups/day	26
Radiation worker, age 18-65 (~200 mSv lifetime)	25
Birth control pills	5

Pediatric Administered Dose Survey

- Surveyed 15 dedicated pediatric hospitals in North America (13 responded)
- Requested information on 16 studies commonly performed in pediatric NM
  - Administered dose per kg
  - Maximum administered dose
  - Minimum administered dose

Treves ST, Davis RT, Fahey FH. *J Nucl Med*, 2008;49:1024-1027.

Review of ^{99m}Tc DMSA Data

		N	Min	Max	Median	Mean
Tc-99m DMSA	MBq/kg (mCi/kg)	8	1.11	3.70	2.22	2.35
	Minimum Activity	11	5.55	74.00	18.50	26.40
	Maximum Activity	11	74.00	222.00	185.00	151.36

Variability in Administered Doses in Pediatrics

- Consider the maximum/minimum for a parameter as the range factor
- For Admin dose/kg and Maximum dose the range factor varied, on average, by a factor of 3, and by as much as a factor of 10
- Minimum dose range factor varied, on average, by a factor of 10 and as much as a factor of 20

Alliance for Radiation Safety in Pediatric Imaging launched in 2007. Now includes over 60 international organizations including partners in industry,

imagegently.org

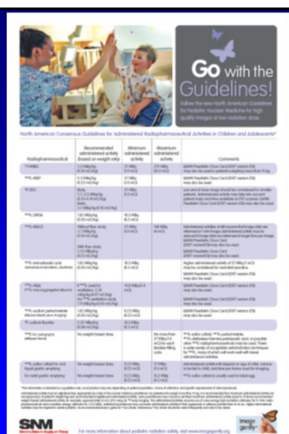
Pediatric Radiopharmaceutical Administered Doses

- Consensus workshops among pediatric nuclear medicine leaders took place at the *2009 and 2010 Society of Nuclear Medicine Annual Meetings* and at the *2009 and 2010 Annual Meetings of the Society for Pediatric Radiology*
- Members represented the SNM, SPR, ACR and Image Gently Campaign

Pediatric NM Pediatric Dose Consensus workshop SPR Boston 2010

Pediatric NM Pediatric Dose Consensus workshop
SPR Boston 2010

Gelfand MJ, Parisi MT, Treves ST *Pediatric radiopharmaceutical administered doses: 2010 North American consensus guidelines.* J Nucl Med. 2011;52:318-22.



Nuclear Medicine Parent Information Brochure

Pediatric Nuclear Medicine Dose Optimization What can be done?

- Implement standard guidelines. reduce large variability
- As new dose standard baselines are adopted, should evaluate methods of dose reduction
- Standardization with EANM (Milan Oct 2012)
- Standardization of pediatric PET/CT
- Expansion of information on Image Gently Website

Image Wisely

- Launched at RSNA 2010
- They sought to address concerns about the surge of public exposure to ionizing radiation from medical imaging.
- Objective is to lower the amount of radiation used in medically necessary imaging studies and eliminating unnecessary procedures
- Participating Organizations
  - ACR, RSNA, ASRT, AAPM

IMAGE WISELY™ Radiation Safety in Adult Medical Imaging

imagewisely.org

Action Plan

- Target audiences addressed in two phases:
  - Radiologists, Technologists, Medical Physicists
  - Patients / Public, Referring Physicians
- Targets Areas (in order of priority)
  - Computed Tomography
  - Nuclear Medicine Procedures
  - Radiography / Fluoroscopy

Image Wisely
Nuclear Medicine Project

- Initially concentrated on CT
- Now expanding to nuclear medicine
- Kick-off Meeting October 27, 2011
- SNM and ASNC asked to participate in addition to ACR, RSNA, ASRT and AAPM

IMAGE WISELY™
Radiation Safety in Adult Medical Imaging

Image Wisely
Nuclear Medicine Project

- IW Leadership
  - Jim Brink (RSNA)
  - William Hendee (AAPM)
  - Greg Morrison (ASRT)
  - Rick Morin (ACR: Not present on 10/27/11)
- SNM/SNMTS
  - Fred Fahey
  - Chris Palestro
  - Brenda King
- ACR
  - Murray Becker
  - Beth Harkness
- AAPM
  - Larry Williams
- ASNC
  - Gordon DePuey
- RSNA
  - Hossein Jadvar (not present on 10/27/11)

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- Develop material for imaging professionals first followed by that for referring physicians and patients
  - General Nuclear Medicine
  - Cardiac Nuclear Medicine
  - PET and PET/CT
- Draft materials due this month
- Target Launch Date – November 2012

Summary

- Radiation Risk
  - Epidemiologic and biological studies of risk are not conclusive, particularly for low-doses.
  - Given contradictory data, linear-no threshold model is prudent for radiation protection
  - Effective communication of risk is essential.
- NM and PET
  - Dose reduction for myocardial perfusion studies possible with new instrumentation/processing
- PET/CT
  - Large reduction in dose if only used for attenuation correction
  - Dose reduction also possible for anatomical correlation
  - For diagnostic CT, consider multi-phase acquisition paradigms
- Image Gently
  - Large variation in administered activities to children
  - North American Consensus Guidelines (“Go to the Guidelines!”)
  - Helpful materials for communication of risk
- Image Wisely
  - Dose reduction in adults
  - Collaborative program (ACR, RSNA, ASRT, AAPM, SNM/SNMTS, ASNC)
  - Target launch data of November 2012

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Thanks!
Questions?

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