Dose Optimization in Pediatric Nuclear Medicine

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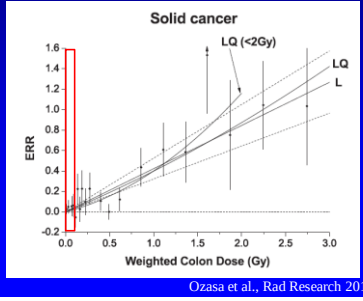
Disclosure

I am PI of a subproject for the following grant based at Johns Hopkins University

Dose Reduction in Pediatric Molecular Imaging
2 R01 EB013558-05A1
(G. Sgouros, PI)

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.



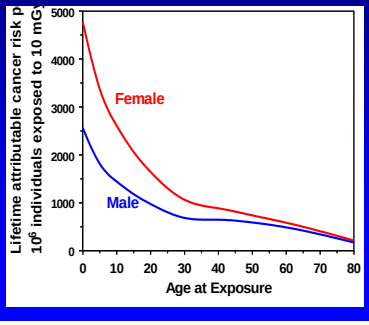
Ozasa et al., Rad Research 2012;177:229-243.

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)



SNMMI Dose Optimization Statement

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. However, 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 right test with the right dose should be given to the right patient at the right time. When nuclear medicine and molecular imaging procedures are performed correctly on appropriate patients, the benefits of the procedure very far outweigh the potential risks.

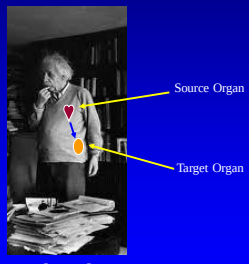
Dose Optimization and Standardization

Although controversies and disagreements may exist regarding the nature and magnitude of health effects associated with ionizing radiation at dose levels associated with diagnostic imaging and nuclear medicine (Siegel et al. JNM 2017;58:1-6 and 865-868), it remains prudent to determine the most appropriate administered activity for the pediatric patient.

It is unlikely that the most appropriate administered activity for a 5-year old child is the same as that for a 40 year-old adult.

It is essential to emphasize the benefits of the examination and to not compromise on diagnostic quality.

MIRD Equation



Medical Internal Radiation Dosimetry Committee of the SNMMI

MIRD Equation

MIRD Pamphlet 21. J Nucl Med 2009;50:477

S factor

$$D_T = \Sigma_S \tilde{A}_s (\Sigma_i \Delta_i \varphi_i / m_T)$$

Where
D_T is radiation dose to target organ in Gy
$\tilde{A}_s$ is the time-integrated activity in source organ in MBq-h
Δ_i is mean energy per nuclear transformation in g-Gy/MBq-h
φ_i is the fraction of energy emitted from the source organ that is absorbed by the target organ
m_T is mass of the target organ in g
Σ_s indicates summed over all source organs
Σ_i indicates summed over all emitted radiations

This allows the calculation of radiation dose to individual target organs.

Effective Dose

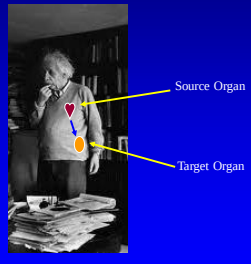
- Equivalent to absorbed dose given to whole body resulting in the same biological effect
- Sum of organ doses weighted by its radiation sensitivity.

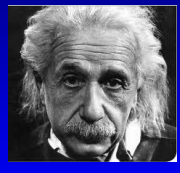
$$ED = \Sigma H_T \times W_T$$

- H_T is dose to organ, T, and W_T is its radiosensitivity weight
- Since WT is based on population averages, ED does **NOT** apply to individual patients, particularly children

Tissue or Organ	ICRP 103
Gonads	0.08
Red bone marrow	0.12
Lung	0.12
Colon	0.12
Stomach	0.12
Breast	0.12
Bladder	0.04
Liver	0.04
Esophagus	0.04
Thyroid	0.04
Skin	0.01
Bone surface	0.01
Brain	0.01
Salivary glands	0.01
Remainder	0.12
Total	1.00

MIRD Equation





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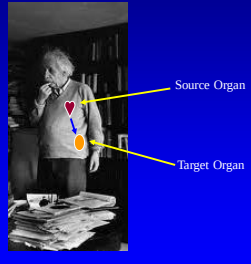
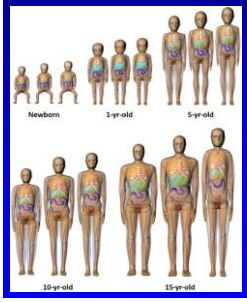


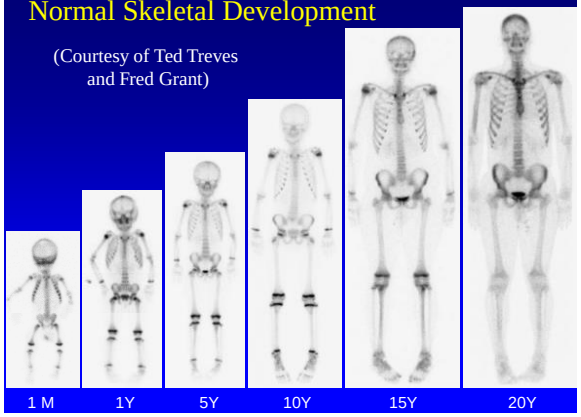
O'Reilly *et al*. A risk index for pediatric patients undergoing diagnostic imaging with ^{99m}Tc-DMSA that accounts for body habitus Phys Med Biol 2016;61:2319-2332



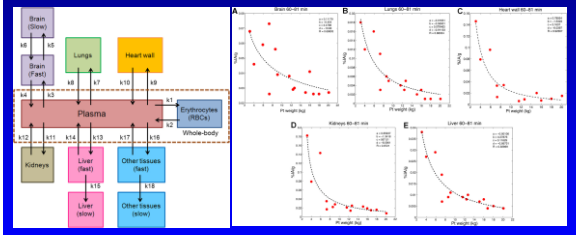
- Image risk index (RI) based on BEIR VII for dose optimization
- Family of phantoms
- Weight-based admin activity of ^{99m}Tc DMSA
- Affect of body habitus on RI
- Body habitus (var upto 18%)
- Dependence of RI on kidney size for ^{99m}Tc DMSA

Normal Skeletal Development

(Courtesy of Ted Treves and Fred Grant)



Khamwan et al. Pharmacokinetic modeling of ^{18}F FDG for premature infants, and newborns through 5-year-olds Eur J NM MI Reseach. 2016;6:28



Developed a pharmacokinetic (PK) mode for FDG in peds using compartmental models and data for literature and BCH

Factors Affecting Dose in NM, SPECT and PET

- Injected activity
  - Total counts and imaging time
- NM/SPECT
  - Choice of camera (Detector material/thickness, # of detectors)
  - Choice of collimator (Hi Sens, Gen Purpose, Hi Res, Pinhole)
  - Image processing and reconstruction
- PET
  - Crystal material and thickness
  - Axial field of view
  - Image processing and reconstruction

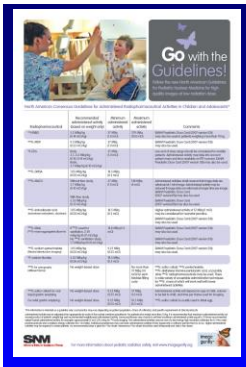
2007 Survey of Administered Activity in Children at Dedicated Pediatric Institutions

- 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.

Variability in Administered Doses in Pediatrics

- Consider the ratio of maximum over minimum reported values as a parameter of variability referred to as the *dose 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



Gelfand MJ, Parisi MT, Treves ST. J Nucl Med. 2011;52:318-22.

Treves ST, Gelfand MJ, Fahey FH, Parisi MT. J Nucl Med. 2016;57:15N-18N. (6 additional protocols)

Pediatric NM in Clinical Practice
Survey of US General Hospitals

- Most children imaged at general hospitals so we sought to characterize practice and familiarity with Guidelines
- 121/194 hospitals (62%) responded. 80% perform pediatric NM studies. Essentially all scaled administered activity in smaller patients (90% by weight).
- Of 5 procedures (MDP, DMSA, MAG3, HIDA, FDG) considered, the median of the surveyed group was consistent with the North American Guidelines in all cases of dose/kg and Min Dose except for MAG3.
- 83% familiar with Image Gently, 58% familiar with North American Guidelines, 55% modified their administered activities based on North American Guidelines

Fahey FH, Ziniel SI, Manion D, Baker A, Treves ST. J Nucl Med. 2016;57:1478-85.

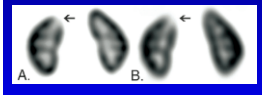
Patient Effective Dose (mSv)

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
FDG (10 mCi*)	5.2	5.9	6.6	7.3	7.4

*max admin activ

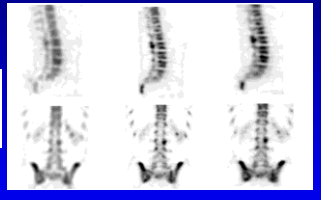
ICRP 128

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

CT Basics

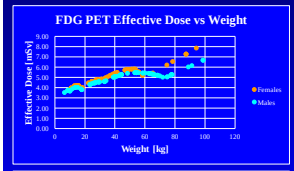
- Tube voltage (kVp)
  - Voltage across anode-cathode axis
  - Defines maximum energy of x-ray spectrum
  - Affects contrast
  - Dose α kVp^2
- Tube current (mA)
  - Electron flow from cathode to anode
  - Number of x-rays α mA
  - Current x time = mAs
  - Dose α mAs
- Scanners vary in design
  - Focal spot to detector distance
  - Bowtie filter (different shape, thickness and composition)

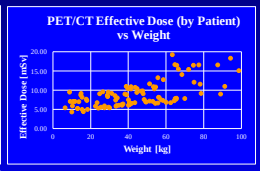
CT Dose in the Context of Hybrid Imaging

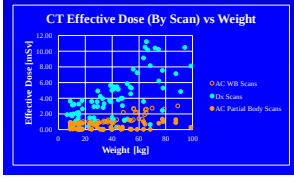
- In helical CT as in hybrid imaging, the radiation dose varies as tube voltage (α kVp^2), linearly with tube current-time product (mAs) and inversely with pitch. Also, beam collimation, patient size and region of patient
- **F**or atten correction (AC), the kVp and mAs can be reduce almost as low as possible.
- For diagnostic (**Dx**), might want to limit high dose to region of clinical interest.
- For anatomical correlation (**non-Dx**), the mAs can be reduced significantly

PET/CT Dose

F Fahey, C Kofler, B Sexton-Stallone, R Reddy, R MacDougall, Wesley Bolch
Boston Children's Hospital, Univ of Florida







- PET/CT data for 163 children
- FDG PET from No Am GLs
- Fit each child to UF phantom DB for CT and modeled TCM
- Estimated organ and ED for PET, CT and combined PET/CT
- Considered low-dose attenuation correction (AC) CT separate from Dx

Questions?

1. Why does the radiation dose to children from the administration of a given amount of a particular radiopharmaceutical vary as compared to adults?

a. The instrumentation used for imaging
b. The use of sedation or anesthesia
c. The anatomy and physiology of the patient
d. The method of image processing or reconstruction used

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References: Fahey FH, Treves ST, Adelstein SJ. Minimizing and communicating radiation risk in pediatric nuclear medicine. J Nucl Med. 2011 Aug;52(8):1240-51.

2. According to the BEIR VII Report, the risk of adverse stochastic effects from ionizing radiation in children as compared to adults is considered to be _____.

a. The same
b. Higher
c. Lower
d. Not of concern

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Reference: Committee to Assess Health Risks from Exposure to Low Levels of Ionizing Radiation. National Research Council, Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2. Washington, D.C.: The National Academies Press; 2006

3. An effective approach to scaling the exposure to pediatric patients from the CT component of PET/CT is the use of _____.

a. Tube current modulation
b. Higher tube current (kVp)
c. Lower pitch (e.g. reducing the pitch form 1.0:1 to 0.75:1)
d. Extending the region of the patient being scanned

Reference: Fahey FH, Goodkind AB, Plyku D et al. Dose Estimation in Pediatric Nuclear Medicine. Semin Nucl Med. 2017 Mar;47(2):118-125.

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