Pediatric Imaging in Nuclear Medicine

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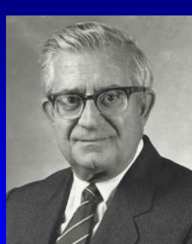
Disclosure

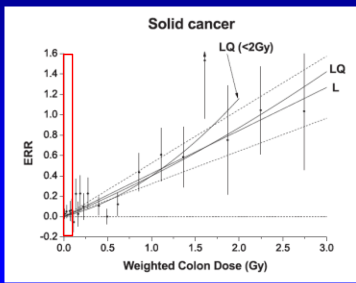
I am PI of a subproject for the following grant based at Johns Hopkins University

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



James G. Kereiakes

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.

SNMMI Dose Optimization Statement

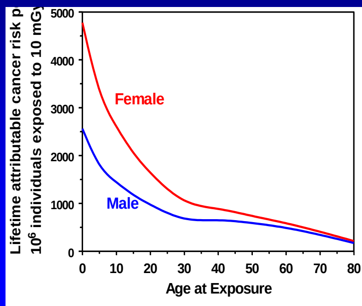
Radiation dose for all nuclear medicine and molecular imaging procedures should be optimized so that the patient receives the smallest possible amount of radiopharmaceutical that will provide the appropriate diagnostic information. However, if an appropriate procedure—one that can provide the physician 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

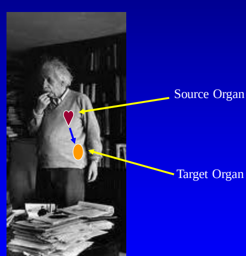
Although controversies and disagreements may exist regarding the nature and magnitude of health effects associated with ionizing radiation at dose levels associated with diagnostic imaging and nuclear medicine (Siegel et al. JNM 2017;58:1-6 and 865-868), it remains prudent to determine the most appropriate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

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



MIRD Equation



Medical Internal Radiation Dosimetry Committee of the SNMMI

MIRD Equation

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

S factor

$$D_T = \Sigma_S \tilde{A}_S \underbrace{(\Sigma_i \Delta_i \varphi_i / m_T)}_{\text{S factor}}$$

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

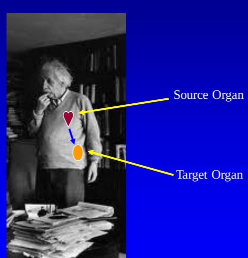
- Equivalent to absorbed dose given to whole body resulting in the same biological effect
- Sum of organ doses weighted by its radiation sensitivity.

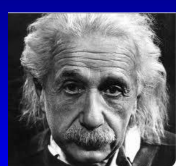
$$ED = \Sigma H_T \times W_T$$

- 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

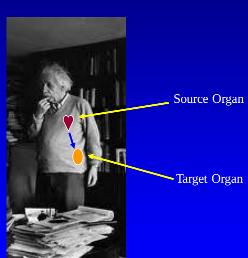
Tissue or Organ	ICRP 103
Gonads	0.08
Red bone marrow	0.12
Lung	0.12
Colon	0.12
Stomach	0.12
Breast	0.12
Bladder	0.04
Liver	0.04
Esophagus	0.04
Thyroid	0.04
Skin	0.01
Bone surface	0.01
Brain	0.01
Salivary glands	0.01
Remainder	0.12
Total	1.00

MIRD Equation



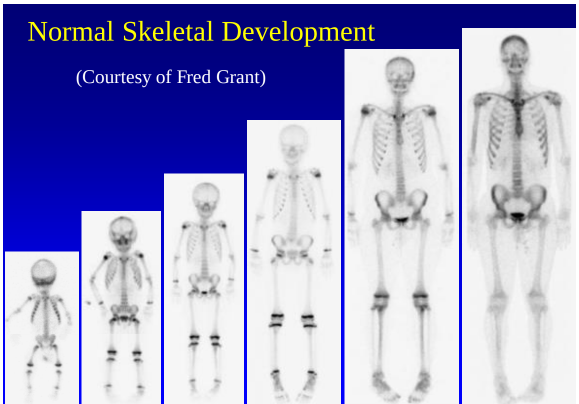


MIRD Equation

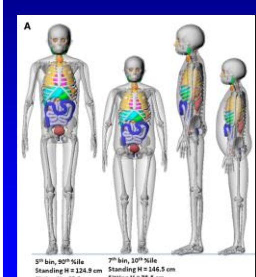


Normal Skeletal Development

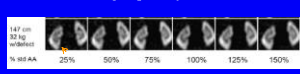
(Courtesy of Fred Grant)



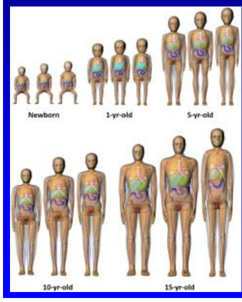
Sgouros *et al*. An approach for balancing diagnostic image quality with cancer risk: application to pediatric diagnostic imaging of ^{99m}Tc (DMSA). J Nucl Med. 2011;52:1923-9.



- Two 10 YO girls: same weight, different body types
- ED varied by 44%
- Used BEIR VII models to assign age- and sex-specific risk factors
- Simulated DMSA studies with lesion at different admin act levels and utilized channelize Hotelling observer models and ROC to assess image quality

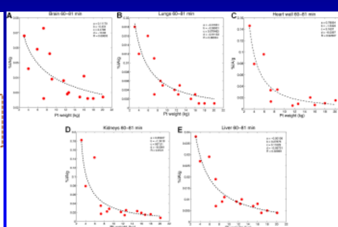


O'Reilly *et al.* A risk index for pediatric patients undergoing diagnostic imaging with ^{99m}Tc-DMSA that accounts for body habitus Phys Med Biol 2016;61:2319-2332



- 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

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

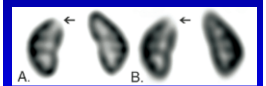


Developed a pharmacokinetic (PK) mode for FDG in peds using compartmental models and data for literature and BCH

Factors Affecting Dose in NM, SPECT and PET

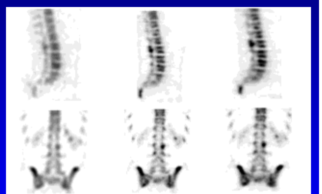
- Injected activity
  - Total counts and imaging time
- NM/SPECT
  - Choice of camera (Detector material/thickness, # of detectors)
  - Choice of collimator (Hi Sens, Gen Purpose, Hi Res, Pinhole)
  - Image processing and reconstruction
- PET
  - Crystal material and thickness
  - Axial field of view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

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

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

Variability in Administered Doses in Pediatrics

- In 2007, surveyed 13 dedicated pediatric hospitals in North America.*
- In 2011, the *North American Guidelines for Administered Activities in Children and Adolescents* was published.[@]
- In 2012, Image Gently and SNM launch the Go to the Guidelines campaign
- In 2013, a follow-up survey of the same 13 pediatric institutions was performed.[#]

*Treves ST, Davis RT, Fahey FH. *J Nucl Med*, 2008;49:1024-1027.
[@]Gelfand MJ, Parisi MT, Treves ST. *J Nucl Med*. 2011;52:318-22.
[#]Fahey F, Ziniel S, Manion D, Treves ST. *J Nucl Med* 2015;56:962-967.

2007 Survey of Administered Activity in Children at Dedicated Pediatric Institutions

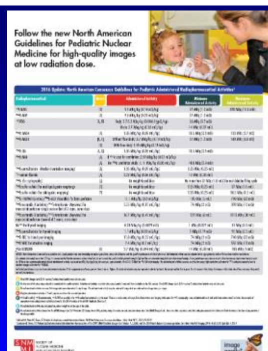
- Surveyed 15 dedicated pediatric hospitals in North America (13 responded)
- Requested information on 16 studies commonly performed in pediatric NM
  - Administered dose per kg
  - Maximum administered dose
  - Minimum administered dose

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.

www.snmmi.org/pedactivitytool

2013 Follow-Up Survey of Dedicated Pediatric Institutions

- Surveyed the same 13 pediatric institutions
- Requested information on the same 16 procedures
- Dose parameters reduced or same in all cases.
- Range factor reduced in dose/kg and min dose but raised in max dose due to dose reduction (some stayed the same while some lowered).
- All familiar with Image Gently and North American Guidelines. 10/13 modified their administered activities based on North American Guidelines

Fahey F, Ziniel S, Manion D, Treves ST. J Nucl Med 2015;56:962-967.

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.

Pediatric NM in Clinical Practice

(General Hospitals)

Procedure	Number of Respondents			Value Based on Guideline (MBq)	Percentage of Respondents Using Guideline +/- 20%		
	Familiarity with 2010 Guidelines				Familiarity with 2010 Guidelines		
	Total	Yes	No		Total	Yes	No
Boy, 5 years old, 20 kg, 110 cm							
^{99m}Tc MDP	50	26	18	185.0	66.0%	88.5%	38.9%
^{99m}Tc MAG3	42	27	12	111.0	45.2%	55.6%	25.0%
^{99m}Tc DMSA	37	23	12	37.0	54.1%	69.6%	25.0%
^{99m}Tc HIDAs	27	15	10	37.0	48.2%	73.3%	10.0%
^{18}F FDG	20	14	5	74.0-103.6	70.0%	78.6%	60.0%
Girl, 10 years old, 30 kg, 140 cm							
^{99m}Tc MDP	50	26	18	277.5	50.0%	84.6%	44.4%
^{99m}Tc MAG3	43	27	12	166.5	45.2%	55.6%	25.0%
^{99m}Tc DMSA	37	23	12	55.5	51.4%	65.2%	33.3%
^{99m}Tc HIDAs	27	15	10	55.5	40.7%	73.3%	10.0%
^{18}F FDG	20	14	5	111.0-155.4	70.0%	85.7%	60.0%

NMGI Project 1 Report

Part 1

- Literature Review
- Educational Resources in Pediatric Dose Optimization

Part 2

- Current Standards For Pediatric Administered Activities
- Variations in the Practice of Pediatric Nuclear Medicine
- Observations and Recommendations

Fahey FH *et al*. Part 1 Report. *J Nucl Med*. 2015;56:646-651.
Fahey FH *et al.* Part 2 Report. *J Nucl Med*. 2016;57:1148-1157.

CT Dose in the Context of Hybrid Imaging

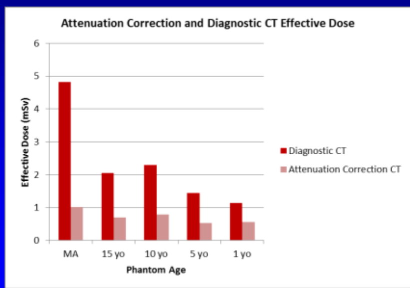
- In helical CT as in hybrid imaging, the radiation dose varies as tube voltage (α kVp^2), linearly with tube current-time product (mAs) and inversely with pitch. Also, beam collimation, patient size and region of patient
- For atten correction (AC), the kVp and mAs can be reduce almost as low as possible.
- 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

Effective Dose from CT of PET/CT

Fahey et al, J Nucl Med. 2017;58:1360-1366

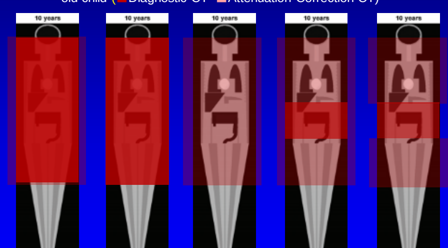
- Six anthropomorphic tissue equivalent phantoms (CIRS, Model 007TE) were utilized. The head, thorax and abdomen phantoms of medium-sized adults and 15-, 10-, 5- and 1-year-old children were scanned on a Siemens mCT 40 PET/CT scanner according to our Dx (CARE Dose 4D Quality Reference mAs {QRM} = 150,) and AC (QRM = 35) protocols.
- $CTDI_{vol}$ (mGy) was recorded for each acquisition. DLP (mGy-cm) was calculated for both Dx and AC scans by multiplying $CTDI_{vol}$ by a nominal scan length (cm) from Deak et al. (Radiol. 2010;257:158-66) for each region (abdomen, thorax, head) and age.
- Effective dose (ED) was calculated for the Dx and AC series using DLP conversion factors for ICRP 103 ED organ radiosensitivity weights.

Effective Dose from CT of Siemens mCT PET/CT



Effective Dose from CT of PET/CT

Visual representation of the different scenario protocols for imaging a 10 year old child (Diagnostic CT Attenuation Correction CT)



Scenario 1: Whole body Dx + Whole body AC

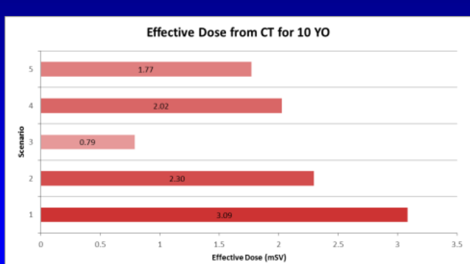
Scenario 2: Whole Body Dx only

Scenario 3: Whole Body AC

Scenario 4: Abdomen Dx + Whole Body AC

Scenario 5: Abdomen Dx + Head and Chest AC

Effective Dose from CT of Siemens mCT PET/CT



Thanks!
Questions?