RADIOPHARMACEUTICALS & NUCLEAR MEDICINE IN PEDIATRICS

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iCare 2024 Nuclear Pharmacy Conference
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OBJECTIVES

1. Recognize commonly used pediatric nuclear medicine studies and protocols.
2. Identify pearls and considerations for pediatric use of radiopharmaceuticals.
3. Summarize key points regarding pediatric radiobiology.
4. Evaluate different dosing methods for pediatrics and calculate correct doses for pediatrics.
5. Explore advantages and challenges with using PET MRI versus PET CT in pediatrics.

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Questions

What is the estimated radiation dose from an Tc99m bone scan for a 5 year old patient?

NM is a 3 yoF weighing 14 kg who is scheduled to receive a staging scan for recently diagnosed neuroblastoma. What is the appropriate dose of I-123 MIBG based on EANM and NACG guidelines? Which guideline offers a lower dose?

What are two results/pieces of information obtained from the Swedish study?

What are two advantages of PET MRI vs PET CT?

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Importance

- Pediatrics are not little adults![1]
- Annual collective population radiation dose has increased over 750%[1]
- CT is where most radiation exposure comes from for pediatrics
- Amount of activity administered to pediatric patients can vary up to 20 fold between institutions[2]
- Pharmacists are pivotal for educated and ensuring safe use

"The risk of cancer proceeds in a linear fashion at lower doses without a threshold and that the smallest dose has the potential to cause a small increased risk to humans."

-Biological Effects of Ionizing Radiation (BIER) Committee of the National Academy of Sciences National Research Council[5]

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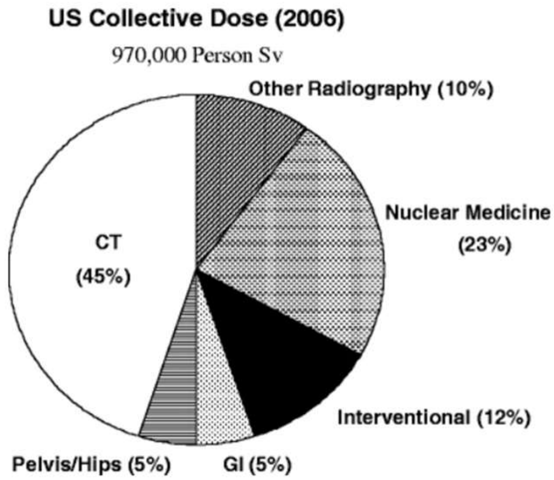

Hall EJ. Radiation biology for pediatric radiologists. *Pediatr Radiol.* 2009;39:S57-S64. doi: 10.1007/s00247-008-1027-2.

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COMMON PEDIATRIC NUCLEAR MEDICINE STUDIES

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Common Indications for Pediatric Nuclear Medicine Studies

- Lymphoma - F-18 FDG PET[6]
  - staging, restaging, response to tx assessments
  - long term complications from cancer tx - restaging
  - prognostic indicator of Hodgkin's lymphoma - early PET response
- Sarcomas - F-18 FDG PET/CT[6]
  - staging restaging, monitoring of lung mets
  - mainstay = MRI
  - FDG PET/CT can predict effect of neoadjuvant chemo
  - replacing bone scans for evaluation of multifactorial disease
- Neuroblastoma - I-123 MIBG + MRI/CT[6]
  - staging
  - higher sensitivities with PET - I-124 MIBG, F-18 FDOPA, Ga-68 DOTATATE

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Common Indications for Pediatric Nuclear Medicine Studies

- Pheochromocytomas/paraganglioma - MIBG, F-18 FDG PET[6]
  - MIBG traditionally used for evaluation
  - PET radiopharmaceuticals are more sensitive and should be used when available
  - FDA or FDG PET preferable for staging paragangliomas with RET mutations
  - Ga-68 DOTATATE has higher accuracy for staging SDH-related paragangliomas
- Gastrointestinal stromal tumors, mixed germ cell tumors - F-18 FDG PET[6]
  - staging, restaging
- NETs, insulinomas - Ga-68 DOTATATE[6]
  - characterization, staging
- Thyroid cancer[6]
  - iodine scans +/- SPECT/CT and ultrasound - standard imaging
  - non-iodine avid disease - FDG PET

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Common Indications for Pediatric Nuclear Medicine Studies

- Congenital hypothyroidism - pertechnetate scan[6]
  - distinguishing etiologies
- Hyperparathyroidism - sestamibi scan[6]
  - localizing parathyroid adenomas
  - hybrid imaging for localization in eutopic or ectopic locations
- Chronic UTIs and kidney scarring - DMSA + SPECT[6]
  - PMSA PET not yet FDA-approved
- Biliary atresia - HIDA[6-7]
  - excretion of radiopharmaceutical into bowel excludes biliary atresia
  - prep with phenobarbital is essential[8]
- Lymphodysplasias - lymphoscintigraphy +/- SPECT/CT

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Common Indications for Pediatric Nuclear Medicine Studies

- Myocardial perfusion studies[6]
  - cardiac MRI, echo, cardiac CT = mainstays
  - congenital heart disease, hypoplastic heart, cardiac transplants
- Lung perfusion pathology - MAA[6]
  - assess pulmonary artery anomalies, congenital cardiac malformations before or after interventions
- GI motility disorders - sulfur colloid[6]
  - delayed gastric emptying is common in pediatrics
  - solid or liquid based gastric emptying studies are utilized
- Device infections - F-18 FDG PET/CT[6]
  - assess cardiac devices or implanted skeletal hardware[9]

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Estimated Medical Radiation Doses for a 5 Year Old Child[10]

Study	Radiation Dose (mSv)	Equivalent CXR
Anteroposterior and lateral abdominal CT	0.05	2.5
Tc99m cystogram	0.18	9
Chest CT	3	150
Head CT	4	200
Abdominal CT	5	250
Tc99m bone scan	6.2	310
FDG PET scan	15.3	765

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CONSIDERATIONS FOR PEDIATRIC USE OF RADIOPHARMACEUTICALS

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General Considerations

- Immobilization
- Sedation[11,12]
  - PO chloral hydrate 50-70 mg/kg
  - Midazolam alone
    - PO 0.5-0.75 mg/kg
    - Intranasal 0.2 mg/kg
  - IV pentobarbital 2-6 mg/kg +/- midazolam
- "Feed and Swaddle" protocol[13]
- Preparation[6]
  - Fasting differences
  - Tour of scanning area beforehand
  - Distraction devices
- Scanning time[6]
- Dose vs scan time

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Minimizing Radiation

- Perform only necessary studies[14,15]
- Use minimum administered activity[15]
- Adjust exposure parameters[14]
- Consider lower scan resolution[14]
- Avoid multiphase exams[14]
- Image Gently campaign[15]

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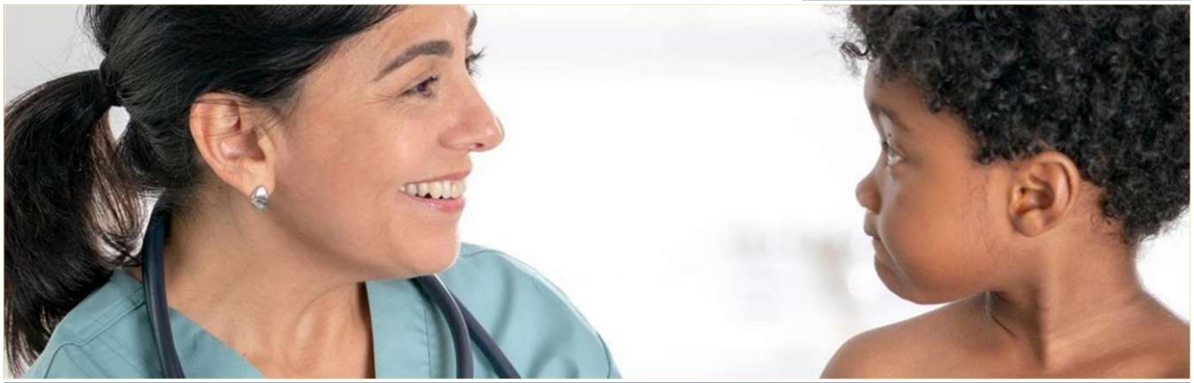

PEDIATRIC RADIOBIOLOGY

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Key Points[1,16]

- Children are more sensitive to the effects of radiation versus adults
- Pediatrics population has longer life expectancy
- Smaller body size
- Different spatial relationship of organs
- Organs have different radiosensitivity compared to adults
- Biodistribution, pharmacokinetics
- Biggest concern = carcinogenesis

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Pathogenesis

- Damage to DNA via base and sugar damage, single strand breaks, and double strand breaks[17]
  - Most biological effects of radiation are caused by double strand breaks
- Broken ends stick to other broken fragments to create dicentric chromosomes
  - Dicentric chromosomes undergo cell death during cell division
- Depletion of tissue stem cells, progenitor cells, vascular endothelial microvessels[17]
- Ongoing damage after radiation exposure

- Deterministic effects vs stochastic effects[1]
  - Deterministic = threshold exists
  - Stochastic = no threshold

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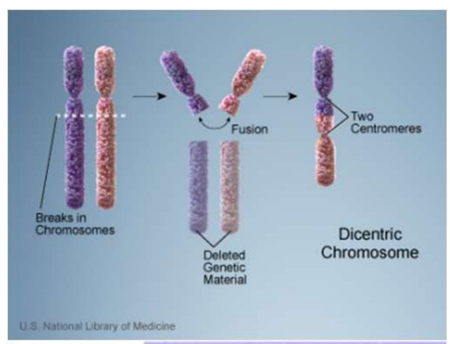
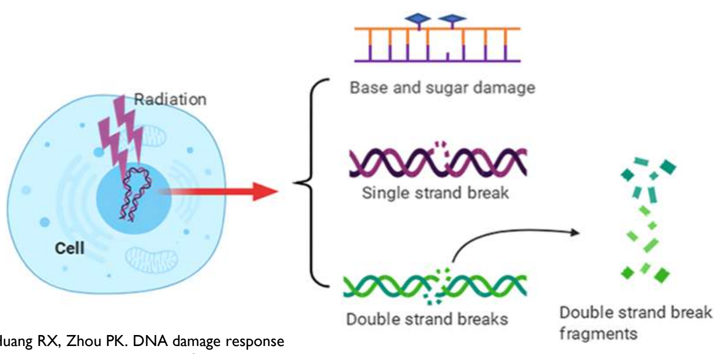
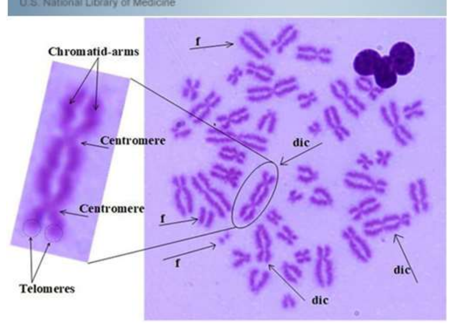
US Department of Health & Human Services. About Dicentric Chromosome Assays. Radiation Emergency Medical Management. Accessed September 24, 2024.





Huang RX, Zhou PK. DNA damage response signaling pathways and targets for radiotherapy sensitization in cancer. Signal Transduction and Targeted Therapy. 2020;60: https://doi.org/10.1038/s41392-020-0150-x



Shen X, Qi Y, Ma T, Zhou Z. A dicentric chromosome identification method based on clustering and watershed algorithm. *Scientific Reports*. 2019;9(2285): doi: https://doi.org/10.1038/s41598-019-38614-7

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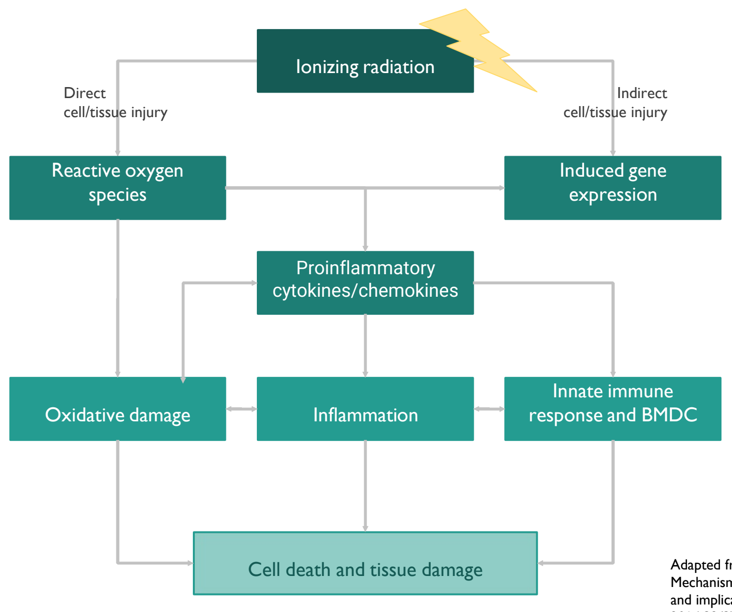
Pathogenesis



Adapted from: Kim JH, Jenrow KA, Brown SL. Mechanisms of radiation-induced normal tissue toxicity and implications for future clinical trials. *Radiat Oncol J.* 2014;32(3):103-115. doi: 10.3857/roj.2014.32.3.103

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Biological Effects

- Heritable effects[6]
  - Mendelian fashion mutations
  - Multifactorial diseases
  - Estimated to occur at 0.2%/Sv
- Carcinogenesis
  - A bomb survivors
- Effects on embryo and fetus[6]
  - Growth retardation
    - 0-9 days post conception: temporary
    - 10+ weeks (fetal period): permanent
  - Congenital abnormalities
    - Organogenesis (10 days - 6 weeks)
  - Microcephaly
    - Organogenesis
  - Severe mental retardation
    - Highly likely if irradiated at 8 - 15 weeks
  - Neonatal death

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A-Bomb Survivors in the Life Span Study Cohort[6,18]

- 86,572 people in cohort
- Mean dose 200 mSv
- 440 radiation attributable deaths from solid cancer
- 250 radiation attributable deaths from non-cancer
- Includes all ages

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Carcinogenesis[6,18-19]

- Credible evidence that significant excess cancer risk starts at doses ~20 mSv
- Linear relationship between relative risk of cancer and radiation dose
- Lifetime attributable risk of radiation-induced cancer varies with age of exposure
- Children are significantly more radiosensitive than adults

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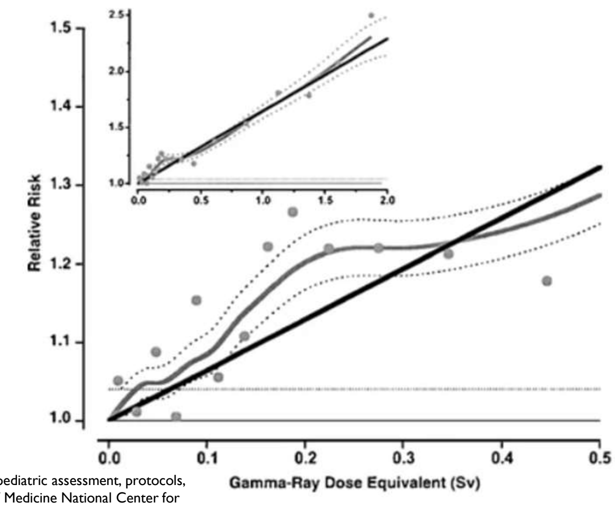
Estimated Relative Risks for Cancer in A-Bomb Survivors



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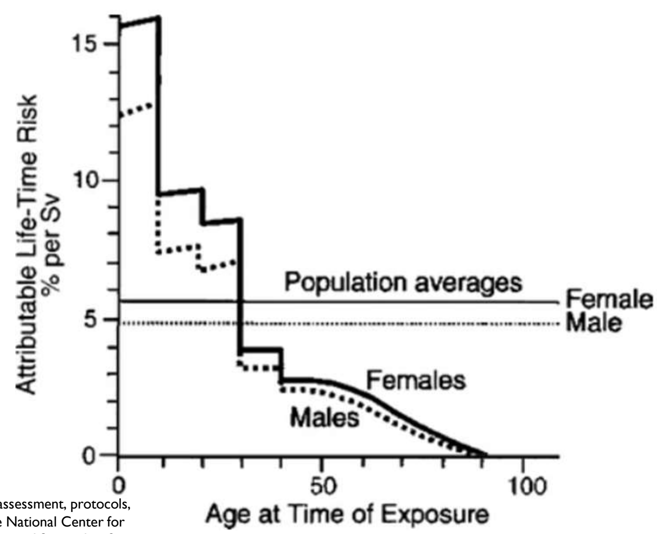
Attributable Lifetime Risk from a Single Small Dose of Radiation



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What is the lowest dose that has direct evidence of excess cancer risk?

- Lowest doses at which there is a significant excess cancer incidence has been estimated from data from A-bomb survivors and nuclear workers[6]
  - 30-40 mSv (3-4 rads)
  - 19.4 mSv (~2 rad)
- Data used to calculate risk associated with CT
  - Greatest risk with younger age
  - Risk for abdominal CT > head CT

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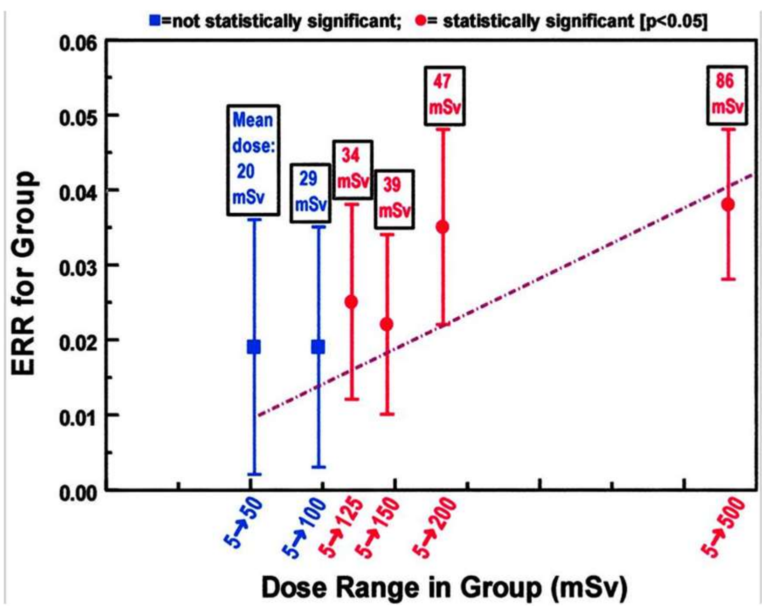
Estimated Excess Relative Risk of Mortality from Solid Cancers After Exposure to Low Doses of Radiation[18]

among A-bomb survivors in life span cohort



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Effect of low doses of ionizing radiation in infancy on cognitive function in adulthood: Swedish population based cohort study[16]

- > 2000 infant males <18 mo received radiation treatment for cutaneous hemangioma
- Evaluated effect on cognitive exams and high school attendance

- Average absorbed dose to brain = 52 mGy
  - Frontal lobe dose was 100+ mGy in 23.5% of infants
  - Posterior lobe dose was 100+ mGy in 12.6% of infants

- Statistically significantly decreased high school attendance by all infants who received >100 mGy
- Significant dose-response relation for all cognitive tests except spatial recognition

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Swedish study[16]

Dose to frontal part of brain (mGy)	No	Category of military test: Concept discrimination and general instruction	Technical instruction	Spatial recognition
0	638	5.50 (0.07)	5.45 (0.08)	5.36 (0.09)
1-20	400	5.67 (0.09)	5.40 (0.10)	5.37 (0.11)
>20-100	677	5.63 (0.07)	5.37 (0.08)	5.49 (0.08)
>100-250	410	5.42 (0.09)	5.31 (0.10)	5.48 (0.10)
>250	86	5.34 (0.18)	4.78 (0.21)	5.44 (0.21)
P for trend*		0.03	0.003	0.50

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PEDIATRIC DOSING

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Dosing Recommendations

- European Association of Nuclear Medicine
- North American Consensus Guidelines

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EANM vs North American Consensus Guidelines[20]

- Grant FD, GElfand MG, Drubach LA, et al compared 12 nuclear medicine studies' radiation exposure with dosages from each guideline
  - Effective dose and critical organ dose
- EANM was developed to so that patients in all age groups receive similar estimated effective doses
- North American Consensus Guidelines are strictly weight based for most studies
- Use different referenced adult administered activities
- Images from children dosed with either guideline result in similar quality images

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EANM vs North American Consensus Guidelines Continued

Nuclear Medicine Studies Compared	
18F-FDG PET torso	dynamic renography - 99mTc-MAG3
18F-FDG PET brain	renal cortical scan - 99mTc-DMSA
skeletal scintigraphy - 99mTc-methylene diphosphonate	radionuclide cystography - 99mTc-sodium pertechnetate
skeletal scintigraphy - 18F-sodium fluoride PET	Meckel scan - 99mTc-sodium pertechnetate
lung perfusion - 99mTc-MAA	gastric emptying/reflux (solid) - 99mTc-labeled sulfur colloid
hepatobiliary scintigraphy - 99mTc-disofenin	whole body 123I-MIBG scan

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EANM vs North American Consensus Guidelines Continued

- Age groups: 1 year olds, 5 year olds, 10 year olds, 15 year olds, and adults
- Used age specific nominal whole body weight reported by Cristy and Eckerman
- No adjustment based on gender
- Used conversion factors from International Commission for Radiological Protection to obtain effective dose (mSv/MBq) from administered activity
- Tissue-weighting factors in ICRP Publication 60 were used for effective dose calculations[21]
- Critical organ doses based on biokinetic models for all ages
- Differences of 20% or greater between each guideline's effective dose were identified

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EANM vs North American Consensus Guidelines Continued

Age:	1 year	5 years	10 years	15 years	Adult
Nominal weight (kg):	**9.8**	**19**	**32**	**55**	**70**
Fluorodeoxyglucose (FDG) PET torso					
^{18}F-FDG	ICRP 106				
EANM administered activity (MBq)	70	120	189	302	370
EANM effective dose (mSv)	6.7†	6.7†	7.0	7.2	7.0
NA administered activity (5.2 MBq/kg)	51	99	166	286	364
NA effective dose (mSv)	4.8	5.5	6.2	6.9	6.9
NA critical organ dose (mGy) – Bladder	24	34	42	46	47
Fluorodeoxyglucose (FDG) PET brain					
^{18}F-FDG	ICRP 106				
EANM administered activity (MBq)	70*	70*	102	163	200
EANM effective dose (mSv)	6.7†	3.9	3.8	3.9	3.8
NA administered activity (3.7 MBq/kg)	37*	70	118	204	259
NA effective dose (mSv)	3.5	3.9	4.4	4.9†	4.9†
NA critical organ dose (mGy) – Bladder	17	24	30	33	34

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EANM vs North American Consensus Guidelines Continued

Age:	1 year	5 years	10 years	15 years	Adult
Nominal weight (kg):	**9.8**	**19**	**32**	**55**	**70**
Bone scan					
^{99m}Tc-methylene diphosphonate (MDP)	ICRP 80				
EANM administered activity (MBq)	80	162	255	408	500
EANM effective dose (mSv)	2.2	2.3	2.8	2.9	2.8
NA administered activity (10.6 MBq/kg)	91	177	298	512	651
NA effective dose (mSv)	2.5	2.5	3.3	3.6†	3.7†
NA critical organ dose (mGy) – Bone	48	39	39	42	41
Bone scan					
^{18}F-sodium fluoride	ICRP 53				
EANM administered activity (MBq)	70*	70*	102	163	200
EANM effective dose (mSv)	11.9†	6.0†	5.3†	5.5†	5.4†
NA administered activity (2.22 MBq/kg)	22	42	71	122	155
NA effective dose equivalent (mSv)	3.7	3.6	3.7	4.2	4.2
NA critical organ dose (mGy) – Bladder	24	26	28	33	39

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EANM vs North American Consensus Guidelines Continued

Age:	1 year	5 years	10 years	15 years	Adult
Nominal weight (kg):	**9.8**	**19**	**32**	**55**	**70**
Lung perfusion scan					
^{99m}Tc-MAA (macroaggregated albumin)	ICRP 80				
EANM administered activity (MBq)	15	26	41	65	90
EANM effective dose (mSv)	0.95	0.88	0.94	1.04	0.88
NA administered activity (1.1 MBq/kg)	15*	22	37	63	78
NA effective dose (mSv)	0.93	0.72	0.82	0.98	0.85
NA critical organ dose (mGy) – Lung	5.8	4.2	4.6	5.9	5.1
Hepatobiliary scan					
^{99m}Tc-disofenin	ICRP 80				
EANM administered activity (MBq)	28	49	77	122	150
EANM effective dose (mSv)	2.8†	2.2†	2.2†	2.6†	2.5
NA administered activity (1.85 MBq/kg)	18*	35	59	102	130
NA effective dose (mSv)	1.8	1.6	1.7	2.1	2.2
NA critical organ dose (mGy) – Gallbladder	17.6	9.8	9.5	12.2	14.2

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EANM vs North American Consensus Guidelines Continued

Age:	1 year	5 years	10 years	15 years	Adult
Nominal weight (kg):	**9.8**	**19**	**32**	**55**	**70**
Dynamic renography					
^{99m}Tc-mercaptoacetyltriglycine (MAG3)	ICRP 80				
EANM administered activity (MBq)	23	33	45	61	70
EANM effective dose (mSv)	0.51	0.40	0.54	0.55	0.50
NA administered activity (3.7 MBq/kg)	37*	70	118	204	259
NA effective dose (mSv)	0.81†	0.84†	1.42†	1.83†	1.81†
NA critical organ dose (mGy) – Bladder	1.2	1.3	2.0	2.8	2.8
Renal cortical scan					
^{99m}Tc-dimercaptosuccinic acid (DMSA)	ICRP 80				
EANM administered activity (MBq)	33	48	64	87	100
EANM effective dose (mSv)	1.22†	1.00†	0.96	0.96	0.88
NA administered activity (1.85 MBq/kg)	18	35	59	102	130
NA effective dose (mSv)	0.67	0.73	0.89	1.12	1.14†
NA critical organ dose (mGy) – Kidney	0.76	0.43	0.30	0.22	0.18

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EANM vs North American Consensus Guidelines Continued

Age:	1 year	5 years	10 years	15 years	Adult
Nominal weight (kg):	9.8	19	32	55	70
Radionuclide cystography					
[^{99m}Tc] sodium pertechnetate	MIRD				
EANM administered activity (MBq)	20*	20*	20*	20*	–
EANM effective dose (mSv)	0.03	0.02	0.01	0.01	–
NA administered activity (MBq)	37*	37*	37*	37*	–
NA effective dose (mSv)	0.06†	0.03†	0.02†	0.02†	–
NA critical organ dose (mGy) – Bladder	0.90	0.50	0.33	0.23	–
Meckel scan					
[^{99m}Tc] sodium pertechnetate	ICRP 80				
EANM administered activity (MBq)	20*	26	41	65	80
EANM effective dose (mSv)	1.60†	1.09†	1.06	1.11	1.04
NA administered activity (1.85 MBq/kg)	11	21	36	61	78
NA effective dose (mSv)	0.86	0.89	0.92	1.04	1.01
NA critical organ dose (mGy) – Colon	2.9	3.0	3.1	3.2	3.3

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EANM vs North American Consensus Guidelines Continued

Age:	1 year	5 years	10 years	15 years	Adult
Nominal weight (kg):	9.8	19	32	55	70
Gastric emptying/reflux (solid)					
^{99m}Tc-labeled sulfur colloid	ICRP 80				
EANM administered activity (MBq)	10*	13	20	33	40
EANM effective dose (mSv)	1.40	0.99†	0.98	1.01†	0.96†
NA administered activity (MBq)	9.25*	9.25*	18.5*	18.5*	18.5*
NA effective dose (mSv)	1.30	0.70	0.89	0.57	0.44
NA critical organ dose (mGy) – Colon	6.1	3.2	4.1	2.4	1.9
Whole-body meta-iodobenzylguanidine (MIBG) scan					
^{123}I-MIBG	ICRP 80				
EANM administered activity (MBq)	80*	130	204	326	400
EANM effective dose (mSv)	5.4†	4.8†	5.3†	5.5	5.2
NA administered activity (5.2 MBq/kg)	51	99	166	286	364
NA effective dose (mSv)	3.5	3.7	4.3	4.9	4.7
NA critical organ dose (mGy) – Liver	17	18	22	25	24

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EANM vs North American Consensus Guidelines Continued

- Highest exposure will come from 18F or 123I
- Lowest exposure with 99mTc
- Bladder was identified as the critical organ for 5 out of 12 procedures
- EANM dosage card resulted in over 20% greater effective dose vs NA guidelines in 39% of cases
- NA guidelines resulted in over 20% greater effective vose vs EANM in 25% of cases
- Differences in effective dose were greater in the 1 year old and 5 year old age groups
- Need for adjustments to guidelines to reduce differences in exposure

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Harmonization of Dosing Guidelines[22]

- Based on 2007 EANM dosage card and 2010 NACG
- GIves recommendations for changes to both sets of guidelines
- Tc-99m DMSA
  - EANM - assigned class B
- I-123 MIBG
  - EANM - reduce minimum from 80 Mbq to 37 MBq

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EANM Dosage Card[23]

Administered Activity in MBq = (Baseline Activity)*(Multiple)

- Multiple retrieved from table based on weight (kg)
- If calculated activity < recommended minimum activity, use minimum activity

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EANM Dosage Card

Weight kg	Class A	Class B	Class C	Weight kg	Class A	Class B	Class C
3	1	1	1	32	3.77	7.29	14.00
4	1.12	1.14	1.33	34	3.88	7.72	15.00
6	1.47	1.71	2.00	36	4.00	8.00	16.00
8	1.71	2.14	3.00	38	4.18	8.43	17.00
10	1.94	2.71	3.67	40	4.29	8.86	18.00
12	2.18	3.14	4.67	42	4.41	9.14	19.00
14	2.35	3.57	5.67	44	4.53	9.57	20.00
16	2.53	4.00	6.33	46	4.65	10.00	21.00
18	2.71	4.43	7.33	48	4.77	10.29	22.00
20	2.88	4.86	8.33	50	4.88	10.71	23.00
22	3.06	5.29	9.33	52-54	5.00	11.29	24.67
24	3.18	5.71	10.00	56-58	5.24	12.00	26.67
26	3.35	6.14	11.00	60-62	5.47	12.71	28.67
28	3.47	6.43	12.00	64-66	5.65	13.43	31.00
30	3.65	6.86	13.00	68	5.77	14.00	32.33

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EANM Dosage Card

Radiopharmaceutical	Class	Baseline Activity (for calculation purposes only) MBq	Minimum Recommended Activity[1] MBq
^{123}I (Thyroid)	C	0.6	3
^{123}I Amphetamine (Brain)	B	13.0	18
^{123}I HIPPURAN (Abnormal renal function)	B	5.3	10
^{123}I HIPPURAN (Normal renal function)	A	12.8	10
^{123}I mIBG	B	28.0	37
^{131}I mIBG	B	5.6	35
^{18}F FDG-PET torso	B	25.9	26
^{18}F FDG-PET brain	B	14.0	14
^{18}F Sodium fluoride	B	10.5	14
^{67}Ga Citrate	B	5.6	10
^{68}Ga-labelled peptides	B	12.8	14
^{99m}Tc ALBUMIN (Cardiac)	B	56.0	80
^{99m}Tc COLLOID (Gastric Reflux)	B	2.8	10
^{99m}Tc COLLOID (Liver/Spleen)	B	5.6	15
^{99m}Tc COLLOID (Marrow)	B	21.0	20

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EANM Dosage Card

^{99m}Tc DMSA	B	6.8	18.5
^{99m}Tc DTPA (Abnormal renal function)	B	14.0	20
^{99m}Tc DTPA (Normal renal function)	A	34.0	20
^{99m}Tc ECD	B	51.8	100
^{99m}Tc HMPAO (Brain)	B	51.8	100
^{99m}Tc HMPAO (WBC)	B	35.0	40
^{99m}Tc IDA (Biliary)	B	10.5	20
^{99m}Tc MAA / Microspheres	B	5.6	10
^{99m}Tc MAG3	A	11.9	15
^{99m}Tc MDP	B	35.0	40
^{99m}Tc Pertechnetate (Cystography)	B	1.4	20
^{99m}Tc Pertechnetate (Ectopic Gastric Mucosa)	B	10.5	20
^{99m}Tc Pertechnetate (Cardiac First Pass)	B	35.0	80
^{99m}Tc Pertechnetate (Thyroid)	B	5.6	10
^{99m}Tc RBC (Blood Pool)	B	56.0	80
^{99m}Tc SestaMIBI/Tetrofosmin (Cancer seeking agent)	B	63.0	80
^{99m}Tc SestaMIBI/Tetrofosmin[2] (Cardiac rest scan 2-day protocol min)	B	42.0	80
^{99m}Tc SestaMIBI/Tetrofosmin[2] (Cardiac rest scan 2-day protocol max)	B	63.0	80
^{99m}Tc SestaMIBI/Tetrofosmin[2] (Cardiac stress scan 2-day protocol min)	B	42.0	80
^{99m}Tc SestaMIBI/Tetrofosmin[2] (Cardiac stress scan 2-day protocol max)	B	63.0	80
^{99m}Tc SestaMIBI/Tetrofosmin[2] (Cardiac rest scan 1-day protocol)	B	28.0	80
^{99m}Tc SestaMIBI/Tetrofosmin[2] (Cardiac stress scan 1-day protocol)	B	84.0	80
^{99m}Tc Spleen (Denatured RBC)	B	2.8	20
^{99}Tc TECHNEGAS (Lung ventilation)[3]	B	49.0	100

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Example 1

JP is a 10 yoM weight 58 lb who is schedule to receive a renal cortical scan. What is the appropriate dose of Tc-99m DMSA JP should receive using the EANM dosage card?

58 lb = 26.3 kg

Multiple = 6.14

Administered Activity = 6.14*6.8 = **41.75 MBq**

Weight kg	Class A	Class B	Class C
20	2.88	4.86	8.33
22	3.06	5.29	9.33
24	3.18	5.71	10.00
26	3.35	6.14	11.00

Radiopharmaceutical	Class	Baseline Activity (for calculation purposes only) MBq	Minimum Recommended Activity[1] MBq
^{99m}Tc DMSA	B	6.8	18.5

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Question 1

KT is a 16 yoF with Hodgkins lymphoma. Her current weight is 50 kg. She is scheduled for an abdominal PET scan. What is the appropriate dose of F-18 FDG based on the EANM dosage card?

Weight kg	Class A	Class B	Class C
50	4.88	10.71	23.00

Multiple = 10.71

Administered Activity = 10.71*25.9

277.39 MBq

Radiopharmaceutical	Class	Baseline Activity (for calculation purposes only) MBq	Minimum Recommended Activity[1] MBq
^{18}F FDG-PET torso	B	25.9	26

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EuroNet PHL-C2 Trial[24]

- Analyzed 2082 F-18 FDG PET scans
- Compared administered activity to recommended administered activity based on EANM dosage card
- Detailed quality assessment on 91 scans
- 94.1% of scans were completed with a lower administered activity than recommended (median 99.4 MBq less)
- 5.7% scans exceeded recommended EANM dose (median 15.1 MBq more)
- Assessment of visual image quality found lower activity were suitable for reporting
- Potential to have a mean activity reduction of 39% for updated card

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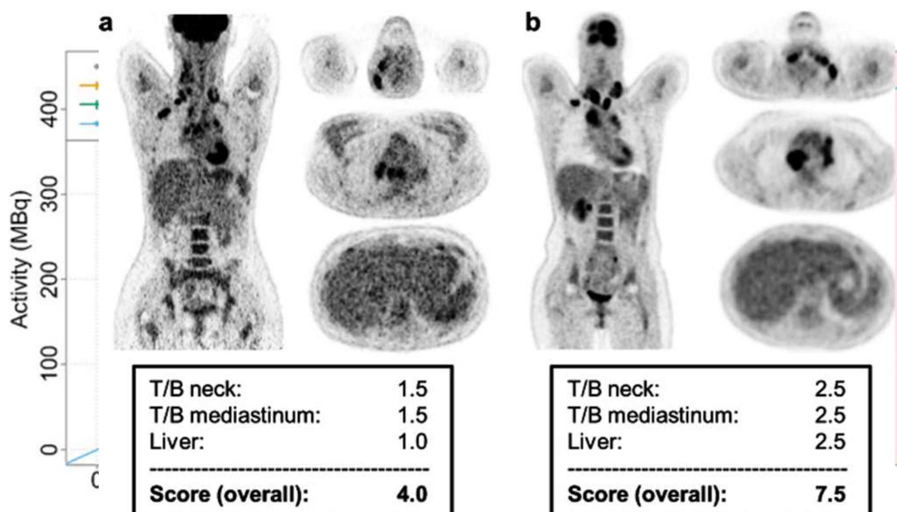
EuroNet PHL-C2 Trial



Tran-Gia J, Eberlain U, Lassmann M, Mauz-Korholz C, Korholz D, Zuccetta P, et al. Analysis of image data from the EuroNet PHL-C2 trial indicates a potential reduction in injected F-18 FDG activities in children: a proposal to update the EANM Paediatric Dosage Card. *Eur J Nucl Med Mol Imaging.* 2024;51(2):405-411. doi:10.1007/s00259-023-06396-w

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North American Consensus Guidelines[25]

Radiopharmaceutical	Notes	Administered Activity/kg	Minimum Administered Activity	Maximum Administered Activity
^{123}I-MIBG		5.2 MBq/kg (0.14 mCi/kg)	37 MBq (1.0 mCi)	370 MBq (10.0 mCi)
^{99m}Tc-MDP		9.3 MBq/kg (0.25 mCi/kg)	37 MBq (1.0 mCi)	740 MBq (20 mCi)
^{18}F-FDG	A	Body, 2.96-5.2 MBq/kg (0.08-0.14 mCi/kg)	26 MBq (0.7 mCi)	370 MBq (10 mCi)
		Brain, 1.85-3.7 MBq/kg (0.05 -0.10 mCi/kg)	14 MBq (0.37 mCi)	148 MBq (4 mCi)
^{18}F-FDOPA		2.96-5.92 MBq/kg (0.08-0.16 mCi/kg)	29.6 MBq (0.8 mCi)	222 MBq (6 mCi)
^{99m}Tc-DMSA		1.85 MBq/kg (0.05 mCi/kg)	18.5 MBq (0.5 mCi)	100 MBq (2.7 mCi)
^{99m}Tc-MAG3	B	Without flow study, 3.7 MBq/kg (0.10 mCi/kg)	37 MBq (1.0 mCi)	148 MBq (4.0 mCi)
		With flow study, 5.55 MBq/kg (0.15 mCi/kg)	37 MBq (1.0 mCi)	148 MBq (4.0 mCi)
^{99m}Tc-IDA		1.85 MBq/kg (0.05 mCi/kg)	18.5 MBq (0.5 mCi)	
^{99m}Tc-MAA		With ventilation using ^{99m}Tc agent, 2.59 MBq/kg (0.07 mCi/kg)		
		Without ventilation using ^{99m}Tc agent, 1.11 MBq/kg) (0.03 mCi/kg)	14.8 MBq (0.4 mCi)	

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North American Consensus Guidelines[25]

Radiopharmaceutical	Notes	Administered Activity/kg	Minimum Administered Activity	Maximum Administered Activity
^{99m}Tc-pertechnetate (Meckel diverticulum imaging)		1.85 MBq/kg (0.05 mCi/kg)	9.25 MBq (0.25 mCi)	296 MBq (8 mCi)
^{18}F-sodium fluoride		1.85 MBq/kg (0.05 mCi/kg)	18.5 MBq (0.5 mCi)	148 MBq (4 mCi)
^{99m}Tc (for cystography)	C	No weight-based dose		No more than 37 MBq (1.0 mCi) for each bladder filling cycle
^{99m}Tc-sulfur colloid (for oral liquid gastric emptying)	D	No weight-based dose	18.5 MBq (0.5 mCi)	37 MBq (1.0 mCi)
^{99m}Tc-sulfur colloid (for solid gastric emptying)	D	No weight-based dose	9.25 MBq (0.25 mCi)	18.5 MBq (0.5 mCi)
^{99m}Tc- HMPAO (Ceretec)/ ^{99m}Tc-ECD (Neurolite) for brain perfusion		11.1 MBq/kg (0.3 mCi/kg)	185 MBq (5 mCi)	740 MBq (20 mCi)
^{99m}Tc-sestamibi (Cardiolite)/ 99mTc-tetrofosmin (Myoview) for myocardial perfusion (single scan or first of 2 scans, same day)		5.55 MBq/kg (0.15 mCi/kg)	185 MBq (5 mCi)	370 MBq (10 mCi)
^{99m}Tc-sestamibi (Cardiolite)/ 99mTc-tetrofosmin (Myoview) for myocardial perfusion (second of 2 scans, same day)		16.7 MBq/kg (0.45 mCi/kg)	185 MBq (5 mCi)	1110 MBq (30 mCi)

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North American Consensus Guidelines[25]

Radiopharmaceutical	Notes	Administered Activity/kg	Minimum Administered Activity	Maximum Administered Activity
$^{13}NH_3$ for cardiac imaging		10.4 MBq/kg *(0.28 mCi/kg)*	74 MBq *(2 mCi)*	
^{82}Rb for cardiac imaging		7.4 MBq/kg *(0.2 mCi/kg)*	370 MBq *(10 mCi)*	
Na^{123} I for thyroid imaging		0.28 MBq/kg *(0.0075 mCi)*	1 MBq *(0.027 mCi)*	11 MBq *(0.3 mCi)*
Na^{123} I for thyroid cancer imaging		3.7 MBq/kg *(0.10 mCi/kg)*	74 MBq *(2 mCi)*	148 MBq *(4 mCi)*
^{99m}Tc-pertechnetate for thyroid imaging		1.1 MBq/kg *(0.03 mCi/kg)*	7 MBq *(0.19 mCi)*	93 MBq *(2.5 mCi)*
^{99m}Tc-RBC for blood pool imaging		11.8 MBq/kg *(0.32 mCi/kg)*	74 MBq *(2 mCi)*	740 MBq *(20 mCi)*
^{99m}Tc-WBC for infection imaging		7.4 MBq/kg *(0.2 mCi/kg)*	74 MBq *(2 mCi)*	555 MBq *(15 mCi)*
^{68}Ga-DOTATATE		2.0 MBq/kg *(0.054 mCi/kg)*	14 MBq *(0.38 mCi)*	200 MBq *(5.4 mCi)*
^{68}Ga-DOTATOC		1.59 MBq/kg *(0.043 mCi/kg)*	11.1 MBq *(0.30 mCi)*	111 MBq *(3 mCi)*

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Example 2

MA is a 5 yoM weighing 18 kg scheduled for a bone scan. What is the appropriate activity to administer of Tc-99m MDP based on the NACG?

Administered Activity = 18*9.3

167.4 MBq

Radiopharmaceutical	Notes	Administered Activity/kg	Minimum Administered Activity	Maximum Administered Activity
^{99m}Tc-MDP		9.3 MBq/kg *(0.25 mCi/kg)*	37 MBq *(1.0 mCi)*	740 MBq *(20 mCi)*

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Question 2

DY is a 13 yoF weighting 41 kg scheduled to receive a single cardioperfusion scan. What is the appropriate dose of Tc-99m sestamibi based on the NACG?

Radiopharmaceutical	Notes	Administered Activity/kg	Minimum Administered Activity	Maximum Administered Activity
^{99m}Tc-sestamibi (Cardiolite)/ 99mTc-tetrofosmin (Myoview) for myocardial perfusion (single scan or first of 2 scans, same day)		5.55 MBq/kg (0.15 mCi/kg)	185 MBq (5 mCi)	370 MBq (10 mCi)

Administered Activity = 41*5.55

227.55 MBq

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Comparison of EANM and NACG Doses by Weight for MDP

Guideline	Weight		
	22 kg	**26 kg**	**30 kg**
EANM	185 MBq (5 mCi)	215 MBq (5.8 mCi)	240 MBq (6.5 mCi)
NACG	205 MBq (5.5 mCi)	242 MBq (6.5 mCi)	279 MBq (7.5 mCi)

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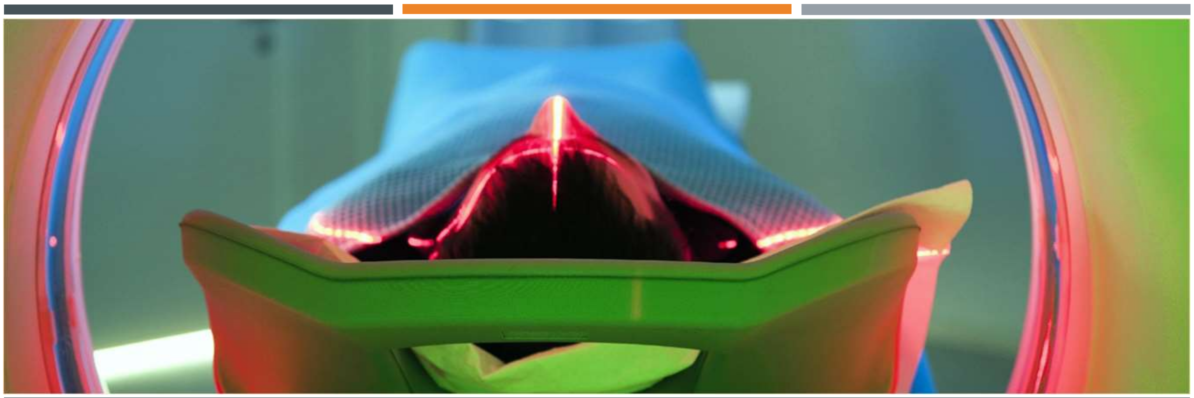

PET MRI VERSUS PET CT IN PEDIATRICS

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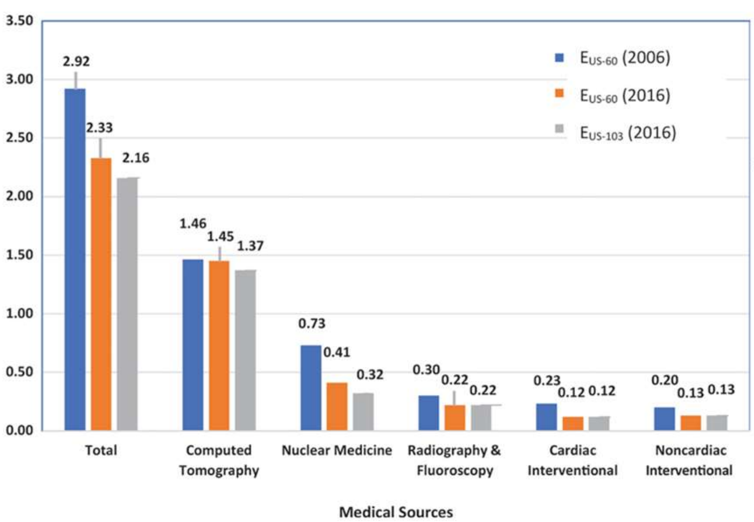
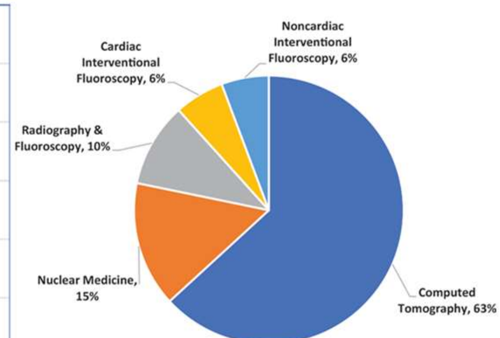
Patient Radiation Exposure from CT in the US





Mettler FA Jr, Mahesh M, Bhargavan-Chatfield M, Chambers CE, Elee JG, Frush DP, et al. Patient exposure from radiologic and nuclear medicine procedures in the United States. Radiology. 2020;295(2):418-427. doi: 10.1148/radiol.2020192256

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CT Overutilization in the ED for Pediatrics

- CT overuse due to availability, cost, rapid acquisition[26]
- Overuse occurring mostly in non-academic non-pediatric specific facilities[27]
- CT use has started to decline[28]
- MRI usage rates in pediatric EDs have increased from 0.3% in 2009 to 0.6% in 2018[29]

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Pediatric CT Radiation Doses

- CT is the most important exposure to pediatric population[14]
- Patients/guardians are not being adequately educated on risks
  - 7% report a discussion on radiation risks vs benefits of CT[3]
- Pearce, Salotti, Little, et al[30]
  - Cumulative doses of 50 mGy have the potential to triple risk of leukemia
  - Cumulative doses of 60 mGy may triple the risk of brain cancer

Study	Radiation Dose (mSv)	Equivalent CXR
Anteroposterior and lateral abdominal CT	0.05	2.5
Chest CT	3	150
Head CT	4	200
Abdominal CT	5	250

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Cancer Risk from Pediatric CT

- Brenner, Elliston, Berdon[31]
  - Pediatric CT will result in significantly increased lifetime radiation risk vs adult CT
  - Larger doses saw sharp increase in lifetime radiation risks
- Atomic bomb survivor data estimates 1 cancer case/1000 scans[6]
  - Max incidence 1 case/500 scans

Estimated lifetime cancer mortality risk in a 1 year old attributable to CT radiation	
Abdominal	0.18%
Head	0.07%

"the weight of evidence on fundamental cellular processes supports the view that in the low dose range up to a few tens of mSv, it is scientifically reasonable to assume that in general and for practical purposes cancer risk will rise in direct proportion to absorbed dose in organs and tissues."
The International Commission on Radiological Protection

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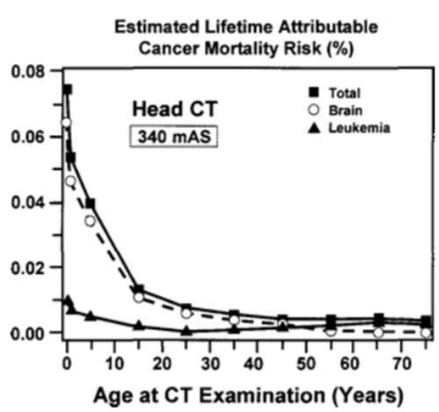
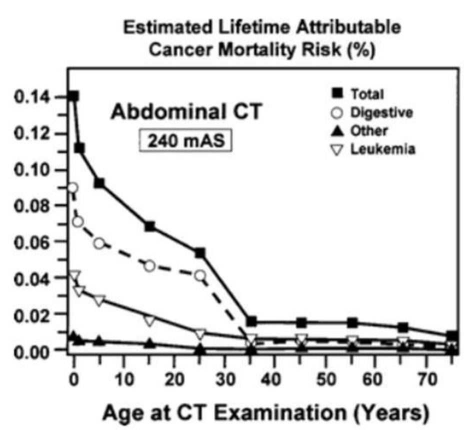
Estimated Lifetime Attributable Cancer Mortality Risk for Head and Abdominal CT[31]





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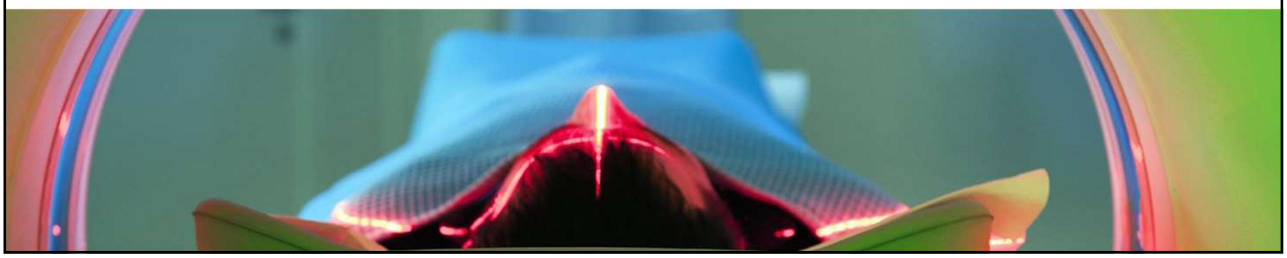
Advantages of PET CT

- Widely available[31]
- Less expensive[31]
- Faster[33]
  - Shorter sedation times
- Better for lung and cortical bone assessment[33]

Disadvantages of PET CT

- Increased radiation dose[32,33]
- Possible increased cancer risk[32]
- Lower soft tissue contrast[33]
- Metabolism of FDG in liver can obscure images[33]



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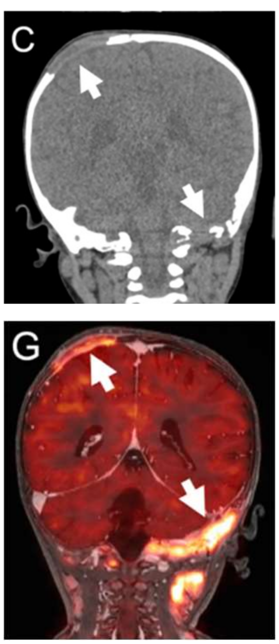

CT [C] and MRI [G] of lytic lesions in cavalarium in a 2 yo[33]

Advantages of PET MRI

- Preferred in pediatrics for many conditions[33]
- Lower radiation exposure[33]
- Better soft tissue contrast[33]
- Both PET CT and PET MRI can have a 50% FDG reduction via time of flight acquisition[34]

Disadvantages of PET MRI

- More costly[31]
- Not as widely available[31]
- Longer image acquisition time[32]

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REVIEW

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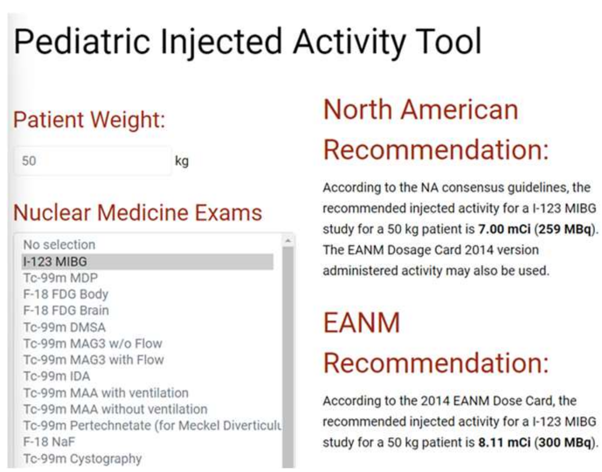
Resources

- EANM Dosage Card
  - PedDose app
- NACG and EANM
  - SNMMI Pediatric Injected Activity Tool
- ImageGently.org



EANM® European Association of Nuclear Medicine

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Review Questions

What is the estimated radiation dose from an Tc99m bone scan for a 5 year old patient?

NM is a 3 yoF weighing 14 kg who is scheduled to receive a staging scan for recently diagnosed neuroblastoma. What is the appropriate dose of I-123 MIBG based on EANM and NACG guidelines? Which guideline offers a lower dose?

What are two results/pieces of information obtained from the Swedish study?

What are two advantages of PET MRI vs PET CT?

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Key Takeaways

- Additional considerations are required for pediatric NM studies
  - sedation, immobilization, distraction
- Children are more radiosensitive
  - Use minimum administered activities when possible
  - Perform only necessary studies, avoid multiphase exam, adjust machine settings
- Gold standard data retrieved from atomic bomb survivor studies
  - Lowest dose for which there is significant excess cancer incidence = 30-40 mSv (3-4 rads)
  - Radiation dose from FDG PET scan is 15.3 mSv
- PET MRI offers lower radiation exposure and should be considered when appropriate

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THANK YOU

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