Pediatric Nuclear Medicine: A Physicist's Perspective on Clinical Imaging

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Children's Mercy KANSAS CITY

BEST CHILDREN'S HOSPITALS U.S.News 2014-15

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Disclosures

- Funding from GE
- Funding from NIH
- Funding from RSNA

Outline

Chapter 1. Tales of Mercyland!
Chapter 2. Clinical challenges of peds imaging
Chapter 3. Physical challenges of peds imaging
    i. Planar imaging
    ii. SPECT
Chapter 4. Toils of an in-house physicist

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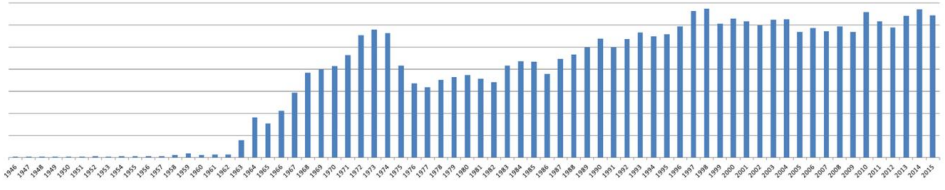


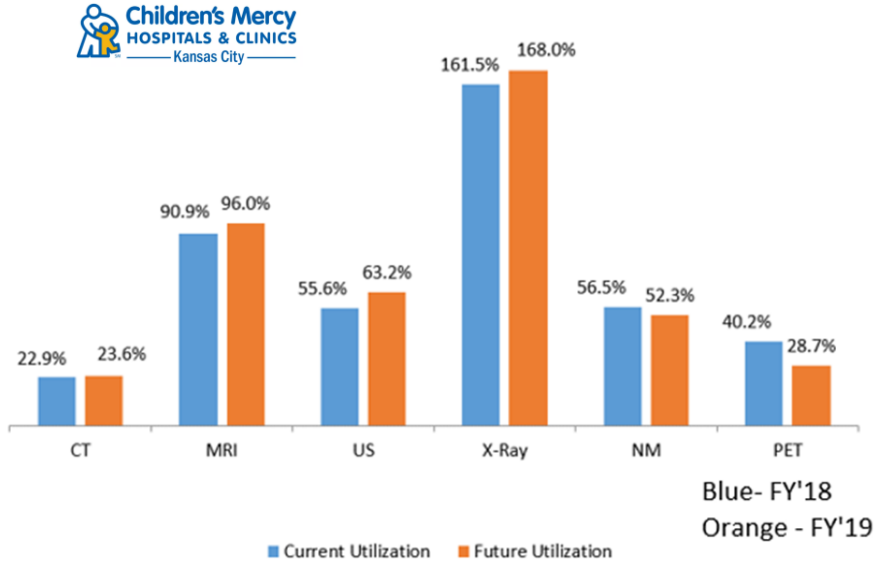
Pediatric Nuclear Medicine Practice in 2005[3]

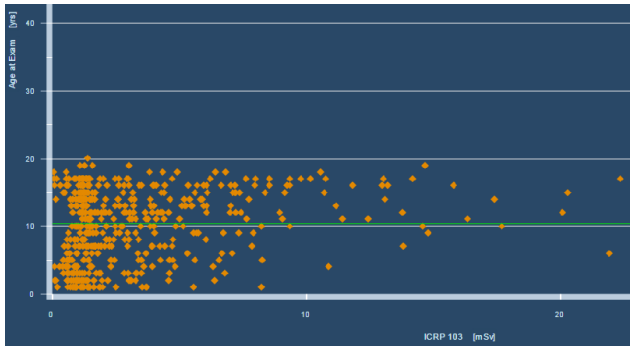
	Brussels	Chicago	Sidney	Vancouver	Munich	Cincinnati	Paris	Boston	UK 1	UK 2
Exams	1300	1303	2259	3800	394	4013	2409	5719	1805	2340
Renal	50%	49%	43%	37%	57%	57%	29%	53%	90%	74%
Bone	20%	19%	22%	20%	6%	17%	44%	18%	4%	8%
Tumor-brain	5%	12%	15%	22%	24%	11%	7%	11%	3%	10%
GI	15%	15%	14%	17%	13%	8%	0%	6%	2%	3%
Heart-lung	10%	2%	6%	4%	0%	4%	20%	11%	1%	5%

(Conway ,JJ)

The outlook

Current and future capacity utilization





	Most common age group of our patients (years)	Estimated Effective Dose (mSv)
PET study	5	4.1
Tc99m-MAG3	1	0.8
Tc99m-Sulphur Colloid (oral)	10	0.4
Tc99m-DTPA	5	0.1
Tc99m-Mebrofenin	10	2.1
I123-MIBG	10	1.9

Table 2

Adult Effective Doses for Various CT Procedures

Examination	Average Effective Dose (mSv)	Values Reported in Literature (mSv)
Head	2	0.9–4.0
Neck	3	. . .
Chest	7	4.0–18.0
Chest for pulmonary embolism	15	13–40
Abdomen	8	3.5–25
Pelvis	6	3.3–10
Three-phase liver study	15	. . .
Spine	6	1.5–10
Coronary angiography	16	5.0–32
Calcium scoring	3	1.0–12
Virtual colonoscopy	10	4.0–13.2

(Mettler FA,et al)

Table 5

Effective Doses for Adults from Various Nuclear Medicine Examinations

Examination*	Effective Dose (mSv)	Administered Activity (MBq)†	Effective Dose (mSv/MBq)‡
Brain (^{99m}Tc-HMPAO–exametazime)	6.9	740	0.0093
Brain (^{99m}Tc-ECD–Neurolite)	5.7	740	0.0077
Brain (^{18}F-FDG)	14.1	740	0.019
Thyroid scan (sodium iodine 123)	1.9	25	0.075 (15% uptake)
Thyroid scan (^{99m}Tc-pertechnetate)	4.8	370	0.013
Parathyroid scan (^{99m}Tc-sestamibi)	6.7	740	0.009
Cardiac stress-rest test (thallium 201 chloride)	40.7	185	0.22
Cardiac rest-stress test (^{99m}Tc-sestamibi 1-day protocol)	9.4	1100	0.0085 (0.0079 stress, 0.0090 rest)
Cardiac rest-stress test (^{99m}Tc-sestamibi 2-day protocol)	12.8	1500	0.0085 (0.0079 stress, 0.0090 rest)
Cardiac rest-stress test (Tc-tetrofosmin)	11.4	1500	0.0076
Cardiac ventriculography (^{99m}Tc-labeled red blood cells)	7.8	1110	0.007
Cardiac (^{18}F-FDG)	14.1	740	0.019
Lung perfusion (^{99m}Tc-MAA)	2.0	185	0.011
Lung ventilation (xenon 133)	0.5	740	0.00074
Lung ventilation (^{99m}Tc-DTPA)	0.2	1300 (40 actually inhaled)	0.0049
Liver-spleen (^{99m}Tc–sulfur colloid)	2.1	222	0.0094
Biliary tract (^{99m}Tc-disofenin)	3.1	185	0.017
Gastrointestinal bleeding (^{99m}Tc-labeled red blood cells)	7.8	1110	0.007
Gastrointestinal emptying (^{99m}Tc-labeled solids)	0.4	14.8	0.024
Renal (^{99m}Tc-DTPA)	1.8	370	0.0049
Renal (^{99m}Tc-MAG3)	2.6	370	0.007
Renal (^{99m}Tc-DMSA)	3.3	370	0.0088
Renal (^{99m}Tc-glucoheptonate)	2.0	370	0.0054
Bone (^{99m}Tc-MDP)	6.3	1110	0.0057
Gallium 67 citrate	15	150	0.100
Pentreotide (^{111}In)	12	222	0.054
White blood cells (^{99m}Tc)	8.1	740	0.011
White blood cells (^{111}In)	6.7	18.5	0.360
Tumor (^{18}F-FDG)	14.1	740	0.019

* DMSA = dimercaptosuccinic acid, DTPA = diethylenetriaminepentaacetic acid, ECD = ethyl cysteinate dimer, ^{18}F = fluorine 18, FDG = fluorodeoxyglucose, HMPAO = hexamethylpropyleneamine oxime, ^{111}In = indium 111, MAA = macroaggregated albumin, MAG3 = mercaptoacetyltriglycine, MDP = methylene diphosphonate, ^{99m}Tc = technetium 99m.

† Recommended ranges vary, although most laboratories tend to use the upper end of suggested ranges.

‡ From reference 74.

(Mettler FA,et al)

Weight based dosing with 20% window

CHILDREN'S MERCY HOSPITAL
DATE EFFECTIVE 03/19 INDEX GENERAL MANUAL
SUPERSEDES 1/2009 - 8/2015, 8/16, 11/17 APPROVED
Page 1 OF 2 REVIEWED/REVISED 03/2019

PRESCRIBED DOSE LIMIT RECOMMENDATIONS

1. The following is a list of the routine dose limit recommendations for pediatric studies. These are based on package insert information or on recognized standard practices.
2. Physicians may request higher (or lower) doses than normal if in his/her opinion the benefit of using this dose outweighs the risks involved.
3. Each radiopharmaceutical has a package insert section titled "Dosage and Administration". This section specifies a recommended dose and route of administration. Consult the package insert if questions arise regarding dose limits or for newly approved radiopharmaceuticals which are not listed.

Radionuclide	Chemical Form	Procedure	Range for Pediatric Dose	Recommend Dosage
Technetium-99m	Pertechnetate	G.I. Scan/Meckels	250 µCi-10mCi	0.05 mCi/kg
" "	"	Thyroid Scan	1-5 mCi	71 µCi/kg
" "		Cystogram	500 µCi-1 mCi	
Technetium-99m	DTPA	Renal Scan (G.F.R)	1 mCi	
" "	"	VP Shunt	1 mCi	
Technetium-99m	Sulfur Colloid	Gastric Emptying	250 µCi -1 mCi	350 µCi
" "	"	Liver / Spleen Scan	1 mCi -6mCi	86 µCi/kg
Technetium-99m	Filtered Sulfur Colloid	Lymphoscintigraphy	1 mCi in 0.1 ml for each injection site	
Technetium-99m	MAG3	Renal Scan	1-4 mCi	143 µCi/kg
Technetium-99m	MDP	Bone Scan	1-20 mCi	0.25 mCi/kg
Technetium-99m	Sestamibi	Myocardial-Rest	4-10 mCi	143 µCi/kg
" "	"	Myocardial-Stress	8-20 mCi	300 µCi/kg
Technetium-99m	Sestamibi	Parathyroid	5-25 mCi	360 µCi/kg
Technetium-99m	Choletec	Hepatobiliary	1-5 mCi	0.05 mCi/kg
Technetium-99m	(Ultra-Tag Kit)	G.I. Bleed	3-20 mCi	300 µCi/kg
Technetium-99m	Bicisate (Neurolite)	Brain SPECT	5-20 mCi	300 µCi/kg*
Technetium-99m	MAA	Lung Scan	400 uCi-3 mCi	0.03 mCi/kg**

Radionuclide	Chemical Form	Procedure	Range for Pediatric Dose	Recommend Dosage
Technetium-99m	HM-PAO (Ceretec)	White Cell Label	1-10 mCi	150 µCi/kg
Technetium-99m	"	Brain (CBF)	3-20 mCi	290 µCi/kg
Iodine-123	Sodium Iodide	Thyroid Uptake	15-300 µCi	5 µCi/kg
" "	"	Thyroid Ca WB	1-3 mCi	
Iodine-123	MIBG	Brain/Adrenal Imaging	1-10 mCi	0.14 mCi/kg
Indium-111	Oxine	White Cell Label	75-500 µCi	10 µCi/kg
Indium-111	DTPA	Baclofen Shunt	50-500 µCi	7 µCi/kg
" "	"	CSF Shunt Patency	200 µCi into shunt by MD	
" "	"	Cisternogram	50-500 µCi	7 µCi/kg
Indium-111	Octreoscan	Tumor Imaging	500 µCi - 6 mCi	86 µCi /kg
Fluorine-18	FDG	Brain Imaging	1-10 mCi	0.1 mCi/kg
Fluorine-18	FDG	Body Imaging	1-10 mCi	0.10-0.14 mCi/kg
Gallium-68	Dotatate	Tumor Imaging	0.5?-5.4 mCi	54 µCi /kg
Gallium-67	Citrate	FUO	300 uCi-5 mCi	70 µCi /kg
" "	"	Tumor	500 uCi-10 mCi	140 µCi /kg

*Double the calculated Neurolite amount for duration of EEG Monitoring.
**Lung dose and particle size parameters

Newborn	1 year	5 years	10 years	15 years	> 70kg	Rt to Lt Shunt
200 µCi	500 µCi	1 mCi	1.5 mCi	2.5 mCi	3 mCi	
10-50 k	50-150 k	200 - 300 k	200-300 k	200-700k	200-700k	<10 k particles

Follow the new North American Guidelines for Pediatric Nuclear Medicine for high-quality images at low radiation dose.

2016 Update: North American Consensus Guidelines for Pediatric Administered Radiopharmaceutical Activities[1]

Radiopharmaceutical	Notes	Administered Activity	Minimum Administered Activity	Maximum Administered Activity
^{123}I-MIBG	[A]	5.2 MBq/kg (0.14 mCi/kg)	37 MBq (1.0 mCi)	370 MBq (10.0 mCi)
^{99m}Tc-MDP	[A]	9.3 MBq/kg (0.25 mCi/kg)	37 MBq (1.0 mCi)	
^{18}F-FDG	[A, B]	Body: 5.7-5.2 MBq/kg (0.104.14 mCi/kg) Brain: 3.7 MBq/kg (0.10 mCi/kg)	26 MBq (0.7 mCi) 14 MBq (0.37 mCi)	
^{99m}Tc-DMSA	[A]	1.85 MBq/kg (0.05 mCi/kg)	18.5 MBq (0.5 mCi)	100 MBq (2.7 mCi)
^{99m}Tc-MAG3	[A, C] [A]	Without flow study: 3.7 MBq/kg (0.10 mCi/kg) With flow study: 5.55 MBq/kg (0.15 mCi/kg)	37 MBq (1.0 mCi)	148 MBq (4.0 mCi)
^{99m}Tc-IDA	[A, D]	1.85 MBq/kg (0.05 mCi/kg)	18.5 MBq (0.5 mCi)	
^{99m}Tc-MAA	[A] [A]	If ^{99m}Tc used for ventilation: 2.59 MBq/kg (0.07 mCi/kg) No ^{99m}Tc ventilation study: 1.11 MBq/kg (0.03 mCi/kg)	14.8 MBq (0.4 mCi)	
^{99m}Tc-pertechnetate (Meckel diverticulum imaging)	[A]	1.85 MBq/kg (0.05 mCi/kg)	9.25 MBq (0.25 mCi)	
^{18}F-sodium fluoride	[A]	2.22 MBq/kg (0.06 mCi/kg)	14 MBq (0.38 mCi)	
^{99m}Tc (for cystography)	[E]	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)	[F]	No weight-based dose	9.25 MBq (0.25 mCi)	37 MBq (1.0 mCi)
^{99m}Tc-sulfur colloid (for solid gastric emptying)	[F]	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 (Cardolite)/^{99m}Tc-tetrofosmin (Myoview) for myocardial perfusion (single scan or first of 2 scans, same day)		5.55 MBq/kg (0.15 mCi/kg)	74 MBq (2 mCi)	370 MBq (10 mCi)
^{99m}Tc-sestamibi (Cardolite)/^{99m}Tc-tetrofosmin (Myoview) for myocardial perfusion (second of 2 scans, same day)		16.7 MBq/kg (0.45 mCi/kg)	222 MBq (6 mCi)	1110 MBq (30 mCi)
^{123}I/^{131}I for thyroid imaging		0.28 MBq/kg (0.0075 mCi)	1 MBq (0.027 mCi)	11 MBq (0.3 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)
^{99m}Tc-HYNIC-IDOC or ^{99m}Tc-DOTATATE	[G]	2.7 MBq/kg (0.074 mCi/kg)	14 MBq (0.38 mCi)	185 MBq (5 mCi)

NOTES: *Use administered activities as a guideline only. Local practice may vary depending on patient population, choice of radiotracer, and the specific requirements of clinical protocols. Administered activity may be adjusted when appropriate by state of the nuclear medicine practitioner.*

For patients who weigh more than 70 kg, it is recommended that the maximum administered activity not exceed the product of the patient's weight (kg) and the recommended weight-based administered activity. Some practitioners may choose to set a fixed maximum administered activity equal to 70 times the recommended weight-based administered activity expressed as MBq/kg or mCi/kg. For example, approximately 1 mCi/kg (37 MBq) for ^{99m}Tc-MDP bone imaging. The administered activities assume use of a low-energy high-resolution collimator for ^{99m}Tc and pharmaceutical and a medium-energy collimator for ^{123}I-MIBG.

Individual practitioners may use lower administered activities if their equipment or software permits them to do so. Higher administered activities may be required in selected patients. The recommended dose is given for intravenous ^{99m}Tc activity. Intravenous ^{99m}Tc activity should be used only infrequently and only if other doses.

A The EANM Dosage Card 2014 version 2 administered activity may also be used.

B The low end of the dose ranges should be considered for smaller patients. Administered activity may take into account patient mass and time available on the PET scanner. The EANM Dosage Card 2014 version 2 administered activity may also be used.

C The administered activities assume that image data are reformed at 1 min/image. The administered activity may be reduced if images data are reformed at a longer time per image.

D A higher administered activity of 7 mCi may be considered for neonatal jaundice.

E ^{99m}Tc-sulfur colloid, ^{99m}Tc-pertechnetate, ^{99m}Tc-DTPA or practically other ^{99m}Tc-radiopharmaceuticals may be used. There is a wide variety of oral/gastric administration and imaging techniques for ^{99m}Tc-S cystography, many of which will work well with lower administered activities. An example of appropriate lower administered activities is found in the 2014 revision of the EANM Paediatric Dose Card.

F The administered activity may be lower, in patient weight or on the age of the child.

G The administered activity is based on the EANM Dosage Card 2014 version 2.2 change for a 60 kg patient, using the maximum and maximum doses from the EANM Dosage Card. These were little experience with this radiopharmaceutical in children in North America at the time of preparation of this dosage table.

[1]Gelfand MJ, Parisi MT, Treves ST. Pediatric Radiopharmaceutical Administered Doses: 2010 North American Consensus Guidelines. J Nucl Med. 2011; 52 (2): 318-322.
[2]Lassmann M, Treves, ST. Pediatric Radiopharmaceutical Administration: Harmonization of the 2007 EANM Paediatric Dosage Card (Version 1.5.2008) and the 2010 North American Consensus guidelines. Eur J Nucl Med Mol Imaging. 2014; 41 (10):1424-9.Epub May 6. 2014.

SNMMI SOCIETY OF NUCLEAR MEDICINE AND MOLECULAR IMAGING

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EANM European Association of Nuclear Medicine — BIOMEDICAL IMAGING AND THERAPY FOR PERSONALIZED HEALTHCARE

Dosage Card (Version 5.7.2016)

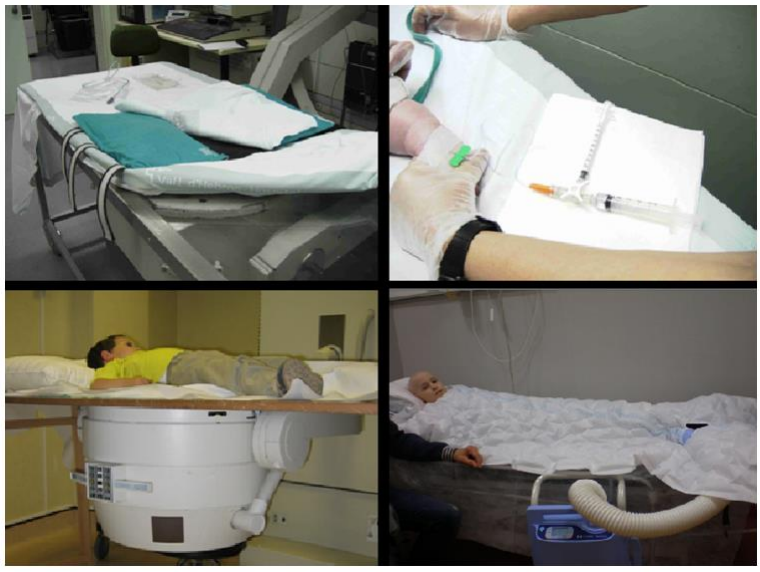
Multiple of Baseline Activity

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

$$A[MBq]_{\text{Administered}} = BaselineActivity \times Multiple$$

Recommended Amounts in MBq

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
^{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 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



(Bielsa IR)

Immobilization

- Swaddling (any age)
  - Baby Blankets, Sheets, Positioning Sponges, Velcro, and Tape
- Feed before imaging (e.g. Renal MAG3)
- Sleep deprived – CT commonly uses
- Favorite toy or blanket
- Safety straps
- Medication Assistance
  - Oral: Versed, Ativan, Benadryl, prescriptions for pain meds
  - Conscious Sedation: Nitrous Oxide, Fentanyl, Versed
  - Anesthesia: Propofal and Precedex (dexmedetomidine)

Renal MAG3 (Kidney c/Lasix)

Indications are different in pediatrics

- Commonly ordered for:
  - Duplicated systems
  - Hydronephrosis
  - UPJ/UVJ Obstruction
  - Horseshoe Kidney
  - Post Transplant (no Lasix, 30 min imaging)

Imaging variations

Infant Swaddle (0-5m)

Anesthesia (6m to 5-6yrs)

Non-sedate over 6yrs

Renal MAG3 Exam Prep

Infant Swaddle (0-6 months)

NPO 4 hrs prior to exam
IV catheter
IV fluids- 15 mL/kg; 30 min infusion
Urinary Catheter- typically 8Fr
Feed immediately prior to imaging
Swaddle
Scan
Darkened room, soft music, snoozellen

Non-sedate 6yrs and Older

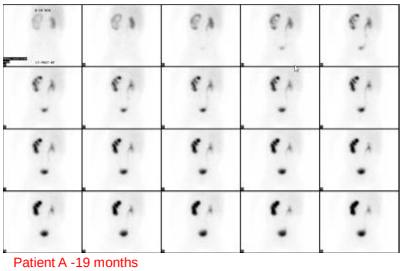
Oral Hydration – 16 oz water (240 mL)
IV catheter
No urinary catheter
Pick out a MOVIE!!!
Scan

Anesthesia (6 months – 6 years)

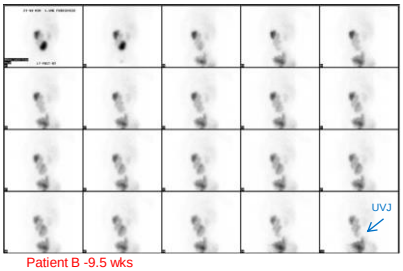
NPO 6 hrs solids/milk; NPO 2 hrs for clear liquid
IV catheter
IV fluids- 15 mL/kg; 30 minute infusion
Urinary catheter – typically 8Fr
Anesthesia administered
Scan
Recovery

- Planar imaging remains most commonly performed NM procedure in peds
- Acquisition can be:
  - Static: ^{123}I-MIBG for neuroblastoma
  - Dynamic: ^{99m}Tc-MAG3 renal scan

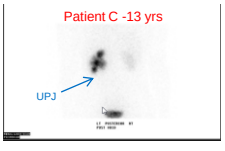
MAG3 Renal - Hydronephrosis

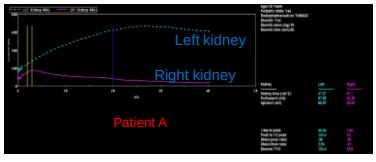


Patient A -19 months

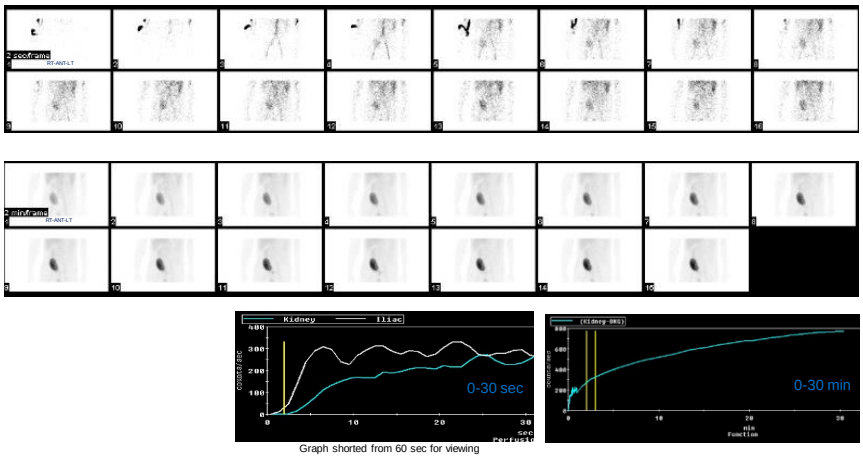


Patient B -9.5 wks



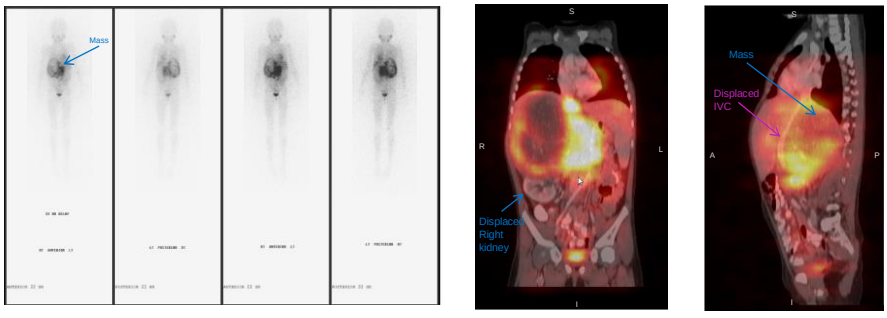


MAG3 Renal - Transplant



Graph shorted from 60 sec for viewing

123-I mIBG Imaging

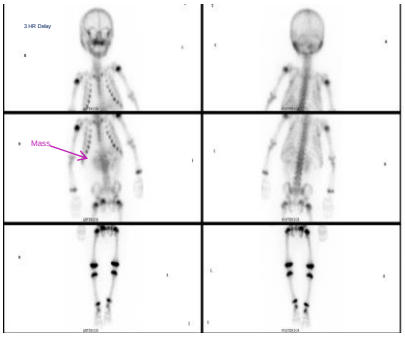


SPECT fused with previous diagnostic CT

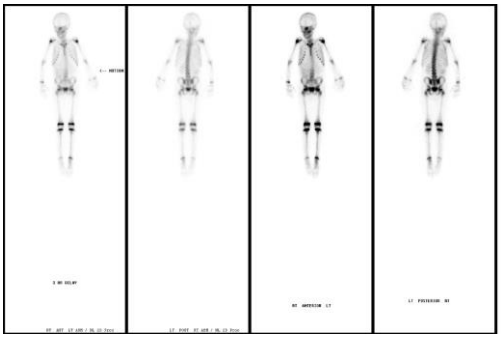
Bone Scan (WB and 3 Phase)

- Done very similar to adults: Metastatic Disease, Osteomyelitis, FUO, Pain
- Differences
  - Length of time to hold still – approx 1 hour
  - Possible need for a urinary catheter
  - Osteosarcoma, Rhabdomysarcoma, Ewing's Sarcoma
- Spot imaging for WB under 12 months
- SPECT/CT
  - Spine: PARs Defect, Fractures, Spondyolisthesis (slipping), AVN hips
  - Area requested by radiologist

Bone Imaging



Spot views WB for an infant



Whole body bone scan

Same patient that demonstrated large mass on previous slide with mIBG

Outline

Chapter 1. Tales of Mercyland!
Chapter 2. Clinical challenges of peds imaging
Chapter 3. Physical challenges of peds imaging
  i. Planar imaging
  ii. SPECT
Chapter 4. Toils of an in-house physicist

Why NM for peds?

- NM procedures are *extremely* safe
- Total mass and volume administered tracer is very small
- Therefore do not produce hemodynamic/ osmotic effects
- Below allergic trigger levels

Table 1.1 Comparison of mass and volumes for certain radiopharmaceuticals and contrast agents. Example in a 1-year-old

	Volume (mL)	Mass (mg)
^{99m}Tc-MDP	0.06	0.64
^{99m}Tc-DMSA	0.03	0.22
^{99m}Tc-MAG$_3$	0.10	1.1
Gd-DTPA	2.0	940
Optiray 320	20	6,400

(Treves, p.2)

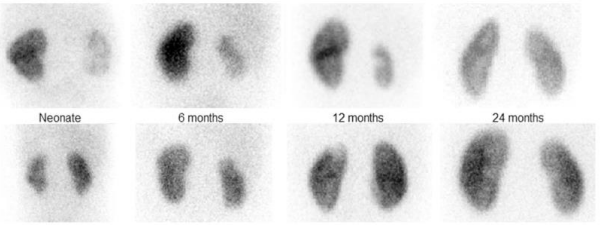
That being said, why are peds different?

- Lower renal function
- Lower GFR
- Faster washout of radioactive gases from the lungs
- Faster circulation times
- Faster lymphatic flow

TABLE 12.1. Normal glomerular filtration rate (GFR) for different ages

Age	GFR (mL/min/1.73 m²) Mean	Range (±2 SD)
Premature	47	29–65
2–8 days	38	26–60
4–28 days	48	28–68
35–95 days	58	30–86
1–5.9 mo	77	41–103
6–11.9 mo	103	49–157
12–19 mo	127	63–191
2–12 years	127	89–165
Adult males	131	88–174
Adult females	117	87–147

(Treves, Ed.3 Table 10.1)



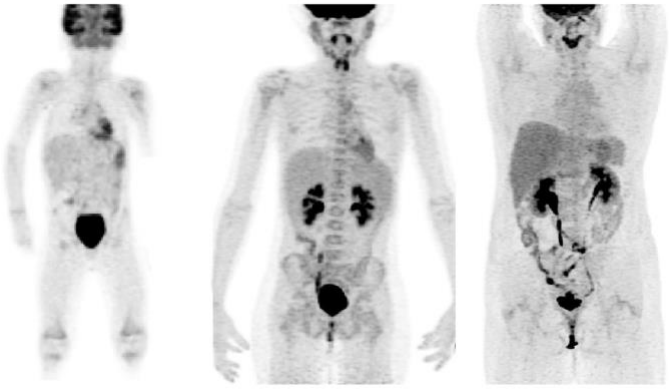
(Bielsa IR)

How are peds different?

- There are peds diseases that do not exist in adults.
  Examples:
  - Perthes disease: Common in 3-5yr
  - Meckel diverticulum is more frequent in children than in adults
- Brain metabolism in neonates is limited to basal ganglia and sensorimotor cortex

How are peds different?

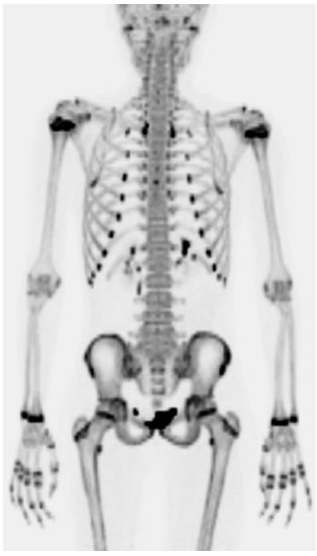
- In some diseases, the location and morphology of the lesions differ during childhood. For example:
  - Bone fractures under 24 months are pandiaphyseal instead of lineal
  - Osteomyelitis has different sensitivity and distribution patterns in adults vs. peds
- More bone marrow activity in peds than adults → FDG or gallium uptake is different in kids



(Bielsa IR)

Different tracer distribution: FDG uptake in young child vs. adolescent vs. adult

- F-18 PET bone scan in a 14yr old female
- Pattern similar to ^{99m}Tc-MDP
- In pediatric patients, physeal uptake indicates skeletal immaturity



(Treves, p.36)

Other challenges

- Any conflicting imaging tests?
  - Example: Has patient been given radiographic contrast during past few days? (can produce shielding artifacts)
- Any medications that may interfere with NM study?
- Can little Johnny's grandma and family stay with him in the PET waiting room?

Outline

Chapter 1. Tales of Mercyland!
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  i. Planar imaging
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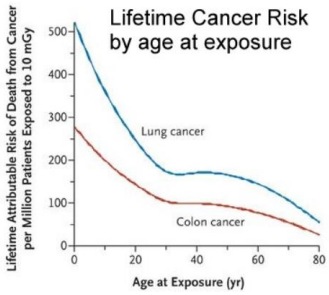
Physical challenges: i. Planar imaging

- Long acquisition times
  - Immobilization
- Higher sensitivity
  - More efficient use of data to reduce acquisition time
  - Minimize administered activity

Physical challenges: i. Planar imaging

- Challenges:
  - Small organs: optimize visualization → maximize spatial resolution
  - Dose: Age issue and latent stochastic effects



General approaches to reducing dose

- Appropriateness of the clinical use
- Most recent radiopharmaceutical dose guidelines

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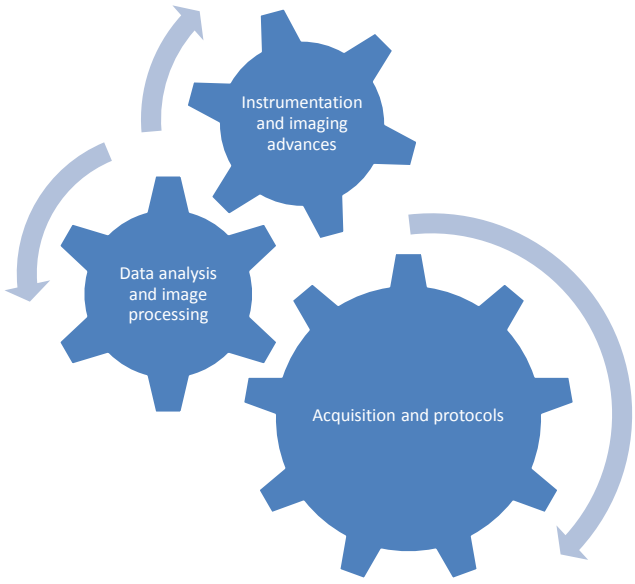
Seminars in NUCLEAR MEDICINE

Pediatric Nuclear Medicine and its Development as a Specialty

Isabel Roca Bielsa

Pediatric Nuclear Medicine (PNM) offers to the pediatrician noninvasive procedures, with high clinical impact and low dosimetry. New techniques have been adapted to children, diminishing doses, always looking for less dosimetry, higher sensitivity and higher resolution images. PNM is and will remain a minority subspecialty, but highly complex for general NM physicians due to the different diagnostics in children and due to the higher technical complexity of the examinations. General NM physicians have to be trained and regularly receive CME in this field.

Semin Nucl Med 47:102-109 © 2017 Elsevier Inc. All rights reserved.



a) Acquisition aspects of planar imaging

- Are your protocols most appropriate given the state of practice?
  - Example 1: A perfusion phase with rapid framing in ^{99m}Tc-MAG3 renal imaging may no longer be current
  - Example 2: Renal DMSA (we don't use anymore)

Protocol Tracker

SETUP Last Updated: 2/20/2019

Protocol	Category	Last Revision Date	Last Reviewed Date
Intrathecal Infusion (Baclofen Pump)	Other	5/1/2016	11/2/2018
Leukocyte WBC Scan	Other	5/1/2016	5/1/2016
Liver Hemangioma	GI	11/2/2018	11/2/2018
Liver-Spleen	GI	5/1/2016	11/2/2018
Lung Perfusion	Pulmonary	5/15/2018	5/15/2018
Lymphoscintigraphy	Other	5/1/2016	11/2/2018
Meckel's Scan	GI	4/1/2017	2/16/2018
Milk Study	GI	10/1/2015	2/16/2018
Myocardial Perfusion	Cardiovascular	7/6/2018	7/6/2018
OctreoScan	Oncology	5/1/2016	2/27/2019
Parathyroid Scan	Endocrine	9/14/2017	9/14/2017
PET-CT Body	Oncology	8/1/2014	8/1/2014
PET-CT Brain	CNS	8/1/2014	8/1/2014
Renal Captopril Scan	GU	4/1/2017	2/27/2019
Renal Cortical Imaging	GU	2/1/2017	2/27/2019
Renal DMSA	GU	5/1/2016	2/27/2019
Renal GFR	GU	4/1/2017	3/21/2018
Renal Scan	GU	9/14/2017	9/14/2017
Renal Transplant Scan	GU	5/1/2016	5/1/2016
Sialogram	GI	3/1/2016	3/1/2016
Salivary Gland Imaging	GI	10/1/2015	10/1/2015
Thyroid Scan	Endocrine	5/1/2016	5/1/2016

Protocol	Category	Last Revision Date	Last Reviewed Date
Bone Scan 3-Phase	Skeletal	1/17/2017	5/15/2018
Bone Scan Whole Body	Skeletal	1/17/2017	1/17/2017
Bone SPECT	Skeletal	5/1/2016	5/15/2018
Bone SPECT-CT	Skeletal	5/1/2016	5/15/2018
Brain SPECT (Ceretec)	CNS	5/1/2016	11/2/2018
Brain SPECT for Seizure	CNS	6/1/2016	7/6/2018
Cardiac MUGA	Cardiovascular	5/1/2016	4/3/2019
Cerebral Blood Flow (Brain Death)	CNS	5/1/2016	7/6/2018
Cisternogram	CNS	5/1/2016	7/6/2018
CSF Shunt	CNS	5/1/2016	7/6/2018
Cystography	GU	11/1/2015	5/15/2018
Gastric Emptying	GI	12/1/2016	2/16/2018
Gastric Emptying - Liquid	GI	10/1/2015	2/16/2018
GI Bleed Study	GI	9/14/2017	5/15/2018
Hepato for Atresia	GI	1/17/2017	3/21/2018
Hepato for Bile leak	GI	5/1/2016	3/21/2018
Hepatobiliary	GI	9/14/2017	3/21/2018
I-123 MIBG	Oncology	9/14/2017	9/1/2017
I-123 Thyroid Uptake	Endocrine	12/1/2015	12/1/2015
I-123 WB Thyroid CA Scan	Endocrine	4/1/2017	12/4/2018

^{68}Ga Dotate

b) Instrumentation aspects of planar imaging

1. Access issues:

- To the patient: Minimizing camera head distance vs. adjustments for greater access for ancillary support apparatus
- Around the OR:
  - Mobile or handheld gamma cameras for intraoperative imaging
  - Example: Surgical removal of osteoid osteomas
    - ^{99m}Tc-MDP is administered
    - Camera is brought to the room

Mobile Gamma Cameras Market Will Account for Revenues Worth US$ 75.2 Million By 2028

Future Market Insights

NEWS PROVIDED BY
Future Market Insights →
Sep 12, 2018, 10.30 ET

SHARE THIS ARTICLE

VALLEY COTTAGE, New York, September 12, 2018 /PRNewswire/ --

Advancements in healthcare technology - particularly in the surgery category - have led to an increasing adoption of gamma cameras. Further, the numerous developments in radio nucleotides are anticipated to favour the adoption of solid state cameras and mobile gamma cameras. SPECT is currently the biggest application of gamma cameras given the low cost, large suite of radioisotopes, and expanded use cases. Having said this, PET is anticipated to witness fastest growth in terms of adoption, owing to the greater special resolution and sensitivity, brought about by the use of positron emitting radioisotope that provides more energy, contrast, and special resolution. These findings are presented in a new research study on the global mobile gamma cameras market by Future Market Insights (FMI).

(Logo: https://mma.prnewswire.com/media/677274/Future_Market_Insights_Logo.jpg)

According to FMI analysis, the high costs of PET as compared to SPECT are expected to be negated in the wake of development of high sensitivity and selective tracers. FMI predicts a growth rate of 4.8% for the mobile gamma cameras market during the 10 year period from 2018 to 2028. Revenue from the sales of mobile gamma cameras is estimated to reach US$ 75.2 Mn by 2028 end, up from US$ 47.2 Mn in 2018.

practical
patient care

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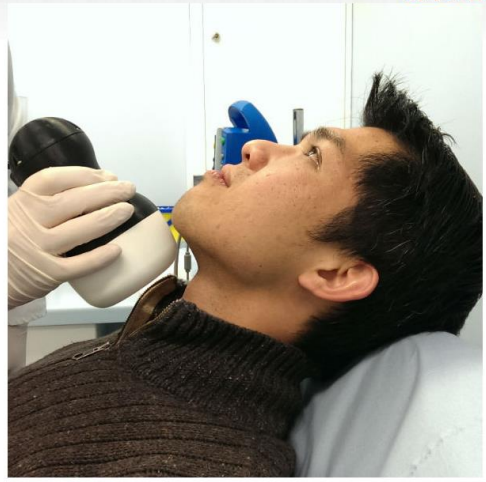
From outer space to life science – compact gamma cameras



A more-portable handheld gamma camera is used to examine a patient.

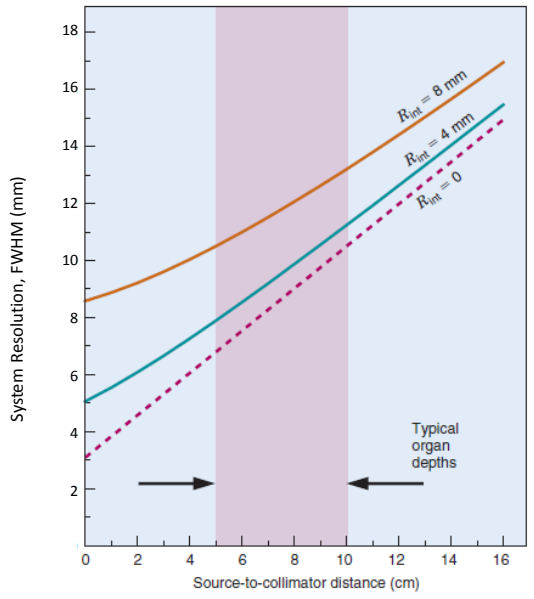
Handheld USB-Gamma Camera "CrystalCam"

(Currently not available as a medical device in Europe.)

2. Collimation:
   - Choice should be determined on a task specific basis
   - Must balance spatial resolution with efficiency
     - Resolution : localization of abnormalities on a bone or renal scan
     - Sensitivity : hepatobiliary imaging for diagnosing biliary atresia

Parallel collimator resolution largely determines system resolution

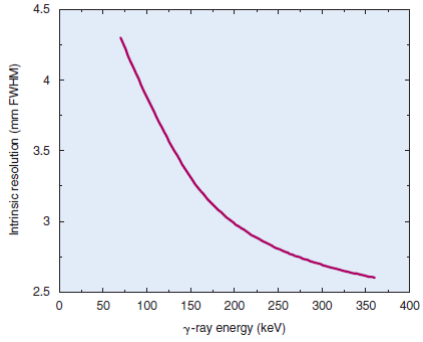
$$R_{sys} = \sqrt{R_c^{\,2} + R_i^{\,2}}$$



(Cherry, p.225)

Parallel hole collimation

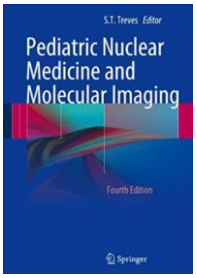
- The choice of collimation:
  - What is the energy of the emissions of the tracers you'll be using?



(Cherry, p.210)

Parallel hole collimation

- The choice of collimation:
  - What is the energy of the emissions of the tracers you'll be using?
  - What about additional emissions?



Improved Quality of Pediatric ^{123}I-MIBG Images with Medium-Energy Collimators

Erin R. Snay, CNMT, S. Ted Treves, and Frederic H. Fahey

J Nucl Med Technol 2011; 39:100–104
DOI: 10.2967/jnmt.110.080309

Parallel hole collimation

- The choice of collimation:
  - Example:
    - ^{123}I used in thyroid imaging or for kids with suspected neuroblastoma
    - Primary emission is 159 keV → LEC is often used
    - However, 4 % of the photons emitted have higher energies

γ-Ray Emissions from ^{123}I (*4*)

Energy (keV)	γ-rays per decay
159	0.828
248	0.0007
281	0.0008
346	0.0013
440	0.0043
505	0.0031
529	0.0138
539	0.0038
625	0.0008
688	0.0003
736	0.0006
784	0.0006

(Snay, p.101)

- Septal thickness in LECs usually has limited effectiveness in stopping these hi-E photons
- **Result 1**: Around 40 % of detected events in a ^{123}I study may result from the septal penetration of these hi-E photons
- **Result 2**: Sensitivity obeys **inverse square law** for LECs when imaging I-123! But for MECs the traditional equation holds:

$$g \approx K^2 \left(\frac{d}{l_{eff}}\right)^2 \frac{d^2}{(d+t)^2}$$

(No b dependence)

	LEHS Low-energy high-sensitivity	LEHR Low-energy high-resolution	LEUHR Low-energy ultrahigh-resolution	ME Medium energy	HE High energy
Hole length (mm)	24	24	36	40	50
Hole diameter (mm)	2.5	1.1	1.1	2.9	3.4
Septal thickness (mm)	0.36	0.15	0.15	1.1	2
Sensitivity (cpm/μCi)	1,000	200	100	310	135
Collimator resolution @10 cm (mm)	14.6	6.4	4.6	10.8	12.6

(Treves, Fahey, p.624)

Conclusion: It may be more appropriate to utilize a MEC rather than a LEC for I-123, because:

1. Better image i.e. higher contrast, less noise
2. Increased sensitivity i.e. shorter scan times

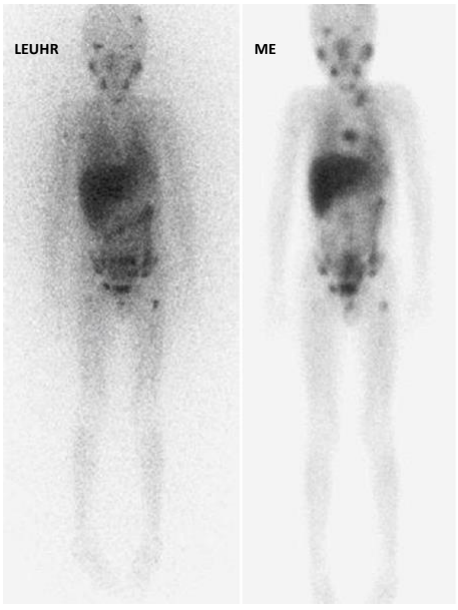
Discovery NM630 Parallel Hole Collimators

DESCRIPTION	NAME	CATALOG NUMBER (a)	RECOMMENDED ISOTOPE	FIELD OF VIEW (cm) (b)	CALCULATED PENETRATION (%)	SYSTEM SENSITIVITY (cpm/μCi) @100 mm 3/8" / 5/8" Per Detector (c)	SYSTEM SENSITIVITY (cps/MBq) @100 mm 3/8" / 5/8" Per Detector (c)	SYSTEM RESOLUTION FWHM (mm) @100mm 3/8" / 5/8" (d)	TYPE OF HOLE	HOLE DIAMETER (mm)	SEPTAL THICKNESS (mm)	HOLE LENGTH (mm)	WEIGHT (kg / lb) 1 pcs
Low Energy** Ultra-High Resolution	LEUHR	H2506TH	Tl-201 / Tc99m Studies	54 x 40	0.3 (Tc-99m)	83 / N.A. (Tc-99m)	38 / N.A. (Tc-99m)	6.1 / N.A.	hex	1.22	0.15	38	80 / 176
Low Energy** High Resolution	LEHR	H2506TB	Tl-201 / Tc99m Studies	54 x 40	0.3 (Tc-99m)	160 / 165 (Tc-99m)	72 / 74 (Tc-99m)	7.4 / 7.7	hex	1.5	0.2	35	60 / 132
Extended** Low Energy General Purpose	ELEGP	H2506TD	I-123 / Kr-81 Studies	54x 40	0.3 (I-123) 2.3 (Kr-81)	320 / 330 (Tc-99m) 224 / 245 (I-123)	144 / 148 (Tc-99m) 101 / 110 (I-123)	10.3 / 10.6	hex	2.5	0.4	40	62 / 136
Medium Energy General Purpose	MEGP	H2506TC	Ga-67 / In-111 studies	54 x 40	2.0 (Ga-67)	144 / 150 (Ga-67)	65 / 67 (Ga-67)	9.4 / 9.8	hex	3.0	1.05	58	103 / 227
High Energy General Purpose	HEGP	H2506TE	I-131 studies	54 x 40	2.0 (I-131)	97 / 165 (I-131)	43 / 73 (I-131)	12.0 / 12.5	hex	4.0	1.8	66	131 / 289

My conclusion: It may be more appropriate to just test this all out on your system and see if switching to a MEC works for you:

1. "Still looks noisy"
2. We only use ME for Octreoscan ^{111}In

4yr old kiddo, ME improves sensitivity by a factor of 3



(Treves, Fahey, p.626)

- The choice of collimation:
  - How will you balance between spatial resolution and sensitivity?
  - Example 1: LEHR vs LEHS
    -

	LEHS Low-energy high-sensitivity	LEHR Low-energy high-resolution	LEUHR Low-energy ultrahigh-resolution	ME Medium energy	HE High energy
Hole length (mm)	24	24	36	40	50
Hole diameter (mm)	2.5	1.1	1.1	2.9	3.4
Septal thickness (mm)	0.36	0.15	0.15	1.1	2
Sensitivity (cpm/μCi)	1,000	200	100	310	135
Collimator resolution @10 cm (mm)	14.6	6.4	4.6	10.8	12.6

    - Here, 5-fold gain in sensitivity (compared to LEHR) can allow imaging time to be cut
    - If spatial resolution is not of primary concern, the LEHS collimator may be a good choice.

- Exan
  - @ e
re

	LEHS Low-energy high-sensitivity	LEHR Low-energy high-resolution	LEUHR Low-energy ultrahigh-resolution	ME Medium energy	HE High energy
Hole length (mm)	24	24	36	40	50
Hole diameter (mm)	2.5	1.1	1.1	2.9	3.4
Septal thickness (mm)	0.36	0.15	0.15	1.1	2
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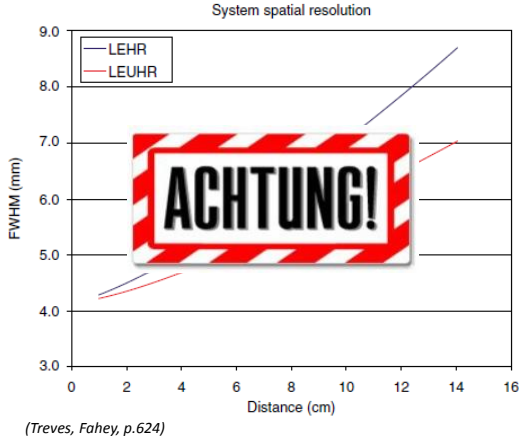
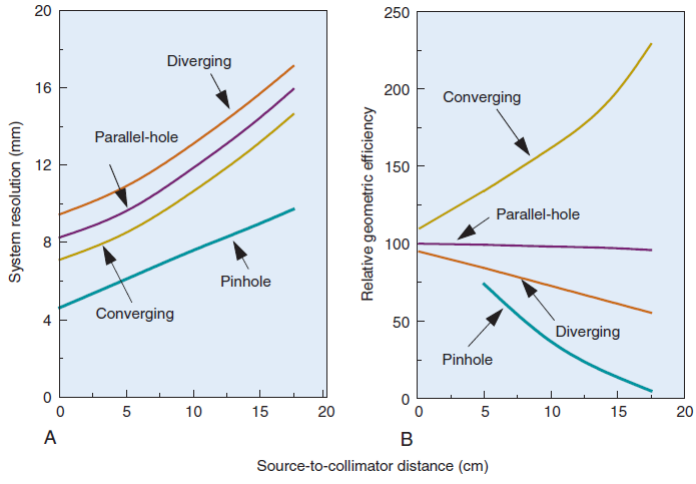


(Treves, Fahey, p.624)

Magnification collimation

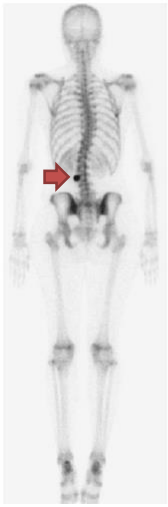
Why magnification collimation

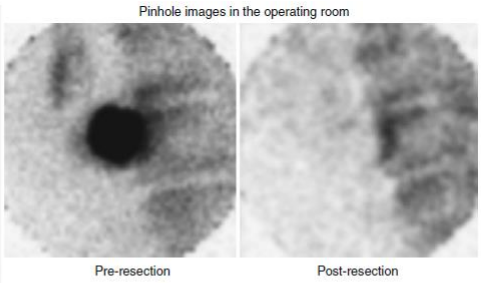


(Cherry, p.227)

Pinhole collimation

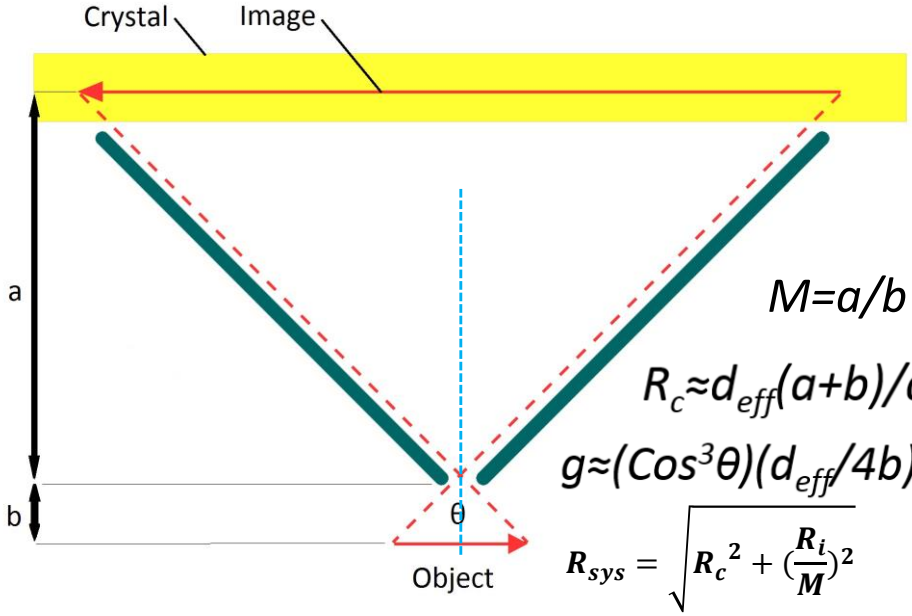
- Examples:
  - In patients < 1yr with possible pyelonephritis, may need high-resolution image of renal cortex using ^{99m}Tc-DMSA to evaluate the extent of scarring
  - If wanting to discern which bone in the foot has enhanced ^{99m}Tc-MDP uptake





- Osteoid Osteoma of the spine
- Whole body Tc-MDP bone scan parallel col vs pinhole
- Used mobile solid state camera in OR

(Treves, p.379)



$$M=a/b$$

$$R_c \approx d_{eff}(a+b)/a$$

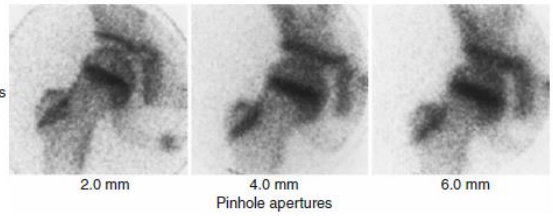
$$g \approx (Cos^3\theta)(d_{eff}/4b)^2$$

$$R_{sys} = \sqrt{R_c^{\,2} + (\frac{R_i}{M})^2}$$

Notice efficiency deteriorates faster than R_c with b

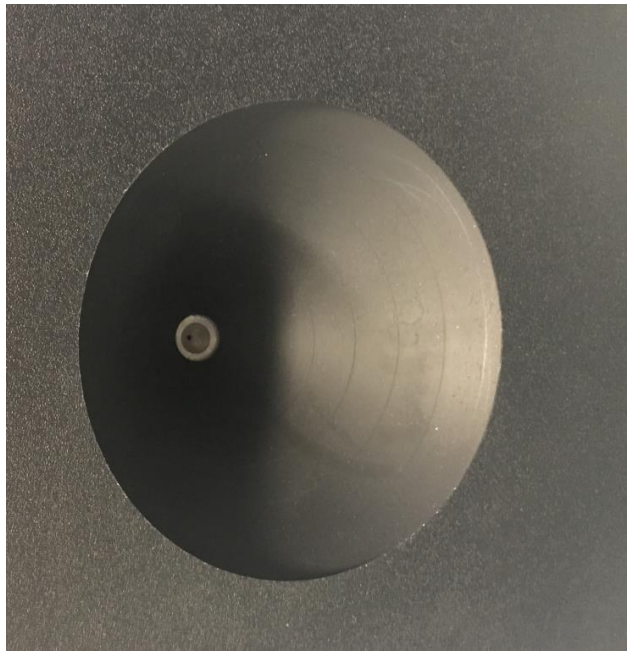
Discovery NM630 Pinhole Collimator

DESCRIPTION	NAME (a)	CATALOG NUMBER	RECOM MENDED APPLI-CATION / ISOTOPE	FIELD OF VIEW (mm)	Weight (kg/lb)	Insert hole diameter (mm)	3/8" SYSTEM SENSITIVITY (cpm/μCi) @100 mm Per Detector (b)	3/8" SYSTEM SENSITIVITY (cps/MBq) @100 mm Per Detector (b)	3/8" SYSTEM RESOLUTION FWHM (mm) @100mm (c)
General Purpose Pin Hole (3 inserts)	GPPH	H2506TF	Thyroid / Tc99m, I123, I131	200 diameter	98/216	2	43	19	3.8
						4.45	200	90	6.5
						8	570	258	11.4



(Treves, p.377)

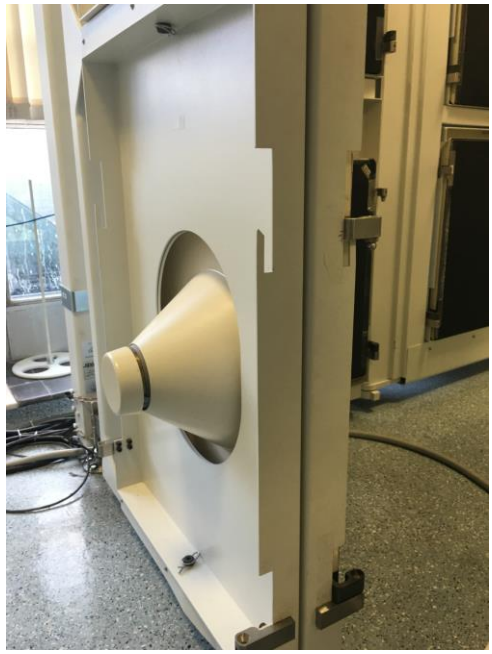
- Moral of story: When decreasing aperture size, there is a trade off between col sensitivity (and therefore acquisition time) and spatial resolution
  - Notice however, reducing aperture size has bigger effect on g than on R_c



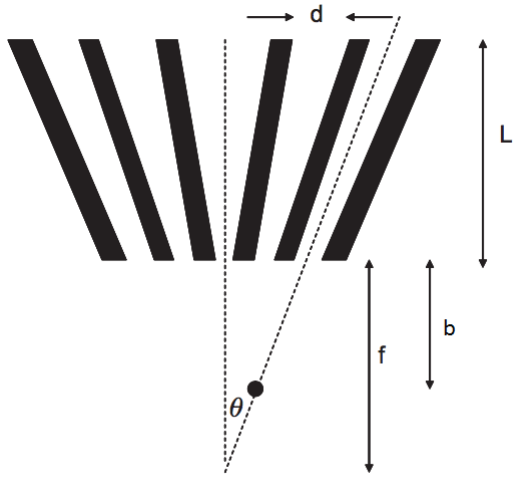
- Pros:
  - Excellent spatial resolution → good for small organs or babies
- Cons:
  - Magnification distortions → for bigger patients
  - g↓ if (θ or b)↑ (unlike converging collimators)

My conclusion: It may be more appropriate to just test this all out on your system and see if a Pinhole collimator works for your particular type of exam:

1. We only use Pinholes for femoral hips and thyroids in newborns. We use the SPECT for other former pinhole usages (e.g. 3-phase bone scan)
2. “takes too long to position it”



Converging collimation



$$R_c \cong \left(\frac{d}{L'_{eff}}\right)\left(L'_{eff} + b\right)\left(\frac{1}{\cos\theta}\right)\left(1 - \frac{L'_{eff}/2}{f + L'_{eff}}\right)$$

$$g \cong K^2 \left(\frac{d^2}{L'^2_{eff}}\right)\frac{d^2}{(d+t)^2}\frac{f^2}{(f-b)^2}$$

g↑ if b↑
(provided f>b)

c) Image processing aspects of planar imaging

- Adaptive filtering
  - The size and type of the filtering kernel is spatially modified depending on the local image content
  - Apply lots of smoothing to areas of uniform activity
  - Apply less smoothing to areas of varying spatial content such as those containing edges and fine detail

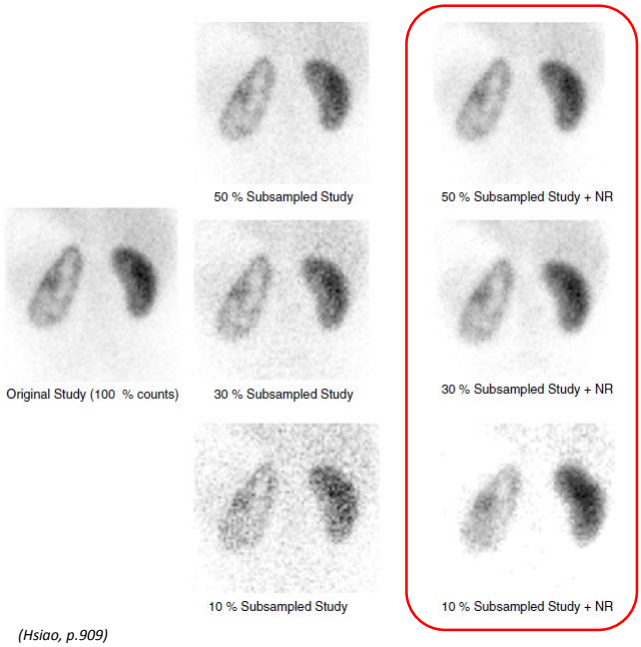
- Apparent noise level is reduced while preserving image sharpness
- Allows for reduction in the administered activity (i.e. absorbed dose) to patient
- Example 1: Apply adaptive filtering to dynamic ^{99m}Tc-MAG3 renal study

Radiology

Reduction in Radiation Dose in Mercaptoacetyltriglycerine Renography with Enhanced Planar Processing[1]

Edward M. Hsiao, MD

Radiology: Volume 261: Number 3—December 2011 • radiology.rsna.org



(Hsiao, p.909)

- Example 2: Apply *Enhanced Planar Processing* (EPP) to scintigraphic hepatobiliary studies in infants for the diagnosis of biliary atresia
- With EPP, clinically acceptable images may be produced with a reduction of 75 % of the minimum administered activity

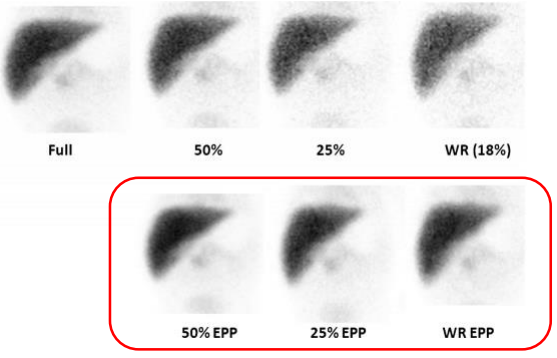
Eur J Nucl Med Mol Imaging (2014) 41:2346–2353
DOI 10.1007/s00259-014-2860-1

ORIGINAL ARTICLE

Beyond current guidelines: reduction in minimum administered radiopharmaceutical activity with preserved diagnostic image quality in pediatric hepatobiliary scintigraphy

Frederic Fahey · Katherine Zukotynski · David Zurakowski · Robert Markelewicz · Anthony Falone · Marie Vitello · Xinhua Cao · Frederick Grant · Laura Drubach · A. Hans Vija · Manojeet Bhattacharya · Xinhong Ding · Zvi Bar-Sever · Michael Gelfand · S. Ted Treves

A 2-month old boy (4.5 kg) with hepatocellular dysfunction w/o (top) and w/ (bottom) EPP



(Fahey ref [5])

ELSEVIER

Seminars in NUCLEAR MEDICINE

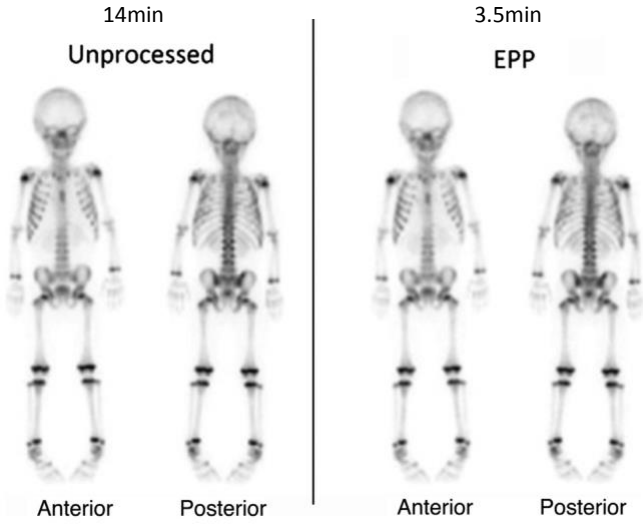
Pediatric Nuclear Medicine and Radiation Dose

S. Ted Treves, MD,[*,†] Anthony E. Falone, MS,[†] and Frederic H. Fahey, DSc[†]

Nuclear medicine is a unique and valuable method that contributes to the diagnosis and assessment of many diseases in children. Radiation exposures in children undergoing diagnostic nuclear medicine studies are low. Although in the past there has been a rather large variation of pediatric radiopharmaceutical administered activities, adhering to recent standards for pediatric radiopharmaceutical administered doses can help assure that the lowest administered activity are employed and that the diagnostic value of the studies is preserved. Radiation exposures in children can be reduced further by optimizing routine protocols, application of advanced image processing and potentially with the use of advanced imaging systems.

Semin Nucl Med 44:202-209 © 2014 Elsevier Inc. All rights reserved.

Using EPP to reduce imaging time while preserving diagnostic information. 3yr old boy Tc-MDP @3.7mCi..



(Treve, Ref.8)

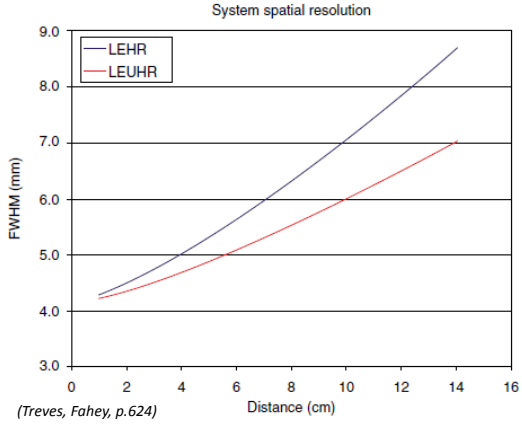
Physical challenges:
ii. SPECT

- A little bit more challenging than planar:
- 100 proj x 20 sec/proj = enough time for kiddo to move around
- Age group for sedation or general anaesthesia is between 1-5yr olds

Resolution-Sensitivity Tradeoff

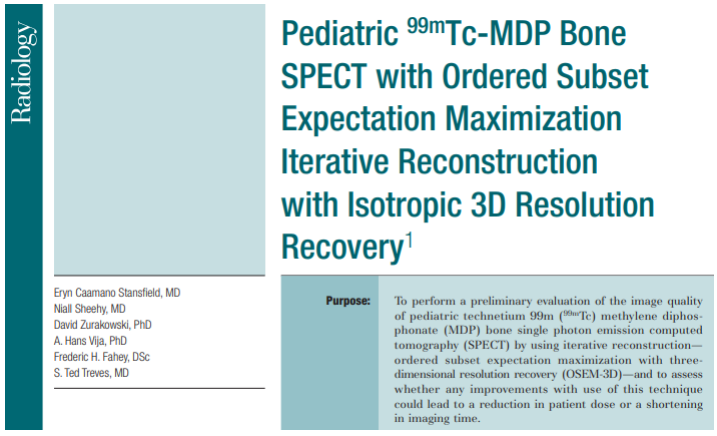
- Use dual heads to improve sensitivity → reduce to 180 degree acquisition
- In peds, the highest spatial resolution is essential. Therefore:
  - body contour orbits
  - L-config for cardiac SPECT
  - Which collimator? LEHR or LEUHR?

	LEHS	LEHR	LEUHR	ME	HE
	Low-energy high-sensitivity	Low-energy high-resolution	Low-energy ultrahigh-resolution	Medium energy	High energy
Hole length (mm)	24	24	36	40	50
Hole diameter (mm)	2.5	1.1	1.1	2.9	3.4
Septal thickness (mm)	0.36	0.15	0.15	1.1	2
Sensitivity (cpm/μCi)	1,000	200	100	310	135
Collimator resolution @10 cm (mm)	14.6	6.4	4.6	10.8	12.6



(Treves, Fahey, p.624)

In SPECT, objects are at a distance from the collimator, thus the difference in resolution is more striking, therefore using the LEUHR may be more appropriate.


Radiology

Pediatric ^{99m}Tc-MDP Bone SPECT with Ordered Subset Expectation Maximization Iterative Reconstruction with Isotropic 3D Resolution Recovery[1]

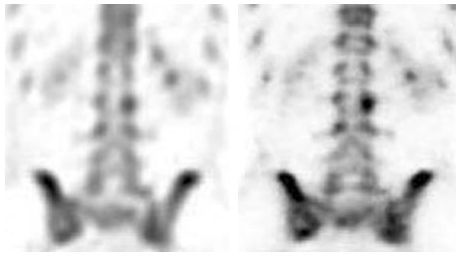
Eryn Caamano Stansfield, MD
Niall Sheehy, MD
David Zurakowski, PhD
A. Hans Vija, PhD
Frederic H. Fahey, DSc
S. Ted Treves, MD

Purpose: To perform a preliminary evaluation of the image quality of pediatric technetium 99m (^{99m}Tc) methylene diphosphonate (MDP) bone single photon emission computed tomography (SPECT) by using iterative reconstruction—ordered subset expectation maximization with three-dimensional resolution recovery (OSEM-3D)—and to assess whether any improvements with use of this technique could lead to a reduction in patient dose or a shortening in imaging time.

Recon innovations to bring down administered activity or acquisition time

- Use OSEM (iterative recon) with *resolution recovery* to improve IQ

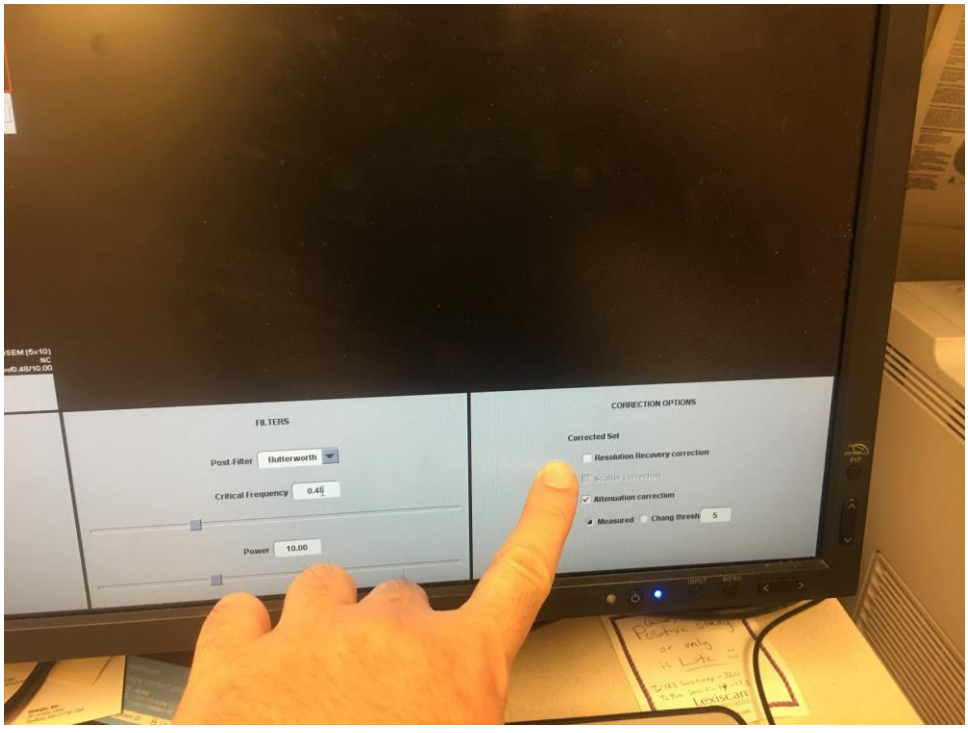
Bone SPECT using Tc-MDP

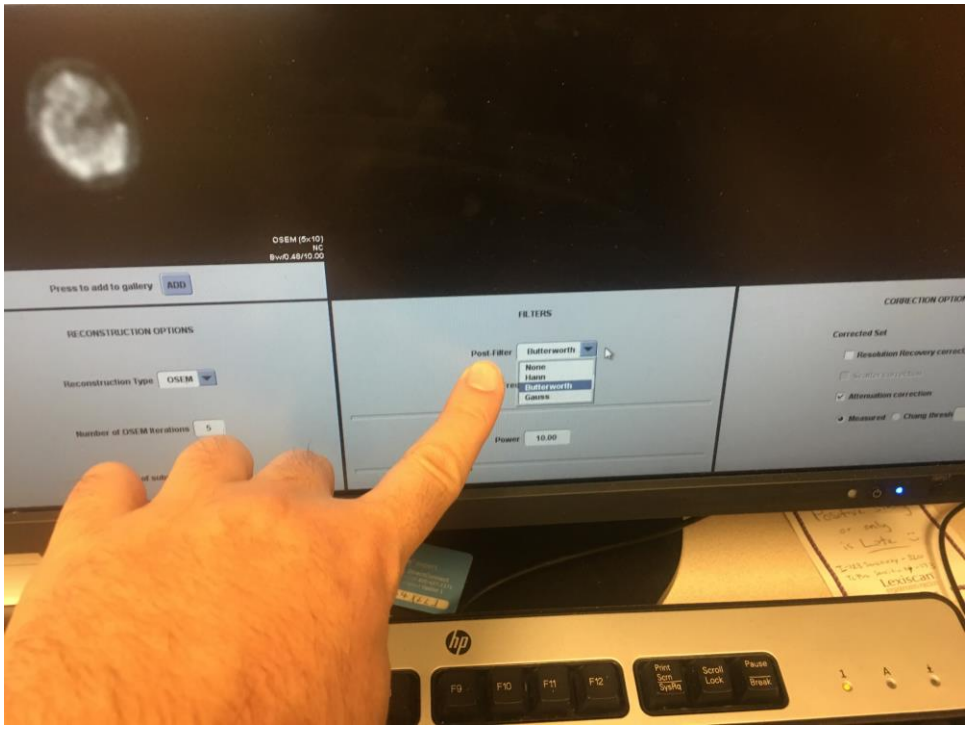


FBP with full counts

OSEM with resolution recovery with half of the counts

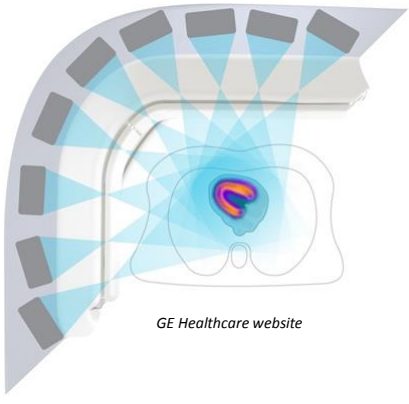
(Stansfield et al.)





Adopting recent technologies for peds?

- CZT det, Multiple pinhole collimation,…?



GE Healthcare website

- Preclinical (i.e. small animal imaging) systems,…?

ORIGINAL RESEARCH Open Access

Feasibility study of a novel general purpose CZT-based digital SPECT camera: initial clinical results

Elinor Goshen[1,2*], Leonid Beilin[3], Eli Stern[3], Tal Kenig[3], Ronen Goldkorn[2,4] and Simona Ben-Haim[1,5]

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Full list of author information is available at the end of the article

Abstract

Background: The performance of a prototype novel digital single-photon emission computed tomography (SPECT) camera with multiple pixelated CZT detectors and high sensitivity collimators (Digital SPECT; Valiance X12 prototype, Molecular Dynamics) was evaluated in various clinical settings.
Images obtained in the prototype system were compared to images from an analog camera fitted with high-resolution collimators. Clinical feasibility, image quality, and diagnostic performance of the prototype were evaluated in 36 SPECT studies in 35 patients including bone ($n = 21$), brain ($n = 5$), lung perfusion ($n = 3$), and parathyroid ($n = 3$) and one study each of sentinel node and labeled white blood cells. Images were graded on a scale of 1–4 for sharpness, contrast, overall quality, and diagnostic confidence.

Results: Digital CZT SPECT provided a statistically significant improvement in sharpness and contrast in clinical cases (mean score of 3.79 ± 0.61 vs. 3.26 ± 0.50 and 3.92 ± 0.29 vs. 3.34 ± 0.47 respectively, $p < 0.001$ for both). Overall image quality was slightly higher for the digital SPECT but not statistically significant (3.74 vs. 3.66).

Conclusion: CZT SPECT provided significantly improved image sharpness and contrast compared to the analog system in the clinical settings evaluated. Further studies will evaluate the diagnostic performance of the system in large patient cohorts in additional clinical settings.

Keywords: CZT, General purpose, SPECT, Clinical

Review of SPECT collimator selection, optimization, and fabrication for clinical and preclinical imaging

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(Received 31 March 2015; revised 7 July 2015; accepted for publication 8 July 2015; published 24 July 2015)

Outline

Chapter 1. Tales of Mercyland!
Chapter 2. Clinical challenges of peds imaging
Chapter 3. Physical challenges of peds imaging
  i. Planar imaging
  ii. SPECT
Chapter 4. Toils of an in-house physicist

Which one can we trust?

Multi-Wiper Multi-Well Wipe Counter

Captus 3000 Single-Well Wipe Counter

Wiper Well Counter

Facility: Children's Mercy Hospitals & Clinics
Location: Kansas City, Missouri
Dept: Nuclear Medicine
System Location: Hot Lab

Testing Date: 04/21/14

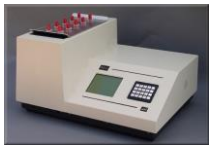
Annual Calibration
The annual calibration with the facility Co-57 NIST rod source was performed. All parameters tested were acceptable. Refer to additional comments at the bottom of this page.

Manufacturer: Laboratory Technologies, Inc.
Model & Serial #'s: Multi-Wiper/Multi-Well
Detector Model, Serial #'s: 10130106
Software Version: 3.1.0
Constancy/Chi Square Settings: Co-57 Window
Source: Facility Co-57 Rod
Half-Life: 271
Manufacturer: Cardinal
Serial No.: 1693-63-3
Activity: 0.1061
Calibration Date: 11/01/13

	Well Efficiency Co-57	Well Efficiency Tc-99m	Chi-Sq	FWHM	Results
Well 1:	72.7%	67.4%	2.3	15.42%	Pass
Well 2:	73.3%	67.4%	2.5	16.03%	Pass
Well 3:	73.3%	67.4%	2.7	16.70%	Pass
Well 4:	73.4%	67.4%	3.0	15.69%	Pass
Well 5:	73.3%	67.4%	1.2	16.03%	Pass
Well 6:	73.1%	67.4%	5.7	15.77%	Pass
Well 7:	72.7%	67.4%	5.2	18.69%	Pass
Well 8:	73.0%	67.4%	2.9	15.90%	Pass
Well 9:	73.3%	67.4%	5.1	16.40%	Pass
Well 10:	72.9%	67.4%	5.1	15.84%	Pass
Average:	73.1%	67.4%	3.6	16.25%	Pass
System Calculated Average:	73.4%	67.4%			

Tc-99m efficiency calculated from Co-57 standard results by system.

System Calibration: April 21, 2014, 10:18 a.m.



	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Well 8	Well 9	Well 10
Gain:	520	440	524	512	512	504	524	512	512	512

High Voltage (V): 809 Zero Setting: 119 Low Level Detection Setting: 10

Co-57 Efficiency

	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Well 8	Well 9	Well 10
Background:	179	185	178	194	191	186	185	182	190	176
Count 1:	108226	110017	109916	107718	111431	109690	106063	109968	108393	111385
Count 2:	108324	110380	109678	108331	111357	109586	108930	110737	108469	110516
Count 3:	108381	110172	109878	108872	111257	109640	108795	110763	108846	110514
Count 4:	108445	110316	109893	108470	111209	109860	108811	110622	108639	110329
Count 5:	108361	110271	109903	108527	111278	109680	108810	110623	108428	110274
Average:	108347	110231	109854	108384	111306	109691	108282	110363	108555	110604
Measured on :	04/21/14	04/21/14	04/21/14	04/21/14	04/21/14	04/21/14	04/21/14	04/21/14	04/21/14	04/21/14
Calculated Activity (uCi):	0.0685	0.0685	0.0685	0.0685	0.0685	0.0685	0.0685	0.0685	0.0685	0.0685
Calculated Activity (dpm):	152110.7	152110.7	152110.7	152110.7	152110.7	152110.7	152110.7	152110.7	152110.7	152110.7
Efficiency for Co-57:	71.1%	72.3%	72.1%	71.1%	73.0%	72.0%	71.1%	72.4%	71.2%	72.6%
System Calculated:	72.7%	73.3%	73.3%	73.4%	73.3%	73.1%	72.7%	73.0%	73.3%	72.9%
Timer/chamber:	1.47 minutes for all chambers for system calculated efficiency									
FWHM:	15.42%	16.03%	16.70%	15.69%	16.03%	15.77%	18.69%	15.90%	16.40%	15.84%

Chi-Square:

(60 sec counts)	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Well 8	Well 9	Well 10
Count 1:	118852	118673	119003	119549	119243	118194	119268	119173	119090	119002
Count 2:	119380	119032	119203	119763	119675	118382	118864	119472	118264	119359
Count 3:	119240	119433	119261	120027	119696	118097	119203	119386	119246	118308
Count 4:	119561	119147	119318	119211	119500	119107	119114	119286	118621	119089
Count 5:	119353	119096	119722	119669	119436	118680	118365	119942	118850	119028
Average:	119277	119076	119311	119644	119510	118452	118951	119452	118814	118957
Stddev:	264.1	224.4	283.5	299.2	186.2	405.4	392.3	295.3	399.5	389.6
c.v.:	0.22%	0.23%	0.24%	0.25%	0.16%	0.35%	0.33%	0.25%	0.33%	0.33%
chi-square:	2.3	2.5	2.7	3.0	1.2	5.7	5.2	2.9	5.1	5.1
1.064 < value < 7.779:	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass

Well Counter and Uptake Probe

Facility: Children's Mercy Hospitals & Clinics
Location: Kansas City, Missouri
Dept: Nuclear Medicine
System Location:

Testing Date: 04/21/14

All parameters tested were acceptable.
Results: PASS

Manufacturer: Capintec
Model & Serial #'s: Captus 2000
Detector Model, Serial #'s: 20173
Constancy/Chi Square Settings: wipes
Source: Facility Cs-137 Pencil
Half-Life: 10957.5
Manufacturer: Isotope Products
Serial No.: 1181-63-70
Activity: 0.500
Calibration Date: 06/01/06

	Well	Probe
System Test:	Pass	Pass
Efficiency Cs-137:	29%	
Expected:	29%	
Tl-201 efficiency:	46%	
Tc-99m efficiency:	78%	
Co-57:	78%	

Captus 2000 Well

WIPE COUNTER chi square
Counting time (sec): 60
Background: 338

Counts	Net Counts
270800	270500
269900	269600
270200	269900
269800	269500
269900	269600

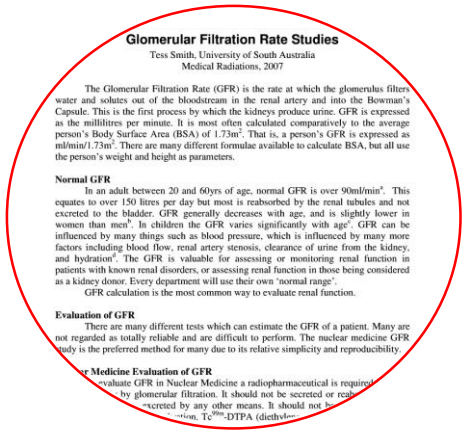
Average: 269820
Stddev: 408.7
c.v.: 0.15%
chi-square: 2.5
1.064<value<7.779: Pass
factor to get cpm: 1.0
Average CPM: 269820.0

Auto Calibration

High Voltage (v):	1000
Gain	29.67
Zero Offset:	-0.84%
FWHM:	7.8
Constancy Deviation:	-0.80%

How does one verify the numbers these machines provide us?

By reproducing them using theoretical models



Glomerular Filtration Rate Studies

Tess Smith, University of South Australia
Medical Radiations, 2007

The Glomerular Filtration Rate (GFR) is the rate at which the glomerulus filters water and solutes out of the bloodstream in the renal artery and into the Bowman's Capsule. This is the first process by which the kidneys produce urine. GFR is expressed as the millilitres per minute. It is most often calculated comparatively to the average person's Body Surface Area (BSA) of 1.73m^2. That is, a person's GFR is expressed as ml/min/1.73m^2. There are many different formulae available to calculate BSA, but all use the person's weight and height as parameters.

Normal GFR

In an adult between 20 and 60yrs of age, normal GFR is over 90ml/min[a]. This equates to over 150 litres per day but most is reabsorbed by the renal tubules and not excreted to the bladder. GFR generally decreases with age, and is slightly lower in women than men[b]. In children the GFR varies significantly with age[c]. GFR can be influenced by many things such as blood pressure, which is influenced by many more factors including blood flow, renal artery stenosis, clearance of urine from the kidney, and hydration[d]. The GFR is valuable for assessing or monitoring renal function in patients with known renal disorders, or assessing renal function in those being considered as a kidney donor. Every department will use their own 'normal range'.

GFR calculation is the most common way to evaluate renal function.

Evaluation of GFR

There are many different tests which can estimate the GFR of a patient. Many are not regarded as totally reliable and are difficult to perform. The nuclear medicine GFR study is the preferred method for many due to its relative simplicity and reproducibility.

Medicine Evaluation of GFR

evaluate GFR in Nuclear Medicine a radiopharmaceutical is required by glomerular filtration. It should not be secreted or reab- excreted by any other means. It should not b- ...tion. ^{99m}Tc-DTPA (diethyle-

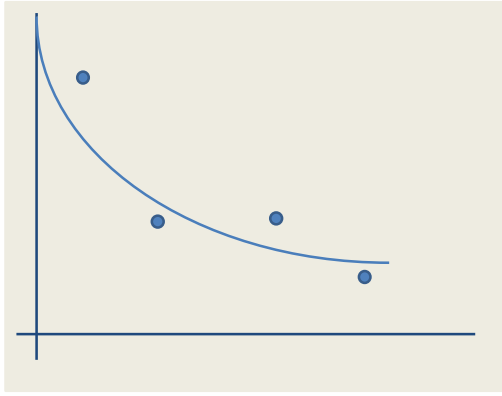
cpm µCi mL

$$GFR_{raw} = \frac{(\text{std count})(\text{patient dose})(0.693)(1000)}{(\text{counts at } t_0)(t_{\text{half-clearance}})(\text{std dose})}$$

mL/min

cpm min µCi

Reconstruct the decay curve using 4 points



10 vials in total

SWC_{theory}	SWC_{raw}
104.9345	118
	12.45108
24.95928	25
	0.163155
87.04764	99
	13.73082
88.10758	87
	1.257074
50.10131	53
	5.785661
74.77385	80
	6.98928
27.30581	28
	2.542282
51.96546	53
	1.990815
27.29043	28
	2.600069
139.4404	144
	3.269896
73.28331	71
	3.115728

MWC_{theory}	MWC_{raw}
108.24619	109.4
	1.06591
24.625336	24.6
	0.102885
88.722622	91
	2.566851
92.426811	92.8
	0.403768
50.391074	50.5
	0.216161
77.773471	76.1
	2.151724
27.671443	27.7
	0.103199
52.787587	52.8
	0.023516
27.974022	28
	0.092863
148.29971	149.7
	0.944229
76.643132	75.3
	1.752449

Question 1: Deviation from the theoretical model
Question 2: Is there consistency

Question 3: What corrections are being used?

1. *Decay correction*
2. *Body Surface Area normalization*
3. *Single exponential assumption (SEA) correction*

Body Surface Area

$GFR_{BSA} = (GFR_{raw})(1.73)/BSA$

Various calculations have been published to arrive at the BSA without direct measurement. In the following formulas, BSA is in m^2, W is weight in kg, and H is height in cm.

The most widely used is the Du Bois formula:[3][4] [5]

$$BSA = 0.007184 \times W^{0.425} \times H^{0.725}$$

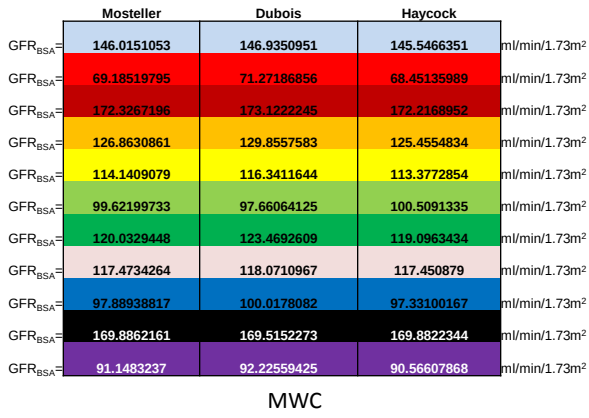
A commonly used and simple one is the Mosteller formula:[6]

$$BSA = \sqrt{\frac{W \times H}{3600}} = 0.016667 \times W^{0.5} \times H^{0.5}$$ or even simpler : $BSA = \sqrt{W \times H}/60$ or if Ht is height in m : $BSA = \sqrt{W \times Ht}/6$

Other formulas for BSA in m^2 include:

Haycock[7]	$0.024265 \times W^{0.5378} \times H^{0.3964}$
Gehan and George[8]	$0.0235 \times W^{0.51456} \times H^{0.42246}$
Boyd [9][10]	$0.0003207 \times weight(\mathrm{g})^{(0.7285 - 0.0188 \log_{10} weight(\mathrm{g}))} \times H^{0.3}$
or equivalently	$0.03330 \times W^{(0.6157 - 0.0188 \log_{10} W)} \times H^{0.3}$
Fujimoto[11]	$0.008883 \times W^{0.444} \times H^{0.663}$
Takahira[11]	$0.007241 \times W^{0.425} \times H^{0.725}$
Schlich[12]	$0.000975482 \times W^{0.46} \times H^{1.08}$ (women) $0.000579479 \times W^{0.38} \times H^{1.24}$ (men)

A weight-based formula was proposed by Costeff and recently validated for the pediatric age group that does not include a square root, making it easier to use. It is [4Wkg+7]/[90+Wkg].[13][14]



Question 4: Is it even that big of a difference anyway?

What corrections are being used

1. *Decay correction*
2. *Body Surface Area normalization*
3. ***Single exponential assumption (SEA) correction***

Assessment of Glomerular Filtration Rate Measurement with Plasma Sampling: A Technical Review*

Anthony W. Murray[1], Mark C. Barnfield[2], Michael L. Waller[1], Tania Telford[1], and A. Michael Peters[2]

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This article reviews available radionuclide-based techniques for glomerular filtration rate (GFR) measurement, focusing on clinical indications for GFR measurement, ideal GFR radiopharmaceutical tracer properties, and the 2 most common tracers in clinical use. Methods for full, 1-compartment, and single-sample renal clearance characterization are discussed. GFR normalization and the role of GFR measurement in chemotherapy dosing are also considered.

Key Words: GFR measurement; glomerular filtration rate; radiopharmaceutical tracer; GFR normalization; technical review

J Nucl Med Technol 2013; 41:67–75
DOI: 10.2967/jnmt.113.121004

Glomerular filtration rate (GFR) is used clinically as a measure of kidney function (*1*). GFR represents the plasma volume presented to the nephrons per unit time during urine formation. It is usually measured in milliliters per minute.

Radionuclide-based techniques allow for the rapid and reliable measurement of GFR from plasma samples taken after intravenous administration of a bolus of radionuclide-labeled tracer (*2*). The tracer diffuses across the capillary endothelium and between intravascular and extravascular spaces and mixes throughout the extracellular fluid volume (*3*). GFR can be measured through the quantification of ... and standard-volume sample activity using a qual- ... and γ-counter. These techniques hold the central ... the tracer is cleared solely by glomerular ... Medicine Society (BNMS) and In- ... of Radionuclides in Neph- ... elines for GFR ...

measurement using radionuclide techniques in adults and children (*3,4*). The European Association of Nuclear Medicine (EANM) has recommended pediatric guidelines (*5*).

Although this article focuses on isotopic measurement of GFR, there are a range of other methods for GFR determination, details of which can be found elsewhere (*6*). The method chosen is a clinical decision based on accuracy, convenience for the patient, and the most appropriate measurement of renal function required for the clinical question being asked.

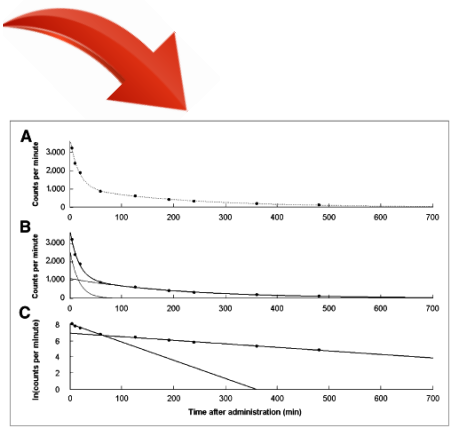
PRACTICALITIES OF GFR MEASUREMENT

There are 4 broad stages in the GFR measurement process using radiopharmaceutical tracers: tracer preparation, administration, sampling, and counting (Fig. 1).

Tracer Preparation

First, a stock solution of the tracer is prepared or diluted according to the manufacturer's recommendations. The tracer is subjected to radiopharmaceutical quality control. The patient dose and the standard dose are drawn into syringes from this solution. The administered doses can be measured in terms of volume, activity, or weight, as all are from the stock solution with a common activity concentration. The quantity of tracer in the doses, the time of measurement, the weight of the patient, and the standard doses are recorded before administration. From this point onward, this article will refer only to weight for dose measurement. Several investigations can be performed using the same standard ... patient doses are drawn from the same stock ... weight of the tracer is recorded for residual ... purposes. The dose for administration ... tient weight or body surface area ... tices in nuclear medicine ...

Administ...



- "Plasma clearance has widely been pragmatically considered to be bi-exponential,"
  - "…the early phase or exponential is considered **to represent diffusion** of the tracer between intra- and extravascular fluid volumes"
  - "….the late phase **reflects solely renal clearance**".

- "…One-compartment characterization is the clinical workhorse for GFR measurement."
- "Only the late exponential is characterized"
- **"GFR is systematically overestimated because of the absent data from the early compartment."**

- "published corrections can be used to compensate for the missing early-compartment data".

This overestimation can be corrected using various published corrections. The quadratic Bröchner-Mortensen and linear Chantler corrections (2 separate Chantler corrections exist) have been recommended (*4*). The Bröchner-Mortensen has been preferred (*3*). The corrections are as follows:

Bröchner-Mortensen Correction. In adults (*16*),

$$GFR_{BM} = (0.9908 \times GFR_{NON}) - (0.001218 \times (GFR_{NON})^2), \quad \text{Eq. 7}$$

and in children (*17*),

$$GFR_{BM} = (1.01 \times GFR_{NON}) - (0.0017 \times (GFR_{NON})^2), \quad \text{Eq. 8}$$

where GFR_{BM} is Bröchner-Mortensen–corrected GFR and GFR_{NON} is noncorrected GFR (BSA-normalized).

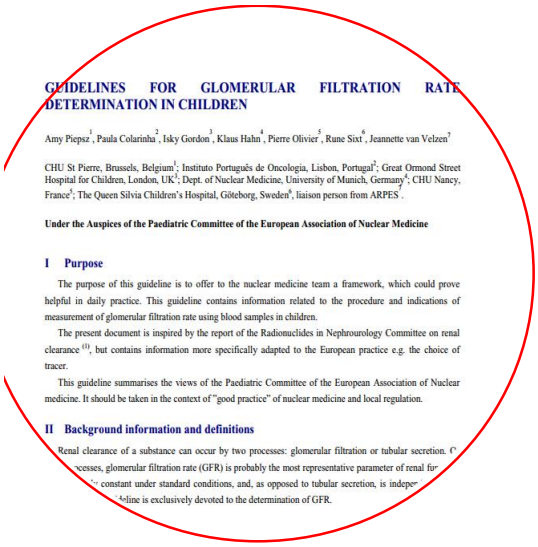
Chantler Correction. In adults and children (*18*),

$$GFR_{CH} = 0.87 \times GFR_{NON}, \quad \text{Eq. 9}$$

	Mosteller	Dubois	Haycock	
GFR_{BSA}=	146.0151053	146.9350951	145.5466351	ml/min/1.73m²
GFR_{BSA}=	69.18519795	71.27186856	68.45135989	ml/min/1.73m²
GFR_{BSA}=	172.3267196	173.1222245	172.2168952	ml/min/1.73m²
GFR_{BSA}=	126.8630861	129.8557583	125.4554834	ml/min/1.73m²
GFR_{BSA}=	114.1409079	116.3411644	113.3772854	ml/min/1.73m²
GFR_{BSA}=	99.62199733	97.66064125	100.5091335	ml/min/1.73m²
GFR_{BSA}=	120.0329448	123.4692609	119.0963434	ml/min/1.73m²
GFR_{BSA}=	117.4734264	118.0710967	117.450879	ml/min/1.73m²
GFR_{BSA}=	97.88938817	100.0178082	97.33100167	ml/min/1.73m²
GFR_{BSA}=	169.8862161	169.5152273	169.8822344	ml/min/1.73m²
GFR_{BSA}=	91.1483237	92.22559425	90.56607868	ml/min/1.73m²

GFR_{BM}=	118.7035	ml/min/1.73m²
GFR_{BM}=	61.73984	ml/min/1.73m²
GFR_{BM}=	123.5659	ml/min/1.73m²
GFR_{BM}=	100.7715	ml/min/1.73m²
GFR_{BM}=	93.13447	ml/min/1.73m²
GFR_{BM}=	86.61738	ml/min/1.73m²
GFR_{BM}=	96.73983	ml/min/1.73m²
GFR_{BM}=	95.18815	ml/min/1.73m²
GFR_{BM}=	82.57832	ml/min/1.73m²
GFR_{BM}=	133.1702	ml/min/1.73m²
GFR_{BM}=	80.19059	ml/min/1.73m²

Question 5: Will these corrections make a difference anyway?



GUIDELINES FOR GLOMERULAR FILTRATION RATE DETERMINATION IN CHILDREN

Amy Piepsz [1], Paula Colarinha [2], Isky Gordon [3], Klaus Hahn [4], Pierre Olivier [5], Rune Sixt [6], Jeannette van Velzen [7]

CHU St Pierre, Brussels, Belgium[1]; Instituto Português de Oncologia, Lisbon, Portugal[2]; Great Ormond Street Hospital for Children, London, UK[3]; Dept. of Nuclear Medicine, University of Munich, Germany[4]; CHU Nancy, France[5]; The Queen Silvia Children's Hospital, Göteborg, Sweden[6], liaison person from ARPES[7].

Under the Auspices of the Paediatric Committee of the European Association of Nuclear Medicine

I Purpose

The purpose of this guideline is to offer to the nuclear medicine team a framework, which could prove helpful in daily practice. This guideline contains information related to the procedure and indications of measurement of glomerular filtration rate using blood samples in children.

The present document is inspired by the report of the Radionuclides in Nephrourology Committee on renal clearance [1], but contains information more specifically adapted to the European practice e.g. the choice of tracer.

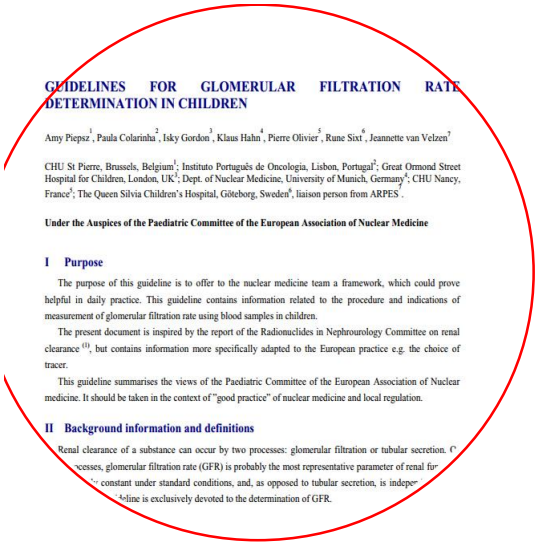
This guideline summarises the views of the Paediatric Committee of the European Association of Nuclear medicine. It should be taken in the context of "good practice" of nuclear medicine and local regulation.

II Background information and definitions

Renal clearance of a substance can occur by two processes: glomerular filtration or tubular secretion. C
cesses, glomerular filtration rate (GFR) is probably the most representative parameter of renal fu
constant under standard conditions, and, as opposed to tubular secretion, is indepe
deline is exclusively devoted to the determination of GFR.

Question 6: Why are we even using 4 time points?

"Some investigators consider that a better determination of the slope can be obtained by using more blood samples within the 2-4-hr time interval."



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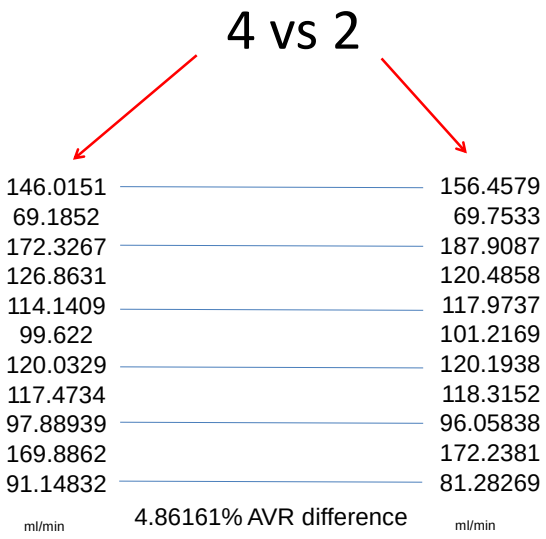
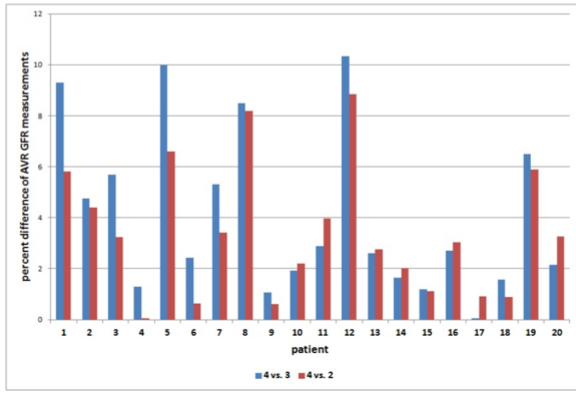
"However, it has been shown that no significant benefit is gained by adding a third intermediate blood sample."



Conclusions: There is a statistical difference between GFR values measured using 4 blood samples compared to 3 blood samples, while there is no statistical difference between measured GFR values using the same 4 vs. only 2 blood samples, provided the timing interval between the two points is prolonged. There is hence no significant loss of accuracy in going from 4 blood samples to two for determining renal clearance, while no significant benefit is gained by using three blood samples instead of four.

Figure-1: Comparison of absolute difference of GFR values obtained using 4, 3 and 2 blood samples



60min, 90min, 120min, 180min

- Using 4 blood draws

120min, 240min

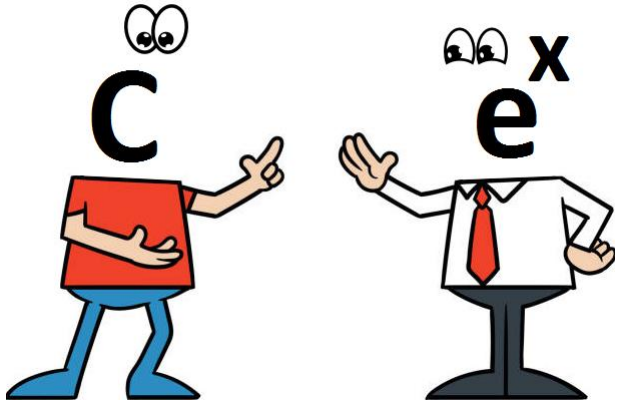
- Using 2 blood draws

Clinical outcome?

Benefit 1 of a 2 point GFR: Happier patients

Clinical outcome?

Benefit 2 of a 2 point GFR: Higher throughput



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