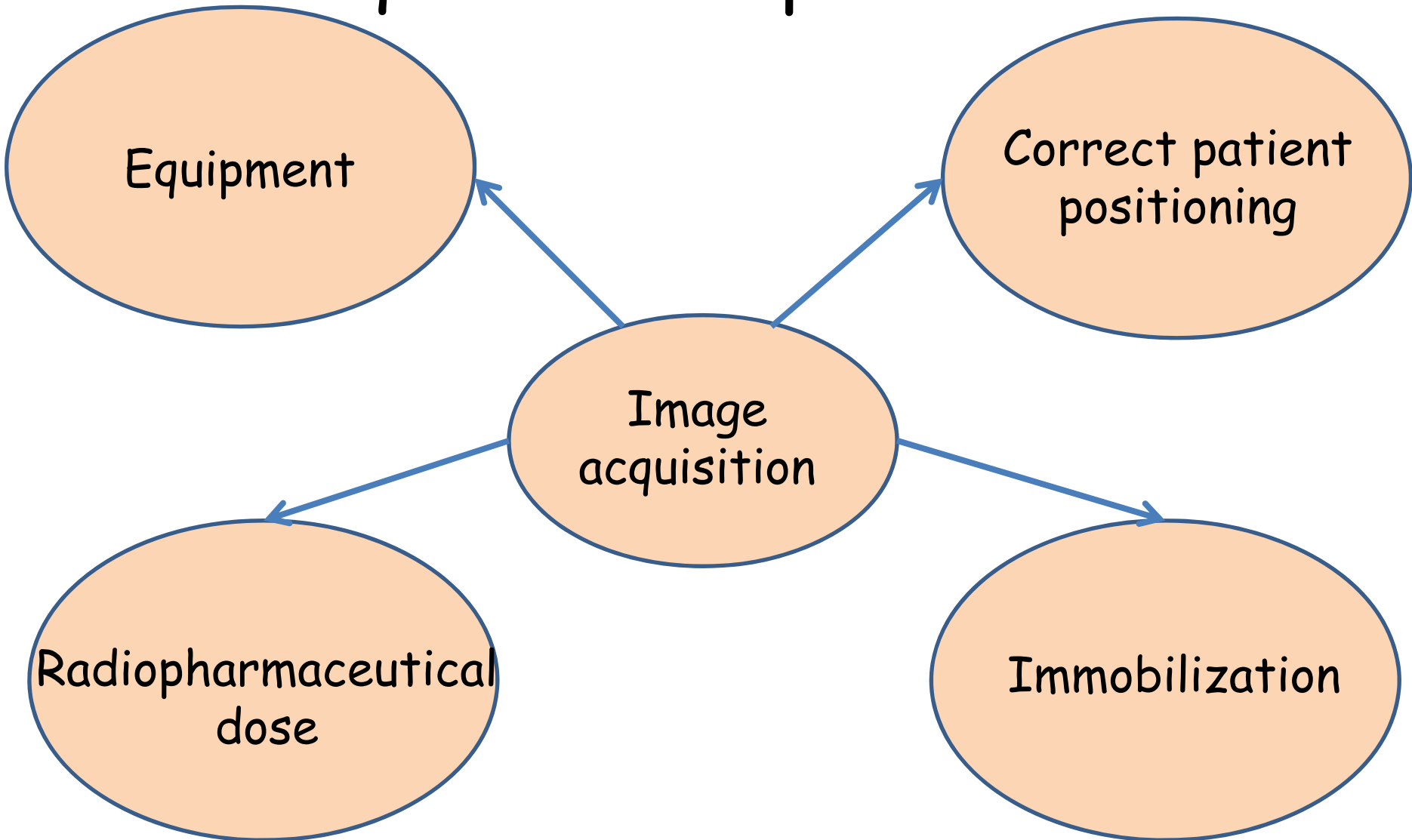


Dose Selection For Pediatric Nuclear Medicine Procedures

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Important factors of image acquisition in pediatrics



Pediatric Imaging Procedures

- **Tumor Imaging**
 - Gallium
 - Thallium and Sestamibi
 - MIBG scintigraphy
 - PET in pediatric tumor evaluation
- **Bone Scintigraphy**
- **Gastro esophageal Reflux Imaging**
- **Hepatobiliary Imaging**
- **Vesicoureteric Reflux Imaging**
- **Renal Imaging**
- **Brain Perfusion Imaging**
- **Thyroid Scintigraphy**
- **Lung Perfusion Imaging**
- **Meckel scintigraphy**

Estimation of effective dose to pediatrics?

- **The bio-distribution and kinetics of radio-pharmaceuticals are different from adults, particularly in neonates**
- **The administered radioactive dose is distributed over smaller volumes in infants, giving rise to a higher absorbed dose.**

Factors affecting pediatric effective dose

- ❑ Pediatric organ size, density, differences in biokinetic due to age related differences in uptake
- ❑ Excretion and frequency of voiding
- ❑ Children have immature renal and hepatic systems so manifest variances in drug absorption, distribution, metabolism and excretion
- ❑ Alteration in biological localization of tracer elements especially in young children

Dose Selection?

- **The diagnostic information produced must not be compromised by reduction in activity**

Image Quality
“Count density”

Statistical
Reliability

Optimisation

It is important that the activity for each exposure is optimised such that appropriate diagnostic information obtained with the lowest practicable dose to the patient

The health risk for the patient is incomparably higher by false diagnosis or insufficient therapy than by an exposure higher than usual in similar procedures.

Optimisation



Radionuclide

**Method of
processing**

**Camera
Collimator
geometry**

Radiation Long Term Risk

- **Children have high potential risk to develop cancer and leukemia because of the higher tissue radio-sensitivity of infants and children.**
- **Solid tumors (75% of excess cancer mortality), radiation-induced malignancy was about 1.0–1.8 times higher in a 10-y-old child than in a young adult.**
- **Leukemia (25% of excess cancer mortality), radiation-induced malignancy was about twice as high for a 10-y-old child as for a young adult.**

The administered activity can't easily be scaled down in proportion to body weight:

- **Children aged under 10 tends to result in a low count density e.g. due to relatively larger organ mass or a shorter retention time.**

Dose Calculation for Pediatrics

- **The standard adult dose is based on the “reference man”**
- **The reference man has a weight of 70 Kg , and a BSA of 1.78 m²**
- **The reference man is used to determine standard radiopharmaceutical dose ranges and the predicted radiation dose to organs and the total body “effective dose”**

Pediatric dose calculations using Clark's formula

- Clark's formula allows calculation of pediatric doses by comparing the child's weight to an average adult weight of 150 lb.

$$\text{Child's dose} = \frac{(\text{child's weight in lb})(\text{adult dose})}{150 \text{ lb}}$$

Clark's formula may NOT provide an accurate determination for doses for children with very low body weights or with excessive weight.

Pediatric dose calculations using body surface area

- **Organ mass, metabolic rates and blood fluid volumes are more closely related to body surface area (BSA) than to body weight**
- **BSA is more accurate method for calculation of pediatric dose**

- **The BSA in m²=**

$$\frac{(body\ weight\ in\ kg)^{0.7}}{11} \quad (1)$$

- **Fraction of adult dose=**

$$\frac{child's\ BSA\ in\ m^2}{1.78\ m^2} \quad (2)$$

- **Fraction of adult dose=**

$$\frac{(body\ weight\ in\ kg)^{0.7}}{(11)(1.78\ m^2)} \quad (3)$$

Body Surface Area Table

Weight (Kg)	BSA (m ²)	Fraction of adult dose	Weight (Kg)	BSA (m ²)	Fraction of adult dose
2	0.15	0.08	14	0.58	0.32
3	0.20	0.11	15	0.61	0.34
4	0.24	0.13	20	0.74	0.42
5	0.28	0.16	25	0.87	0.49
6	0.32	0.18	30	0.98	0.55
7	0.35	0.20	35	1.10	0.62
8	0.39	0.22	40	1.20	0.68
9	0.42	0.24	45	1.31	0.73
10	0.46	0.26	50	1.41	0.79
11	0.49	0.27	55	1.50	0.84
12	0.52	0.29	60	1.60	0.90
13	0.55	0.31	65	1.69	0.95

A adapted from O'Connor, M.(Ed). (1996). The Mayo Clinic manual of nuclear medicine. NY: Churchil Livingstone Table A-2, p.569.

Pediatric dose calculations using body surface area

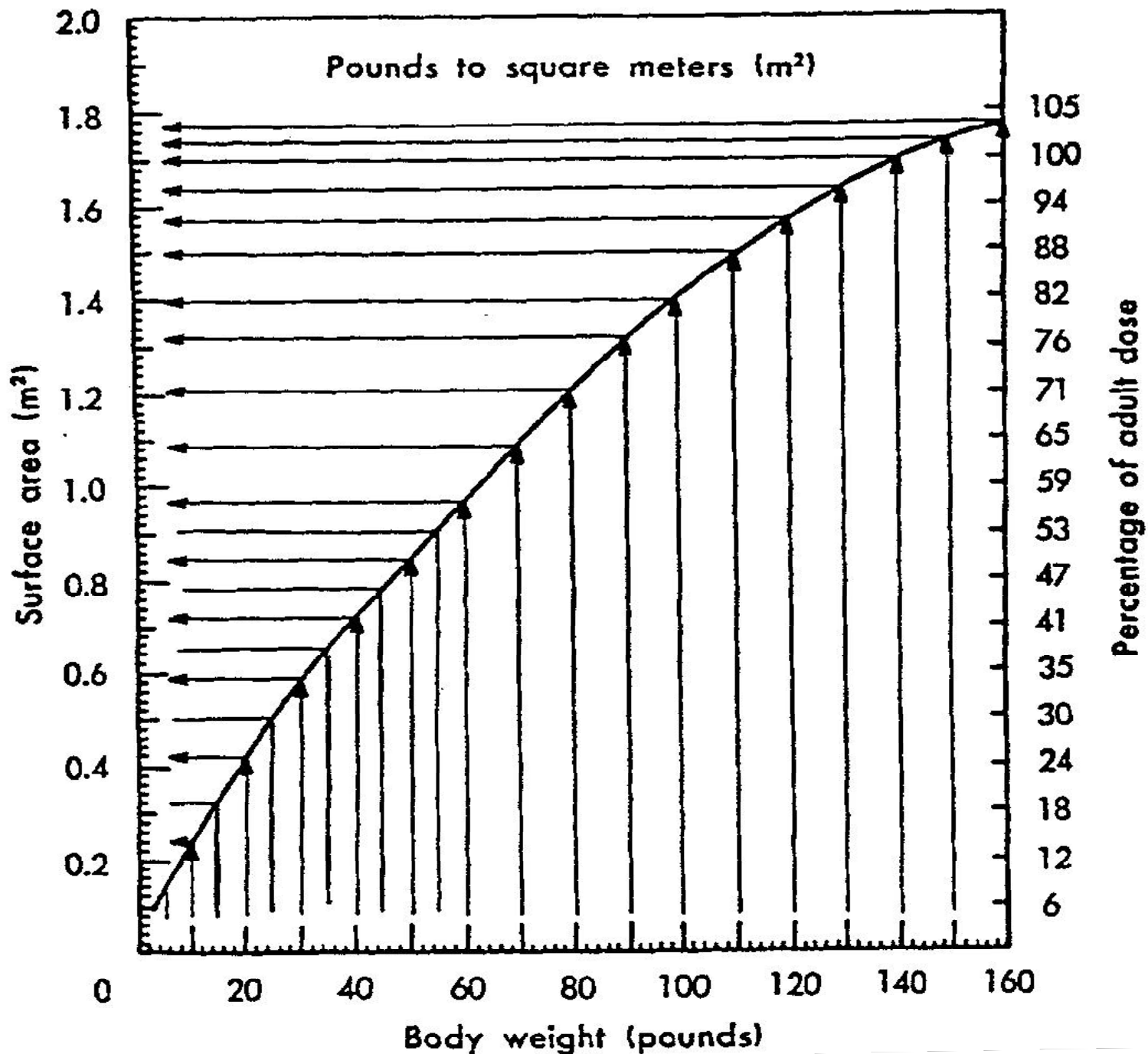
How to calculate pediatric doses using the body surface area (BSA):

1. Calculate the fraction of adult dose (Eq. 3)
2. Calculate the child's dose:

$$\text{Pediatric dose} = (\text{adult dose}) \times (\text{fraction of adult dose})$$

Pediatric dose calculations using Talbot's Nomogram

- **A nomogram represents the relationship between variables (weight or BSA and the fraction of adult dose)**
- **Talbot's nomogram was calculated using body surface area which then correlated with body weight**



(Talbot, N. & Richie, R. (1959). The advantages of surface area of the body as a basis for calculating pediatric dosages. *Pediatrics*, 24, 495-498)

2 Yrs old

Weight= 13.6 Kg

body surface area=0.53 m²

Adult

70 Kg man, 56 Kg woman

1.8 m² man, 1.6 m² woman

Young's Rule	
$\frac{\text{Child's age (y)}}{\text{Child's age (y)} + 7} = \frac{2}{2 + 7} = \frac{2}{9} = 22\%$	22% of 10 mCi = 2.2 mCi
Webster Rule	
$\frac{\text{Child's age (y)} + 1}{\text{Child's age (y)} + 7} = \frac{2 + 1}{2 + 7} = \frac{3}{9} = 33\%$	33% of 10 mCi = 3.3 mCi
Clark's Rule	
$\frac{\text{Child's weight (Kg)}}{\text{Adult's weight (Kg)}} = \frac{13.6}{70} = 19\%$	19% of 10 mCi = 1.9 mCi
Body surface area	
$\frac{\text{Child's body surface area (m}^2\text{)}}{\text{Adult's body surface area (m}^2\text{)}} = \frac{0.53}{1.8} = 29\%$	29% of 10 mCi = 2.9 mCi

Minimum and maximum pediatric dose standards

Principles:

- In order to obtain a valid scan, the photon flux produced in the organ or area of interest must be sufficiently high to produce a diagnostic study.
- Although we want to minimize the radiation dose, we cannot compromise the quality of the study.

Minimum and maximum pediatric doses standards

- For newborns & infants, the calculated radio-pharmaceutical dose may provide too low photon flux
- Minimum & maximum doses have been determined for most studies
 - 1) Determine the pediatric dose using one of the pediatric dose calculation methods
 - 2) Compare the calculated dose to the minimum and maximum dose list
 - 3) If the calculated dose is $<$ the minimum, the minimum must be used. If the calculated is $>$ the maximum dose, the maximum dose must be used

What is the maximum administered dose?

- Many adolescent patients weigh more than 70 kg and a few exceed 100 kg.

Maximum administered activity ($Wt > 70\text{Kg}$) =

- approximately 70 times the recommended weight-based (mCi/Kg) administered activity
- Should not exceed the product of child weight and weight-based dose

The Pediatric Administered Dose Regimens

- **The European Association of Nuclear Medicine's Task Group on Paediatrics (EANM90)**
- **The North American Consensus Guidelines**
- **EANM Pediatric Dose Card**

Scaling of adult administered activity for children or young persons by body weight provided by the European Association of Nuclear Medicine's Task Group on Paediatrics (EANM90)

Weight (Kg)	Fraction of adult administered activity	Weight (Kg)	Fraction of adult administered activity	Weight (Kg)	Fraction of adult administered activity
3	0.10	22	0.50	42	0.78
4	0.14	24	0.53	44	0.80
6	0.19	26	0.56	46	0.82
8	0.23	28	0.58	48	0.85
10	0.27	30	0.62	50	0.88
12	0.32	32	0.65	52	0.90
14	0.36	34	0.68	54	0.92
16	0.40	36	0.71	56	0.96
18	0.44	38	0.73	58	0.98
20	0.46	40	0.76	60	0.99

Recommended minimum administered activity for children by Pediatric Task Group of EANM

Radiopharmaceutical	Investigation	Minimum Activity (MBq)	Minimum Activity (mCi)
⁶⁷ Ga	Tumour imaging	10	0.27
⁶⁷ Ga	Infection/inflammation imaging	10	0.27
^{99m} Tc DTPA	Renal imaging	20	0.54
^{99m} Tc DMSA	Renal imaging	15	0.41
^{99m} Tc MAG3	Renal imaging	15	0.41
^{99m} Tc-pertechnetate	Cystography	20	0.54
^{99m} Tc-pertechnetate	Ectopic gastric mucosa (Meckel's)	20	0.54
^{99m} Tc-pertechnetate	Thyroid imaging	10	0.27
^{99m} Tc-pertechnetate	Cardiac first pass imaging	80	2.16
^{99m} Tc-phosphonate	Bone imaging	40	1.08
^{99m} Tc-colloid	Liver/spleen imaging	15	0.41
^{99m} Tc-colloid	Bone marrow imaging	20	0.54
^{99m} Tc denatured RBCs	Spleen imaging	20	0.54

Radiopharmaceutical	Investigation	Minimum Activity (MBq)	Minimum Activity (mCi)
99mTc RBCs	Cardiac blood pool imaging	80	2.16
99mTc human albumin	Cardiac blood pool imaging	80	2.16
99mTc MAA	Lung perfusion imaging	10	0.27
99mTc-colloid	Gastric reflux imaging	10	0.27
99mTc-exametazine	Cerebral blood flow imaging	100	2.70
99mTc-exametazine-WBCs	Infection/inflammation imaging	40	1.08
99mTc-iminodiacetate	Biliary system imaging	20	0.54
123I-iodide	Thyroid imaging	3	0.08
123I MIBG	Neuroectodermal tumour imaging	70	1.90
131I MIBG	Neuroectodermal tumour imaging	35	0.95

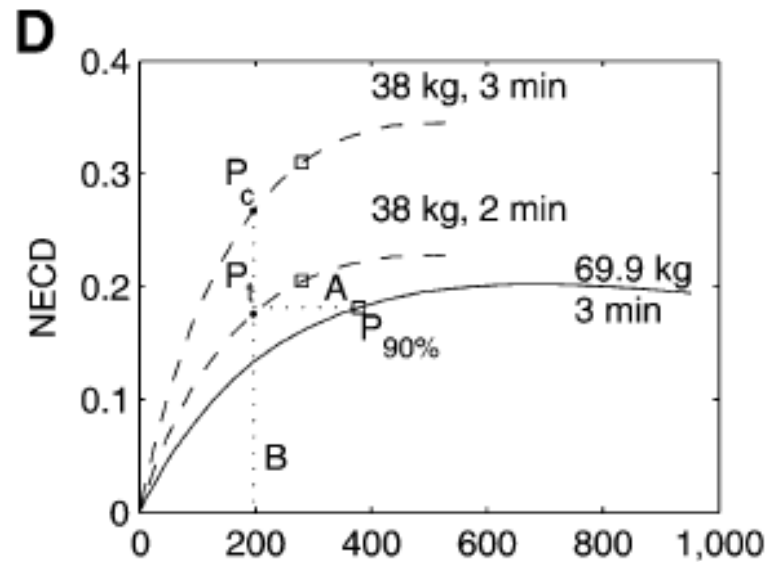
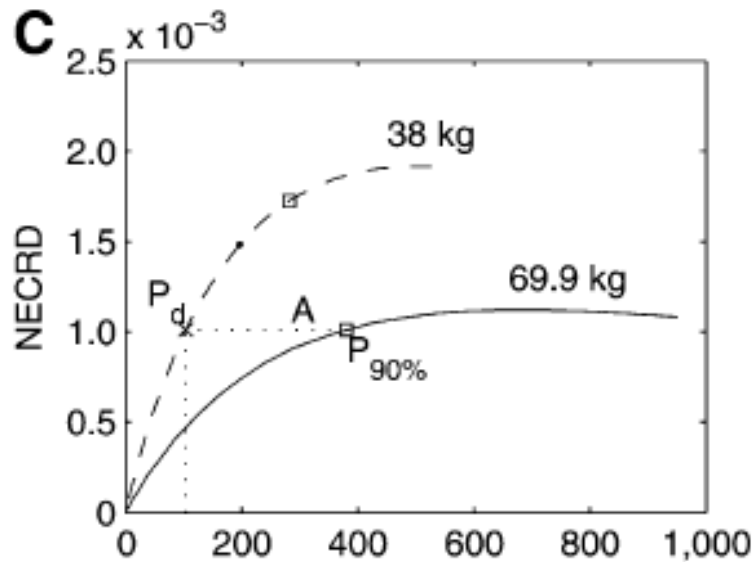
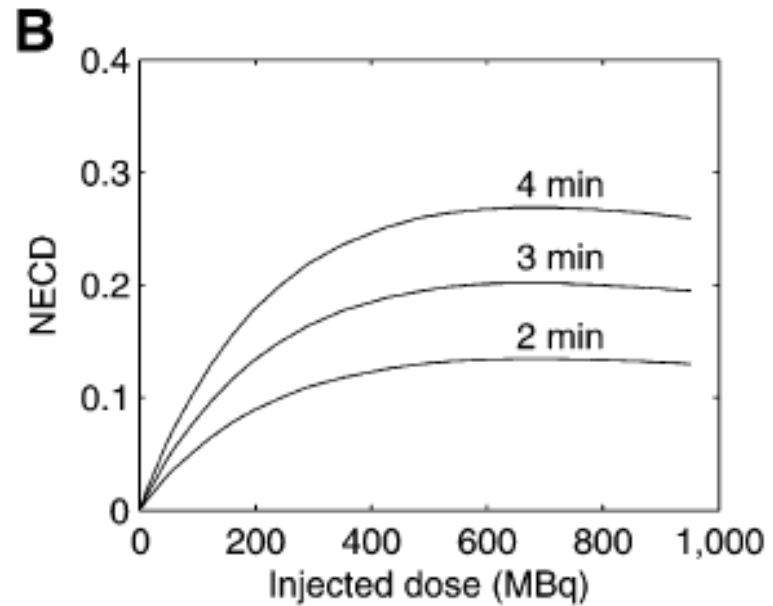
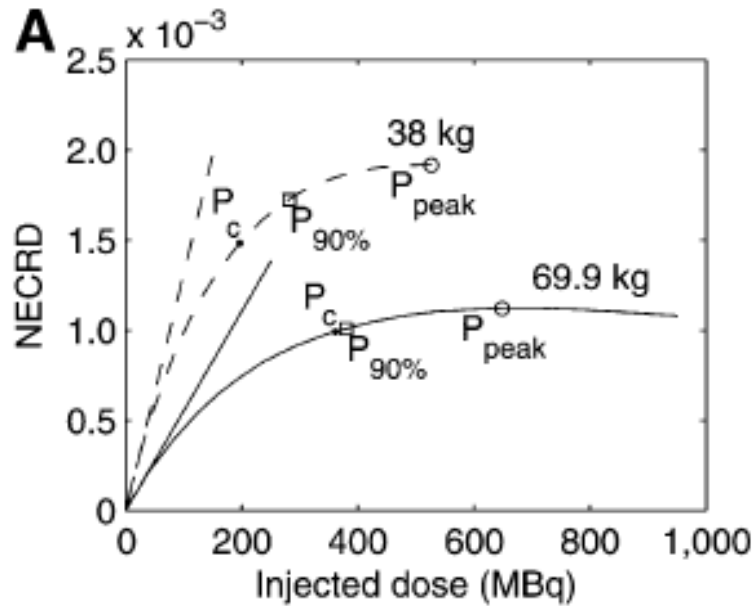
The North American Consensus Guidelines

- **Oral activity will depend on age of the child, volume to be fed to child, and time per frame used for imaging.**
- **Using weight based will result in lower effective dose than the threshold for radiation induced carcinogenesis.**
- **Anthromorphic phantoms used for estimation of DRL using newborn, 1, 5, 10, 15, adult woman, adult man weighing 3, 4, 8.9, 19, 32, 55, 58, 70 respectively**

North American Consensus Guidelines for Administered Radiopharmaceutical Activities in children & adolescents

Radiopharmaceutical	Recommended activity (based on weight only)	Minimum administered activity	Maximum administered activity
123I-MIBG	5.2 MBq/Kg (0.14 mCi/Kg)	37 MBq (1 mCi)	370 MBq (10.0 mCi)
99mTc-MDP	9.3 MBq/Kg (0.25 mCi/Kg)	37 MBq (1.0 mCi)	
18F-FDG	Body: 3.7-5.2 MBq/Kg (0.10-0.14 mCi/Kg) Brain: 3.7 MBq/Kg (0.10 mCi/Kg)	37 MBq (1.0 mCi)	
99mTc-DMSA	1.85 MBq/Kg (0.05 mCi/Kg)	18.5 MBq (0.5 mCi)	
99mTc-MAG3	5.55 MBq/Kg (0.15 mCi/Kg)	37 MBq (1 mCi)	
99mTc-IDA	1.85 MBq/Kg (0.05 mCi/Kg)	18.5 MBq (0.5 mCi)	37 MBq 1 mCi
99mTc-MAA	1.11 MBq/Kg (0.03 mCi/Kg)	14.8 MBq (0.4 mCi)	
99mTcO4 (Meckel Diverticulaum imaging)	1.85 MBq/Kg (0.05 mCi/Kg)	0.25 MBq (0.25 mCi)	
99mTc (cystography)	No weight based dose		Not more than 37 MBq (1.0 mCi)
99mTc sulfur colloid for oral GER & gastric emptying	No weight based dose	9.25 MBq (0.25 mCi)	37 MBq (1.0 mCi)

Noise Equivalent Count Rate Density (NECRD)



The new EANM paediatric dosage card

- **The activities to be administered result in weight independent effective doses and count rate to the children.**
- **Minimum activities guarantees a minimum standard of image quality throughout Europe and avoids a variety of administered activities in children of the same weight in different countries**

The new EANM paediatric dosage card

- The dosage card calculates the administered activity by multiplying a baseline activity by different multiples for the three clusters A, B and C.
- ***Class A*** :renal tracers, ***B*** :other tracers, ***C*** : iodinated tracers for thyroid imaging

$$A (MBq)_{Administered} = \text{Baseline Activity} \times \text{Multiple}$$

Baseline Activity and Multiple are weight- and radiopharmaceutical-dependent factors
Baseline activity equals the activity to be administered to a child weighing 3 kg

Multiples of the 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

Radiopharmaceutical	Class	Baseline Activity (MBq) / mCi	Minimum recommended activity (MBq) / mCi
123I (Thyroid)	C	0.6 / 0.016	3 / 0.08
123I Amphetamine (Brain)	B	13 / 0.35	18 / 0.49
123I Hippuran	A	12.8 / 0.35	10 / 0.27
123I MIBG	B	28.0 / 0.76	80 / 2.16
131I MIBG	B	5.6 / 0.15	35 / 0.95
18F FDG (2D)	B	25.9 / 0.70	70 / 1.89
18F FDG (3D), recom in children	B	14.0 / 0.38	70 / 1.89
67Ga citrate	B	5.6 / 0.15	10 / 0.27
99mTc colloid (gastric reflux)	B	2.8 / 0.08	10 / 0.27
99mTc colloid (liver/spleen)	B	5.6 / 0.15	15 / 0.41
99mTc colloid (marrow)	B	21.0 / 0.57	20 / 0.54
99mTc DMSA	A	17.0 / 0.46	15 / 0.41
99mTc DTPA	A	34.0 / 0.92	20 / 0.54
99mTc ECD (brain perfusion)	B	32.0 / 0.86	110 / 2.97
99mTc HMPAO (brain)	B	51.8 / 1.40	100 / 2.97
99mTc Technegas (lung ventilation)	B	70.0 / 1.89	100 / 2.97
99mTc denatured RBC	B	2.8 / 0.08	20 / 0.54

Radiopharmaceutical	Class	Baseline Activity (MBq) / mCi	Minimum recommended activity (MBq) / mCi
99mTc HMPAO (WBC)	B	35.0 / 0.95	40 / 1.08
99mTc IDA (Biliary)	B	10.5 / 0.28	20 / 0.54
99mTc MAA	B	5.6 / 0.15	10 / 0.27
99mTc MAG3	A	11.9 / 0.32	15 / 0.41
99mTc MDP	B	35.0 / 0.95	40 / 1.08
99mTcO4 (cystography)	B	1.4 / 0.04	20 / 0.54
99mTcO4 (Meckels diverticulum)	B	10.5 / 0.28	20 / 0.54
99mTcO4 (cardiac first pass)	B	35.0 / 0.95	80 / 2.16
99mTcO4 (thyroid)	B	5.6 / 0.15	10 / 0.27
99mTc RBC (blood pool)	B	56.0 / 1.51	80 / 2.16
99mTc sestamibi (tumor)	B	63.0 / 1.70	80 / 2.16
99mTc MIBI/Tetrofosmin 2 day protocol (min)	B	42.0 / 1.14	80 / 2.16
99mTc MIBI/Tetrofosmin 2 day protocol (max)	B	63.0 / 1.70	80 / 2.16
99mTc MIBI/Tetrofosmin 1 day protocol rest, (min)	B	28.0 / 0.76	80 / 2.16
99mTc MIBI/Tetrofosmin 1 day protocol stress, (min)	B	84.0 / 2.27	80 / 2.16

The North American Consensus Guidelines vs. EANM Paediatric Dose Card

- The administered activities in the Consensus recommendations are slightly lower for infants and small children e.g. DMSA and ^{18}F -FDG
- In the NACG, the determination of the administered activity for pediatric patient is based on body weight, except for radionuclide cystogram, gastric-emptying and GER studies

Administered Activity for Each Dose Formula According to Patient Age Compared with a Dosage Computer on a Straight Weight Basis:

Age (y)	BSA	Webster	EANM Paediatric Dose card (2007 version (13))
1	194 %	200 %	136 %
5	172 %	300 %	121 %
10	133 %	206 %	113 %
15	116 %	140 %	107 %

How to optimize and establish dose reference levels (DRLs)

- Define the diagnostic criteria (static or dynamic)
- Agree on what acquisition time (and range) is acceptable.
- For each dose level, the registration should be technically optimized can be based on imaging of patients as well as of phantoms
- Optimization should be carried out for camera geometries, collimator and methods of filtering
- After simulation of number of dosage level and evaluation using ROC analysis, it is possible to decide which activity is needed for certain diagnostic

- **Review all dose statistics around the country.**
- **As an initial value, a percentile point on the observed distribution of activities administered is chosen as a preliminary reference level.**
- **Anthromorphic phantoms used for estimation of DRL using newborn, 1, 5, 10, 15, adult woman, adult man weighing 3, 4, 8.9, 19, 32, 55, 58, 70 respectively.**
- **Should establish dose reduction workgroup which include physicians, technologists and physicist also people from national health authority.**

A Preliminary survey of pediatric dose administration policy in Kuwait

- We conducted a review of pediatric nuclear medicine services within Kuwait, with a view to establishing pediatric DRLs for common nuclear medicine examinations**
- 9 hospitals perform nuclear medicine imaging on children.**

A Preliminary survey of pediatric dose administration policy in Kuwait

- 1) What are the different studies performed for pediatrics in NM department?**
- 2) What are the age range for children in your hospital?**
- 3) What is the method by which pediatric administered activities is calculated? do you use more than one?**
- 4) What is the minimum dose injected for each procedure and radiopharmaceutical?**
- 5) What adult reference activities are used?**

A Preliminary survey of pediatric dose administration policy in Kuwait

6) How do you calculate the maximum dose to a child if he weighs 70 Kg or more?

7) Do you usually add few mCi on the calculated dose because some will be remaining in the I V line?

8) Do you change the calculated dose in regards to the type of imaging technique e.g. DMSA static or Tomo, Bone planar with pinhole?

Pediatric Procedures

- Bone scintigraphy
- Renal imaging
- Thyroid scintigraphy
- Hepatobiliary imaging
- Meckel's diverticulum
- Testicular scan
- GOR
- Cystography
- Brain perfusion
- Liver/spleen scan

Preliminary Results of Pediatric Dose Survey

- The minimum activity for different procedures has not been identified in some of the institutions surveyed.
- If the child weight exceeds 70 Kg, he is usually treated as an adult in regards to dose administration
- As a result the maximum administered activity in children older than 1 y varied on average by a factor of 2.

Preliminary Results of Pediatric Dose Survey

- **Pediatric age range was variable between hospitals.**
- **Hospitals commonly use Clark's formula**
- **One hospital uses the EANM factors (Pediatric Task Group) for all examinations.**
- **The adult reference dose is not standard.**

doses given to children were in a very wide range

Preliminary results from the survey, showed that there were no real standards for administering radiopharmaceuticals to pediatric patients in Kuwait

Conclusions

- These DRLs may serve to aid in the standardization of practice in pediatric nuclear medicine imaging in Kuwait
- Individualize doses and technique based on the specific clinical task
- Involve your physicist to review your adult and pediatric nuclear medicine protocols
- Work collaboratively with technologists to implement changes
- Familiarize yourself with recommended administered activities