Pediatric PET-CT
Tips & Technique (Image gently)

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LET
THEM
BE
little

Topics covered

- Introduction Pediatric malignancies
- Changing trends & Radiation burden
- Radiation exposure from PET/CT
- Image gently
  - PET & CT modification
  - PET/CT protocols
- Tips

Pediatric malignancies

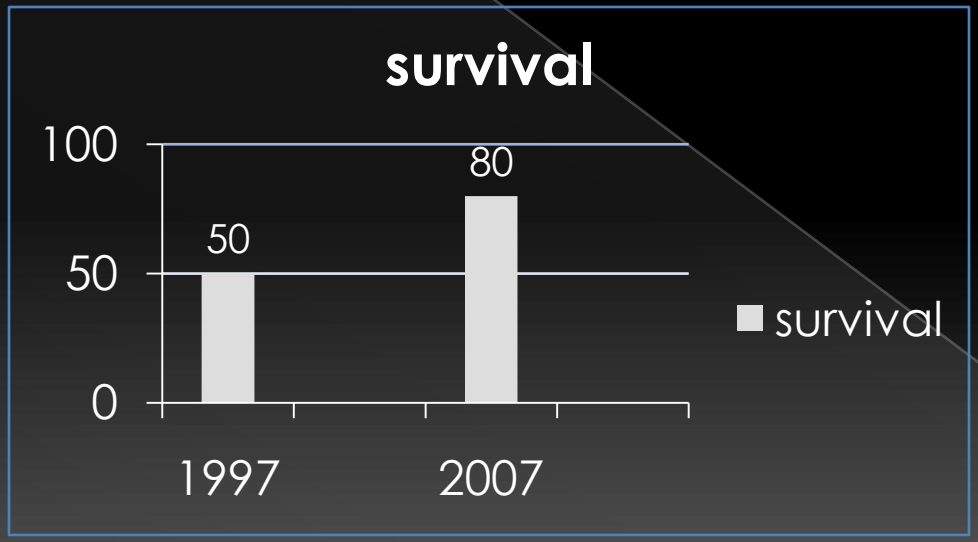
- Leukaemia / lymphoma: ~ 35%
  - acute lymphoblastic leukaemia : 23%
  - Hodgkin disease : 5%
  - acute myelogenous leukaemia : 4%
  - NHL : 5%

- Central nervous system malignancies : ~20%
  - Astrocytomas
  - Gliomas
  - Medulloblastomas

- Solid tumours
  - blastomas : ~15%
    - Neuroblastoma : 7%
    - Wilms tumour : 6%
    - Retinoblastoma
  - sarcomas ~10%
    - Rhabdomyosarcoma : 3%
    - Osteosarcoma : 3%
    - Ewing sarcoma : 2%

Survival of pediatric malignancies

- Childhood malignancies – sensitive to treatment.
- Change in treatment management- multimodality approach (RT, Surgery and chemotherapy)



Efficacy improving, but associated damages

- Secondary malignancies
- Cardiac impairment
- Pulmonary dysfunction
- Infertility
- Chronic hepatitis
- Alteration in growth and cognitive abilities

Aim of treatment - Judicious use

Medications
Investigation

Changing trends

- Tailor made treatment regimes.
- Need for early alterations in therapy.

- Use of imaging for response assessment.
- ✓ *Anatomic imaging – changes identified later.*
- ✓ *Metabolic imaging – need for localization and anatomy.*

- Combined use - HYBRID IMAGING.

Imaging in oncology

- Staging
- Treatment response assessment
- Completion of treatment
- Surveillance
- Restaging

CT and US : incorporated in all guidelines in management.

PET/CT : Introduced into management of pediatric patients later
Incorporated in few guidelines.

Radiation exposure (PET/CT)

- Fear of increased radiation over CIM.
- Radiation from PET & CT

Radiation exposure during PET/CT

Radiation exposure of patients undergoing whole body dual modality 18F FDG PET/CT examinations

- Brix et al, Journal of nuclear medicine ;2005, 46 (4): 608

TABLE 2
Summary of Representative Protocols Used Routinely for Whole-Body ^{18}F-FDG-PET/CT Examinations at 4 German Hospitals Equipped with the Dual-Modality Tomographs Characterized in Table 1

Hospital	Scan: Type	Scan: Abbreviation	Effective dose (mSv): Per scan	Effective dose (mSv): Per examination
H1	2 Topograms*		0.8	
	Diagnostic CT with CA	H1-D-CT	18.6	
	PET, 370 MBq ^{18}F-FDG	H1-PET	7.0	26.4
H2	Topogram		0.1	
	Low-dose CT	H2-LD-CT	4.5	
	PET, 300 MBq ^{18}F-FDG	H2-PET	5.7	
	Diagnostic CT with CA	H2-D-CT	14.1	24.4
H3	Low-dose protocol			
	Topogram		0.2	
	Low-dose CT	H3-LD-CT	1.3	
	PET, 370 MBq ^{18}F-FDG	H3-PET	7.0	8.5
	High-quality protocol			
	Topogram		0.2	
	Diagnostic CT with CA	H3-D-CT	17.6	
	PET, 370 MBq ^{18}F-FDG	H3-PET	7.0	24.8
H4	Topogram		0.2	
	Low-dose CT	H4-LD-CT	2.4	
	PET, 370 MBq ^{18}F-FDG	H4-PET	7.0	
	Diagnostic CT with CA	H4-D-CT	14.1	23.7

*In anteroposterior and lateral direction; dose indicated represents the dose sum from both topograms.
CA = intravenous CT contrast agent administered for most examinations.

Average effective patient dose: 25mSv FDG PET/CT

Suggestion:
Optimization of CT protocol

TABLE 3
Measurement Parameters Used for Low-Dose (LD-CT) and Diagnostic (D-CT) Whole-Body CT Scans Summarized in Table 2

Abbreviation of CT scan	U (kVp)	Q_{el} (mAs)	h_{col} (mm)	p	L (mm)	$CTDI_{vol}$ (mGy)
H2-LD-CT	120	60	6.5	1.5	910	2.9
H3-LD-CT	110	30	4.0	2	851	1.0
H4-LD-CT	120	32.5	0.75	1.25	887	2.0
H1-D-CT	140	150	2.5	1.5	867	14.1
H2-D-CT	120	195	5.0	1.5	890	9.5
H3-D-CT	130	111	4.0	1.0	851	11.9
H4-D-CT	120	200	1.5	1.25	887	11.2

U = tube potential; Q_{el} = electrical mAs-product; h_{col} = slice collimation; p = pitch factor; L = scan length; $CTDI_{vol}$ = volume CT dose index.

Whole-Body PET/CT Scanning: Estimation of Radiation Dose and Cancer Risk

Huang et al , Radiology

Table 2

Parameters of the Three CT Protocols

CT Protocol	Tube Potential (kV)	Rotation Time (sec)	Section Thickness (mm)	Pitch	Tube Current (mA)	Noise Level*
A	120	0.5	0.625	0.984	100–300	20
B	120	0.5	0.625	0.984	250	. . .
C	140	0.5	0.625	0.984	150–350	3.5

* With use of AutomA.

Protocol	Effective dose (mSv)	
	Female	Male
A	13.45	13.65
B	24.79	24.80
C	31.91	32.18

Lifetime cancer incidence with a diagnostic CT and PET would be 0.514% for US population and 0.622% for Hong Kong population (for patient age 20 yrs)

Image gently

Maintain as low pediatric radiation dose as possible

- PET component
- CT component

Pediatric dose calculation of RP's

TABLE 3

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%

Eur J Nucl Med Mol Imaging 2007; 34

Studies have shown higher dose in 1 yr olds as compared to teen using BSA and Websters formula.

FDG dosage

North American consensus guidelines
American College of Radiology, Society of Pediatric Radiology,
Society of Nuclear Medicine and Molecular Imaging (SNMMI)

TABLE 1

North American Consensus Guidelines for Administered Radiopharmaceutical Activities in Children and Adolescents*

Radiopharmaceutical	Recommended administered activity (based on weight only)	Minimum administered activity	Maximum administered activity	Comments
^{123}I-MIBG	5.2 MBq/kg (0.14 mCi/kg)	37 MBq (1.0 mCi)	370 MBq (10.0 mCi)	EANM Paediatric Dose Card (2007 version (*13*)) may also be used in patients weighing more than 10 kg.
^{99m}Tc-MDP	9.3 MBq/kg (0.25 mCi/kg)	37 MBq (1.0 mCi)		EANM Paediatric Dose Card (2007 version (*13*)) may also be used.
^{18}F-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)		Low end of dose range should be considered for smaller patients. Administered activity may take into account patient mass and time available on PET scanner. EANM Paediatric Dose Card (2007 version (*13*)) may also be used.
^{99m}Tc-dimercaptosuccinic acid	1.85 MBq/kg (0.05 mCi/kg)	18.5 MBq (0.5 mCi)		
^{99m}Tc-MAG3	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 mCi)	Administered activities at left assume that image data are reframed at 1 min/image. Administered activity may be reduced if image data are reframed at longer time per image. EANM Paediatric Dose Card (2007 version (*13*)) may also be used.

Eur J Nucl Med Mol Imaging 2007; 34

EANM dose card

1 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

Table 2 Recommended amounts for 39 procedures

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*	80
^{131}I mIBG	B	*5.6*	35
^{18}F FDG (2D)	B	*25.9*	70
^{18}F FDG (3D), Recommended in children	B	*14.0*	70
^{18}F Fluorine (2D)	B	*25.9*	70
^{18}F Fluorine (3D), Recommended in children	B	*14.0*	70
^{67}Ga Citrate	B	*5.6*	10
^{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

a) ^{18}F FDG (whole body, 3D acquisition), body weight: 50 kg: Activity to be administered [MBq]=14.0×10.71 [MBq] ≈ 150 MBq

ple are weight- and radiopharmaceutical-dependent factors

Harmonization of American and EANM

Table 5 Activity values and effective doses for ^{18}F-FDG PET of the torso (ICRP 106 [10])

	Age				
	1 year	5 years	10 years	15 years	Adult
Nominal weight (kg)	10	19	32	55	70
2007 EANM dosage card [1, 2]					
Administered activity (MBq)	70	120	189	302	370
Effective dose (mSv)	6.7	6.7	7.0	7.2	7.0
North American consensus guidelines [3]					
Administered activity (MBq)[a]	51	99	166	286	364
Effective dose (mSv)	4.8	5.5	6.2	6.9	6.9

[a] 5.2 MBq/kg

For 18F RP no change in EANM 2007 card
Upper limit. For EU
North American guidelines - lowest administered activity was 26MBq

Contribution of CT component

Principle determinants of the dose a patient receives during a CT

: X-ray beam energy (related to the peak kilovoltage)

: X-ray beam intensity (milli amperes) or the number of x-ray photons generated (related to the product of the tube current and time).

Balance the mA and KvP factors and pitch.
Protocols based on patient weight or age produce greater variability

Image gently protocol

Obtain Diagnostic reference level (DRL) and Size specific dose estimates (SSDE) for every scanner of department.
Use the reference adjustments of mA and KvP based on tissue

DRL Parameters

Table 1(b) Guidelines for multidetector row computed tomography parameters in children: Abdomen/pelvis[a]

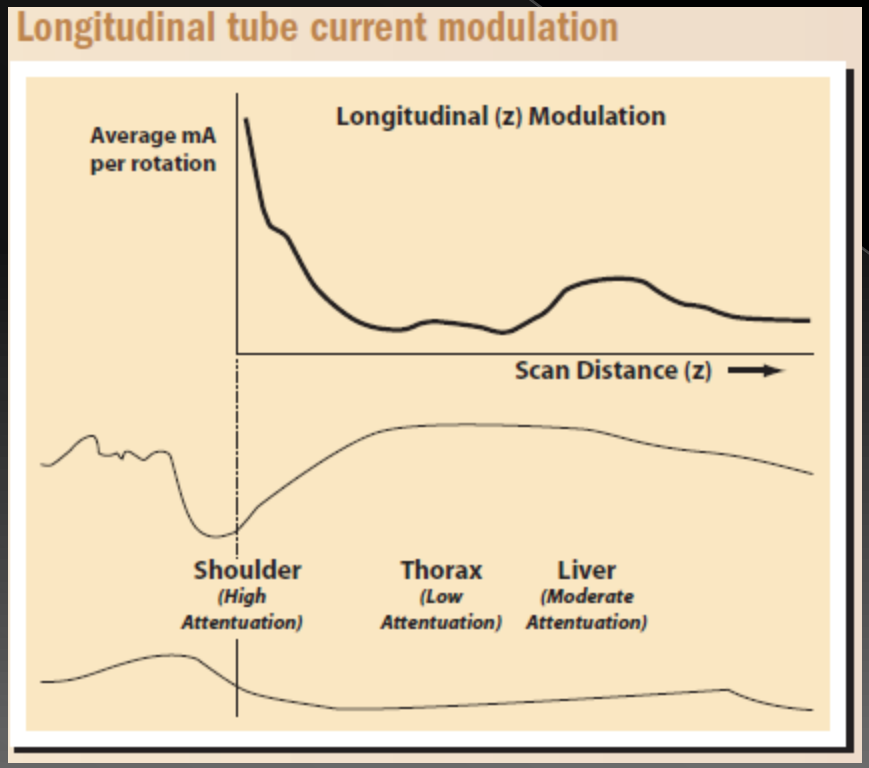
Weight (kg)	Peak kilovoltage	Tube current[b]		Section thickness (mm)	Pitch			Detector thickness[c] (mm)				Increment (mm)
		SDCT	MDCT		4-	8-	16, 64[d]	4-	8-	16-	64-	
5–9.5	100–120	60	50	3.75–5	0.75	0.875	0.9375	2.5	1.25	1.25	0.625	2.5
10–19.5	100–120	70	60	3.75–5	0.75	0.875	0.9375	2.5	1.25	1.25	0.625	2.5
20–29.5	120	80	70	5	0.75–1.5	1.35	1.375	2.5	1.25	1.25	0.625	2.5
30–39.5	120	100	80	5	1.5	1.35	1.375	2.5	1.25	1.25	0.625	2.5
40–49.5	120	120	100	5	1.5	1.35	1.375	3.75	2.5	1.25	0.625	2.5
50–75	120	140–150	110–120	5	1.5	1.35	1.75	3.75	2.5	1.25	0.625	2.5
>75	120	≥170	≥135	5	1.5	1.35	1.75	3.75	2.5	1.25	0.625	2.5

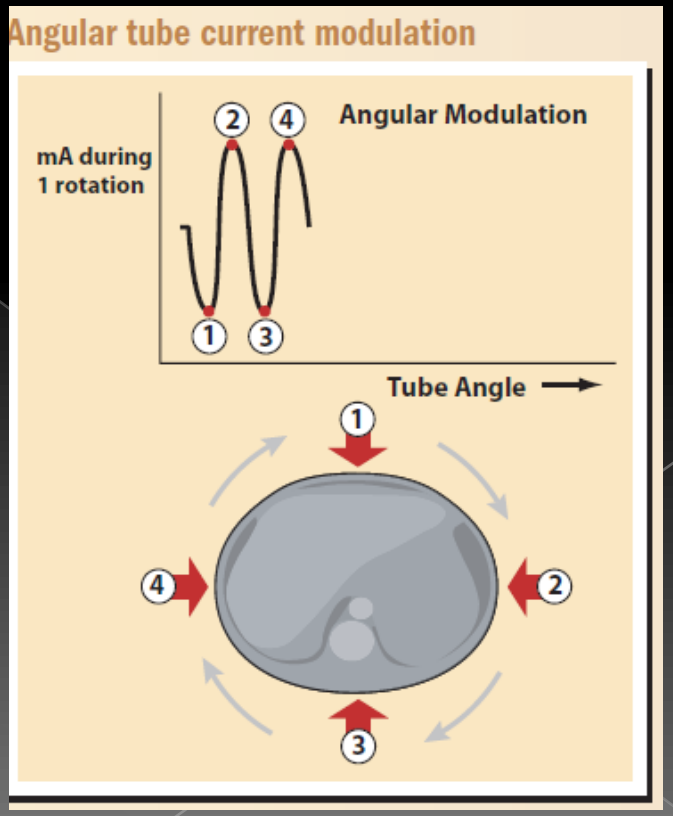
[a] Parameters are based on GE single and multi-detector row CT machines.
[b] Use 0.5 s gantry time when an option; tube current are for four- and eight-section MDCT; 16-section weight-based colour-coded tube current are loaded on the machine.
[c] For anticipated multiplanar reconstructions or three-dimensional rendering, use thinnest detector width (e.g. 0.625 mm) with 16-section at all ages.
[d] For 64-section, pitch of approximately 1 under 20 kg, otherwise 1.375.

Clinical Radiology (2007) **62**, 507–517

Automatic exposure control scanners

PRINCIPLE:
Changes dose based on the thickness and radiation attenuation of tissues along the length of the patient's body (Z axis).
Or along the angle of tube





Automatic exposure control scanners

Procedure

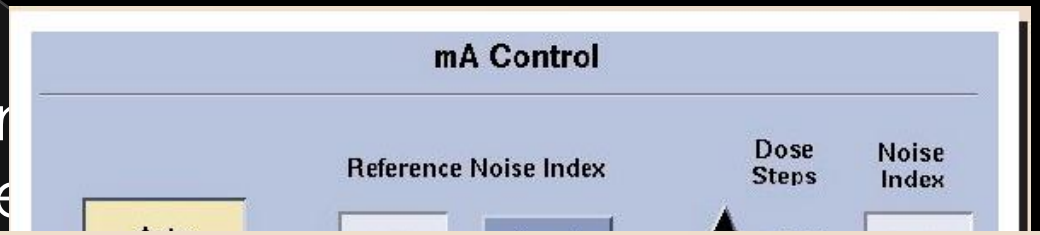
Take a scar

Decides the

Decide

Decide

If low n



Lateral patient width (cm)	Noise Index (at 0.5s)	mA (min)	mA (max)
22.1 - 30	9	150	280
30.1 - 40	11.5	220	500
40.1 - 45	14.5	400	720
45.1 -	17 (0.7s)	450	770

Proble

Small p ge noise

Large patient – high mA – good image – unnecessary radiation dose

Automatic exposure control scanners

Table I: Summary of the four most common AEC strategies

Manufacturer	AEC Trade name	Image Quality Reference	Goal
General Electric	Auto mA, Smart mA	Noise Index	Constant image noise regardless of attenuation level, using tube currents within prescribed minimum and maximum values.
Toshiba	SureExposure	Target Image Quality Level	
Siemens	CARE Dose4D	Quality Reference Effective mAs	Constant image quality regardless of attenuation level, with reference to a target mAs level for a standard-sized patient.
Philips	DoseRight	Reference Image	Keep the same image quality as in the reference image, regardless of attenuation level.

Contribution of CT component

Choice of CT :
Low mA & low Voltage : attenuation

Low mA & high voltage : anatomic localization

High mA and High Voltage : Dedicated CECT.
: Characterization of lesion

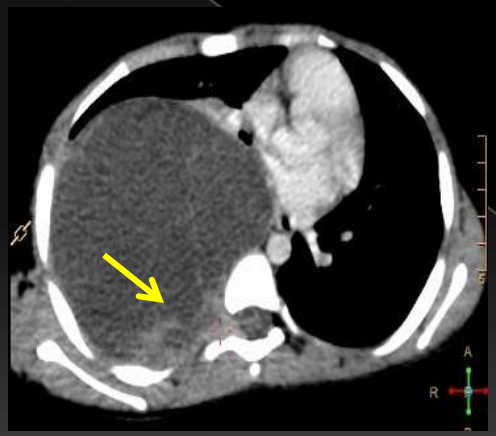
Tube current - Some visible noise accepted

Rotation – 1 to 0.5 sec

Lower Voltage – Regions with inherent tissue contrast

Dedicated CT component

A



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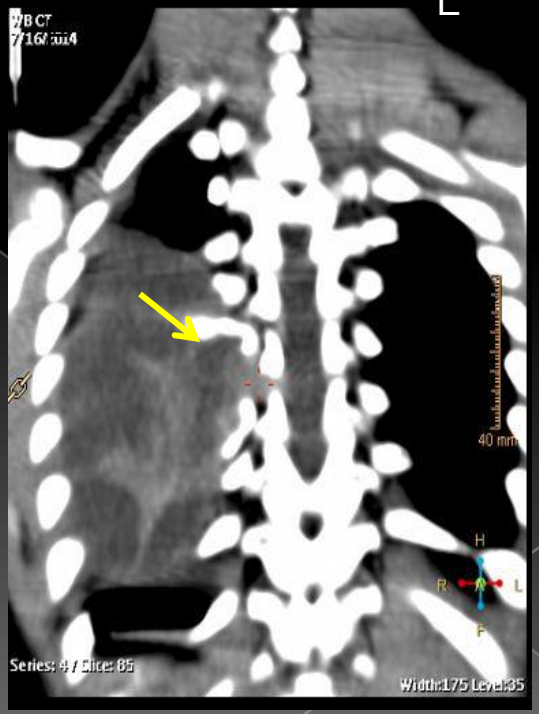
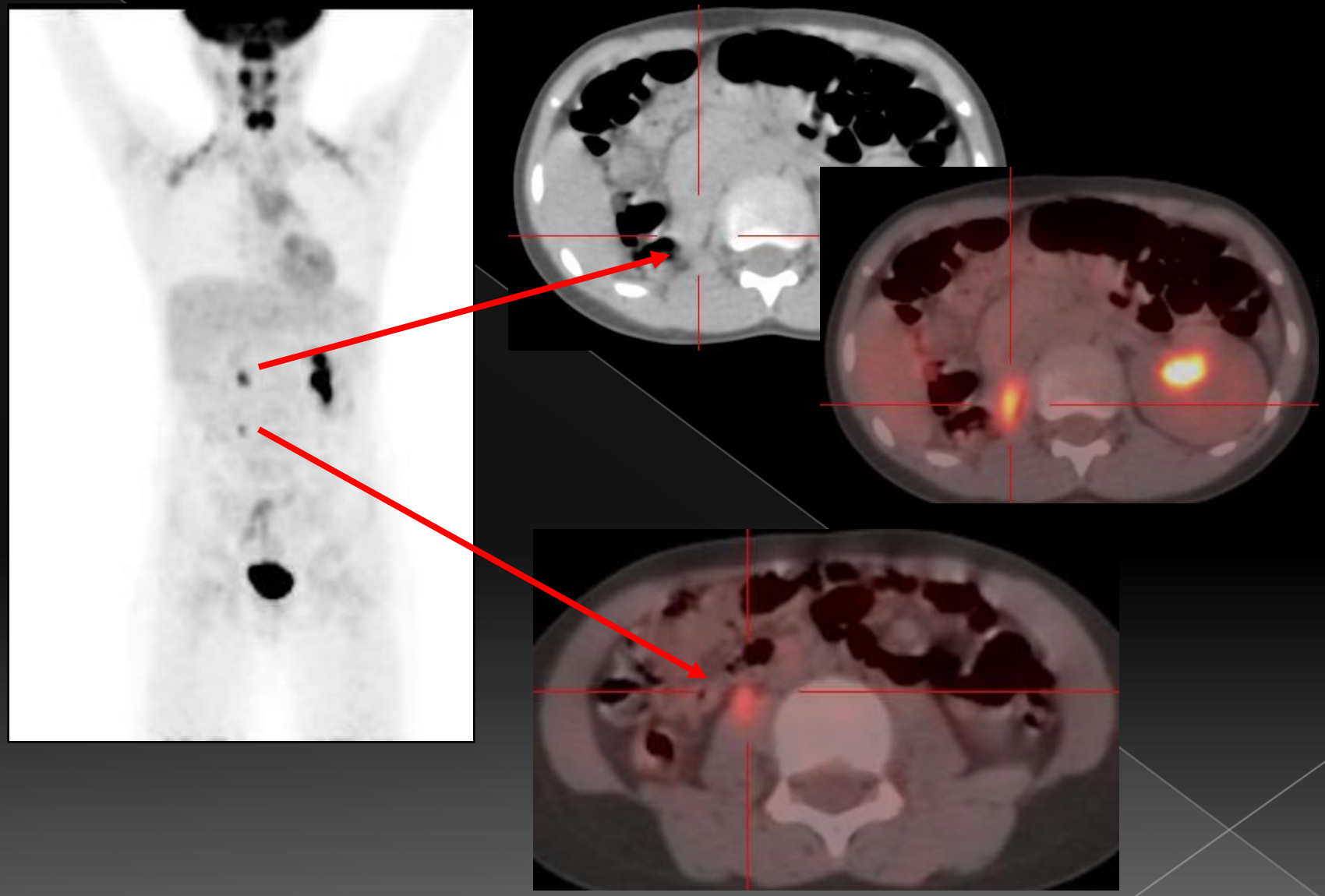
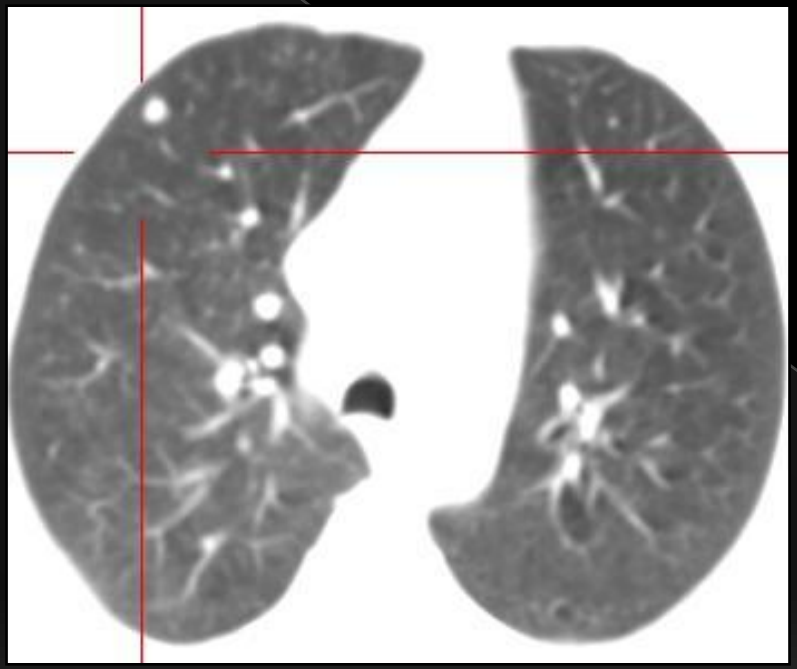


CECT useful for IDRF – complete staging in one scan -

Non contrast low mA CT component



Recurrence of Wilms tumor



Low mA CT

Dedicated high mA CECT thorax

PET/CT protocols for attenuation and localization

TABLE 1. Pediatric Whole-Body PET/CT Protocols Highlighting Acquisition Settings Varied for Each Weight Category

Patient				PET acquisition	
Category	Weight range (kg)	Estimated whole-body scan range (mm)	CT acquisition, maximum tube current for CT (mAs)	Injected activity (MBq [mCi])	Scan time per FOV (min)
Pink	6–7.4	59.5–66.5	10	37 (1.0)	3
Red	7.5–9.4	66.5–74	10	45 (1.2)	3
Purple	9.5–11.4	74–84.5	15	55 (1.5)	3
Yellow	11.5–14.4	84.5–97.5	20	68 (1.9)	3
White	14.5–18.4	97.5–110	20	87 (2.4)	3
Blue	18.5–22.4	110–122	20	108 (2.9)	3
Orange	22.5–31.4	122–137	25	142 (3.9)	5
Green	31.5–40.5	137–150	30	190 (5.1)	5
Black	40.5–55	150–162	30	252 (6.8)	5
Small adult	55–70	162–170	35	330 (8.9)	5
Large adult	>70	>170	40	370 (10.0)	5

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Broselow luten colour scale

PET/CT protocols for attenuation and localization

TABLE 4. Estimated Dosimetry and Additional LAR of Cancer for Proposed PET/CT Protocols

Patient			Approximate effective dosimetry				Lifetime attributable risk			
							Cancer incidence		Cancer mortality	
Category	Weight range (kg)	Average age	PET dose (mSv)	CT dose (mSv)	Total effective PET/CT dose (mSv)	BERT (y)	Females (%)	Males (%)	Females (%)	Males (%)
Pink	6–7.4	4 mo	5.0	3.1	8.1	2.7	0.34	0.18	0.13	0.08
Red	7.5–9.4	8 mo	5.1	2.9	8.0	2.7	0.33	0.18	0.12	0.08
Purple	9.5–11.4	15 mo	5.1	4.1	9.2	3.1	0.36	0.19	0.13	0.08
Yellow	11.5–14.4	2.4 y	5.5	5.2	10.7	3.6	0.38	0.21	0.15	0.09
White	14.5–18.4	3.8 y	5.5	5.0	10.5	3.5	0.34	0.18	0.13	0.08
Blue	18.5–22.4	5.9 y	5.3	4.7	10.0	3.3	0.28	0.15	0.11	0.07
Orange	22.5–31.4	8.5 y	6.0	5.5	11.4	3.8	0.28	0.15	0.12	0.07
Green	31.5–40.5	10.1 y	6.6	6.3	12.8	4.3	0.29	0.16	0.12	0.08
Black	40.5–55	12.8 y	7.5	5.6	13.1	4.4	0.27	0.15	0.12	0.08
Small adult	55–70	15.0 y	7.6	5.9	13.5	4.5	0.25	0.14	0.11	0.07
Large adult	>70	20.0 y	7.0	5.9	12.9	4.3	0.19	0.11	0.09	0.06

Baseline LAR: cancer incidence for females is 36.9% and for males it is 45.5%; cancer mortality for females is 17.5% and for males it is 22.1%.

Tips to consider

Get Involved in acquisition and appointments

- Avoid multi phase acquisitions; post-contrast (single-phase study) is all that is necessary
- Reduce the values of the tube current and peak kilo - voltage used to obtain the scout image(s)
- Follow up scan - limited to the appropriate body region.
- Shielding of radio sensitive organs - eye lens, thyroid gland, and breast can be shielded using bismuth material.

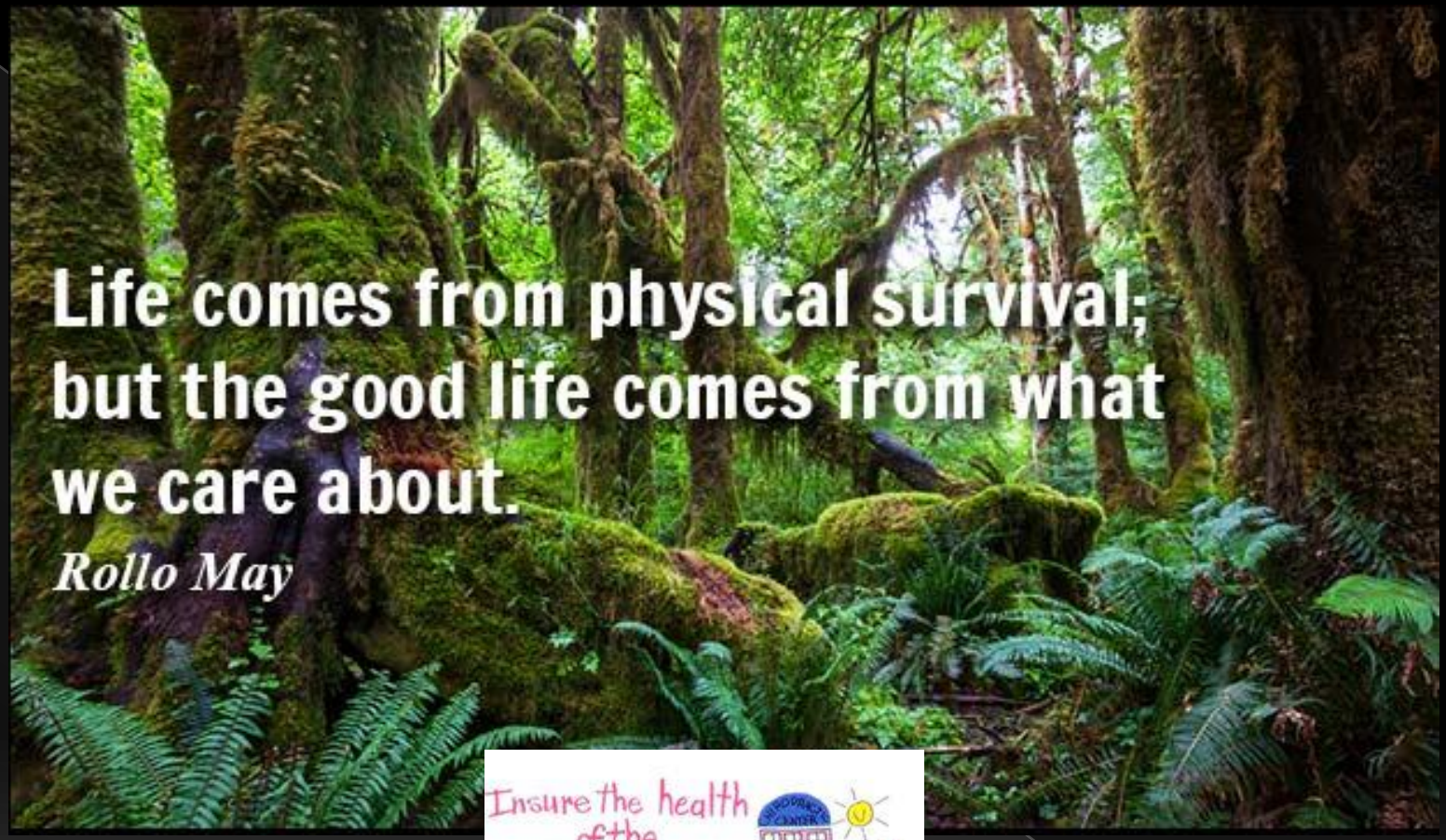
Tips to consider

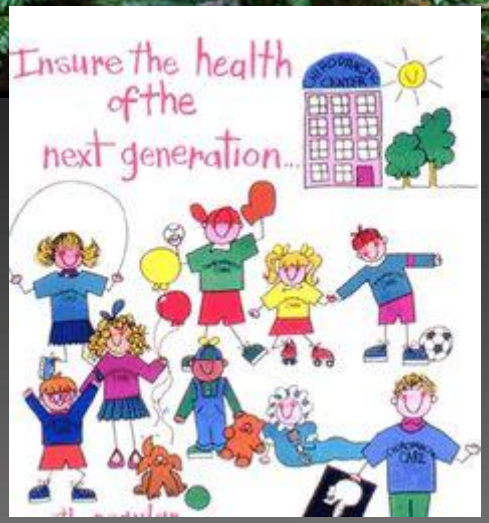
- Child friendly department
- Schedule early appointments – shorter fasting

- Talk to the parent & CHILD.
- Show the machine

- Uptake period:
  read a book/TV/game

- Acquisition:
  Parent allowed
  Can carry toy
  Play music or rhyme


Life comes from physical survival;
but the good life comes from what
we care about.
Rollo May


Insure the health
of the
next generation...