BVS/ABR Workshop 2011
on dose related to multimodality imaging

Optimized PET/CT protocols: how much CT is needed?

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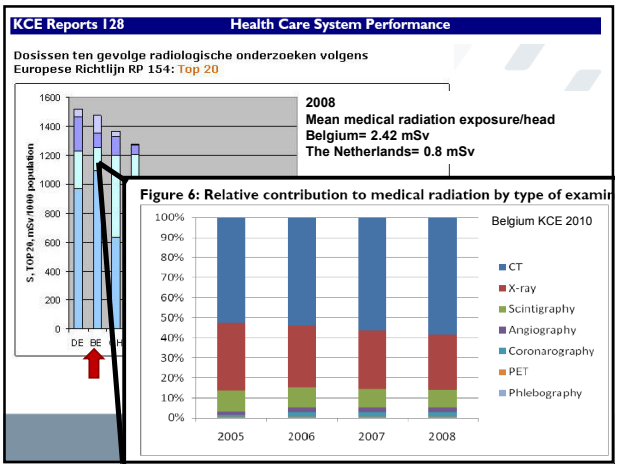


Increasing use of PET-CT

- RIZIV survey 2010
  - 13 accredited PET centra, 7 non-accredited centra
  - 25 "RIZIV billing" systems of which 14 PET-CT
  - 42.000 PET scans in 2008 (50% RIZIV approved indications)
- Portion full CT vs low dose CT is variable
  - ERS/EANM survey 2009

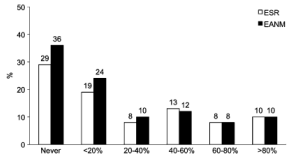


Fig. 3 Answers to question 3 of the survey, "How often is the CT part of PET/CT conducted as a full diagnostic CT+/– contrast enhancement in your facility?"

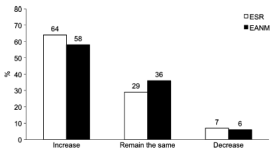


Fig. 4 Answers to question 4 of the survey, "Do you think that the proportion of diagnostic CT+/– contrast enhancement will…?"

Basic Principle = **ALARA**
As Low as Reasonably Achievable

- **Justification**
  - The test must be medically indicated
    - Accurate
    - No alternative test without radiation with similar accuracies available
    - (Cost-effective)
  - → Evidence-based medicine
- **Optimization**
  - Best diagnostic image NOT most "beautiful" image
  - → **Technical Innovations in PET and CT to reduce radiation**
    How much CT is needed in PET/CT

Justification

Example: Evidence for PET or PET/CT for surveillance?

Imaging in Lymphoma

- **Imaging plays a central role in patient management**
  - diagnosis and staging
  - treatment planning and evaluation of treatment effects
  - managing inter-current illness and complications
- **Role of routine imaging procedures for surveillance is questionable**
  - Relapses are diagnosed most often clinically
  - Early detection (and treatment of recurrence) does not improve OS
  - Clinical guidelines (ESMO, NCCN) do not recommend routine imaging during FU but it is often performed in daily practice
  - **Legitimate concern that surveillance imaging may expose patients to unnecessary and ineffective radiation**

Imaging in Lymphoma

Lee Chong et al (Toronto), Pediatr Blood Cancer 2010;55:407–413

- Retrospective estimation of the cumulative radiation exposure from diagnostic and follow-up imaging in a cohort of 150 children diagnosed with a malignancy in the calendar year 2001
- Inventory of number and type of diagnostic and interventional imaging procedures performed during a 5-year period from the first diagnostic procedure
- Cumulative effective dose estimates were calculated, based on both institutional dose data and published literature

Median cummulative Effective dose = 61 mSv
(range <1 - 642 mSv)

Imaging in Lymphoma

Lee Chong et al (Toronto), Pediatr Blood Cancer 2010;55:407–413

TABLE I. Median Cumulative Effective Dose Estimates in a Cohort of Pediatric Oncology Patients

Diagnostic group	Median cumulative effective dose (mSv)
Leukemia	5
Lymphoma	190
Neuroblastoma	214
Brain tumors	12
Assorted solid tumors	90
Total cohort	61

Subgroup analysis of imaging during first-line treatment in 29 lymphoma patients

Imaging in Lymphoma

Lee Chong et al (Toronto), Pediatr Blood Cancer 2010;55:407–413

29 lymphoma patients; Imaging during first-line therapie

	N Scans	%	Effective cum dose (mSv)	%
X-Ray	303	44	17	<0.5
CT	203	29	1740	26
Radionuclide	127	23	4854	73
Interventional	27	4	59	<0.5
Totals	690		6670	

Indications for Imaging Procedures
34% protocol required
66% discretionary investigations

52% → Managing of co-morbid illness

48% → Surveillance (50% low risk of recurrence)

No clear indication in 12.5% of examinations (CT, Gallium scans (>40 mSv!))

Risk-based PET surveillance

Petrausch et al (Zurich), 2x annals of Oncology 2010

- Retrospective study in 134 HD and 75 DLBCL in CR/CRU after firstline therapy (2/3 PET-) with at least 1 PET/CT in FU
- Hybrid PET/CT
- HD 134 patients, 42 recurrences
  - +PET more frequent in sympt (32/51 or 63%) vs asymp (10/83 or 12%)
  - No info on FPR only PPV 98% (1 patient?), NPV 100%
- NHL 75 patients, 27 recurrences
  - +PET more frequent in sympt (23/40 or 57%) vs asymp (4/35 or 11,5%)
  - 3 false positives+ 1 lung cancer PPV 85%, NPV ?

Conclusions: restrict use of PET/CT to patients with a high risk of relapse

Optimization

PET improvements

CT dose reduction strategies

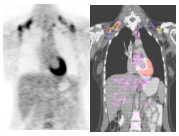
How much CT is needed?

PET technique – Historical Overview

1995 1998 2003 2010

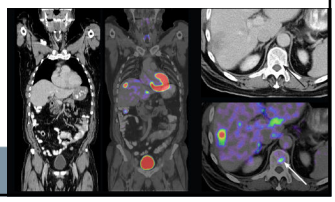
Stand alone PET
10 cm FOV
AC Ge-68 ring source
FBP

3 h/ scan

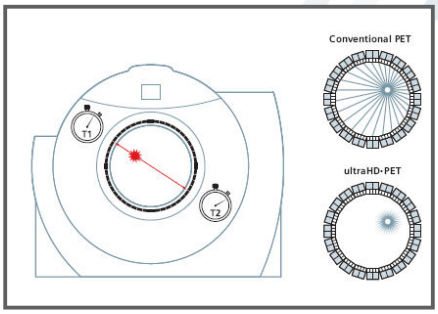


PET-CT (128 slice)
22 cm FOV
AC CT based
HD-TOF

<15 min/scan



Time of Flight (TOF) - PET



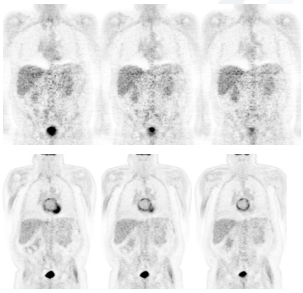
Better signal – to – noise ratio, ↑ sensitivity?
Lower FDG dose, shorter scan times (5 to 15 min/WB)

FDG dose and emission time/bedposition

Boellaard et al. NEDPAS guidelines

Mode	3D	3D	3D	3D	3D	3D	3D
Time/bed	4	3	2	5	4	3	2
Bedoverlap	< 25%	< 25%	< 25%	50%	50%	50%	50%
Scanner	HR+,3D Allegro Biograph	HR+,3D Allegro Biograph	HR+,3D Allegro Biograph	Gemini GeminiToF	Gemini GeminiToF	Gemini GeminiToF	Gemini GeminiToF
Patient weight (kg)							
30-39	120	160	240	40	60	80	120
40-49	150	200	310	60	70	100	150
50-59	180	250	370	70	90	120	180
60-69	220	290	440	80	110	140	220
70-79	250	340	510	100	120	170	250
80-89	290	390	580	110	140	190	290
90-99	320	430	650	130	160	210	320
100-109	360	480	720	140	180	240	360
110-119	390	520	790	150	190	260	390
120-129	430	570	860	170	210	280	430
130-139	460	620	930	180	230	310	460
140-150	500	660	1000	200	250	330	500

TOF- PET



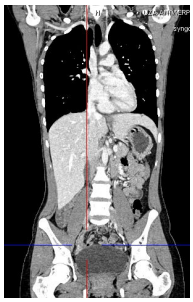
No TOF

TOF

High throughput (upto 25 patients/day)
Use of lower FDG doses (10 mCi~ 7 mSv; 7 mCi ~ 5 mSv)

State-of-the-art CT systems

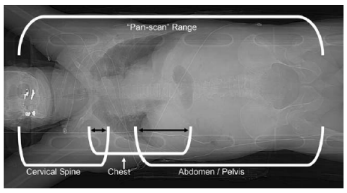
2003 – 2 slice CT



2010 – 64 slice CT

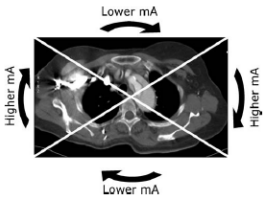
Dose Reduction Strategies in CT

- Omit multiple phase scanning en overlap between scans
- Eyes outside FOV for full CT

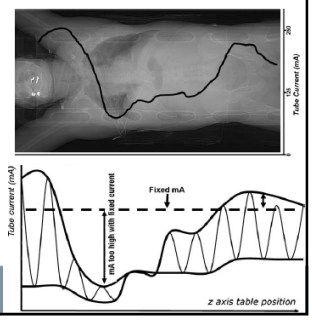


Dose reduction strategies in CT

- **automated exposure controle (AEC)** = Tube current modulation (mA) to change X-ray intensity according to patient attenuation

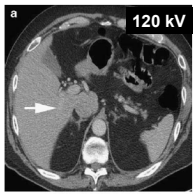


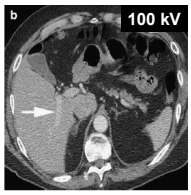
Dose reductions of 20-40%



Dose reduction strategies in CT

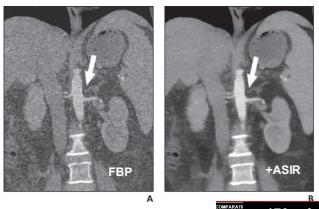
- Adjusting the **tube potential** (kV) to patient size when iodine contrast enhancement is used (attenuation of Iodine increases with lower kV resulting in better contrast)

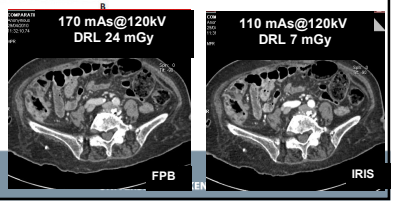




< 60 kg	→	80 kV
60-90 kg	→	100 kV
90-120 kg	→	120 kV
> 120 kg	→	140 kV

State of the art CT scanner
Iterative Reconstruction





How much CT is needed?

Difference in radiation exposure between different scanning protocols is attributed to CT setting!

PET-CT imaging protocols
different strategies

- Low dose WB -CT + WB-PET
- CE-CT (medium-dose) + WB-PET
- Low dose WB-CT + WB-PET + CE-CT Tx-Abd

How much CT is needed in PET-CT?

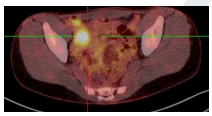
Low dose PET-CT	"diagnostic" PET-CT	Dedicated CT
30 mAs , no contrast	85 mAs, 120 ml contrast	140 mAs, 200 ml contrast
2 mSv	8 mSv	15-20 mSv

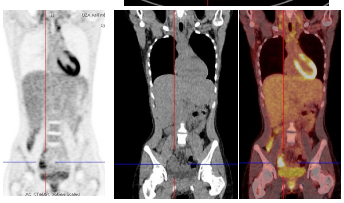
Effective Dose of "Diagnostic PET-CT" using new technical developments should feasible for < 15 mSv

+ new CT tools

PET-CT imaging protocols
Low dose CT WB + WB-PET

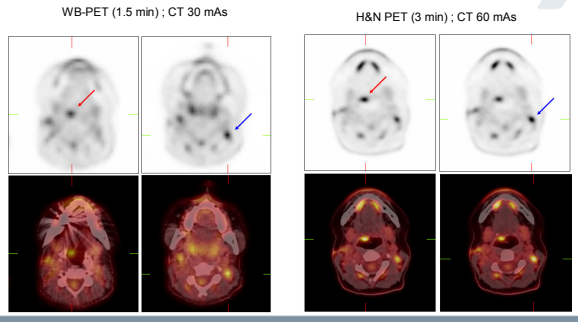
- Total radiation dose < 10 mSv
- When?
  - if full CT was already performed
    - e.g. initial staging
  - If full CT is not needed
    - e.g. FU of Lymphoma





PET-CT imaging protocols

Additional Head and Neck images



PET-CT imaging protocols

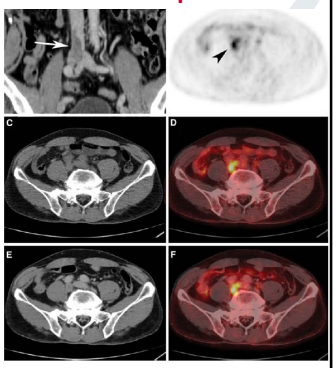
WB-PET with full CT

- Radiation Dose variable and depending on CT settings
  - Define proper settings (ALARA) based on
    - Indication (FOV)
    - Size of patient (tube voltage)
    - Possibilities of scanner (iterative reconstruction software)
- When?
  - If both PET and CT need to be done (one stop shop)
    - e.g. FU of cancer patients, radiation treatment planning

How much CT is needed?
Lymphoma Surveillance Example

- PET/LD-CT >> ceCT
  - Hany et al, Radiology 2004
  - Elstrom et al, Annals of Oncol 2008
  - London et al EJNMMI 2010
- PET/ceCT = PET/LD- CT but higher level of confidence
  - Rodriguez et al, JNM 2006
  - La Fougere , ,Nuklearmedicine 2008
  - *Nakamoto et al, Ann Nuc Med 2010

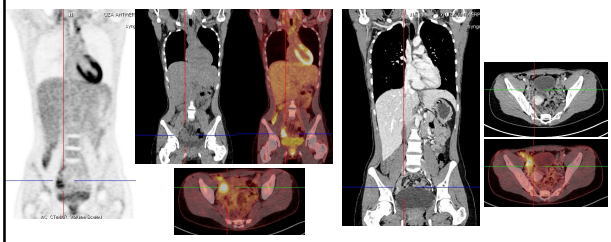
PET/ceCT In surveillance: best protocol in selected indications



PET-CT imaging protocols

Lymphoma surveillance

DD iliacal hot spot



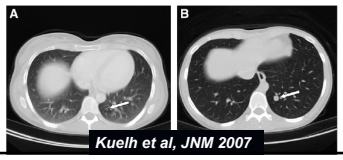
PET-CT imaging protocols

WB-PET with full CT

- Full CT before or after WB-PET

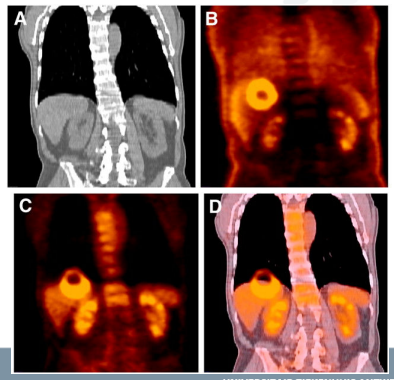
Pro "Before"
- can be used for AC (artefacts contrast on PET quantification miminal)
- Less misalignment artefacts

Pro "After"
- Smaller FOV (Thorax-Abdomen), ideally decide on CT FOV after seeing WB-PET
- More optimal CT protocol (max inspiration) but more misalignment
- No effect on PET examination if allergic reaction on CT contrast

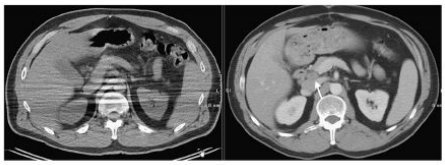


Kuelh et al, JNM 2007

Misalignment Artifacts



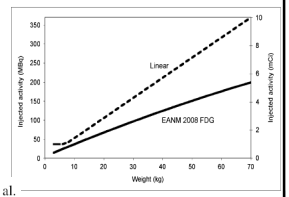
PET-CT imaging protocols
Patient Positioning



Dedicated protocols for children

FDG dose

- Two methods for dose calculation
  - Fixed dose per kg/body weight (3 -7.5 MBq/kg)
  - EANM dose chart (takes into account the higher susceptibility for radiation induced cancers in younger persons
- ALARA
  - trade off between scan time and dose

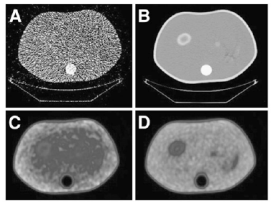


WEIGHT-BASED PEDIATRIC PET/CT PROTOCOLS • Alessio et al.

FIGURE 1. Injected ^{18}F-FDG dose vs. weight for proposed linear approach and EANM pediatric guidelines.

CT acquisition Protocol

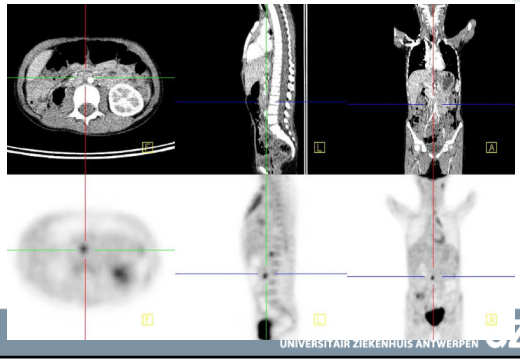
- if possible with Diagnostic CT
  - One stop shop
  - Increased diagnostic confidence
  - Better PET image quality



80 kVp
10 mA
0.5 s/rot
1.5:1

140 kVp
160 mA
0.8 s/rot
1.5:1

FDG biodistribution in children
Less tissue contrast (no fat)



Dedicated PET-CT protocols for Children

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tric Whole-Body PET/CT Protocols Highlighting Acquisition Settings Varied for Each Weight Category

Patient			PET acquisition	
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)
6–7.4	59.5–66.5	10	37 (1.0)	3
7.5–9.4	66.5–74	10	45 (1.2)	3
9.5–11.4	74–84.5	15	55 (1.5)	3
11.5–14.4	84.5–97.5	20	68 (1.9)	3
14.5–18.4	97.5–110	20	87 (2.4)	3
18.5–22.4	110–122	20	108 (2.9)	3
22.5–31.4	122–137	25	142 (3.9)	5
31.5–40.5	137–150	30	190 (5.1)	5
40.5–55	150–162	30	252 (6.8)	5
55–70	162–170	35	330 (8.9)	5
>70	>170	40	370 (10.0)	5

Dedicated PET-CT protocols for Children

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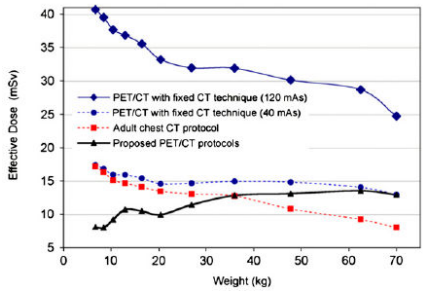

"Optimal" PET-CT protocol

- Differences in radiation dose is dependent on CT protocol
  - → Optimal use of CT radiation reduction tools
  - → Best diagnostic image ≠ most beautifull image
- Avoid duplication!
- Optimal protocol but probably difficult to perform in routine clinical practice
  - Start with low dose CT + WB-PET
  - Decide on need/FOV of full CT after viewing PET images.