# IFMP WORKSHOP IN IONIAN UNIVERSITY, CORFU, GREECE

Tuesday 7/11/2017 9:30

## QC PET-CT AND PET-MR

**Ivo Rausch, PhD**

*Medical University Vienna, Centre Medical Physics and Biomedical Engineering, QIMP Group*

The main purpose of a Positron Emission Tomography (PET) examination is to obtain a quantitative evaluation of a specific metabolic process. To obtain this a quality management system (QMS) has to be set up. A QMS is a program that controls how quality is maintained and ensured throughout an organisation. It consists mainly of Quality Assurance (QA), a concept of actions which ensures that certain requirements are met, and Quality Control (QC) to monitor the procedures and the performance of a system.

Quantification in PET is not only a matter of proper PET system performance. The outcome of a study is influenced by various factors related to technical, biological and physics related factors. QA in the case of PET should incorporate standardised operation procedures (SOP) for the whole work flow. It starts with the instruction to the patient prior to the day of examination (e.g. special diet before an FDG study). Further on, it should include SOPs for patient handling (e.g. tracer / disease specific uptake times) as well as instructions on standardized acquisition and reconstruction protocols. And lastly SOPs for a standardized evaluation of the studies.

One important part of the whole workflow is to ensure the proper function of the PET system itself. This is achieved by proper QC and eventual corrective actions. QC of the system consists of initial tests as part of the acceptance testing after installation and routine QC procedures. Acceptance testing is performed to check if the system meets the specifications provided by the vendor. It follows standardized measurements like described in the NEMA-NU2 standard and consists, for example, of measuring the spatial resolution, sensitivity, count rate performance and image quality. Furthermore, this measurement serves in the following as reference for future testing.

During operation of a PET, routine QC procedures have to be performed. These tests should be simple and specific to the imaging system and sensible to system changes. For these procedures it is essential to properly document the results to estimate the long-time behaviour of the system. Lastly, there should be SOP defining thresholds for the results of the tests and defined corresponding actions if these thresholds are exceeded.

# Positron emission tomography Quality control and quantification

Ivo Rausch, PhD

Center for Medical Physics and Biomedical Engineering

# Introduction

**What is “Quality Control for PET” ?**

?

# Introduction

**Quality management system**

Programme that controls how quality is maintained and ensured throughout an organization

**Quality Assurance**

General concepts of actions that ensure that a delivered service meets the requirements

**Quality control**

A specific set of measurements focused on monitoring the performance of a system.

IAEA Human Health Series No. 1

# Introduction

**The product, which is offered is an evaluation of metabolic activity and the corresponding conclusion**

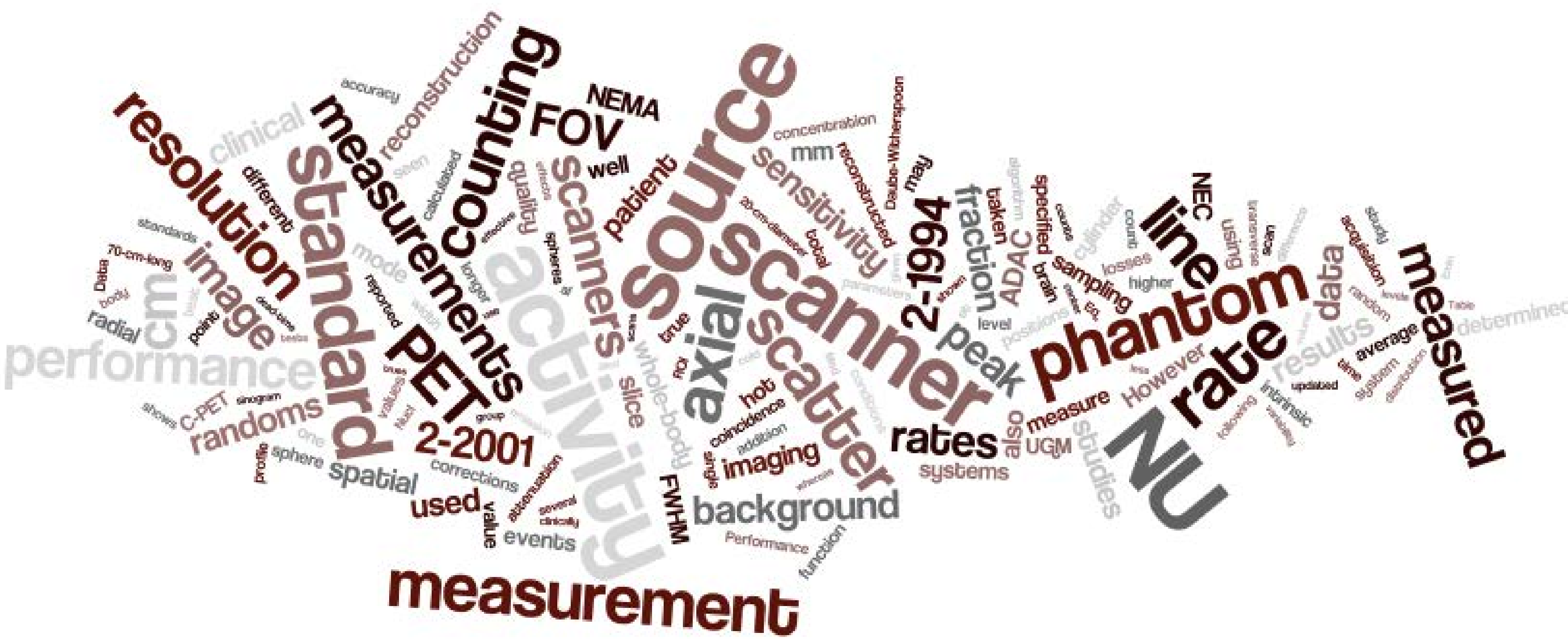
**In other words:**

**a diagnosis**

**This can be influenced by various factors!**

# Quality assurance

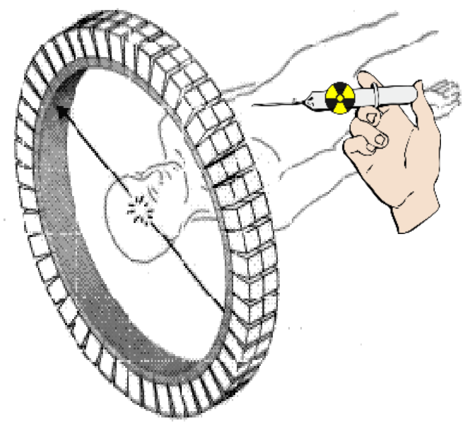
**For a proper „quantitative“ evaluation the whole work flow must be taken into account**

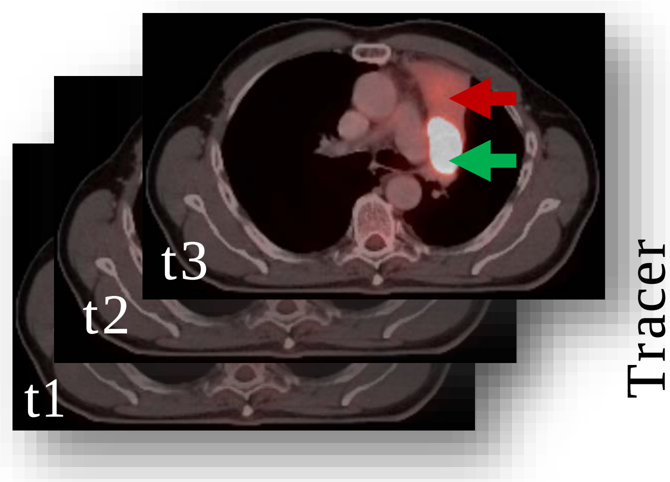


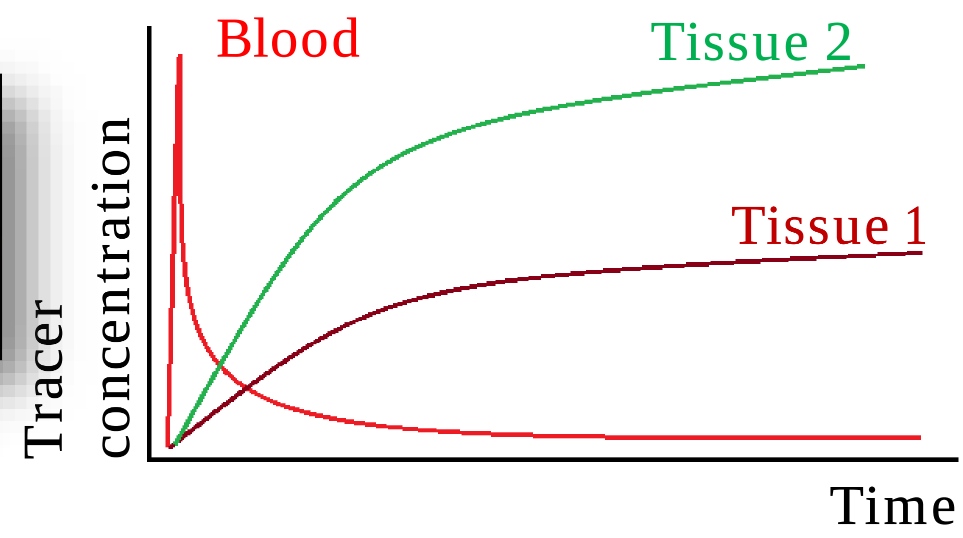
# Quantification of metabolic activity

Clinically relevant is the assessment of metabolic activity.

➢ Requires dynamic measurements and kinetic modeling



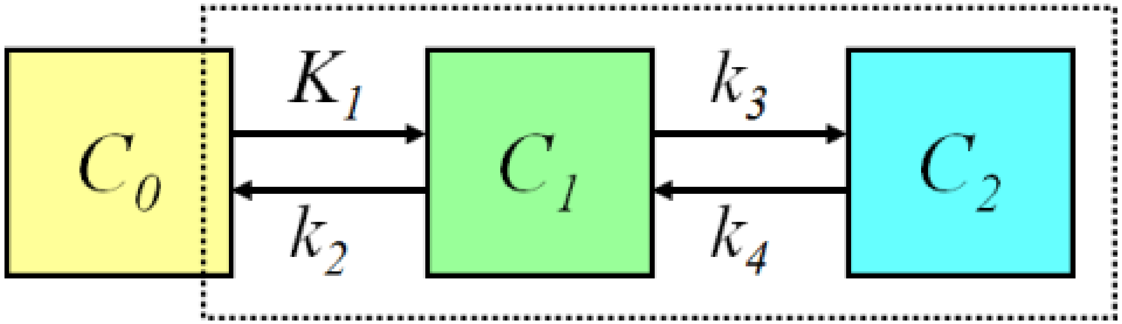


# Quantification

Description of the process with differential equations:

**Kinetic modeling**

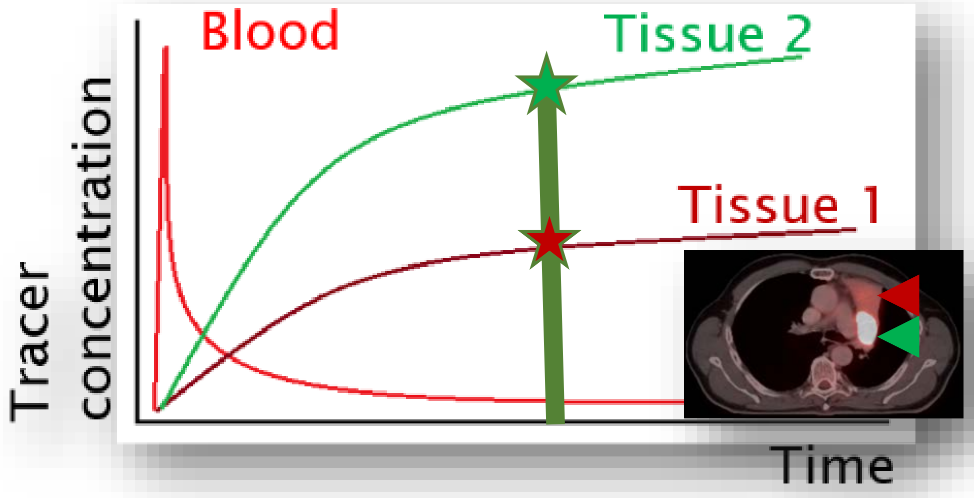



$$\frac{C_1}{} = C_0 * K_1 - (k_2 + k_3)C1 + k_4 * C_2 \ldots$$

Requires: Arterial blood sampling, Dynamic measurements, post-processing….

# Standardized Uptake Value

Tissue uptake after a certain uptake period normalized to an estimate of available tracer




$$SUV = \frac{Act_{VOL}\left[\frac{kBq}{ml}\right]}{\frac{Act_{administrated}[MBq]}{BW[kg]}}$$

**Normalize to**

Body weight

Lean Body mass

SUV: an easy solution to a complicated problem

# Use of SUV

Survey among

128 PET/CT centers:

**Variations in Clinical PET/CT Operations: Results of an International Survey of Active PET/CT Users**

Thomas Beyer[1,2], Johannes Czernin[3], and Lutz S. Freudenberg[1]

[1]*Department of Nuclear Medicine, University Hospita*
[3]*Department of Molecular and Medical Pharmacolog*

Beyer et al. J Nucl Med 2011

- 90% of centers report SUV
- 91% use SUV for therapy response
- 35% use SUV for benign /malign judgment
- SUV sometimes use for grading

**SUV mainly used for therapy response**

# Malignancies in NF1 patients

## Discrimination between malign / benign according to SUV

SUV$_{max}$ Cut-off

...MI 2009: 3.5

SUV: Standard Uptake or Silly Useless Value?

John W. Keyes, Jr.

PET Center, Bowman Gray School of Medicine, Winston-Salem, North Carolina

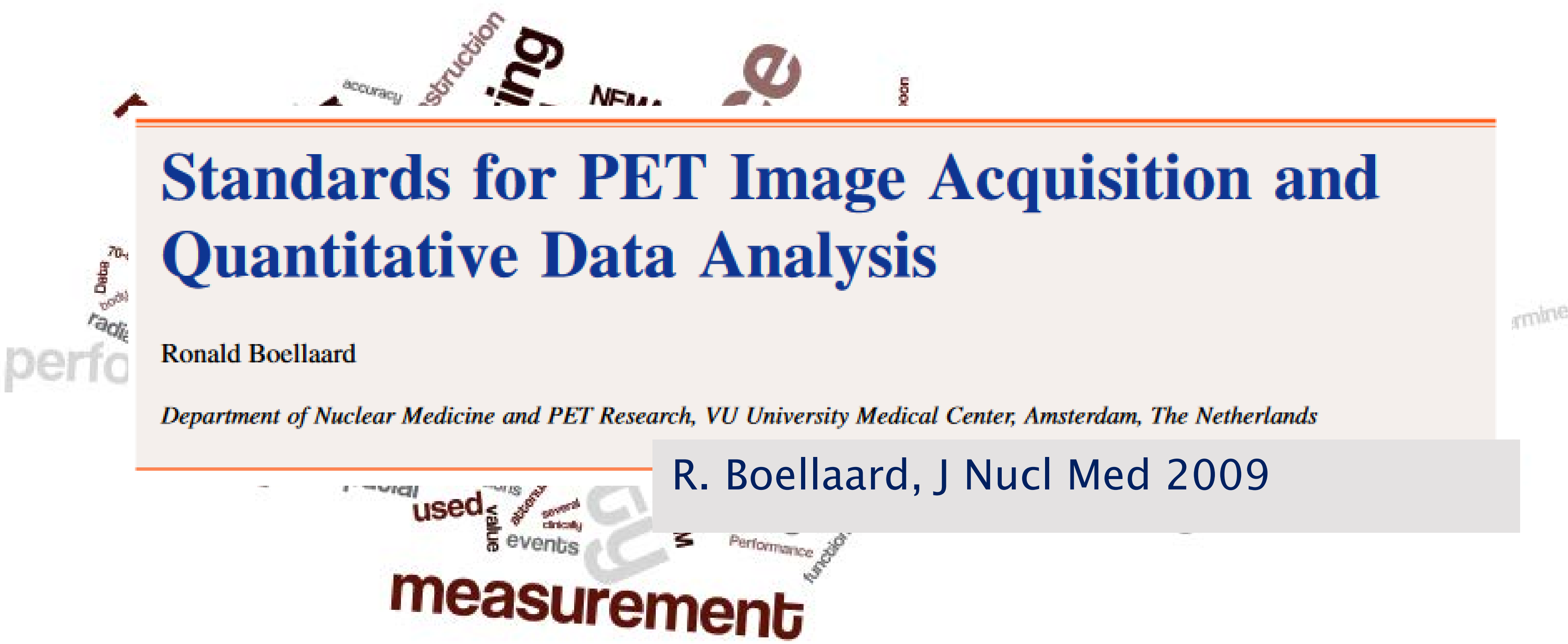
J Nucl Med 1995

Benz... ...1

Tsai et al. J Neurooncol 20... ...0

# SUV influencing factors

SUV is depending on a huge variety of factors




R. Boellaard, J Nucl Med 2009

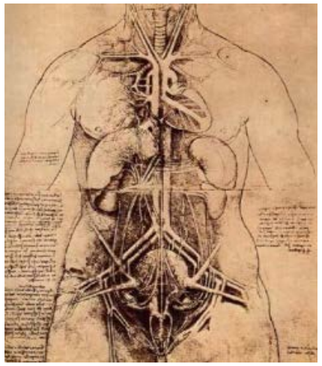
Technical factors / Biological factors / Physical factors

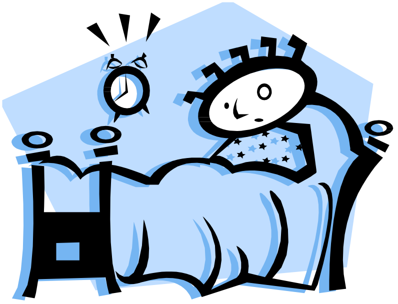
# Technical factors

- Relative calibration between PET scanner and dose calibrator (10%)
- Residual activity in syringe (5%)
- Incorrect synchronisation of clocks (10%)
- Injection vs calibration time (10%)
- Quality of administration (50%)

$\Sigma$: 85%

# Biological factors





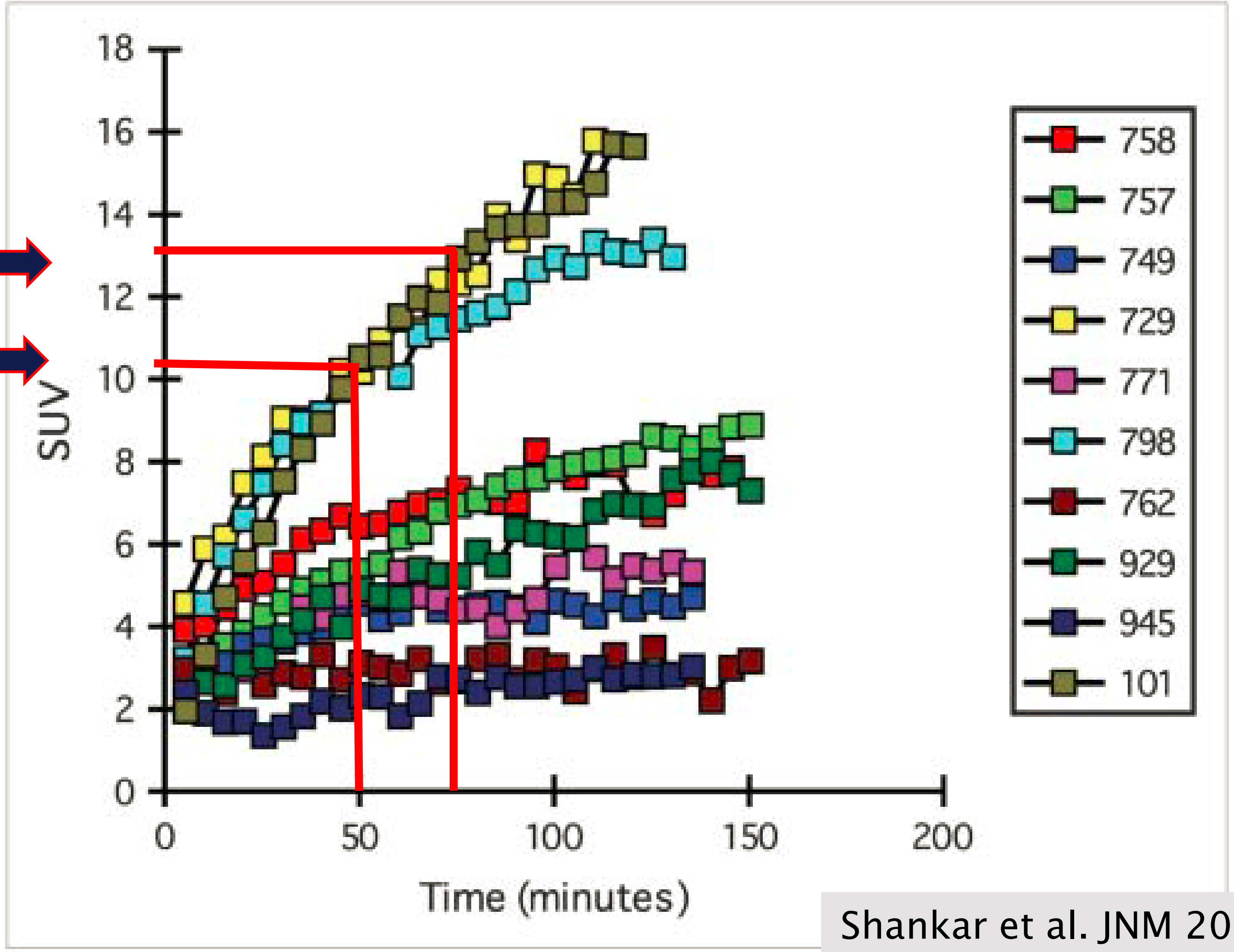
- Uptake period (15%)
- Patient motion and breathing (30%)
- Blood glucose levels (15%)

∑: 60%

# Example: uptake period

**SUV$_{75min}$=13 (+30%)**

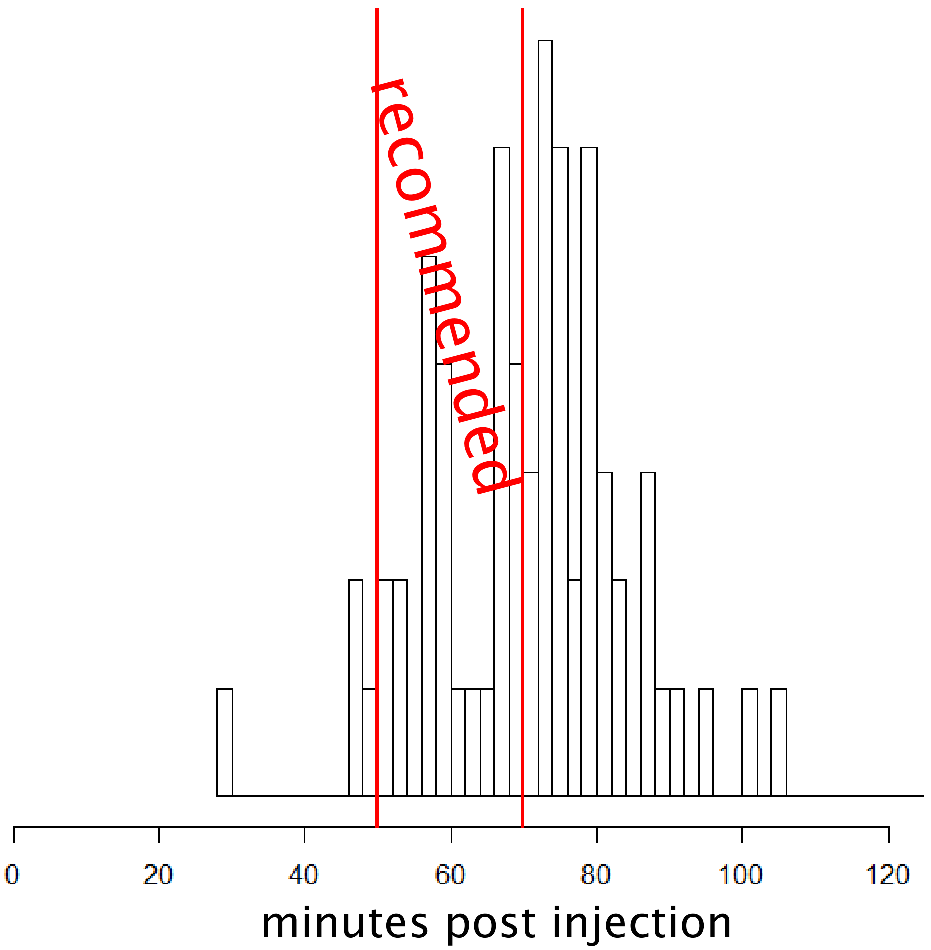
**SUV$_{50min}$=10**




Shankar et al. JNM 2006

# Example: uptake period

Post injection time extracted form the DICOM headers of 70 FDG PET/CT examinations from an undisclosed center




Wrong Cross-calibration translate directly to wrong SUV

# Physics related factors

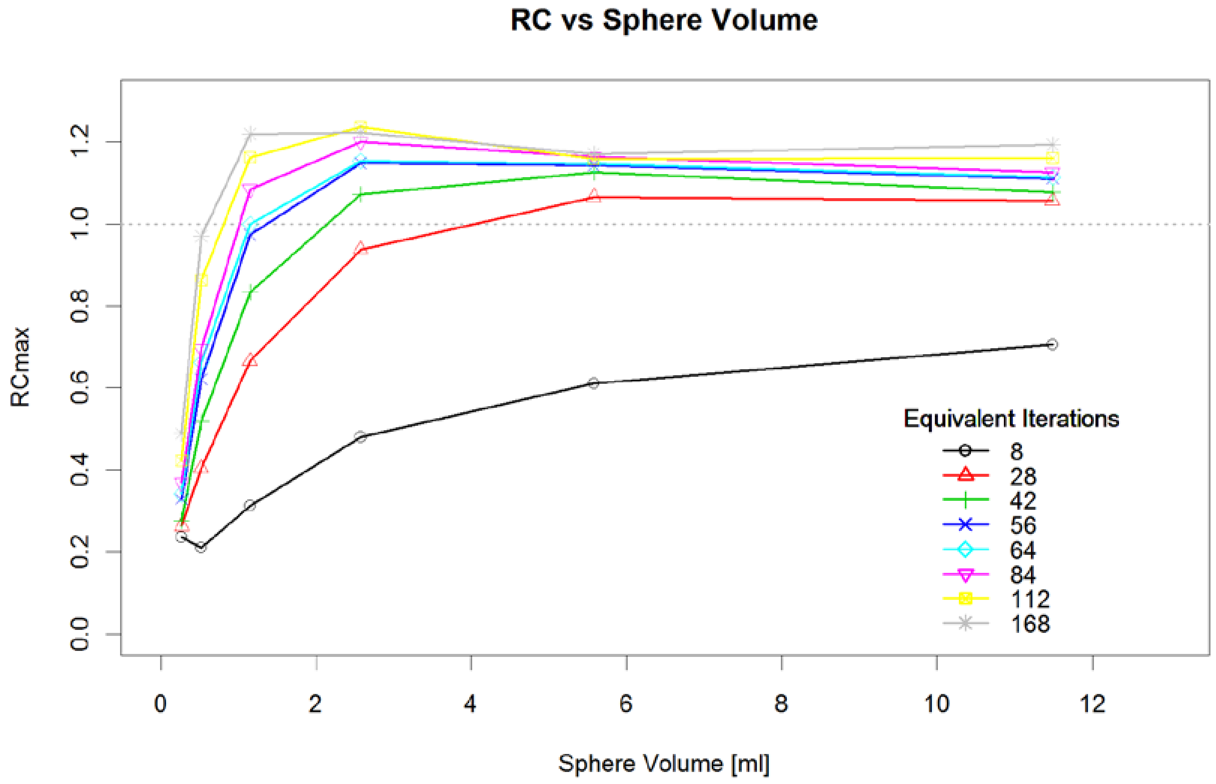
- Scan acquisition parameters (15%)
- Image reconstruction parameters (30%)
- Use of contrast agents (15%)
- ROI (50%)


∑: 110%

# Example: Reconstruction settings

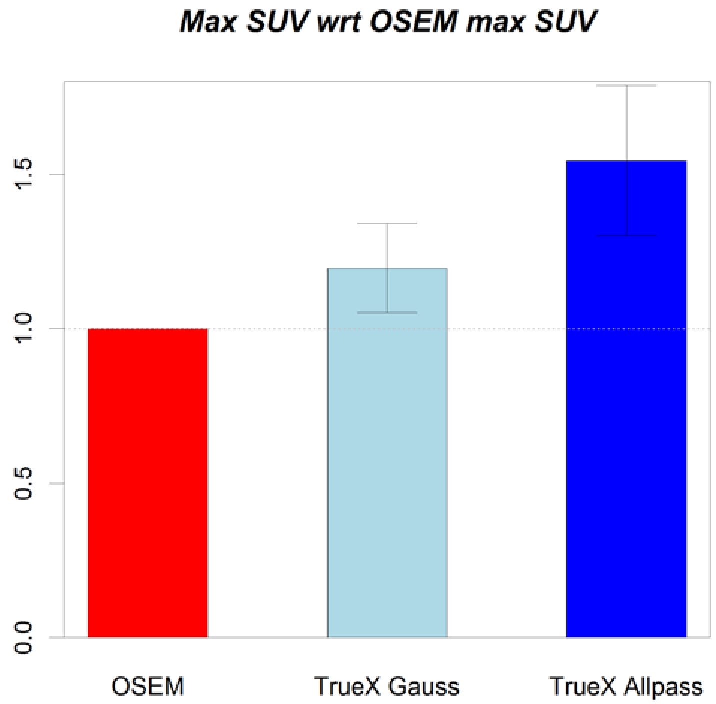
**Algorithm, parameter settings and post filtering influence the outcome**

Different Iterations and Subsets




Same phantom

Different Algorithms




Same patients

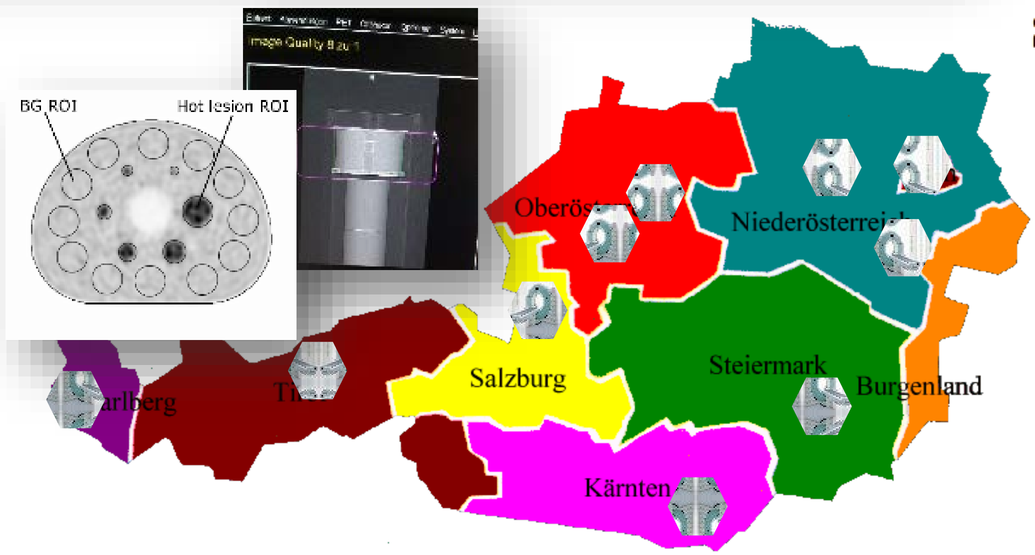
# Example: PET/CT in Austria

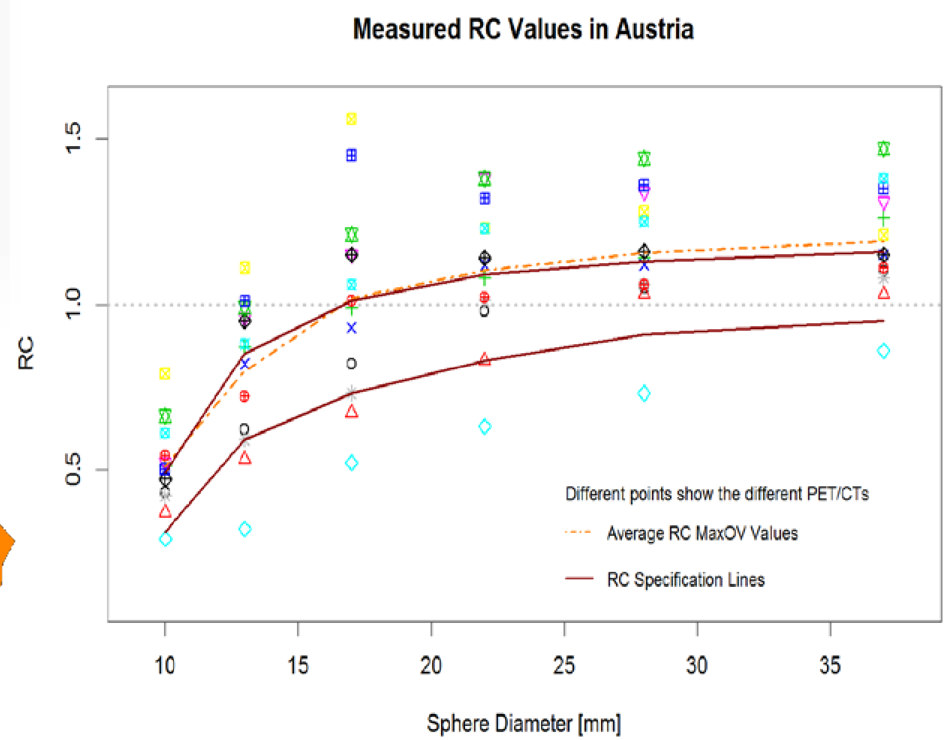
**Variation of system performance, quality control standards and adherence to international FDG-PET/CT imaging guidelines**

**A national survey of PET/CT operations in Austria**

I. Rausch[1,2]; H. Bergmann[1]; B. Geist[2]; M. Schaffarich[1]; A. Hirtl[2]; M. Hacker[2]; T. Beyer[1]
[1]Centre for Medical Physics and Biomedical Engineering, Medical University of Vienna, Austria; [2]Division of Nuclear Medicine, Department of Biomedical Imaging and Image-guided Therapy, Medical University of Vienna, Austria

Nucl med. 2014



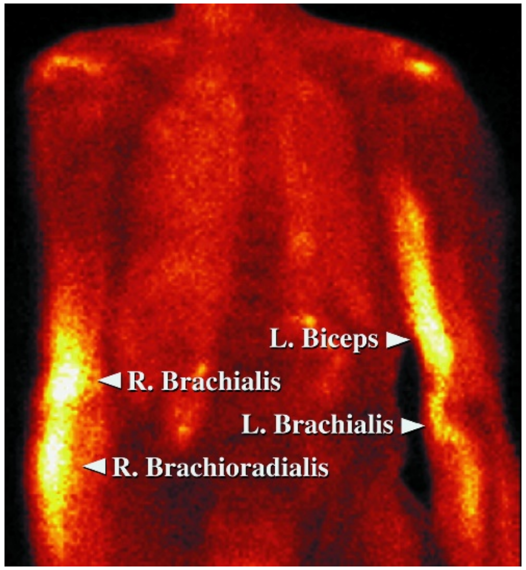

**Substantial differences in quantitative values found between PET/CT centers in Austria**

# Before the tracer is administrated

**Patients instructions**

Example:

(No) exercise
before a study

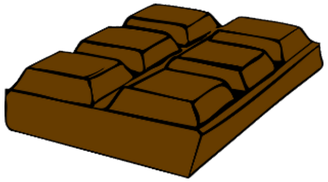



Pappas et al. J Appl Phyiol 2001

**Ensure clear patient instructions**

# Some issues to keep in mind

No food or sugar for at leas 6h prior injection



- To keep blood glucose level low

Adequate pre hydration (e.g. 1l water in the 2h prior injecti

- To ensure sufficiently low FDG in urine (less artefacts)
- Radiation safety

Good practice: Check blood glucose level on arrival to obviate an unnecessary wait

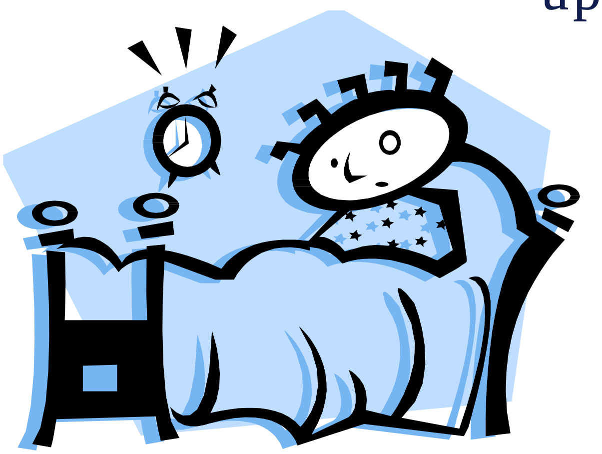
Keep patient warm 30-60 min prior FDG administration

- avoid uptake in brown fat

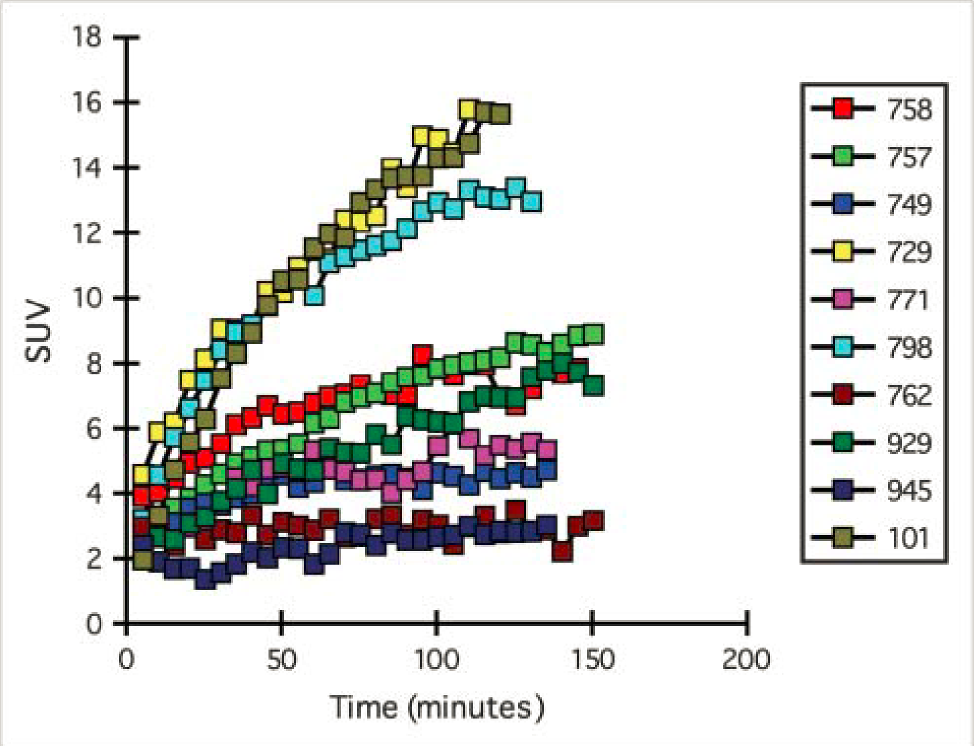
# Before the PET acquisition starts

Patients instructions → Preparation administration

Example:



Different uptake times




Shankar et al. JNM 2006

**Ensure proper patient handling**

# Some issue to keep in mind

Keep patient comfortable post FDG administration

- ➢ Low uptake in brown fat, muscles

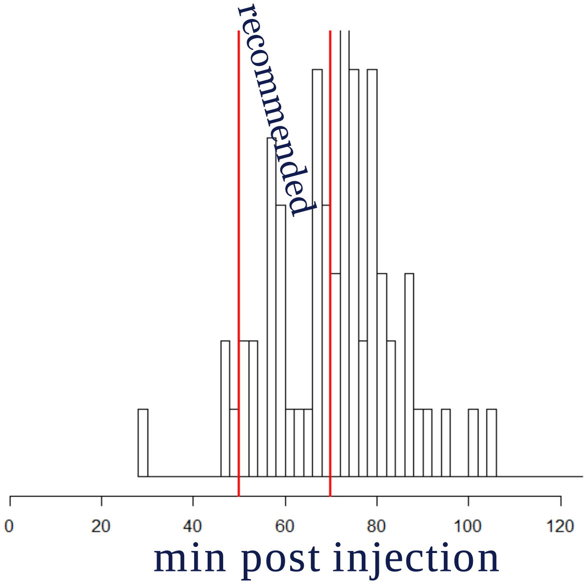
For brain studies no reading, TV, talking and a dimmed light

- ➢ Avoid activating brain regions

Send patient to toilet 5 min before start of the PET study

- ➢ Avoid activity in bladder

Acquisition should start 60 ± 5 min after FDG administration (EANM: ± 10 min)

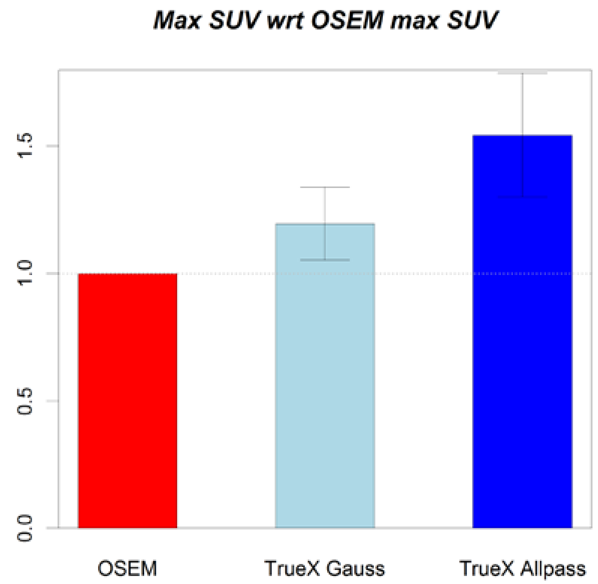


# Acquiring PET data

Patients instructions → Preparation administration → PET/CT Examination

Example:

Different algorithms




Rausch 2011

**Ensure standardized acquisitions**

# Some issue to keep in mind

Injected activity and acquisition time should be appropriate

- ➢ Collect enough counts to not get problems with noise

Reconstruction settings need to be standardized

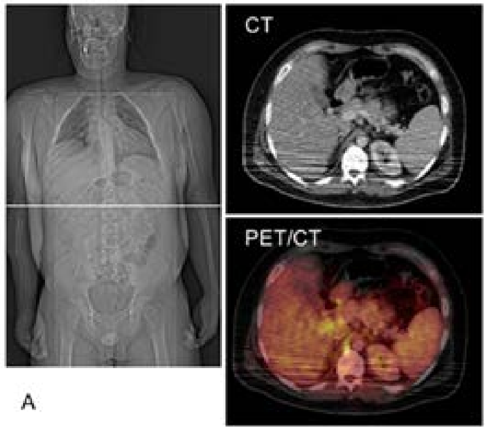
- ➢ Maintain comparability of results

Use appropriate positioning devices

- ➢ Avoid patient motion

Keep an eye on imaging artifacts

- ➢ Beam hardening due to implants, motion artifacts…




A

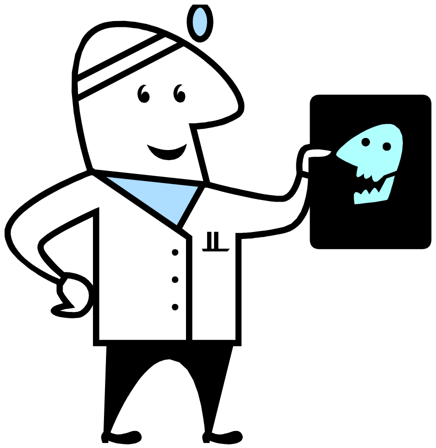

B

Mohnike et al. PET/CT Atlas, Springer 2011

# Acquisition

Patients instructions → Preparation administration → PET/CT Examination → Evaluation & Interpretation

Example:



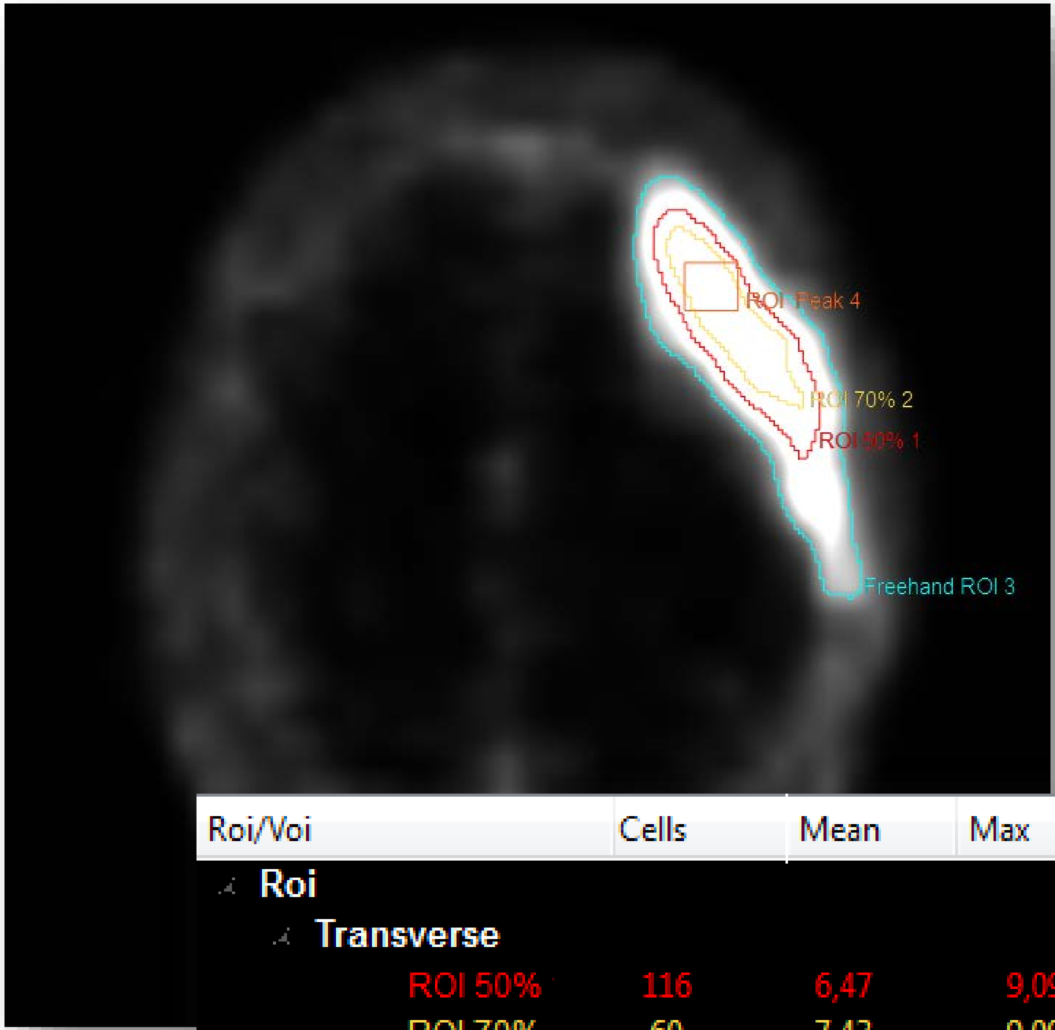
- Different SUV values can be used:
  - Maximum SUV
  - Mean SUV (Threshold segmented)
  - Peak SUV
  - Lean body mass SUV

**Ensure standardized reporting**

# Example: Region of Interest

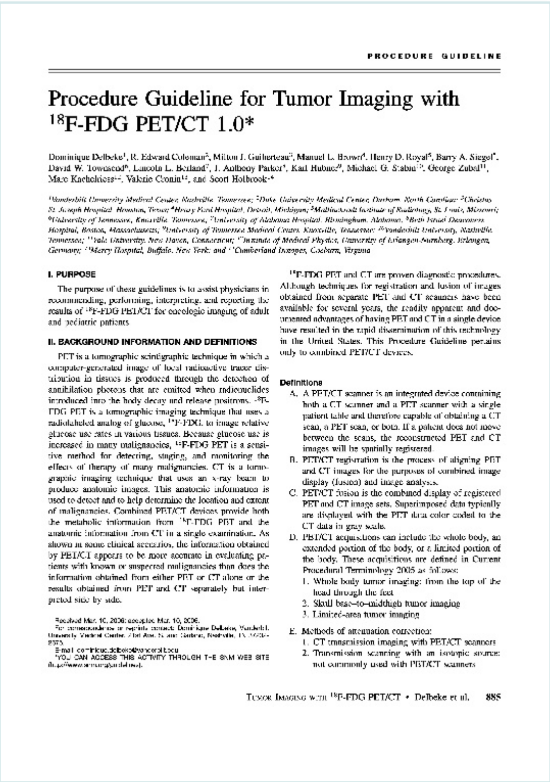
Different SUV measures

- MAXIMUM Pixel value
- MEAN value of a ROI
  - Hand drawn ROIs
  - Fixed size ROIs (e.g. "SUV Peak")
  - Threshold based ROIs
  - Advanced algorithms…




| Roi/Voi | Cells | Mean | Max |
|---|---|---|---|
| Roi | | | |
| Transverse | | | |
| ROI 50% | 116 | 6,47 | 9,09 |
| ROI 70% | 60 | 7,43 | 9,09 |
| Freehand ROI | 269 | 4,50 | 9,09 |
| ROI Peak | 16 | 7,94 | 9,09 |

# Guidelines


PROCEDURE GUIDELINE

Procedure Guideline for Tumor Imaging with $^{18}$F-FDG PET/CT 1.0*

I. PURPOSE

II. BACKGROUND INFORMATION AND DEFINITIONS

Delebeke, JNM 2006


GUIDELINES

FDG PET and PET/CT: EANM procedure guidelines for tumour PET imaging: version 1.0

Abstract

Introduction

Boellaard, EJNM 2010


FDG-PET/CT in oncology*

German Guideline

FDG-PET/CT in der Onkologie*

Leitlinie

Keywords

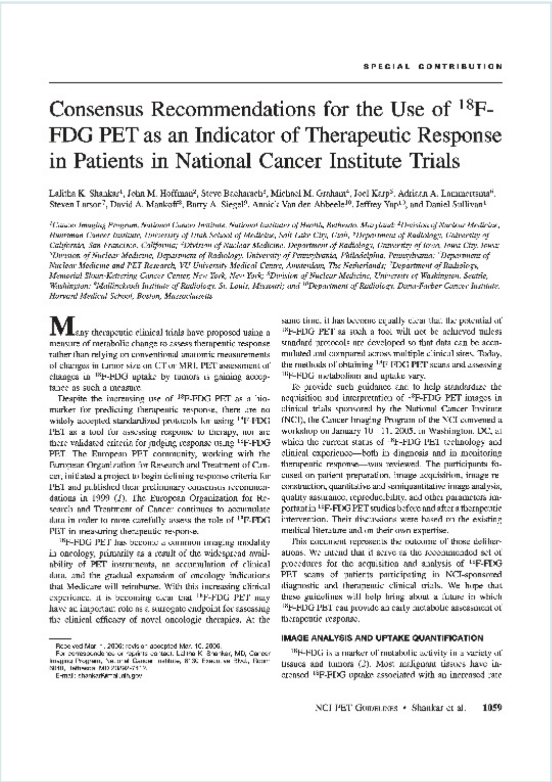
Summary

Schlüsselwörter

Zusammenfassung

Grundlagen, Definitionen

Krause, Nukmed 2007


SPECIAL CONTRIBUTION

Consensus Recommendations for the Use of $^{18}$F-FDG PET as an Indicator of Therapeutic Response in Patients in National Cancer Institute Trials

IMAGE ANALYSIS AND UPTAKE QUANTIFICATION

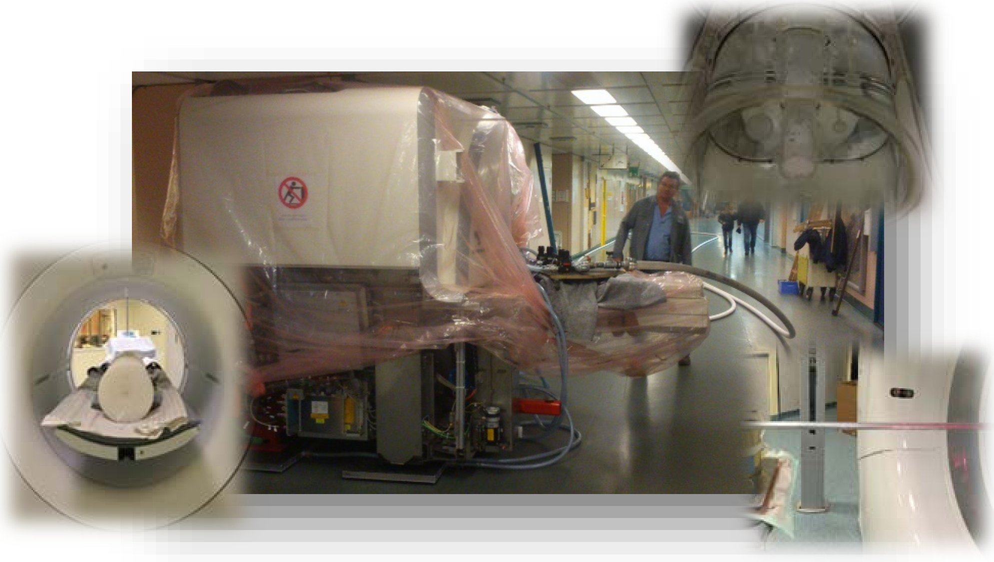
Shankar, JNM 2006

"Guide us through the guidelines !"

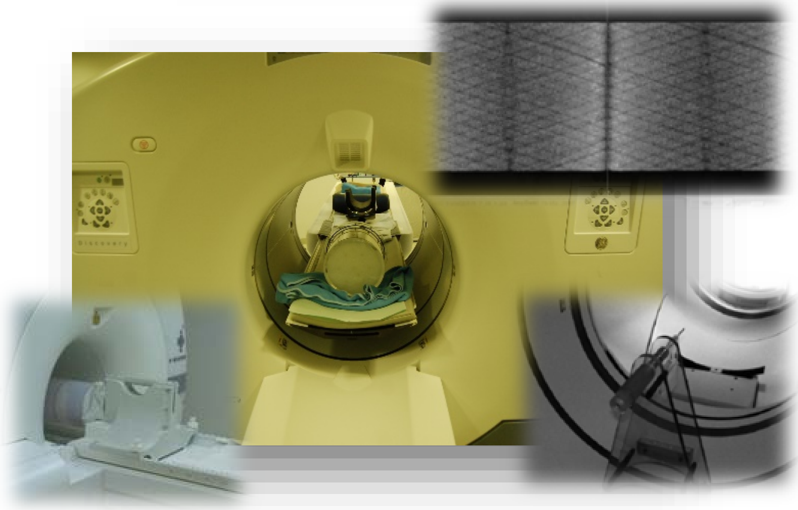
# Quality Control

Consists of:

- Acceptance testing



- Routine QC procedures



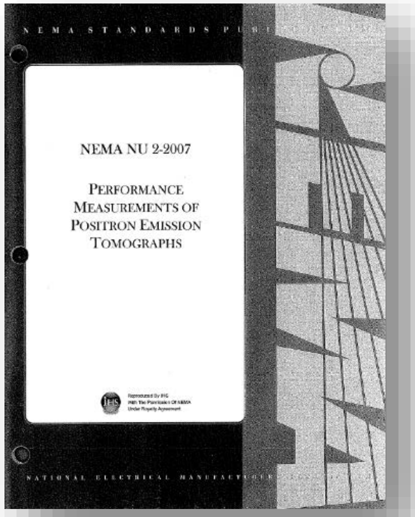
# Acceptance testing

“After installation,…, a nuclear medicine instrument must undergo thorough and careful acceptance testing, the aim being to verify that the instrument performs according to its specifications and its clinical purpose.”

Busemann S. et al. EJNMMI 2010; 37:662–671

Testing

- Standards like NEMA NU2 or IEC performance standards
- Clinical Settings (!?)
- Additional tests for individual components
- Reference data for future QC tests
- Basically the same at end of warranty



# Acceptance: Spatial resolution

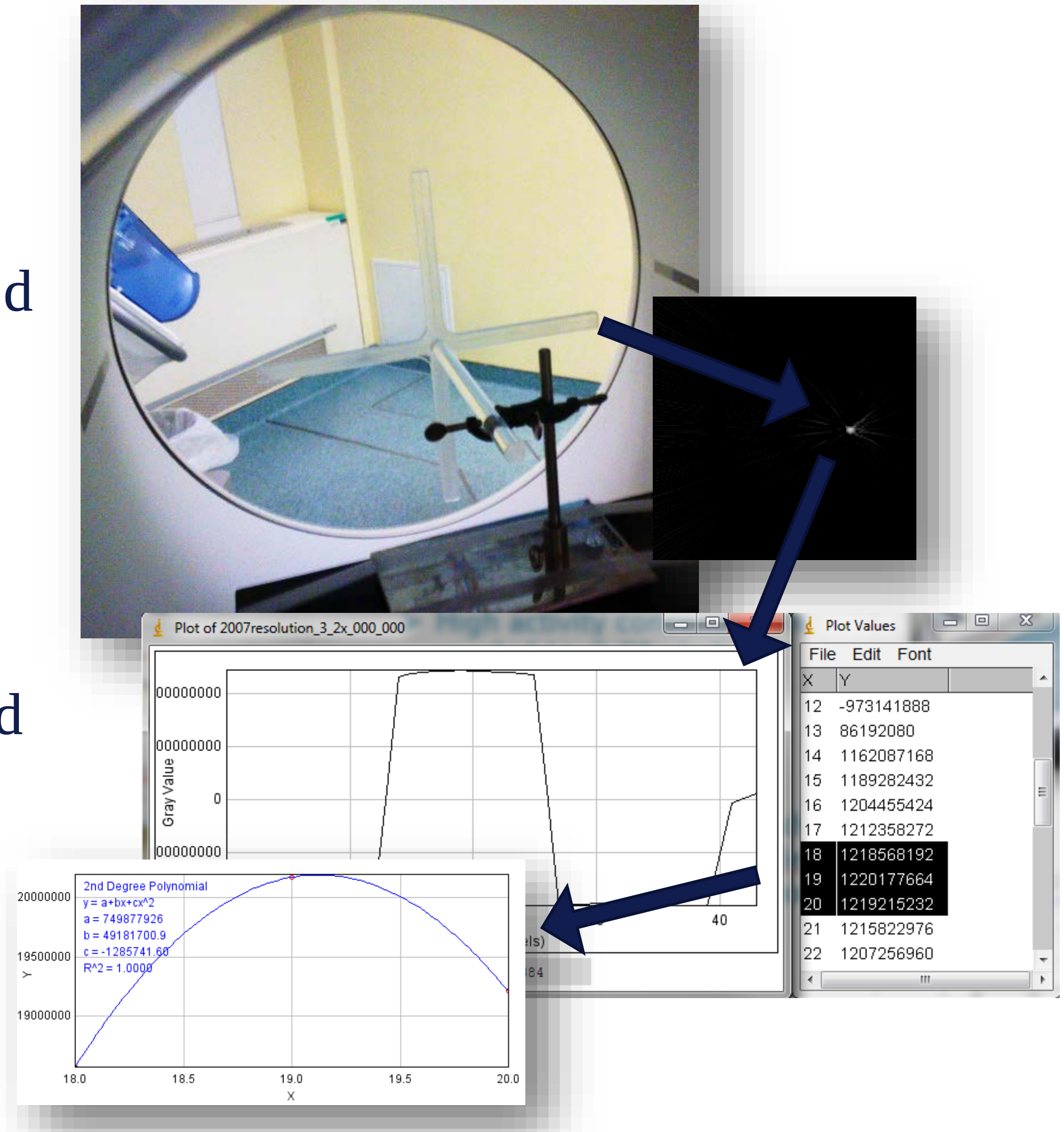
Point source in air
- best possible performance

Collect at least 1 M counts
- High activity concentration needed ( ≥ 2 GBq/ml)

Reconstruction using FBP
- Comparability

Can be reconstructed using advanced reconstructions (e.g. PSF modeling)
- Enhanced special resolution

Report FWHM and FWTM



# Acceptance: Sensitivity

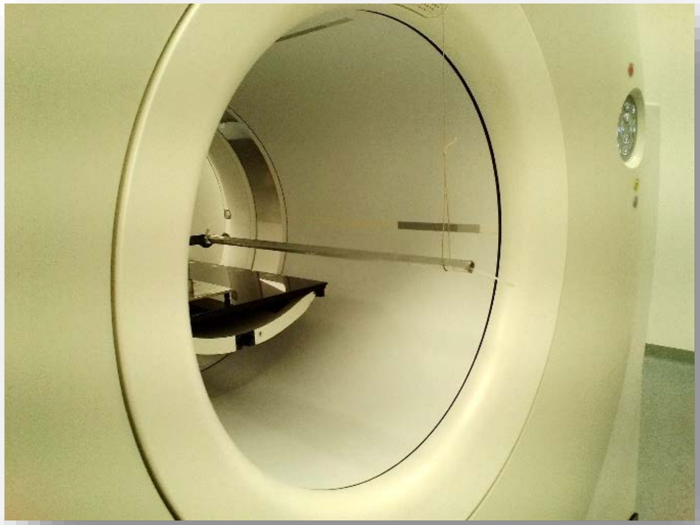
Count rate of true events for a given activity

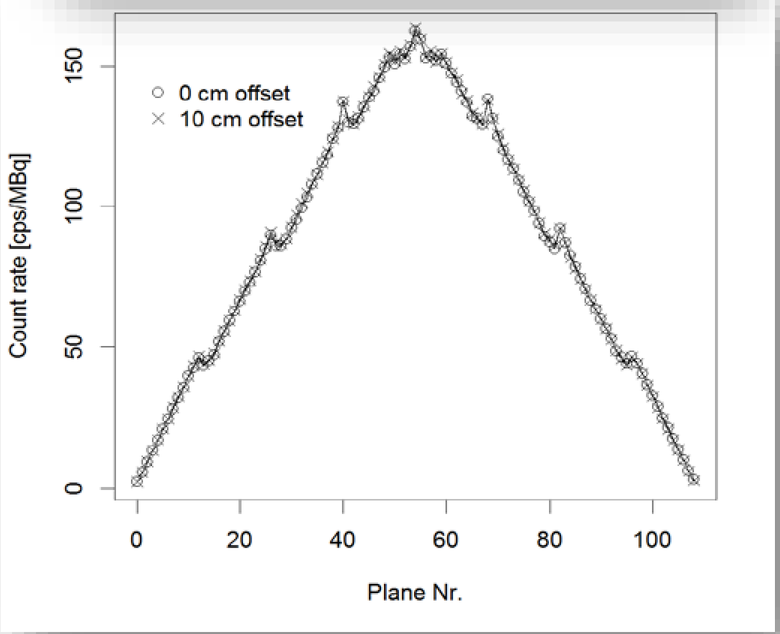
Line source (~6 MBq) surrounded by aluminium tubes (ensure annihilation) with known thickness

Acquisition of 5 images (>10 k counts; ~ 5 min each) with different numbers of Al-tubes @ centre of FOV and 10 cm radial offset

Extrapolation of the data to a zero-thickness Al-tubing

Sensitivity = ∑ count rate / activity





# Acceptance: Count rate performance

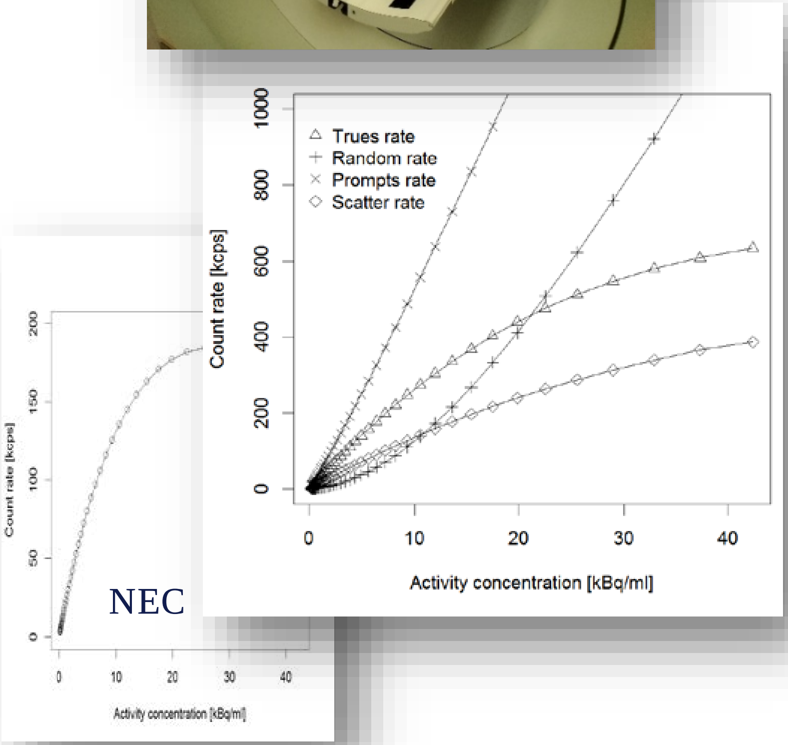
Scatter fraction: the systems sensitivity to scattered radiation (**energy resolution**)

Count losses and random rate: the systems ability to measure highly radioactive sources (timing resolution and dead time)

Noise equivalent count rate (NEC): amount of trues (no scatter and randoms) for similar SNR as with scatter and randoms

Starting activity to be beyond NEC peak (>1 GBq in ~ 5ml)

Evaluation described in NEMA NU2




Count rate performance to asses system behavior with high activities

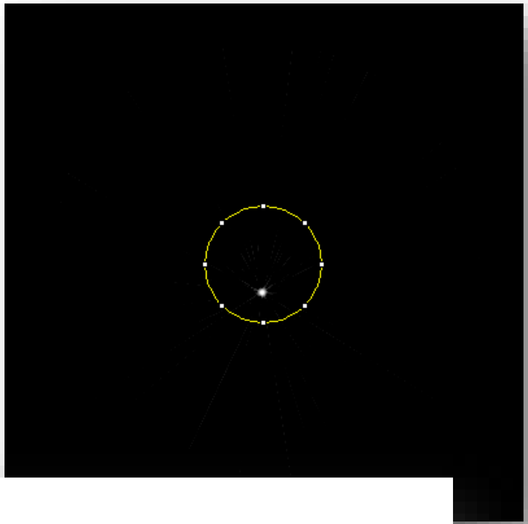
# Acceptance: Accuracy

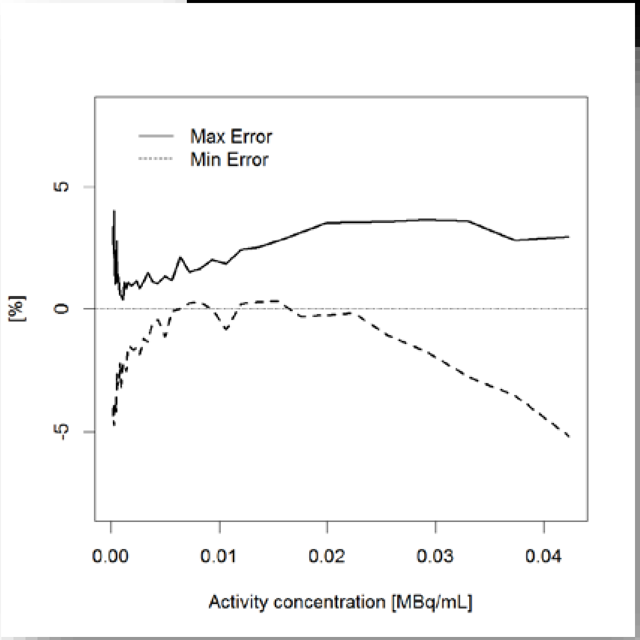
To assess the accuracy of dead time looses and random event.

Count rate performance measurements are used

Reconstruction using “clinical standard settings” (FBP ?)

Report “relative count rate error”: differences of measured count rate to expected count rate in [%]






Systems ability to replicate the true activity

# Acceptance: Image quality

To compare image quality of different systems in a standardized way

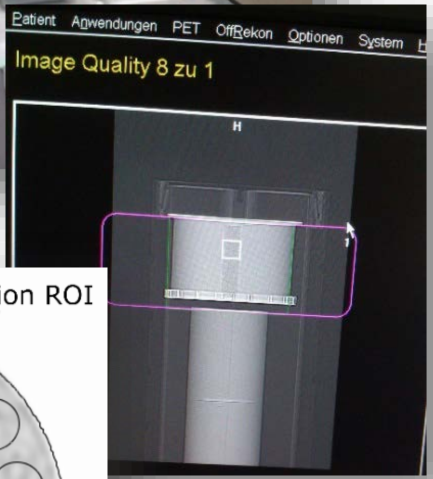
Simulating a total body imaging study: cold- and hot lesions, non uniform attenuation; scatter form outside the FOV

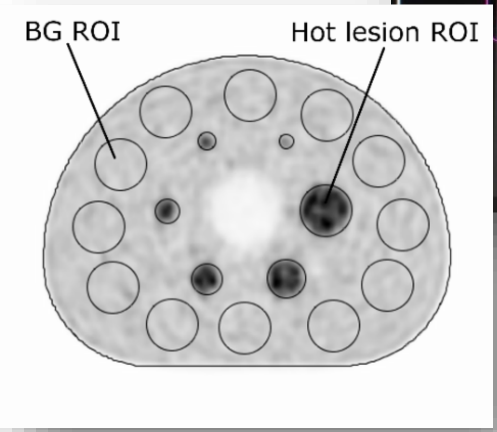
Scanned three times for more stable values

Acquisition time axial FOV dependent !!!

$$T = \frac{30min}{100cm} * axial\ step$$

Report: contrast recovery; BG variability and Lung residual




Standardized evaluation of image quality

# Routine quality control

Simple routine tests specific to imaging system

Sensible to system changes

Detailed SOPs should be available on-site

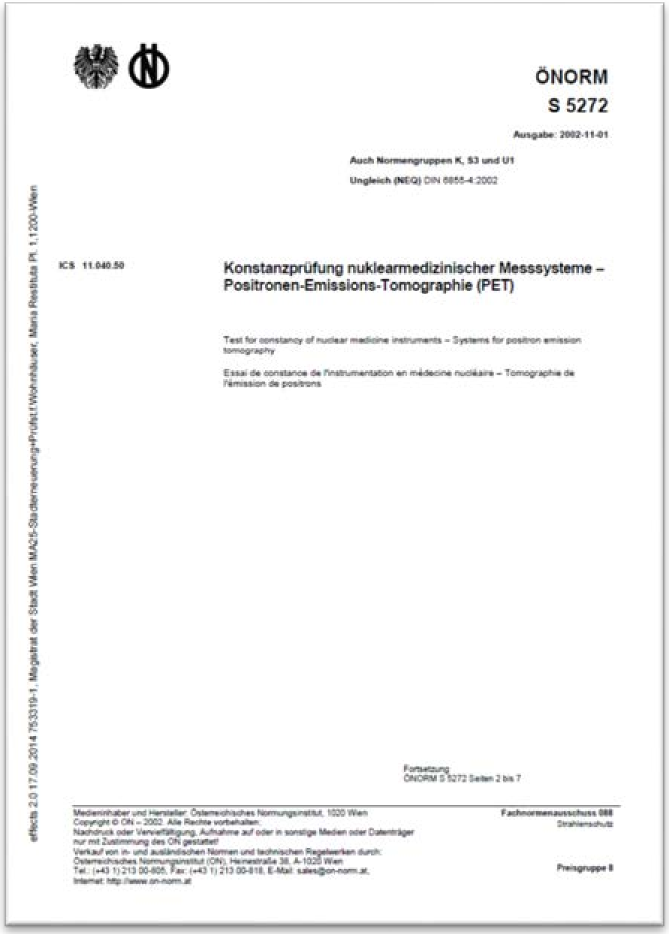
Proper documentation to estimate long time behavior

Thresholds (manufacturers recommendations) and corresponding actions if exceeded in SOP

Define a responsible person

Ensure daily quality in routine operation

# Guidelines



ÖNORM
S 5272

Ausgabe: 2002-11-01

Auch Normengruppen K, S3 und U1

Ungleich (NEQ) DIN 6855-4:2002

ICS 11.040.50

Konstanzprüfung nuklearmedizinischer Messsysteme – Positronen-Emissions-Tomographie (PET)

Test for constancy of nuclear medicine instruments – Systems for positron emission tomography

Essai de constance de l'instrumentation en médecine nucléaire – Tomographie de l'émission de positrons

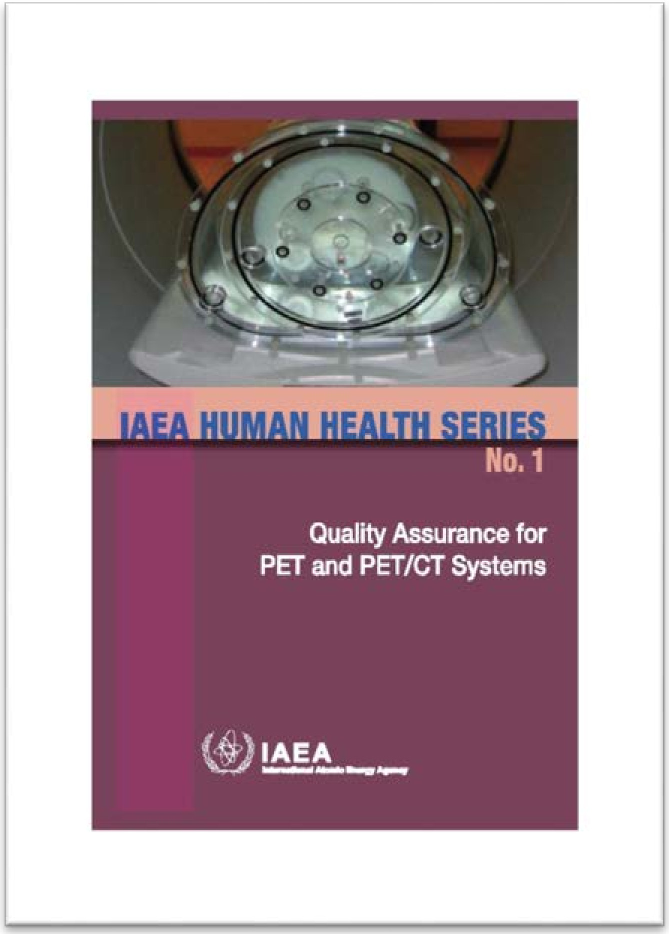
Fortsetzung ÖNORM S 5272 Seiten 2 bis 7

National guidelines

GUIDELINES

Routine quality control recommendations for nuclear medicine instrumentation

EANM guidelines




IAEA guidelines

**Several guidelines exist**

# EANM recommendations

| Test | Purpose | Frequency |
|---|---|---|
| Physical inspection | Check gantry covers and patient handling system | Daily |
| Daily QC | Test proper functioning of detector modules | Daily |
| Uniformity | Axial uniformity across image planes | After maintenance / normalization |
| Normalization | System response to activity in the FOV | Variable (min 6-monthly) |
| Calibration | Calibration factor from voxel to true activity | Variable (min 6-monthly) |
| Spatial resolution | Spatial resolution | Yearly |
| Sensitivity | Volume response to a source of activity concentration | Monthly |
| Image quality | check hot and cold lesions | Yearly |

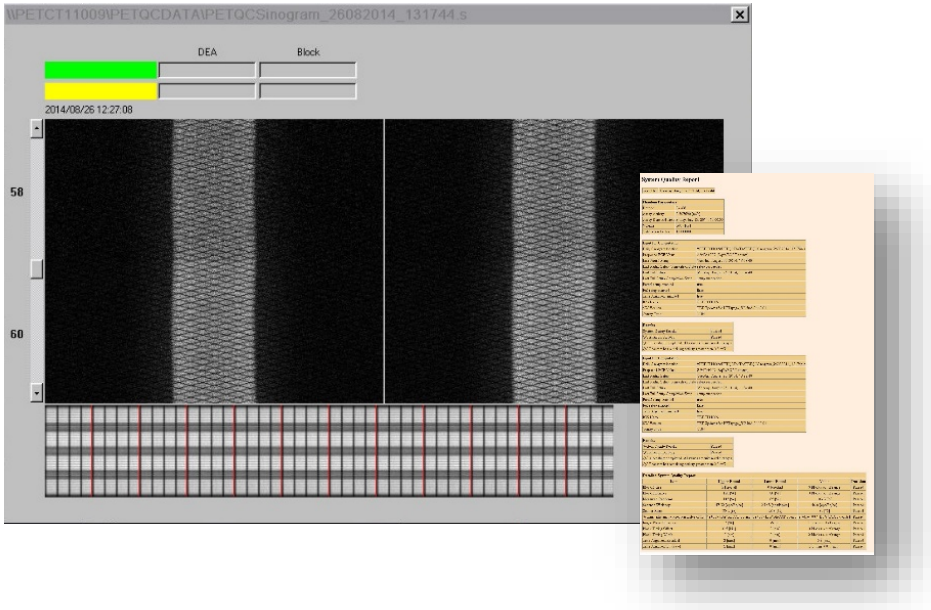
Buseman Sokole E. et al. EJNMMI 2010; 37:662–671

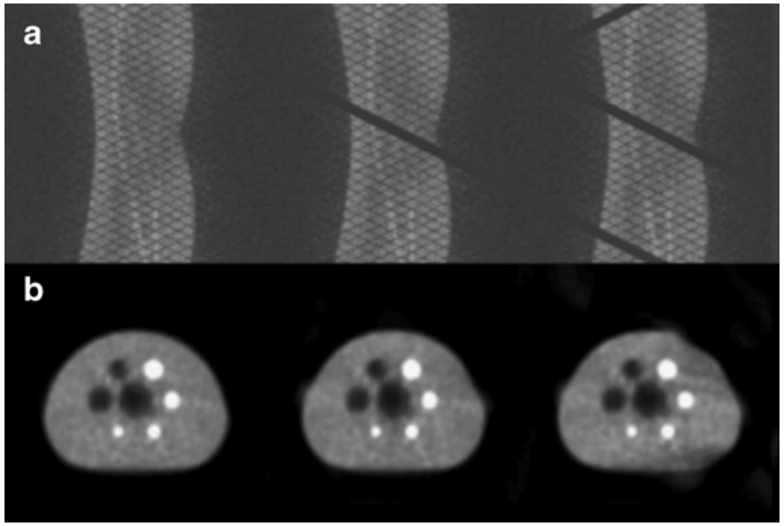
# Routine QC in PET: Daily QC

Different vendors – different methods

$^{68}$Ga/$^{68}$Ge cylinder

$^{22}$Na point source




Elhami E. Mol Imaging Biol 2011

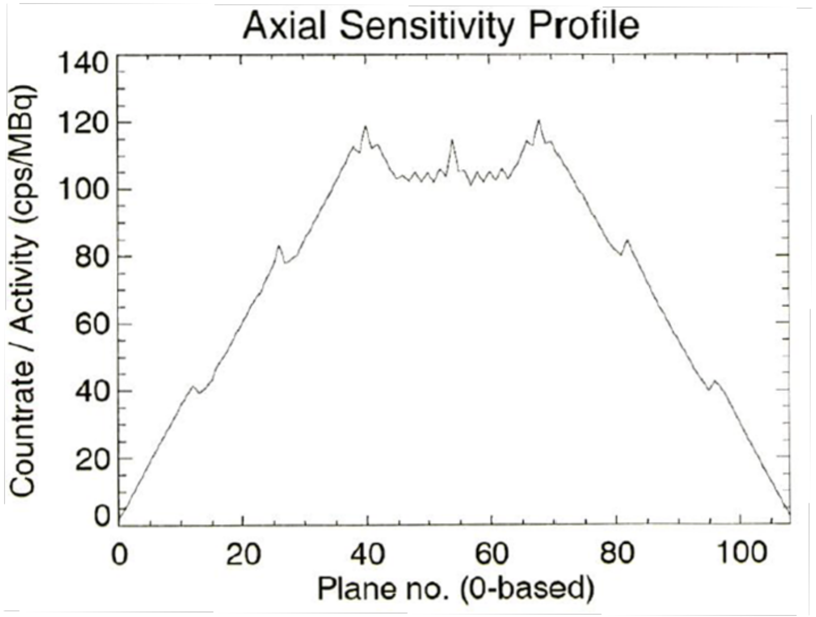
Detector failure can be seen in the sinogram as black lines (a)

Detector failure impacts image quality (b)

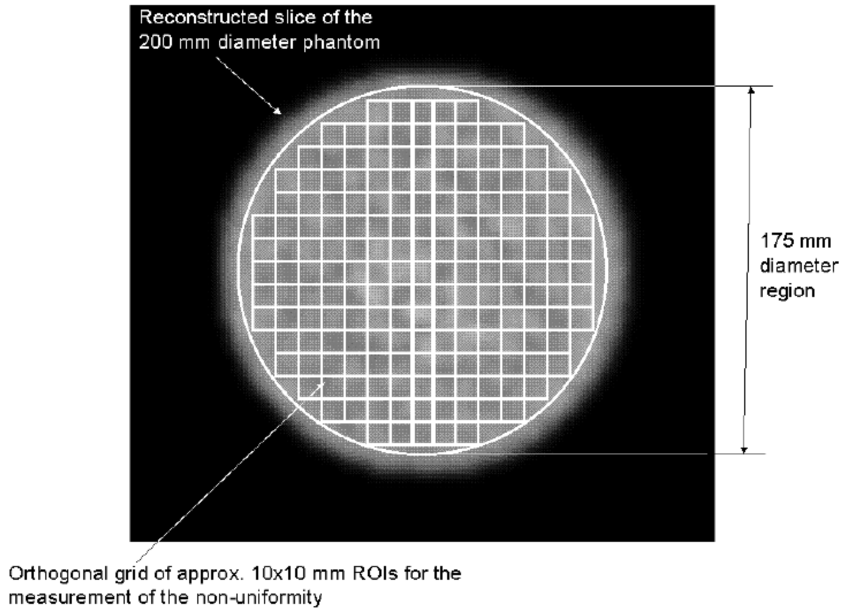
**Assess constancy of detector performance to pick up sudden changes**

# Routine QC in PET: Uniformity

Axial uniformity




In-plane uniformity




IAEA Human Health Series No. 1

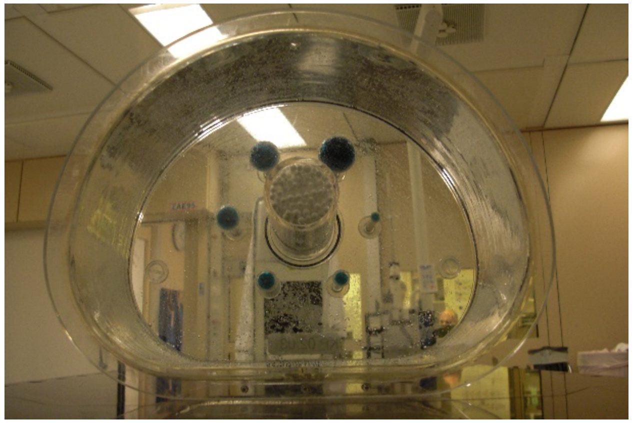
Corrective action: Normalization (+ Calibration)

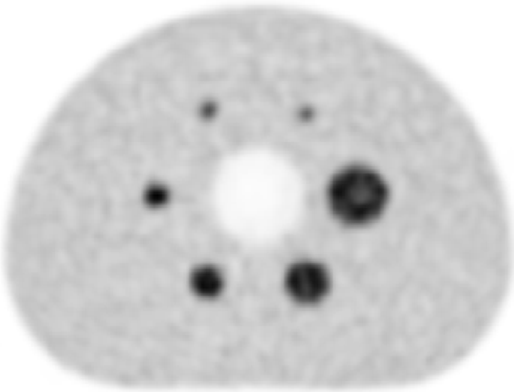
Test if activity is uniform across all planes / within a plane

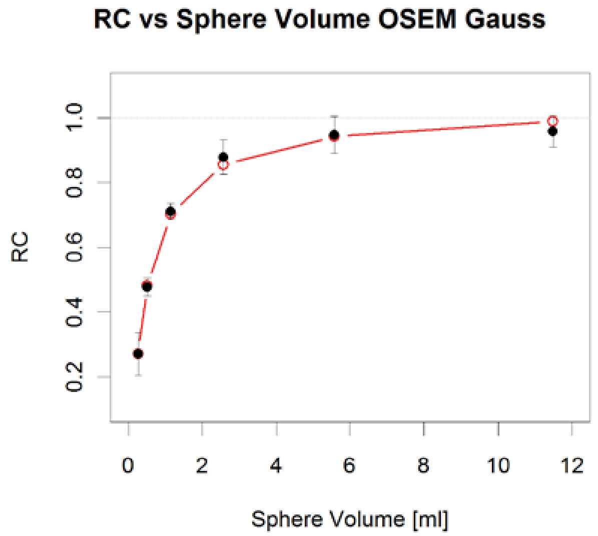
# Routine QC in PET: Image quality

Can be done with the NEMA/IEC Image quality phantom

Evaluation of Recovery Coefficients or Contrast








Evaluate image quality in standardized conditions

# Routine QC in CT

| Test | Purpose | Frequency |
|---|---|---|
| X-ray CT – daily | Daily procedures due to manufacturer`s recommendation | Daily |
| X-ray CT – numbers | Determine CT number accuracy | Monthly |
| X-ray CT – alignment | Determine 3-D alignment of PET and CT | At least monthly |
| X-ray CT – performance | Check according to national radiation safety | As advised |

Buseman Sokole E. et al. EJNMMI 2010; 37:662–671

QC of hybrid Nuc/CT systems = $QC_{Nuc} + QC_{CT}$

# Additional Tests

- Clock syncronization
- Cross calibration

(of PET system and on-site dose callibrator)

Extend QC to include quantification

# Clock syncronization

5 minutes offset imply:

- $^{18}$F - 3% difference
- $^{68}$Ga - 5% difference
- $^{11}$C - 16% difference
- $^{15}$O - 82% difference


"The clocks within the department, within all instruments and all computers must be synchronized"

Buseman S. et al. Routine QC recommendations for nuclear medicine instrumentation, EJNMMI 2010

Check clock synchronization at least weakly

# Cross Calibration

$$SUV = \frac{Act_{VOL}\left[\frac{kBq}{ml}\right]}{\frac{Act_{administrated}[MBq]}{BW[kg] * CC_{factor}}}$$

$$= \frac{Act_{VOL}\left[\frac{kBq}{ml}\right]}{\frac{Act_{administrated}[MBq]}{BW[kg]}} * CC_{factor}$$

≠?

Wrong Cross-calibration translate directly to wrong SUV

# Cross Calibration

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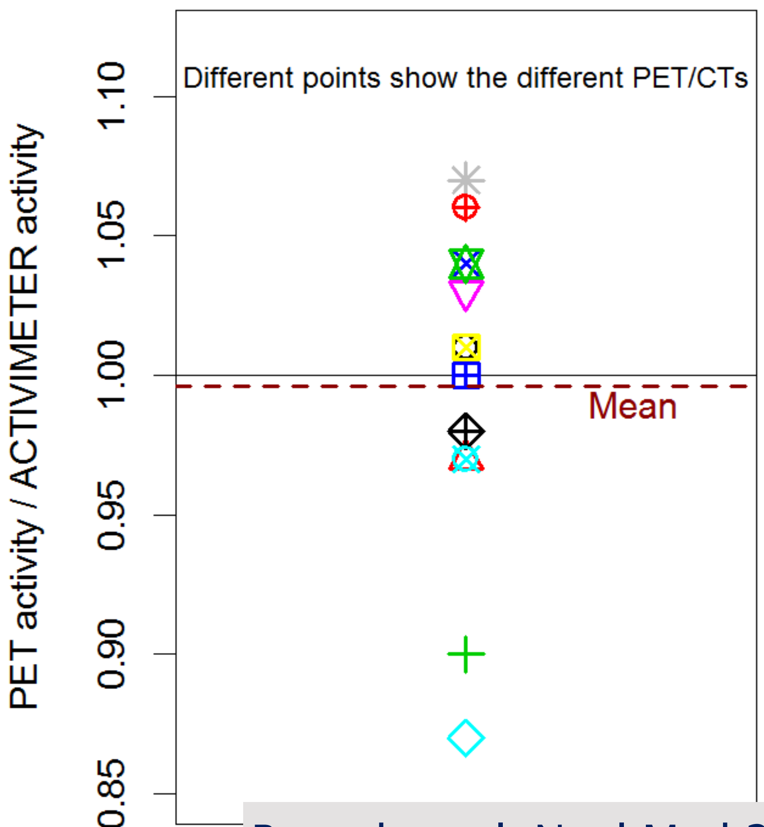
Cross Calibration Factors in Austria




Rausch et al, Nucl Med 2014

**Wrong Cross-calibration translate directly to wrong SUV**

# Summary

Regular QC is important

Proper Quality Assurance is essential

Don`t be afraid of guidelines

Adopt standardized procedures and a proper documentation for QC at your site

Standardized procedures and a proper documentation is essential for QC

# Keep your working-horse working

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