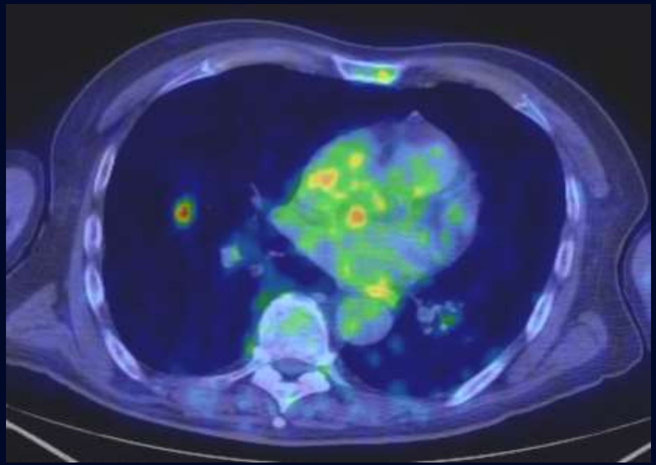
Medical-image Segmentation

Medical Imaging & Big Data | Data Science
Università degli studi di Milano-Bicocca

2019



Tumour

Complex biological object

Macroscopically

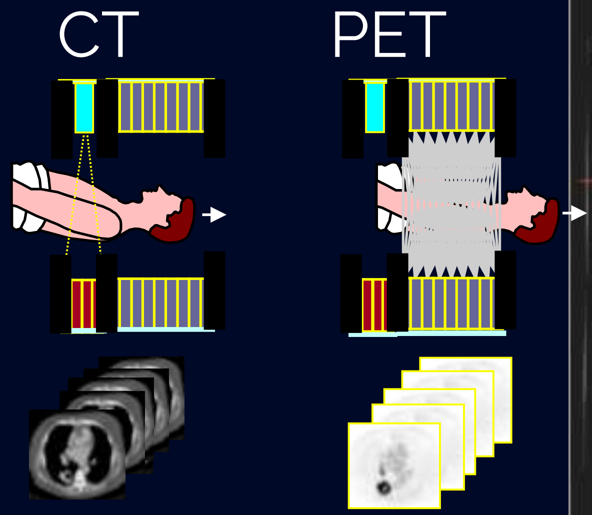
Heterogeneaus shape, density, global metabolism

Microscopically

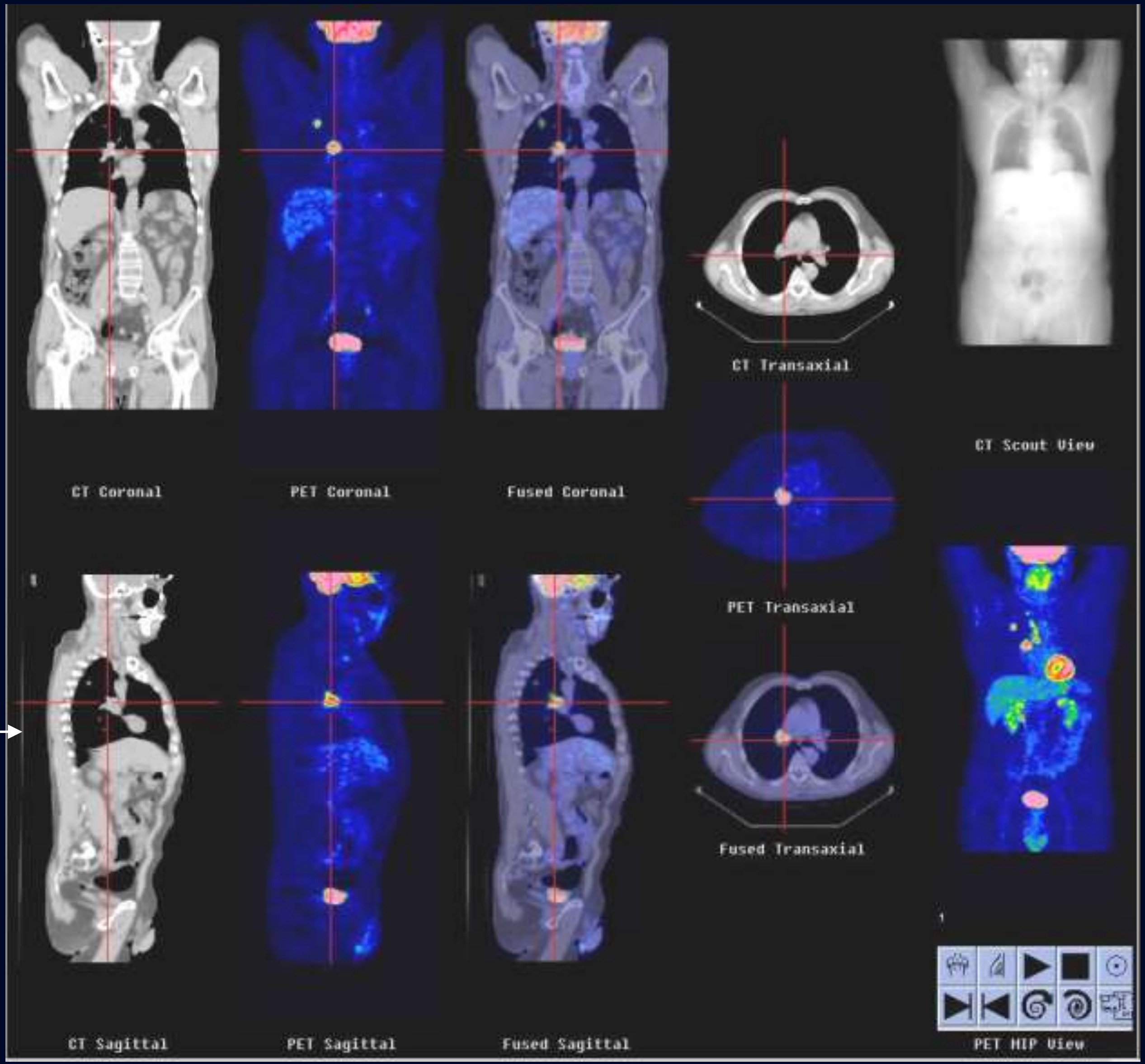
Cell proliferation, hipoxia, noeangiogenesis

PET/CT in oncology

[18F]FDG PET-CT



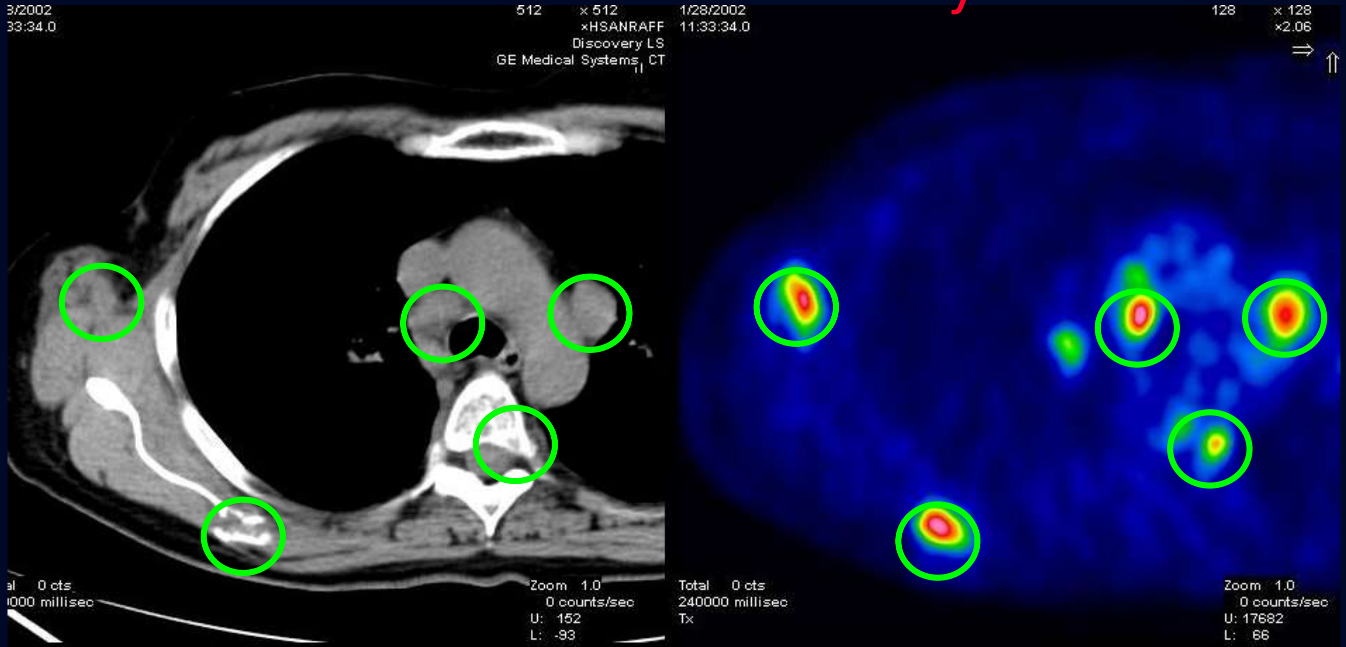
HSR Milan



PET/CT in oncology

- ANATOMICAL LOCATION
- CHARACTERIZATION
- CHOICE OF THERAPY
- THERAPY MONITORING

Qualitative analysis



Z.M. 49 aa
Operated breast cancer with rising of CA 15.3

Anatomical location

PET vs	PET-TC
84,3%	96,6%

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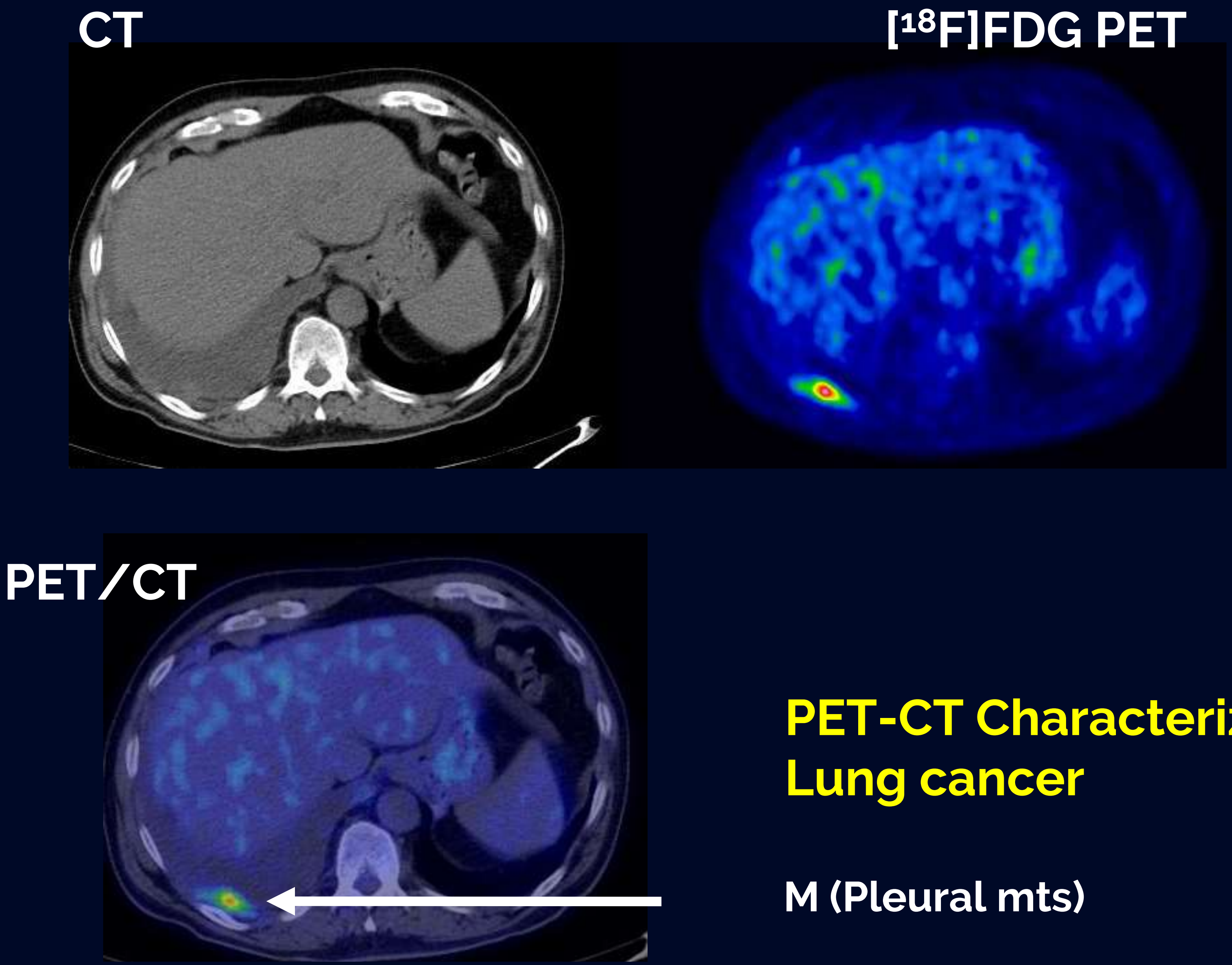
Qualitative analysis



PET-CT Characterization: Lung cancer

M (Pleural mts)

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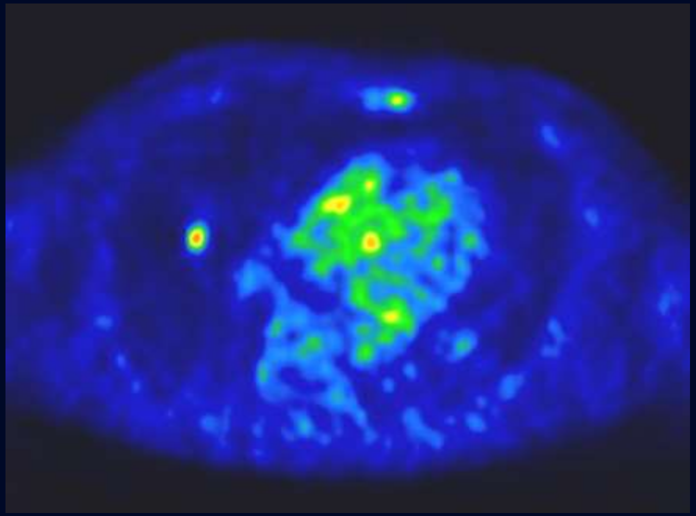
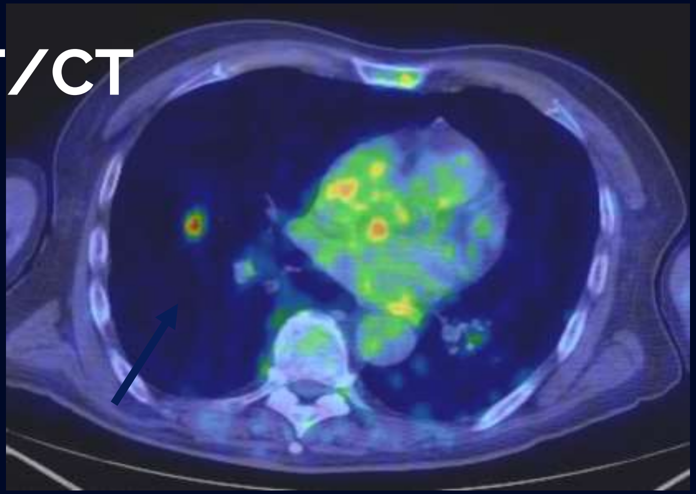
Qualitative analysis

CT

[^{18}F]FDG PET



PET/CT



MF-50 yrs.
Exclusion from radiotherapy treatment for presence of lung metastasis

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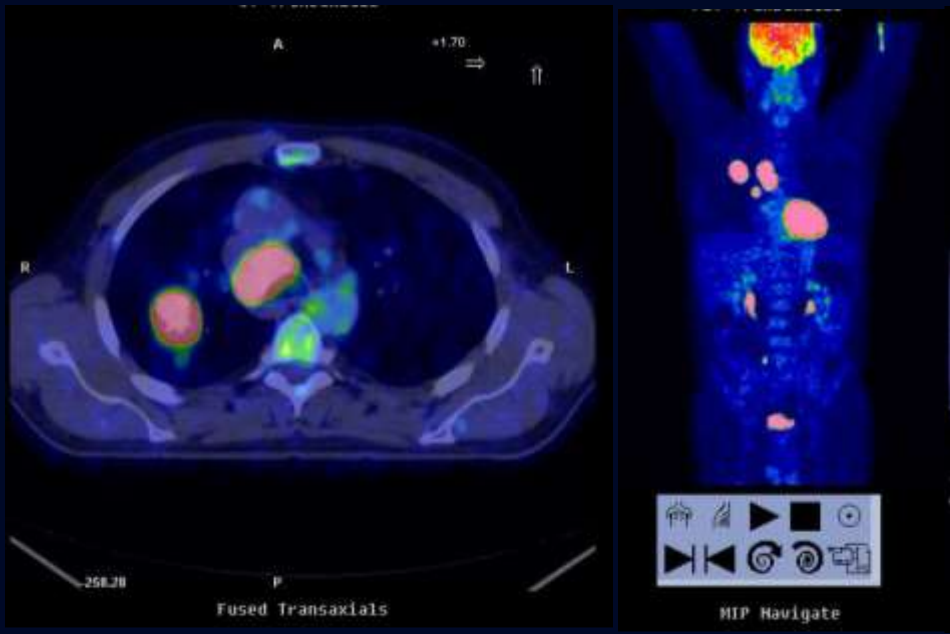
Qualitative analysis

[18F]FDG PET/CT

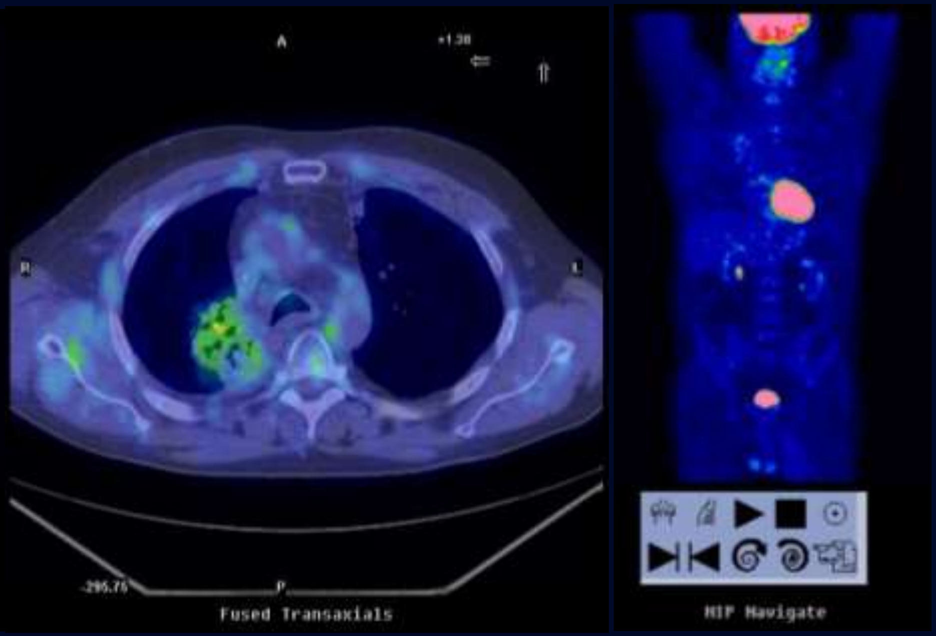
Evaluation of residual mass

Evaluation of recurrence

Evaluation of therapy (early and at the end of treatment)



Before Therapy

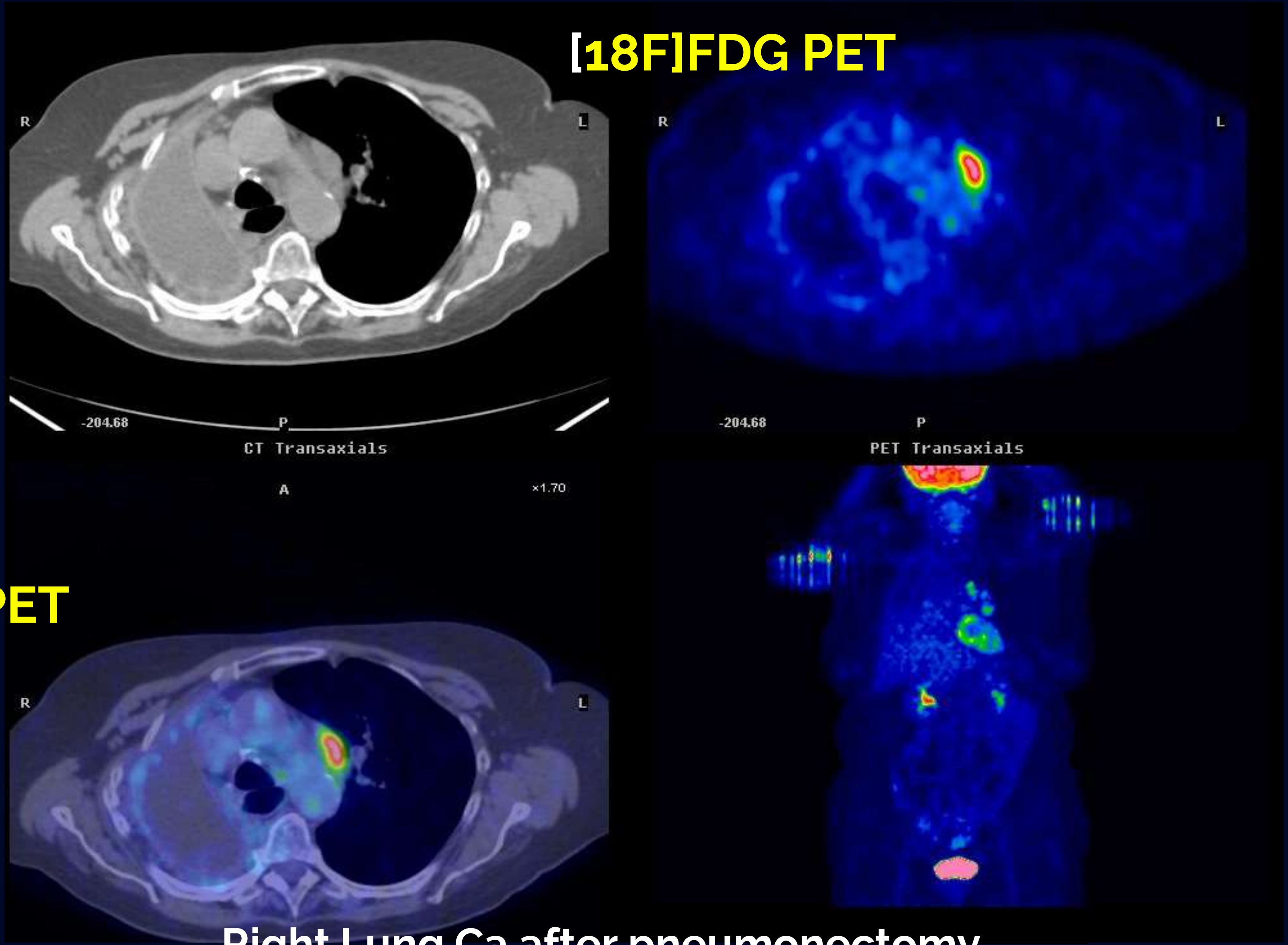


After Therapy

Qualitative analysis

Residual mass

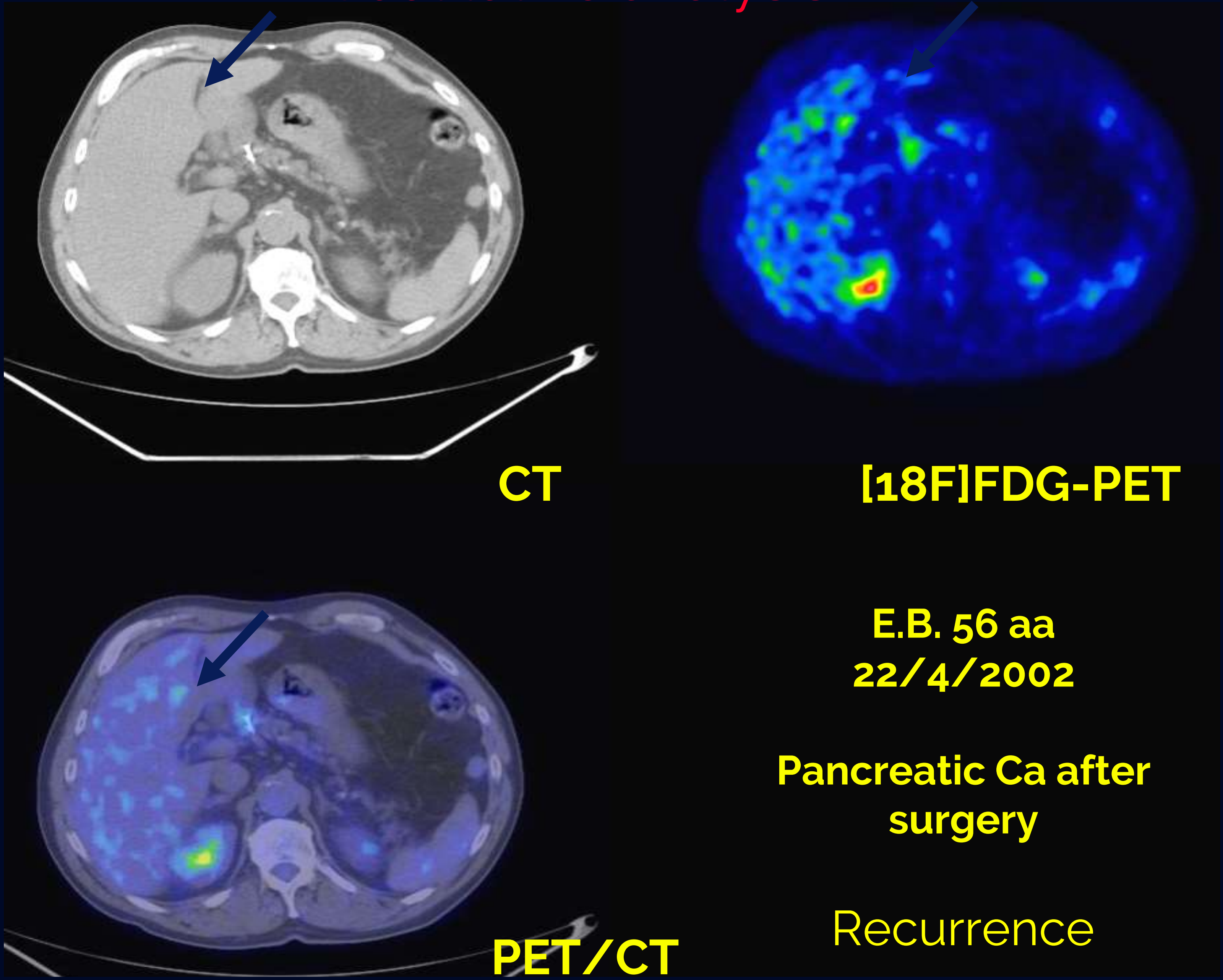
CT



CT- PET

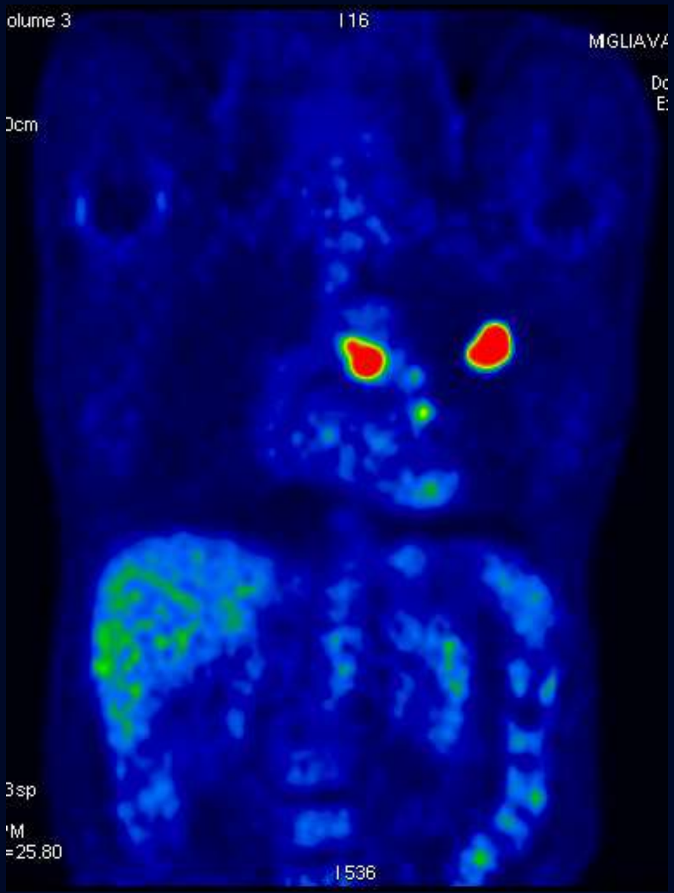
Right Lung Ca after pneumonectomy

Qualitative analysis

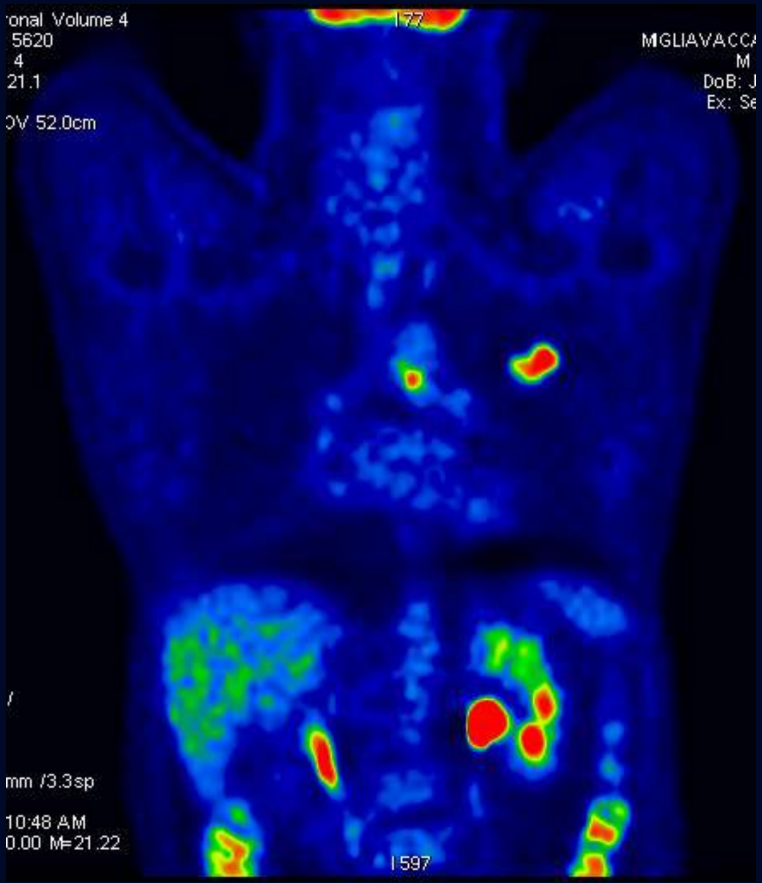


Qualitative analysis

Monitoring therapy responce



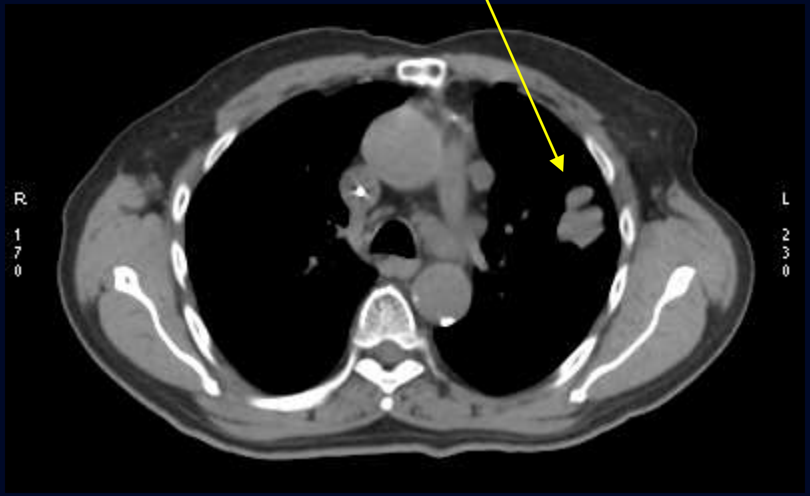
Pre Chemotherapy Study
Apr 03 2007

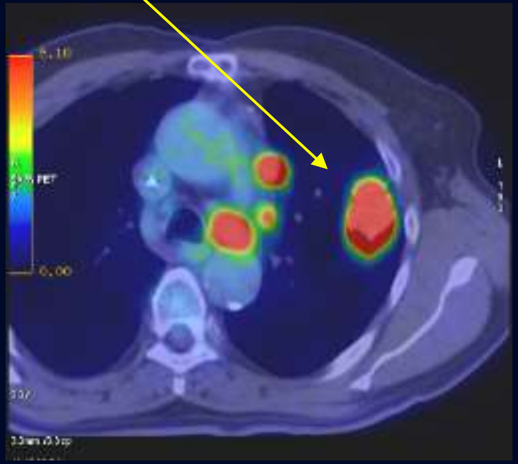


Post Chemotherapy Study
Sept 27 2007

Image-guided radiation therapy treatment planning

PTV: Planning Tumour Volume





PET-CT systems for radioterapy planning

- flat couch insert
- positioning system,
- respiratory gating
- dedicated software (e.g. virtual simulation, visualization and segmentation)
- tools, support of DICOM RT object definition, ...)

workflow for PET/CT-guided radiation therapy treatment planning: strong collaboration between nuclear medicine and radiation oncology

Indication for 18F-FDG PET/CT-guided radiation therapy treatment planning

Well-established indications: head and neck cancer, lung cancer, gynaecological, oesophageal cancer

Experimental indications: colorectal cancer, breast cancer, lymphoma, malignant melanoma….

Tumour

complex biological object

Macroscopically

shape, density, global metabolism

Microscopically

cell proliferation, hipoxia, noeangiogenesis

Problems during radioterapy treatment:

Mispositioning of TV

Changes of TV

PTV?

GTV (Gross tumor Volume)?
CTV (Clinical tumor volume)?
BTV (Biological tumour volume?

International Commission on Radiation Units and Measurements (ICRU)

SUV

Standardized Uptake Value

"Standardized"?

$$\text{SUV} = \frac{\text{Decay corrected dose/ml of tumour}}{\text{Injected dose/patient weight in gr}}$$

- body-weight corrected

$$SUV_{bw} = \frac{\text{Tissue concentration [kBq ml}^{-1}]}{\text{Injected dose [MBq]/ W[Kg]}}$$

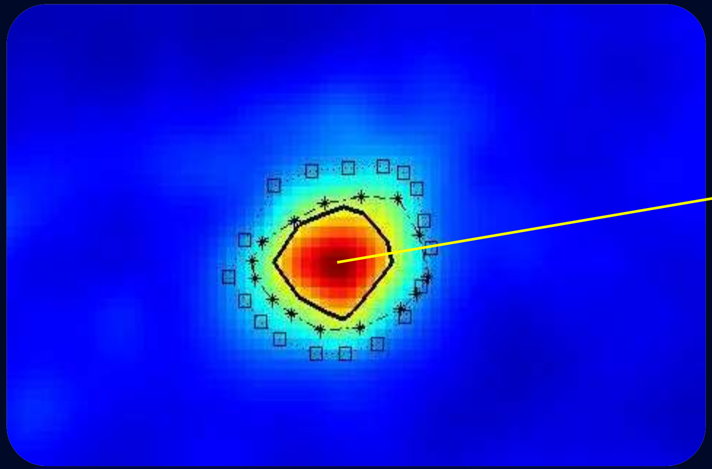
- body-surface-area corrected

$$SUV_{BSA} = \frac{\text{Tissue concentration [kBq ml}^{-1}]}{\text{Injected dose [MBq]/ } 0.007184 x W^{0.425} x\ h^{0.725} \text{[Kg]}}$$

- lean body-mass corrected

$$SUV_{LBM} = \frac{\text{Decay corrected dose/ml of tumour}}{\text{Injected dose/ } 48.0+1.06x(h-152)}$$

Why SUV?



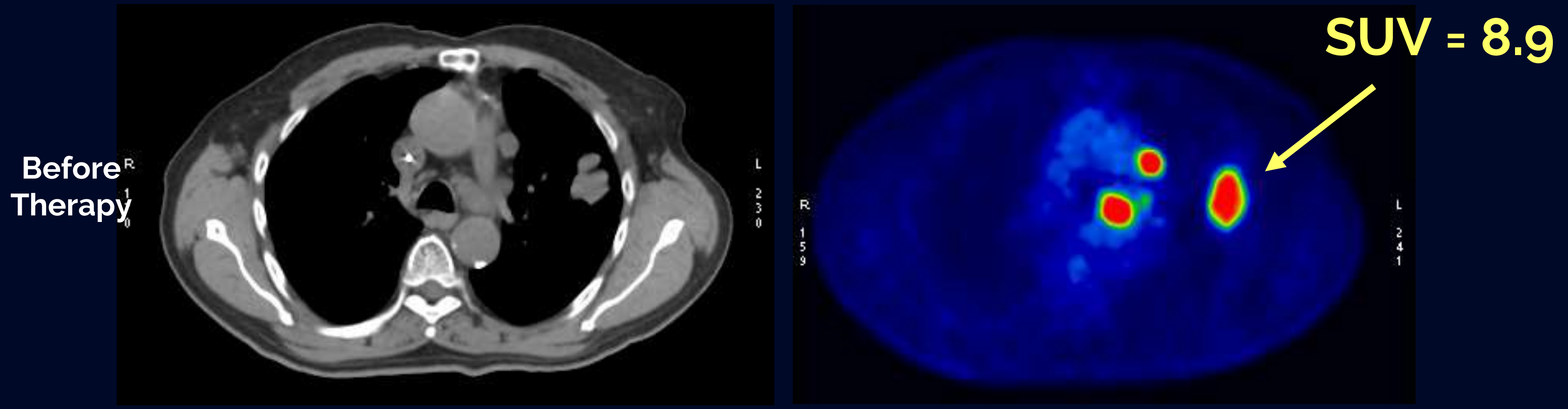
SUV=5.23

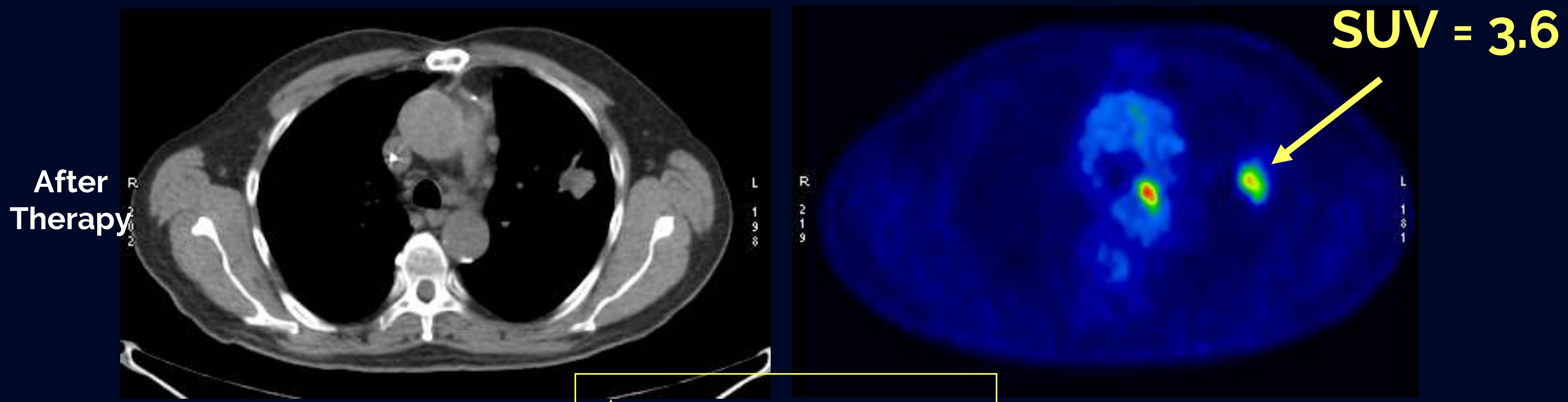
Metabolic response: EORTC Recommendations

Progressive metabolic disease (PD)	SUV > 25% ↑ Visual increase of extent, new locations
Stable metabolic disease (SD)	SUV < 25% ↑, < 15% ↓ No visible increase
Partial metabolic response (PR)	SUV > 15% ↓ one cycle CT SUV > 25% ↓ several cycles CT
Complete metabolic response (CR)	FDG uptake resolved

Young et al., European Journal of Cancer 1999

PET/CT Monitoring therapy responce





ΔSUV = - 59.5%

PET (MRI-DWI) → BTV (SUV/ADC can be derived)

CT, MRI → GTV

↓

LESION SEGMENTATION

PET/MRI-DWI images

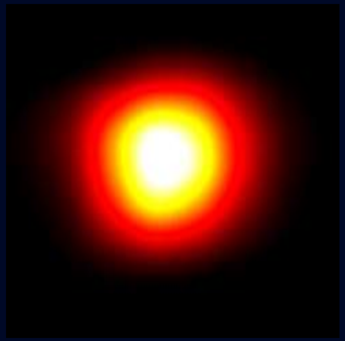
- Poor resolution
- Low signal
- High noise
- Low lesion-to-background contrast
- Movement
- Lesion heterogeneity
- Background heterogeneity

CT/MRI images

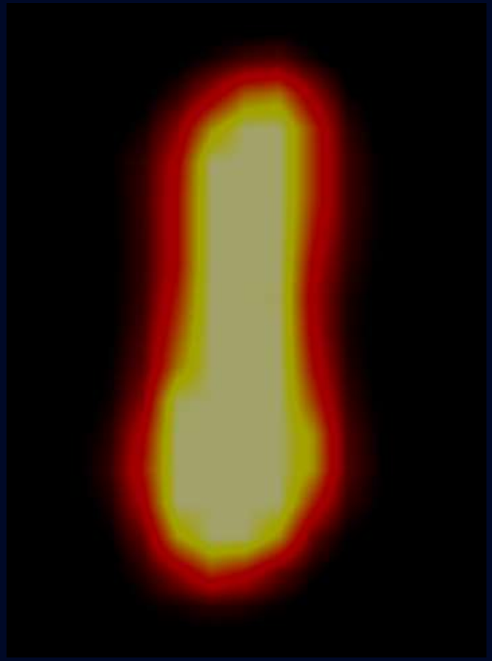
- High resolution
- HIgh signal
- Medium noise
- Low/Medium lesion-to-background contrast
- Movement
- Lesion heterogeneity
- Background heterogeneity

Movement

STATIC TARGET

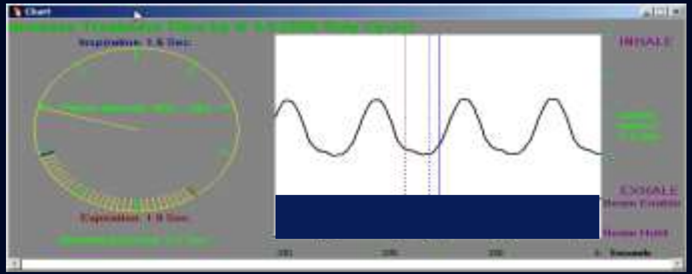


MOVING TARGET



→ apparent increase of lesion size
→ apparent decrease of activity concentration
→ lower threshold for a correct volume definition (10-20% Caldwell 2003)

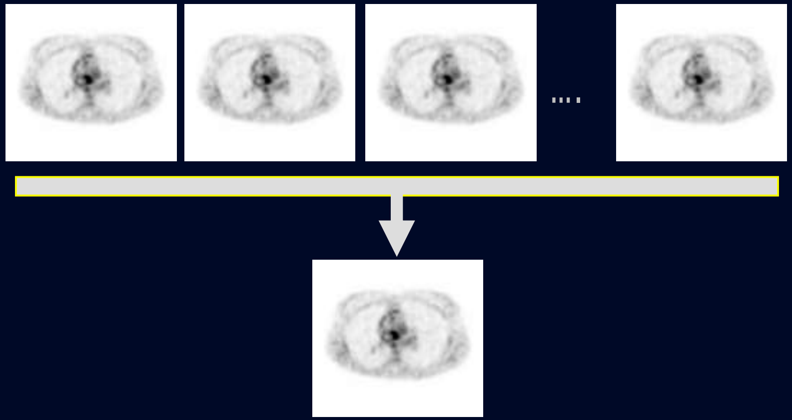
RESPIRATORY GATING



Varian patent 6,279,579
Varian Medical System: GatingSchool

4D PET

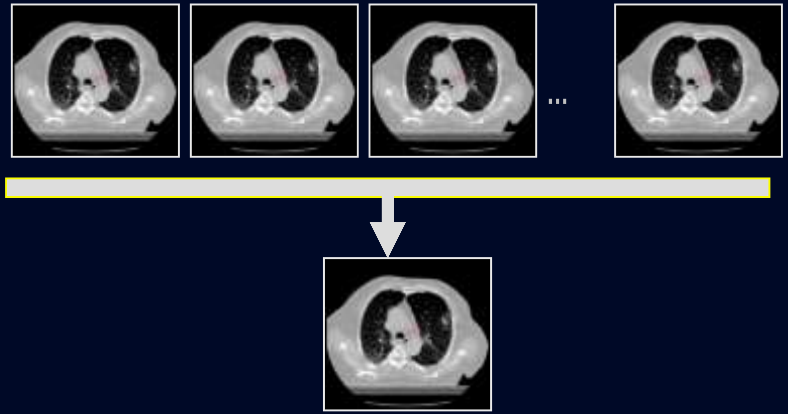
BIN 1 BIN 2 BIN 3 BIN 10



SUM IMAGE

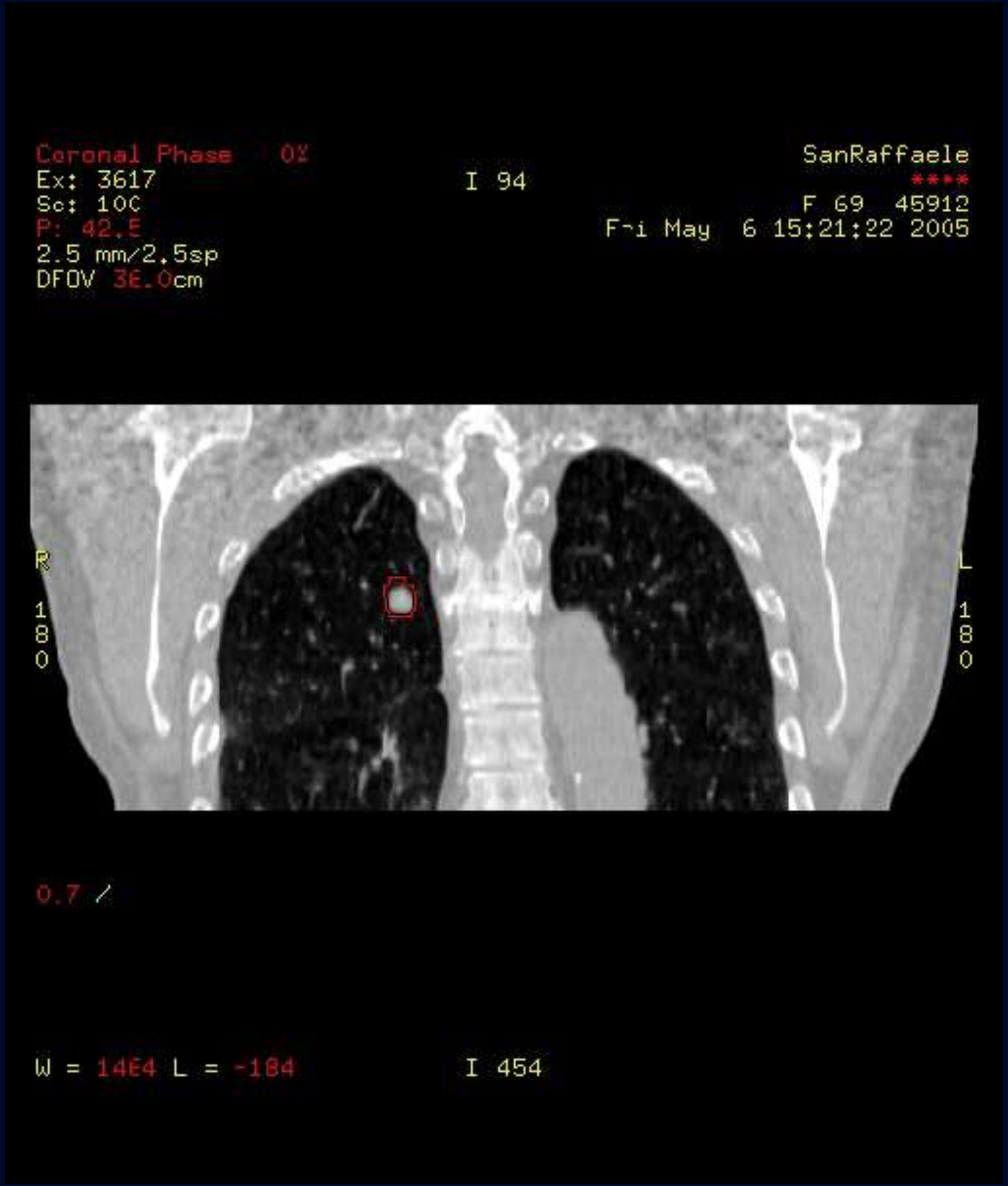
4D CT

BIN 1 BIN 2 BIN 3 BIN 10

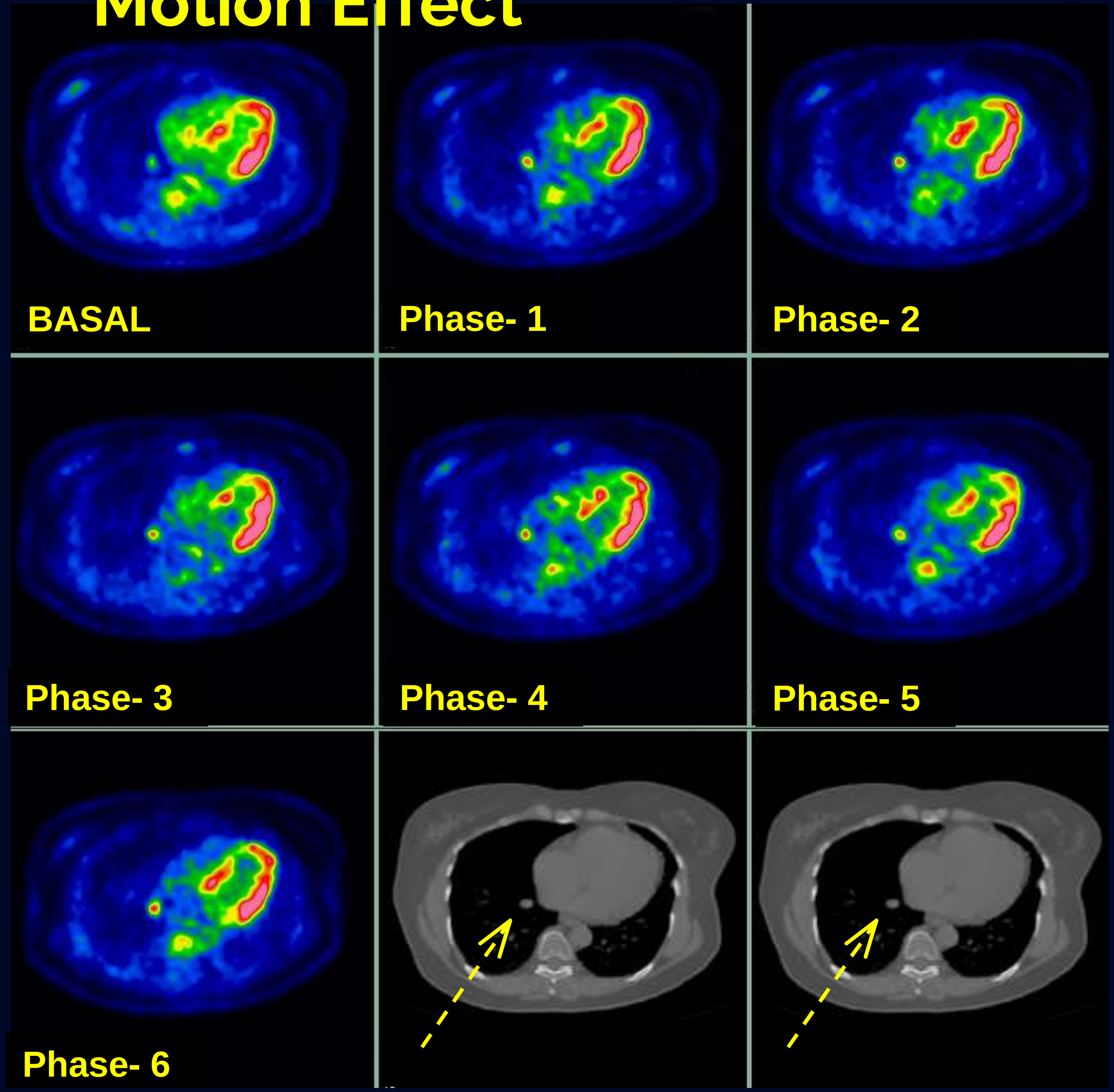


SUM IMAGE

4D PET/CT: IMPROVED DEFINITION



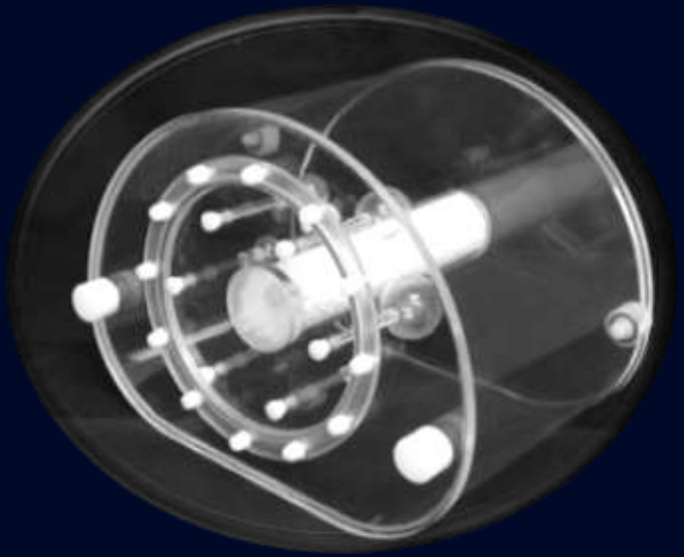
Motion Effect



PET SUV max
BASAL: 2.2
Ph-1: 2.9
Ph-2: 3.1
Ph-3: 3.3
Ph-4: 3.4
Ph-5: 2.9
Ph-6: 3.5

HSR Milan

SUV estimation during movement

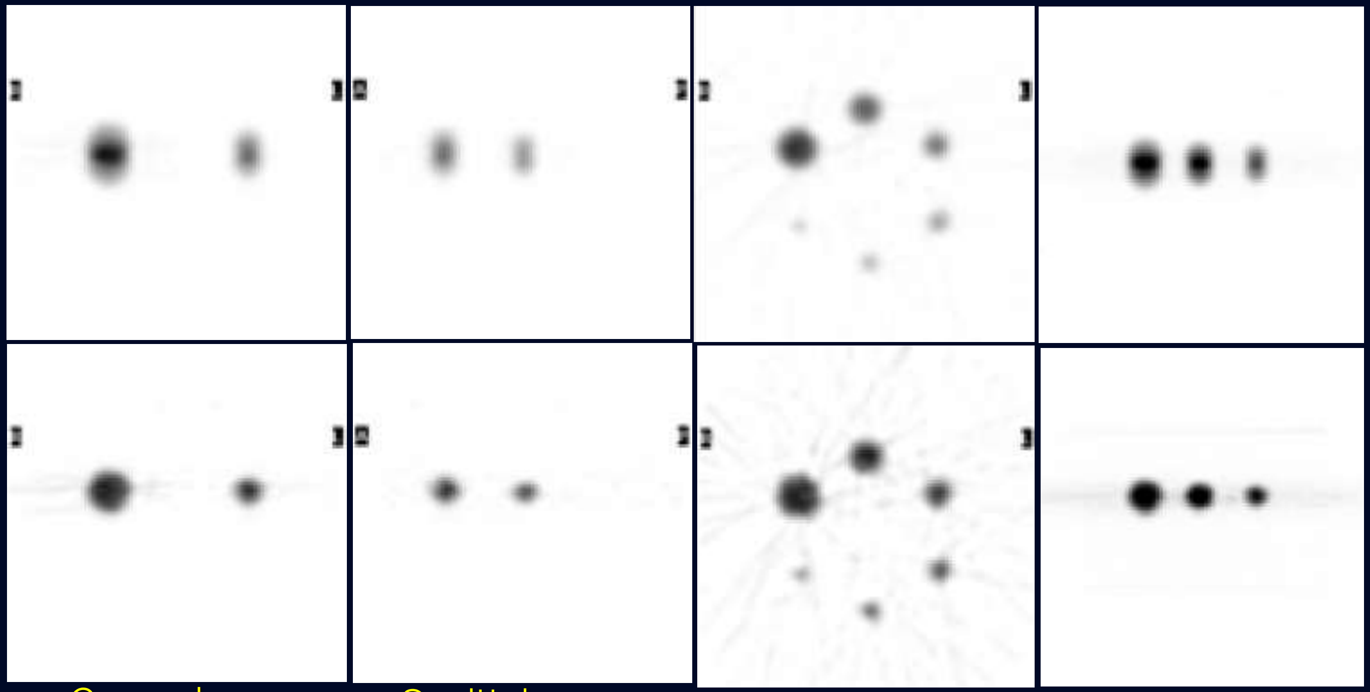


NEMA IQ phantom

Sphere diameter:

10 mm, 13 mm, 17 mm, 22 mm, 28 mm, 37 mm

Motion Effect



	Coronal	Sagittal	Axial	Mip

spheres	*static*	*gated*	*% error*
37 mm	33546	31624	-6.1
28 mm	21872	31316	+30.2
22 mm	20607	29919	+31.1
17 mm	13643	22857	+40.3
13 mm	8264	19087	+56.7
10 mm	5143	11897	+56.8

Mawlawi et al.

PARTIAL VOLUME EFFECT

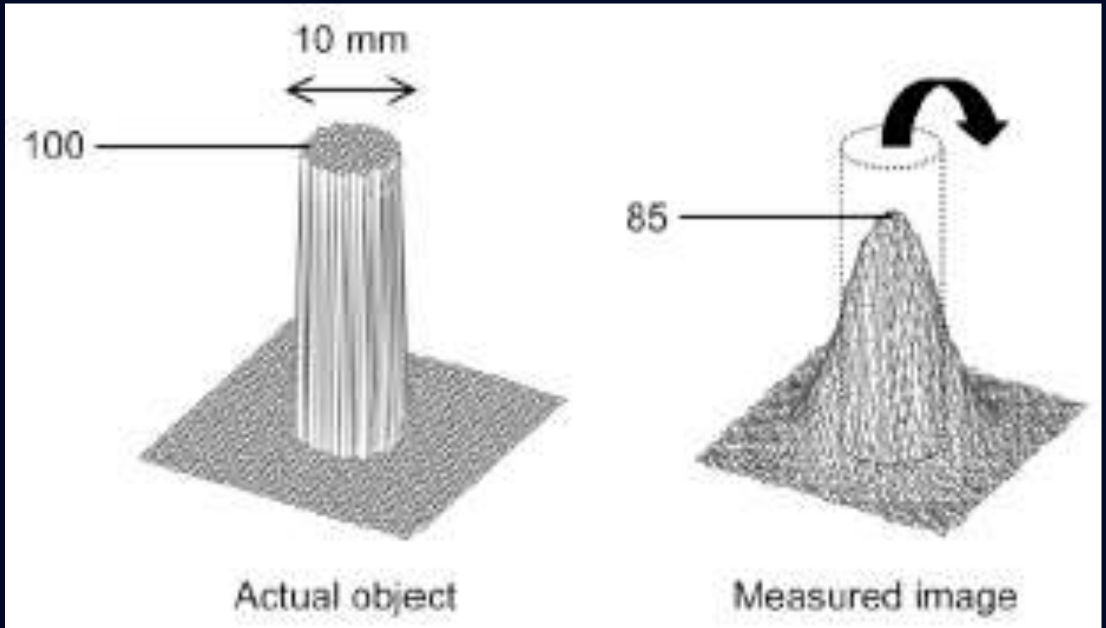


IMAGE BLURRING introduced by the finite spatial resolution of the imaging system

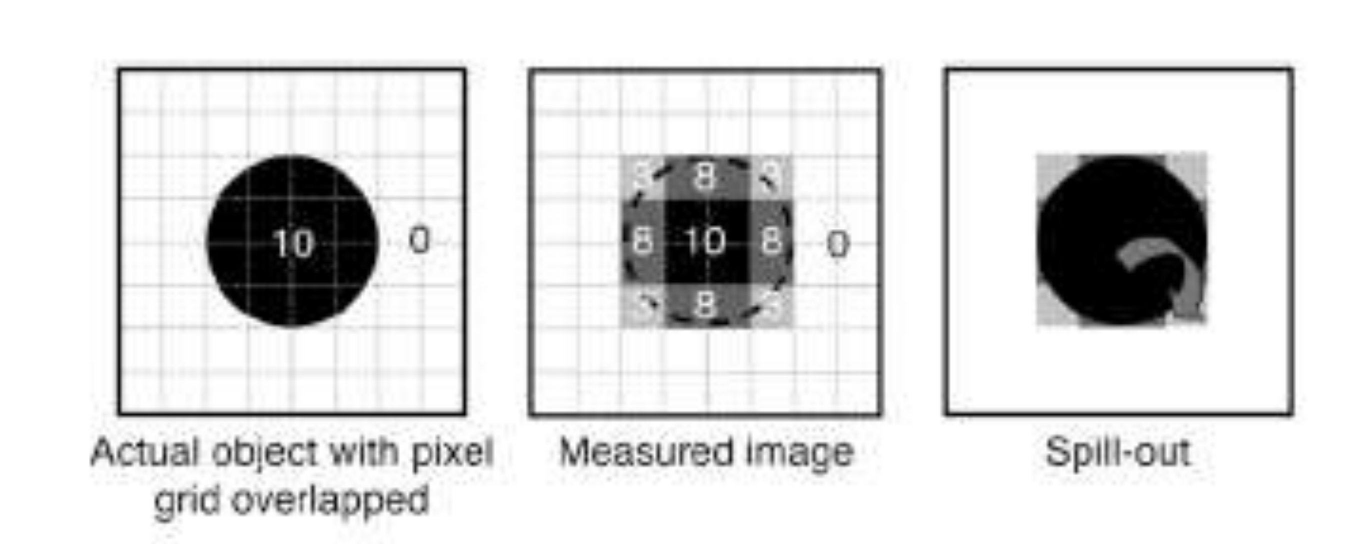
The image is formed by the convolution of the source with the 3D PSF

spill over:part of the signal is seen puside the actual source

reduction of maximum activity

Soret JNM 2007

PARTIAL VOLUME EFFECT

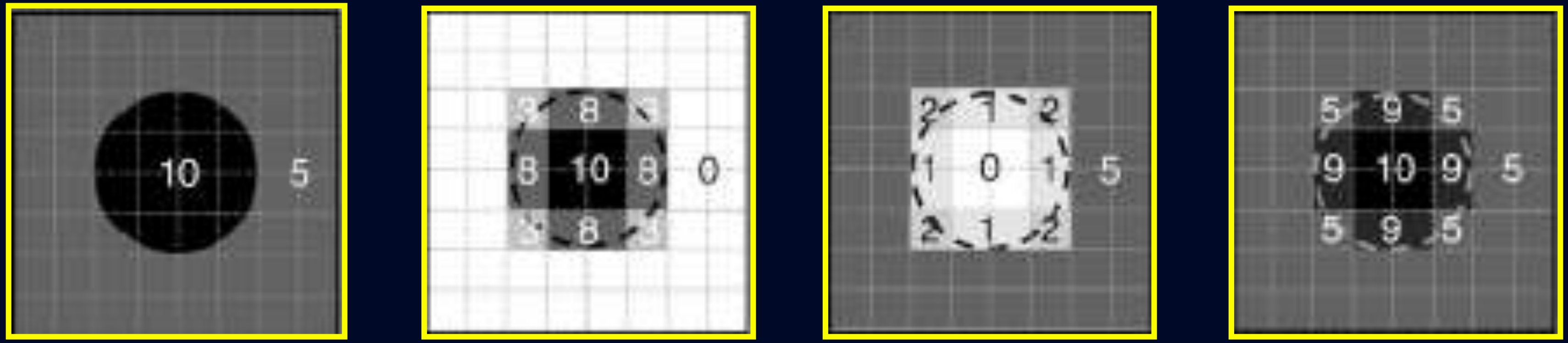


2. TISSUE FRACTION EFFECT introduced by IMAGE SAMPLING
   the contours of teh voxels do not match the contours of the tracer distribution
   most voxels includes different types of tissues

Soret JNM 2007

PARTIAL VOLUME EFFECT

- SPILL IN and SPILL OUT



Actual activity distribution

Spill - out

Spill in

Measured image

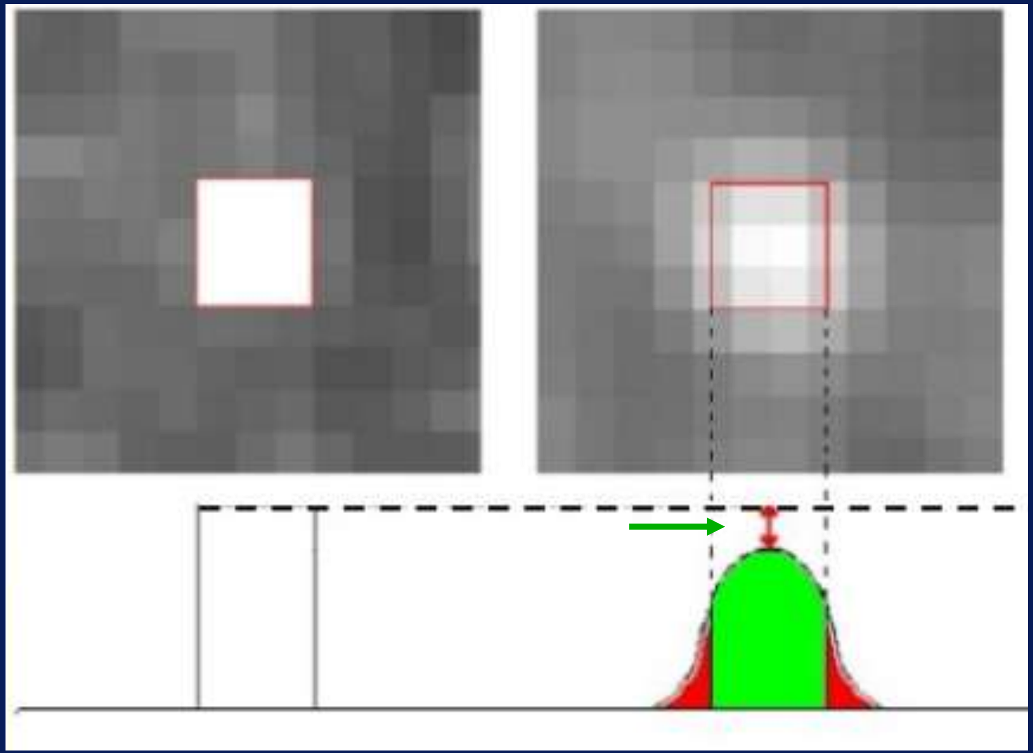
- apparent LESION SIZE

Soret JNM 2007

How to correct SUV for PVE?

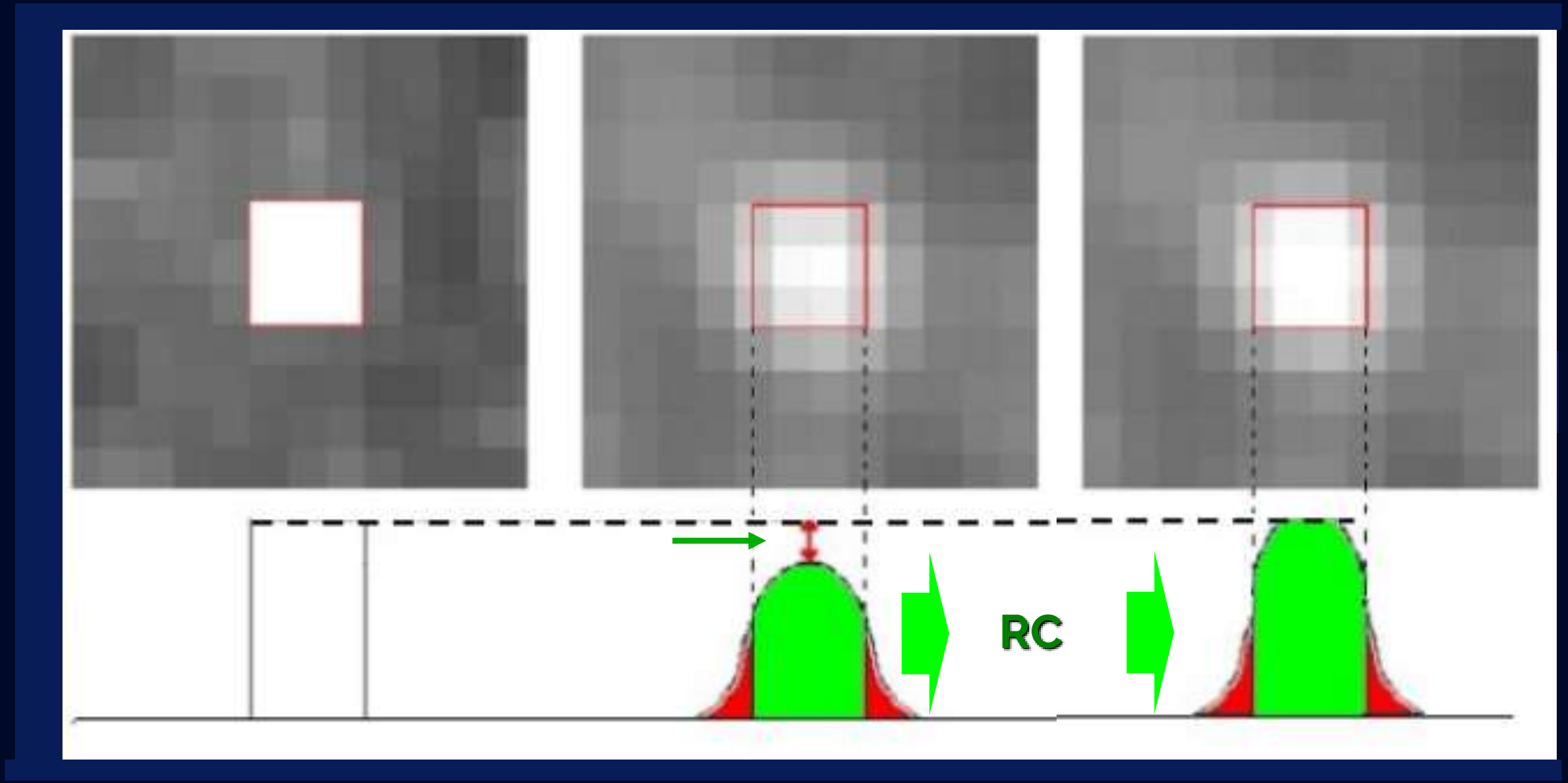
Ideal lesion

Real lesion

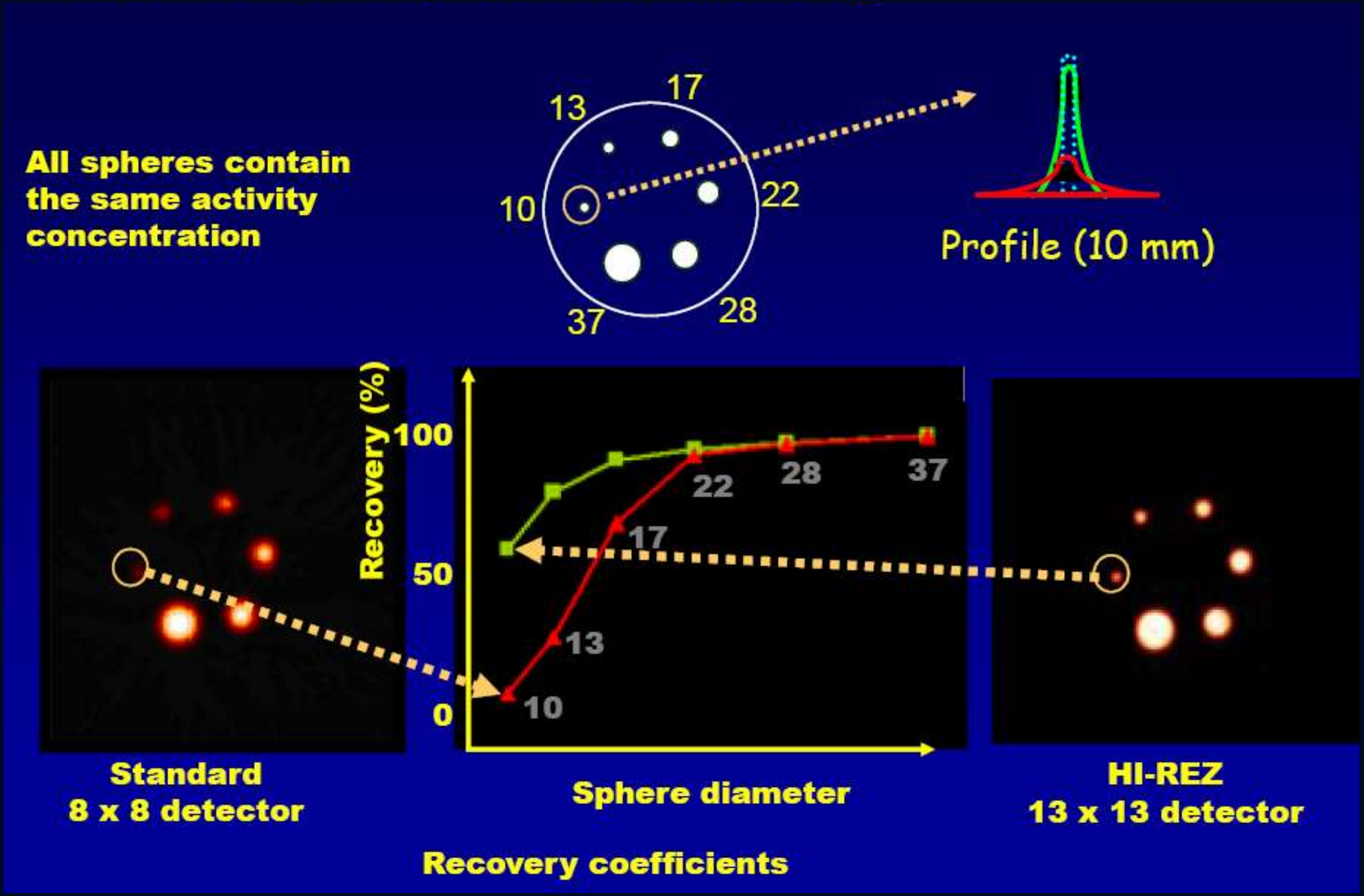


How to correct SUV for PVE?

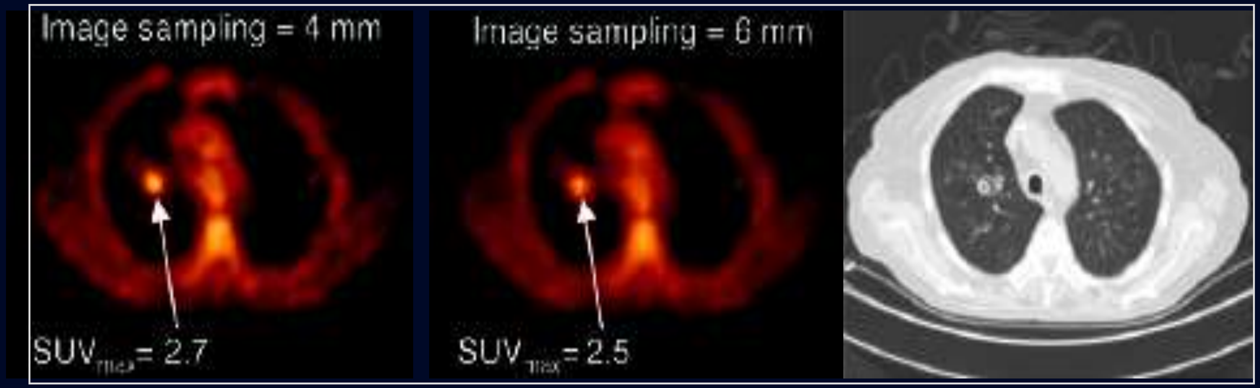
Ideal lesion | Real lesion | Corrected lesion

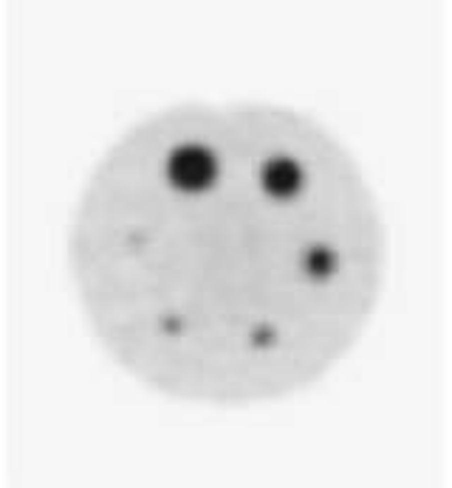


Partial volume



- Image Sampling





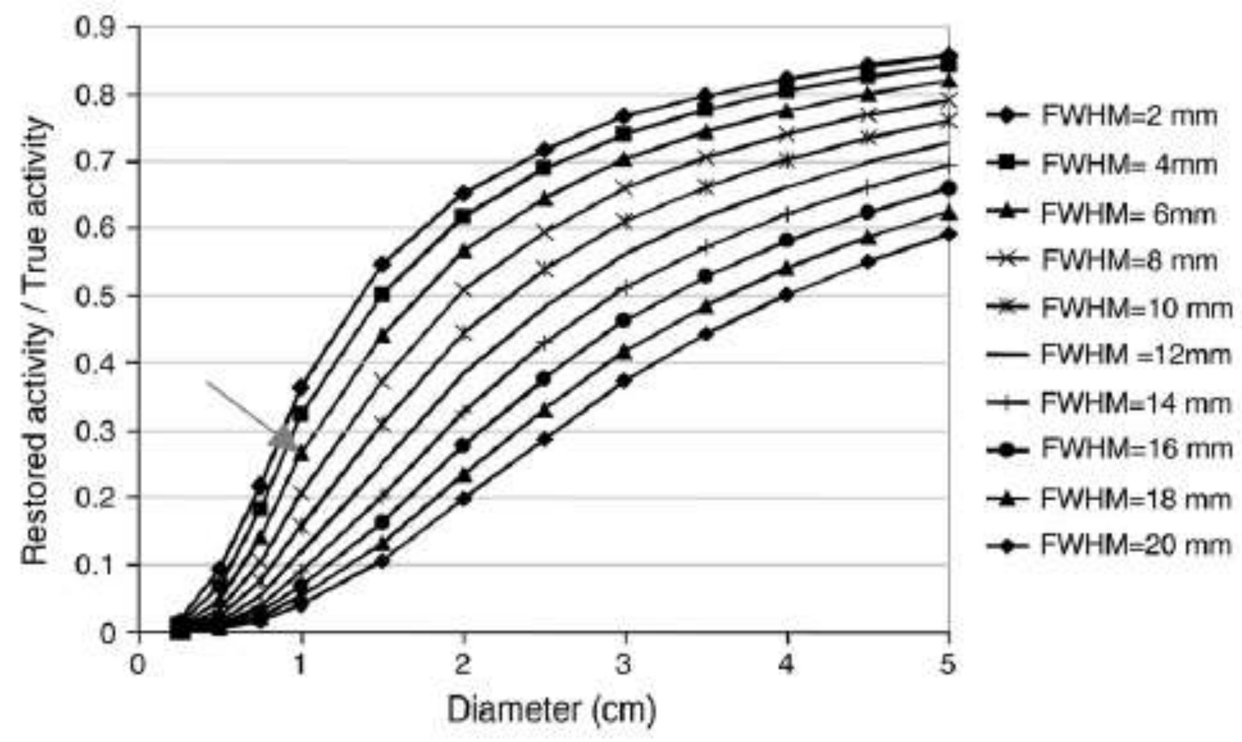
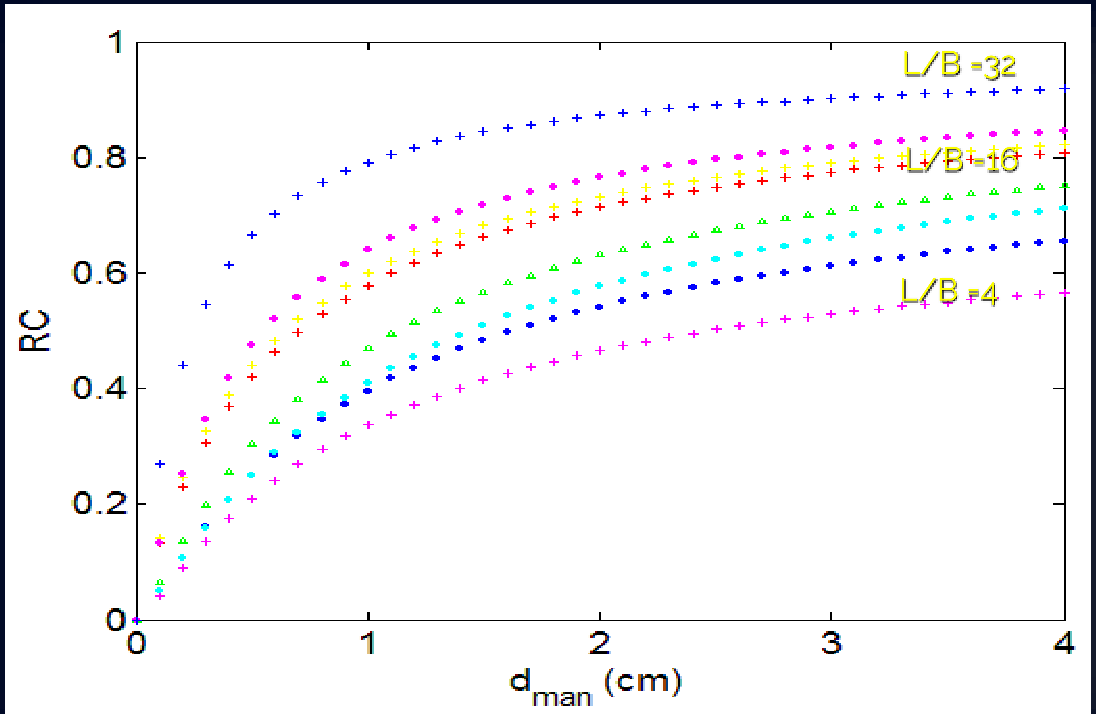


FIGURE 10. Restored activity measured in actual contour of spheres in cold background as function of sphere diameter and spatial resolution of imaging system.



RC dipends from:

- **Lesion volume**
- **Lesion concentration/lesion background (L/B)**

Tumour

complex biological object

Macroscopically

shape, density, global metabolism

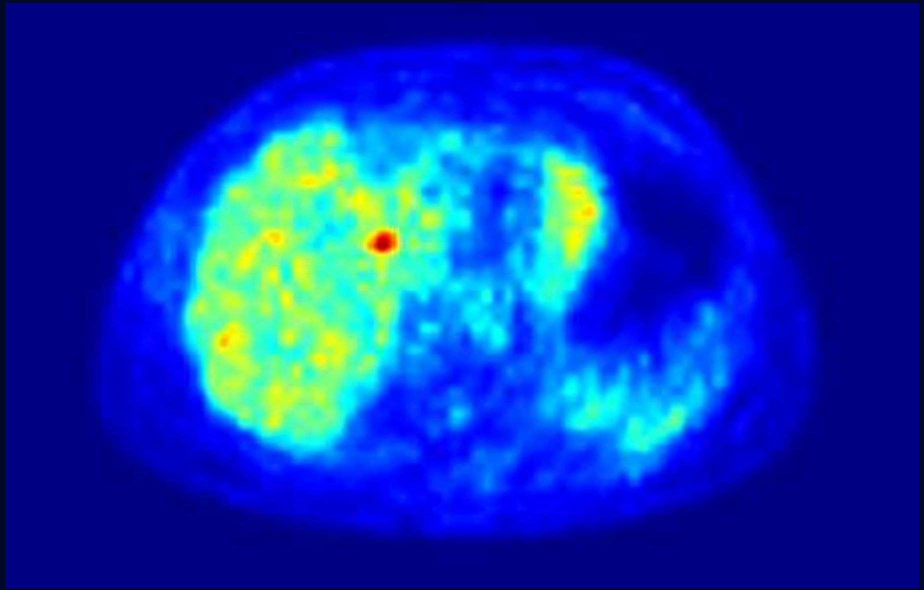
Microscopically

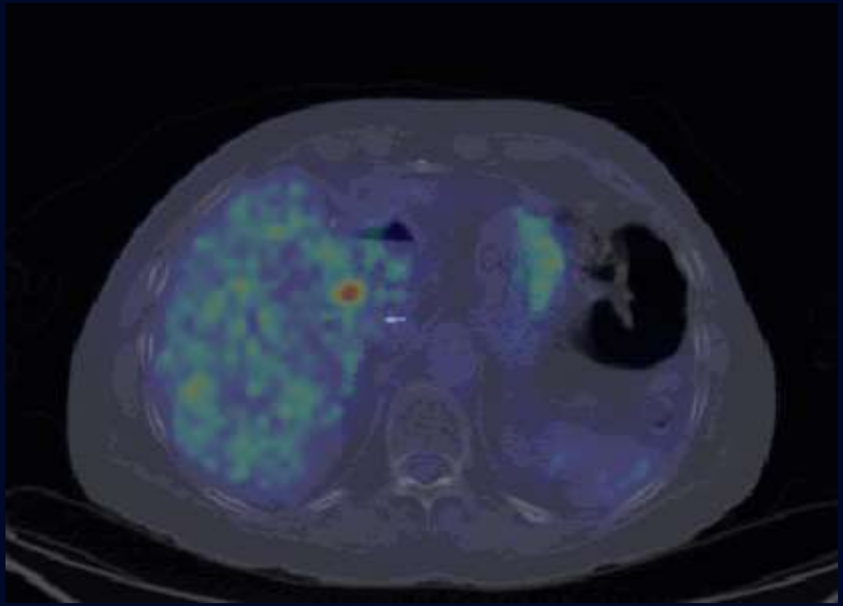
cell proliferation, hipoxia, noeangiogenesis

Lesion heterogeneity different in CT vs PET

FIGURE 12. CT image (left), corresponding PET image (middle), and PET/CT image (right) of tumor with no uptake in center. Delineation of tumor from CT image would yield inappropriate definition of metabolically active part of tumor.

Background heterogeneity different in CT vs PET





LESION SEGMENTATION

Qualitative methods → Visually inspection, manual contourning

Quantitative methods → Image processing, semi-auto/autocontouring

Segmentation : partitioning of an image I into different subregions S

classes

$$I = \sum_i S_i \qquad I = 1,\ldots n$$

$$S_i \subset I \qquad S_i \cap S_j = \emptyset$$

Manual methods

- Image modality-dependence
- Operator-dependence
- Window level-dependence (colorbar)

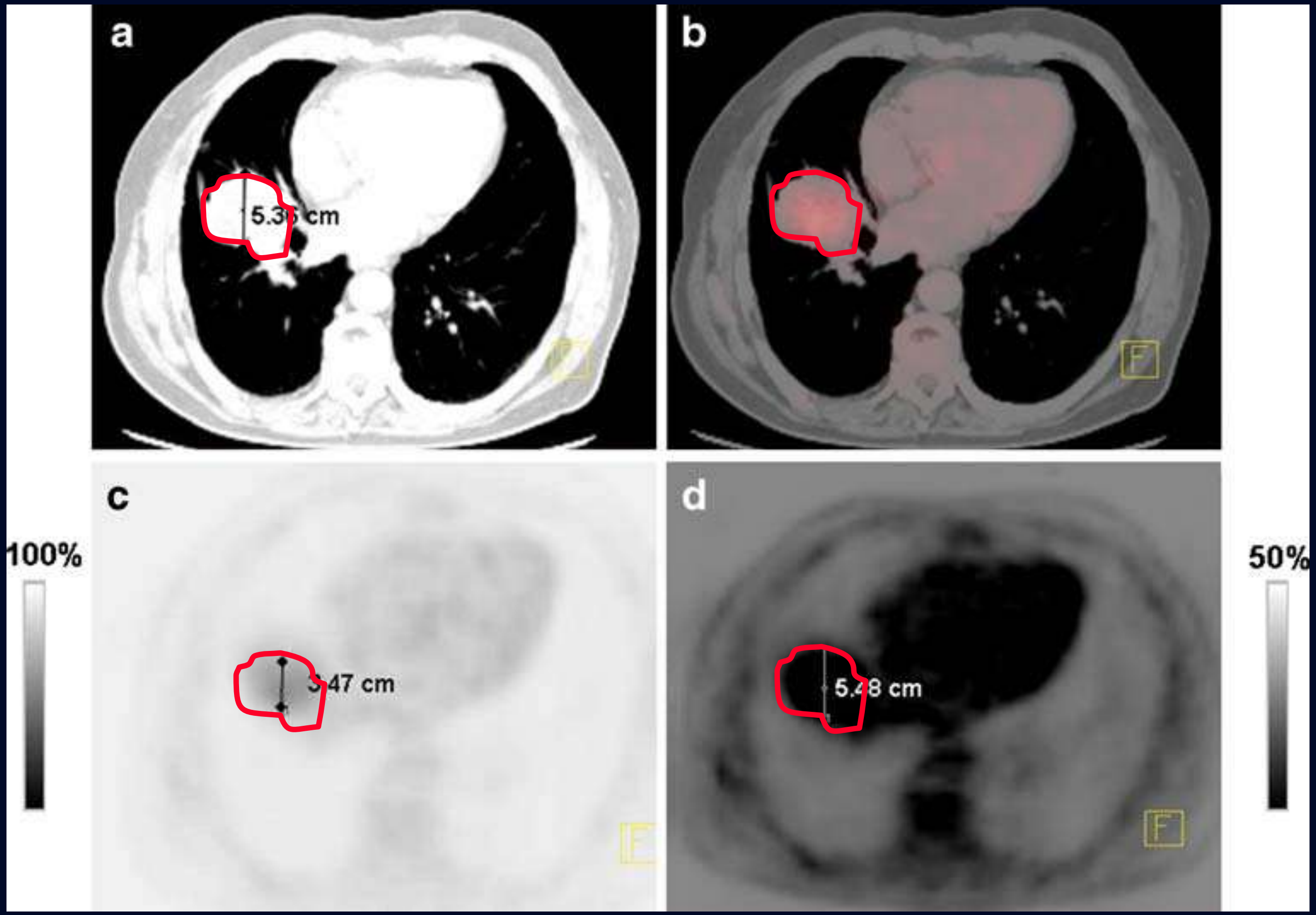
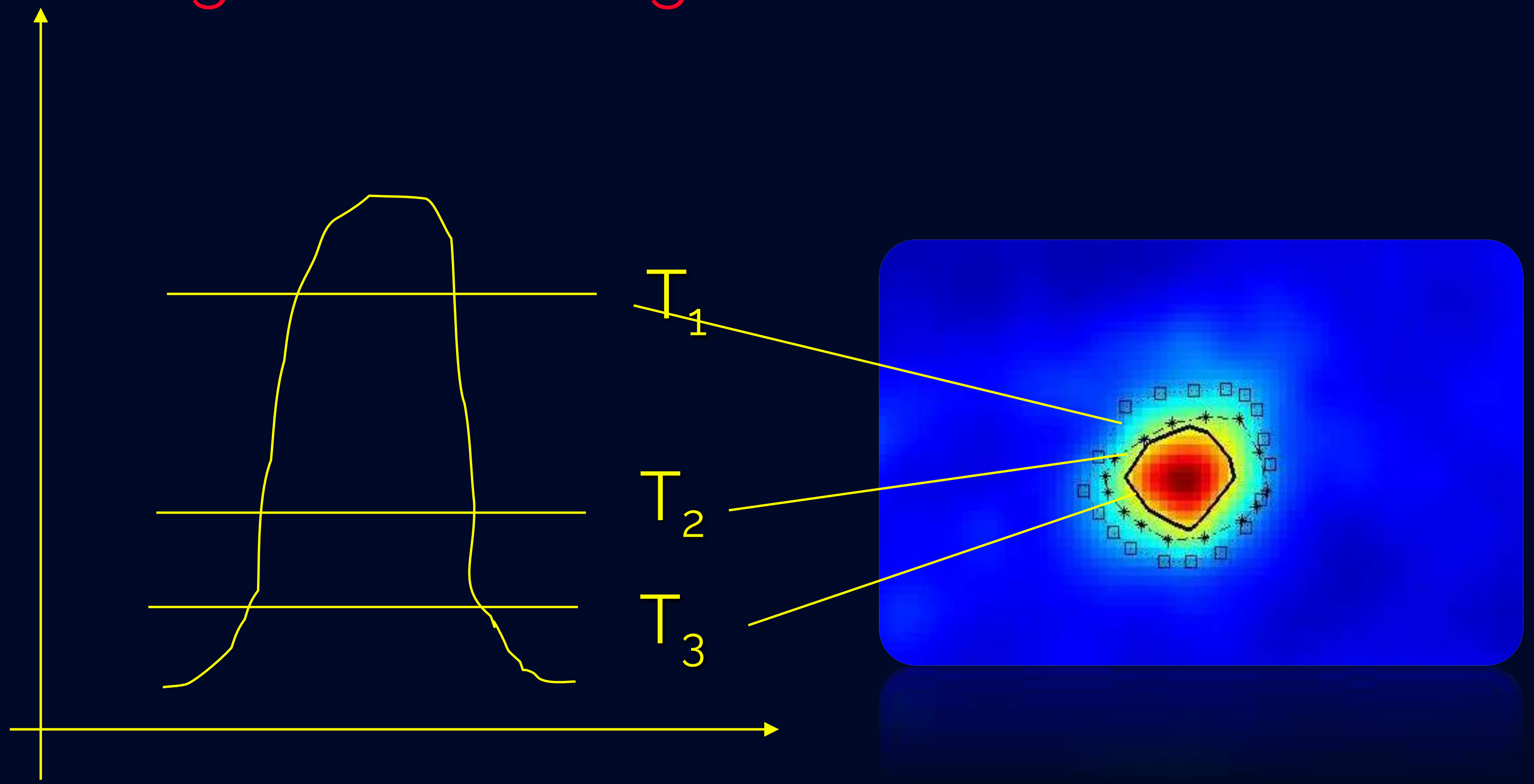


Image thresholding methods



$$\text{lesion} = T[I(x)] = \begin{cases} 1, & I(\mathbf{x}) \geq T \\ 0, & I(\mathbf{x}) < T \end{cases}$$

Image thresholding methods

2a) with respect to lesion uptake (fixed)

%T = 40, 50, 60% of the maximum uptake

2b) with respect to lesion volume

$$\%T = a + b \times \log_{10}(BTV) + q$$

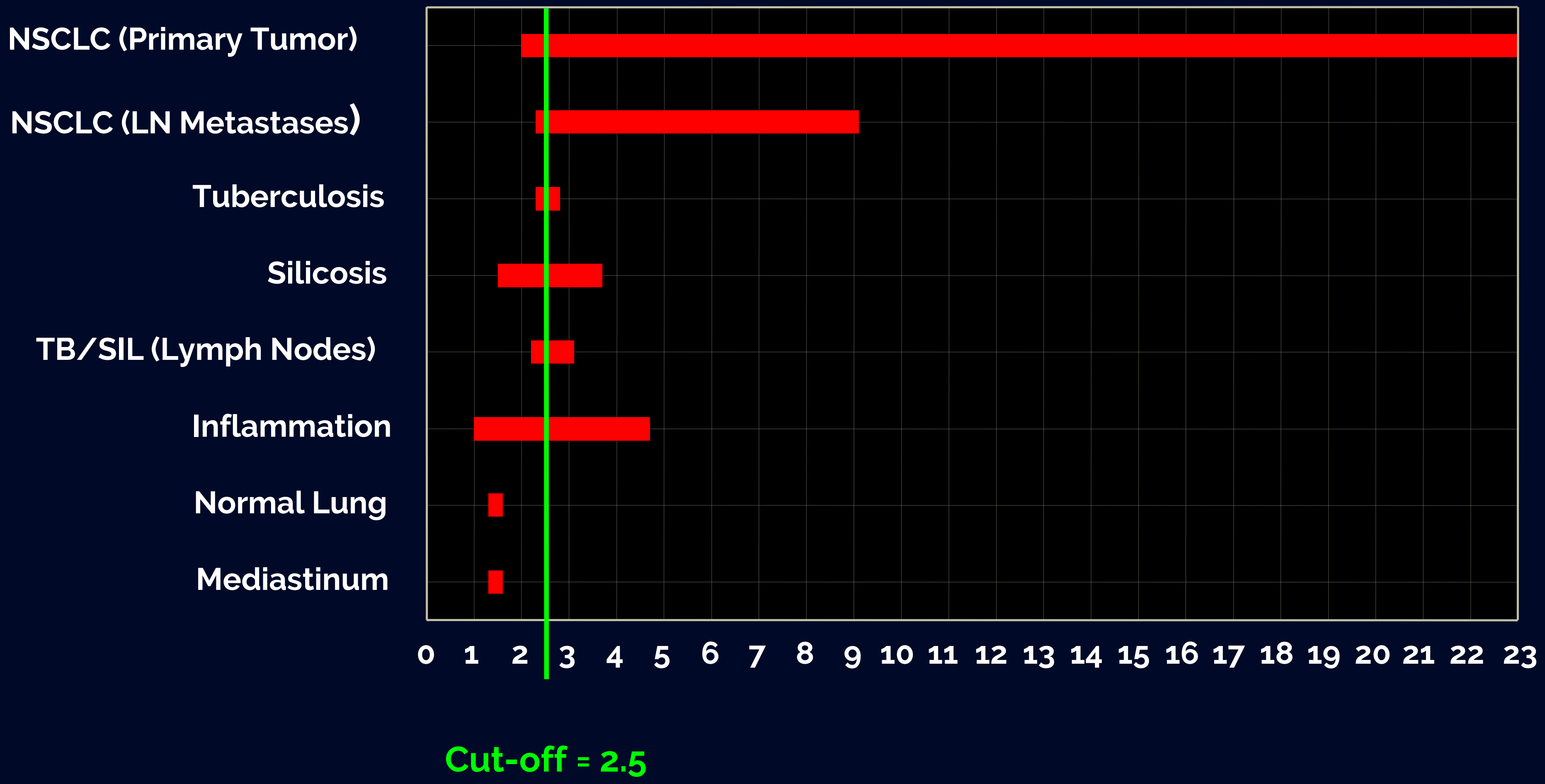
a= 59.1 b = -18.5

→ a priori knowledge of the lesion volume

2c) absolute

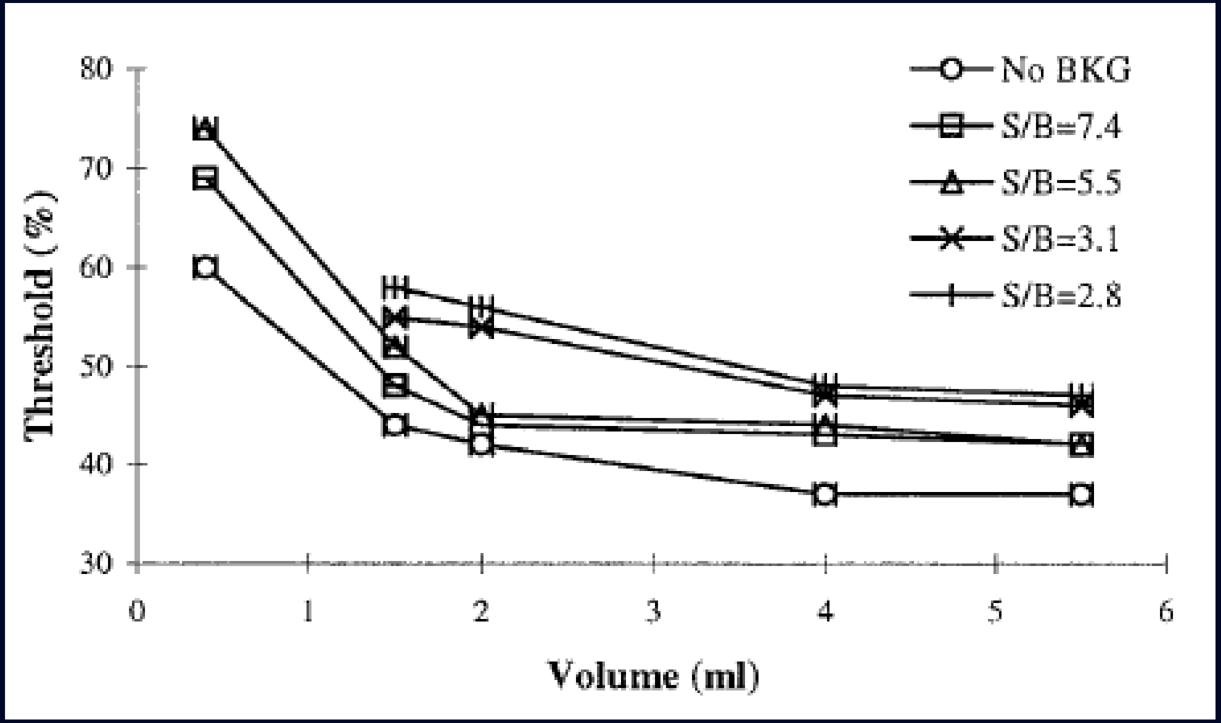
T = 2,5 cut off

SUV in oncological and not-oncological diseases



2d) with respect to lesion-to-background ratio (LB)

$T = a + b \times 1/LB$



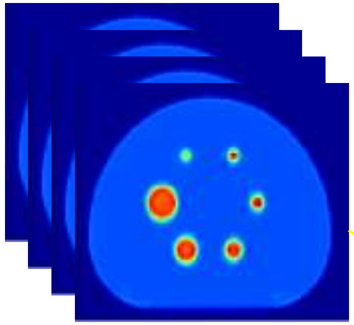
precalibration of LB vs lesion volume is necessary

a priori knowledge of the lesion volume

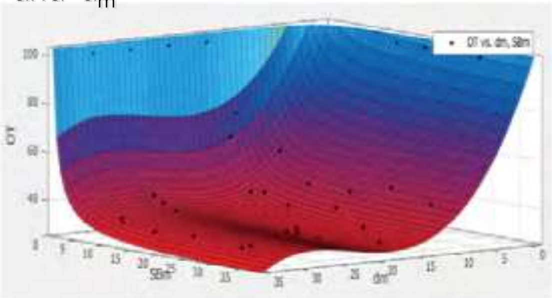
Erdi et al.,1997

Solutions (Repeatable/Reproducible/Accurate)

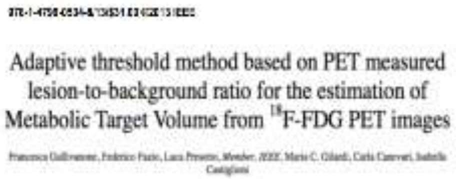
NEMA IQ phantom



Adaptative Threshold = function of L/B_m and d_m



- **Automatic segmentation of lesion volume**



Adaptive threshold method based on PET measured lesion-to-background ratio for the estimation of Metabolic Target Volume from ^{18}F-FDG PET images

Research Article

An Adaptive Thresholding Method for BTV Estimation Incorporating PET Reconstruction Parameters: A Multicenter Study of the Robustness and the Reliability

- **Automatic Partial Volume correction**

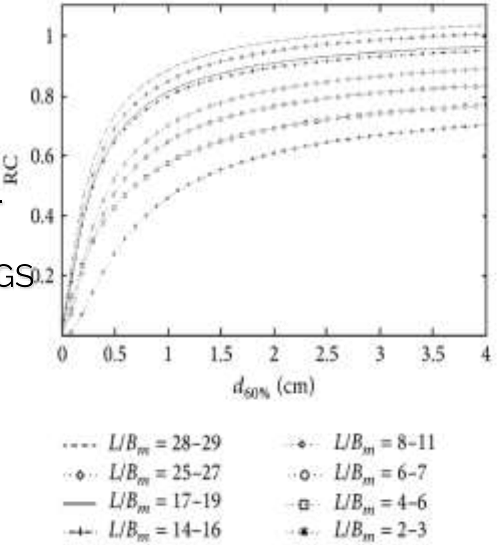
Research Article

A Partial Volume Effect Correction Tailored for ^{18}F-FDG-PET Oncological Studies

F. Gallivanone,[1] C. Canevari,[2] L. Gianolli,[2] C. Salvatore,[3] P. A. Della Rosa,[1] M. C. Gilardi,[1] and I. Castiglioni[1]

PVE Correction in PET-CT Whole-Body Oncological Studies From PVE-Affected Images

$$RC = \frac{L/B_m}{L/B_{GS}}$$



$$T = a + b \times SUV_{mean}$$

Black et al., 1990

$a = 0.588$ $b = 0.307$

$$T = \text{Contrast level} \times (L_{max} - B_{mean}) + B_{mean}$$

Drever et al., 2006

$$T = \beta\, L_{mean-70\%} + B_{mean}$$

Nestle et al., 2005

$\beta = 0.15$

$$T = (a \times SUV_{mean-70\%} + b \times B_{mean}) / SUV_{max}$$

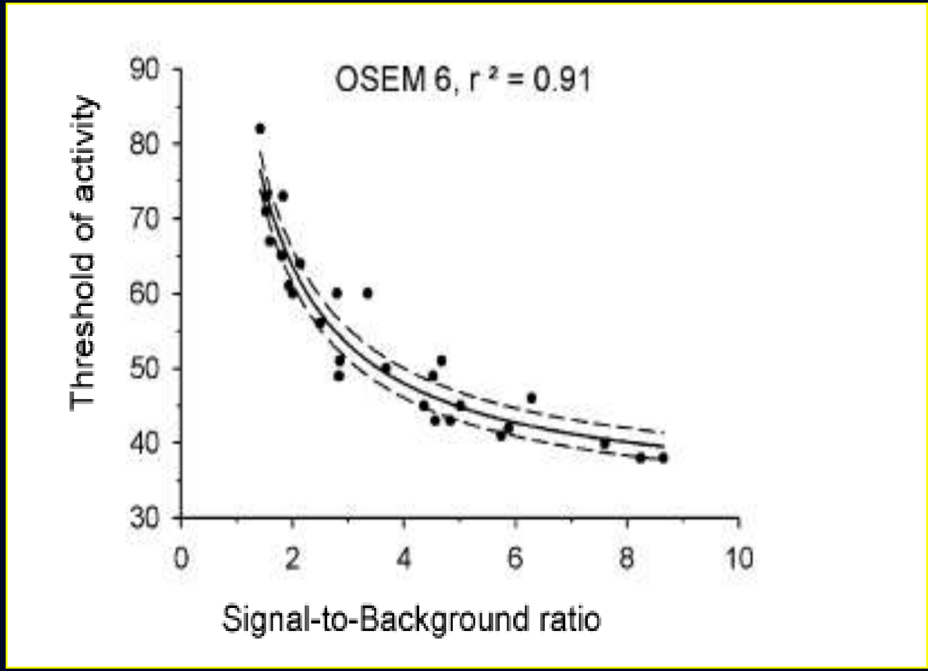
Schaefer et al., 2008

$a = 0.50$ $b = 0.50$ for $d > 3cm$

$a = 0.67$ $b = 0.60$ for $d < 3cm$ (Ecat ART)

$\%T = b \times B/L + c$

Daisne et al. , 2003



2d) iterative

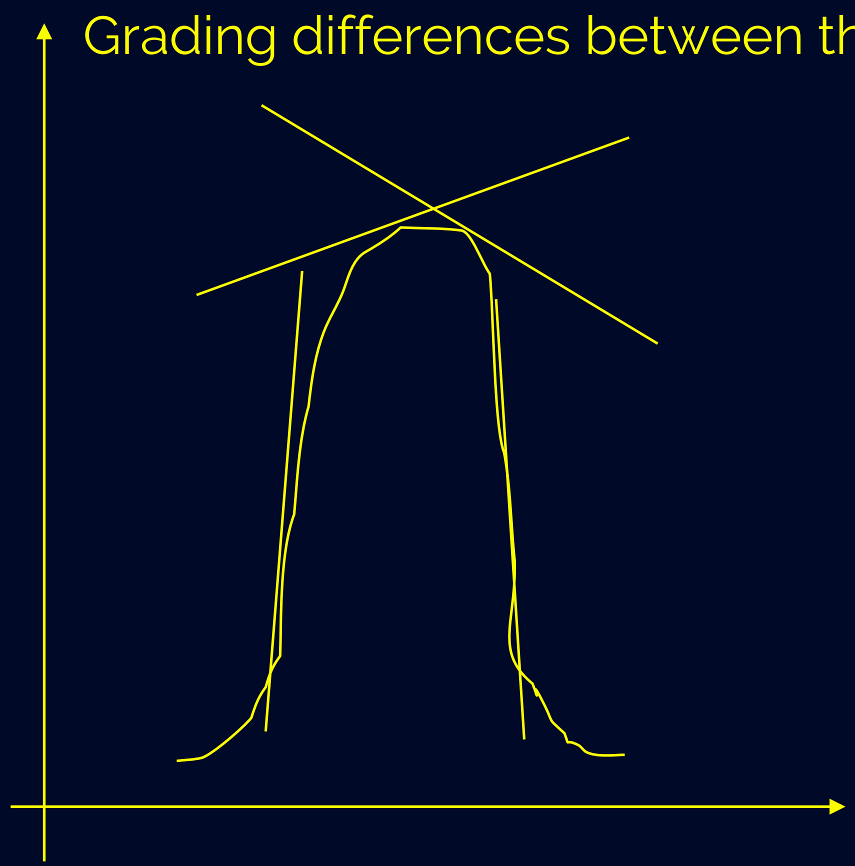
$\%T = a/V_l + b \times B/L + c$ Jentzen et al., 2007

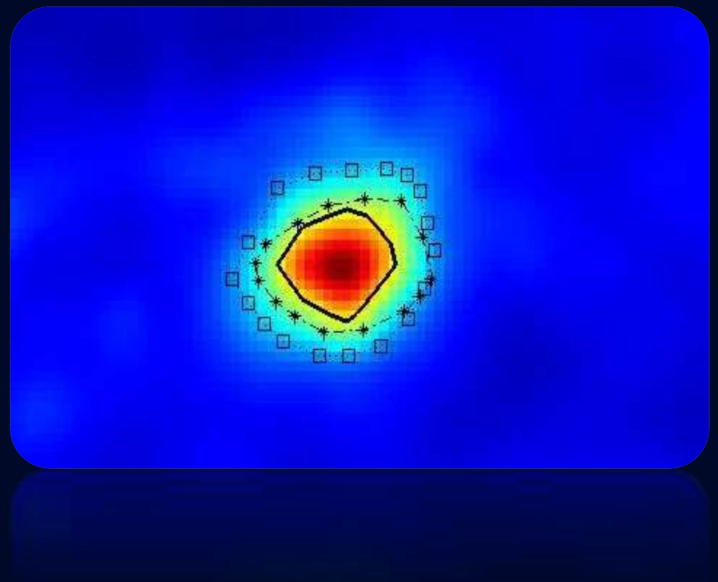
a= 7.8% b=61.7% c= 31.6%

$\%T = a_0 + \exp[a + b/V_l + c\log V_l]$ Nehmeh et al., 2009

$a_0 = 5$ a= 3.568 b=0.197 c= -0.1069

(3) variational





3a) edge detectors (Sobel operator)

3b) ridge detectors (Watershed Transform)

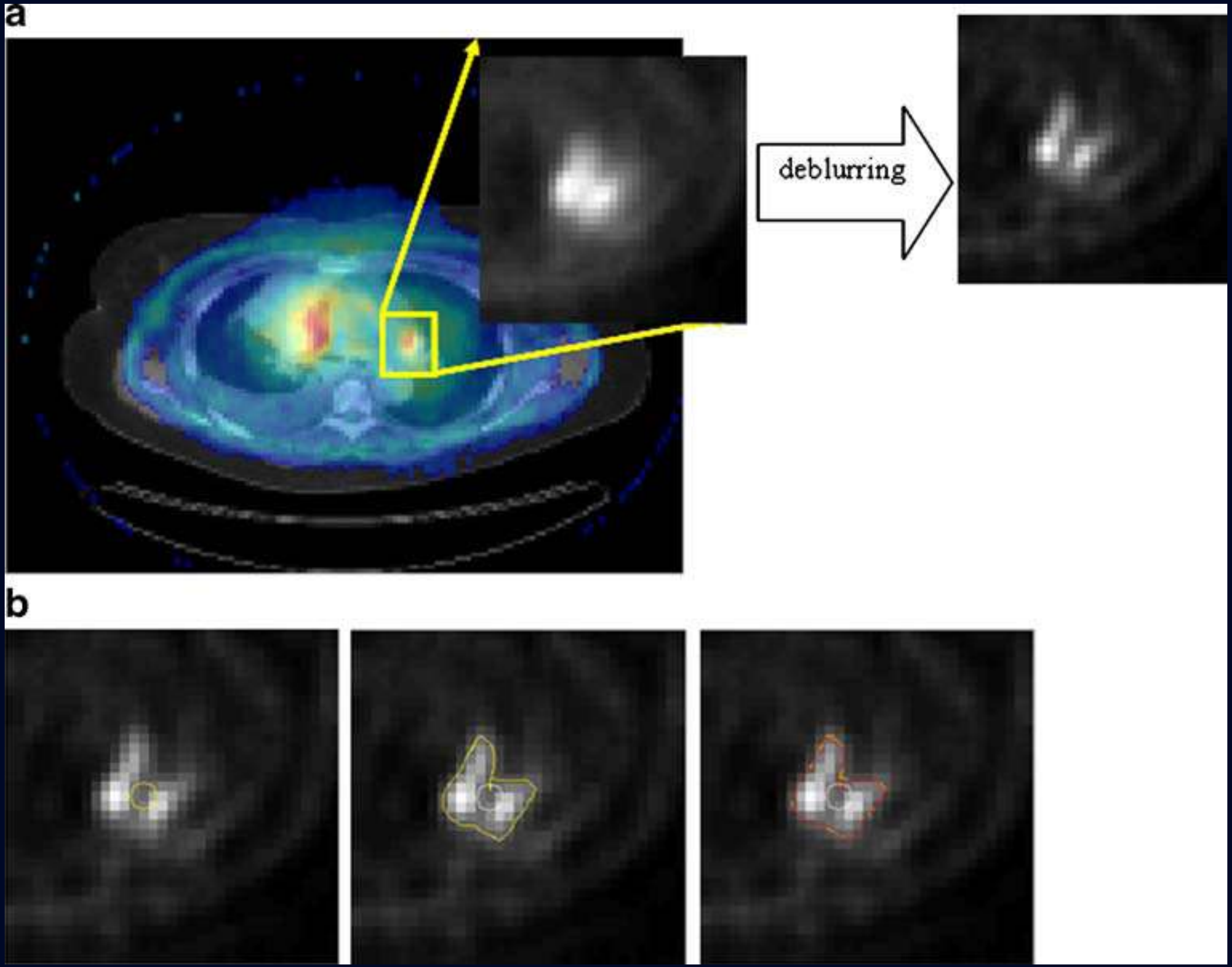
3c) deformable active contour models

Geometric function of surface deforming under internal (surface bending characteristics) and external (directional gradients) forces

Contourns are identified by sharp variations
(“snakes”)

Gradient Vector Flow (GVF), iterative evolutionary Poisson Differerential Equation (up to the balance between internal and external forces) (e.g. level set method,)

level set method



Minimum contours

40 it

(4) learning methods

learning task aims to discriminate signals in the lesion voxels from surrounding normal tissue voxels based on a set of extracted features from these images

supervised

unsupervised

Supervised learning is used to estimate an unknown (input, output) mapping from known labelled samples called the training set (e.g. classification of lesions given a certain number of example images)

In unsupervised learning, only input samples are given to the learning system (e.g. clustering)

Classifiers:
k-nearest neighbour (KNN)
support vector machine (SVM)
artificial neural network (ANN)

Clustering:
k-means algorithm
fuzzy C-means (FCM) algorithm
Expectation maximization (EM) algorithm

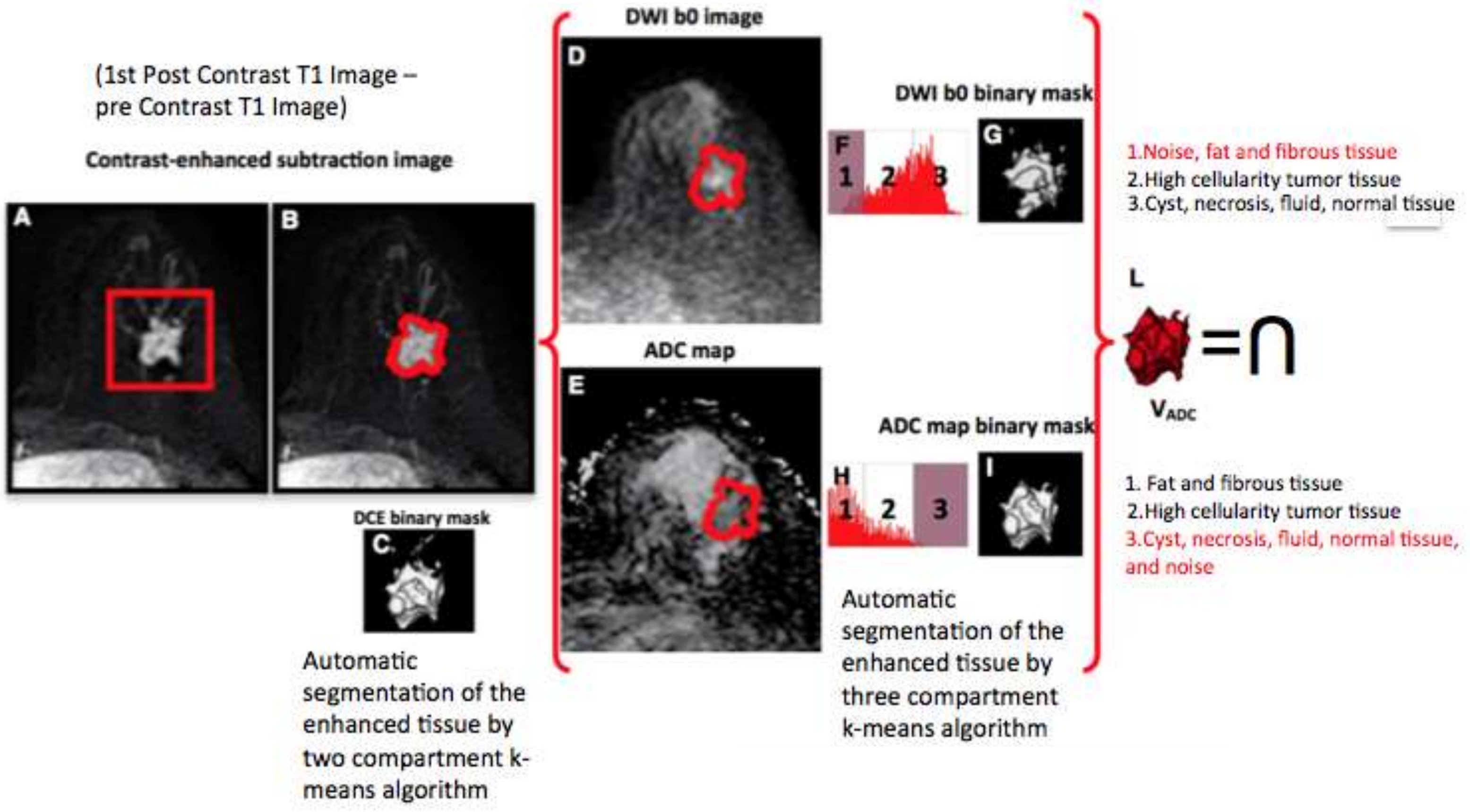
Solutions (Accurate/Repeatable/Reproducible)

- Automatic segmentation of lesion volume on MRI images

An Automatic Segmentation Method for the Measurement of the Functional Volume of Oncological Lesions on MR ADC Maps

Francesca Gallivanone, Marta Maria Panzeri, Carla Canevari, Interlenghi Matteo, Claudio Losio, Luca Gianolli, Francesco De Cobelli, and Castiglioni Isabella

978-1-5090-1642-6/16/$31.00 ©2016 IEEE



(4) Stocastic modeling

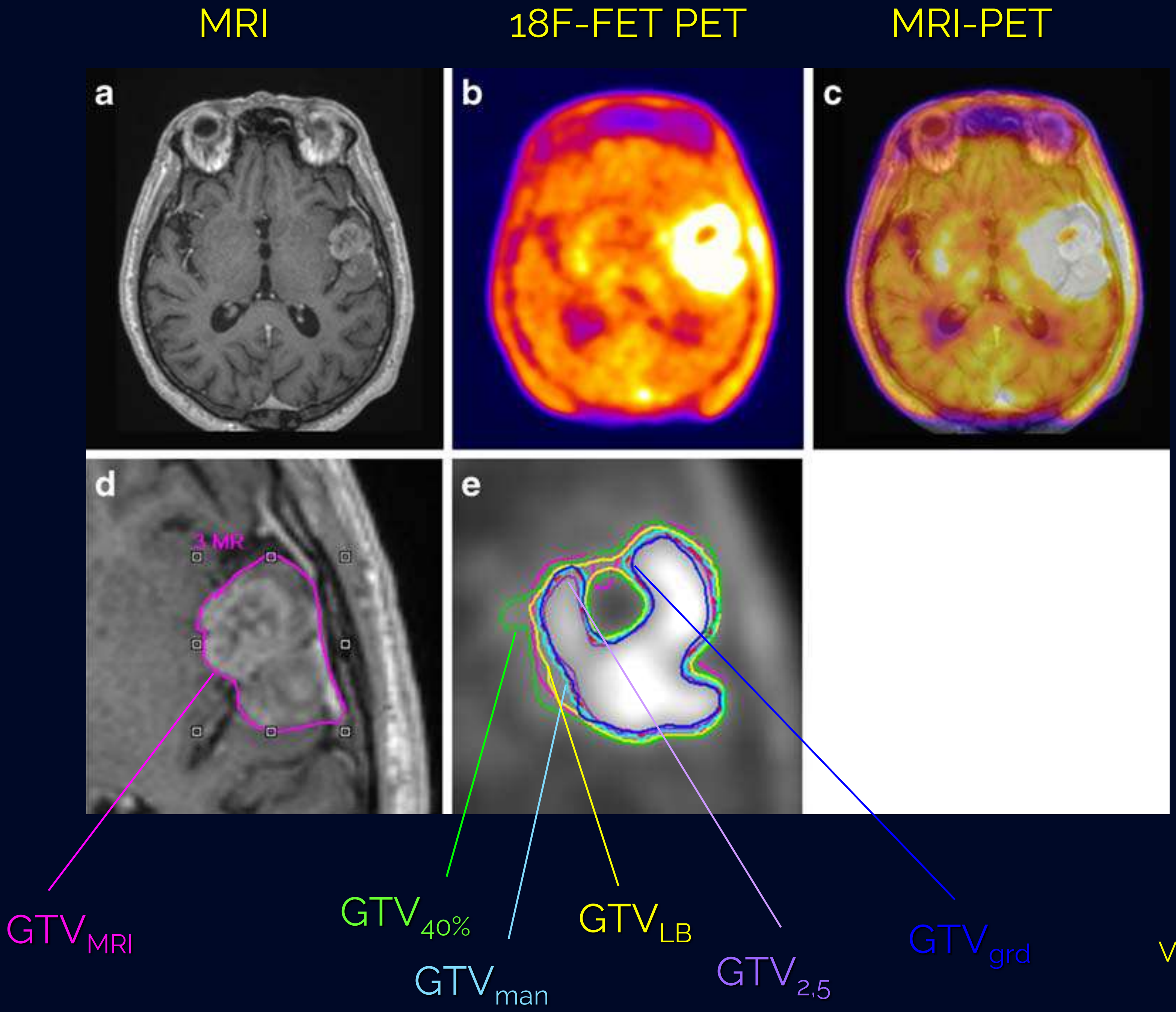
The intensity distribution of tumour and B are statistically different

4a) Gaussian mixture model (GMM)

3 classes:

The maximum likelihood estimates the unknown parameters by the probability of voxel xi belonging to class k p_{ik}

Markov models, wavelet-based multiscale decomposition, Fuzzy locally adaptive Bayesian (FLAB)



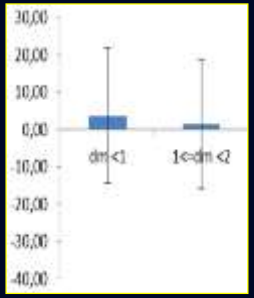
Vees et al., 2009

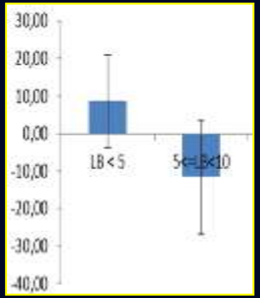
Validation on small, heterogeneous, non-spherical lesions


A fully automatic, threshold-based segmentation method for the estimation of the Metabolic Tumor Volume from PET images: validation on 3D printed anthropomorphic oncological lesions

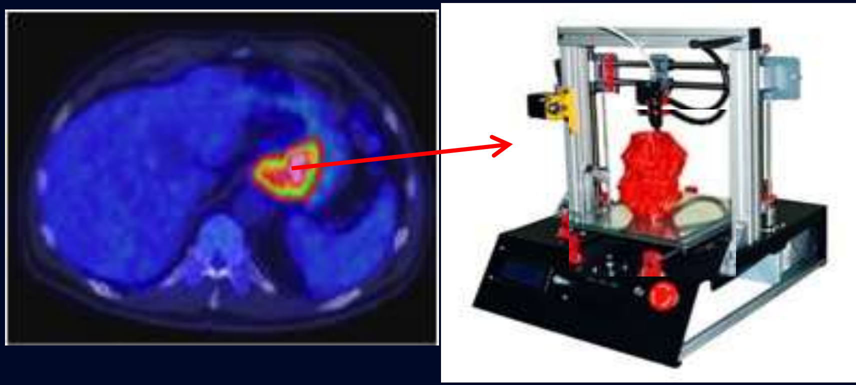
2016 JINST 11 C010

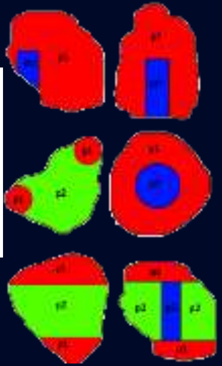
% residual error in V_m



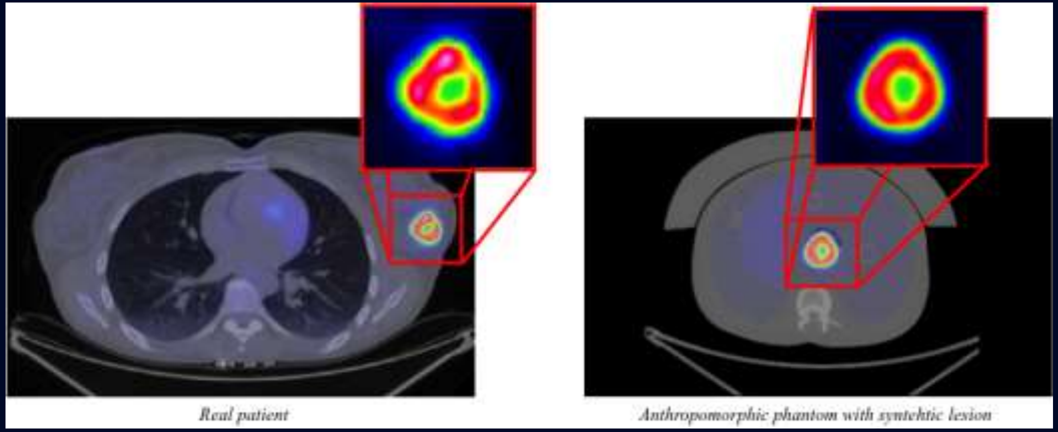


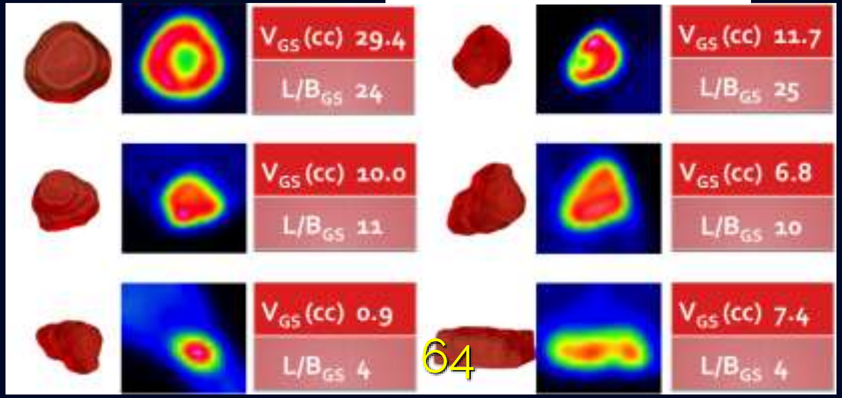
d (mm)	*% residual error after PVE correction*
9.8	0.26±0.12
12.3	0.13±0.06
15.6	0.002±0.002
25.8	0.09±0.03
31.3	0.10±0.01





Selected as highlight at IEEE NSS MIC, Strasburgh, November 2016


Real patient
Anthropomorphic phantom with syntehtic lesion



IN CONCLUSION

- Lesion segmentation is a key challenge in medical imaging

- Respiratory gated acquisitions is mandatory to improve lesion definition when respiration is involved (thorax)

- Partial volume correction is recommended to improve lesion definition when lesion is small and image has low LB (PET, MRI-DWI)

- Segmentation methods can be used to extract lesion volume but should be defined taking into account for lesion complexity and on different image modalities