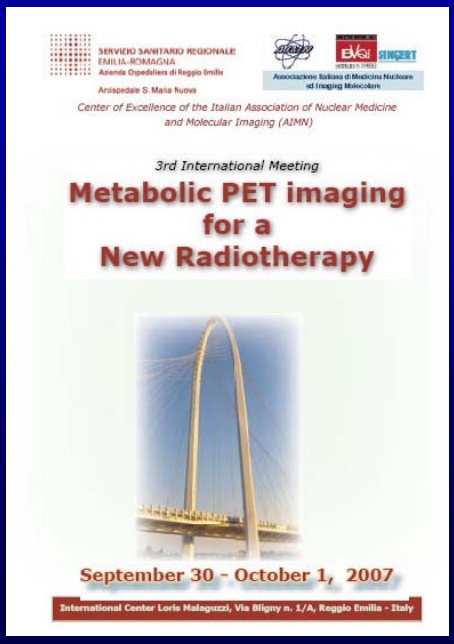
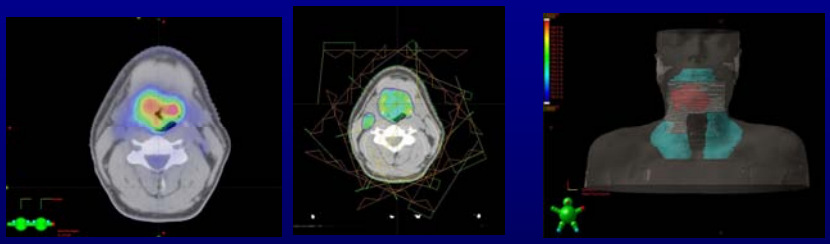


SERVIZIO SANITARIO REGIONALE
EMILIA-ROMAGNA
Azienda Ospedaliera di Reggio Emilia
Arcispedale S. Maria Nuova

Use of PET for target volume definition

F.Fioroni

Multimodality-imaging is an essential tool in Radiotherapy Planning to produce tumor maps for image-guided planning for radiotherapy.

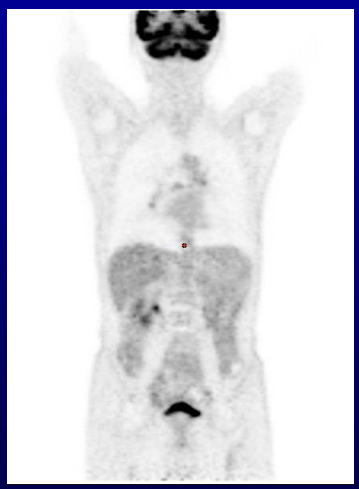


The use of PET for target volume definition in radiotherapy planning purposes has taken on an increasing importance in the last years, because of its ability to provide valuable physiologic data.

GOAL

The development of objective and reproducible methods for segmenting PET images

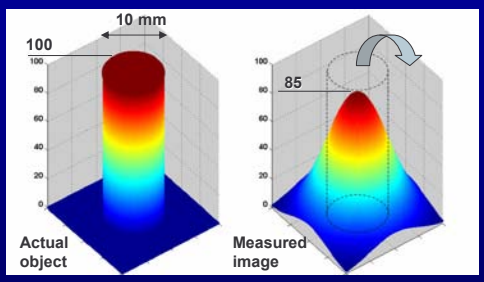
The PET image

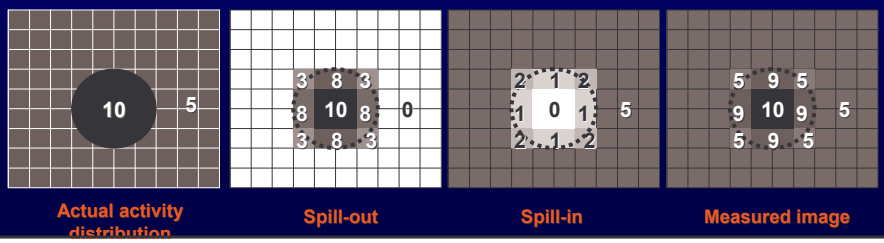


- High noise levels
- Poor resolution
  (partial volume effect)
- Low statistics
- Low contrast among several tissues
- Movement effect

Quantitative accuracy in PET

The Partial Volume Effect influences the quantification of objects smaller than 2 or 3 times the resolution (FWHM) of the imaging system
and the accurate determination of a structure boundary.





Preliminary remarks

PET/CT with adequate gantry

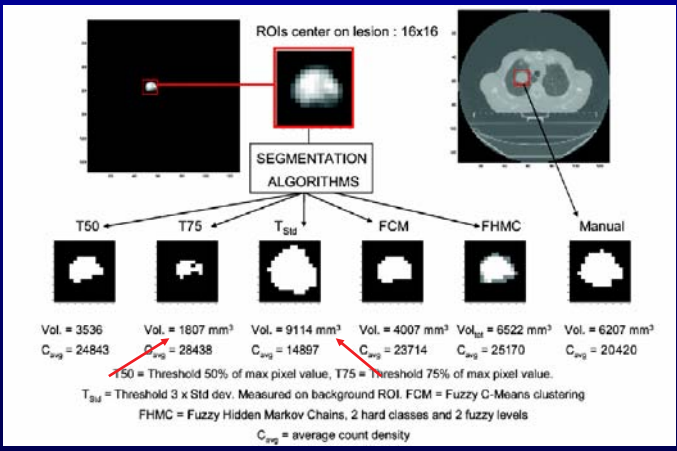
Flat pallet

Alignment lasers

External markers and positioning support devices for identical patient positioning

Volume definition requires great care in acquisition, reconstruction and processing of PET images to achieve reasonable volume accuracy

What is the optimal PET volume for Radiation Therapy?



An example of the variations in segmented volumes for a lung lesion using differing thresholding and analysis techniques.

Jarritt et al (2006)

Target Definition

Several strategies in using PET for target volume definition in radiotherapy treatment planning are being exploited:

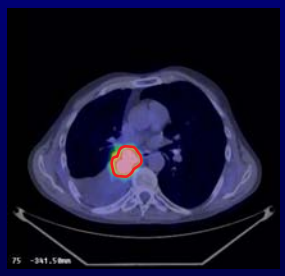
Qualitative approach – Expert clinical review

Quantitative approach- Voxel intensity values

Visual interpretation

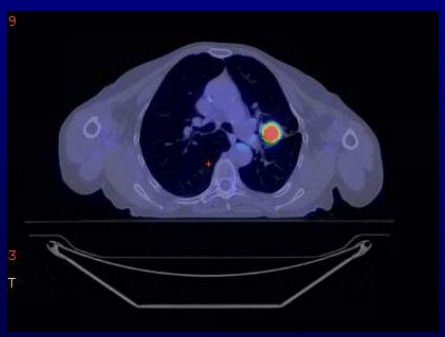
The method widely used is the visual interpretation of the PET scan and the definition of contours as judged by the experienced nuclear medicine physician.

- Inclusion of clinical history and data



Visual judgment is very much dependent on the individual investigator and display window setting.

Window level of PET images change size, shape and contrast of the target volume



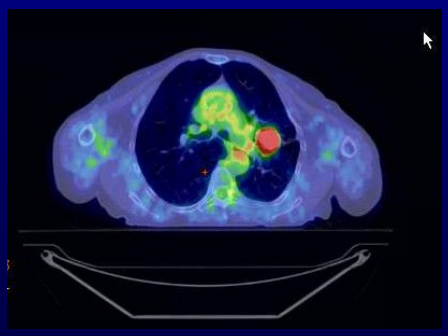


Image segmentation methods

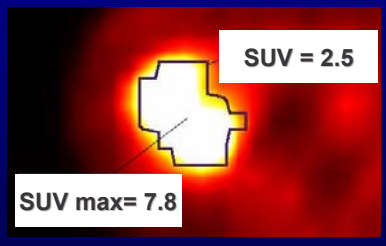
Quantitative - Voxel intensity values

– Thresholding: simple and intuitive method of segmentation in which all pixels that meet a given criteria are regarded as belonging to the target (absolute SUV value, % of the maximal activity of the lesion, local contrast).

– Other algorithms more sophisticated

Standardized Uptake Value (SUV)

In clinical practice the standardized uptake value (SUV) is commonly used for semi-quantitative evaluation, e.g. of the [18F]-FDG uptake in tumors.



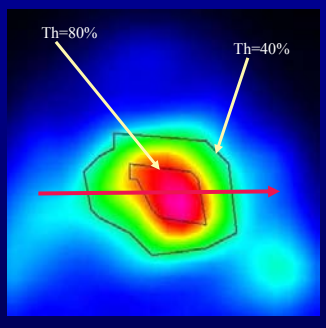
In diagnostic studies, a SUVmax of **2.5** is often used as a threshold for the distinction between malignant and benign lesions.

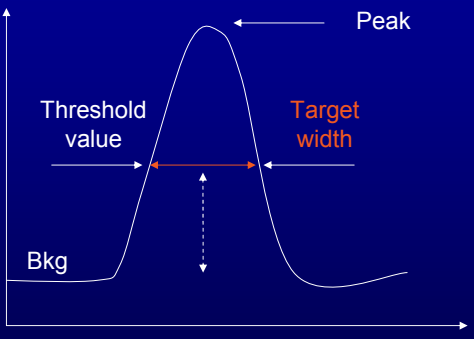
Standardized Uptake Value (SUV)

Technical factors influencing the determination of SUVs and therefore target volumes:

- Plasma glucose and insuline levels, length of uptake period, reconstruction parameters
- Size of the lesion (partial volume effects)
- Tumor heterogeneity (necrosis, variable grade)
- Lesion movement during imaging

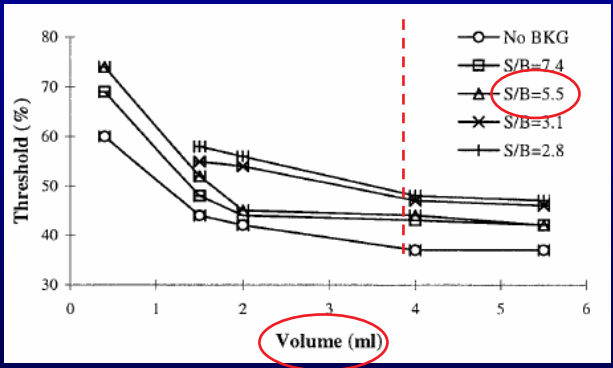
Thresholding segmentation





Autocontouring of all areas with a fixed threshold (40%, 42%, 50%) value of the maximal activity within the tumor.

Threshold (%) vs lesion volume



The threshold variation with respect to the sphere volume and contrast

A fixed threshold value between 36 and 44% of the maximal activity predicts well the true volume, for lesions larger than 4 ml.

Erdi YE et al (1997)

Threshold (%) vs lesion volume (2)

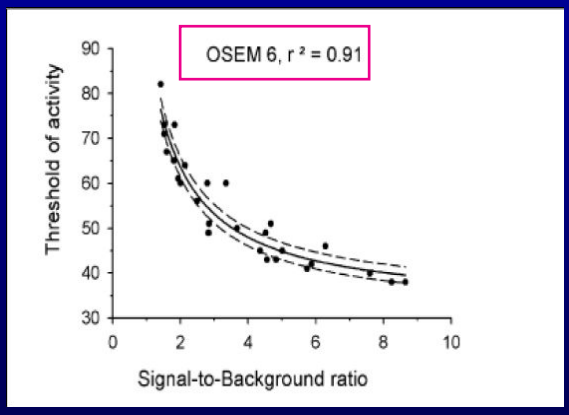
TABLE 1
Comparison of PET_{GTV} and CT_{GTV}

Tumors (*n*)	Mean ± SD SUV_{max}	CT_{GTV} (cm^3)	PET_{GTV} at 40% threshold (cm^3)*	Optimal threshold (%)†
All (20)	12 ± 8	198 ± 277	44 ± 30	24 ± 13
<3 cm (4)	3.0 ± 0.4	13 ± 7	14 ± 14	42 ± 2
3–5 cm (10)	13 ± 9	90 ± 69	38 ± 22	24 ± 9
>5 cm (6)	16 ± 5	502 ± 348	69 ± 28	15 ± 6

*GTV determined by PET with 40% SUV_{max} threshold.
†Optimal threshold is percentage threshold that yields 1:1 volumetric match between PET- and CT-delineated tumors.

Biehl et al (2006)

Threshold (%) vs Lesion/Background ratio



This method is independent of the a priori knowledge of the lesion of interest and is valid for small (>2ml).

Daisne, Gregoire et al. (2003)

Threshold (%) vs regressive function

- SUVthresh = 0.307*(mean target SUV) + 0.588

(Black QC, 2004)

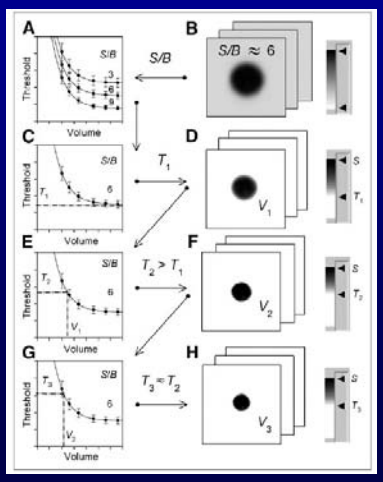
Threshold (%) vs local contrast

- SUVthresh = 0.15*(mean target SUV) + SUVbkg

(Nestle, 2005)

Iterative image thresholding

Segmentation of PET volumes by iterative image thresholding



The iterative thresholding method is based on threshold-volume curves at varying source-to-background ratio acquired from a body phantom (to be determined once for the specific PET camera, image reconstruction algorithm, gray scale and nuclide used)

The ITM sufficiently estimated the clinical volumes in the range of 0.8-7.5 ml.

Jentzen et al. (2007)

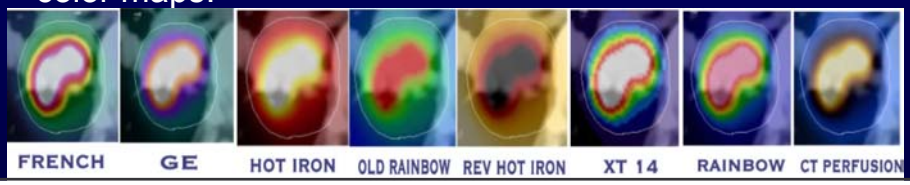
"Anatomical Biological Contour"

Ashamalla et al. (2005)

A distinct "halo" around areas of maximal SUV uptake is observable with thickness of 2±0.2 mm and with a steady decline of SUV uptake of 2 ± 0.4 at the peripheral edge of the GTV-ABC.

The use of the halo method for the contouring reduces interobserver variability.

The color was observed in all commercially avilable color maps.



Gradient-based segmentation method

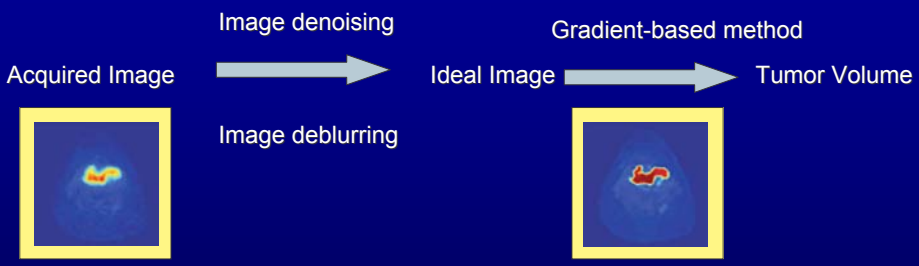
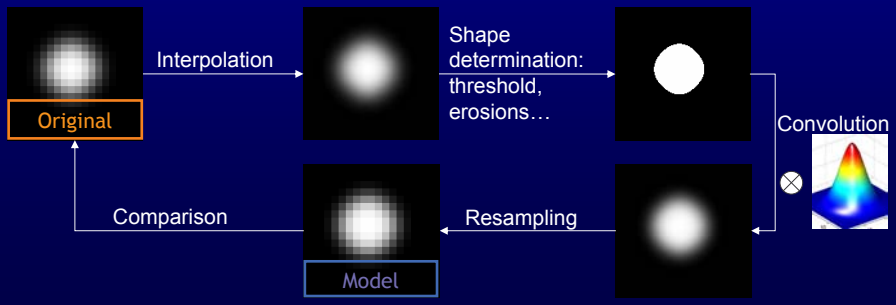


Image restoration tools, such as edge-preserving filters and deconvolution algorithms, generate high-quality images that affirm the use of gradient-based segmentation techniques. Main advantage: the method is purely data driven; no underlying model or calibration curve is necessary.

Geets, Gregoire et al. (2007)

Model fitting

- Principle: Fit a 3-parameter model to the tumor image
- Previous work: Chen et al.
  - « Simultaneous recovery of size and radioactivity concentration of small spheroids with PET data » J Nucl Med 1999; 40:118-130
- Assumptions:
  - Homogeneity of tumor and background activity
  - Stationary spatial resolution over the tumor region
  - Tumor of any shape, estimated from the PET data

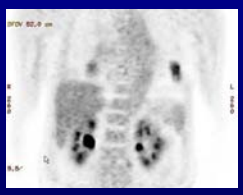


Experimental comparison of three methods for estimating tumor volume in FDG PET. Tylski P, Buvat I, SNM 2007

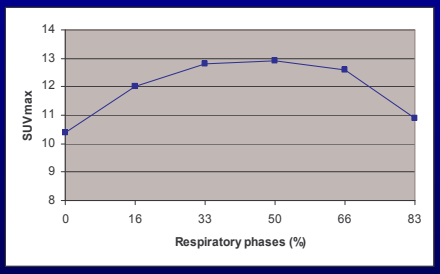
Tumor motion

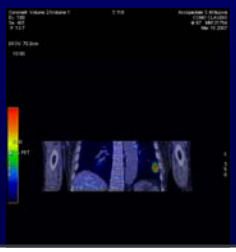
Effects:

- Apparent increase of lesion size
- Apparent reduction of measured SUV
- Loss of small lesion



3D Study
SUVmax = 6
Volume 16 cc

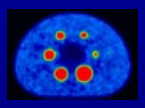
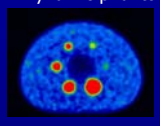
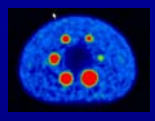
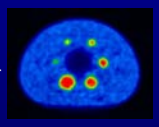
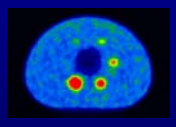
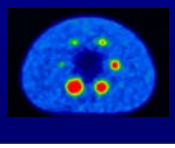


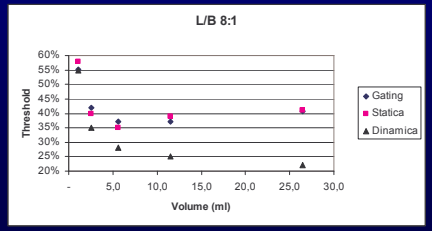


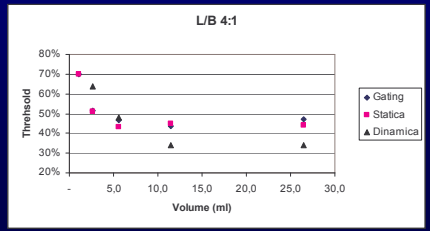
4D Study
SUVmax = 12.9

Volume (cc)	8.5	7.9	8	8.3	8.2	8.1

Tumor motion (2)

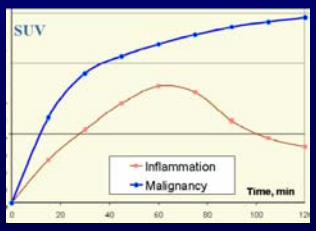
	Static phantom	Dynamic phantom	Gated phantom
L/B 8:1			
L/B 4:1			

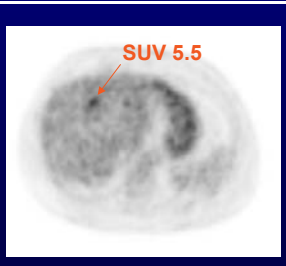




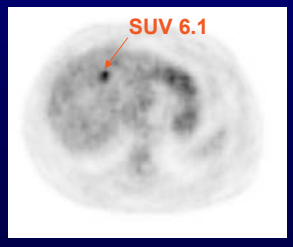
Delayed PET acquisition

- The physiologic distribution of [18F]-FDG varies over time. While normal tissues after an initial peak accumulation show a decrease in FDG-activity, and inflammed tissues, after an initial plateau, also show a decrease, malignant tissues tend to accumulate the tracer continuosly leading to a rise in contrast between normal and malignant tissues over time.





70 min post injection



135 min post injection

Conclusion (1)

At present there is no method for automatic delineation of the GTV based on FDG uptake that can be regarded as a reliable standard.
More robust algorithms of GTV segmentation based on PET-data are being developed and tested clinically.

Next generation of PET systems integrated with new crystal detectors and optimized reconstruction algorithms will likely increase the spatial resolution of the technique and a reduction of the noise, resulting in a better assessment of the volume and shape of small or complex objects.

Conclusion (2)

Respiratory gating techinques improve target definition

The whole chain used to produce PET-based target volume definition (image acquisition, processing and segmentation) has to be carefully validated in individual departments.

A close cooperation of the radiation oncologist with the nuclear medicine specialist is mandatory to ensure the correct diagnostic interpretation of the PET-scan.

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- Diana Salvo - Chief of the Department

Radiotherapy Department

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- Luciano Armaroli - Chief of the Department