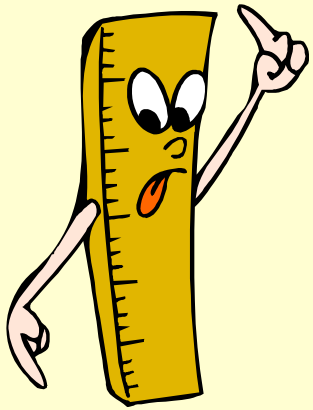
# SUV in PET:
# Silly or Smart Uptake Values ?



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# What is SUV?

## Standardized Uptake Value

$$SUV = \frac{\text{uptake (kBq/mL)}}{\text{injected dose (kBq) @ scan time} \;/\; \text{“patient weight (g)”}}$$

If:
1/ the tracer distributes uniformly throughout the patient
2/ patient density is 1 (1g = 1 mL)

SUV = 1 everywhere

SUV > 1, high uptake

# What is it currently used for?

- Distinguishing between benign and malignant lesions

By ROC analysis using different SUV threshold cutoffs, we decided that an SUV of 3.5 was optimum for differentiating between **benign** and **malignant** tissue on our machines (*15*,*16*).

*Chin et al, J Nucl Med 47: 443-450, 2006*

- Patient monitoring

some predefined, prospective definitions of metabolic **response** were used. For that purpose the population was categorized according to the definitions for metabolic **response** of The European Organization for Research and Treatment of Cancer (**EORTC**), into a group with complete **response** (CR) or partial **response** (PR) ($\Delta < -25\%$), a group with stable disease (SD) ($\Delta$ –25% to +25%), and a group with progressive disease (PD) ($\Delta > +25\%$) (*15*).

*De Geus-Oei et al, J Nucl Med 48: 1592-1598, 2007*

- Delineation of metabolically active volume for treatment planning in radiotherapy

A few early investigations estimated that a threshold of 40% the **$SUV_{max}$** approximated tumor volume (*10*,*22*,*23*).

*Biehl et al, J Nucl Med 47: 1808-1812, 2006*

# Why is SUV Smart ?

• Converting images into SUV makes them more easily comparable between patients, by removing most of the differences in patient weight and injected dose: the expected value is 1 for any patient, whatever the injected activity and the body habitus

Note also that SUV is Simple to calculate !

# So why is it sometimes qualified as Silly?

• Short answer: because it is subject to many flaws that are often ignored, and which can make it completely misleading

> It is often used as a measure to characterize the malignancy versus benignancy of lesions. Indeed, it is almost necessary to include this measure to get a paper past initial review. Yet when viewed objectively, the SUV as it is now currently used is so flawed as a quantitative measure as to be virtually worthless for the purpose for which it is usually used.

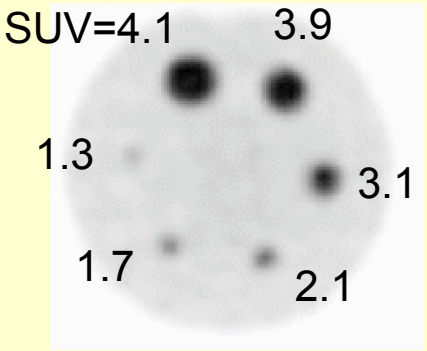
*Keyes JW Jr. SUV: standard uptake or silly useless value? J Nucl Med **1995**;36:1836–1839*

Unfortunately, this is still often true !

# A major flaw (1)

- The measured SUV depends on the tumor size

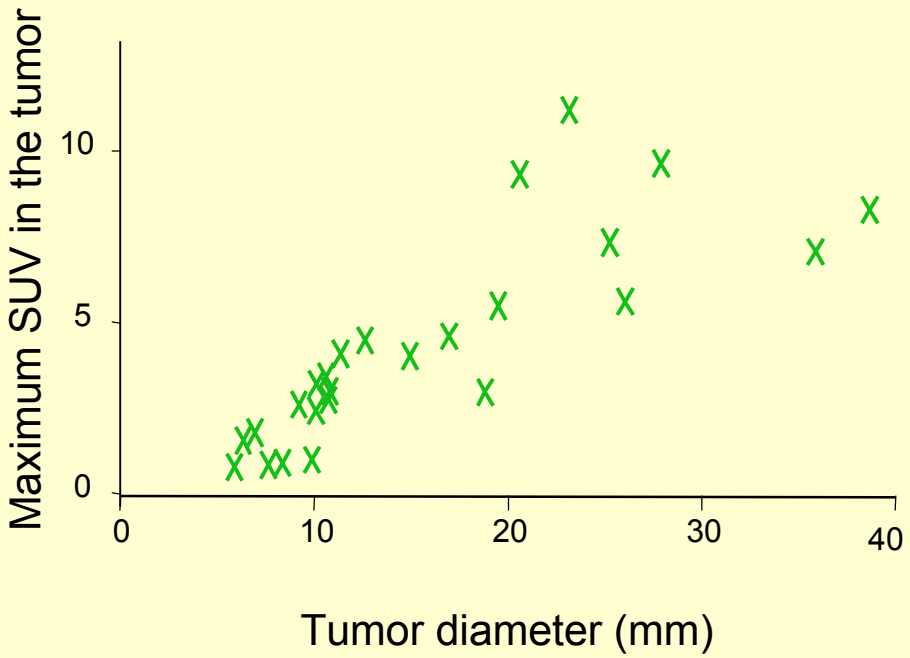
Same activity concentration in each sphere




Same or different SUV?

# Do it yourself…

- Plot SUV =f (tumor size) for a set of tumours

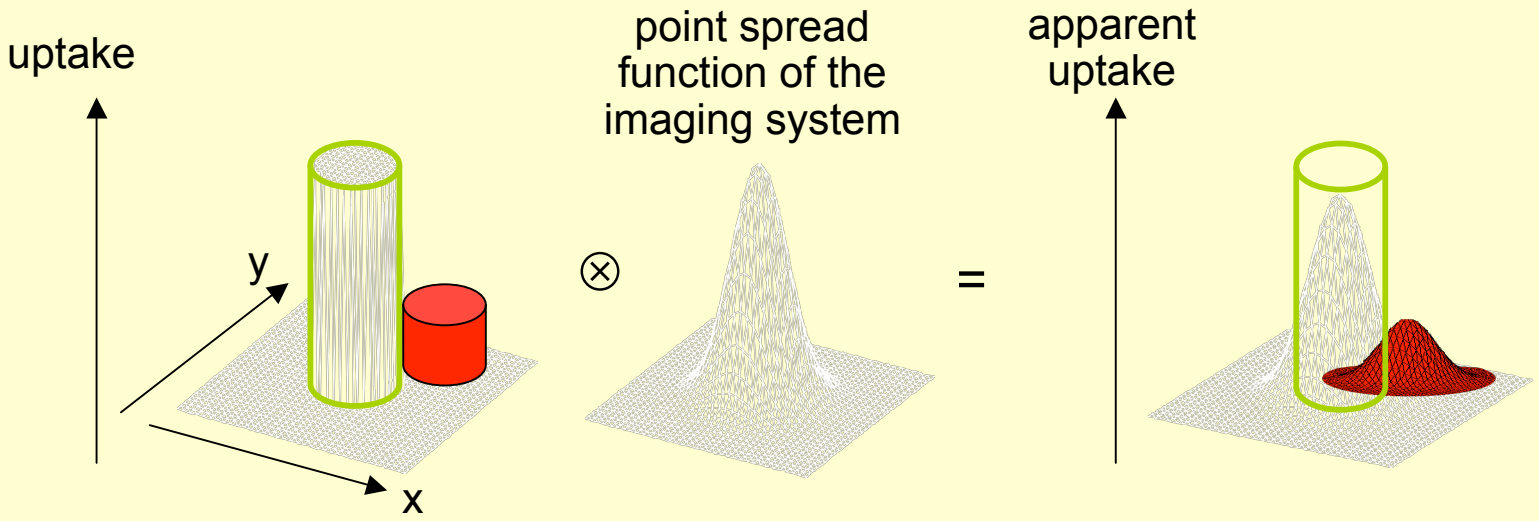



Not that bigger tumours are always more aggressive, but bigger tumours are less affected by partial volume effect !

# What is partial volume effet?

- Resulting from for 2 effects:

1/ spatial resolution effect



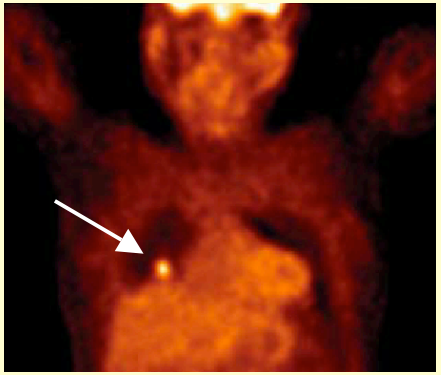

Activity spills out the tumor which results in activity underestimate …

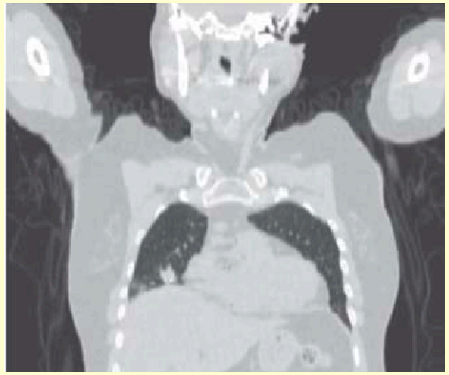
… and activity from neighbouring structures might spill in

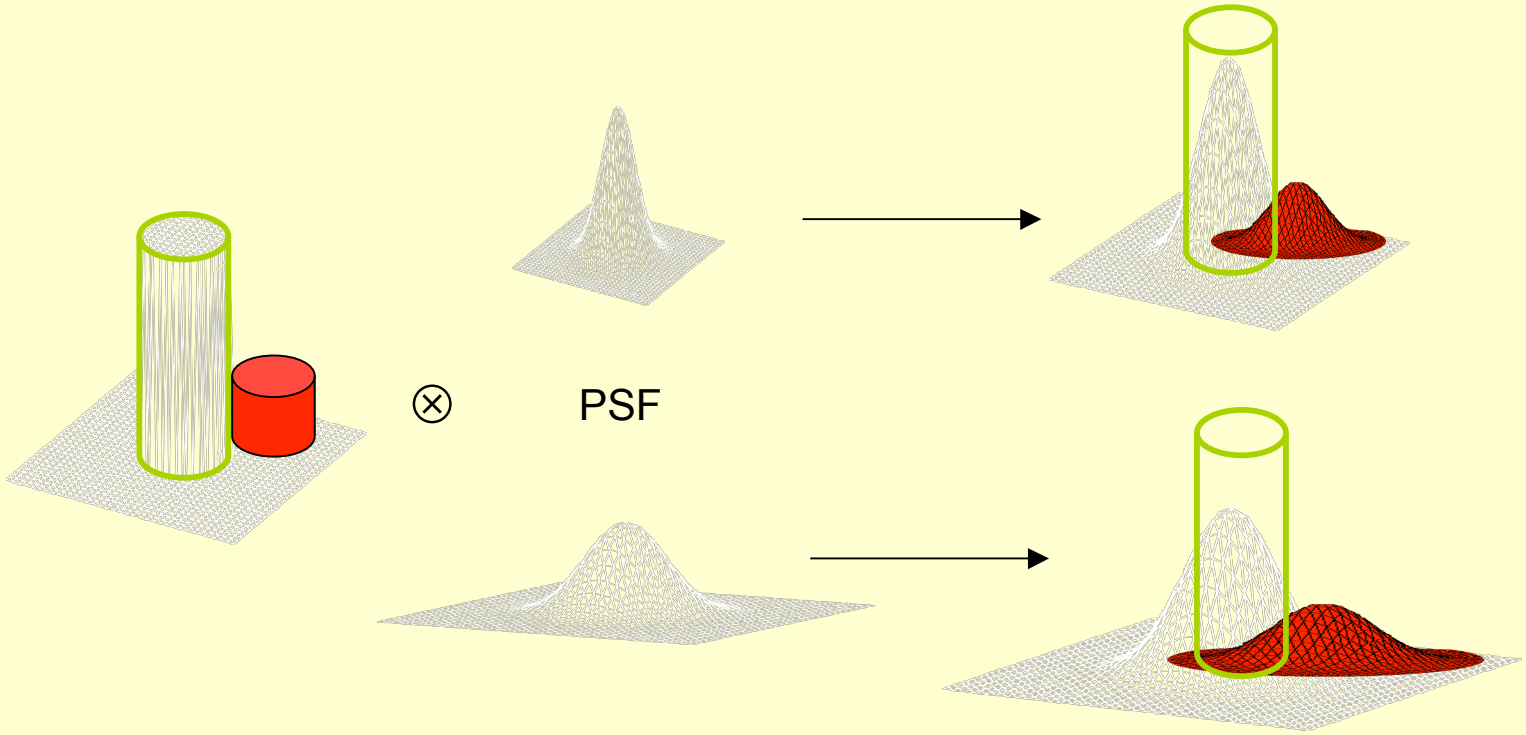
Balance between spill in and spill out depends on the contrast

# Spatial resolution effect

balance between spill in and spill out?



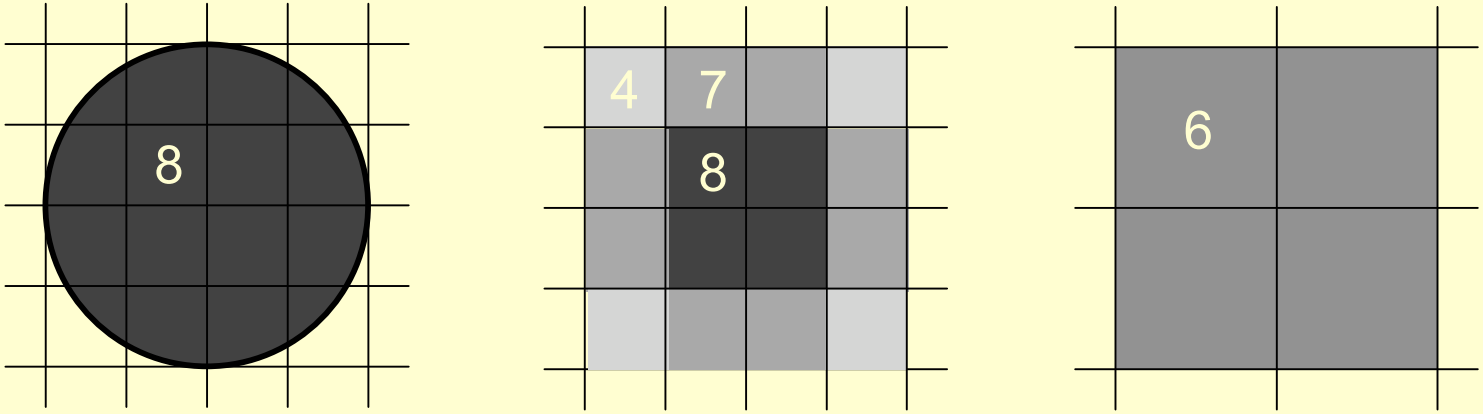


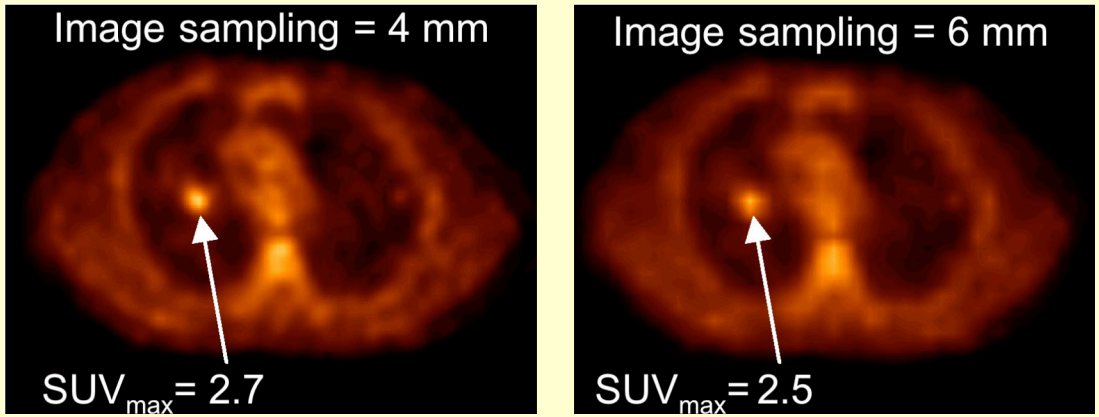



The effect depends on the spatial resolution in the reconstructed image.

# Tissue fraction effect

2/ sampling effect also called tissue fraction effect



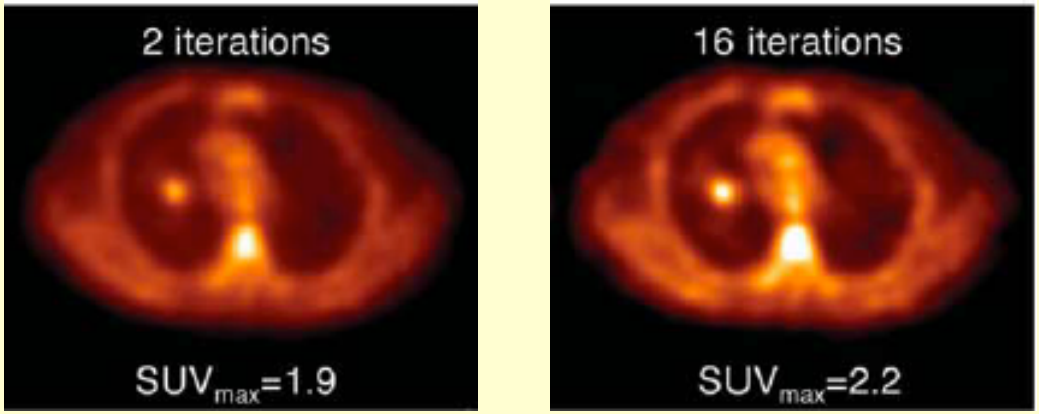




The effect will depend on the image sampling

# So far …

- SUV depends on the tumor size due to partial volume effect
- Partial volume effect depends on spatial resolution
  image sampling
- Spatial resolution and image sampling depend on reconstruction

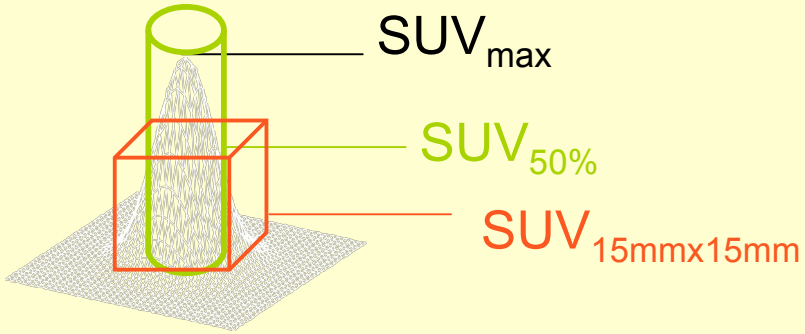
**SUV depends on how the images have been reconstructed**

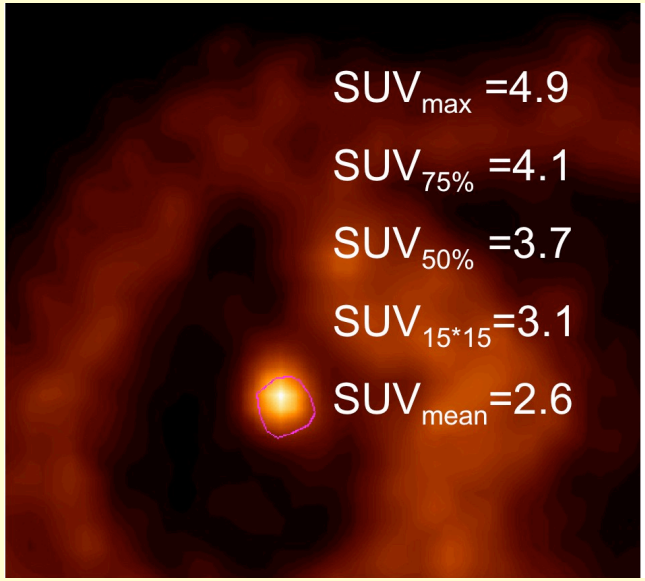


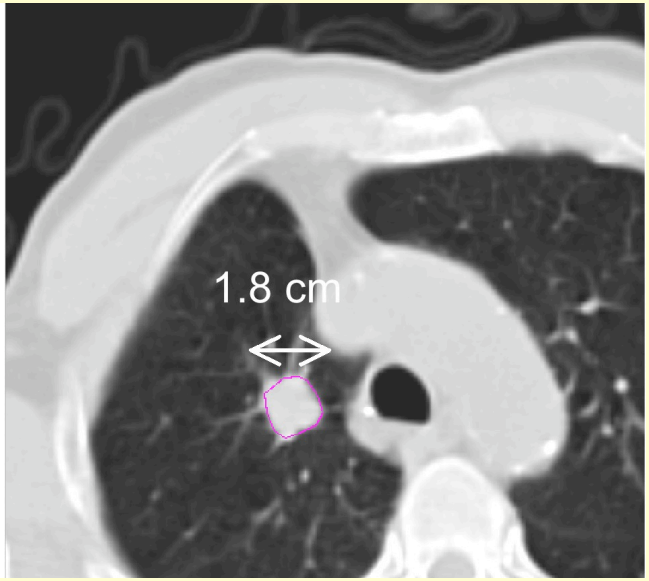

- Even if reconstruction is kept identical, SUV depends on the tumour size

# Second major flaw

- SUV depends on the way it is measured

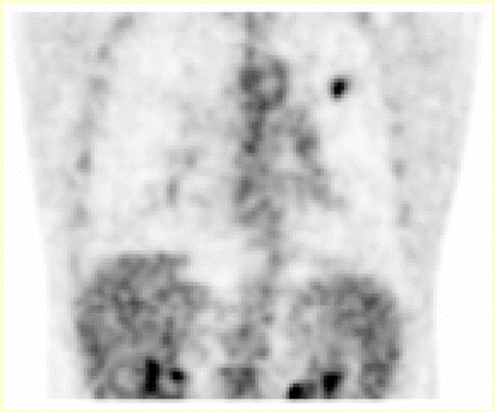


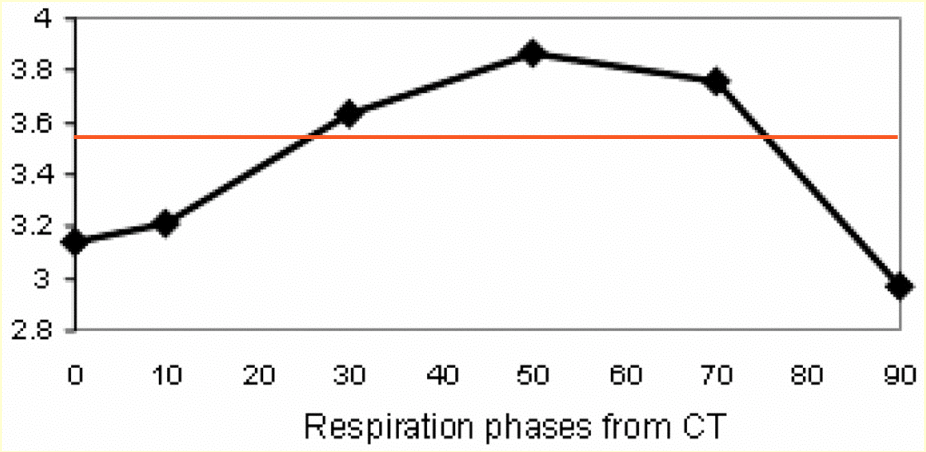



# Another possible flaw

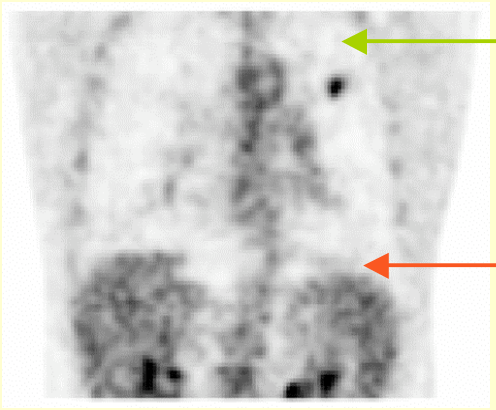
- SUV depends on the respiratory blur






$SUV_{max}$ measured from ungated PET

*Erdi et al, J Nucl Med* 2004:1287-1292



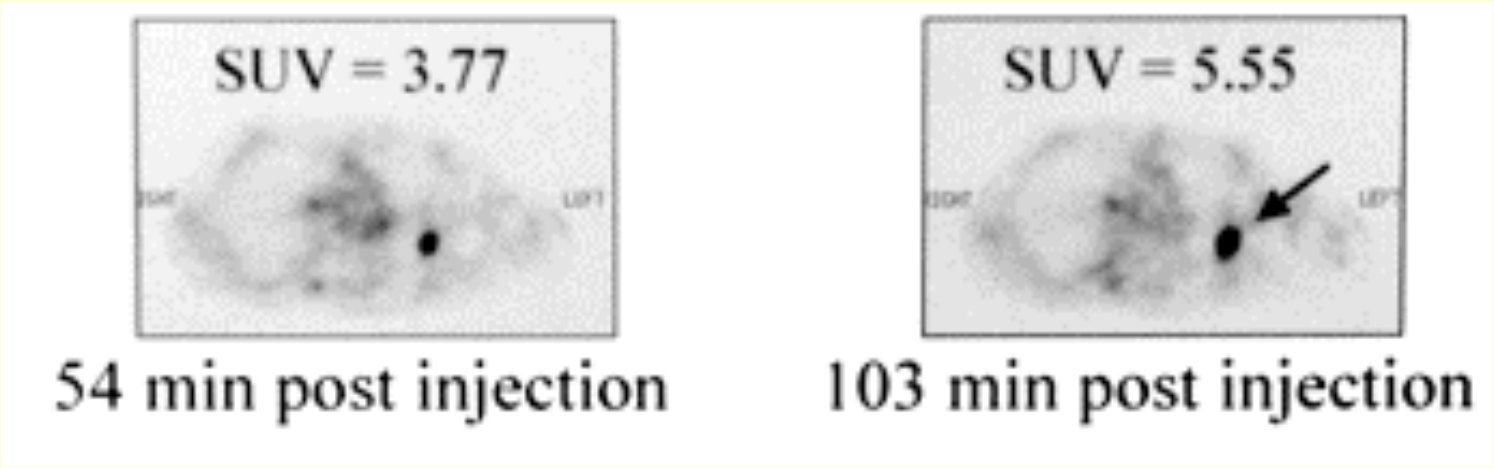
Tumour here: little motion, small SUV underestimate due to respiratory blur

Tumour here: large motion, large SUV underestimate due to respiratory blur

Same tumour volume and uptake but different locations ➡ different SUV

# Last but not least

- SUV depends on the scan time after injection because equilibrium is not reached at 1 h post-injection (usual scan time)




*Zhuang et al, J Nucl Med* 2001:1412-1417

# In summary: why Silly?

- Because a given tumor can yield very different SUV depending on:
  - post-injection PET scan time
  - acquisition protocol (duration, respiratory gating)
  - image reconstruction procedure (+ post-smoothing and voxel size)
  - the way SUV is measured

… not to mention (usually smaller effects):
  - blood glucose level
  - unmetabolized glucose (cannot be distinguished from metabolized glucose using static PET)
  - approximate standardization (patients differ more or less from water)

- Keeping all the above variables constant, 2 tumours with the same metabolic activity might still yield different SUV because:
  - the tumours have different sizes, shapes or locations
  - surrounding tissues have different uptakes (hence spill-in differently in the tumours)

# Is there any hope to make sense of SUV under these conditions?

**YES**

# Distinguishing between benign and malignant tumours

There is a evidence in the literature that SUV can help distinguish between benign and malignant lesions, or between good and poor prognosis.

But part of the correlation might be due to the correlation between measured SUV and tumor volume (the larger the tumor, the poorer the prognosis for instance).

• Ideally, SUV and tumor metabolically active volumes should be looked at independently.

• If possible, partial volume should be compensated for.

• Don’t use a cut-off value found in the literature, it might not be appropriate for your data (scanner, acquisition protocol, processing protocol, …).

# Evidence that cut-off value is center-dependent

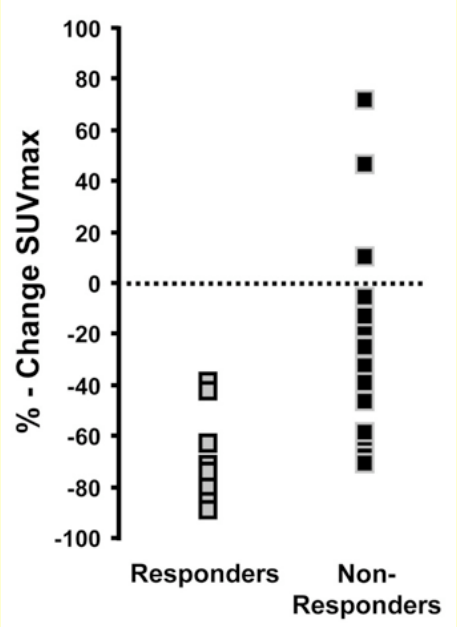
- Meta-analysis of 13 studies considering the prognostic value of the SUV in the primary tumour for NSCLC

| Study | Type of SUV | SUV normalization | SUV threshold definition | SUV threshold |
|---|---|---|---|---|
| Ahuja (26) | SUV mean (SUR) | Weight | Best cut-off | 10 |
| Sugawara (23) | SUV max | Lean body mass | Median | 8.7 |
| Vansteenkiste (22) | SUV max | Weight | Best cut-off | 7 |
| Dhital (20) | SUV max | Weight | Best cut-off | 15 or 20 |
| Higashi (16) | SUV mean | Weight | Best cut-off | 5 |
| Jeong (18) | SUV max | Weight | Best cut-off | 7 |
| Downey (25) | SUV max | Weight | Median | 9 |
| Port (11) | Non specified SUV | - | Arbitrary | 2.5 |
| Sasaki (24) | SUV max | Weight | Best cut-off | 5 |
| Prevost (21) | SUV mean<br>SUV max | Weight<br>Lean body mass | Literature value | 10 |
| Eschmann (19) | SUV mean | Weight | Best cut-off | 12 |
| Borst (14) | SUV max | Weight | Median | 15 |
| Cerfolio (13) | SUV max | Weight | Median | 10 |

*Berghmans et al, J Thoracic Oncol* 2008: 6-12

# Patient monitoring

There is a evidence in the literature that SUV changes can effectively separate histopathologically responding and non responding tumours.



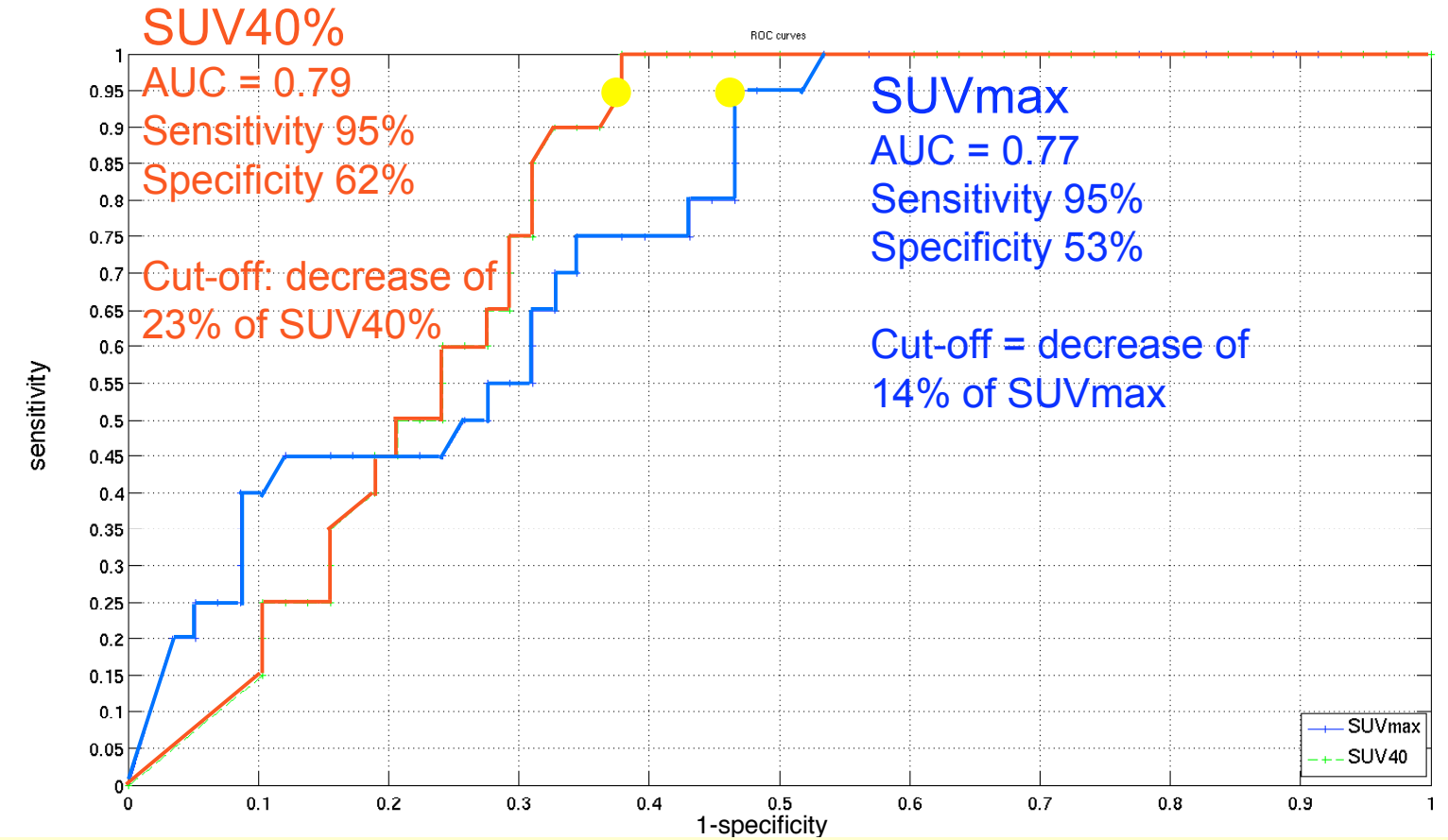

*Benz et al, J Nucl Med* 2008: 1038-1046

• Keep acquisition and processing protocols exactly the same between scans (delay between injection and scanning, injected activity / kg, scanning duration, reconstruction protocol, SUV measurement, …) to reduce variability.

You might still get variability due to different glucose metabolism under treatment, different body compositions (more or less fat, …)

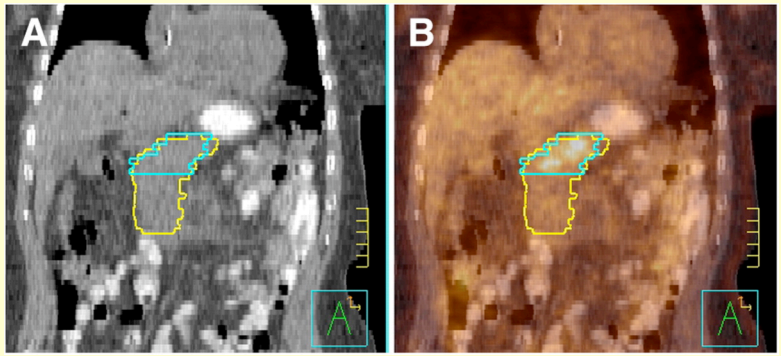
• Don’t use a cut-off value published in the literature under different settings.

# « Optimal » cut-off value as a function of SUV index



# Tumor delineation for radiotherapy treatment planning

PET definitely shows promises in helping in the identification of regions of disease

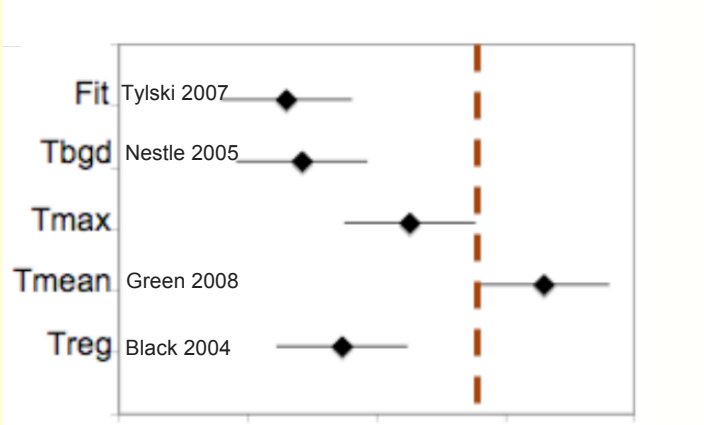



*Ford et al, J Nucl Med* 2009: 1655-1665

• Don’t trust others’ delineation algorithms without performing first a careful evaluation of their performance on your OWN data. Tune your tumor delineation approach to YOUR images using phantom data.

# Impact of the tuning of tumour delineation algorithms

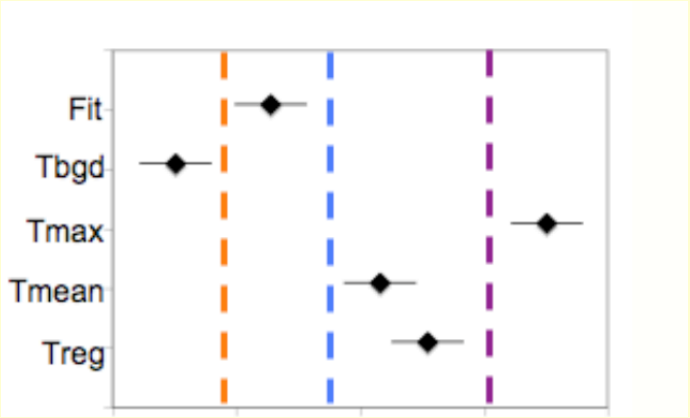
Relative performance of delineation methods depend on how they are tuned




Smallest error in volume estimates

Largest error in volume estimates

Tuning and test on similar phantom data




Smallest error in volume estimates

Largest error in volume estimates

Tuning on phantom data and test on realistic simulated data with similar features

*Tylski et al, J Nucl Med* 2010: 1655-1665

## Conclusion

• SUV is neither Silly nor Smart (sort of excessive qualifiers) but is rather a

**Simple Useful Value**

• When used with care, SUV is definitely not ideal (too simple) but has proven useful.

• SUV still needs an extra level of standardization ($S^2UV$ ?).

Additional recommendations are needed to make the most of it, and greatly increase the statistical power of multicentric studies and meta-analyses.