Healthcare Challenges for CLASP Imaging Technology

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Identified Challenges in Imaging

- Dose reduction in ionizing imaging modalities. Large patient imaging.
- Effect of patient movement, respiratory/cardiac, reducing resolution and accuracy of data.
- Sensitivity of detectors.
- Computer Aided Diagnosis/Pattern Recognition.
- Improved Image Reconstruction; Automatic Image Analysis.
- Image alignment from multiple modalities.

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Challenges Linked to 'Big Data'

- Data mining from large imaging archives – can we use this data to develop computer aided diagnosis which is machine/protocol specific.
- Data migration through system replacement. How do we manage technological advances and the use of normal ranges/results.
- Can we link imaging findings to biochemistry/pathology data.

Potential Clinical Issues

- Ionizing v Non-ionizing modalities
- Function v Structure
- Multimodality
- Technology developments
- Image Guided Therapy – Radiotherapy/IMRT/IGRT
- Image Guided Surgery/Robotic Surgery
- Image Optimization/System Modelling

An Example from PET/CT and Radiotherapy.

- How do we correct for respiratory/cardiac motion across different modalities and therapy regimes
- (Also applies to SPECT and SPECT/CT technologies – May be less of an issue in PET/MR if we can acquire simultaneously)
- (Will apply to any imaging conducted sequentially in different timescales)
- Motion always a degrading factor in any imaging.

What are we trying to achieve with PET in Radiotherapy Planning?

- Identify and treat an anatomical structure/volume with a particular biological function with high sensitivity and specificity (better than current gold standards).
- Identify and quantify an anatomical sub structure volume with a particular (quantifiable) biological function to inform a treatment plan. (IMRT)

What are we trying to achieve with PET in Radiotherapy Planning?

- A 'Biological Target Volume (BTV)'.
- The definition of a planned target volume (PTV) to effect a better cure rate with reduced normal tissue damage/complications.

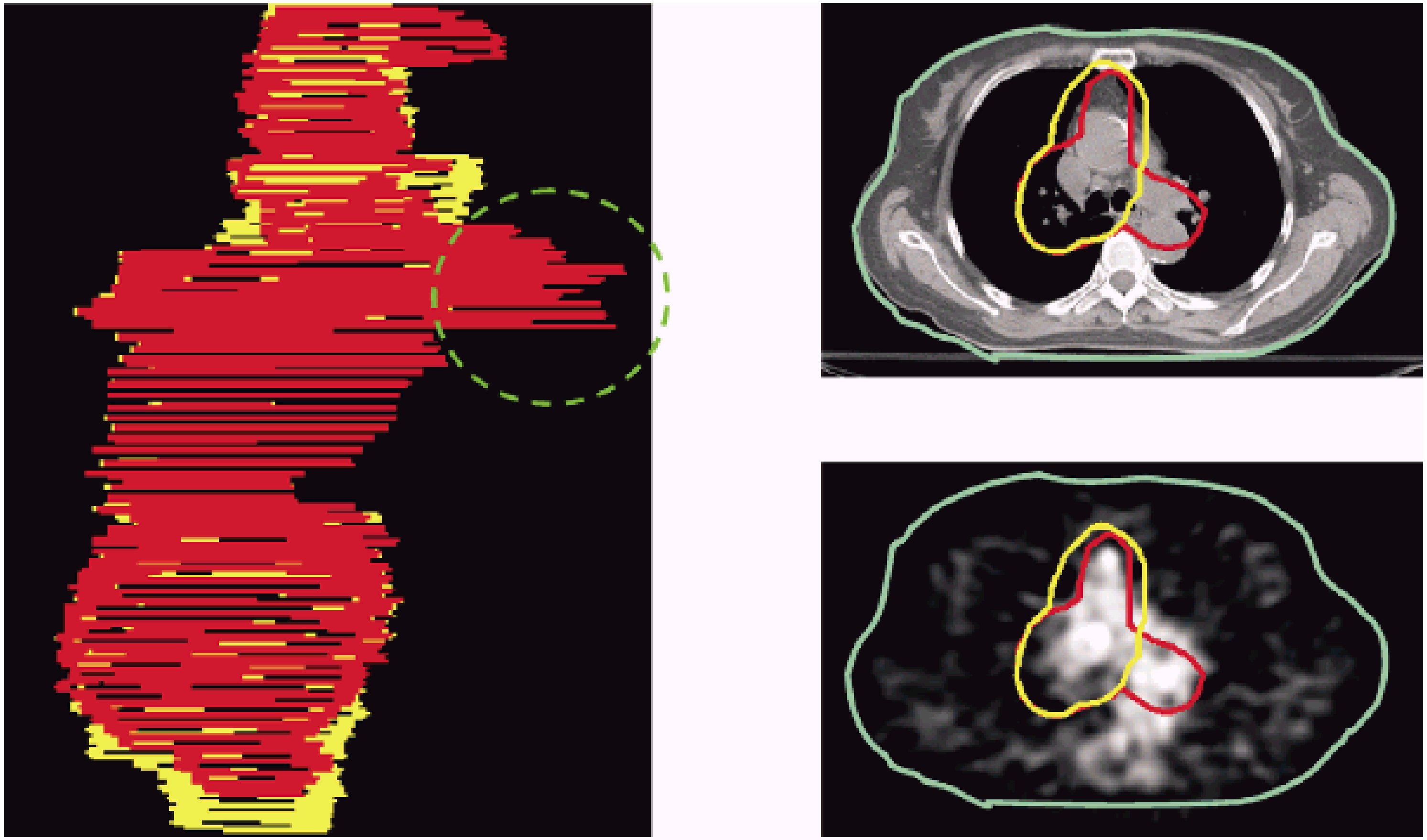
Mah et al, The impact of FDG PET on target and critical organs in CT-based treatment planning of patients with poorly defined NSCLC: a prospective study,
Int. J. Radiat. Onc. Biol. Phys., 52, 339-350, 2002

- 30 patients referred for radical treatment
- 3 radiation oncologists independently identified separate GTV's on the CT and fused PET-CT images
- With inclusion of PET information 7 of 30 patients changed to palliative intent (detection of disease spread)
- Addition of PET information led to change in size (reduction 24%-70%; increases 30%-76%) , shape and location of PTV
- Integration of FDG PET with CT lowers observer variation and provides more consistent definition of GTV

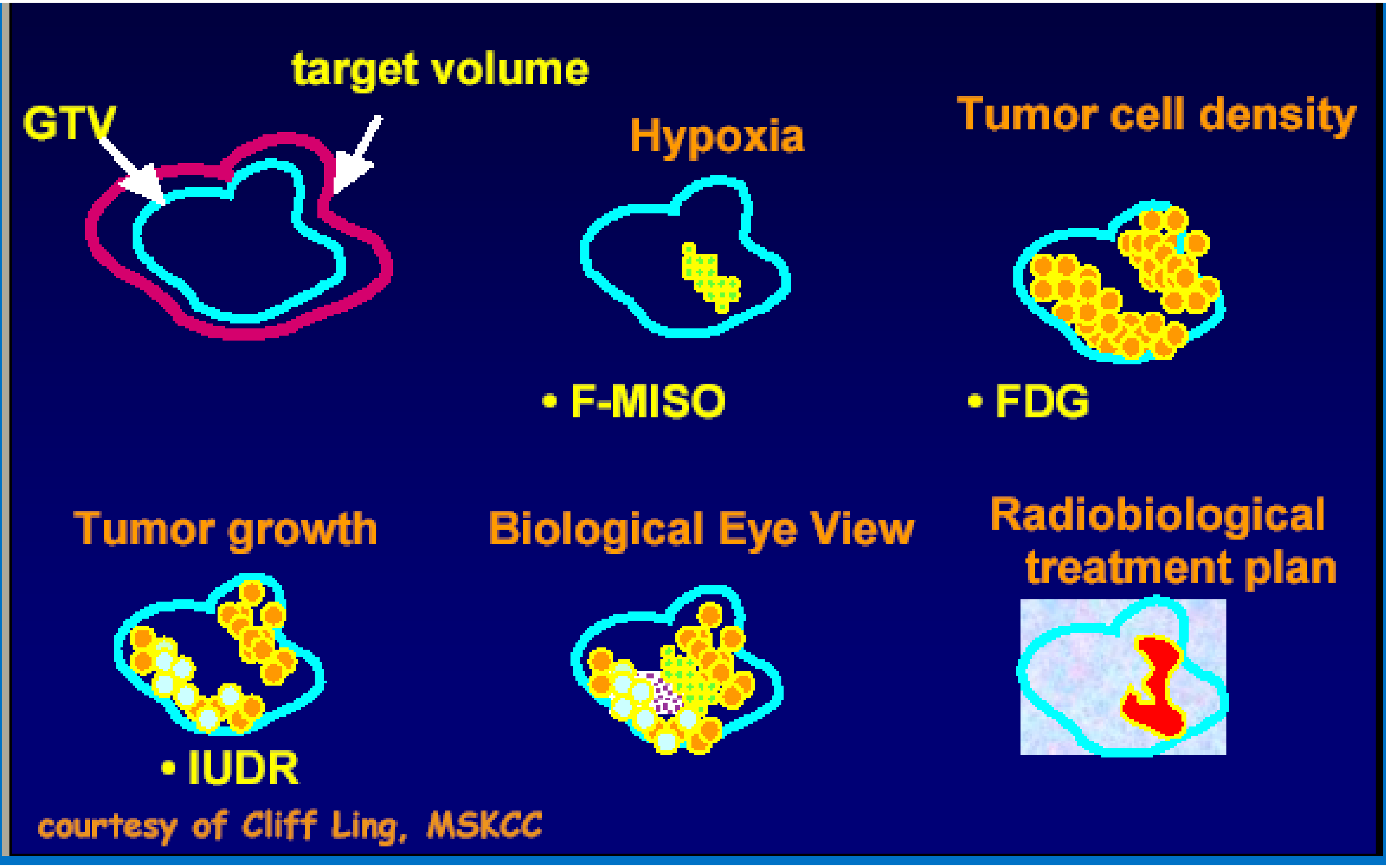
Erdi et al, Radiotherapy treatment planning for patients with NSCLC using PET, Radiotherapy and Oncology, 62, 51-60, 2002

- 11 patients: referred for RT
- GE Advance PET Scanner
- Registered transmission PET with CT
- PET led to change in PTV for all patients - 7 increase, 4 decrease
- PET should be part of treatment planning, but outcome analysis needed to evaluate cost effectiveness and overall utility

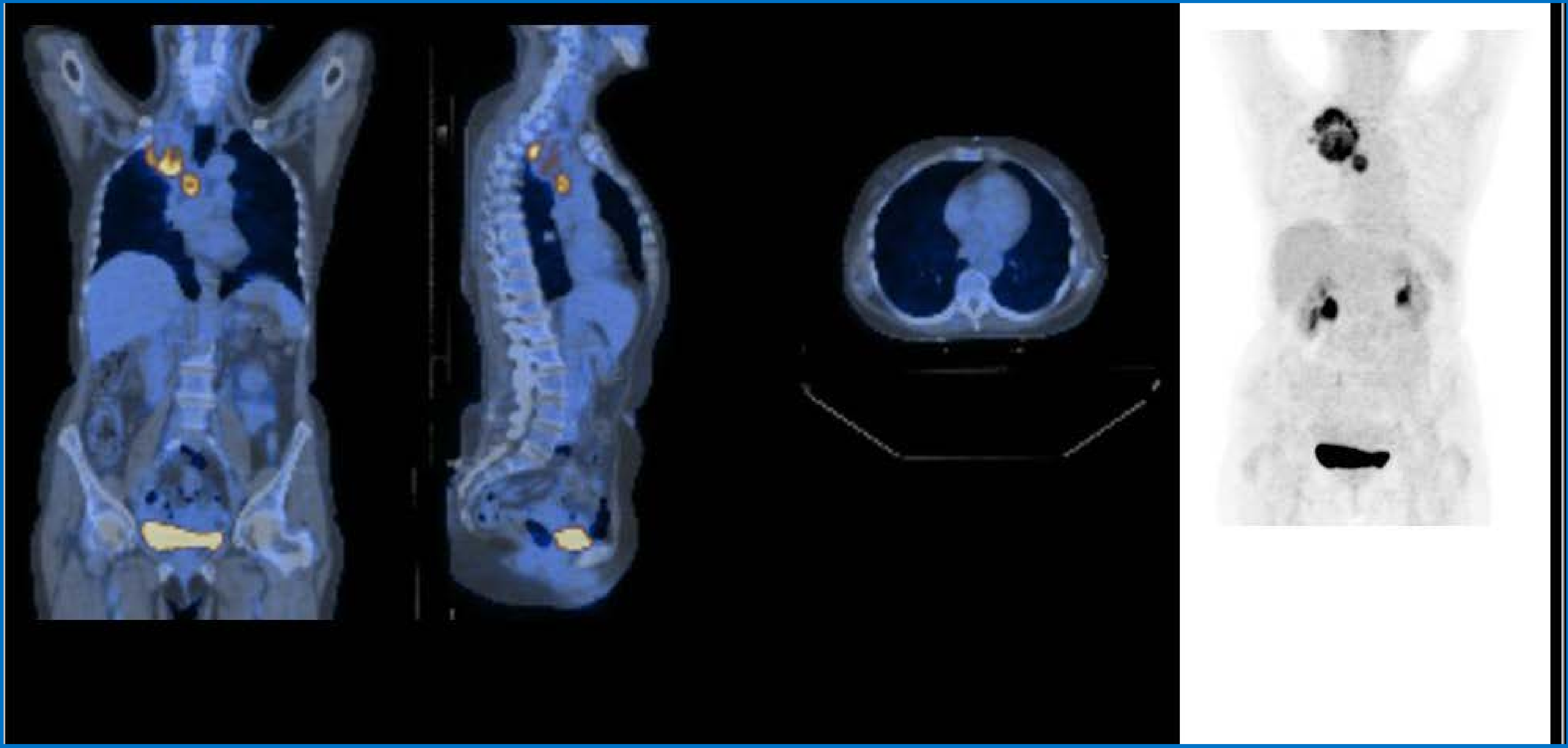
Planning using PET/CT – Erdi et al



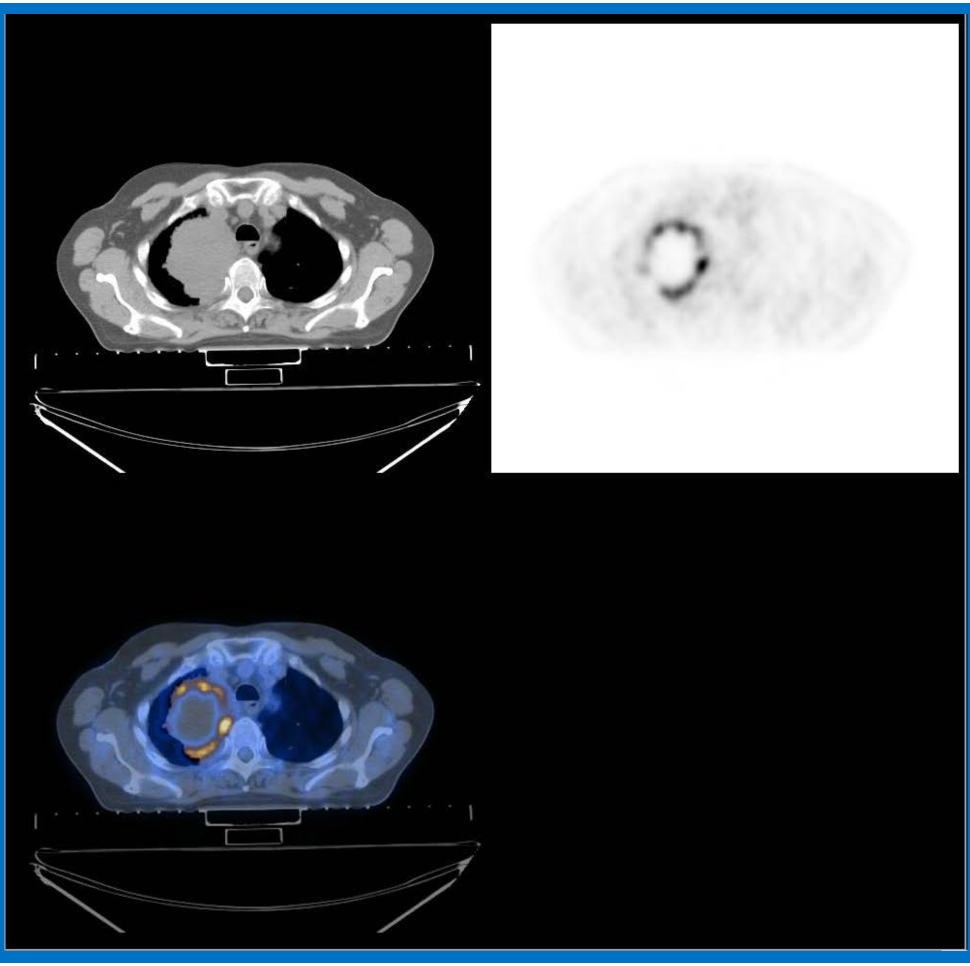
A Biological Treatment Plan



PET-CT images from radiotherapy planning patient



PET/CT Planning Dataset



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PET/CT Integration - Issues

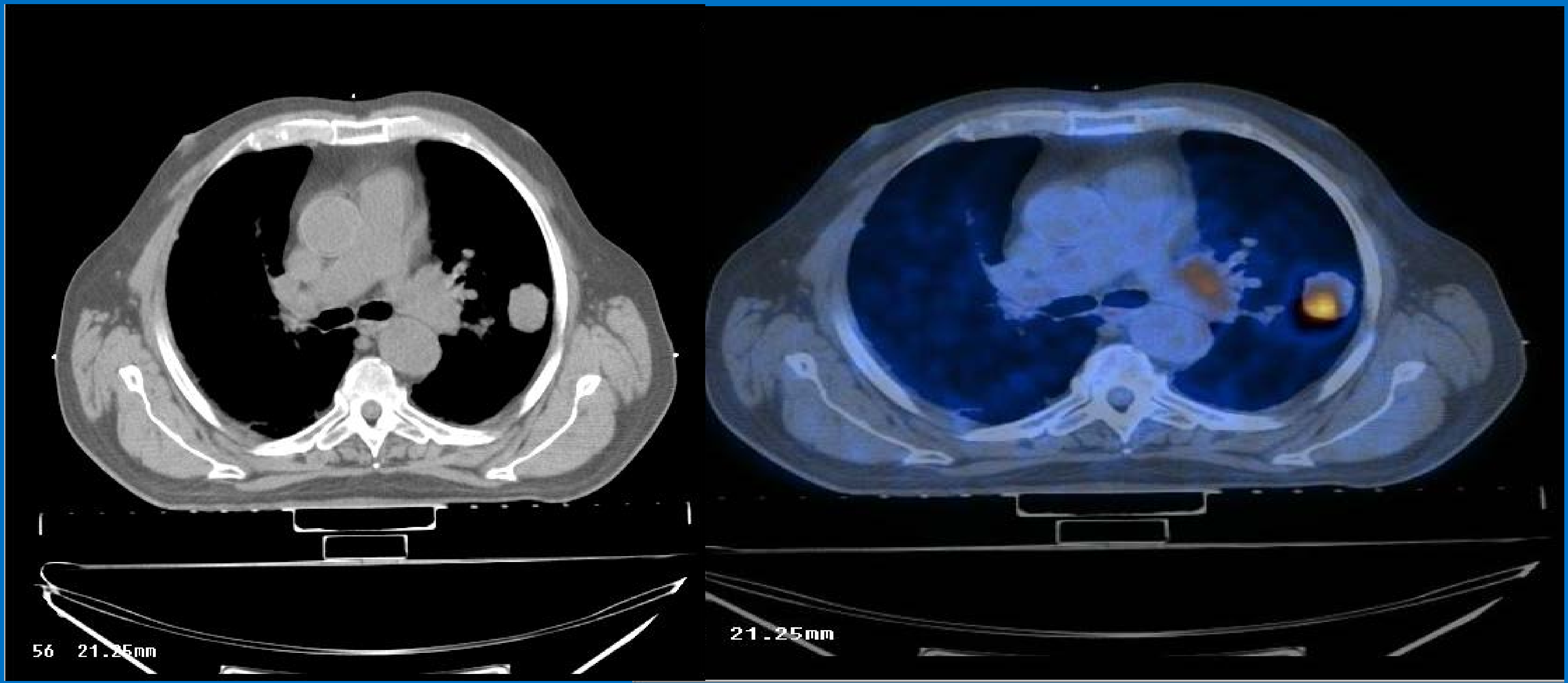
- Misalignment of transmission and emission data primarily due to differential motion either respiratory or gross movement.
- CT generated artefacts from heavy metal objects, IV and Oral contrast.
- Emission acquisition slow and averages patient physiological motion.

Respiratory motion

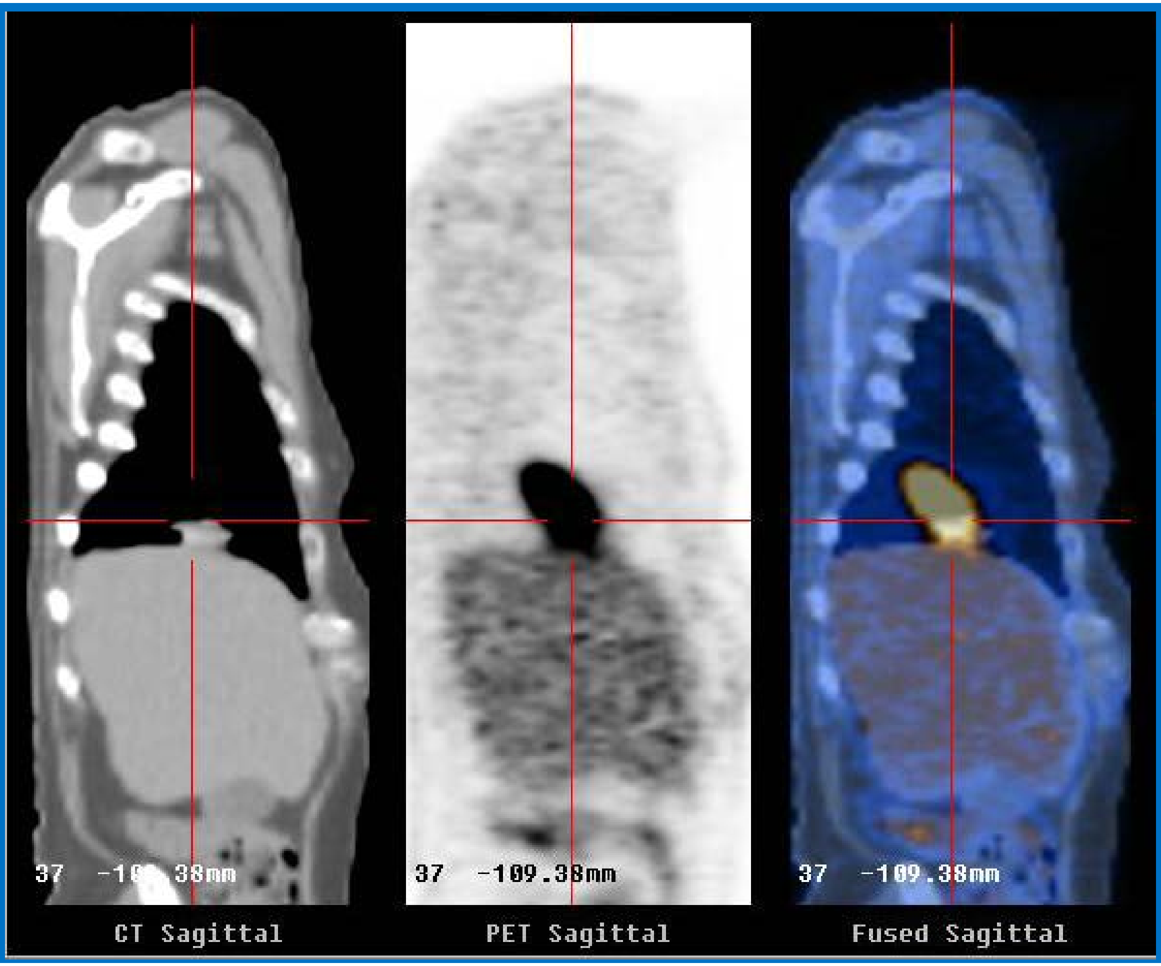
Effect of respiration in PET- CT

- Blurs the PET images
  - Reduces image quality
  - Reduces calculated FDG uptake
  - Reduces contrast in the images
  - Affects size of determined lesion
- Causes mis-alignment with CT
  - position
  - size/shape
- Incorrect Attenuation Correction
  - Unknown impact on uptake values.

Mis-registration of PET and CT due to breathing?



Example of breathing artifact in PET-CT data



Example of breathing artifact in PET-CT data

Attenuation correction using a respiration average transmission map with radioactive rod sources

Attenuation correction using a CT map acquired at end inspiration

Attenuation correction using a CT map acquired at end expiration or under free breathing

Ref: Visvikis D et al, EJNM 2003, 30(3): 344

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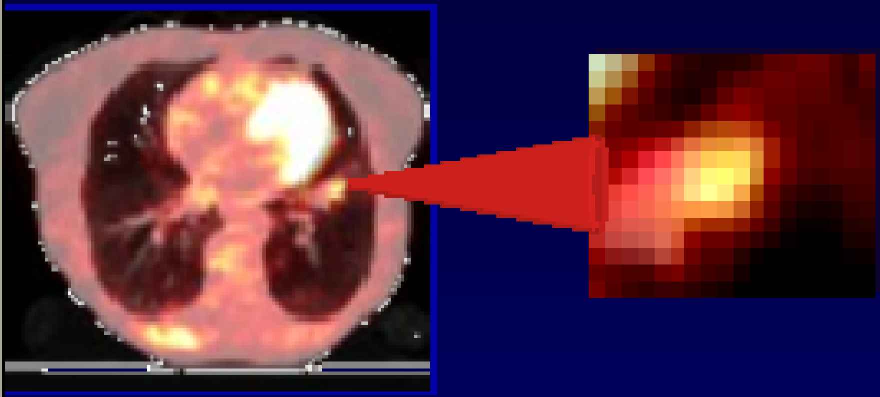
How to deal with respiratory motion?

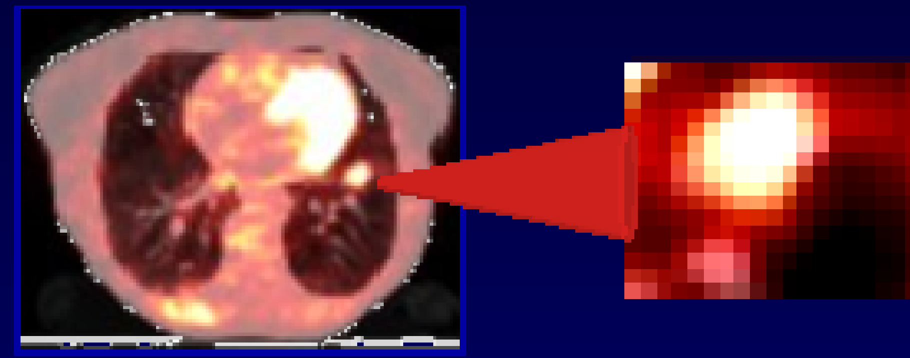
- Assume PET volume includes breathing motion (CTV + IM)
- CT breathing protocols to improve registration with PET e.g. max expiration (inspiration) breath hold
- Respiratory gated PET/CT (and RT)
- Respiratory-correlated Dynamic PET

Effect of Gating

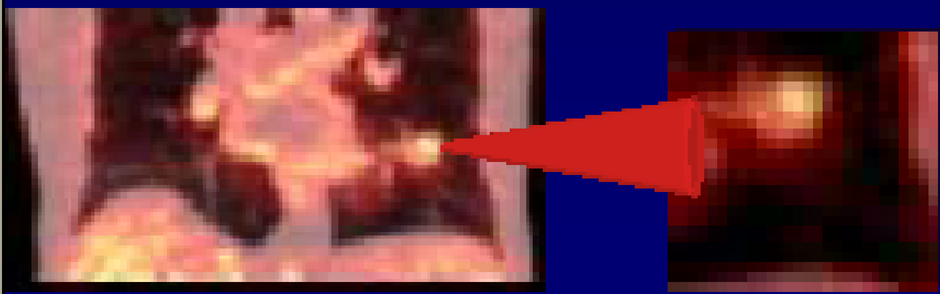
- Reduction in lesion volume
- Improves quantification (increases SUV)
- Improves registration with CT

Advantages of 4D PET – Improved SUV





SUV_{max} = 3.3 ← **34 %** → SUV_{max} = 4.4



4D PET with Clinical CT

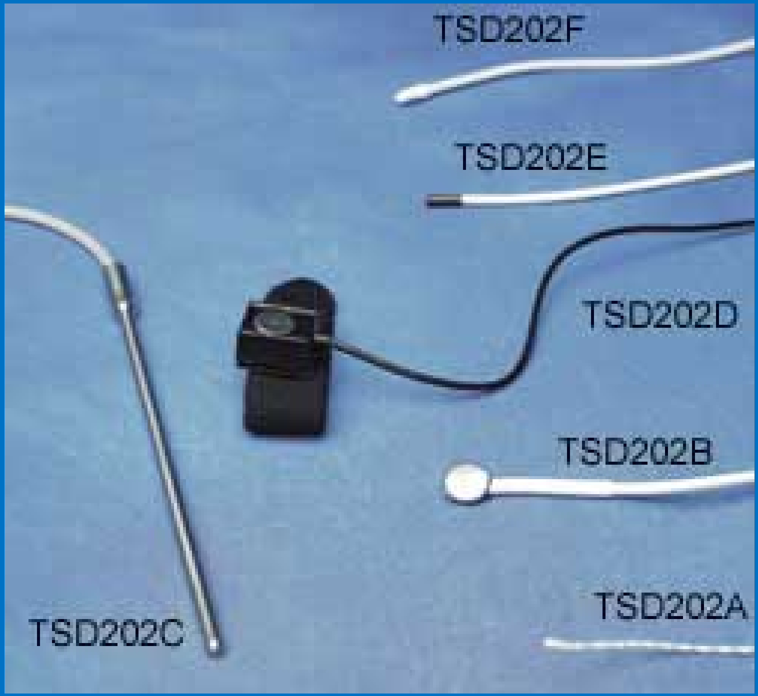
4D PET with 4D CT

courtesy of Sadek Nehmeh, MSKCC

Respiratory Gating

- Breathing synchronisation should be based upon periods of equal lung volume.
- Segmentation based on equal time slices or phase slicing will be inappropriate.
- Physiological signals providing data on lung volume required.
- Intrinsic gating from dynamic/list mode data.
- Synchronization of data streams required.

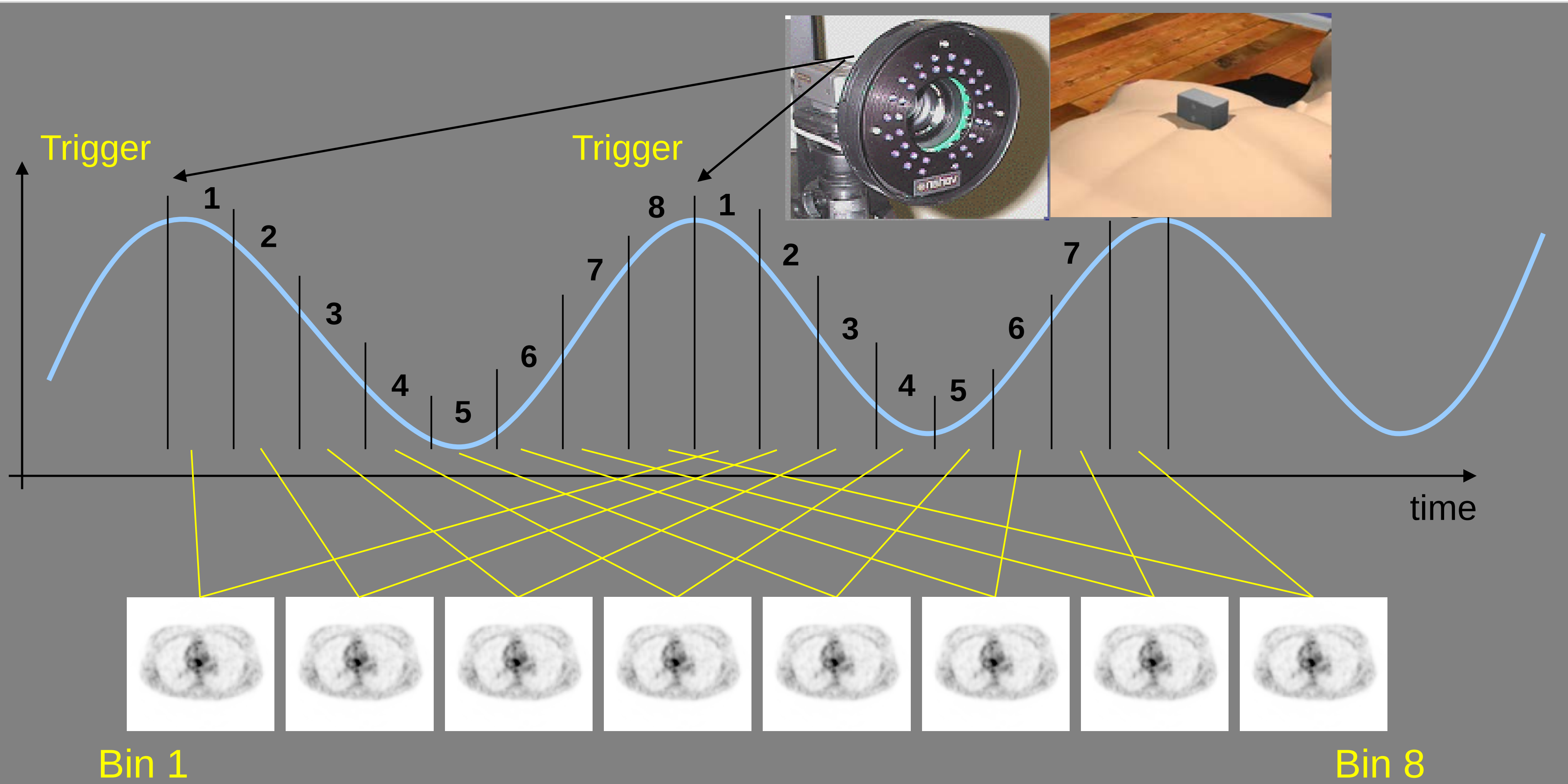
Options for respiratory monitoring



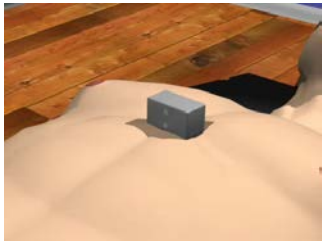
Thermistor

Respiratory belt

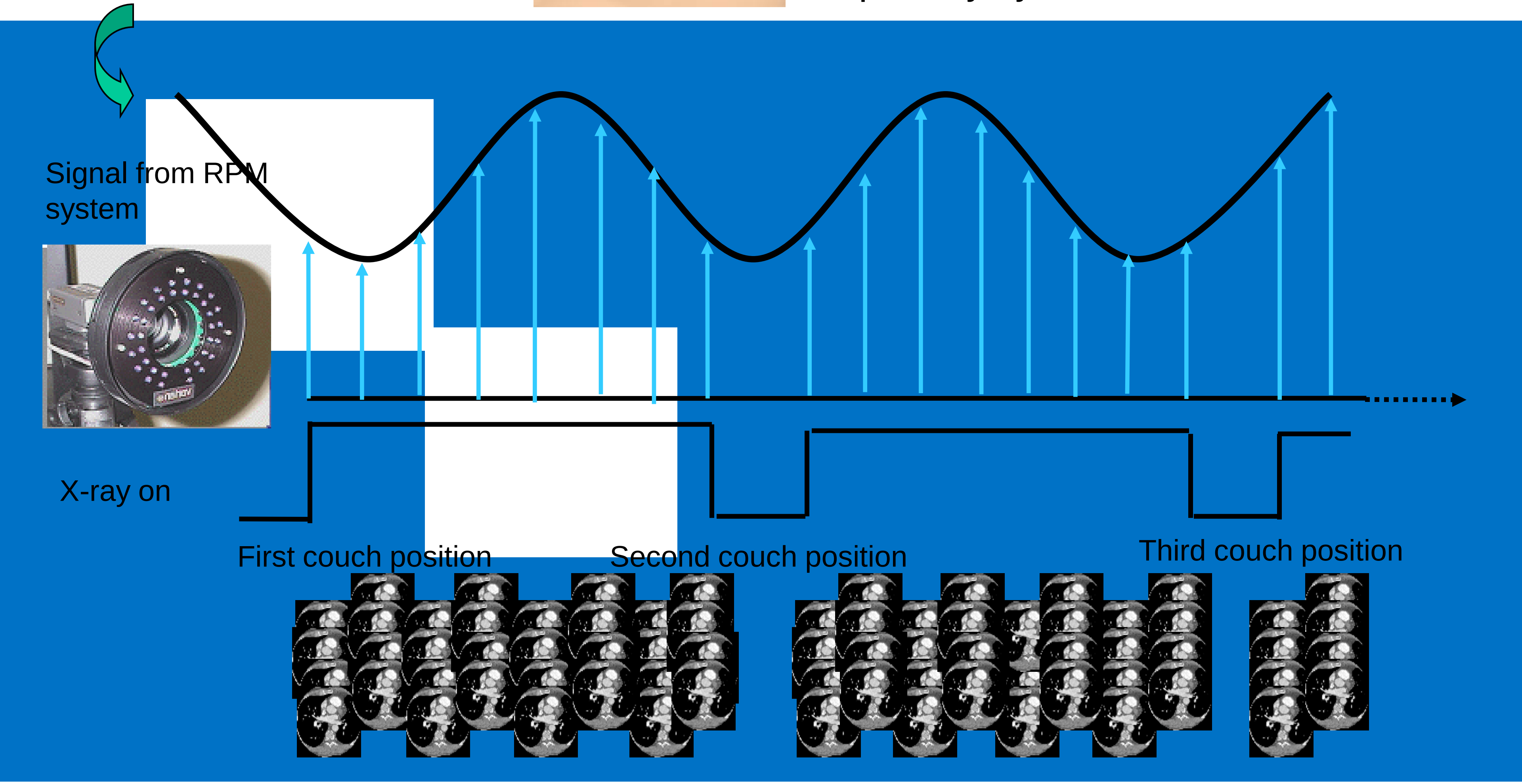
Infra-red reflectors



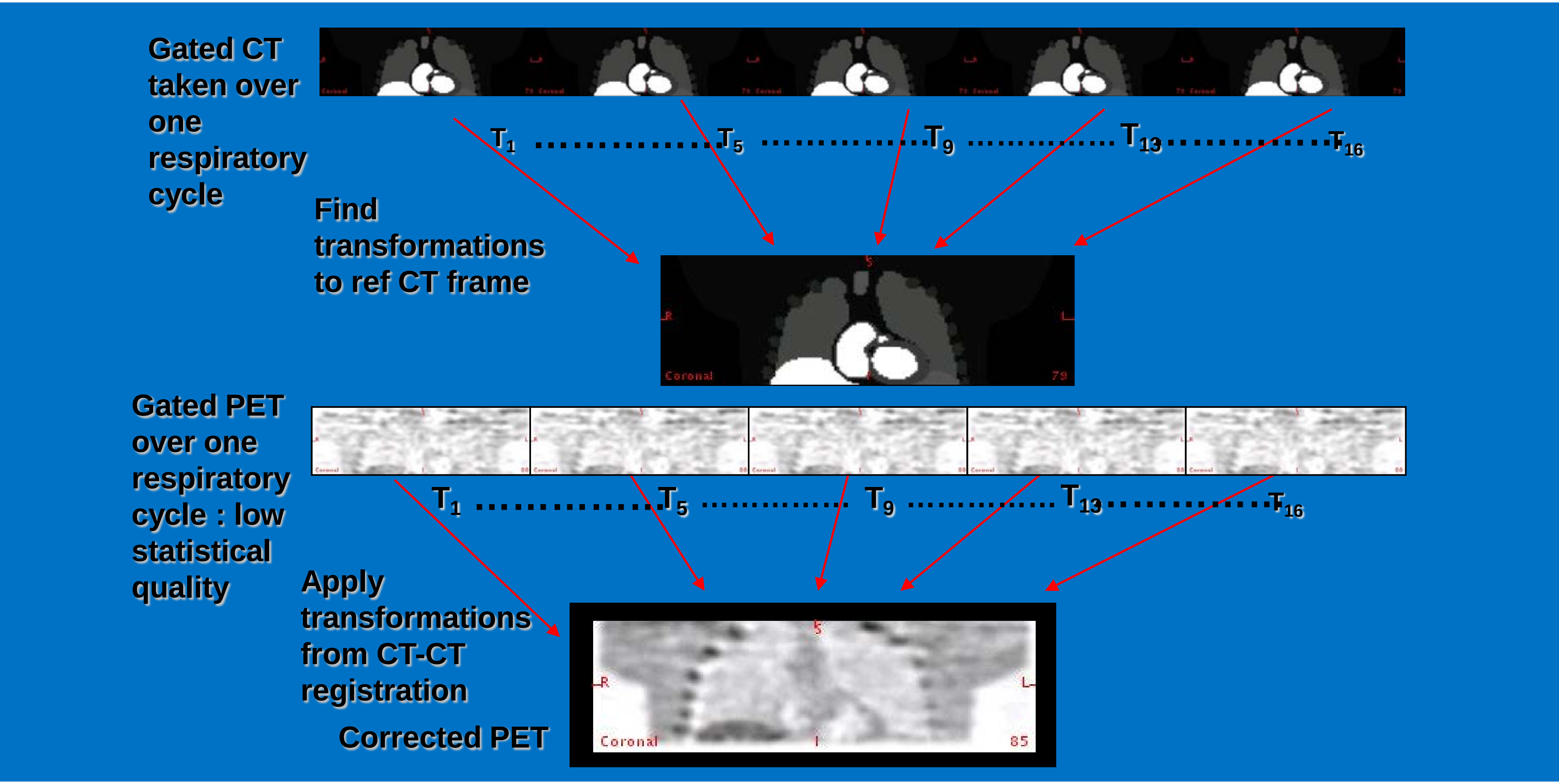
4D PET-CT



- Respiratory tracking with Varian RPM optical monitor
- CT images acquired over complete respiratory cycle



Using Anatomical Information from CT to correct PET



Courtesy Vyas-Patel N, KCL, London

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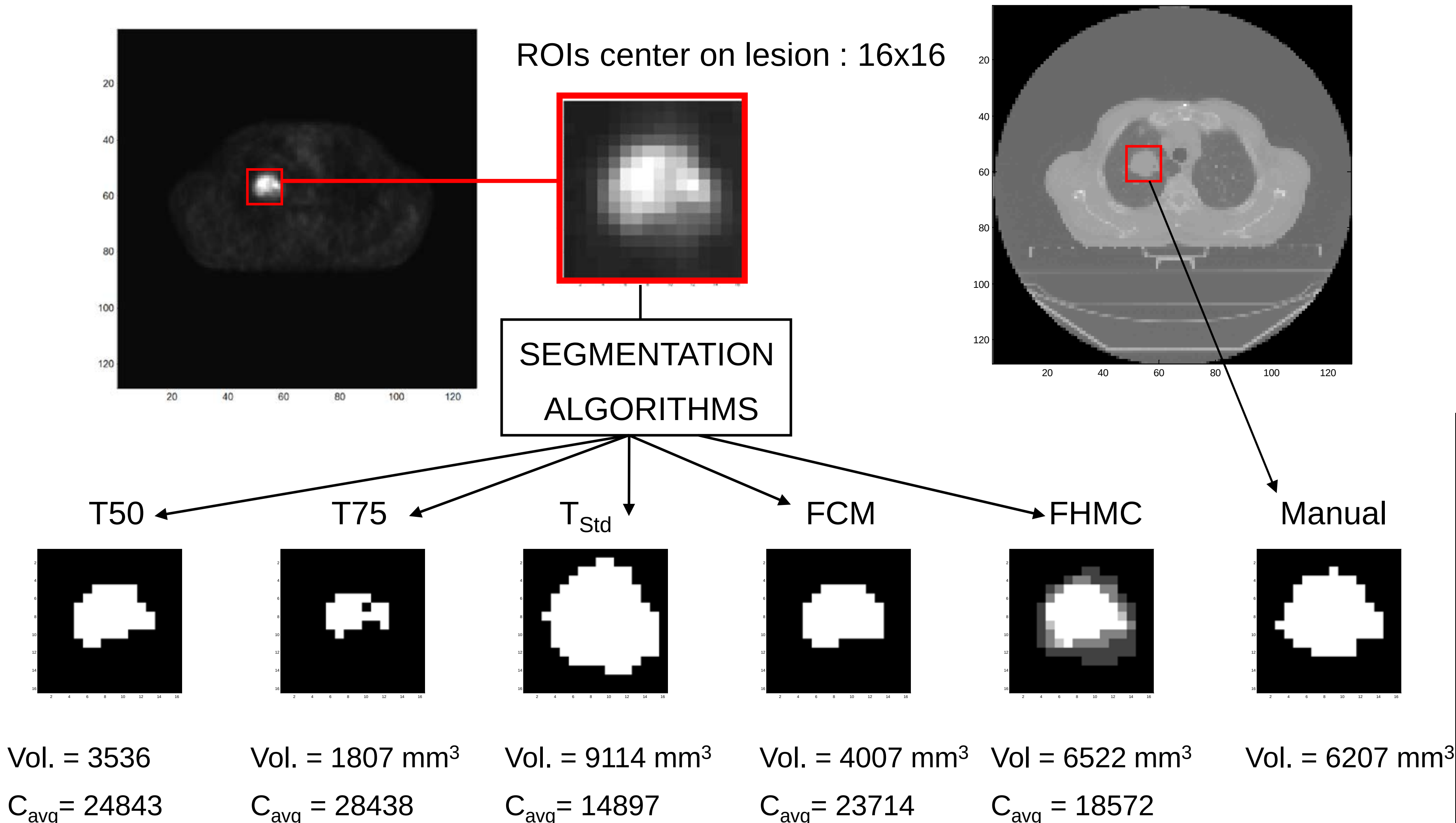
Technology Issues

- Respiration correction during acquisition a compromise.
- How do we manage motion during delivery of therapy?
- How do we manage changes in anatomy/function during therapy treatment?
- Multiple use of ionizing radiation increases dose and cancer risk. Higher sensitivity/different technology required.
- How do we optimize dose/image quality?

Tumour Delineation.

- Identification of tumour volumes if defined from PET still require validation. The use of a fixed threshold value is inadequate for all lesion volumes, shapes and target to background ratios.
- Signal to noise ratios very poor for respiratory gated studies.
- Assumptions of uniform uptake in tumour invalid.



T50 = Threshold 50% of max pixel value, T75 = Threshold 75% of max pixel value.

T_{Std} = Threshold 3 x Std dev. Measured on background ROI. FCM = Fuzzy C-Means clustering

FHMC = Fuzzy Hidden Markov Chains, 2 hard classes and 2 fuzzy levels

C_{avg} = average count density

Challenges

- Routine motion correction methodology for whole body PET imaging.
- Accurate and automatic uptake and volume quantification of uptake distributions.
- The utilization of high resolution anatomical data to restore low resolution PET distributions.

Opportunities

- To ensure that radiotherapy treatments are delivered and optimized to provide the maximum cure rate whilst minimizing damage to normal tissues.
- To integrate the advances in imaging technology with advances in radiotherapy delivery methods.
- To ensure that new methodologies are evaluated through clinical trials