

# Practical Aspects of PET/CT and RTP

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# Practical Aspects of PET/CT and RTP

- Head/Neck protocol
  - 10 patients recruited
  - Performance parameters
  - Patientt scanning
  - PET/CT Registration
  - PET GTV Markup



Radiation Oncology tools include the flat bed insert and bridge-mounted lasers.

Courtesy M. Lodge, University of Maryland



# PET/CT

## Gemini Performance parameters

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### Philips Mx8000 EXP CT

- ✓ helical
- ✓ dual slice
- ✓ gantry diameter: 700 mm
- ✓ Bed travel: 190 cm
- ✓ rotation speed: 0.5 sec
- ✓ FOV: 600 mm transverse
- ✓ minimum slice thickness: 0.5 mm

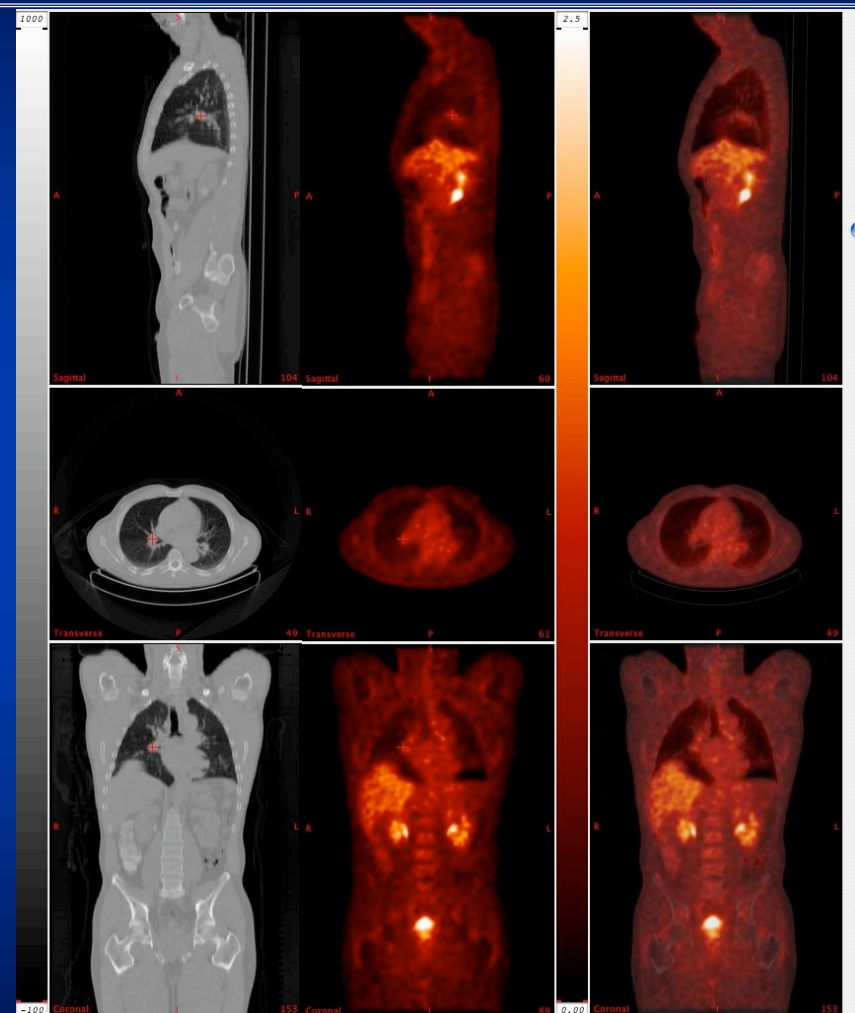
### Philips-ADAC Allegro™ PET

- ✓ GSO crystal detectors
- ✓ septaless, dedicated 3D
- ✓ gantry diameter: 630 mm
- ✓ Bed travel: 190 cm
- ✓ 740MBq <sup>137</sup>Cs transmission source
- ✓ FOV: 180mm axial & 576mm transverse
- ✓ transverse resolution: sub-5mm
- ✓ 3 mins per emission bed
- ✓ 30-40 mins wholebody scanning



# Patient Scanning

- Standard wholebody scan
  - Injected FDG dose
    - 5 - 7 MBq/kg < 400 MBq
  - Tidal breathing throughout
  - CT
    - Surview scan
    - Low Dose Wholebody CT scan
      - $I = 20 \text{ mA.s/slice}, V = 140 \text{ kVp}$
  - PT
    - $^{137}\text{Cs}$  transmission scan
    - Emission scanning @ 60 mins P.I.
    - 3 mins/bed, 7 - 8 beds
    - 21 - 24 mins emission scan
    - RAMLA3D-Cs, RAMLA3D-CT reconstruction



# Patient Scanning

- Head/Neck PET Planning scan
  - RTP Flat bed
  - Fiducial placement
  - Subject + Cast positioning
  - CT
    - Surview scan
    - Low Dose Wholebody CT scan
      - $I = 30 \text{ mA.s/slice}$ ,  $V = 120 \text{ kVp}$
  - PT
    - $^{137}\text{Cs}$  transmission scan
    - Emission scanning @ 90 mins P.I.
    - 3 mins/bed, 4 - 5 beds
    - 12 - 15 mins emission scan
    - RAMLA3D-Cs, RAMLA3D-CT recon.



# Patient Scanning

## Standard Uptake Value

- SUV definition:

- $C_{FDG}(T)$  = FDG concentration in tissue at time T after injection

- D = Injected Dose

- $M_{body}$  = Body Weight

$$SUV = \frac{C_{FDG}(T) * 2^{T/\tau_{1/2}}}{D / M_{body}}$$

- Semi-Quantitative measure of glucose metabolic rate

- Steve Meikle, ANZSNM Physics SIG 2002

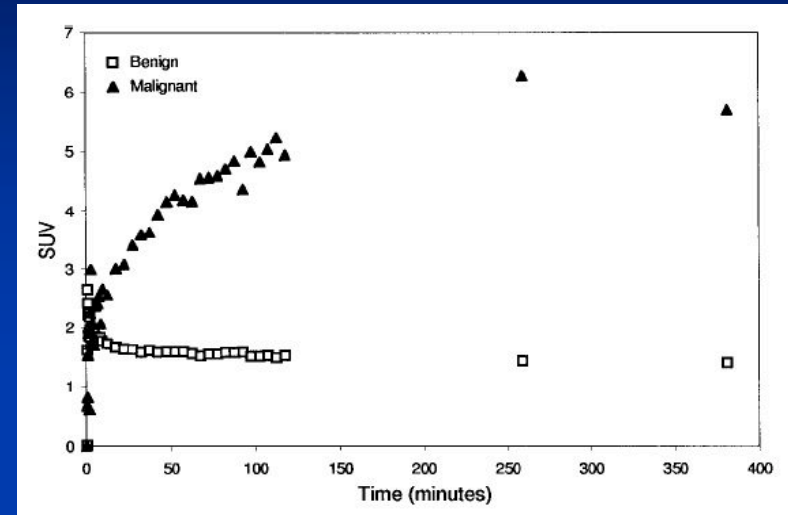
- [www.anzsnm.org.au](http://www.anzsnm.org.au) physics



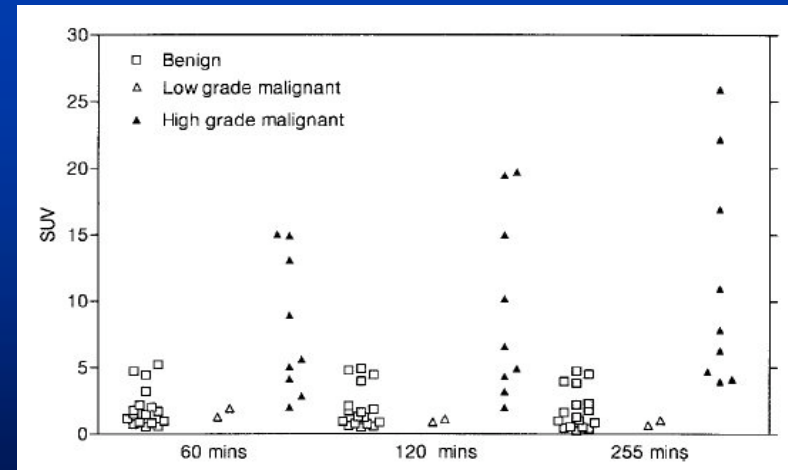
# Patient Scanning

## SUV

- SUV is usually only measured at a fixed time point.
- FDG uptake is a dynamic process
- Normal, benign tissue equilibrates within 45-mins
- Malignant tissue equilibration can take up to 4 hrs
- For intra-patient comparisons, post-injection scanning time reproducibility is critical.



Typical time-activity curves for benign and malignant soft tissue masses.



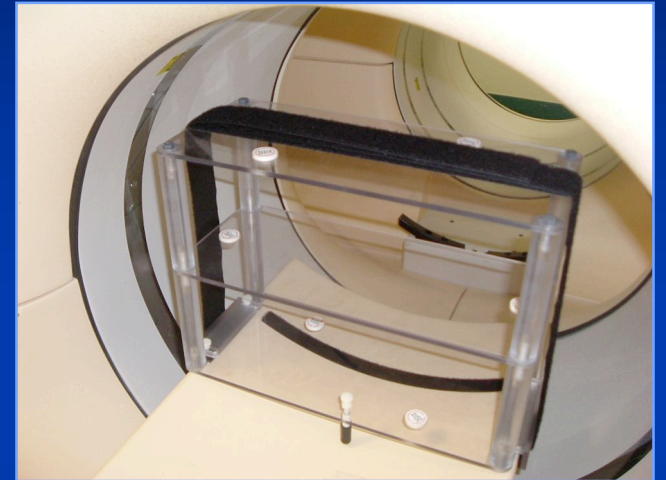
SUVs for 29 patients measured at 3 different times post-FDG administration.



# PET/CT Registration

## Alignment Calibration

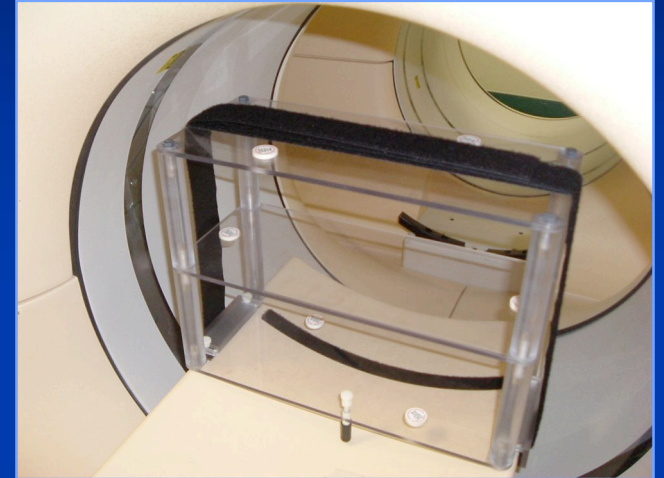
- Critical for
  - CT Attenuation correction
  - Anatomical registration
- Two stages
  - Mechanical alignment
    - CT, PT palette assembly mechanical calibration
  - Residual mis-alignment correction
    - CT, PT imaging calibration
    - Phantom validation



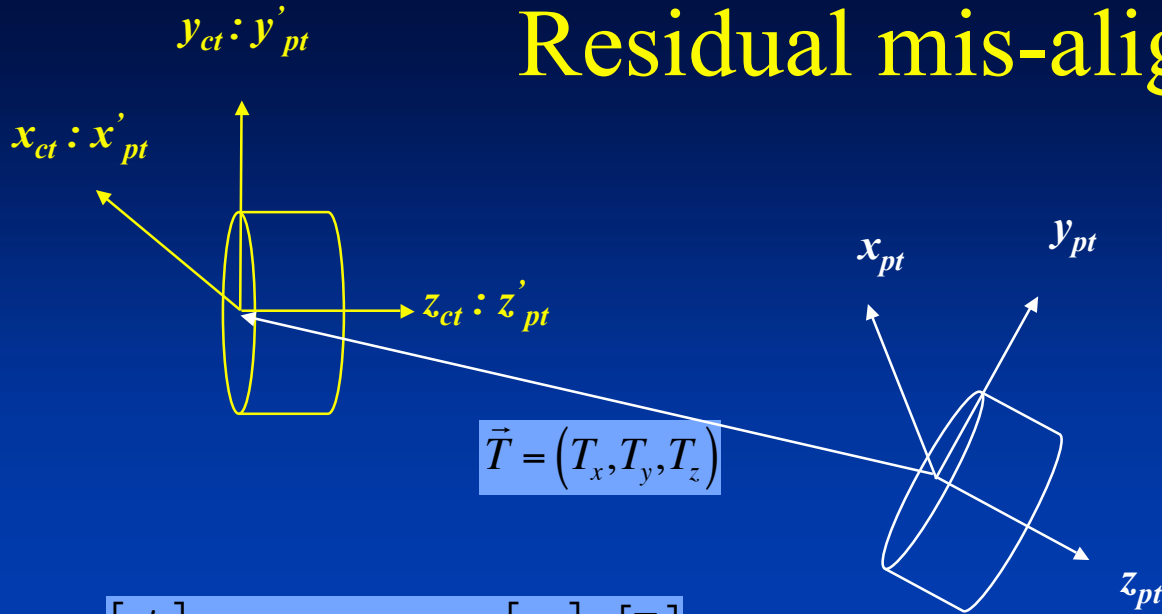
# PET/CT Registration

## Alignment Calibration

- Two stages
  - Mechanical alignment
    - CT, PT bed end limits measured
    - Determines subsequent CT, PT slice co-ordinates
  - Residual mis-alignment
    - CT, PT imaging calibration
    - Multi-layer fixture bearing six  $^{22}\text{Na}$ (370kBq) point sources
    - Determination of transformation matrix between PT & CT frames



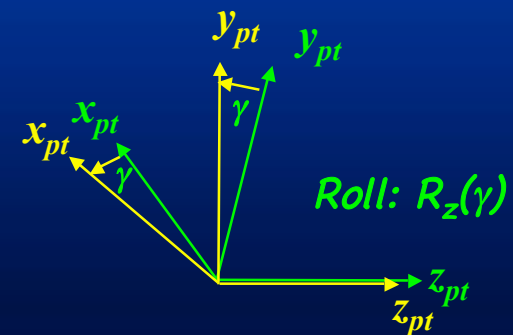
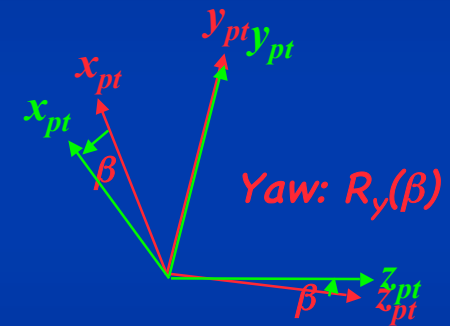
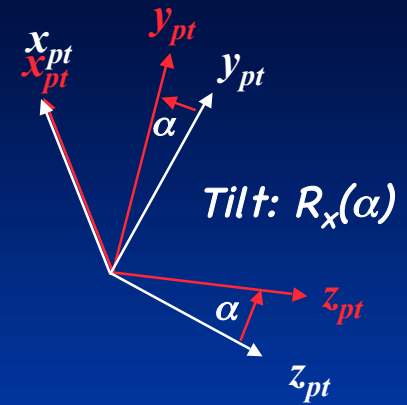
# Residual mis-alignment



$$\begin{bmatrix} x'_{pt} \\ y'_{pt} \\ z'_{pt} \end{bmatrix} = R_z(\gamma)R_y(\beta)R_x(\alpha) \begin{bmatrix} x_{pt} \\ y_{pt} \\ z_{pt} \end{bmatrix} + \begin{bmatrix} T_x \\ T_y \\ T_z \end{bmatrix}$$

$$\begin{bmatrix} x'_{pt} \\ y'_{pt} \\ z'_{pt} \end{bmatrix} = \begin{bmatrix} 0.999998 & 0.001870 & 0 & -9.44901 \\ -0.001870 & 0.999998 & 0 & 3.260223 \\ 0 & 0 & 1 & -0.762329 \end{bmatrix} \begin{bmatrix} x_{pt} \\ y_{pt} \\ z_{pt} \\ 1 \end{bmatrix}$$

$\Rightarrow 0.14^\circ$  tilt correction



# PET/CT Registration Validation

- Phantoms
  - Multi-layer calibration frame
  - Alderson Rando<sup>®</sup> Man
- Subject Scans
- Fiducial markers
  - 6 point sources
    - 370 kBq <sup>22</sup>Na
  - 9 metal crimped cannula's
    - Length:  $7.0 \pm 0.5$  mm
    - Diameter: 1.2 mm
    - 500 kBq/mL <sup>18</sup>F-FDG

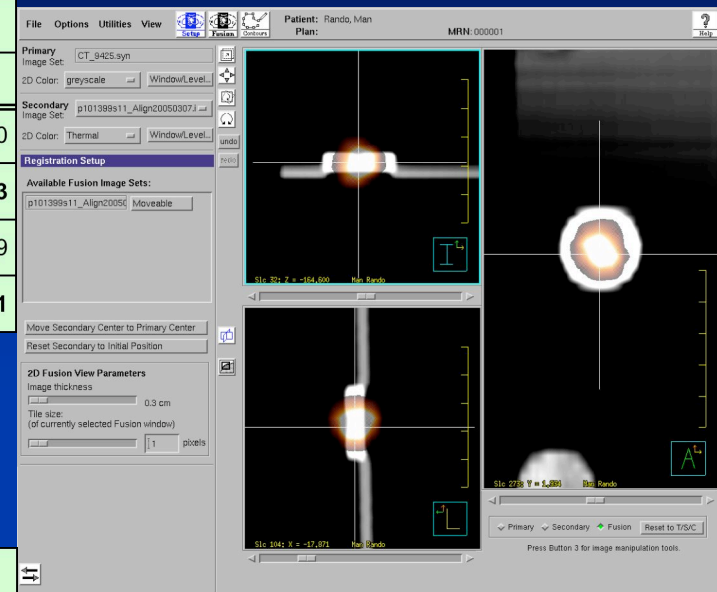


# PET/CT Registration

## Phantom Validation

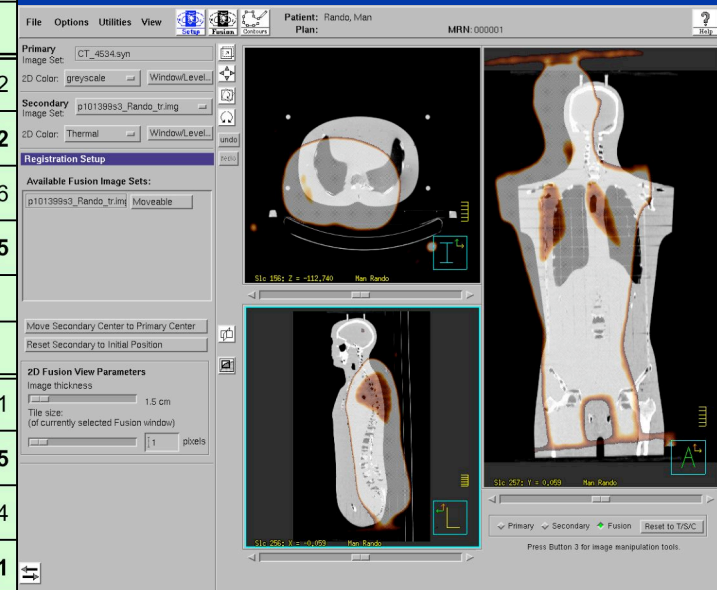
- Residual mis-alignment
  - Point based registration

Image Sets with Intrinsic Alignment			Mis-alignment (mm)		
			$x \pm \sigma$	$y \pm \sigma$	$z \pm \sigma$
Independent Fiducial Localization	multi-layer (6 fiducial points)	pre	$0.75 \pm 0.39$	$0.82 \pm 0.54$	$0.82 \pm 0.90$
		post	<b><math>0.94 \pm 0.62</math></b>	<b><math>1.39 \pm 0.89</math></b>	<b><math>1.36 \pm 1.33</math></b>
	Rando (9 fiducial points)	pre	$1.31 \pm 1.10$	$1.03 \pm 0.75$	$2.57 \pm 2.49$
		post	<b><math>1.22 \pm 2.93</math></b>	<b><math>1.00 \pm 2.28</math></b>	<b><math>1.54 \pm 2.31</math></b>



- Simulated misalignment
  - Point-based registration
  - CT/PET transmission
    - Normalised mutual information

Image Sets with Simulated Misalignment			Registration Error (mm)		
			$x \pm \sigma$	$y \pm \sigma$	$z \pm \sigma$
point-based image registration	multi-layer (3 fiducial pairs)	trans.	$0.22 \pm 0.09$	$0.19 \pm 0.12$	$0.07 \pm 0.02$
		trans. & rot.	<b><math>0.14 \pm 0.13</math></b>	<b><math>0.33 \pm 0.11</math></b>	<b><math>0.09 \pm 0.22</math></b>
	Rando (6 fiducial pairs)	trans.	$0.10 \pm 0.06$	$0.09 \pm 0.05$	$0.05 \pm 0.06$
		trans. & rot.	<b><math>0.08 \pm 0.06</math></b>	<b><math>0.11 \pm 0.07</math></b>	<b><math>0.05 \pm 0.05</math></b>
Image Sets with Simulated Misalignment			Registration Error (mm)		
			$x \pm \sigma$	$y \pm \sigma$	$z \pm \sigma$
image-based image registration	multi-layer	trans.	$2.25 \pm 0.59$	$2.48 \pm 0.11$	$1.78 \pm 2.01$
		trans. & rot.	<b><math>3.18 \pm 0.97</math></b>	<b><math>2.41 \pm 0.37</math></b>	<b><math>1.87 \pm 1.85</math></b>
	Rando	trans.	$1.28 \pm 0.67$	$1.55 \pm 0.30$	$2.14 \pm 0.34$
		trans. & rot.	<b><math>1.56 \pm 0.60</math></b>	<b><math>1.77 \pm 0.47</math></b>	<b><math>2.64 \pm 0.31</math></b>



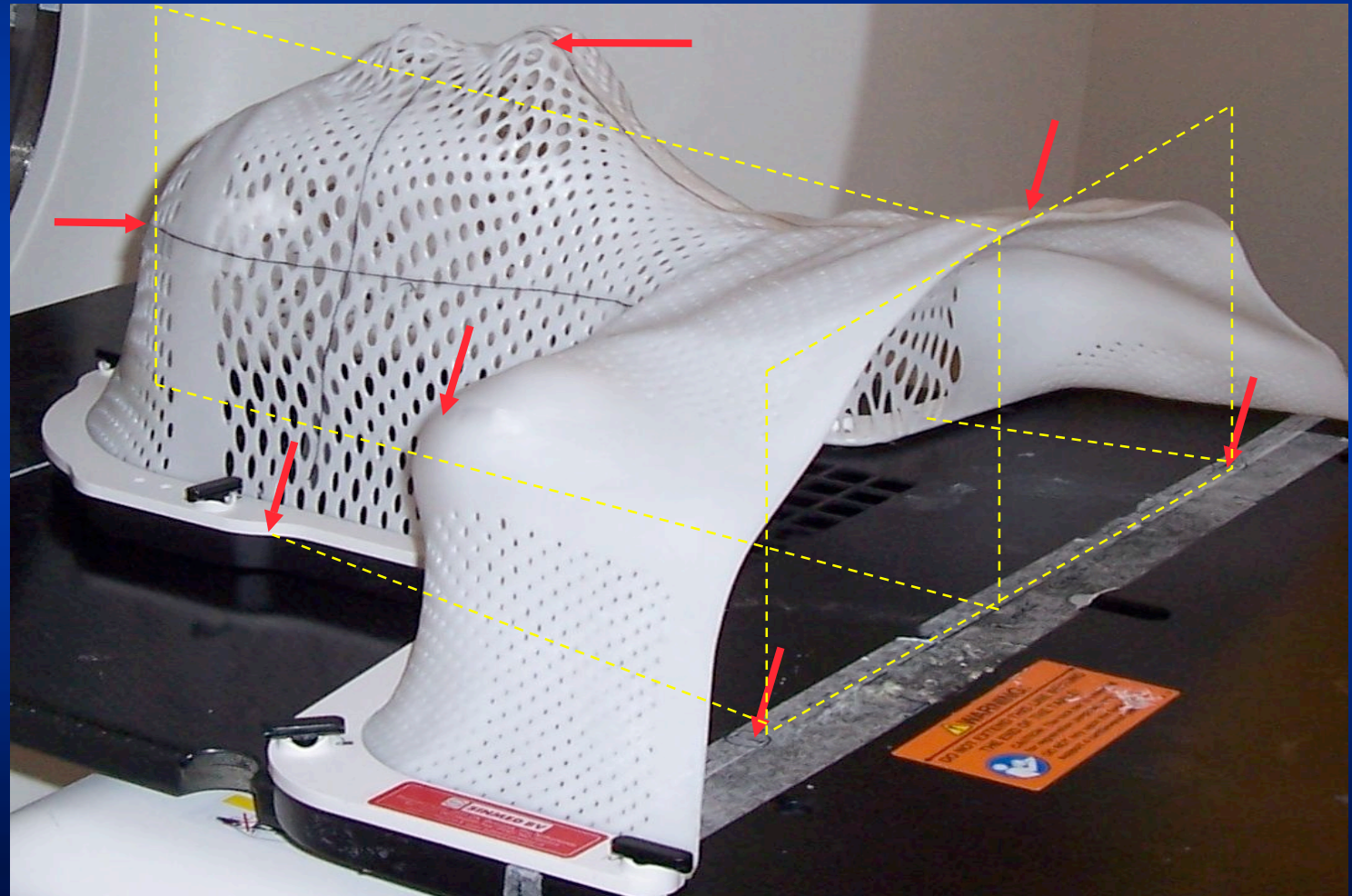
# PET/CT Registration

## Fiducial Locations

8 Fiducials define 3 orthogonal planes

10 MBq/mL per cannula

- Baseboard - 4 points
- Cast - 4 points
  - right shoulder
  - top of skull
  - chin
  - sternal notch



# PET/CT Registration

## Fiducial Locations

File Options Utilities View **Setup Fusion Contours** Patient: Plan: Plan\_0 MRN: Help

undo redo

Primary Secondary Fusion Reset to T/S/C

**Automated Registration Tools**

Images Points

Fiducial Points		
Primary	Secondary	Distance
1	1	
2	2	0.137262 cm
3	3	0.203059 cm
4	4	0.186366 cm
5	5	0.137735 cm
6	6	0.286758 cm

3D display for all fiducial pairs On Off

Add New Fiducial Pair

Delete Current Fiducial Pair

**Proceed with Fusion**

Mean distance between points: 0.158564 cm

Chin

Sternal notch

Baseboard - 4 points

Slice 615; Z = -137.592

Slice 256; X = -0.058

Slice 233; Y = -2.754



# PET/CT Registration

## Patient Validation

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- PET-CT intrinsic alignment
  - CT image  $2 \times 2 \times 2 \text{ mm}^3$
  - PT image  $2 \times 2 \times 2 \text{ mm}^3$
- Simulated Misalignment
  - Up to 30mm in x,y,z
  - Up to 2-deg about x,y,z
- Point-based registration of misaligned PET



# PET/CT Registration

## Patient Validation - System Aligned

File Options Utilities View Patient: \_\_\_\_\_ MRN: 115798

Plan: \_\_\_\_\_

Primary Image Set: p103601s0\_HN\_IdCT\_ref.syn 2D Color: greyscale Window/Level...

Secondary Image Set: p103601s0\_ART\_HN\_PET\_si 2D Color: Thermal Window/Level...

**Automated Registration Tools**

Images Points

**Fiducial Points**

	Primary	Secondary	Distance	
1	1	0.17592	cm	
2	2	0.198894	cm	
3	3	0.168963	cm	
4	4	0.227872	cm	
5	5	0.148255	cm	
6	6	0.172591	cm	

3D display for all fiducial pairs  On  Off

Add New Fiducial Pair

Delete Current Fiducial Pair

**Proceed with Fusion**

Mean distance between points: 0.182086 cm

Slic 183: Z = 36.400 Lyle ARTHUR

Slic 151: X = 0.100 Lyle ARTHUR

Slic 231: Y = 16.100 Lyle ARTHUR

Primary Secondary  Fusion Reset to T/S/C

Press Button 3 for image manipulation tools.



# PET/CT Registration

## Patient Validation - Simulated mis-alignment

File Options Utilities View **Setup** Fusion Contours Patient: MRN: 115798 Plan: Help

Primary Image Set: p103601s0\_HN\_IdCT\_ref.syn 2D Color: greyscale Window/Level...

Secondary Image Set: p103601s0\_ART\_HN\_PET\_si 2D Color: Thermal Window/Level...

**Automated Registration Tools**

Images Points

**Fiducial Points**

Primary	Secondary	Distance
1	1	4.03719 cm
2	2	4.1581 cm
3	3	3.94935 cm
4	4	3.70639 cm
5	5	4.11257 cm
6	6	4.05843 cm

3D display for all fiducial pairs  On  Off

Add New Fiducial Pair

Delete Current Fiducial Pair

**Proceed with Fusion**

Mean distance between points: 4.00334 cm

undo redo

Slic 170: Z = 33,800 Lyle ARTHUR

Slic 238: Y = 17,500 Lyle ARTHUR

Slic 165: X = 2,900 Lyle ARTHUR

Primary Secondary  Fusion Reset to T/S/C

Press Button 3 for image manipulation tools.



# PET/CT Registration

## Patient Validation Results

RTP Studies	FMs	PET-CT Replacement of Fiducial Pairs (mm)								
		Intrinsic			Simulated			Point-based Registration		
		min	max	mean $\pm$ std	min	max	mean $\pm$ std	min	max	mean $\pm$ std
<b>1</b>	<b>7</b>	1.00	2.83	1.70 $\pm$ 0.67	37.07	42.54	40.09 $\pm$ 1.94	1.01	2.93	2.03 $\pm$ 0.75
<b>2</b>	<b>6</b>	1.00	4.24	2.09 $\pm$ 1.24	37.12	41.79	39.98 $\pm$ 1.66	1.48	2.28	1.82 $\pm$ 0.28
<b>3</b>	<b>7</b>	1.41	4.24	1.81 $\pm$ 1.07	37.18	42.31	39.86 $\pm$ 2.27	0.79	4.47	2.30 $\pm$ 1.44
<b>4</b>	<b>6</b>	1.41	3.16	2.05 $\pm$ 0.75	35.75	39.82	37.79 $\pm$ 1.47	0.61	2.64	1.68 $\pm$ 0.73
<b>5</b>	<b>5</b>	2.45	3.74	2.97 $\pm$ 0.71	36.70	40.42	38.17 $\pm$ 1.37	1.21	2.30	1.94 $\pm$ 0.44
<b>6</b>	<b>6</b>	1.41	4.24	3.09 $\pm$ 1.16	37.34	43.70	40.25 $\pm$ 2.51	0.80	3.51	2.52 $\pm$ 0.95
<b>7</b>	<b>6</b>	1.41	3.74	2.36 $\pm$ 1.14	36.52	41.79	38.83 $\pm$ 1.94	0.90	2.26	1.51 $\pm$ 0.5
<b>8</b>	<b>6</b>	1.41	2.45	1.93 $\pm$ 0.57	37.01	45.22	39.69 $\pm$ 2.99	1.29	4.42	2.34 $\pm$ 1.17
<b>Total</b>	<b>49</b>	<b>1.00</b>	<b>4.24</b>	<b>2.22 <math>\pm</math> 1.00</b>	<b>35.75</b>	<b>45.22</b>	<b>39.33 <math>\pm</math> 0.55</b>	<b>0.61</b>	<b>4.47</b>	<b>2.02 <math>\pm</math> 0.39</b>



# PET GTV

## FDG Markup

- PET GTV markup
  - Within RTP environment
  - and now, within PET reporting environment
- Transferred to RTP
  - DICOM\_CD
  - DICOM\_PT
  - DICOM\_CT
  - DICOM\_RT(soon)

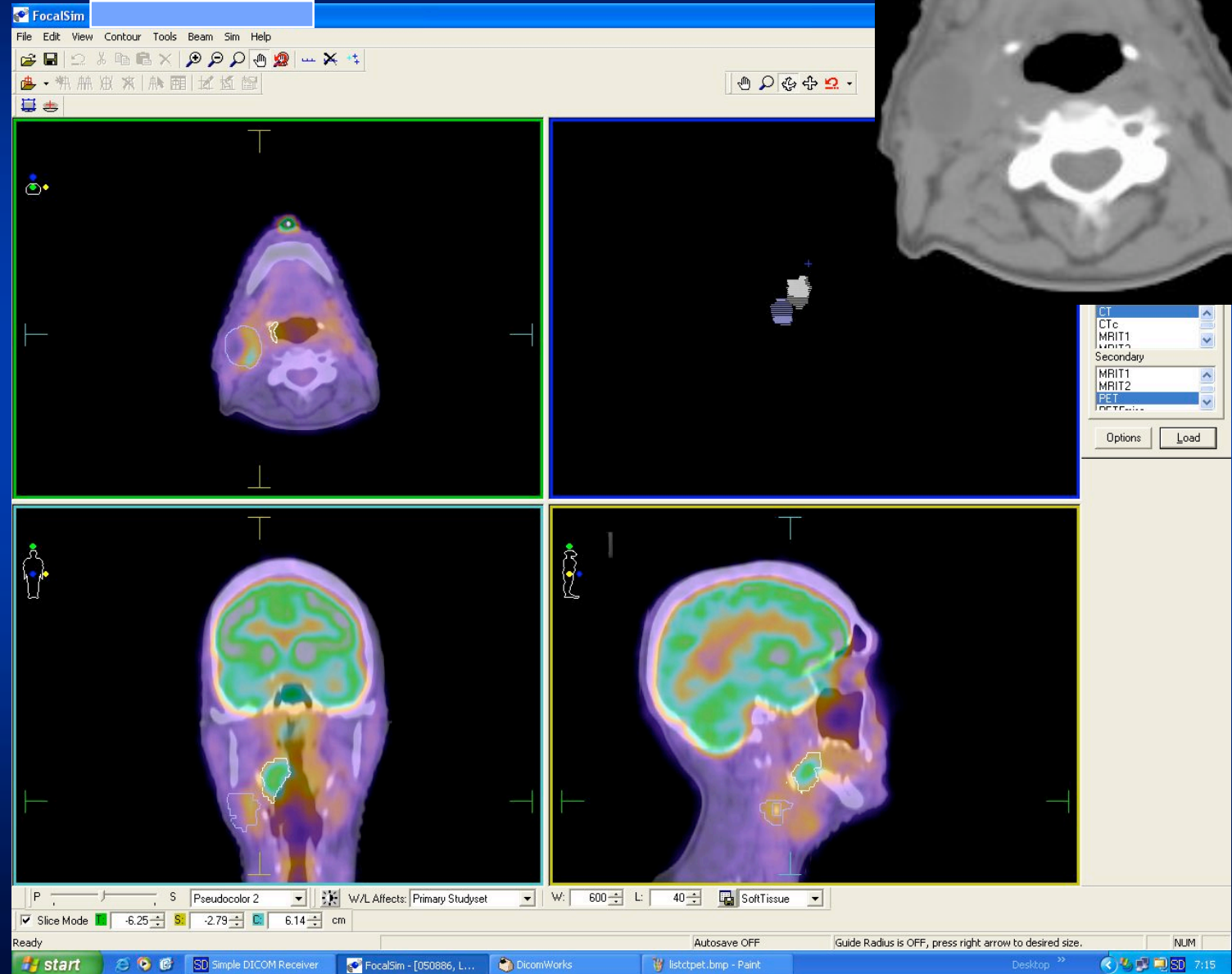
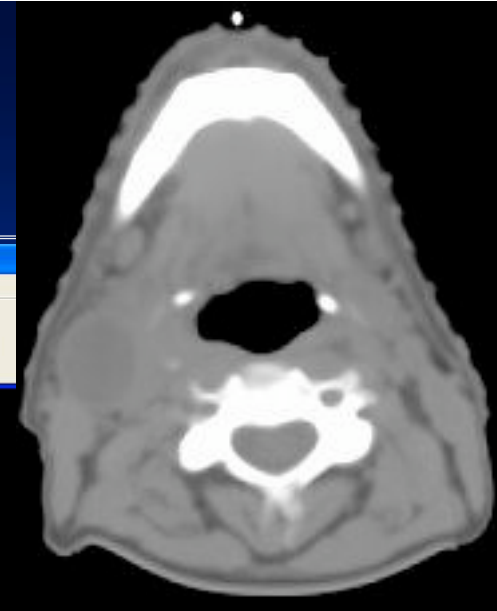
The screenshot displays the RTP software interface for PET GTV markup. The main workspace shows three 2D slices (axial, sagittal, and coronal) and a 3D volume rendering of the patient's head and neck. The 'Regions Of Interest' panel on the left shows a region named 'lymph' with 33 contours and a volume of ? cm³. The 'Display Options' panel shows the region is colored green. The 'Edit Options' panel shows autocontour thresholds of 800 (Lower) and 4096 (Upper). The '3D Window Controls' panel shows the primary render is set to 'skin' with a threshold of 1200 to 1400, and the secondary render is also set to 'skin' with a threshold of 500 to 4095. The 3D view shows a skull and neck with a green region highlighted.



# PET GTV

## FDG - RTP markup

- FDG
  - Tonsillar
    - Hypermetabolic
  - Lymph node
    - Hypermetabolic
- CT contrast
  - Tonsillar
    - Low
  - Lymph node
    - Good



FocalSim

File Edit View Contour Tools Beam Sim Help

CTc  
MRIT1  
MRIT2  
PET  
PETc

Options Load

P S Pseudocolor 2 W/L Affects: Primary Studysset W: 600 L: 40 SoftTissue

Ready Autosave OFF Guide Radius is OFF, press right arrow to desired size. NUM



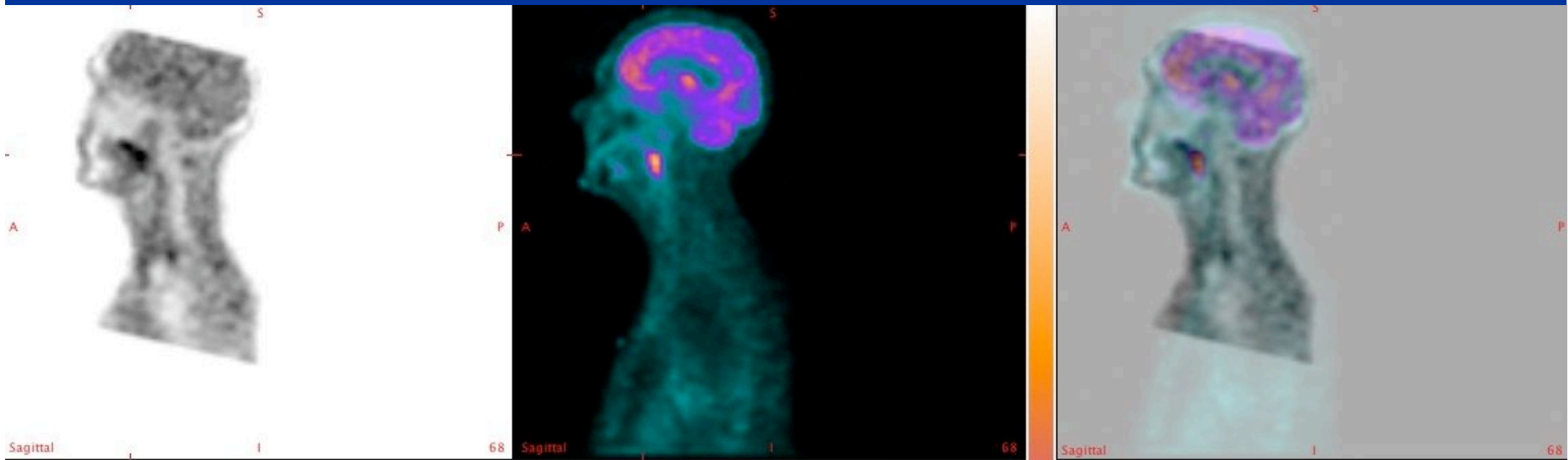
# PET GTV

## FDG/FMISO

FMISO

FDG

FMISO/FDG

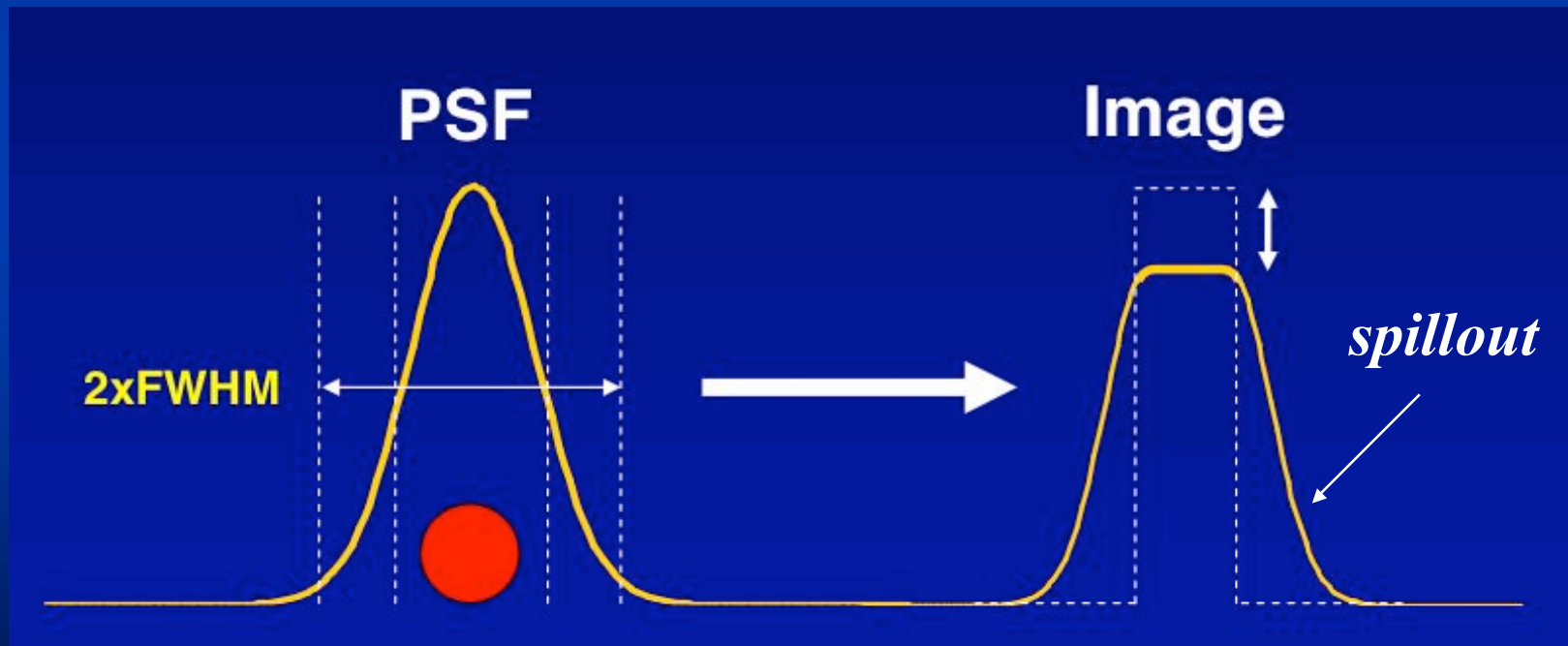


Austin Health

# PET GTV

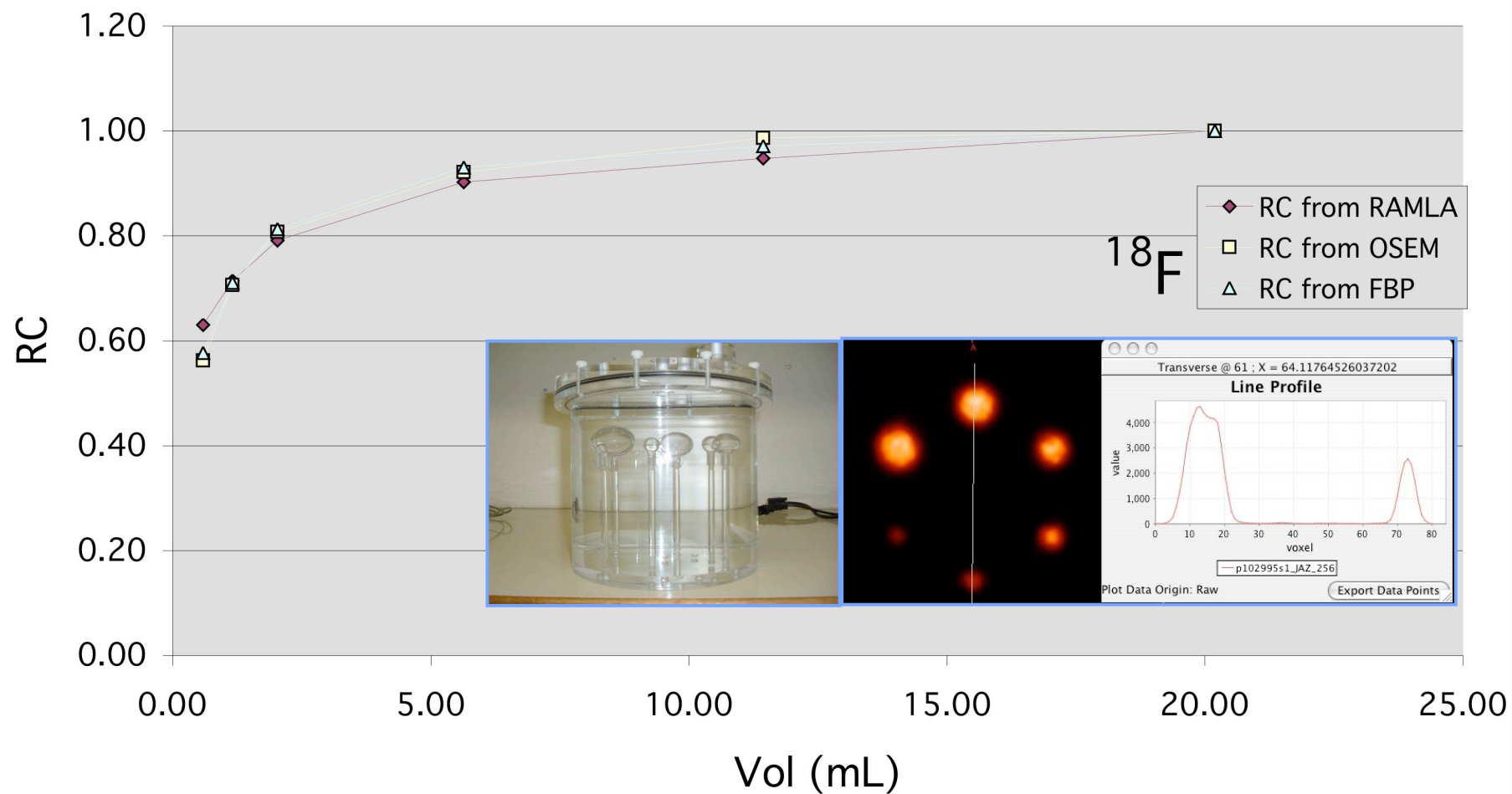
## Partial Volume Effect

- When an object partially occupies the sensitive volume of an imaging instrument (in space or time), the measured signal will be reduced in amplitude (diluted)



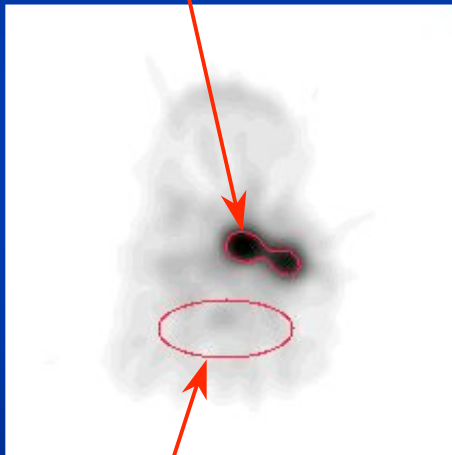
# PET/CT GTV Markup

## Partial Volume Effect



# Monitoring/Staging

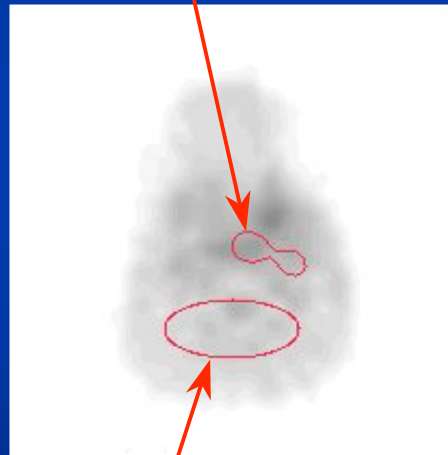
Tumour ROI  
SUVmean = 9.3  
SUVmax = 13.1



Background ROI  
SUVmean = 1.1

Oct 18, 2000

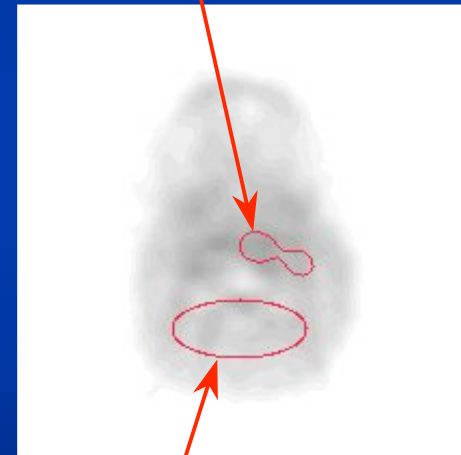
Tumour ROI  
SUVmean = 2.1  
SUVmax = 3.0



Background ROI  
SUVmean = 1.1

Jan 8, 2001

Tumour ROI  
SUVmean = 1.8  
SUVmax = 2.3



Background ROI  
SUVmean = 1.1

May 1, 2001

Radiotherapy started  
Oct 19 2000



Austin Health

Courtesy M. Lodge, University of Maryland

# Summary

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- RT Planned PET/CT
  - Provides complementary functional information
  - Requires awareness of
    - PET imaging characteristics
    - Subject preparation
    - Bio-physical properties of tracer
  - Can achieve sub-mm external registration accuracy
  - Auto-fusion accuracy sub-4mm



# Acknowledgements

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## Centre for PET, Austin Hospital

- Sylvia Gong
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- Carmel Mantle
- Judene Pigou
- Mori Wada
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- Darryl Lim Joon

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- David Sebok

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- Andrew McDonald

