

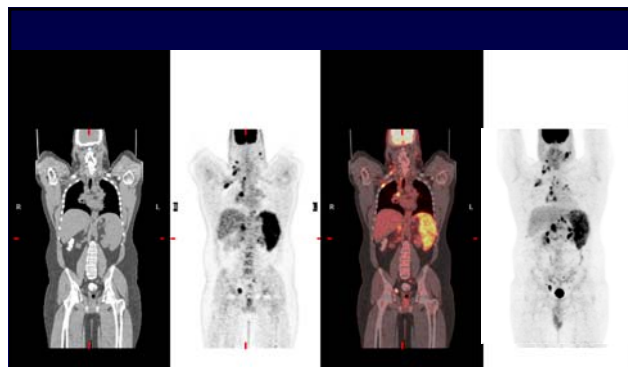
Factors Affecting Accurate Quantification In PET/CT

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Department of Imaging Physics
MD Anderson Cancer Center



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53 year old man with lymphoma with increased FDG uptake in the spleen and multiple intra and extra-thoracic nodes consistent with Multi-focal malignancy.

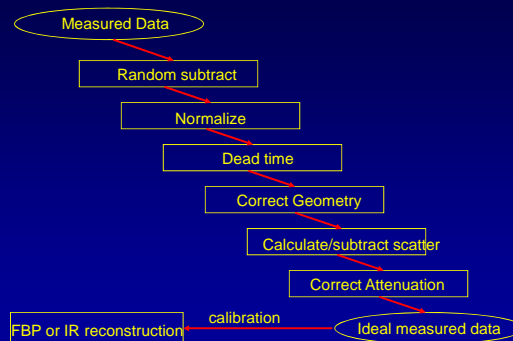
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Power of PET : Quantification



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Quantification: Power of PET



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SUV

$$SUV = \frac{\text{decay-corrected dose/ml of tumor}}{\text{injected dose/patient weight in grams}}$$

- The standardized uptake value (SUV) is one means of making PET results more quantitative.
- Tracer kinetic modeling is used extensively in quantitative PET (may include blood samples and dynamic imaging).

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SUV Modifiers

- SUV_{bw} (gm/ml)

Corrected for body weight: $SUV_{bw} = C_t / (I/W)$

- C_t : tissue concentration [kBq ml⁻¹]
- I : injected dose [MBq]
- W : body weight [kg]

- SUV_{BSA} (m2/ml)

Corrected for body surface area: $SUV_{BSA} = C_t / (I/BSA)$

- BSA : body surface area [m²]
- $BSA = 0.007184 \cdot W^{0.425} \cdot h^{0.725}$

- SUV_{LBM} (gm/ml)

Corrected for lean body mass: $SUV_{LBM} = C_t / (I/LBM)$

- LBM : lean body mass [kg]
- Men: $LBM = 48.0 + 1.06 \cdot (h - 152)$
- h : height [cm]
- Women: $LBM = 45.5 + 0.91 \cdot (h - 152)$

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SUV Modifiers

- SUV_{ig} (gm/ml)

$$SUV_{ig} = C_{glu} \cdot SUV_i$$

- SUV_i : any of the SUV definitions above
- C_{glu} : plasma concentration of glucose [mmol l⁻¹]

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Quantitative PET Performance

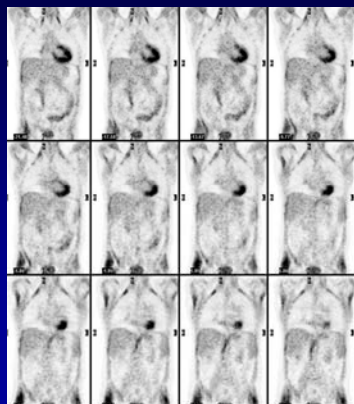
3 categories that "might" affect SUV measurements

- Patient Compliance
 - Fasting
 - Blood Glucose levels
- Scan Conditions
 - Scan time post injection
 - Patient anxiety/comfort during uptake (room temperature, etc.)
 - Patient motion during acquisition
 - PET/CT vs dedicated PET
- Intrinsic System Parameters and Capability
 - Calibration
 - QA – Maintenance of operating parameters
 - Performance characteristics of scanners – *Partial Volume effects*
 - Image processing algorithms

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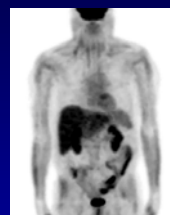
Improper Prep. Non fasting

- High protein/low carbs.
- 6-8 glasses of water
- 6 hrs fasting
- Avoid strenuous exercise



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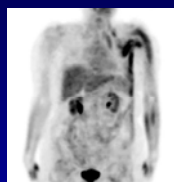
Fast Track Insulin Scan



- 70 —150 mg/dL – Ideal
- 150 —200 mg/dL - clinical decision
- > 200 mg/dL - cancel

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Muscle Uptake



Crutch Utilized Left Side

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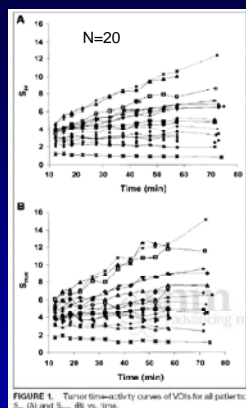
Quantitative PET Performance

3 Categories that "might" affect SUV measurements

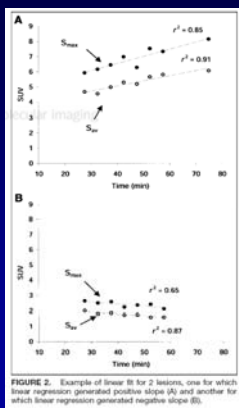
- **Patient Compliance**
 - Fasting
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- **Scan Conditions**
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 - PET/CT vs Dedicated PET
- **Intrinsic System Parameters and Capability**
 - Calibration
 - QA – Maintenance of operating parameters
 - Performance characteristics of scanners – Partial Volume Effects
 - Image processing algorithms

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Effect of Scan time post injection: Breast Cancer

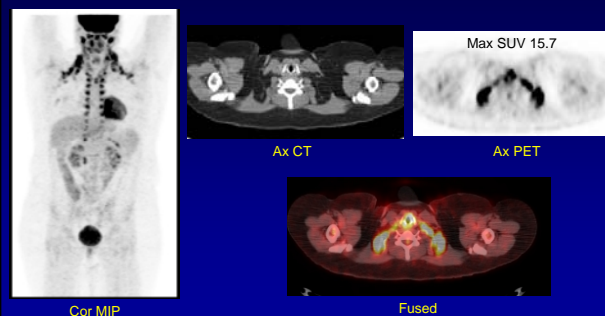


Beaulieu S et al JNM 2003



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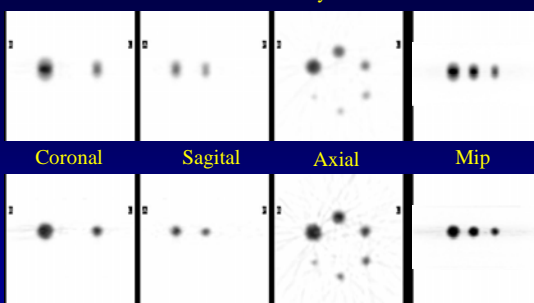
PET-CT Normal "Brown" Fat



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Motion Effects

Phantom Study

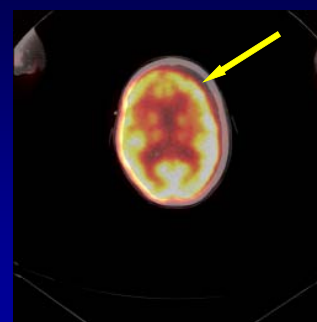


Sphere (volume)	Gated	Static	Error (%)
1 (16.5 cc)	31624	33546	-6.1
2 (8.4 cc)	31316	21872	30.2
3 (4 cc)	29919	20607	31.1
4 (2 cc)	22857	13643	40.3
5 (1 cc)	19087	8264	56.7
6 (0.5 cc)	11897	5143	56.8

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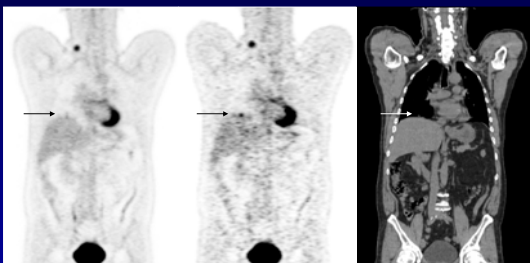
Patient Movement

Patient movement occurred after the CT image was acquired.



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Impact of Whole-body Respiratory Gated PET/CT



Static wholebody

Single respiratory phase
(1 of 7, so noisier)

1 cc lesion on CT

The max SUV of the lesion goes from 2 in the static image to 6 in the respiratory-gated image sequence

Courtesy of P Kinahan, UW

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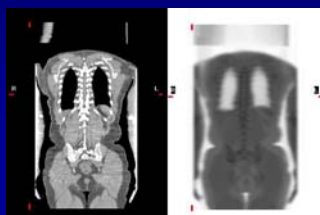
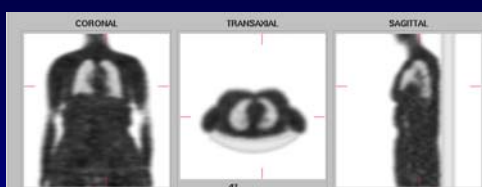
PET/CT vs Dedicated PET

Disadvantages of dedicated PET imaging techniques

- Transmission
 - Noise due to low gamma ray flux from rod source
 - Transmission is contaminated by emission data
- Scan duration
 - Time consuming (emission & transmission)
 - Increased patient movement (image blurring)
- Efficiency
 - Decreased patient throughput
 - Difficulty in accurately correlating images to other diagnostic modalities

© Masawa MDACC

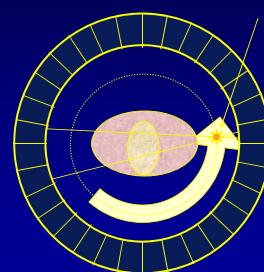
Short duration, low noise CT-based attenuation correction



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Attenuation Measurement

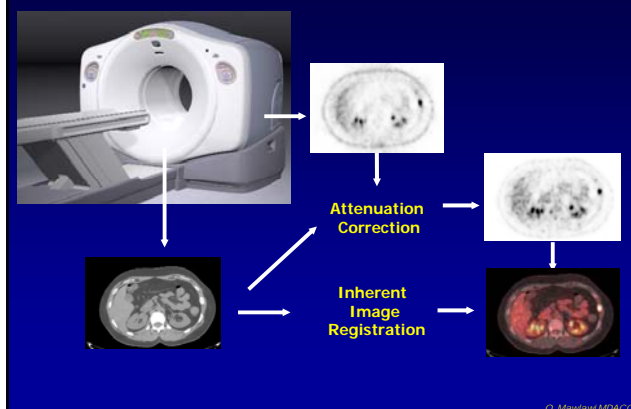
Rod or Pin Source (^{68}Ge , $T_{1/2} = 271$ days)



Patient Transmission Scan

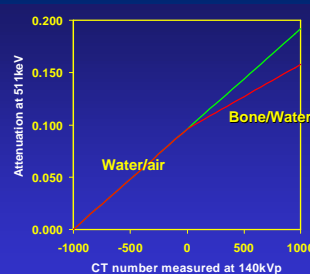
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PET-CT



Converting CT Numbers to Attenuation Values

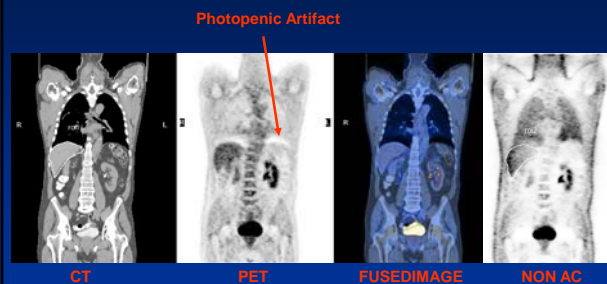
- For CT values < 0 , materials are assumed to have an energy dependence similar to water
- For CT values > 0 , material is assumed to have an energy dependence similar to a mixture of bone and water
- The green line shows the effect of using water scaling for all materials



PET/CT imaging artifacts are due to :

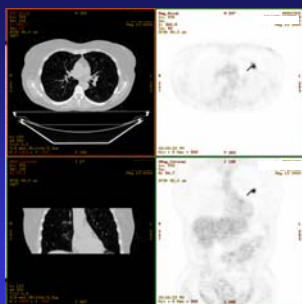
- Respiratory motion
- Metal implants
- Truncation
- Contrast media

Breathing Artifact-Curvilinear Cold Areas



Breathing Artifact

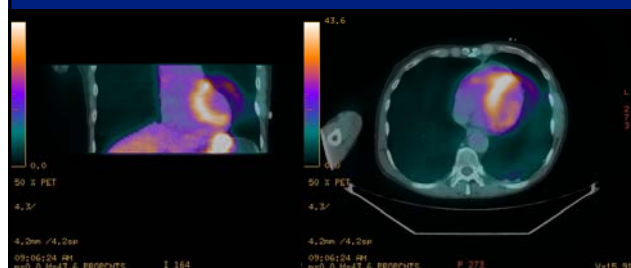
Mismatch of lesion location between helical CT and PET



Inaccurate attenuation correction → inaccurate quantification

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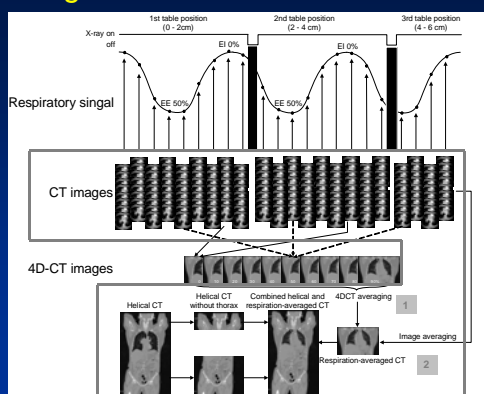
Mismatch between PET and CT – Cardiac Application



Courtesy of J. Brunetti, Holly name

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Average CT – 4D CT

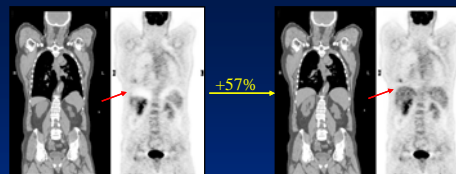


Courtesy of Tinsu Pan, MDAAC

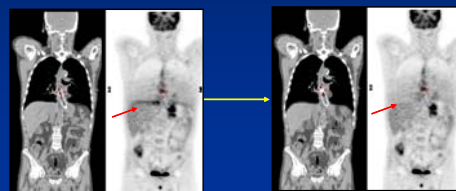
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Clinical Studies

Mismatch 1:
CT diaphragm
position lower
than PET



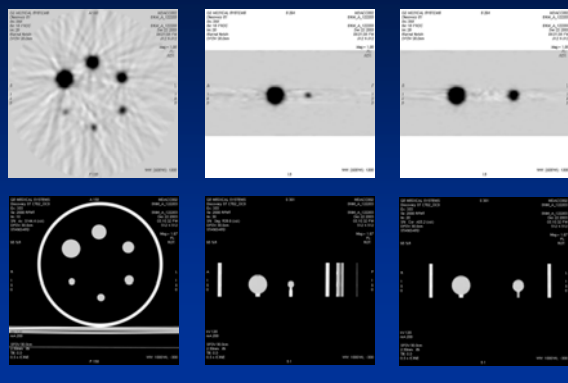
Mismatch 2:
CT diaphragm
position higher
than PET



Courtesy of Tinsu Pan, MDAAC

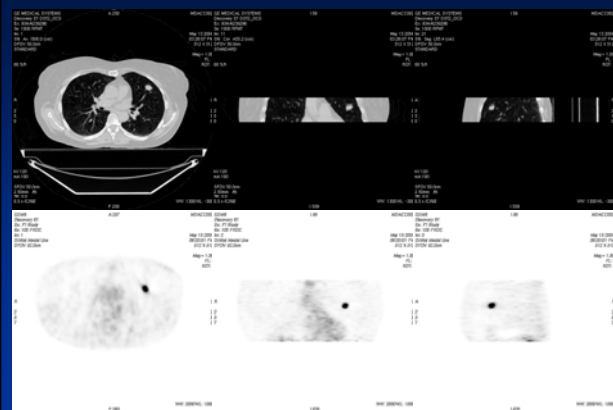
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4D-PET/CT



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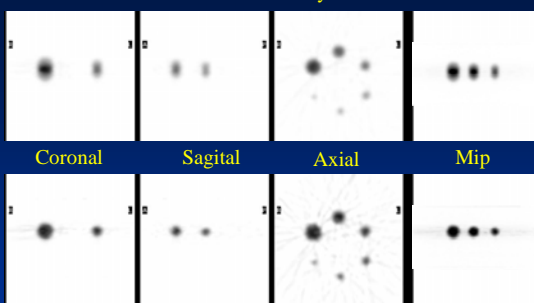
4D PET/CT



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Motion Effects

Phantom Study

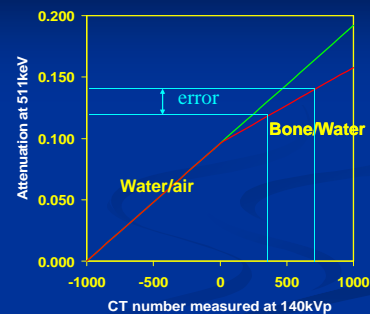


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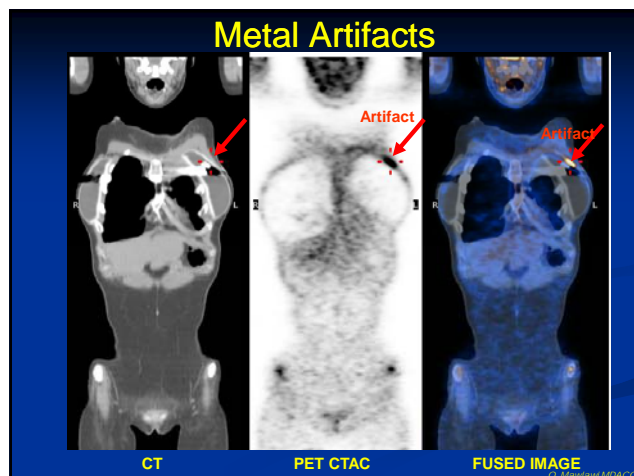
METAL & CONTRAST artifacts

- For CT values < 0 , materials are assumed to have an energy dependence similar to water
- For CT values > 0 , material is assumed to have an energy dependence similar to a mixture of bone and water
- The green line shows the effect of using water scaling for all materials

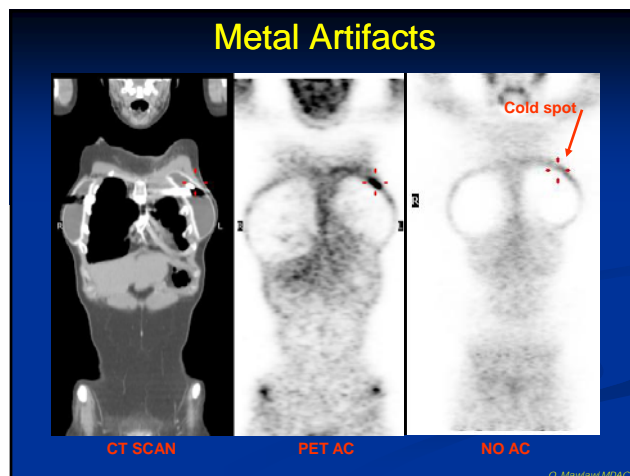


Q. Mawlaw MDACC

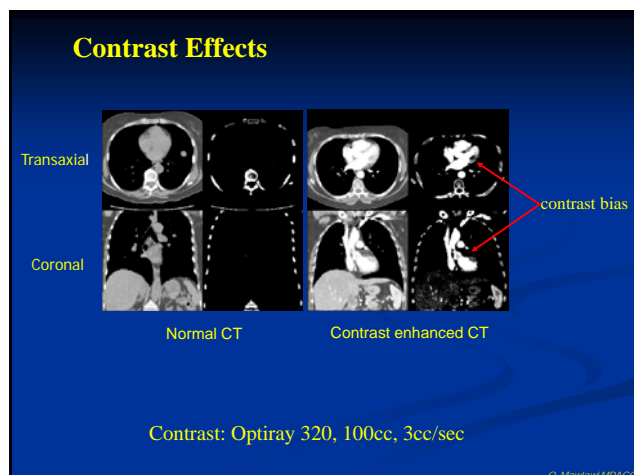
Metal Artifacts



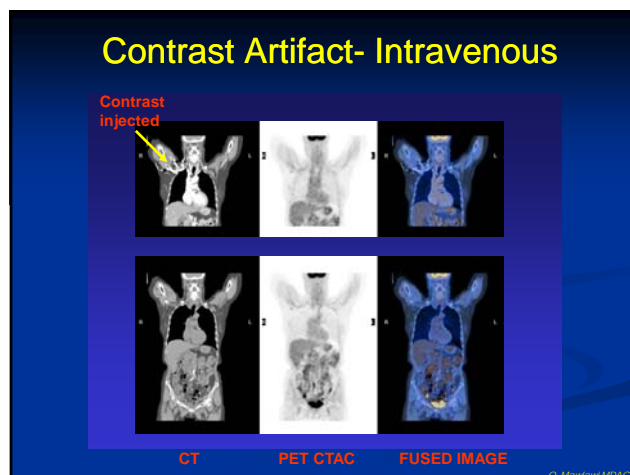
Metal Artifacts

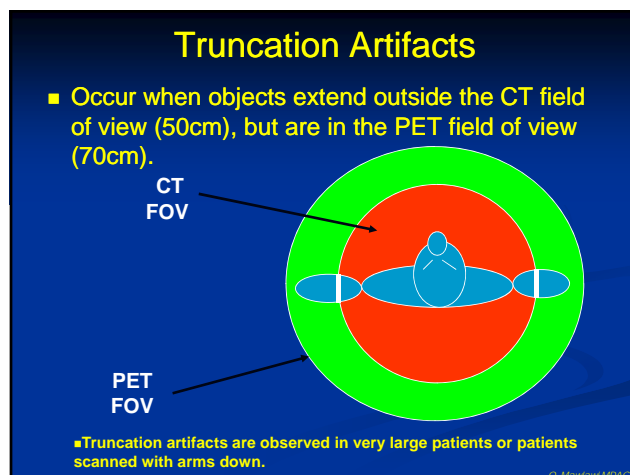
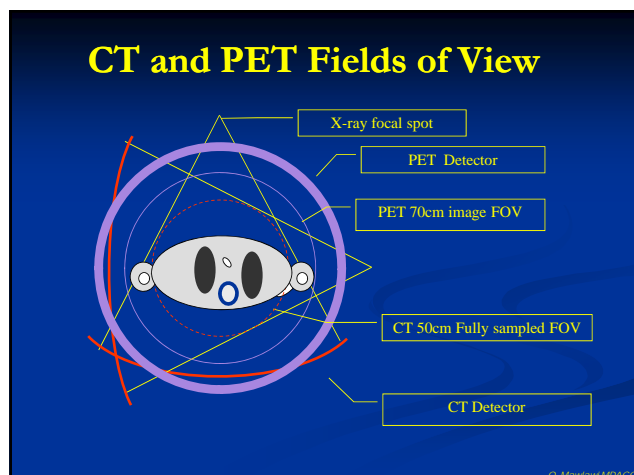
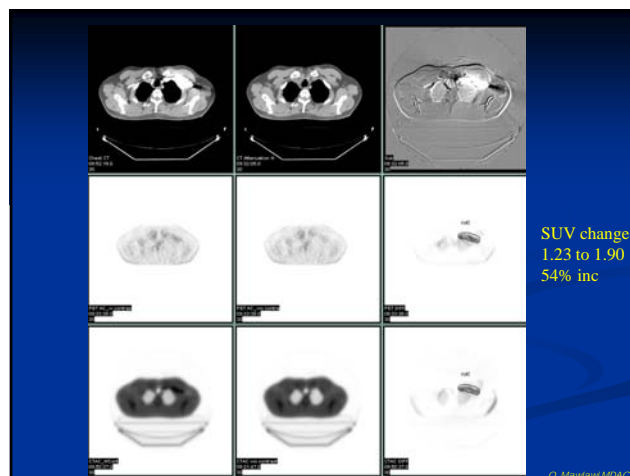
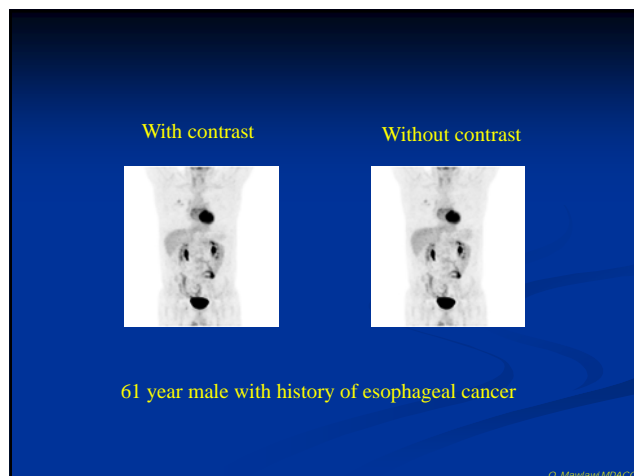


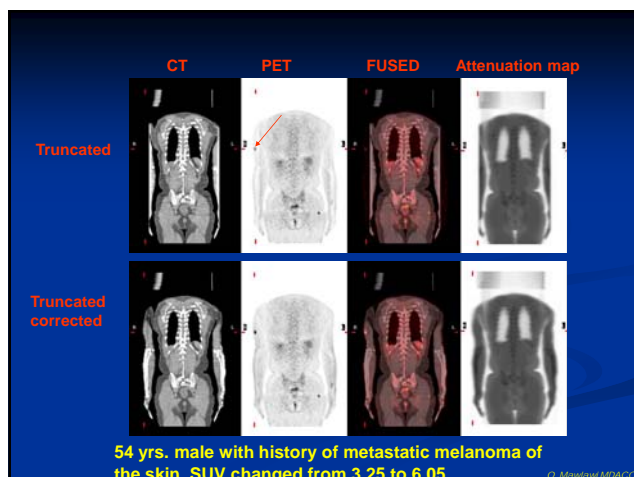
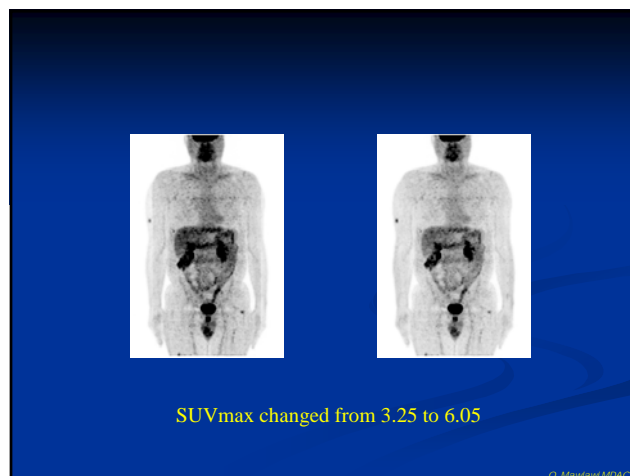
Contrast Effects



Contrast Artifact- Intravenous







Quantitative PET Performance

3 Factors that may affect SUV measurements

- **Patient Compliance**
 - Fasting
 - Blood Glucose levels
- **Scan Conditions**
 - Scan time post injection
 - Patient anxiety/comfort during uptake (room temperature, etc.)
 - Patient motion during acquisition
 - PET/CT vs dedicated PET
- **Intrinsic System Operating Parameters**
 - Calibration
 - QA – Maintenance of operating parameters
 - System performance characterization – Partial Volume
 - Image processing algorithms

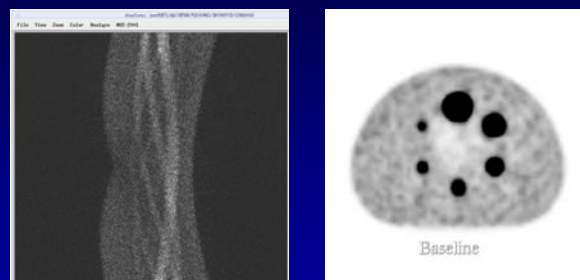
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Coincidence Calibrations

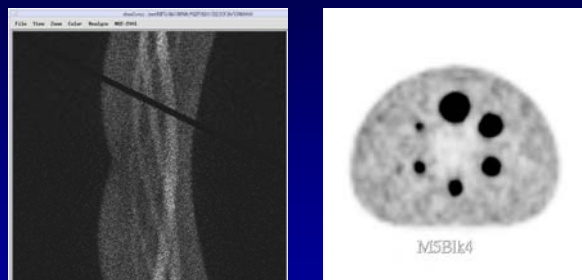
- Well Counter Correction (WCC)



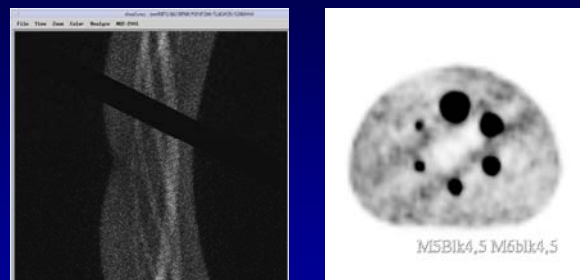
Effects of Bad Blocks

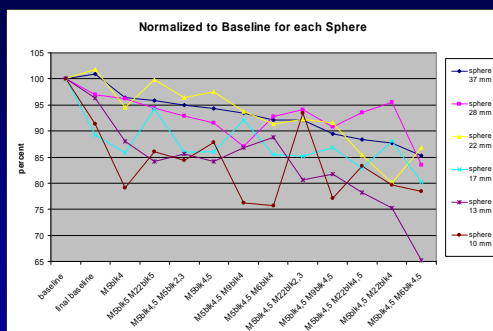


Effects of Bad Blocks



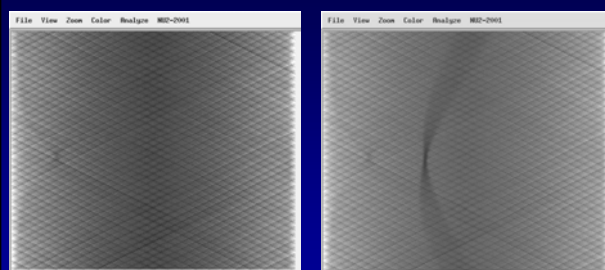
Effects of Bad Blocks





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Normalization effects

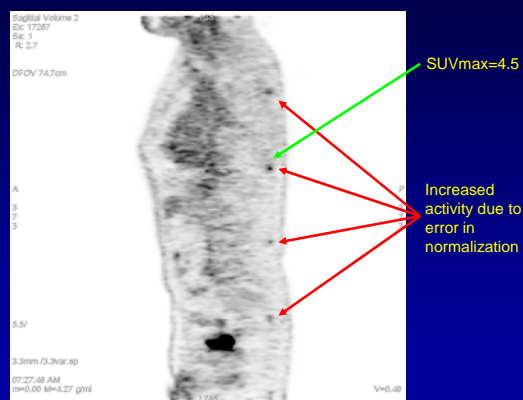


Good Norm

Bad Norm

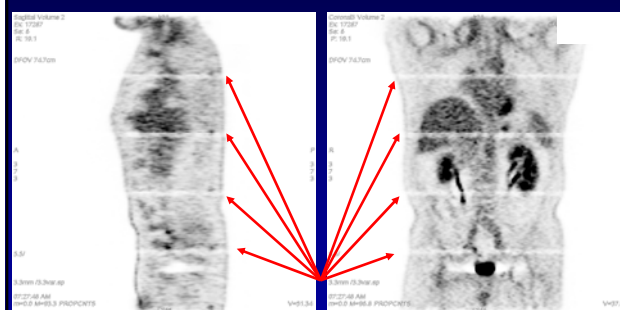
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Effect of bad Normalization



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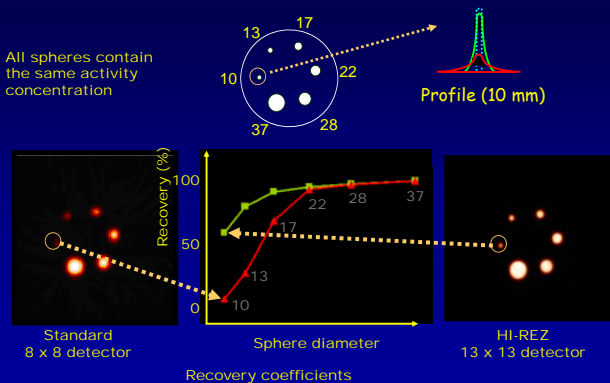
Effect of wrong WCC



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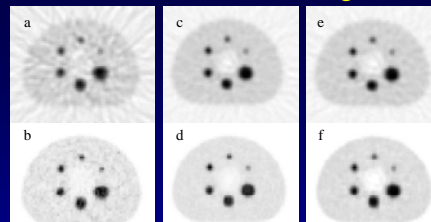
Effect on Partial voluming

All spheres contain the same activity concentration



Chatterjee et al. 2004

Effect of Reconstruction Algorithm



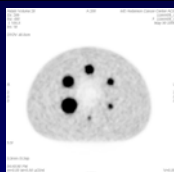
(a) 2D-FBP; (b) 2D-OSEM; (c) 3D-RP; (d) 3D-IR; (e) 3D-FORE+FBP; (f) 3D-FORE+OSEM.

AC max under different reconstruction algorithms (Bq/cc)						
(x10 ³)	Sphere 1	Sphere 2	Sphere 3	Sphere 4	Sphere 5	Sphere 6
Algorithm a	3.03	2.74	2.52	2.30	1.75	1.12
Algorithm b	3.14	3.14	2.82	2.90	2.14	1.74
Algorithm c	2.83	2.76	2.62	2.41	1.60	1.07
Algorithm d	2.93	2.92	2.98	3.21	2.19	1.33
Algorithm e	2.78	2.75	2.64	2.40	1.59	1.10
Algorithm f	2.85	2.74	2.71	2.52	1.65	1.09

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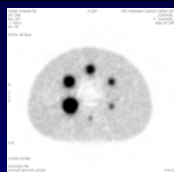
A

3D IR
2it 20sub



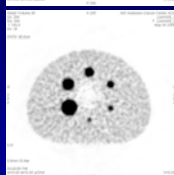
B

3D FORE
2it 5sub



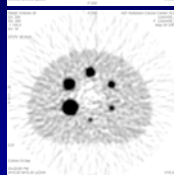
C

3D FORE
5it 28sub



D

3D FORE
FBP



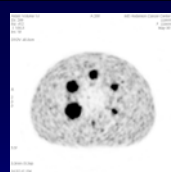
Max SUVbw
in different
spheres

	1	2	3	4	5	6
A	10.8	10.3	9.9	8.9	6.5	3.8
B	8.6	7.6	6.6	5.5	3.9	2.8
C	10.3	9.7	9.1	8.3	6.3	4.7
D	10.4	9.3	9.3	7.7	5.9	4.8

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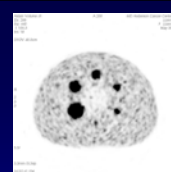
A

2D
OSEM
2it 20sub



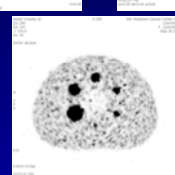
B

2D
OSEM
2it 28sub



C

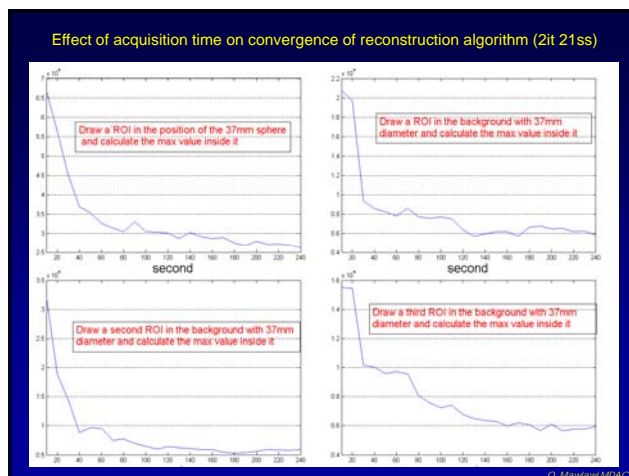
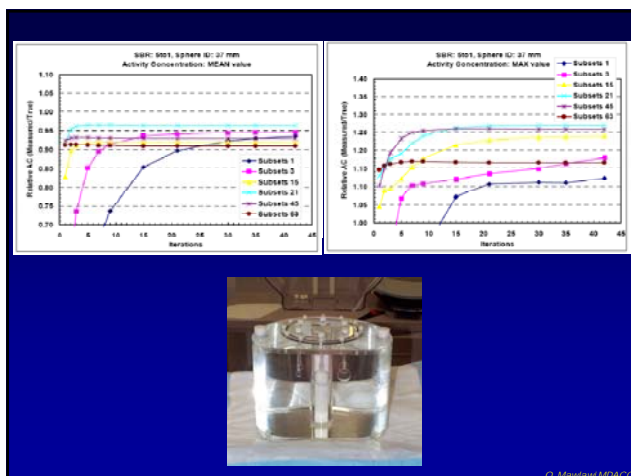
2D
OSEM
4it 28sub



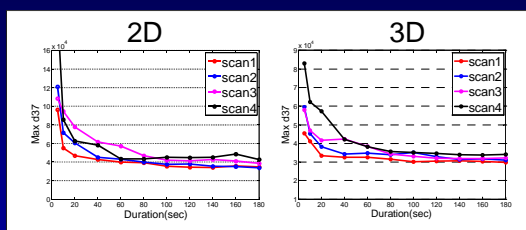
Max SUVbw
in different
spheres

	1	2	3	4	5	6
A	12.7	11.9	11.7	12.7	7.4	4.1
B	15.0	12.3	11.7	13.4	9.6	5.4
C	16.0	13.6	11.9	14.7	10.3	6.3

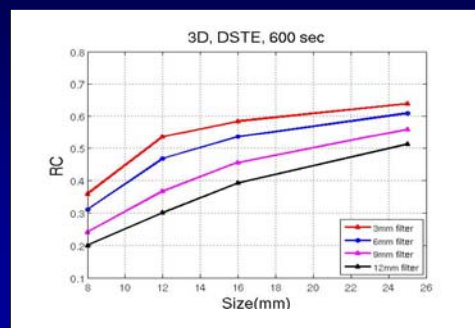
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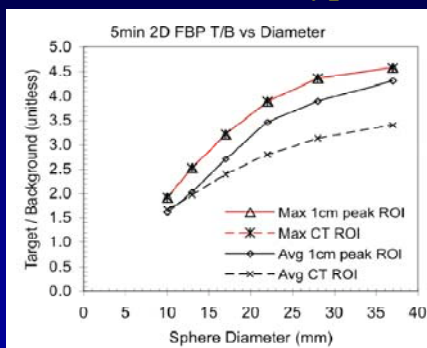
Effect of scan duration and count density on maximum AC



Effect of smoothing on measured AC



Effect of ROI type



Courtesy of P. Kinahan UW

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Conclusion

- SUV is reproducible
- SUV is reliable as long as mediating factors are accounted for
- Standardization across institutions might be a more difficult task

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