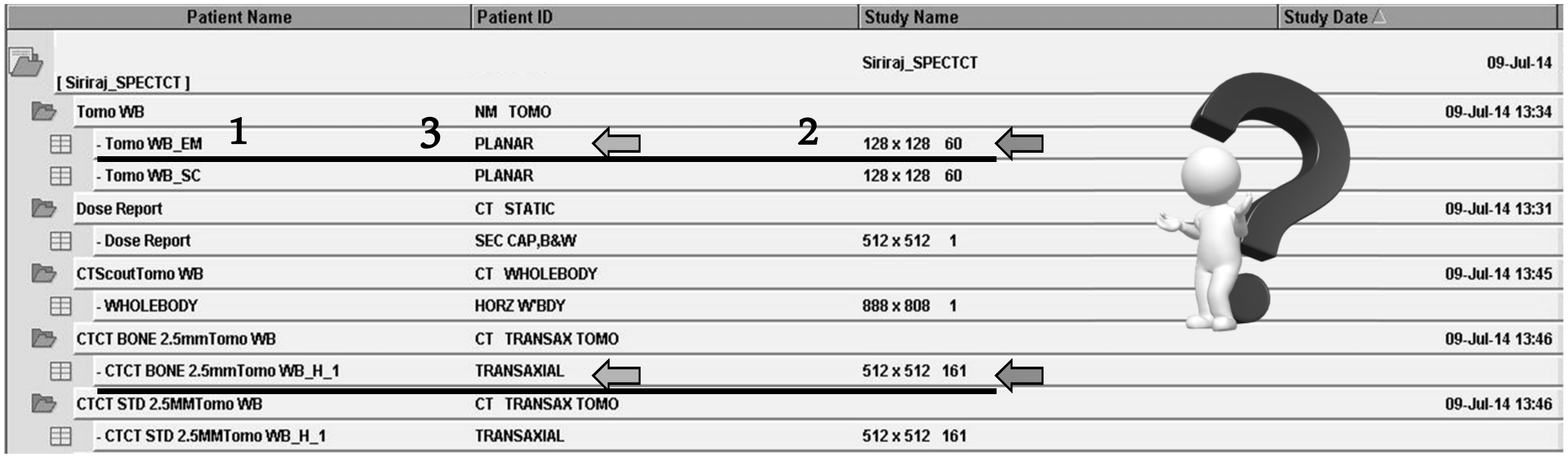
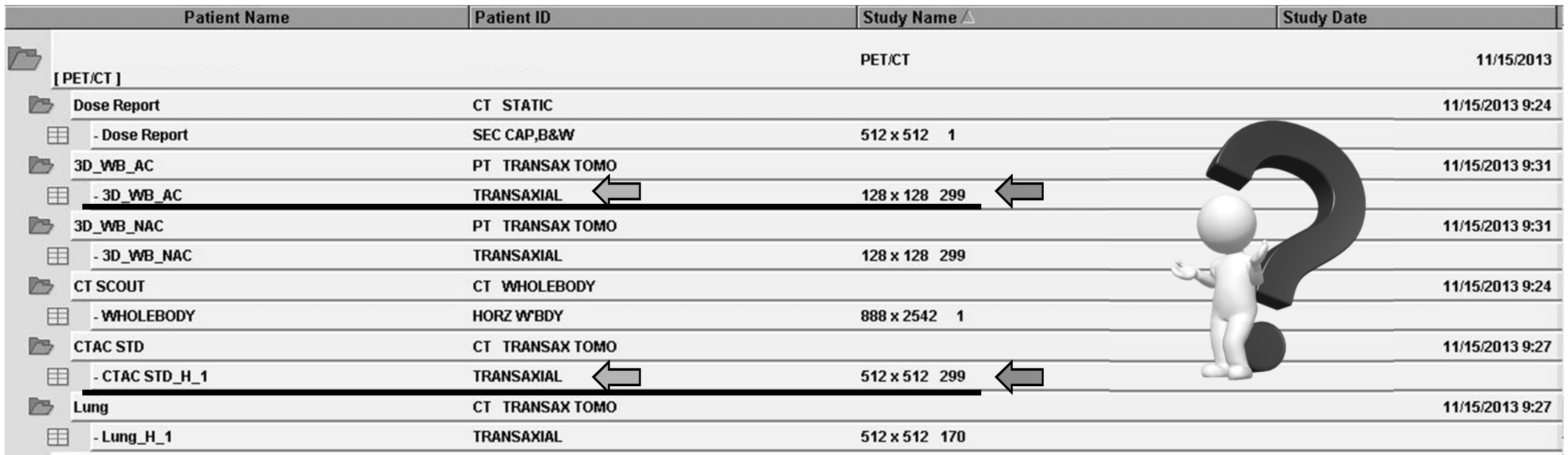
CT ATTENUATION CORRECTION EFFECT ON FUSION IMAGE

POTJANEE KANCHANAPIBOON

WHAT ARE MY QUESTIONS ?

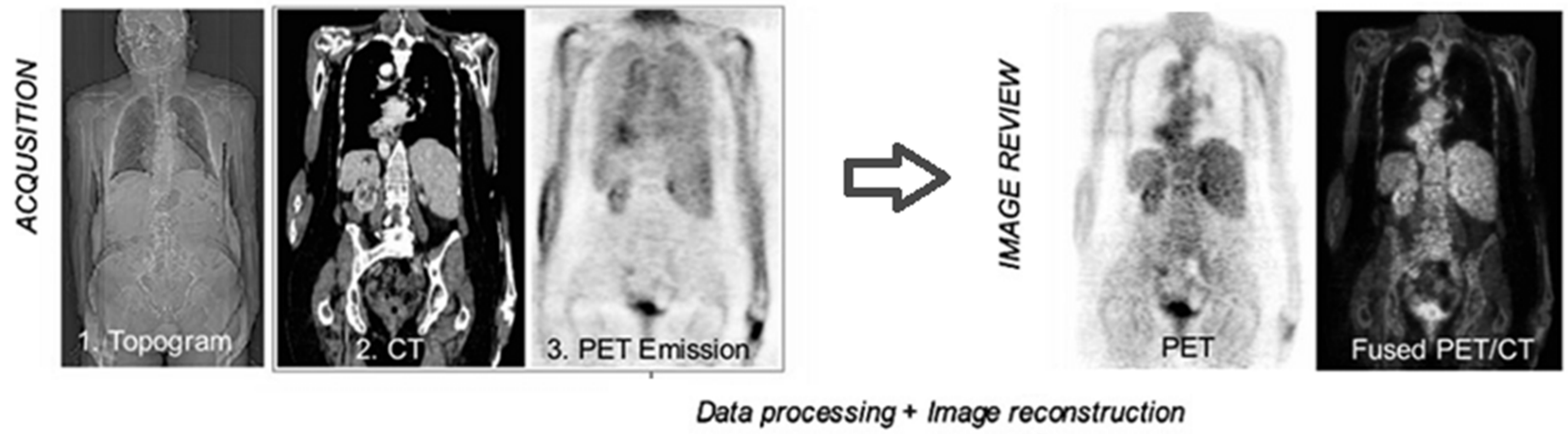


Patient Name	Patient ID	Study Name	Study Date
[Siriraj_SPECTCT]		Siriraj_SPECTCT	09-Jul-14
Tomo WB	NM TOMO		09-Jul-14 13:34
- Tomo WB_EM	PLANAR	128 x 128 60	
- Tomo WB_SC	PLANAR	128 x 128 60	
Dose Report	CT STATIC		09-Jul-14 13:31
- Dose Report	SEC CAP,B&W	512 x 512 1	
CTScoutTomo WB	CT WHOLEBODY		09-Jul-14 13:45
- WHOLEBODY	HORZ W'BDY	888 x 808 1	
CTCT BONE 2.5mmTomo WB	CT TRANSAX TOMO		09-Jul-14 13:46
- CTCT BONE 2.5mmTomo WB_H_1	TRANSAXIAL	512 x 512 161	
CTCT STD 2.5MMTomo WB	CT TRANSAX TOMO		09-Jul-14 13:46
- CTCT STD 2.5MMTomo WB_H_1	TRANSAXIAL	512 x 512 161	



Patient Name	Patient ID	Study Name	Study Date
[PET/CT]		PET/CT	11/15/2013
Dose Report	CT STATIC		11/15/2013 9:24
- Dose Report	SEC CAP,B&W	512 x 512 1	
3D_WB_AC	PT TRANSAX TOMO		11/15/2013 9:31
- 3D_WB_AC	TRANSAXIAL	128 x 128 299	
3D_WB_NAC	PT TRANSAX TOMO		11/15/2013 9:31
- 3D_WB_NAC	TRANSAXIAL	128 x 128 299	
CT SCOUT	CT WHOLEBODY		11/15/2013 9:24
- WHOLEBODY	HORZ W'BDY	888 x 2542 1	
CTAC STD	CT TRANSAX TOMO		11/15/2013 9:27
- CTAC STD_H_1	TRANSAXIAL	512 x 512 299	
Lung	CT TRANSAX TOMO		11/15/2013 9:27
- Lung_H_1	TRANSAXIAL	512 x 512 170	

SEQUENCE DIAGRAM OF FUSION IMAGE



1.CT LOCALIZER IMAGE → 2.CT IMAGE → 3.EMISSION IMAGE: SPECT OR PET → 4.FUSION IMAGE

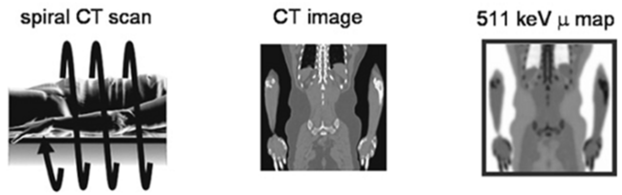
SEQUENCE DIAGRAM OF FUSION IMAGE

1.CT LOCALIZER IMAGE

- Start to end location
- Size (x,y planes) or thickness (z plane)
- 10-30 mA
- 120-140 kV
- Matrix size 512x512

2.CT IMAGE

- AEC strategies : Fix kV but Vary mA
- Matrix size 512x512
- Use 2 reconstruction tech.
  - Prepare registration*
  - Prepare fusion (1)



* = Step of mu-map generation: Convert CT transmission to CT emission (mu-map) and change matrix size 128 x 128

SEQUENCE DIAGRAM OF FUSION IMAGE

3.EMISSION IMAGE: SPECT OR PET

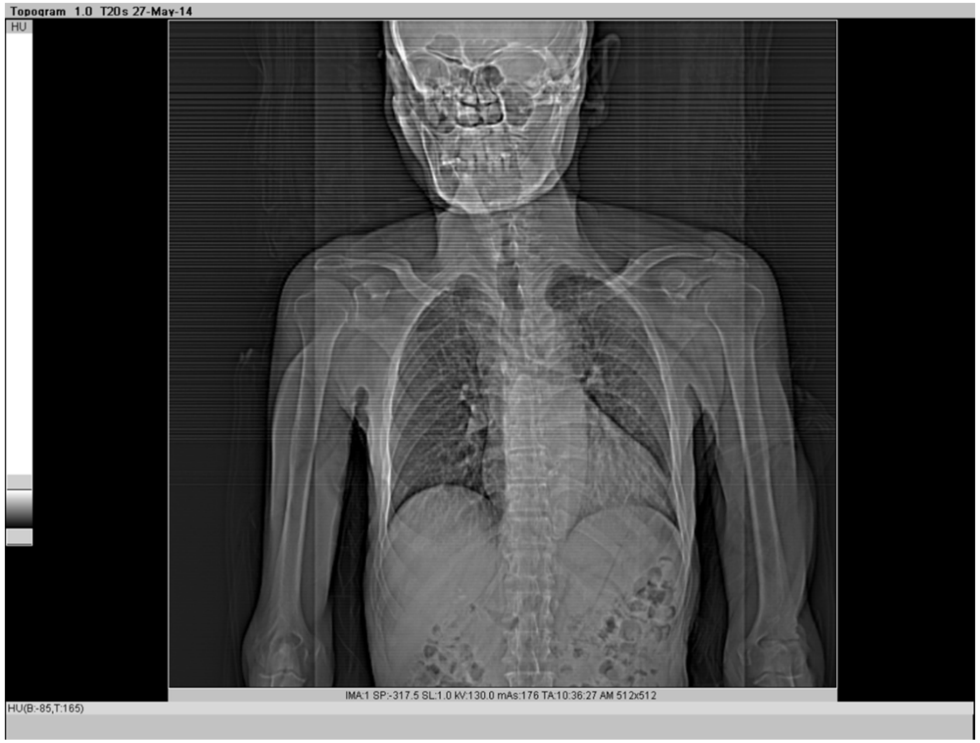
- Matrix size 128x128
- Registration tech.
- Scaling tech.
- Use 2 reconstruction tech
  - AC (2*)
  - Non-AC (2)

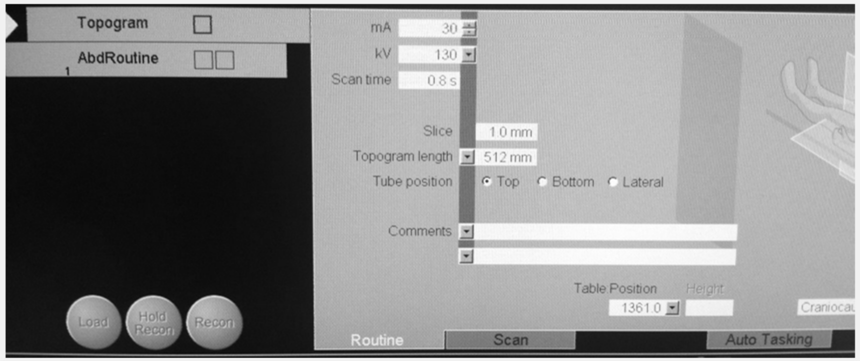
4.FUSION IMAGE

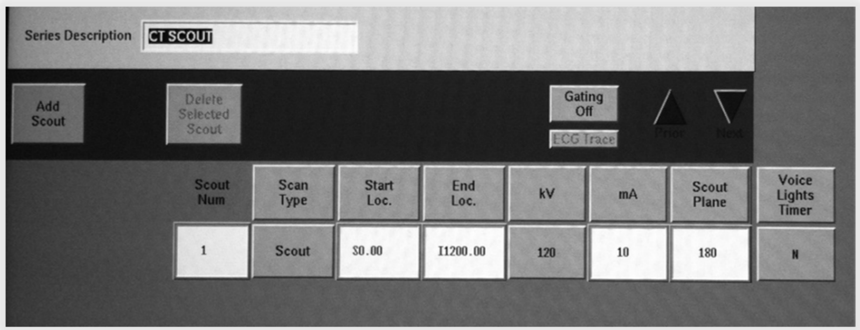
- Image fusion tech.
  - (1) + (2*)
  - (1) + (2)

* = Step of mu-map generation: Convert CT transmission to CT emission (mu-map) and change matrix size 128 x 128

CT LOCALIZER RADIOGRAPH



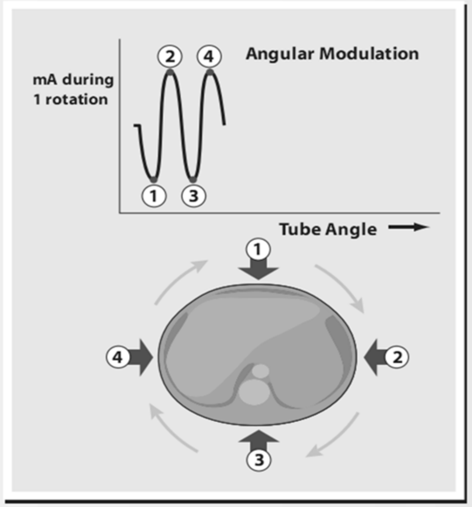




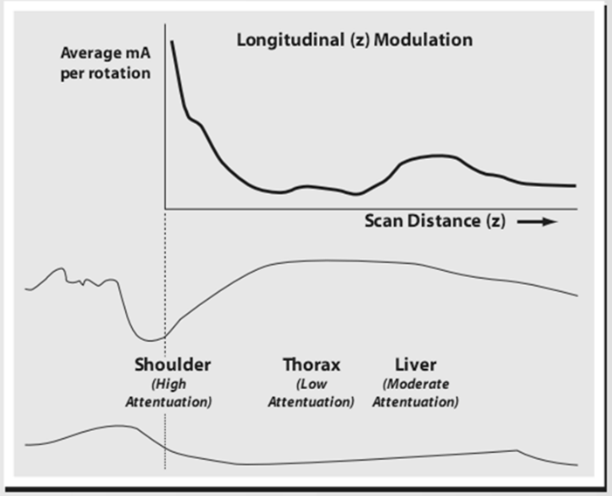
130 kV, 30 mA (176 mAs), matrix size 512x512

AUTOMATIC EXPOSURE CONTROL BASIC PRINCIPLES

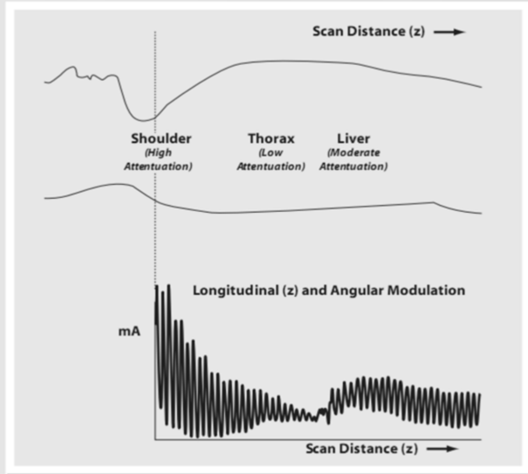
- AEC is a generic name for any technique aimed at optimizing dose utilization adjusting by adjusting the tube current in real-time to accommodate differences in attenuation due to patient anatomy, shape, and size. The tube current may be modulated as a function of projection angle, longitudinal location along the patients or both.



Angular tube current modulation

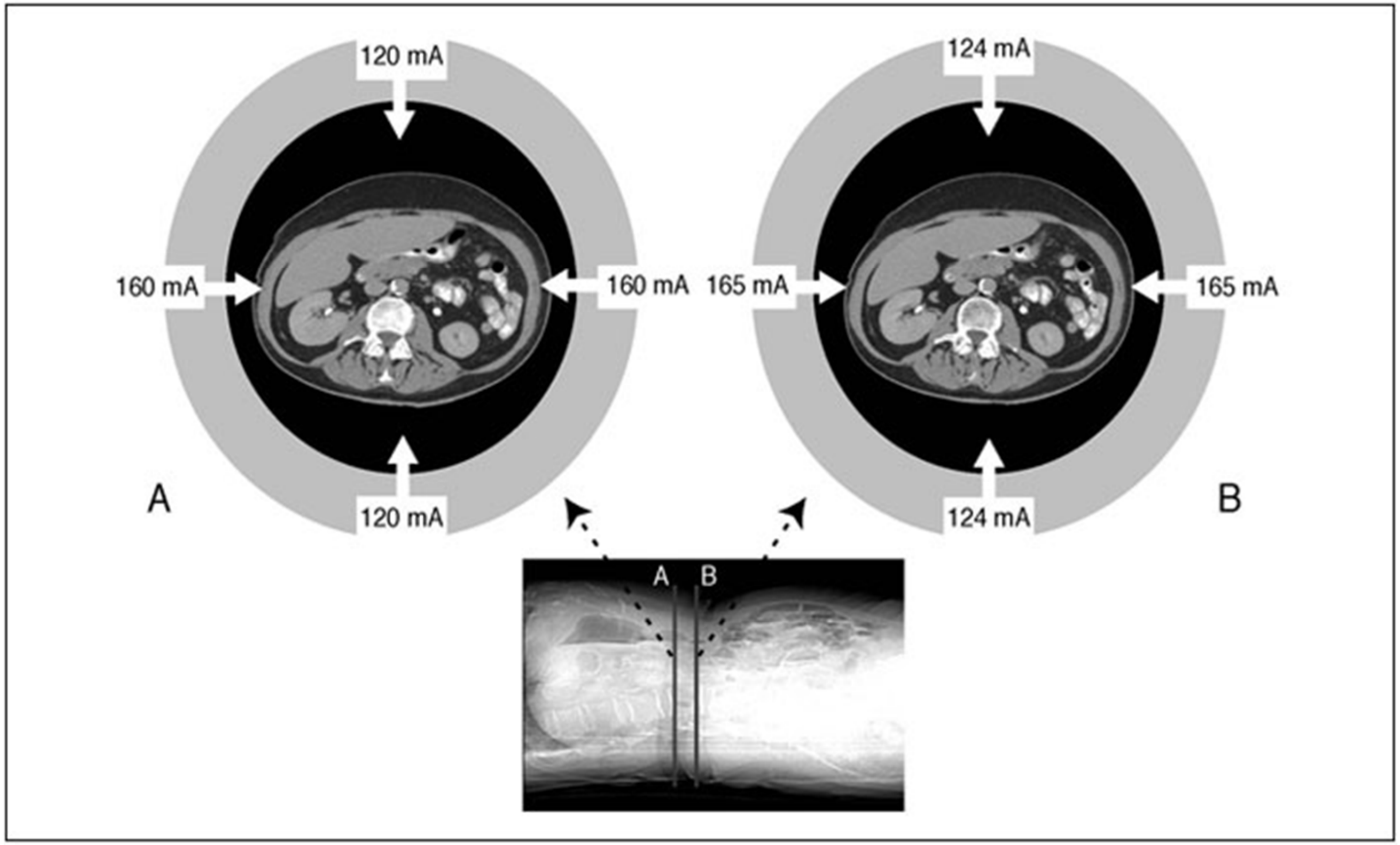


Longitudinal tube current modulation



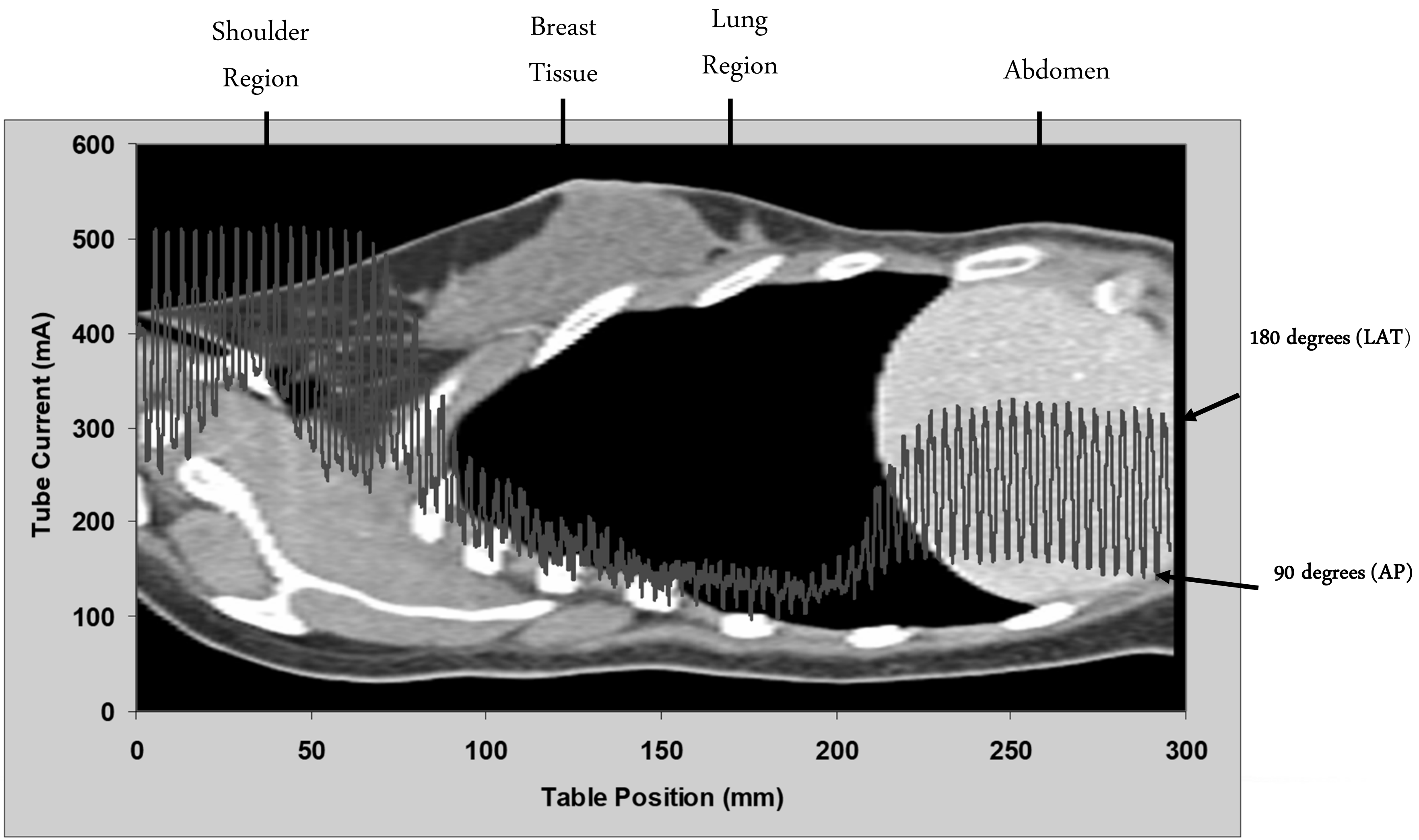
Longitudinal and Angular tube current modulation

Care Dose4D CT Automatic Exposure Control System



Automatic Exposure Control for CT examinations. The attenuation through one region of the body, A, is less than another, B, and is less in the anterior-posterior projection than the lateral. With automatic exposure control, the average x-ray tube current is lower at A than in B. In both A and B, the tube current is lower in the anterior-posterior projection than in the lateral projection.

LONGITUDINAL AND ANGULAR TUBE CURRENT MODULATION



AUTOMATIC EXPOSURE CONTROL BASIC PRINCIPLES

Table 1 Different types of AEC techniques available on current multidetector CT scanners

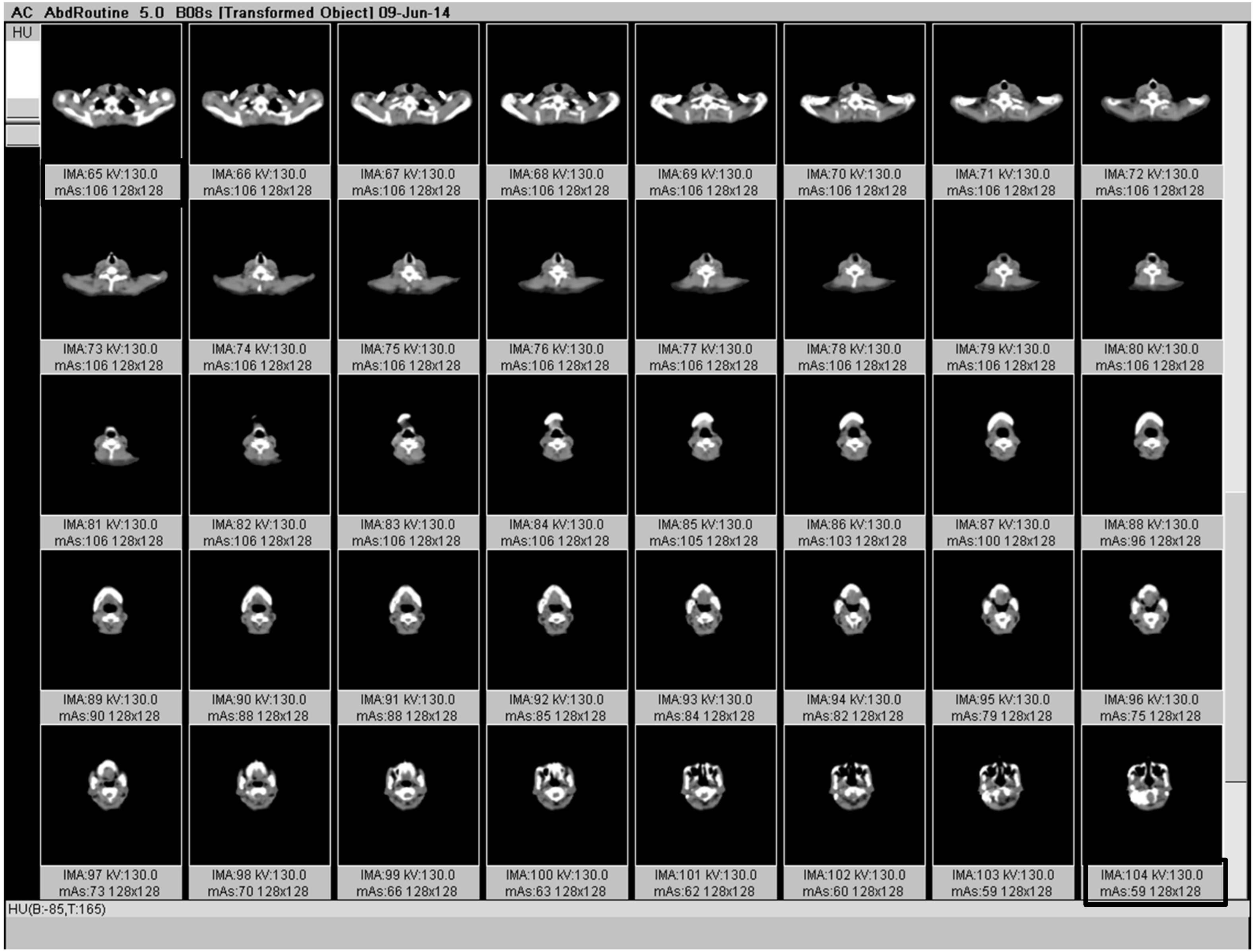
Technique	GE	Hitachi	Philips	Siemens	Toshiba
Angular AEC	Smart mA	Adaptive mA	D-DOM	CARE Dose	SURE Exposure
Z-axis AEC	Auto mA	Not available	Z-DOM	Not available	Not available
Combined AEC	Auto mA 3D	IntelliEC	Work in progress	CARE Dose 4D	SURE exposure 3D

Table 2 Summary of mechanism of use of different ACE techniques

AEC techniques	Mechanism of use
Angular AEC Smart mA DOM CARE Dose	Specify mA mAs/slice Effective mAs
Z-axis AEC (Auto mA)	Specify noise index as well as minimum and maximum mA thresholds for tube current modulation
Z-axis AEC (ZEC)	Specify quality reference mAs (rarely used without angular AEC also)
Z-axis AEC (Real EC)	Choose from four levels of image noise based on diagnostic requirement
Combined AEC (Auto mA 3D)	Specify noise index, minimum and maximum mA thresholds for current modulation
Combined AEC (CARE Dose 4D)	Specify quality reference mAs (modulation strength—weak, average, or strong, for small and large patients can be preset)

D-DOM = Dose modulation technique, Z-DOM = combination of Automatic Current setting and D-DOM

IS AEC WORK ?


AC AbdRoutine 5.0 B08s [Transformed Object] 09-Jun-14
HU
IMA:65 kV:130.0 mAs:106 128x128
IMA:66 kV:130.0 mAs:106 128x128
IMA:67 kV:130.0 mAs:106 128x128
IMA:68 kV:130.0 mAs:106 128x128
IMA:69 kV:130.0 mAs:106 128x128
IMA:70 kV:130.0 mAs:106 128x128
IMA:71 kV:130.0 mAs:106 128x128
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IMA:75 kV:130.0 mAs:106 128x128
IMA:76 kV:130.0 mAs:106 128x128
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IMA:85 kV:130.0 mAs:105 128x128
IMA:86 kV:130.0 mAs:103 128x128
IMA:87 kV:130.0 mAs:100 128x128
IMA:88 kV:130.0 mAs:96 128x128
IMA:89 kV:130.0 mAs:90 128x128
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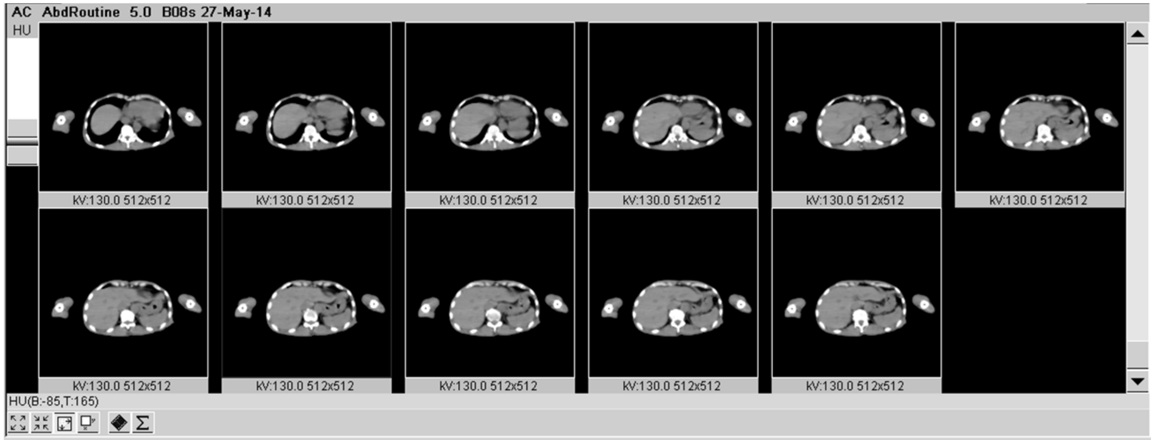
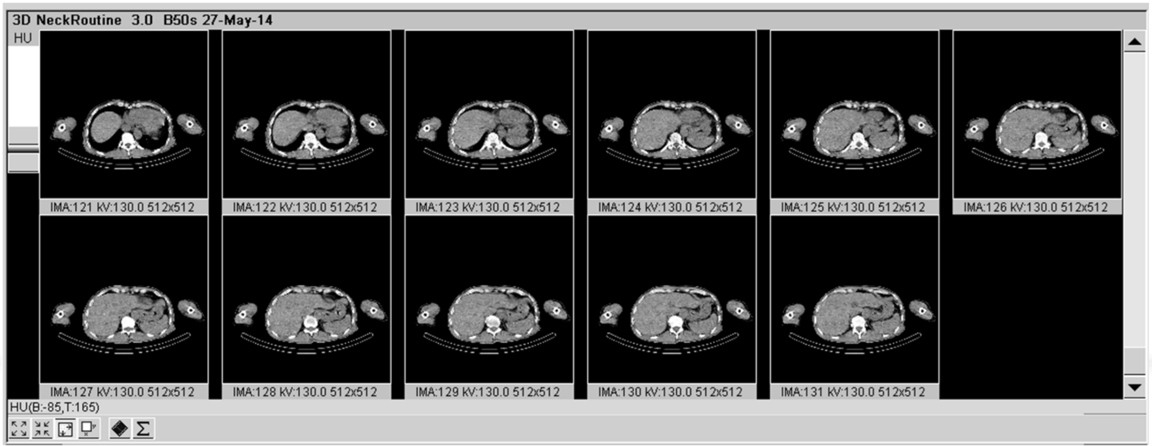
IMA:103 kV:130.0 mAs:59 128x128
IMA:104 kV:130.0 mAs:59 128x128
HU(B:-85,T:165)

CT FOR PREPARE REGISTRATION AND FUSION

1. Kernel: B08s SPECT AC (CT-AC)



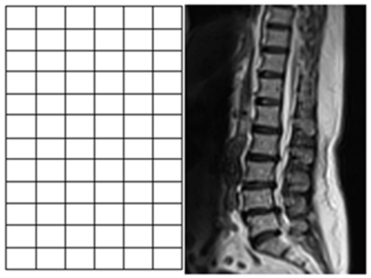
2. Kernel: B50s medium sharp (CT-3D)



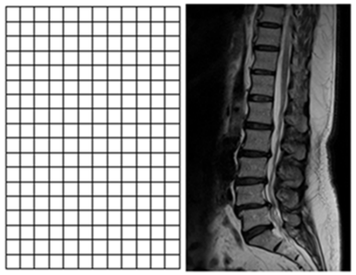
FUSION IMAGE

Medical image fusion is used when multiple patient images are registered and merged to provide additional information. Fused images may be created from multiple images from the same imaging modality, or by combining information from multiple modalities

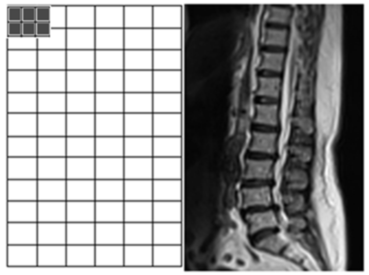
IMAGE REGISTRATION



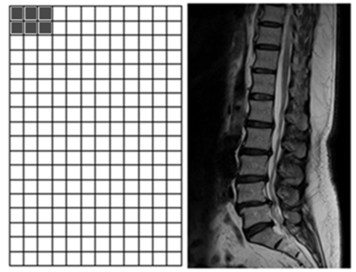
Large pixel size low resolution image



Small pixel size high resolution image



Large pixel size low resolution image



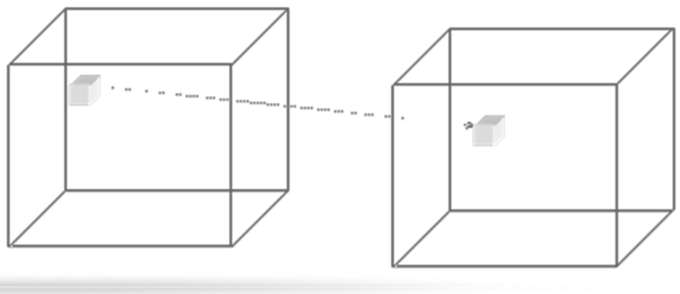
Small pixel size high resolution image

Data from both devices must be correctly combined to produce accurate images. The main condition for registering the information is that a relationship between the coordinates of the corresponding points in the two images is determined

I.Data and Correlation

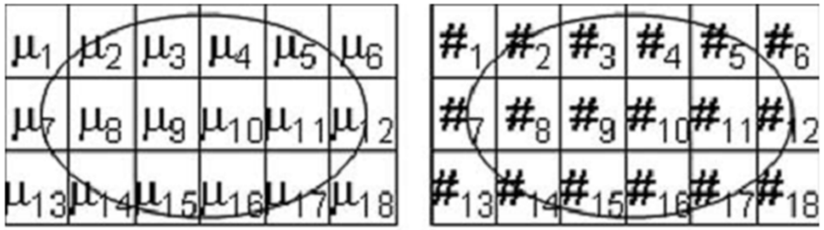
II. Registration algorithm :

1. Linear transformation (Rigid)
2. Non-linear transformation (Non-Rigid)



III. Geometric transformation

SCALING METHOD

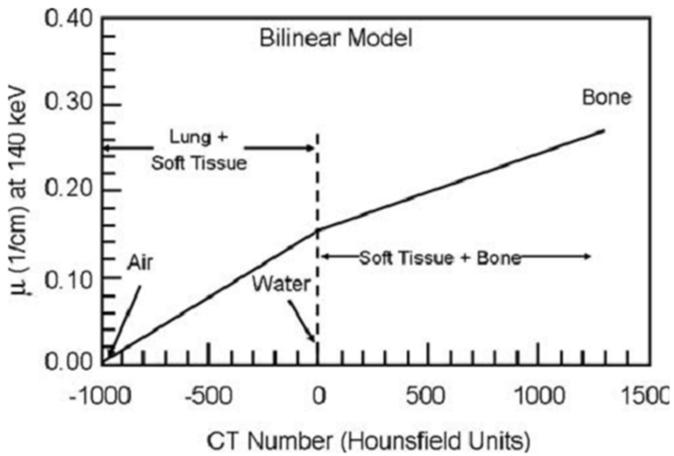


A B

$$\text{CT number} = [(\mu_{\text{tissue}} - \mu_{\text{water}})/\mu_{\text{water}}] \times 1000.$$

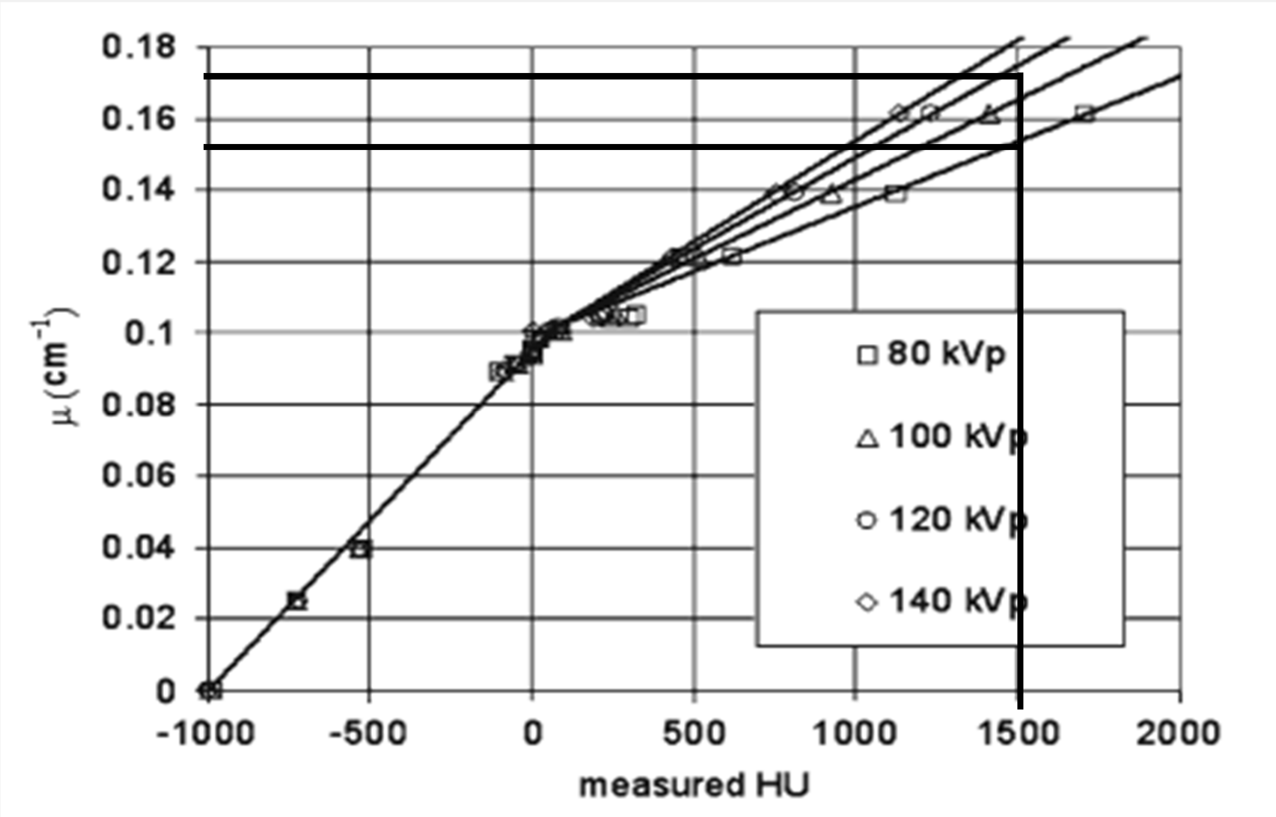
The transmitted intensities can be used to solve for attenuation coefficient (μ) by using the un-attenuation intensities by **$I=I_0\exp(-\mu x)$.** Using filtered backprojection, an array of attenuation coefficient for each slice can be determined (A) and converted to an array of CT numbers for display purposes(B)

Bilinear model commonly used for converting measured CT numbers to attenuation coefficients for a specific radionuclide such as Tc-99m

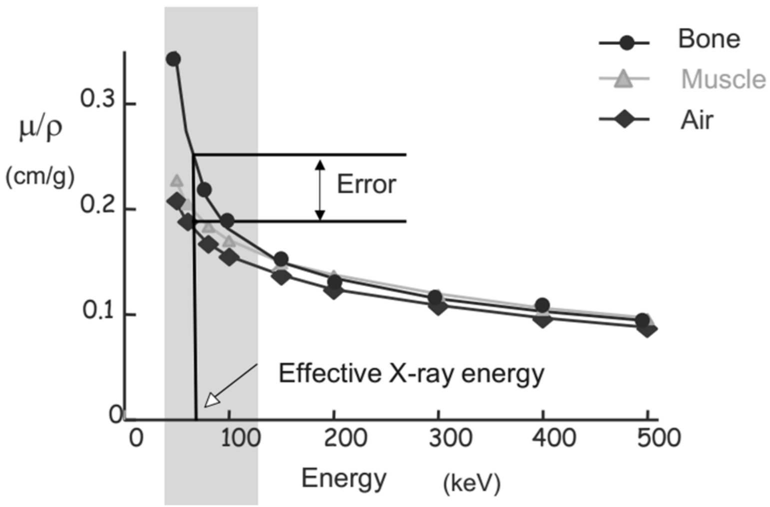


$$\mu_{\text{tissue, 140 keV}} = \mu_{\text{water, 140 keV}} + \frac{\text{CT\#} * \mu_{\text{water, keVeff}} * (\mu_{\text{bone, 140 keV}} - \mu_{\text{water, 140 keV}})}{1000 * (\mu_{\text{bone, keVeff}} - \mu_{\text{water, keVeff}})}$$

SCALING METHODS: ENERGY EFFECT

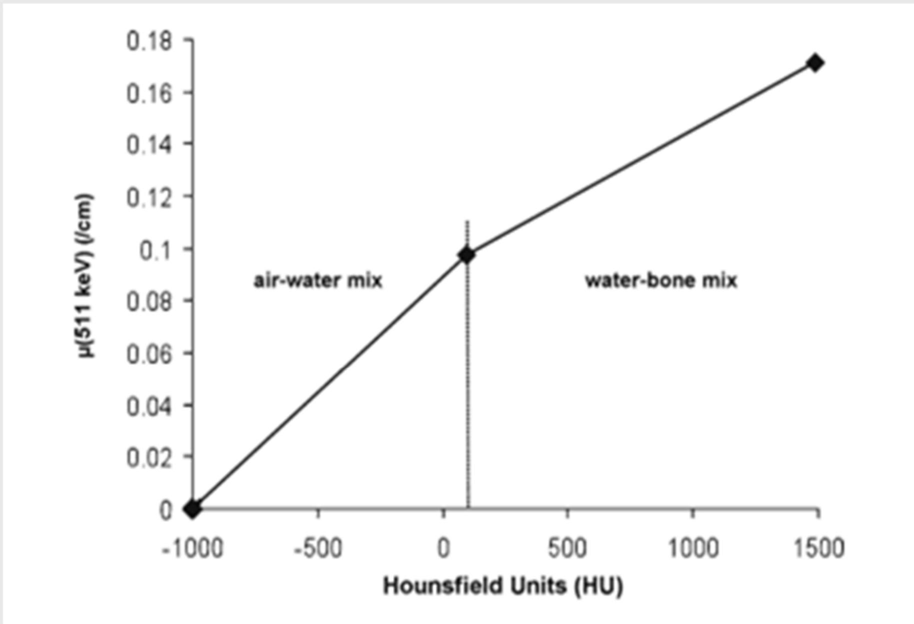


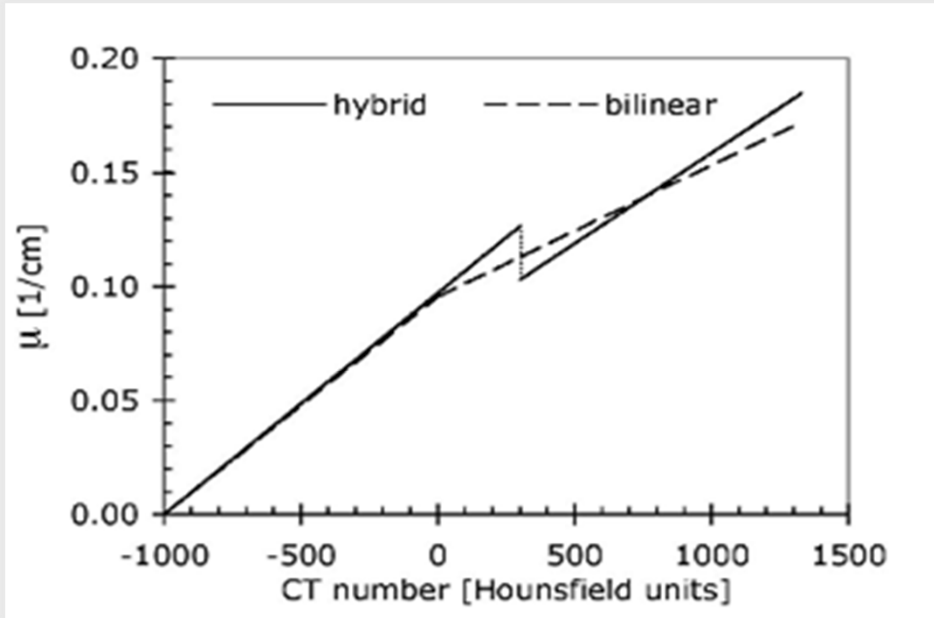
SCALING METHOD



The image values produced by CT are approximately linearly related to the physical attenuation coefficient of the corresponding tissue type. LaCroix et al found that linear scaling leads to proper attenuation coefficients for low-atomic number materials (for example air, water, and soft tissue). For bone, however, linear scaling is a poor approximation because photoelectric contributions dominate at the lower CT energies .

SCALING METHOD: TISSUE TYPE EFFECT





Bi-linear method

Continuous slope

Hybrid method

Discontinuous slope

ACCURACY OF CT-BASED ATTENUATION CORRECTION IN PET/CT BONE IMAGING

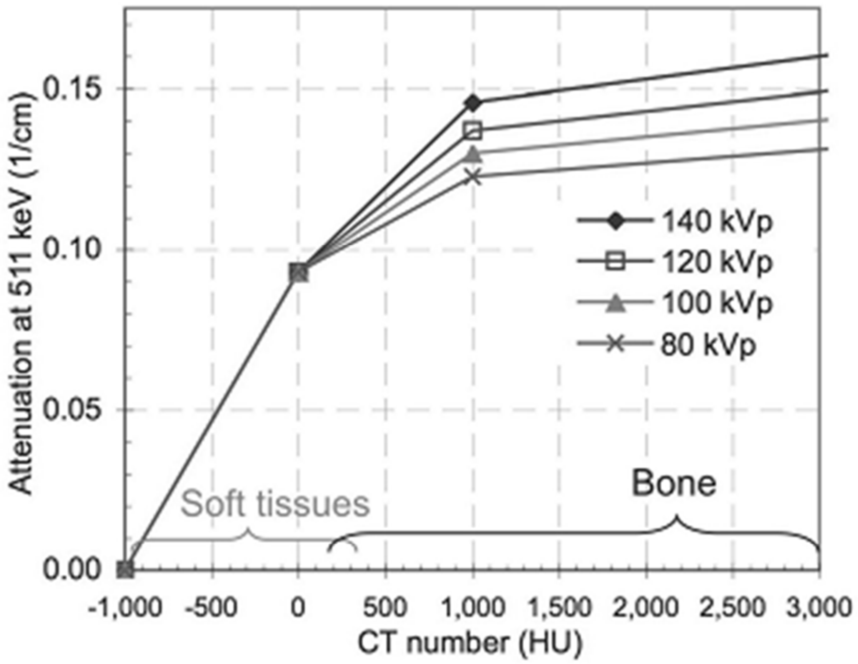


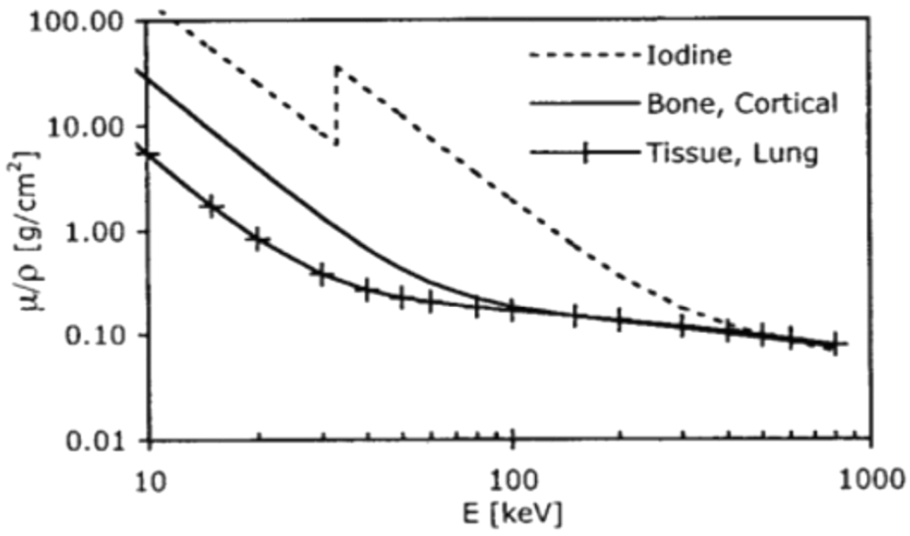
Figure 1.
Tri-linear scaling method used to convert CT numbers to linear attenuation coefficients at 511 keV for different x-ray tube potentials (values provided by the manufacturer). Approximate ranges for CT numbers of soft tissues and osseous tissues are indicated.

Coefficients used for tri-linear scaling according to $LAC = a \times CT + b$.

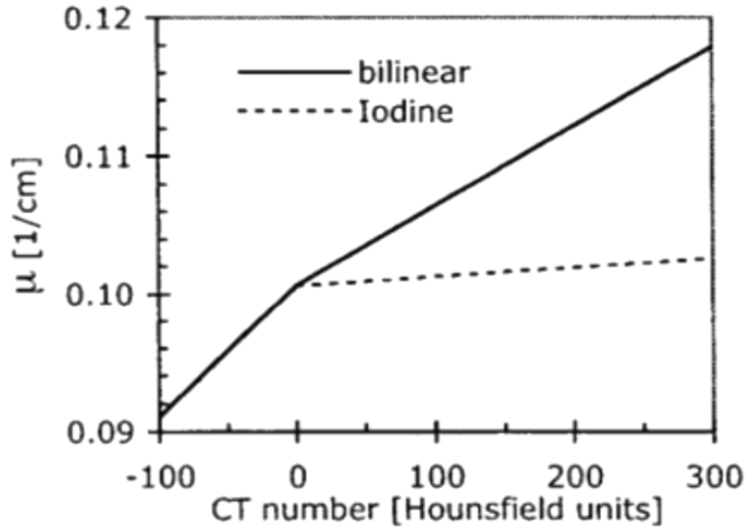
Tube potential (kVp)	−1000 < CT < 0		0 < CT < 1000		1000 < CT < 30000	
	a (cm^{-1}-HU)	b (cm^{-1})	a (cm^{-1}-HU)	b (cm^{-1})	a (cm^{-1}-HU)	b (cm^{-1})
80	9.30e-5	0.093	3.28e-5	0.093	4.10e-6	0.122
100	9.30e-5	0.093	4.00e-5	0.093	5.00e-6	0.128
120	9.30e-5	0.093	4.71e-5	0.093	5.89e-6	0.134
140	9.30e-5	0.093	5.59e-5	0.093	6.98e-6	0.142

Accuracy of CT-based attenuation correction in PET/CT bone imaging. Phys Med Biol. 2012

SCALING METHOD: CONTRAST EFFECT

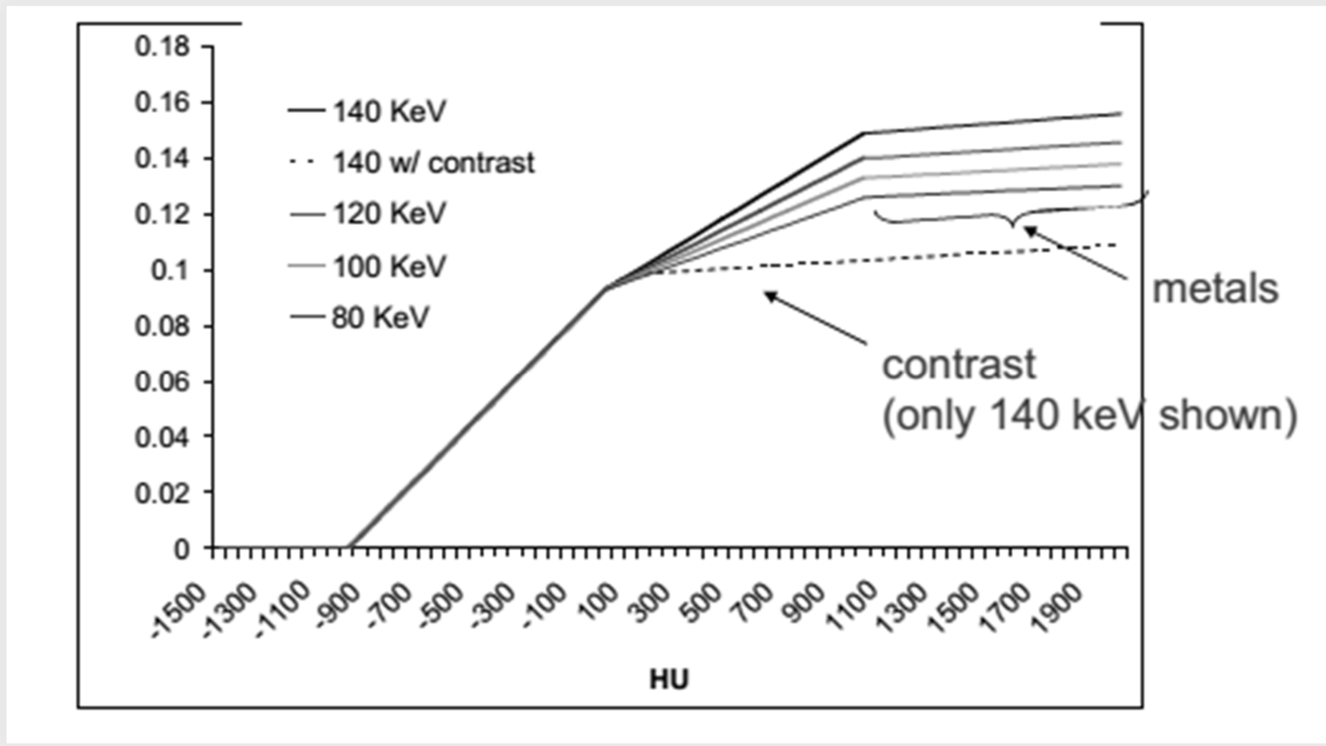


(a) Mass attenuation coefficient vs. energy



(b) Linear attenuation coefficient vs. CT #

SCALING METHODS: METALLIC EFFECT



CONVERSION EQUATION MODEL

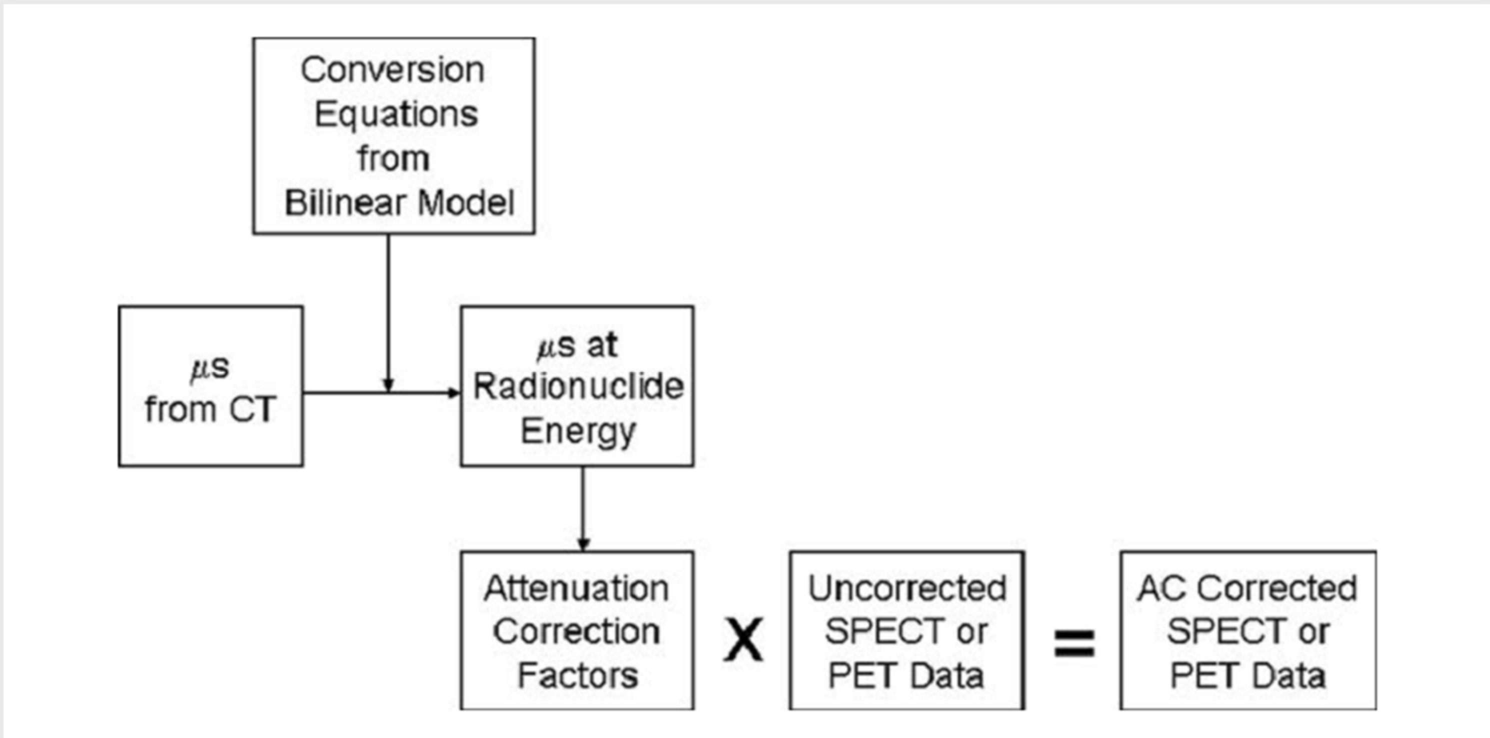
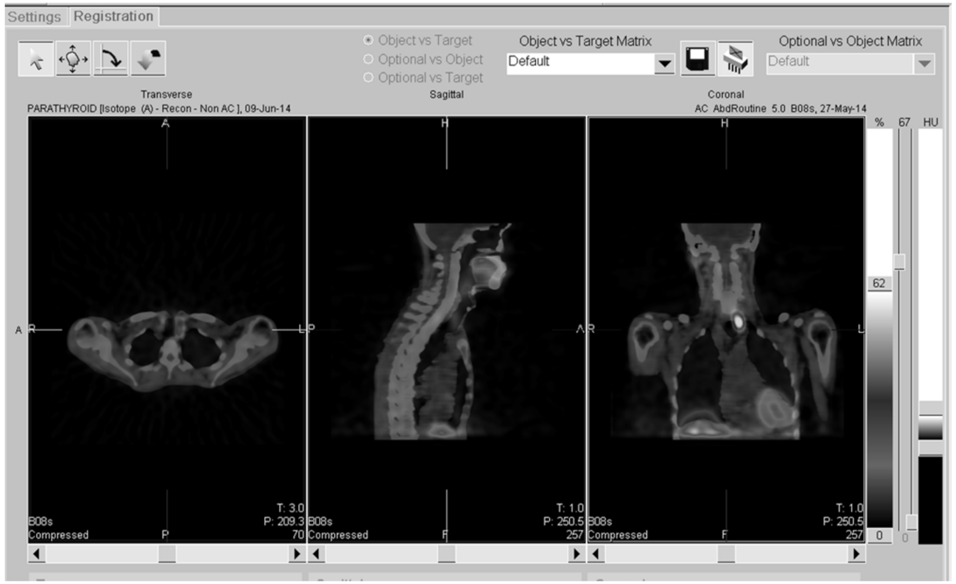


IMAGE REGISTRATION AND SCALING TECHNIQUE: GENERATED MU MAP

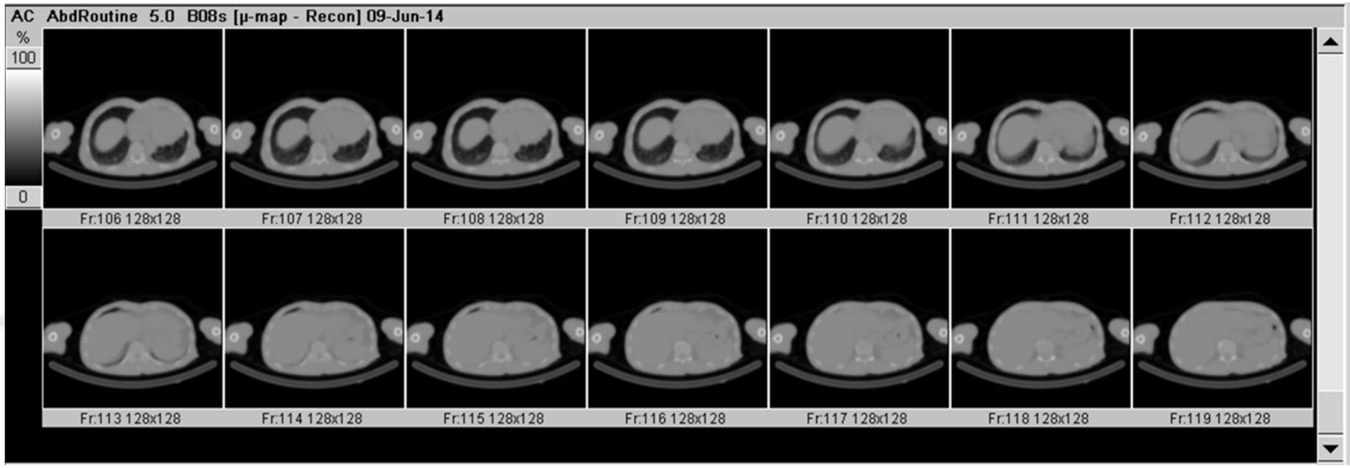
SPECT/PET reconstruction

(Analytical method : FBP)

VS CT-AC

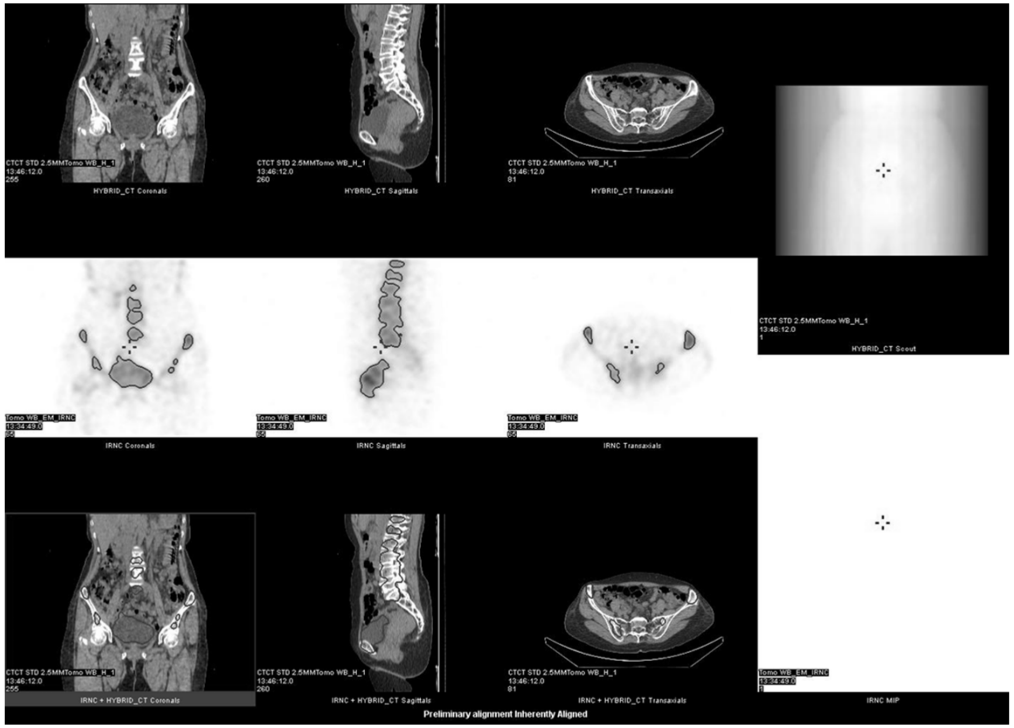


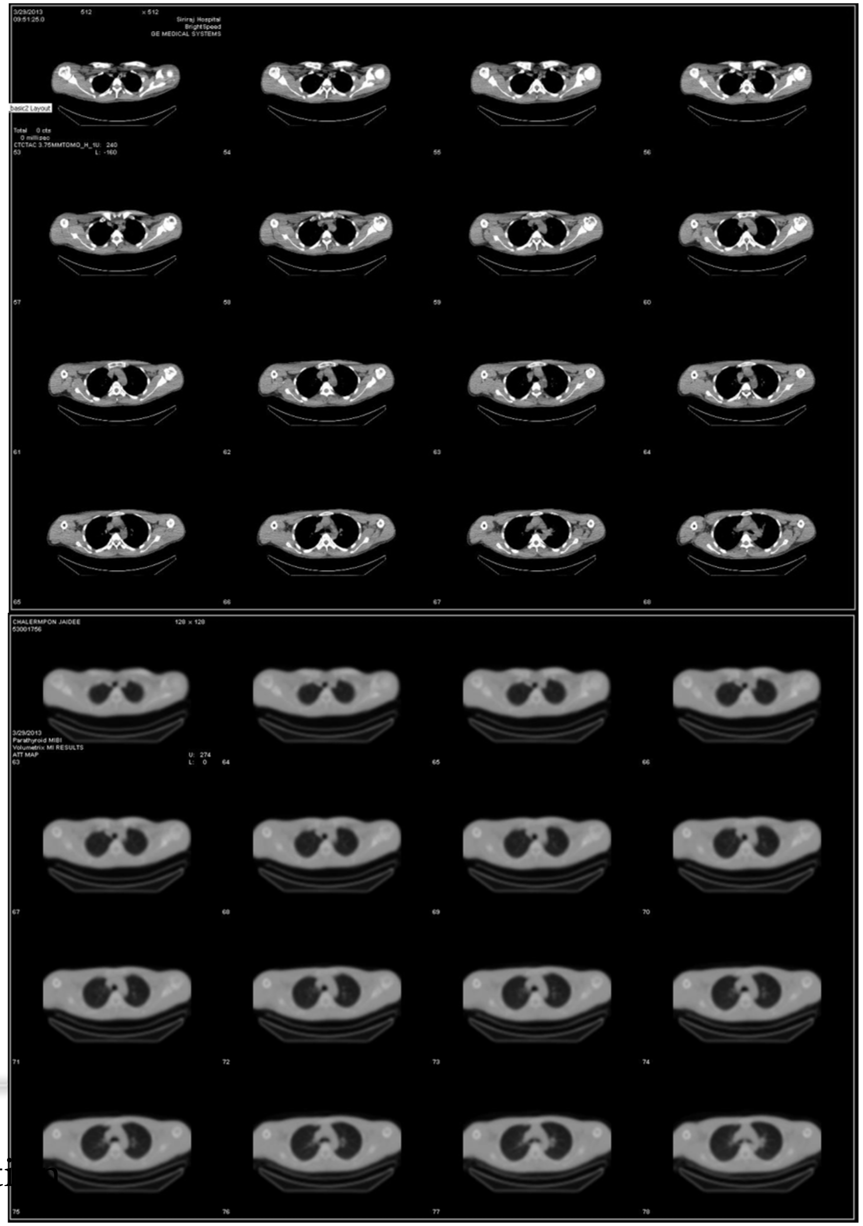
Mu-map Reconstruction



MU-MAP RECONSTRUCTION

Rigid Registration



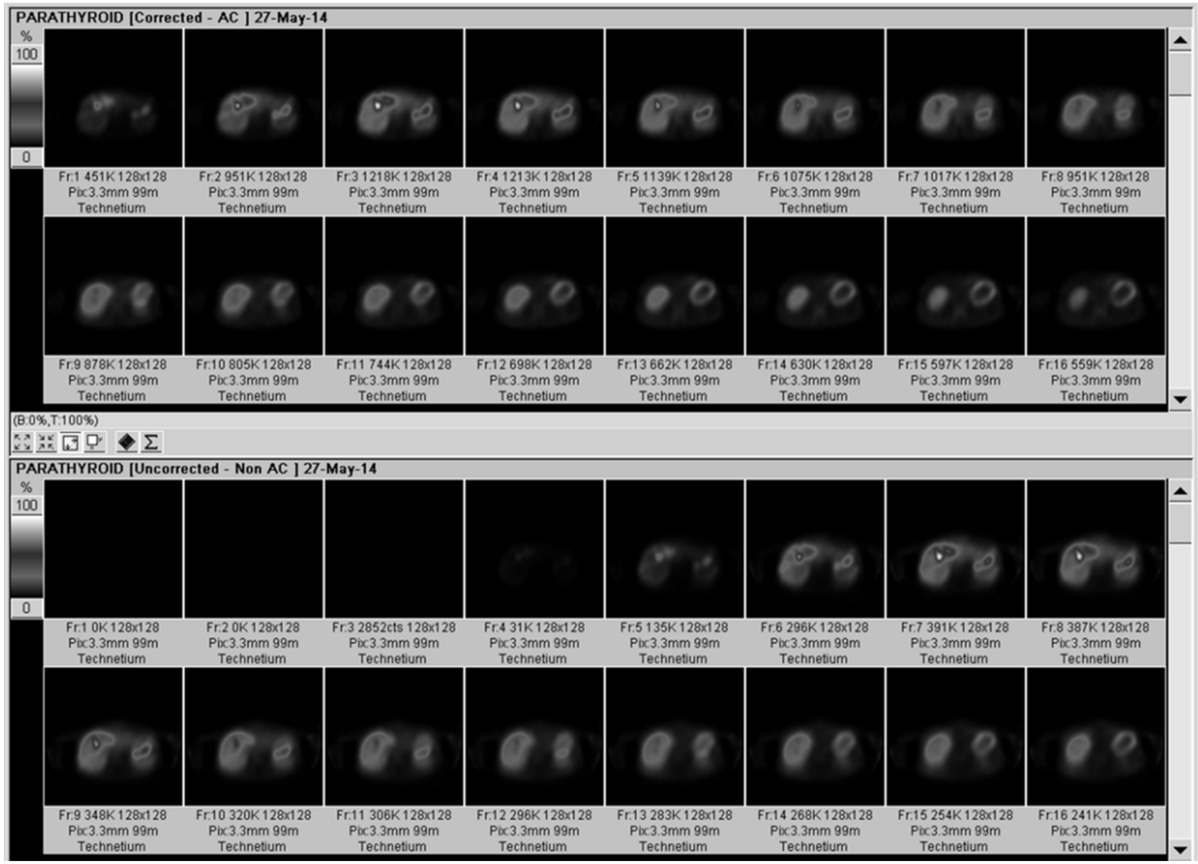


Mu-map Reconstructi

FUSION BETWEEN MU-MAP AND SPECT/PET IMAGES

Fusion between
Iterative reconstruction (SPECT)
and Mu-map reconstruction (CT)
: Corrected-AC images

Iterative reconstruction (SPECT)
: Uncorrected-Non AC images

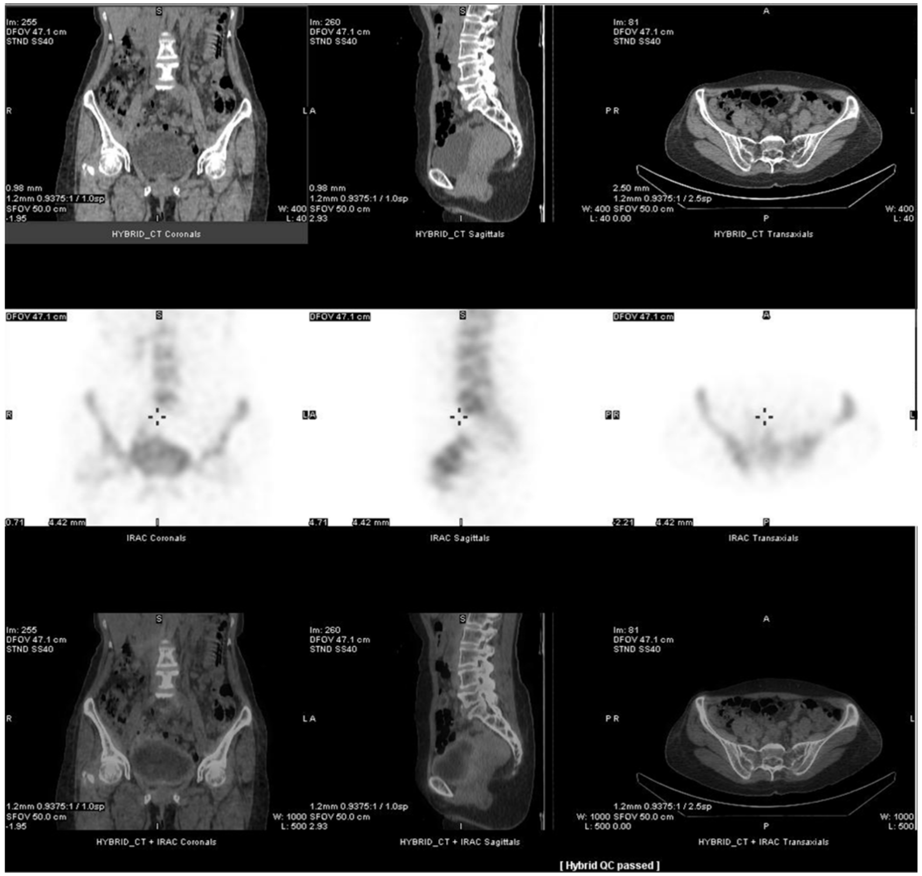


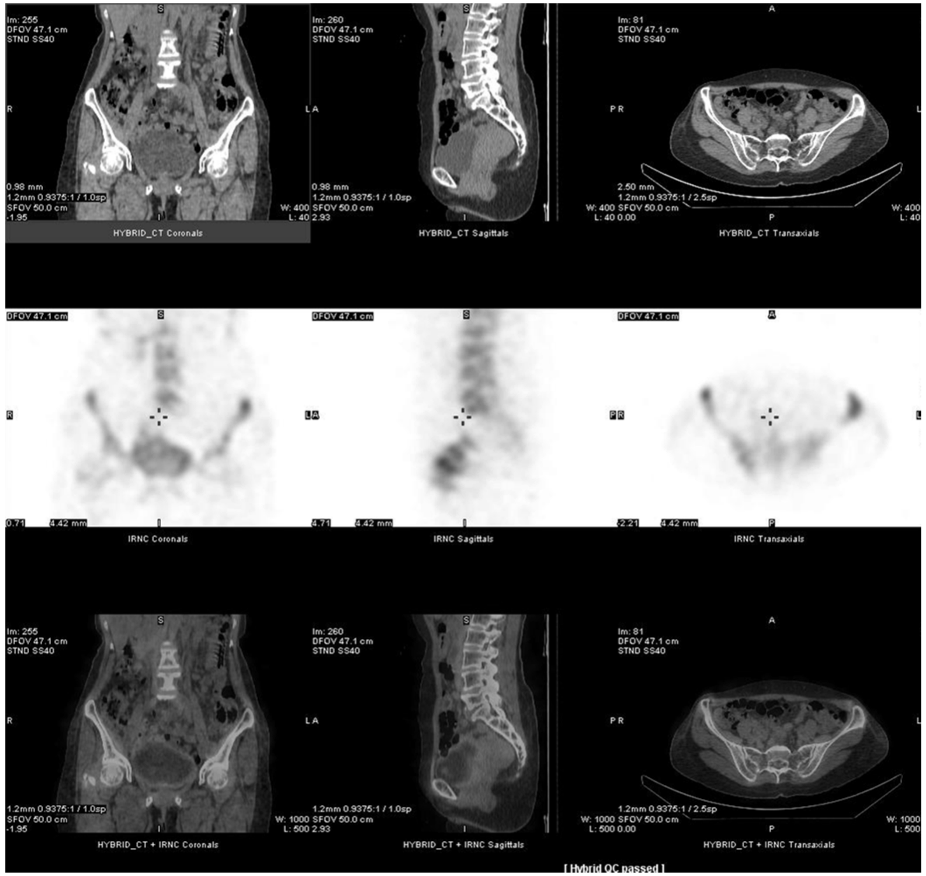
MY ANSWERS

[Siriraj_SPECTCT]		Siriraj_SPECTCT	3/19/2014
Tomo WB-1 (FOV 1)	NM TOMO		3/19/2014 10:40
- Tomo WB-1 (FOV 1)_EM	PLANAR	128 x 128 60	
- Tomo WB-1 (FOV 1)_SC	PLANAR	128 x 128 60	
Tomo WB-1 (FOV 2)	NM TOMO		3/19/2014 10:57
- Tomo WB-1 (FOV 2)_EM	PLANAR	128 x 128 60	
- Tomo WB-1 (FOV 2)_SC	PLANAR	128 x 128 60	
Volumetrix MI RESULTS	OT RESULTS SERIES		3/19/2014 11:49
- RESULTS	TRANSAXIAL	2 x 2 1	
- Tomo WB-1 (FOV 2)_EM_IRNC	TRANSAXIAL	128 x 128 128	
- Tomo WB-1 (FOV 1)_EM_IRNC	TRANSAXIAL	128 x 128 128	
- ATT MAP	TRANSAXIAL	128 x 128 128	
- ATT MAP.01	TRANSAXIAL	128 x 128 128	
- Tomo WB-1 (FOV 2)_EM_IRAC	TRANSAXIAL	128 x 128 128	
- Tomo WB-1 (FOV 1)_EM_IRAC	TRANSAXIAL	128 x 128 128	
Dose Report	CT STATIC		3/19/2014 10:21
- Dose Report	SEC CAP,B&W	512 x 512 1	
CTScoutTomo WB-1	CT WHOLEBODY		3/19/2014 11:16
- WHOLEBODY	HORZ W'BDY	888 x 1467 1	
CTCT BONE 2.5mmTomo WB-1	CT TRANSAX TOMO		3/19/2014 11:17
- CTCT BONE 2.5mmTomo WB-1_H_1	TRANSAXIAL	512 x 512 305	

Patient Name	Patient ID	Study Name	Study Date
[PET/CT]		PET/CT	11/15/2013
Dose Report	CT STATIC		11/15/2013 9:24
- Dose Report	SEC CAP,B&W	512 x 512 1	
3D_WB_AC	PT TRANSAX TOMO		11/15/2013 9:3
- 3D_WB_AC	TRANSAXIAL	128 x 128 299	
3D_WB_NAC	PT TRANSAX TOMO		11/15/2013 9:3
- 3D_WB_NAC	TRANSAXIAL	128 x 128 299	
CT SCOUT	CT WHOLEBODY		11/15/2013 9:24
- WHOLEBODY	HORZ W'BDY	888 x 2542 1	
CTAC STD	CT TRANSAX TOMO		11/15/2013 9:2
- CTAC STD_H_1	TRANSAXIAL	512 x 512 299	
Lung	CT TRANSAX TOMO		11/15/2013 9:27
- Lung_H_1	TRANSAXIAL	512 x 512 170	

FUSION IMAGES AC AND NON-AC CORRECTED

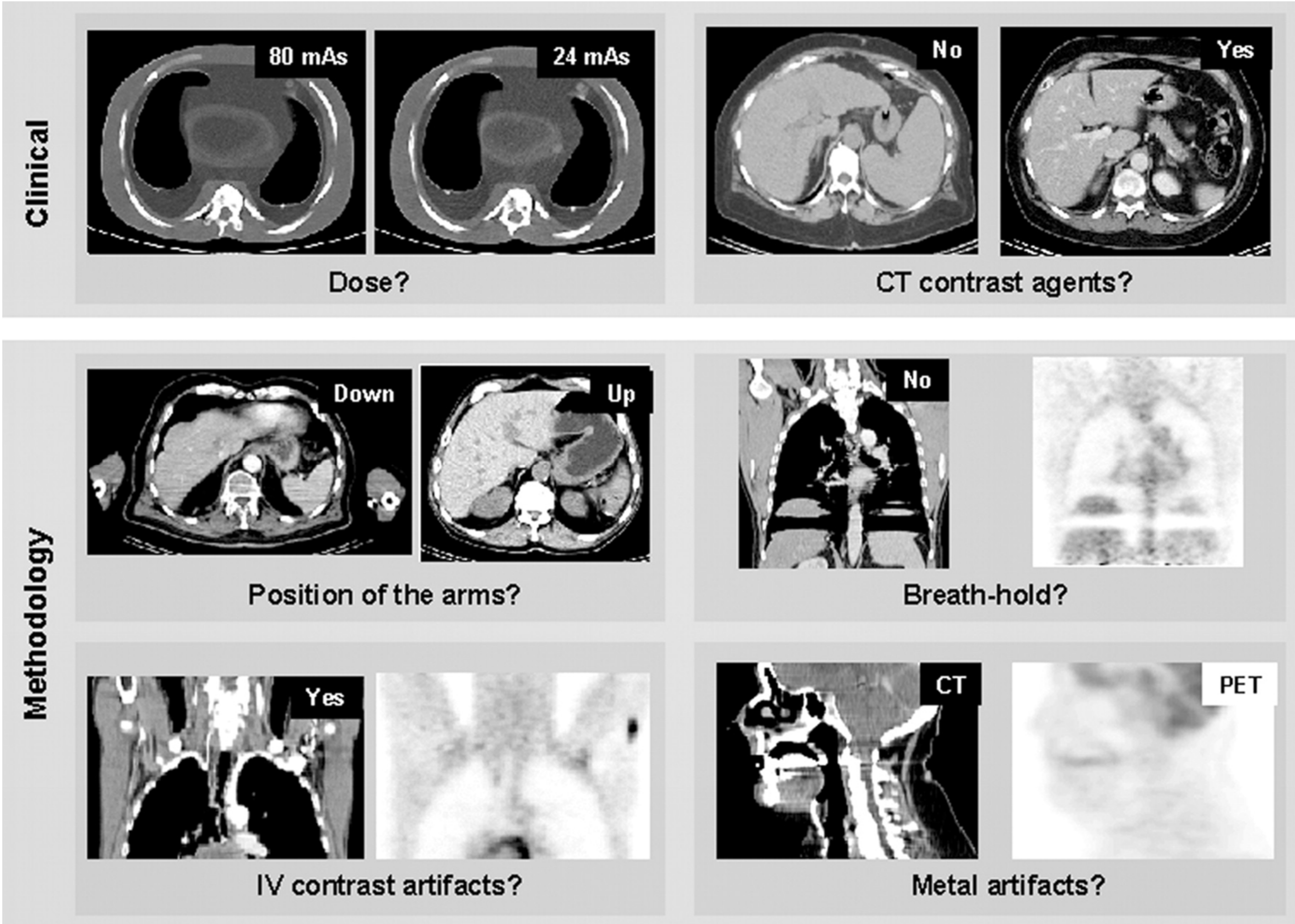




AC corrected

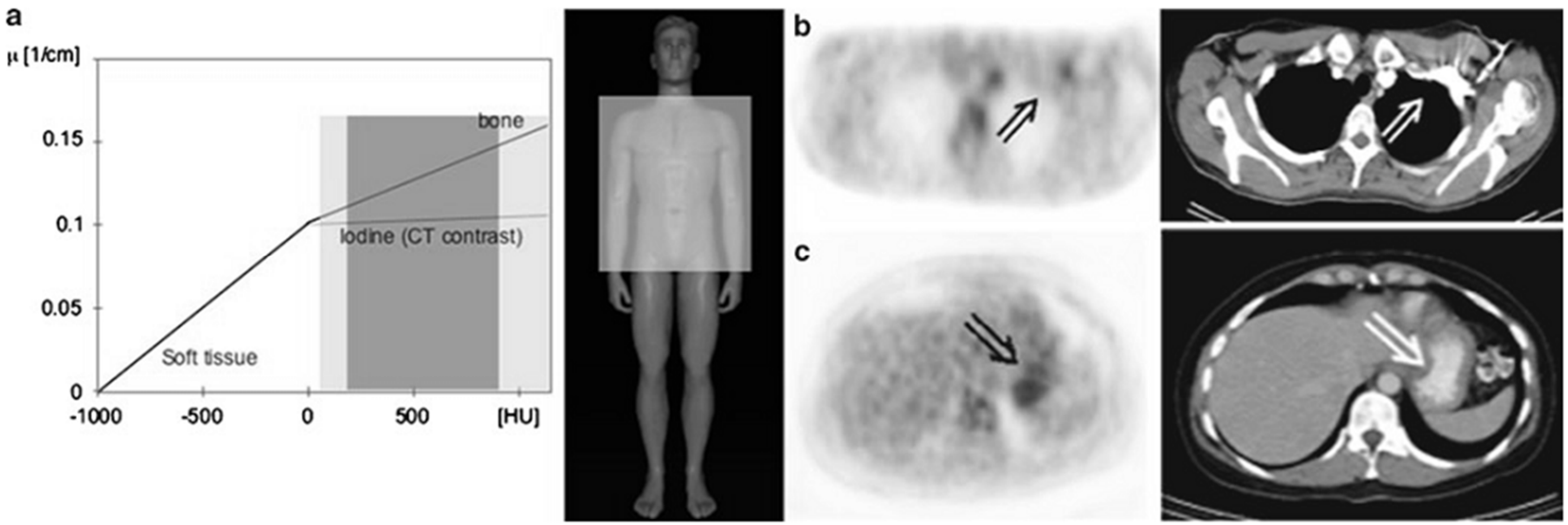
Non-AC corrected

CT FACTORS EFFECT ON FUSION IMAGES

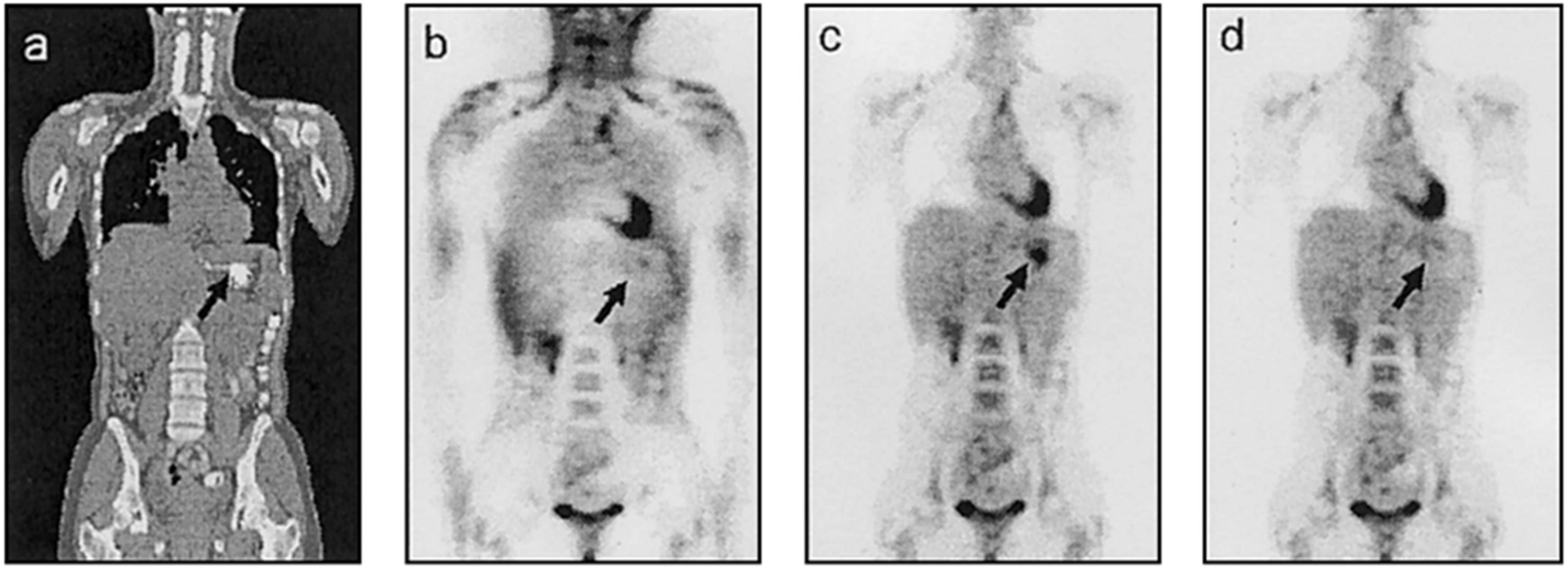


CONTRAST

- CT contrast agent may be given as part of the PET-CT protocol, either orally or intravenously. The degree of enhancement may be in the tens of HU for intravenous contrast or in the hundreds of HU for oral contrast.
- It is clear from this look-up table that contrast-enhanced pixel values are overestimated from the bilinear scaling approach. In practice, this may lead to an artificially increased uptake patterns on attenuation-corrected PET when the contrast-enhanced CT scan is used



CONTRAST



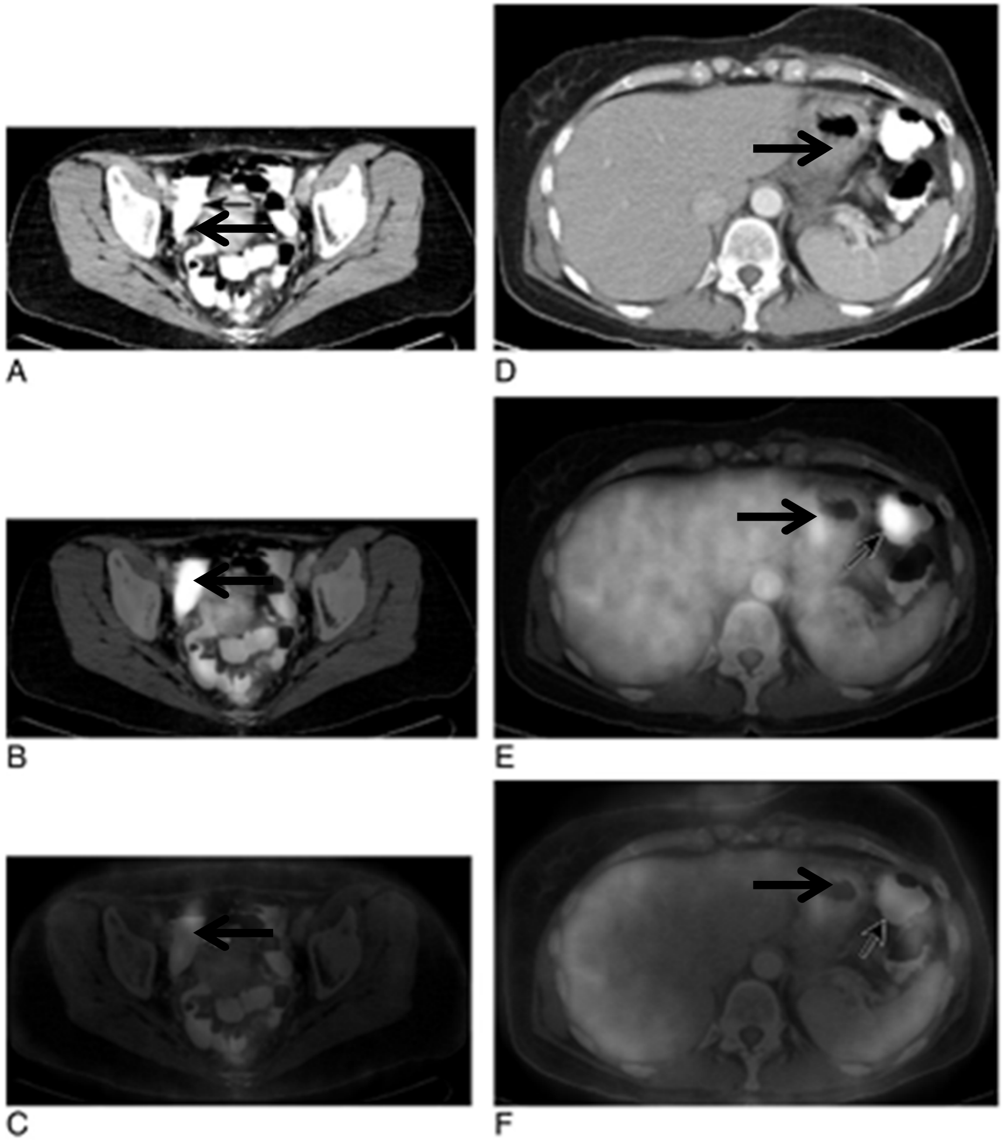
CT | Non-AC PET | AC PET | AC PET+ Contrast correction

ORAL CONTRAST

Axial CT

Fused PET/CT with AC PET

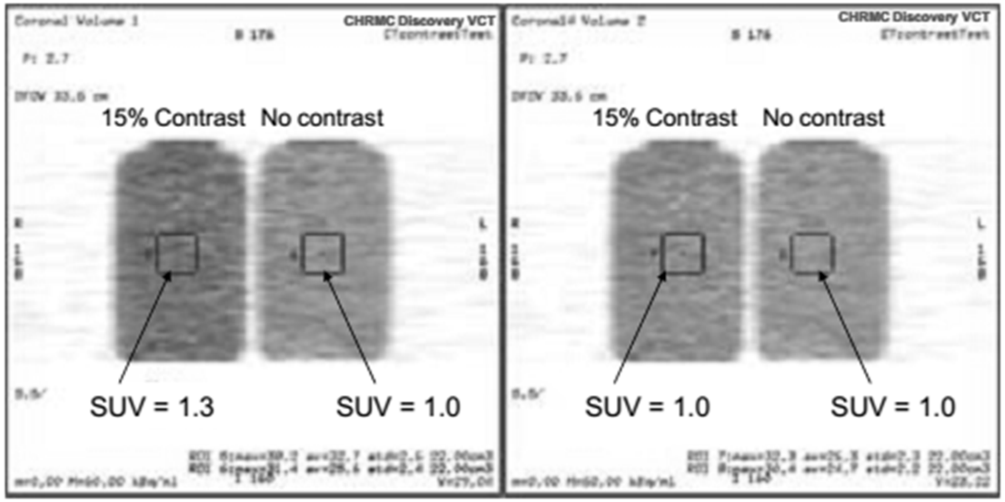
Fused PET/CT with non-AC PET



CONTRAST

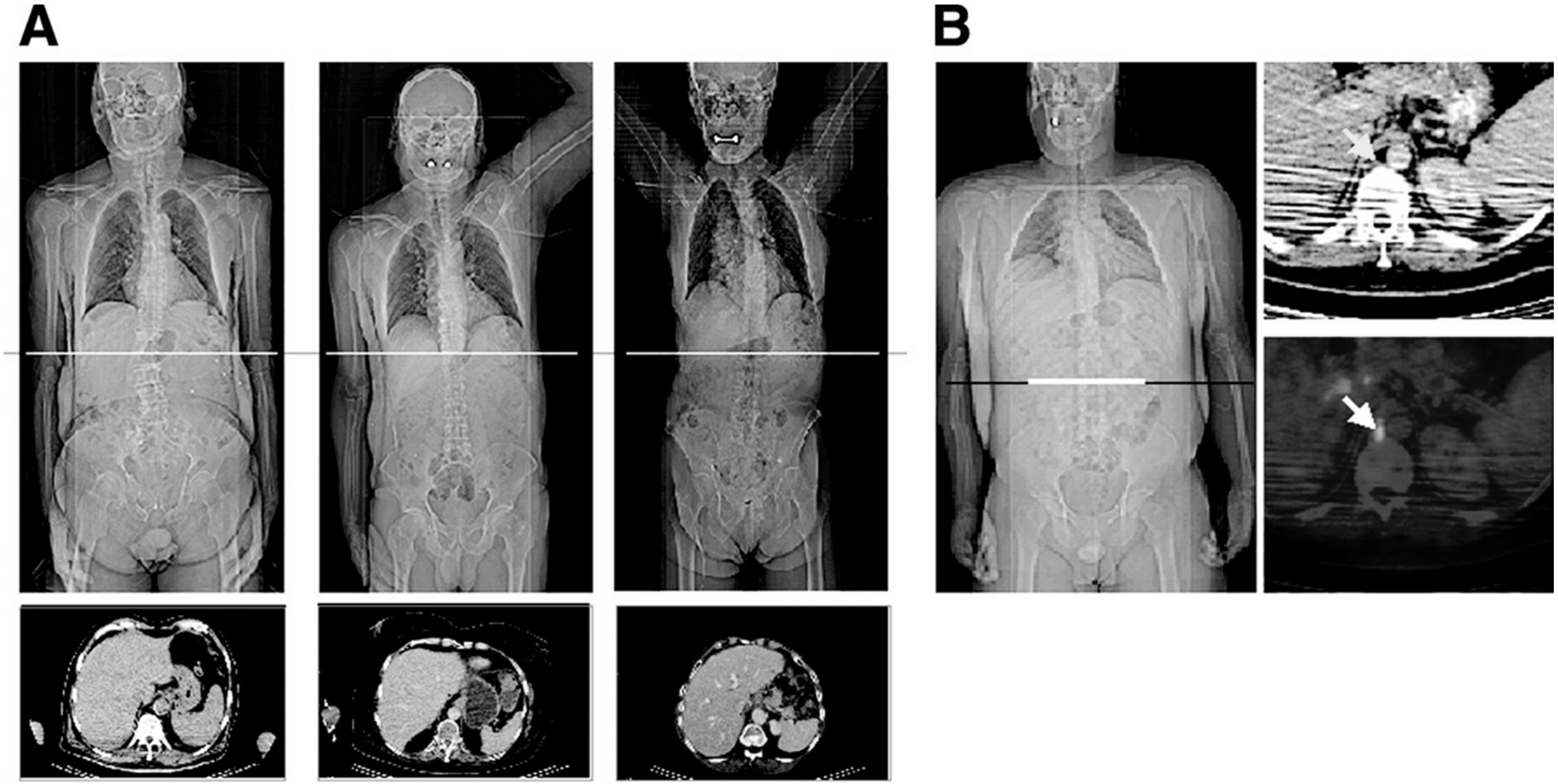
Effect of contrast agent

- FDG in 1 L water filled jugs
- True SUV = 1



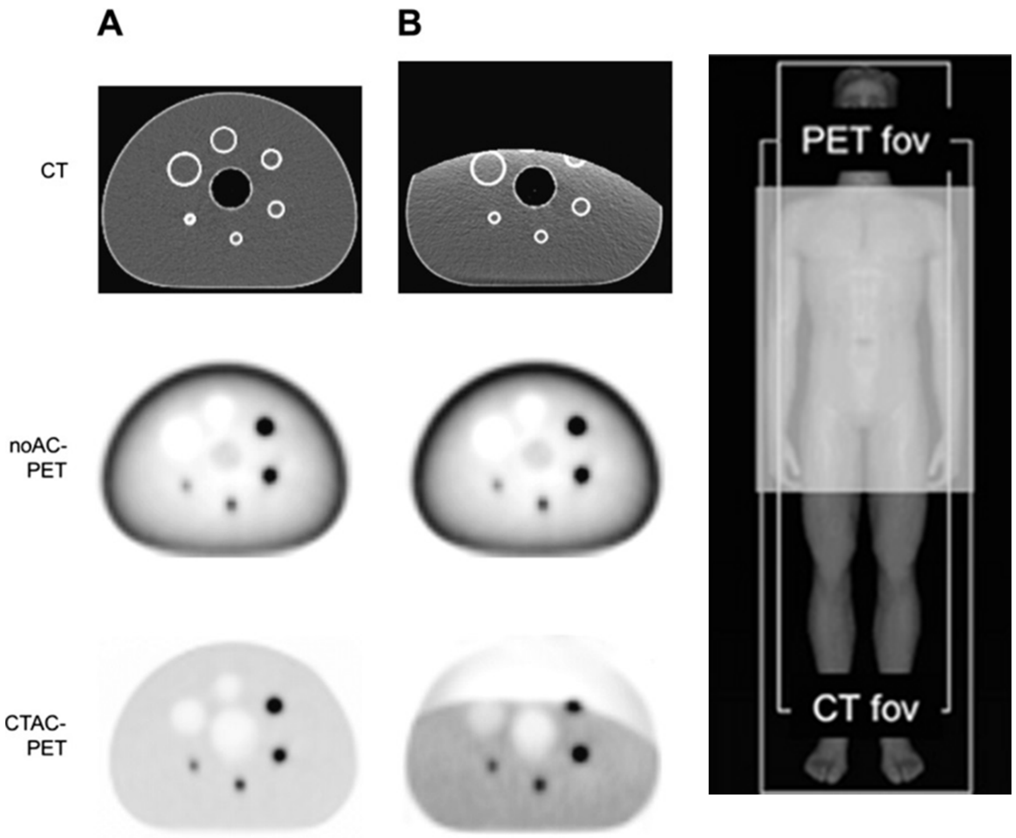
Without contrast agent correction With contrast agent correction

POSITION OF ARMS



(A) Topogram scans of 3 patients with different arm positions. Selected transverse CT images at level of midliver are shown to illustrate magnitude of streaking artifacts. Streaks are reduced most in case when both arms are raised (right). (B) Male patient with lymphoma. Streak artifacts originating from positioning of patient with arms down degrade quality of CT and fused PET/CT images.

TRUNCATIONS



- Diameter of FOV : 50 cm in CT and 70 cm in PET
- Axial CT images and PET images before (noAC) and after CT-based AC (CTAC)

A: Positioned centrally inside the FOV

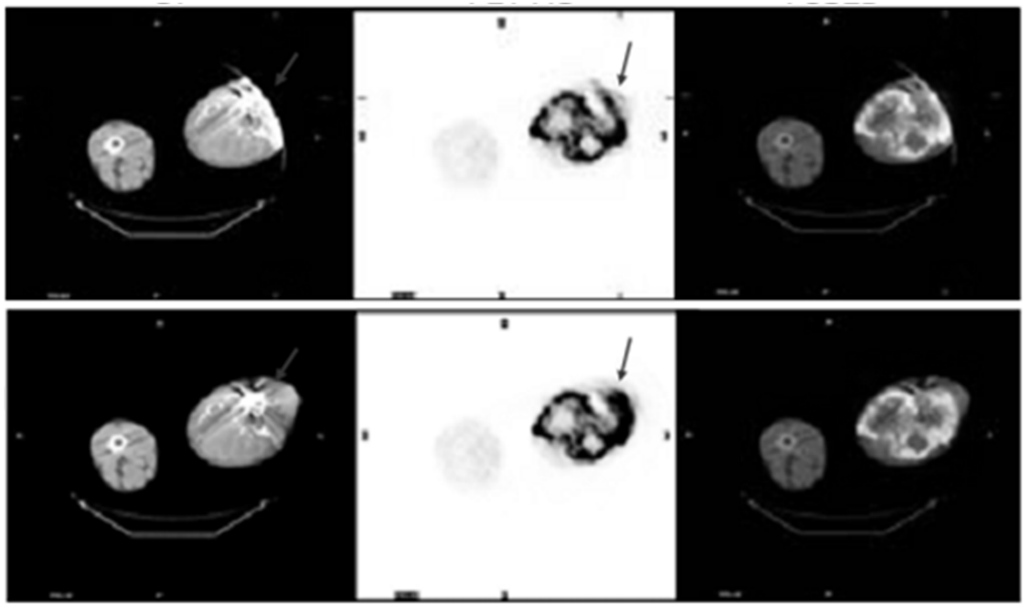
B: Edge of the FOV such that the largest hot lesion is on edge of the CT FOV

TRUNCATION

CT AC-PET FUSED

TRUNCATED CT

TRUNCATED CORRECTED



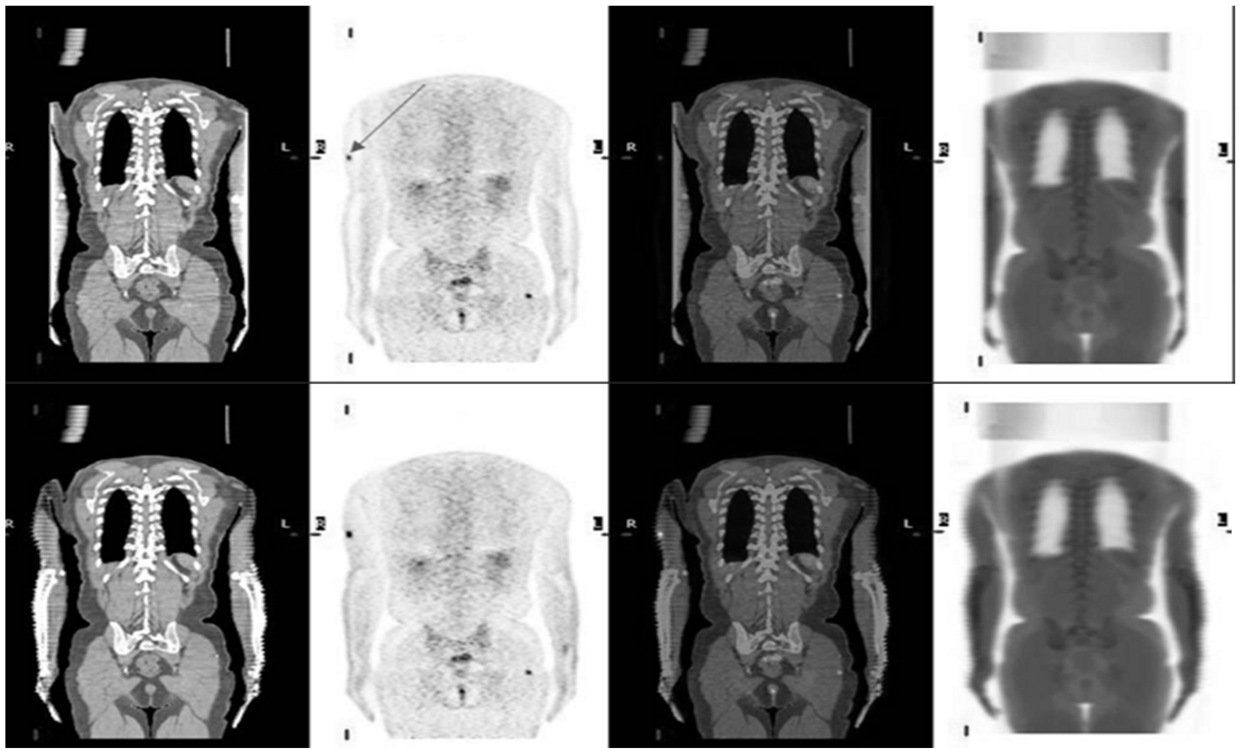
Max SUV changed from 3.4 to 12.7 with extended field of view CT

POSITION OF ARMS AND TRUNCATION

CT AC-PET FUSE ATTENUATION MAP

TRUNCATED

TRUNCATED CORRECTED

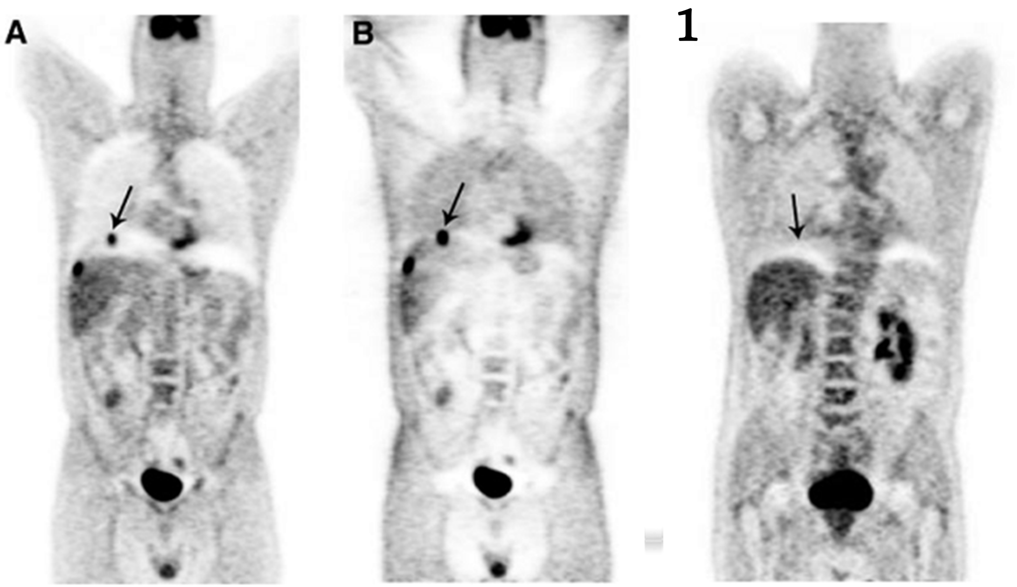


Males with history of metastatic melanoma of the skin : SUV 3.25 => 6.05

PET/CT Technology Updates: Quality assurance and applications, Osama Mawlawi, Ph.D.

RESPIRATION

- Respiratory motion is due to the discrepancy between the chest position on the CT image and the chest position on the PET image. This difference in respiratory motion between PET scans (long acquisition time) and CT scans (short acquisition time) causes breathing artifacts on PET/CT images. The most common type of breathing artifact results in curvilinear cold areas. Therefore, it leads to be underestimated value when using attenuation correction



A: Lesion at dome of liver is mis-localized to right lung with attenuation correction

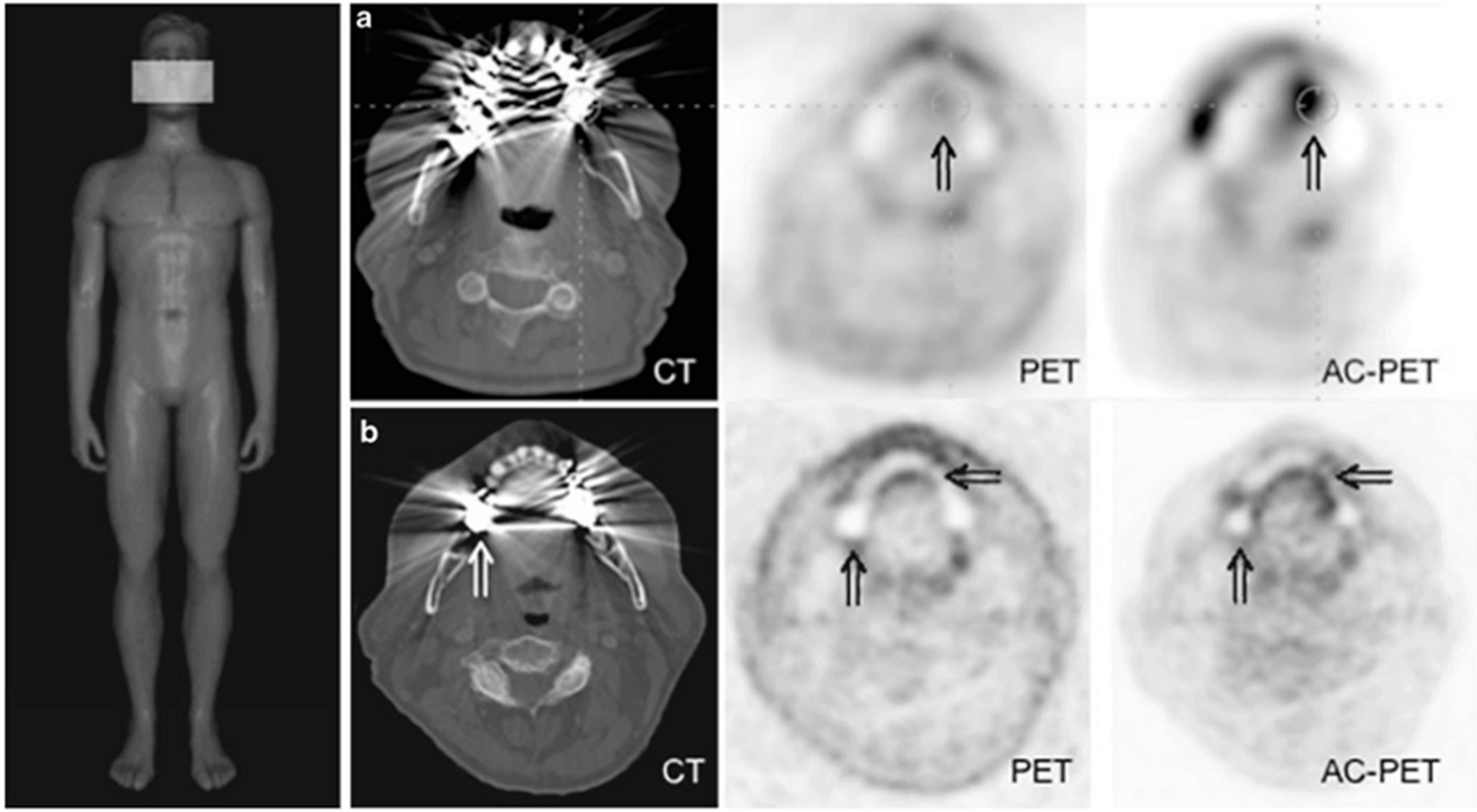
B: Image A but without attenuation correction

1: Mismatch on dome of diaphragm/liver or at lung base

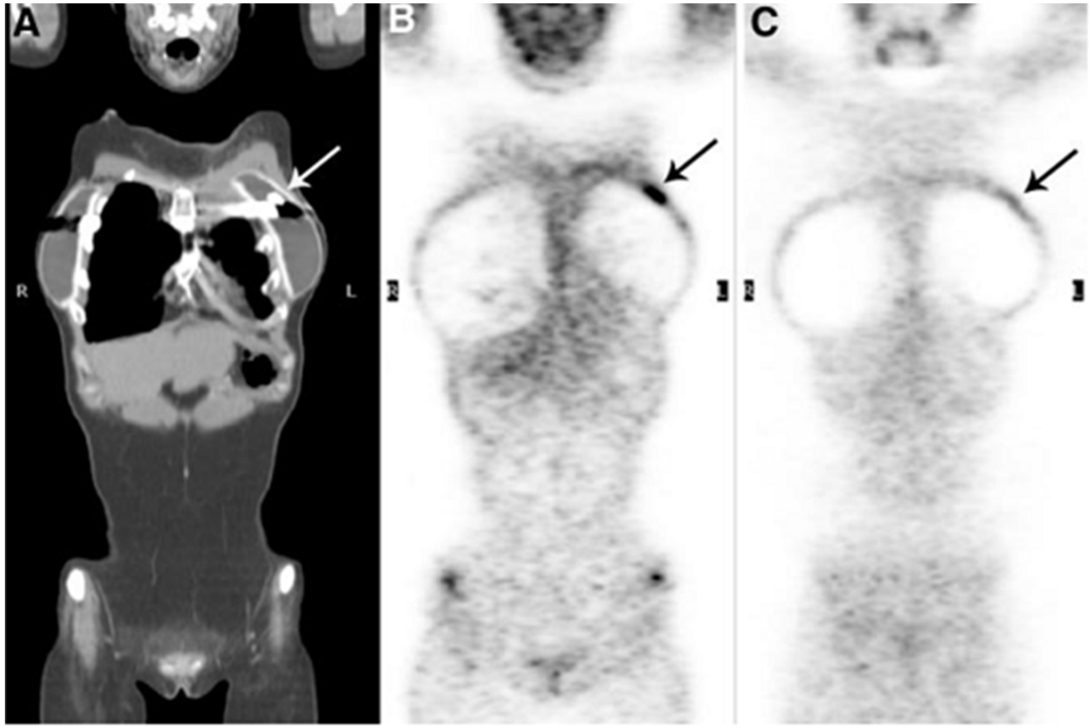
METALLIC IMPLANT

- This increase in CT (or Hounsfield) numbers results in correspondingly high PET attenuation coefficients, which lead to an overestimation of the PET activity in that region and thereby to a false positive. Non-attenuated PET images, which do not manifest this error, can be used in these cases to aid the interpretation of these metal-induced artifacts.

METALLIC IMPLANT



METALLIC IMPLANTS



CT AC-PET NON AC PET

OVERVIEW OF FACTORS AFFECTING ^{18}F-FDG PET QUANTIFICATION

Categories	factor	Explanation	Typical range
Biologic factors :	Patient motion or breathing	Image artifacts result from mismatches in positions between CT-AC and PET emission scans, and lower SUV may result from respiratory motion (resolution loss)	0%-30%
Physical factors:	Image reconstruction parameters	Insufficient convergence and lower resolution result in lower SUV and increase in partial-volume effects; insufficient convergence makes SUV more dependent on surrounding activity distributions	0-30%
	Use of contrast agents in CT-AC	Overestimation of attenuation and therefore higher SUV (upward bias) may occur	0-15%*

* In general, use of contrast agents produces artifacts of up to about 20%. However, very large errors may occur when high-density oral contrast agents (e.g., barium) are used.

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