PET Applications in Oncology

الدكتور قصي المقبل

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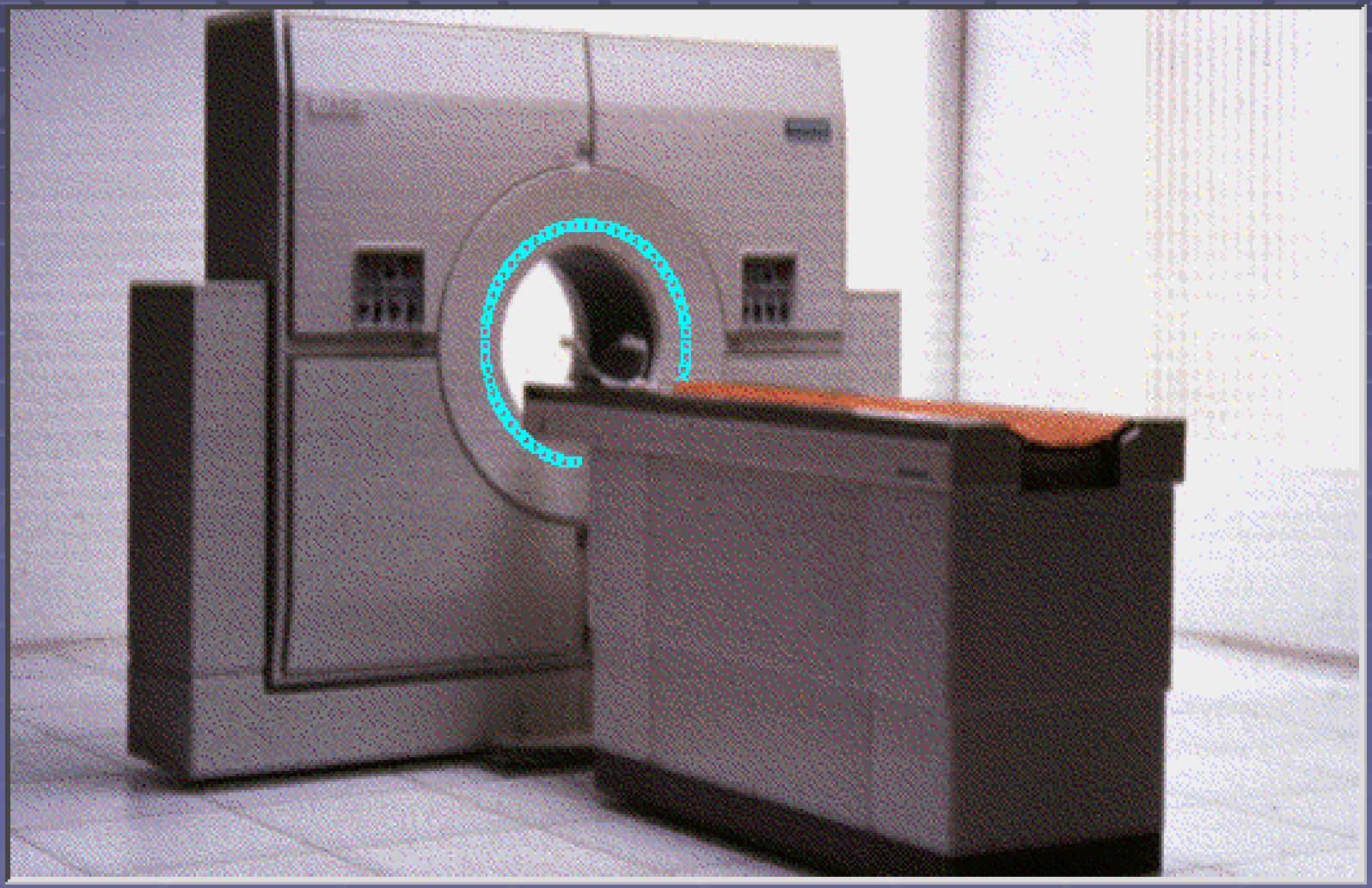
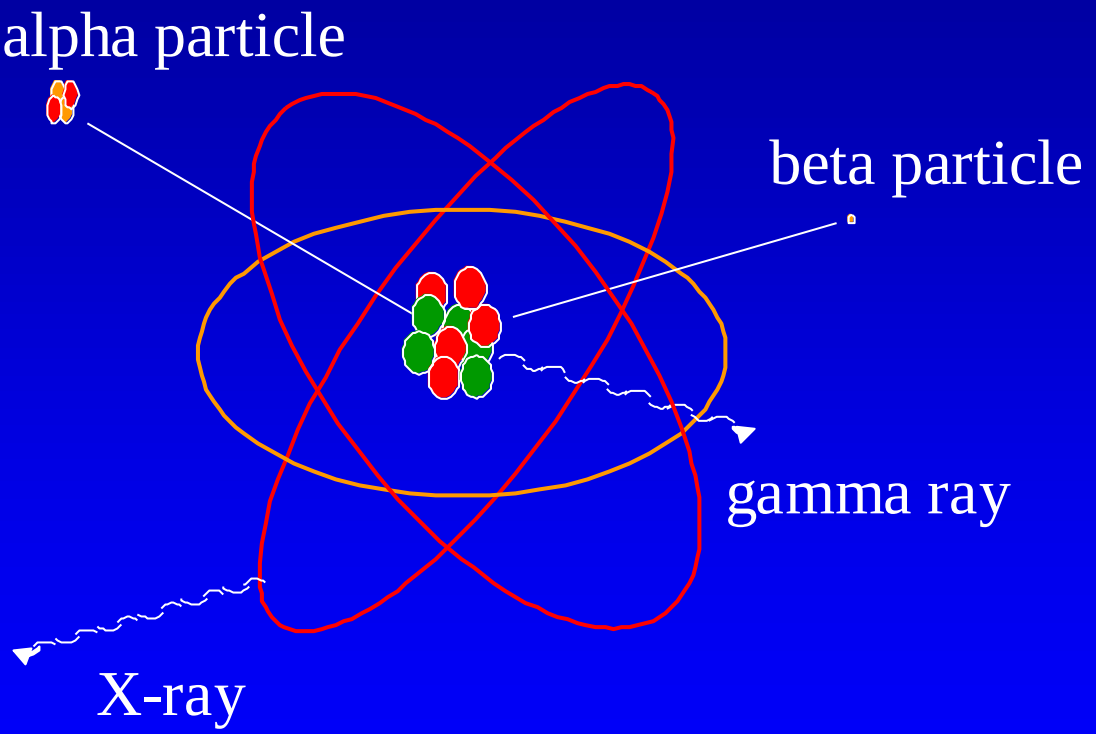
كلية الطب-جامعة العلوم والتكنولوجيا الأردنية

PET Scanner



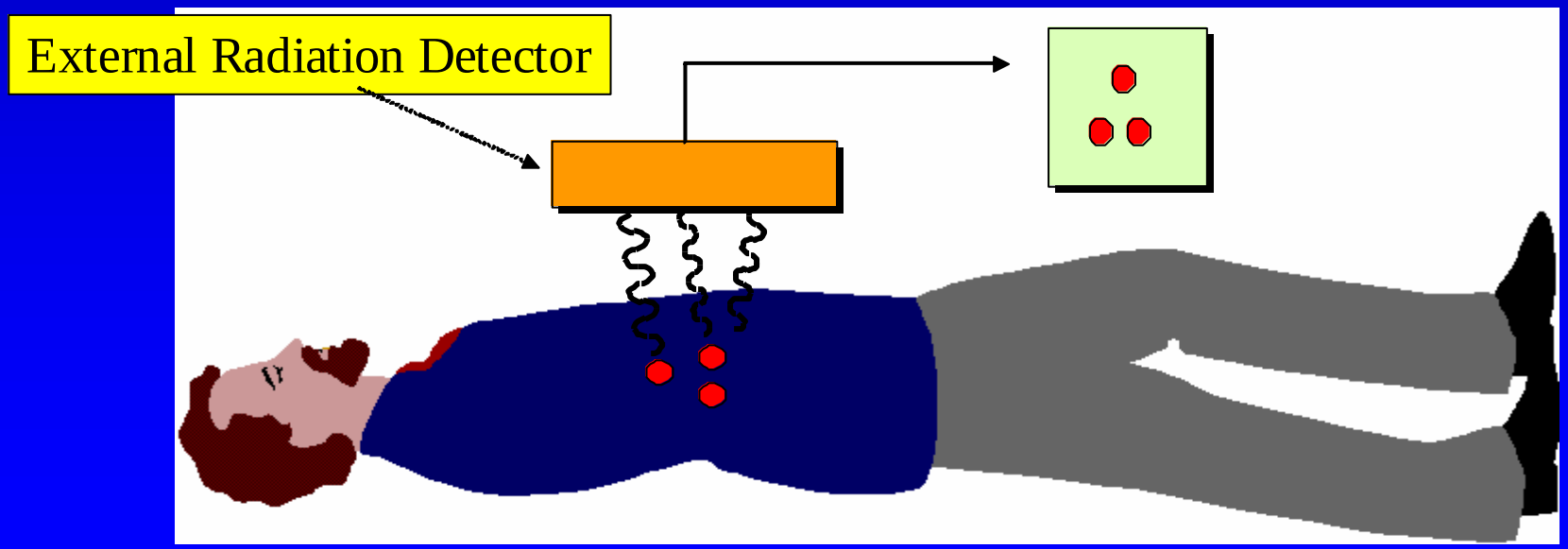
What is Radioactivity?

- Emitted energy *from the nucleus of an atom*
- "N"ucleus
- "U"nstable,
- "D"ecays by
- "E"mitting
- "B"etas,
- "A"lphas, and
- "G"ammas



Nuclear Imaging

- Not enough to detect just radioactive “levels” or concentrations
- Need device to “map” the radioactive distribution



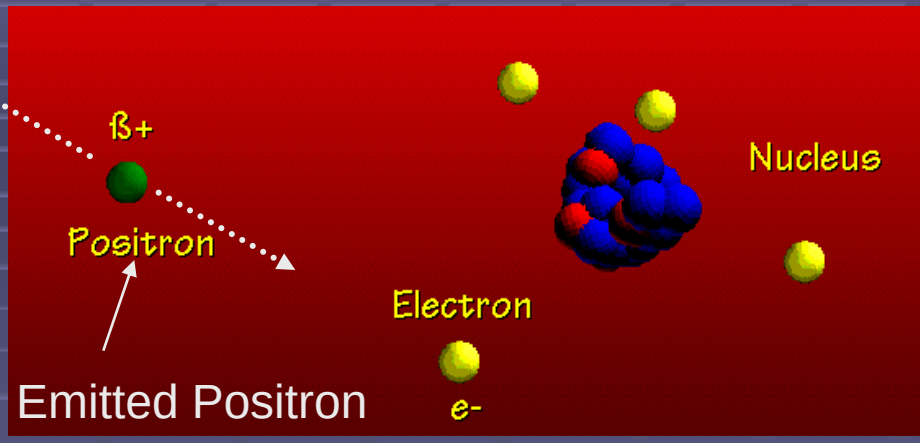
Positron Annihilation

As positrons pass through matter, they experience the same interactions as electrons, including loss of energy through ionization and excitation of nearby atoms and molecules.

After losing enough energy, and having traveled a distance in the neighborhood of 1 mm (depending on the initial positron energy), the positron will annihilate with a nearby electron:

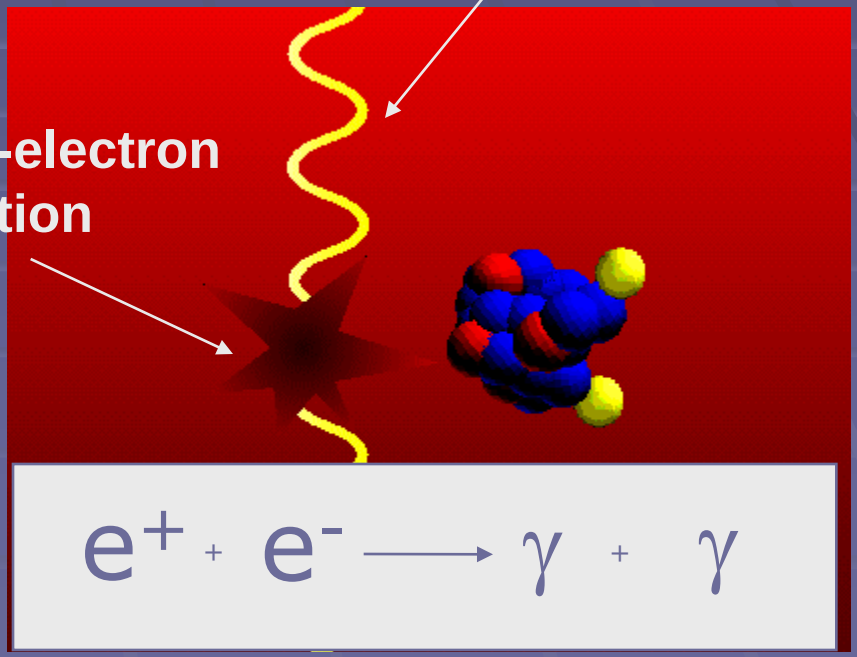
Conservation of energy and momentum dictate, therefore, that the 2 photons are emitted each with an energy of 511 keV (the electron mass times the speed of light squared) and in opposite directions, as shown in Figure 1.

It is the simultaneous emission of these two photon which is the basis of "coincidence detection"



511 keV photons

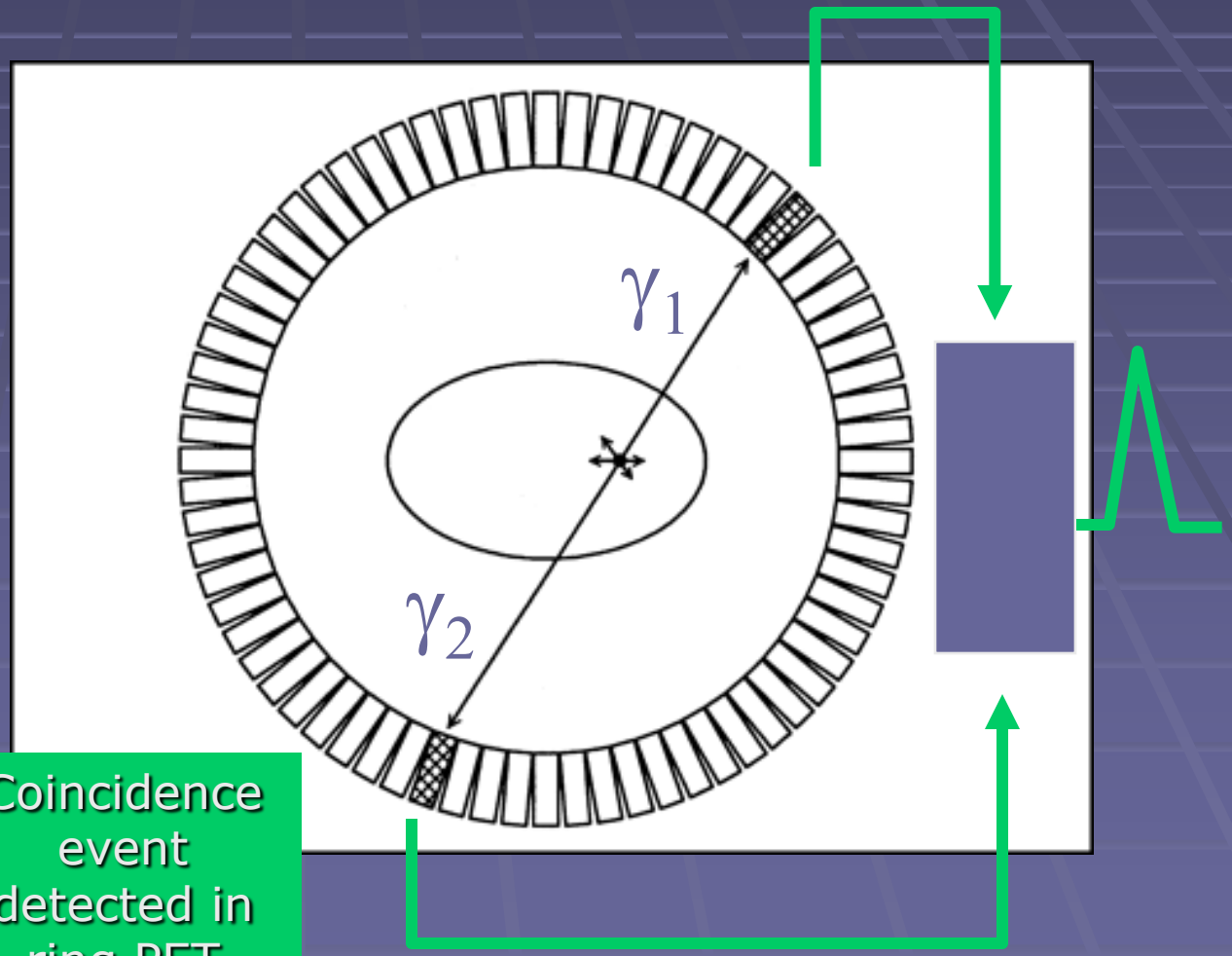
Positron-electron annihillation



Coincidence Detection

Simultaneous detection of the two photons in opposite directions is the basis of "coincidence detection and coincidence imaging.

Although most of the annihiliation photons will not be detected, some will remain in the plane of the detecotr ring, and 2 detectors hit, yeild electronic signals.
Simultaneous pulses from 2 detectors indicate that the event occurred somewhere along the path between them.
The path is referred to as the line of response (LOR)
The number of coinidence events between two detectors indicates how much activity there was along the LOR.



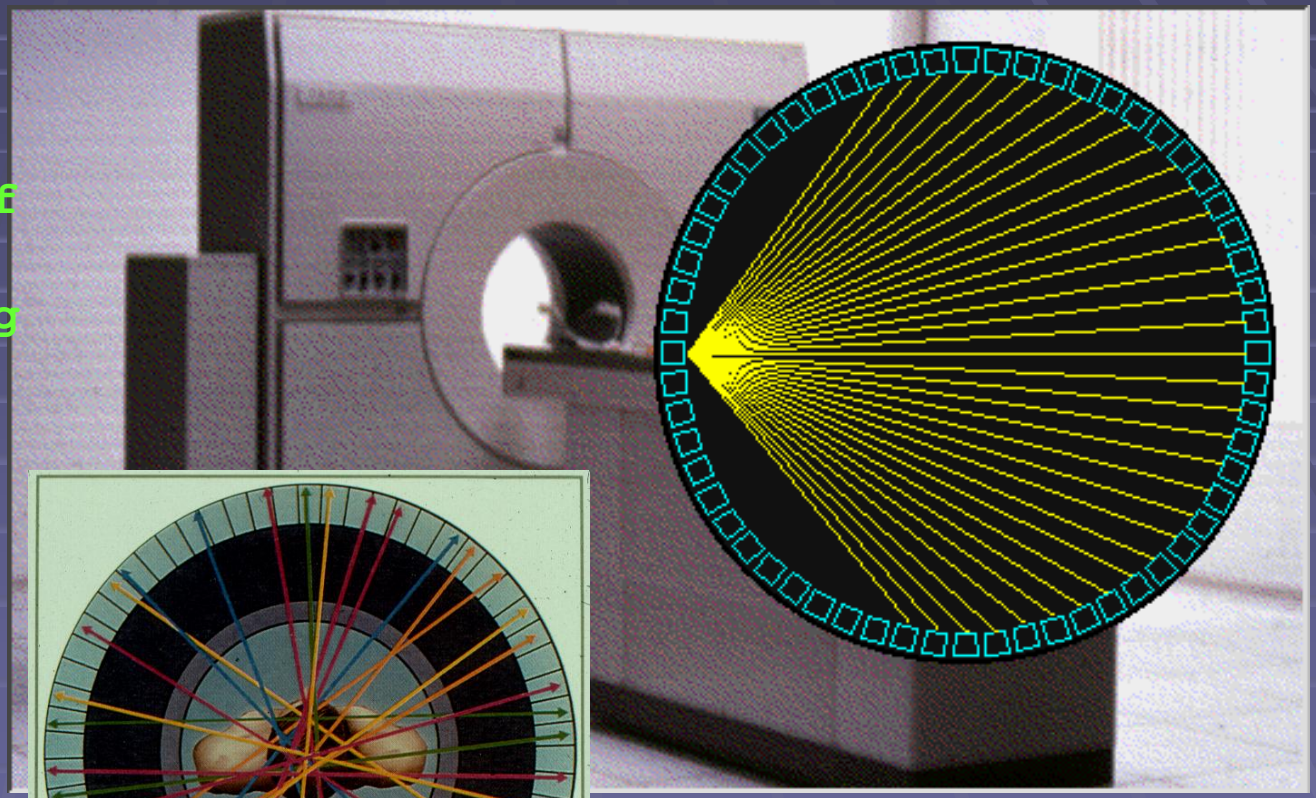
Coincidence event detected in ring PET scanner

Lines of Response

Each pair of detectors defines a possible emission path. Or line of response…..

Over the course of a PET scan, the system is counting how many times each pair of detectors is hit in coincidence.

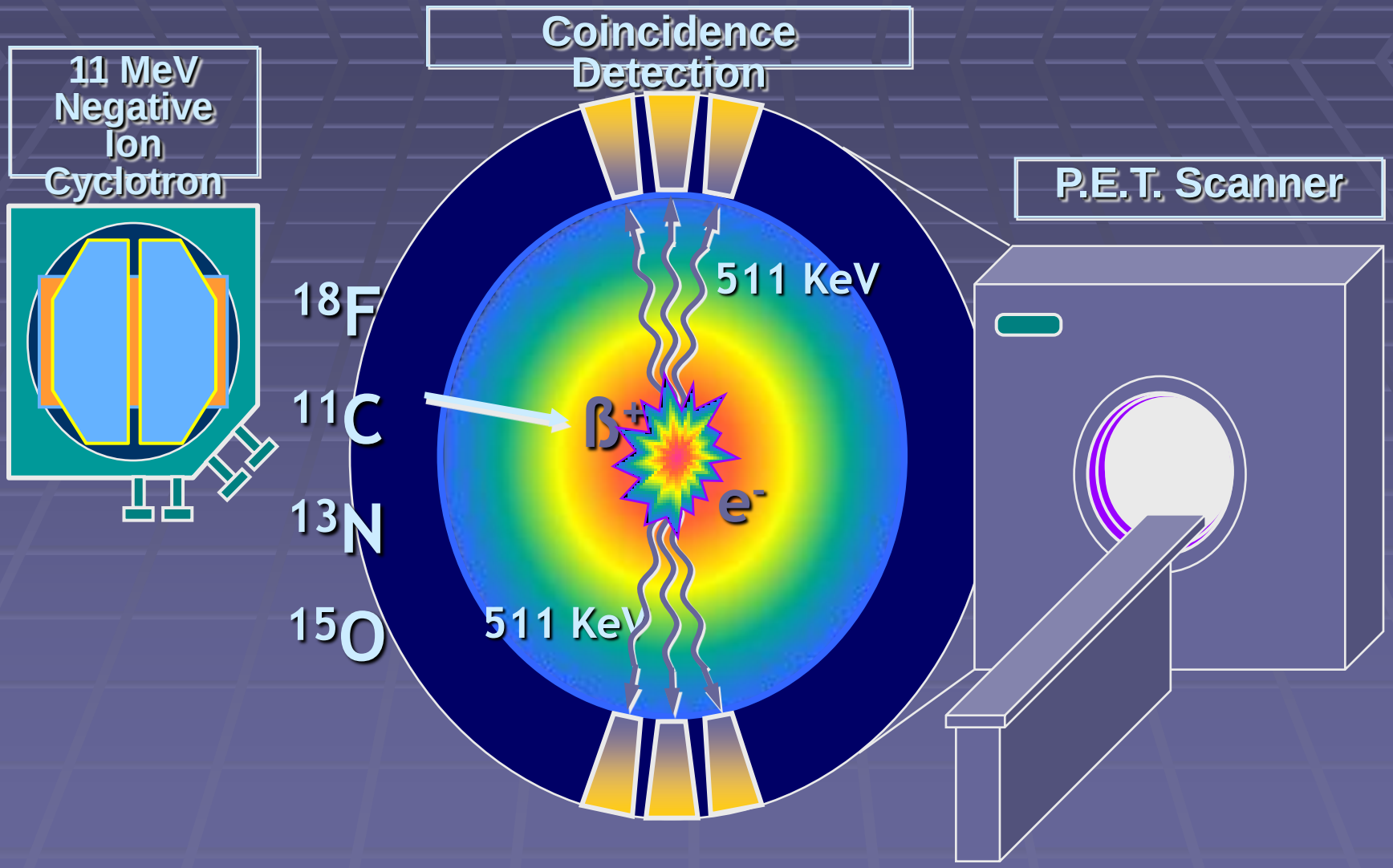
For a ring with n detectors, there are $n^2/2$ ways to pair up the detectors, so a great deal of information is recorded.



6. The multiple LORs through multiple points.

Possible LOR's from one detector

Coincidence



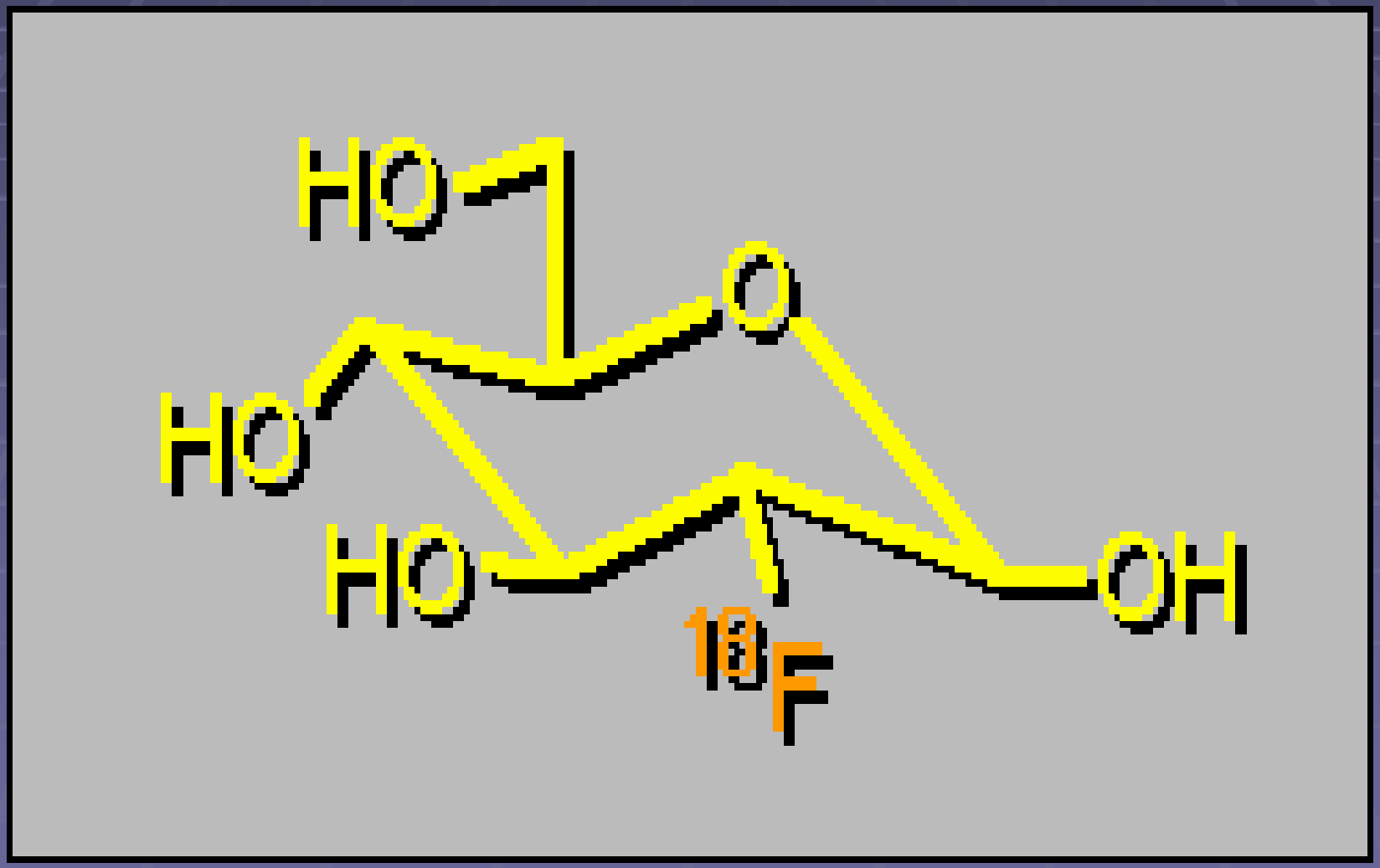
FDG

- The main application of PET scanning is in staging and restaging of cancer.
- Theoretically, cancer and its metastatic lesions have high metabolic rate. This means that glucose consumption is high.
- Attempts have been made unsuccessfully to label glucose with *single photon emitters*, like Tc99m, gallium (Ga67).

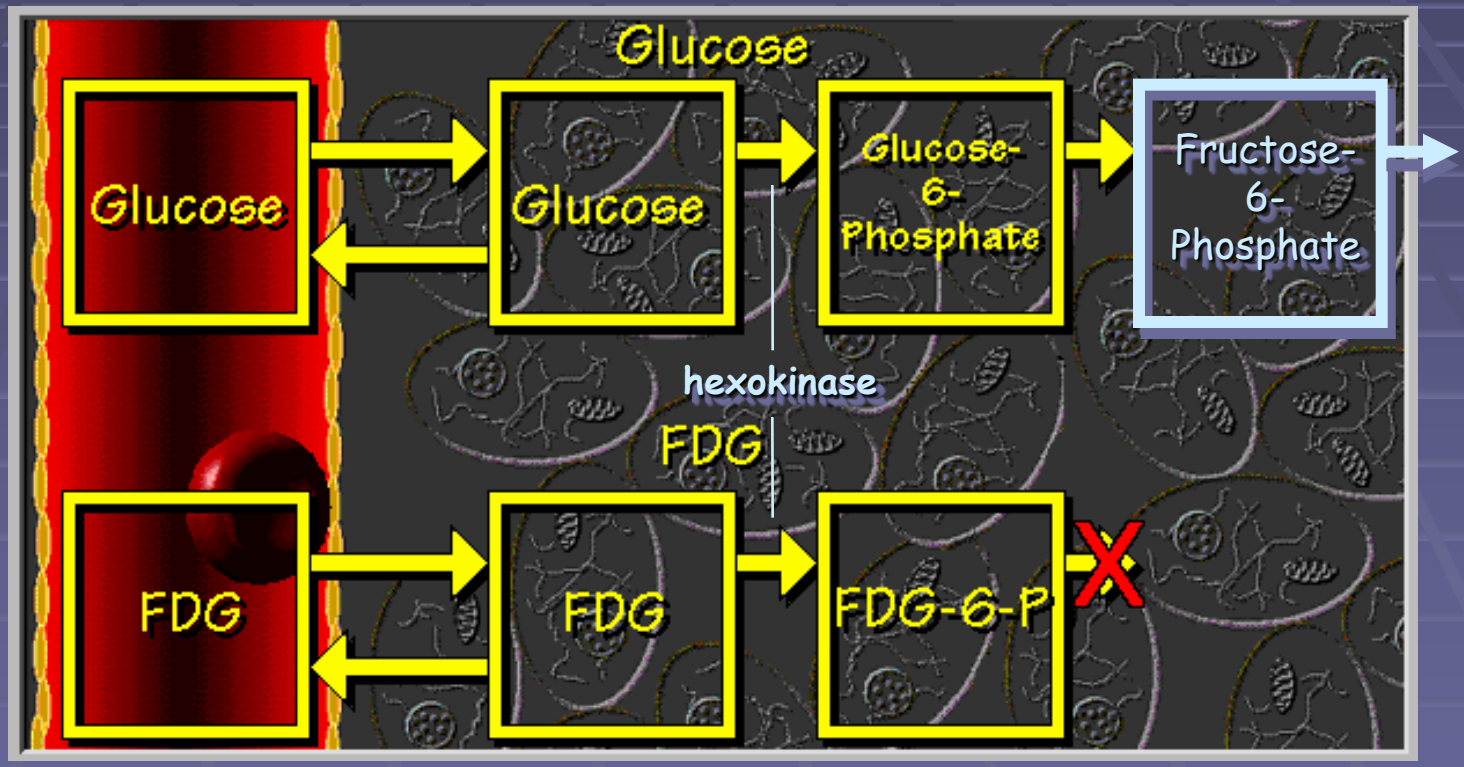
FDG-Cont..

- Eventually, glucose has been labeled with Fluorine-18 (F18) by replacing oxygen atom by F18. This radiopharmaceutical is called flourodeoxy glucose or F18 FDG.
- But F18 is a positron emitter, where two 511 Kev photons are produced at 180˚ (coincidence event).
- F18 has short half life of 110 minutes.

FDG (Flourodexyglucose)



Biokinetics of ^{18}FDG



FDG mimics glucose metabolism

PET defined:

- Positron
  - Radionuclide imaging using “unconventional” positron emitting radiopharmaceuticals
- Emission
  - Detection of radiation energy emitted from the patient rather than transmitted through the patient
- Tomography
  - Computer generated 3 dimensional images of the radionuclidic distribution within the patient

Tomographic Views

Transverse: perpendicular (at right angle) to the long axis of the patient
Sagittal: parallel to the long axis of the patient, slicing lateral to lateral
coronal: parallel to the long axis of the patient, slicing anterior to posterior

Oblique angles

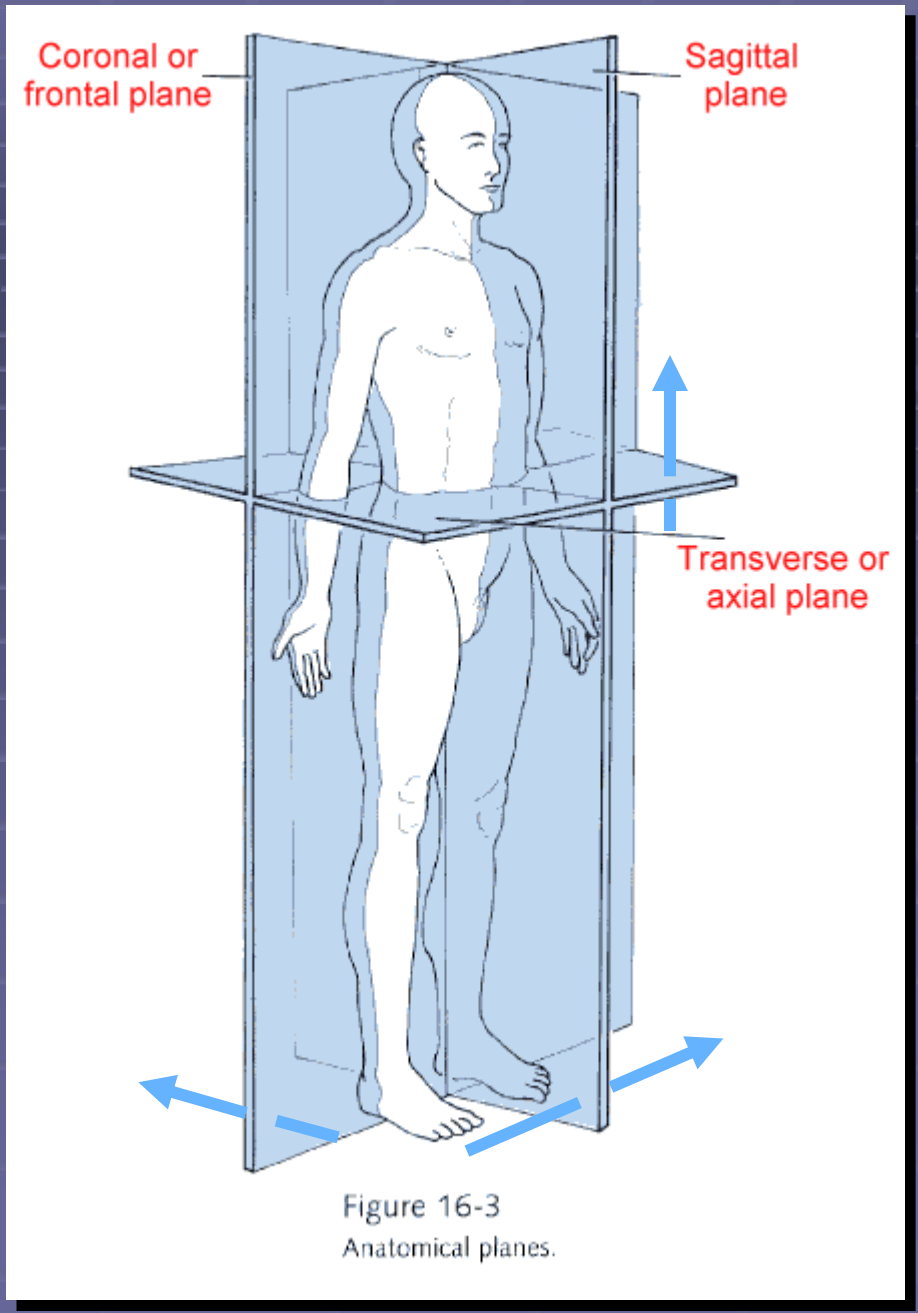
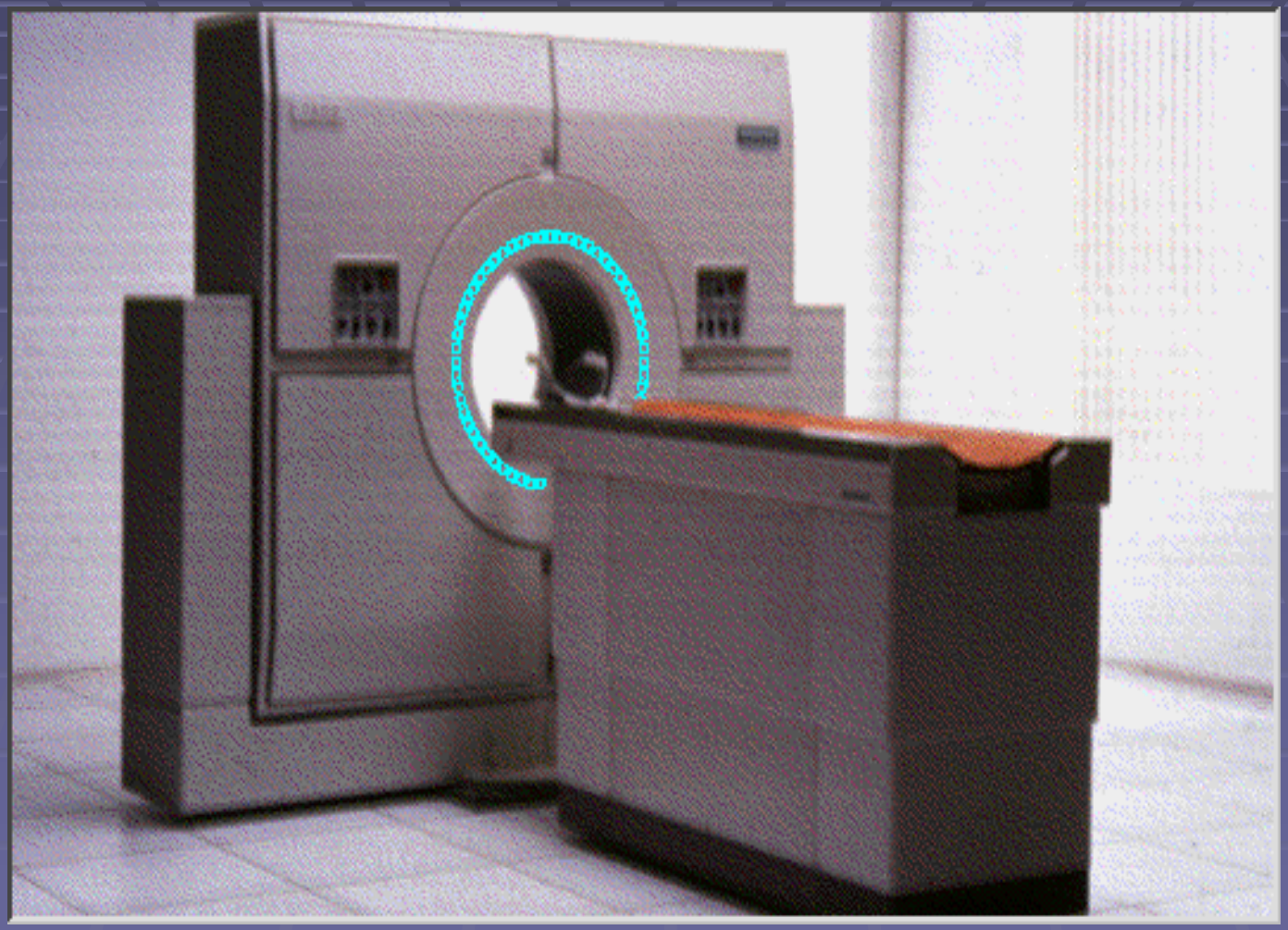


Figure 16-3
Anatomical planes.

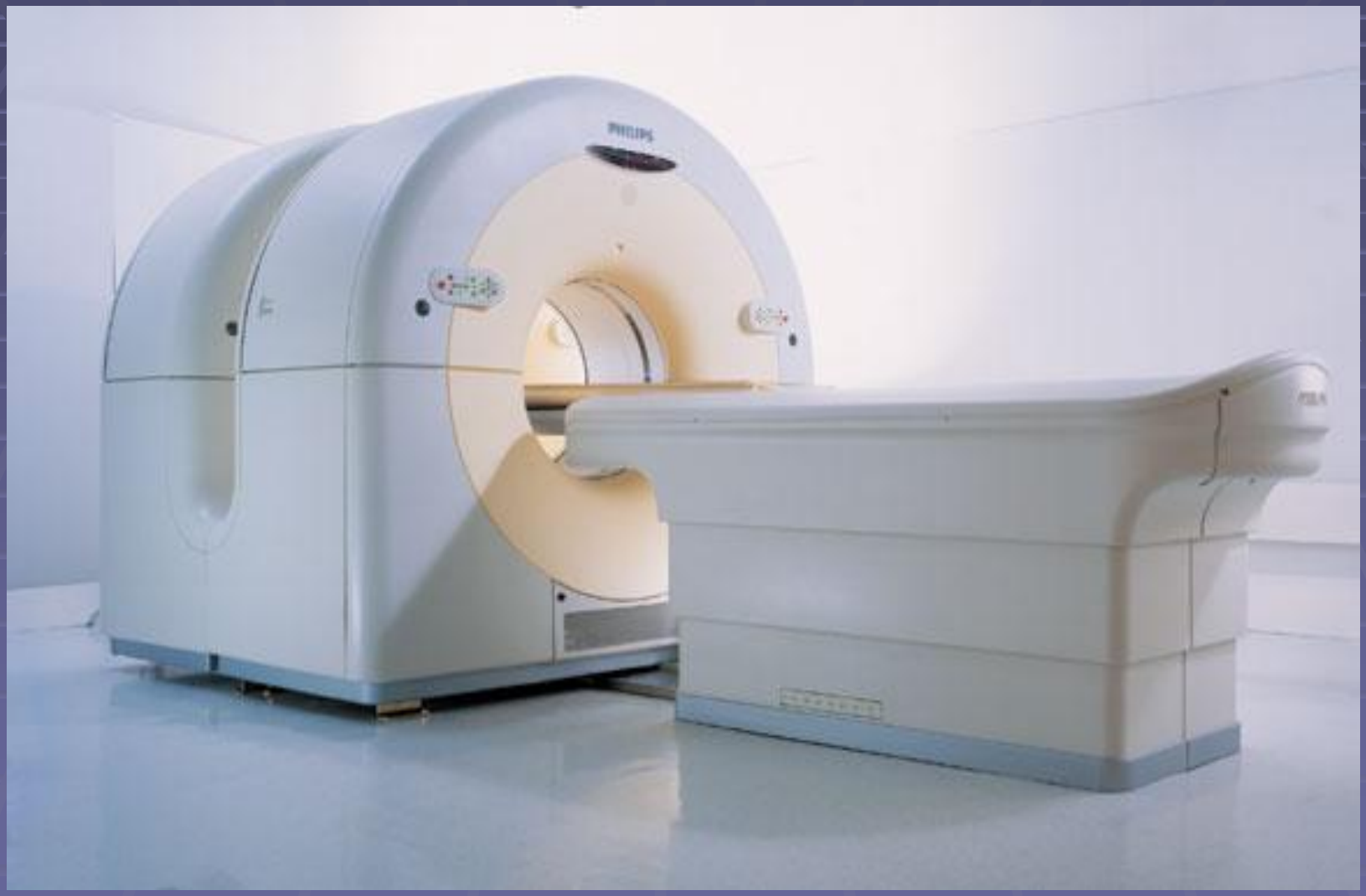
What Makes PET different than conventional nuclear medicine?

- Positron emitter physics
  - B^+ annihilation resulting in two 511KeV photons emitted in opposite directions
- Instrumentation differences:
  - Detect coincidence events
  - Can stop the energetic 511 Kev photons.
- Short lived radionuclides requiring near production site (cyclotron).

Dedicated PET Scanner



PET/CT Scanner



PET/CT scanner

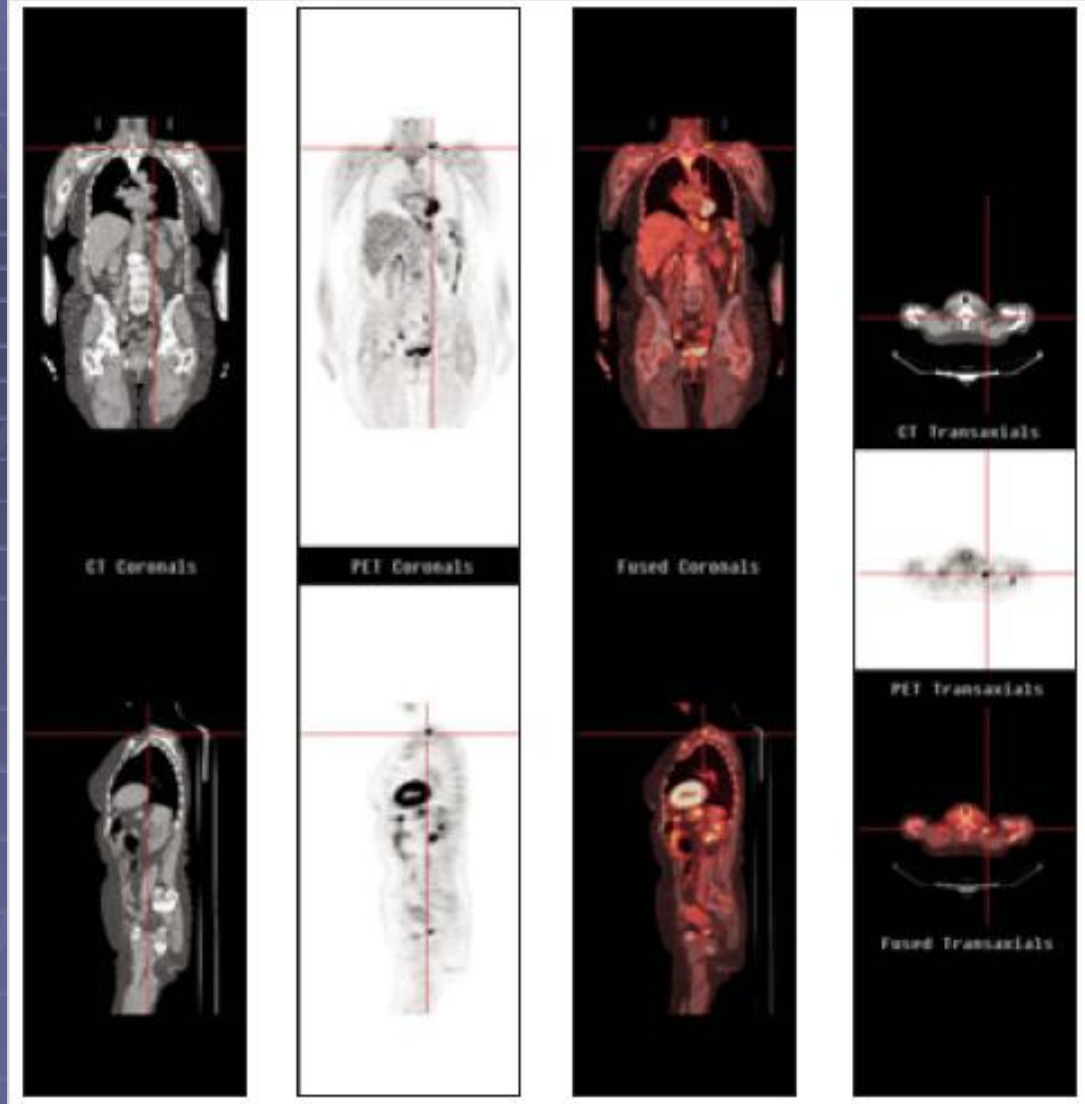
- PET scanner is combined with CT scanner
- CT image is taken first followed by PET image.
- CT image is obtained with low dose x-ray and no contrast.
- CT image is fused with PET image for anatomical correlation (lesion localization).
- CT image in PET/CT is a non-diagnostic image.

Normal PET Scan

- The following structures are somewhat take up FDG: Heart, liver, spleen, kidneys and urinary collecting systems.
- Brain cortex takes significant amount of FDG which makes it difficult to see abnormally hot lesions.

Normal PET scan

PET/CT scan



CT provides the patient's anatomical reference.

PET pinpoints the patient's cancer cells.

PET/CT fuses the images showing the lesions in the proper anatomical context.

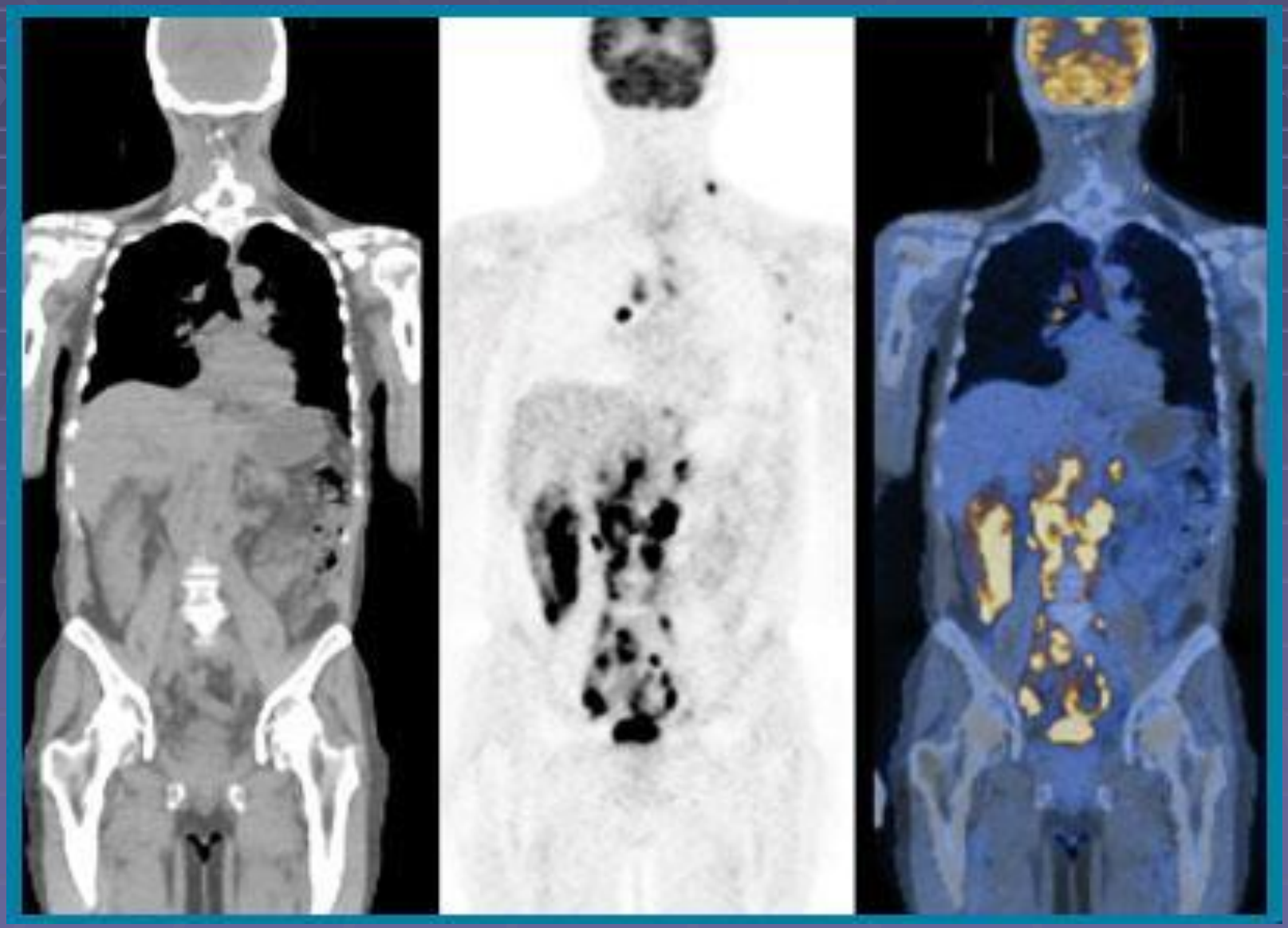
Abnormal Patterns

- Hot lesions due to malignancy.
- Hot lesions due to inflammatory process.
- Hot lesions due to acute infection.

Abnormal PET scan

Hypermetabolic lesions in the medistinum (active lymphnodes)

Abnormal PET/CT scan



PET Applications in Oncology

Specific Purpose of PET Examinations

- Preoperative staging of cancer
- Differentiation of scar from residual disease
- Demonstration of suspected recurrent cancers
- Follow-up of therapy

Impact of PET on Solitary Lung Nodules Management

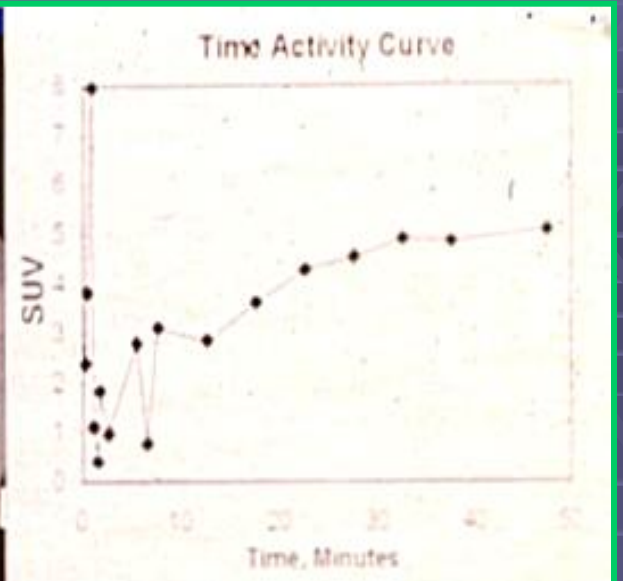
- The sensitivity of PET is high enough that negative results on PET scan is reasonably considered to rule out malignancy.
- False negative in well-differentiated adenocarcinoma and BronchioAlviolar carcinoma

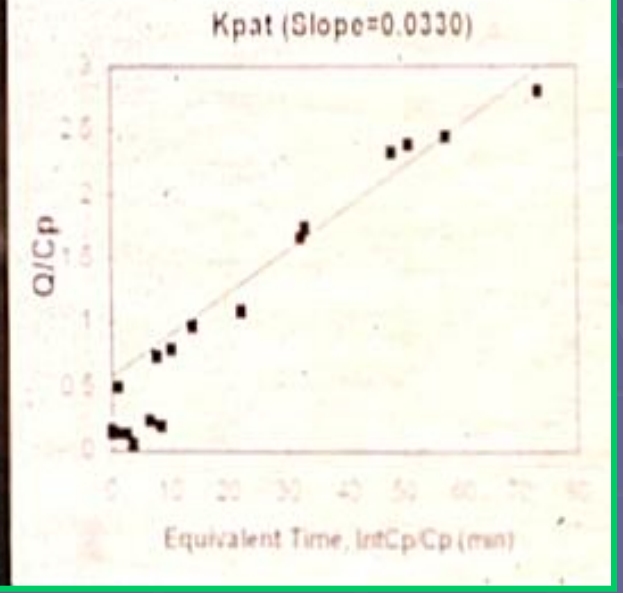
75y male

CT: 2.4x1.7cm lesion with spiculated marginsand in spite of some eccentric calcifications was considered suspicious for neoplasm

PET: SUV of 5.07 and Kpat of 0.033 (r^2=0.93), + for neoplasm

Bx: Primary Lung CA





Lung Cancer

- Staging of non-small cell lung cancer.
- Assessment of recurrence.
- Monitoring therapy.
- Assessment of pleural malignancy.

NSCLC Staging-Nodal Disease

- Negative predictive value of PET evaluation for mediastinal lymph nodes is greater than 95%.
- Positive predictive value of PET for mediastinal disease is lower.
- PET scan is more accurate than diagnostic CT scan for mediastinum evaluation.

NSCLC Staging-Distant Mets

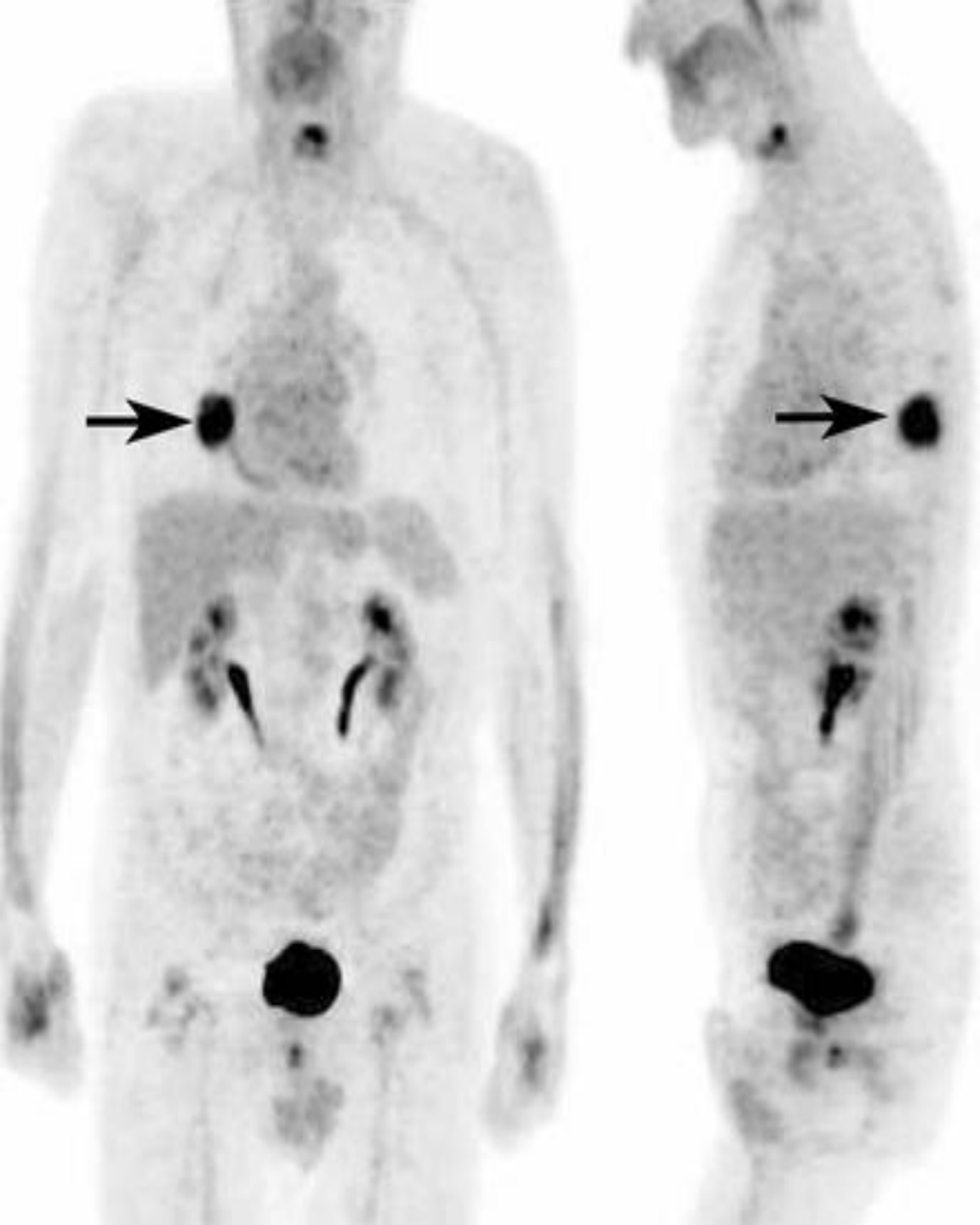
- PET scan is superior to conventional imaging techniques for distant metastatic disease.
- PET is limited for brain metastasis.

NSCLC Staging-Adrenal Mets

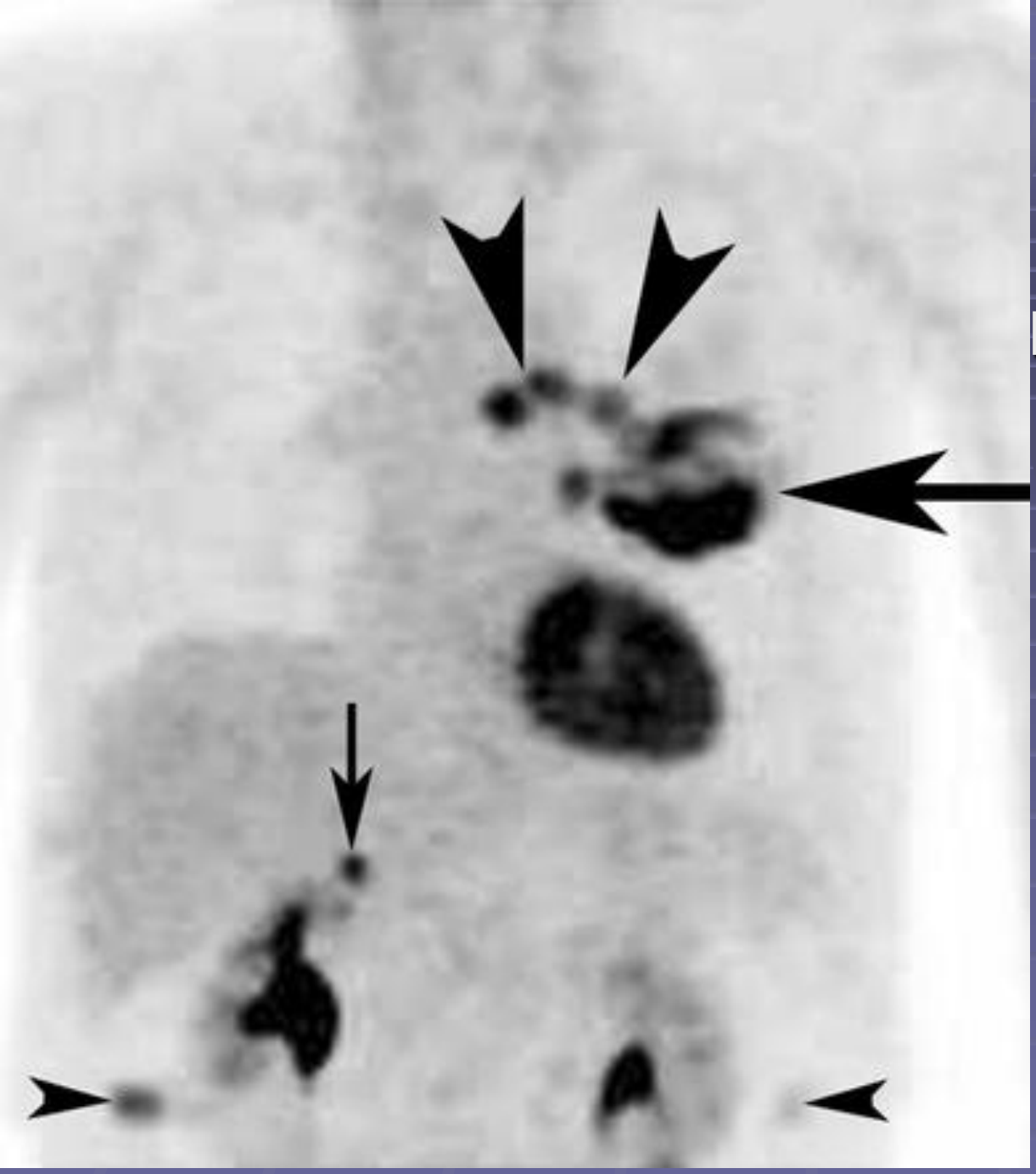
- PET has been shown to help reliably differentiate between adrenal metastases and benign adrenal nodules.

NSCLC Restaging

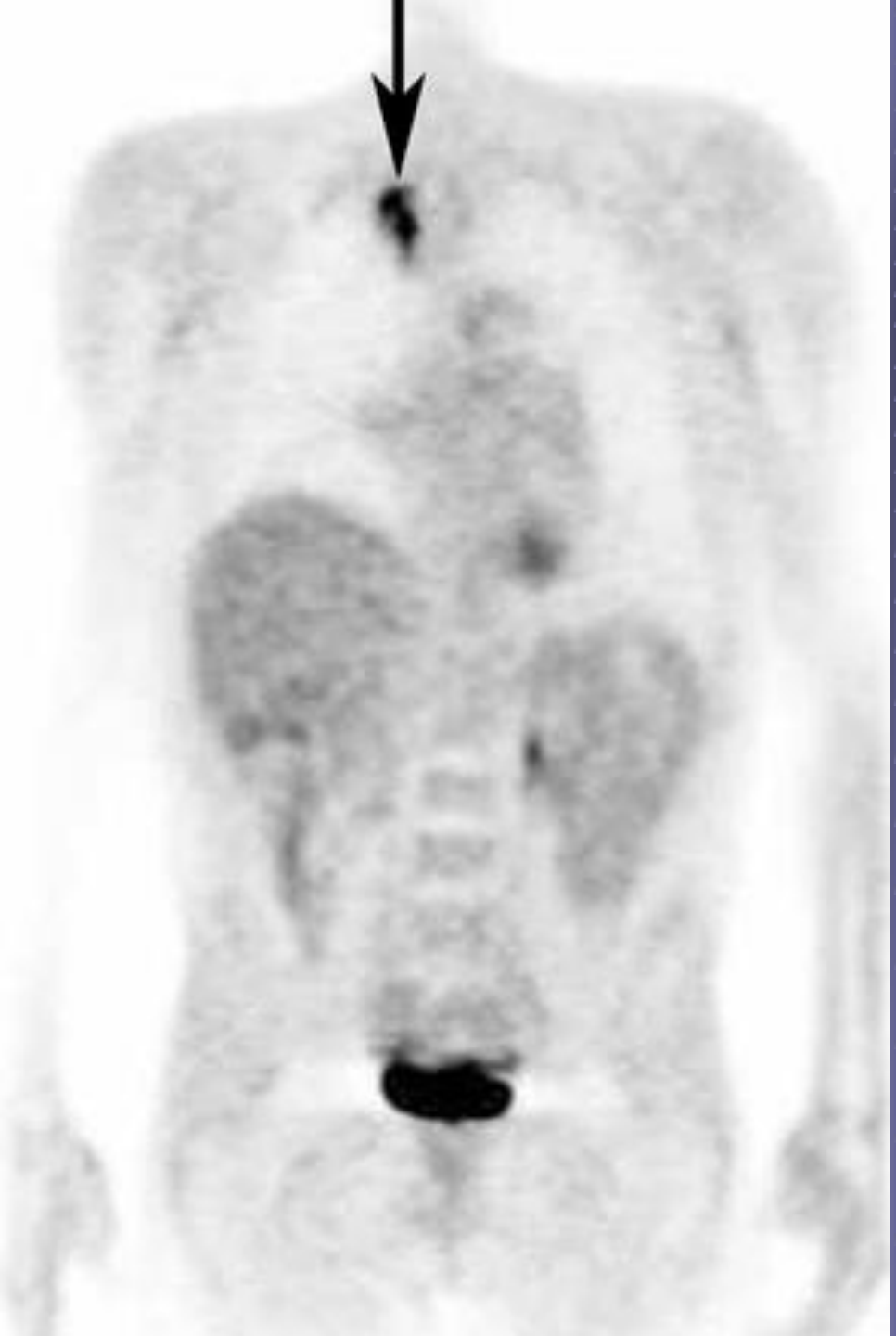
- PET imaging is accurate in differentiating postsurgical/post-radiation changes from recurrent tumor.



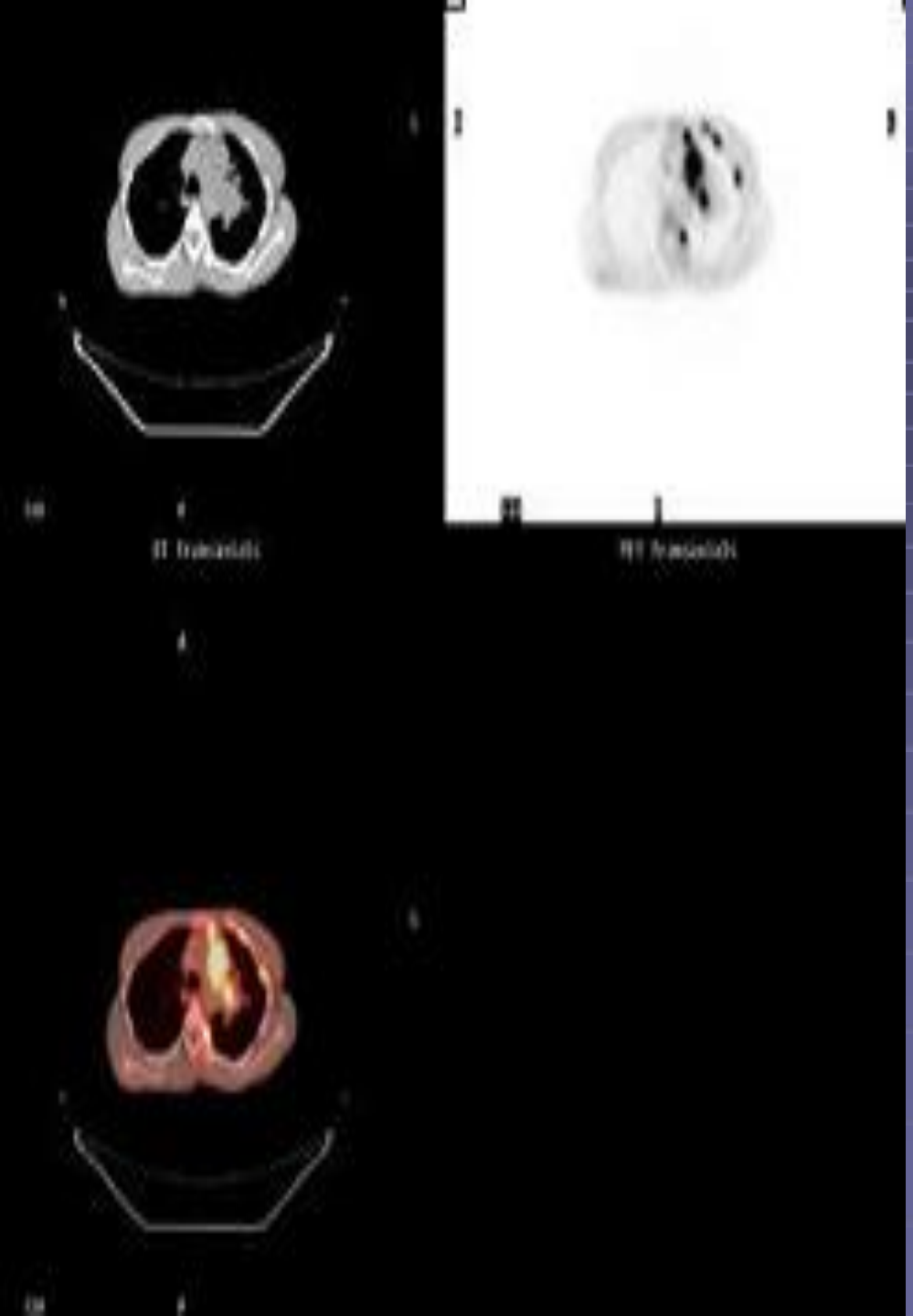
Staging of NSCLC.



NSCLC with Mets



- Recurrent NSCLC



- Recurrent NSCLC
.

Colorectal Cancer

- Staging
- Recurrence after primary surgery
  - Rising CEA, CT/MRI negative
  - CT/MRI positive “indeterminate mass”
- Evaluation of extra-hepatic extent prior to hepatic resection
- Follow-up post chemotherapy.

Colorectal cancer staging and re-staging

- PET was found to be more sensitive than diagnostic CT for intra-abdominal metastatic disease.
- PET was found to be more sensitive than both CT and CEA level for detection of disease recurrence.

Colorectal cancer Re-staging

- PET is accurate for differentiation of benign from malignant presacral changes and is superior to CT and MR imaging in this regard.

Colorectal Cancer

50 year old female with poorly differentiated adenocarcinoma of transverse colon and right hemicolectomy.

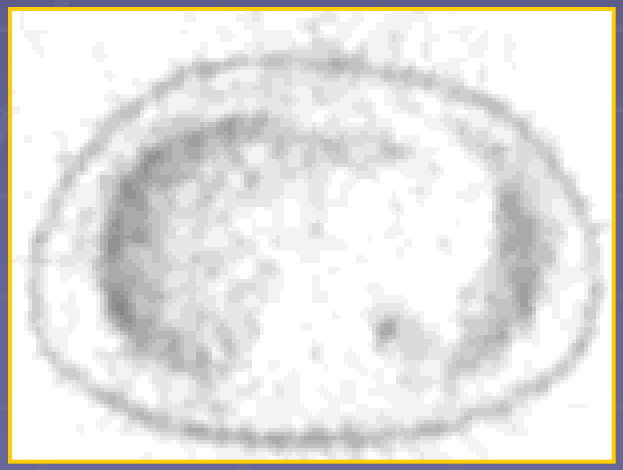
2 liver lesions seen on CT 7 months later.

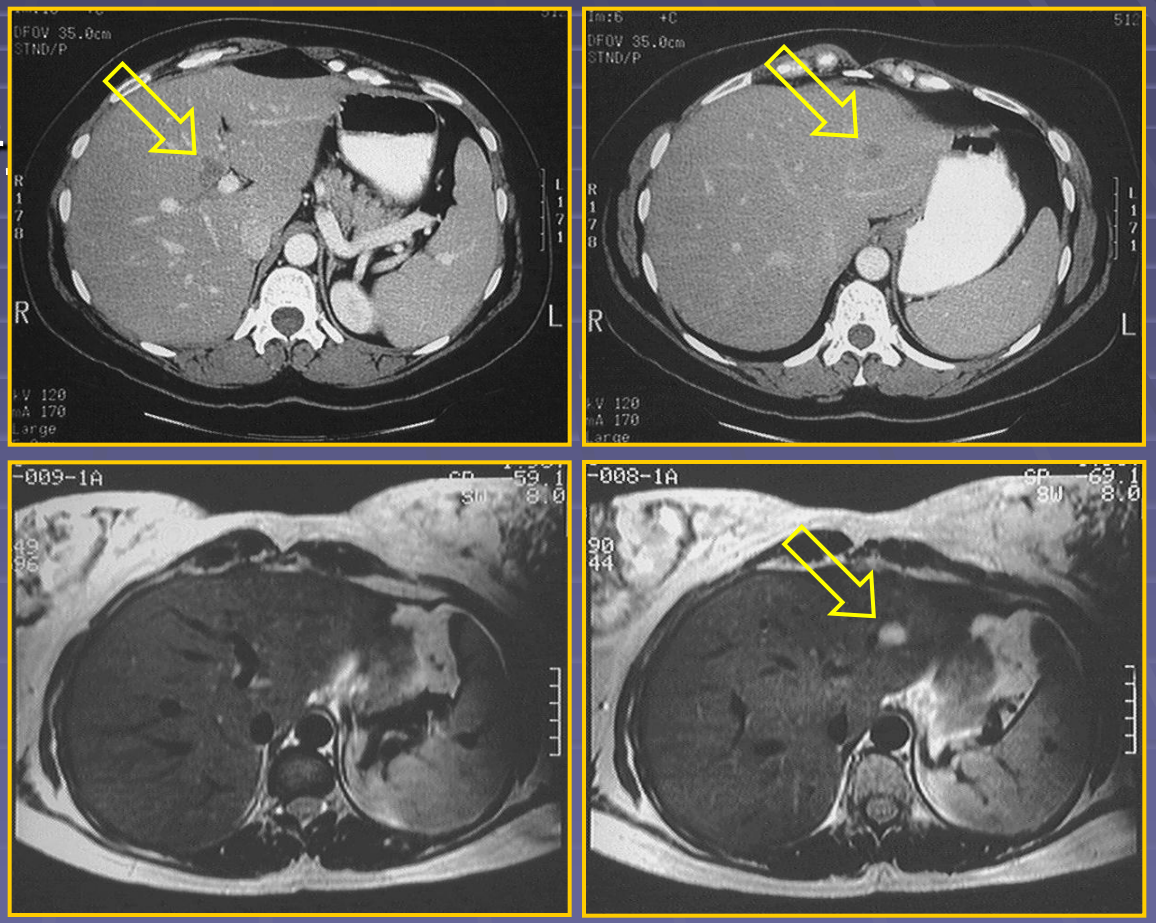
PET: Negative

Bx: Negative

Patient alive 6yrs later.

^{18}FDG-PET Axial Plane #67

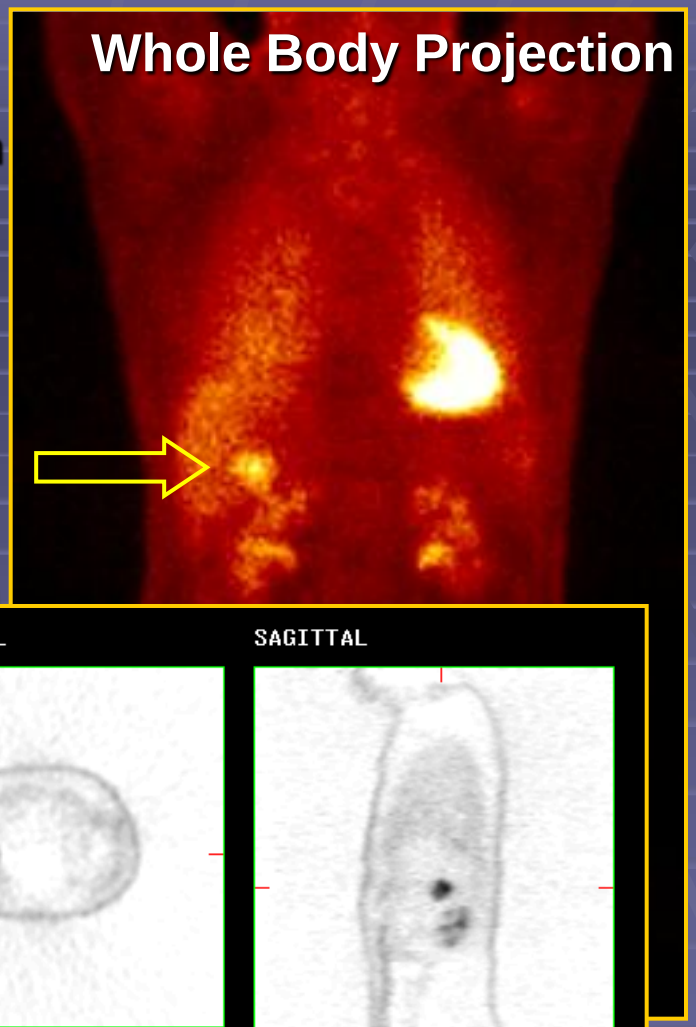


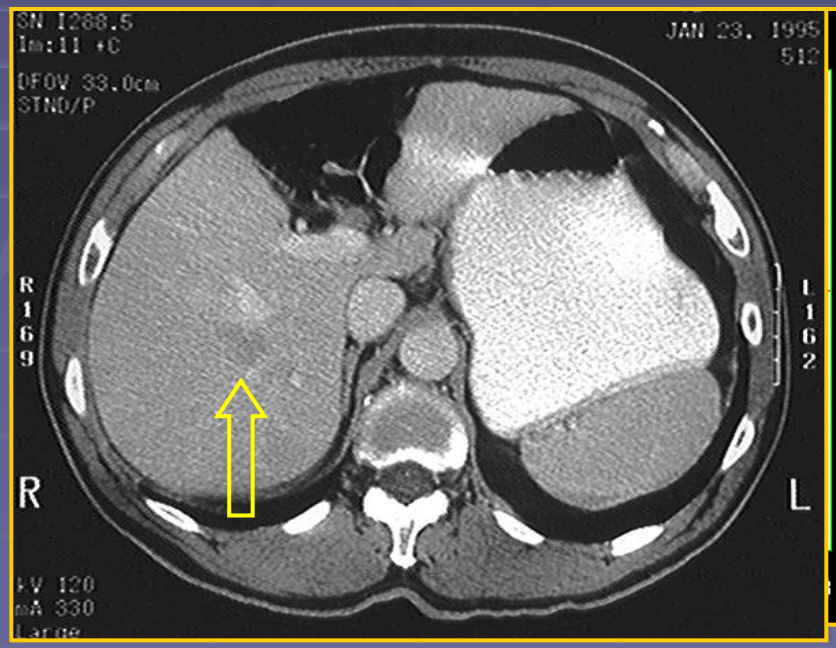


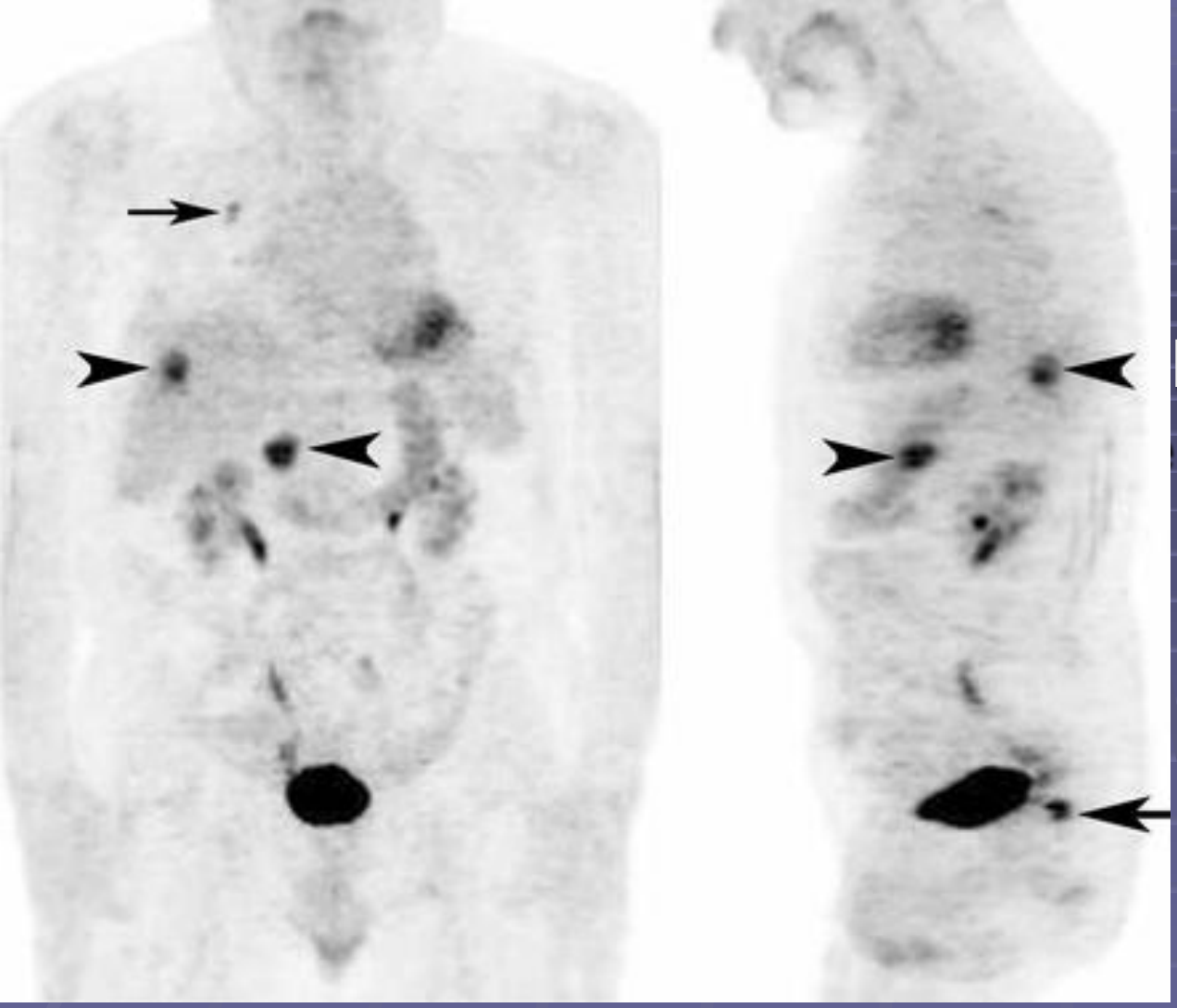
Colorectal Case

73 yr old male with adenocarcinoma of rectum post Sx/RadTx/Chemo.
Suspicious lesion on CT 6 months later.
PET: Positive
Bx: Positive; Proceeded with lobectomy.

Comment: Both cases demonstrate CT's poor specificity and PET's ability to guide therapy.

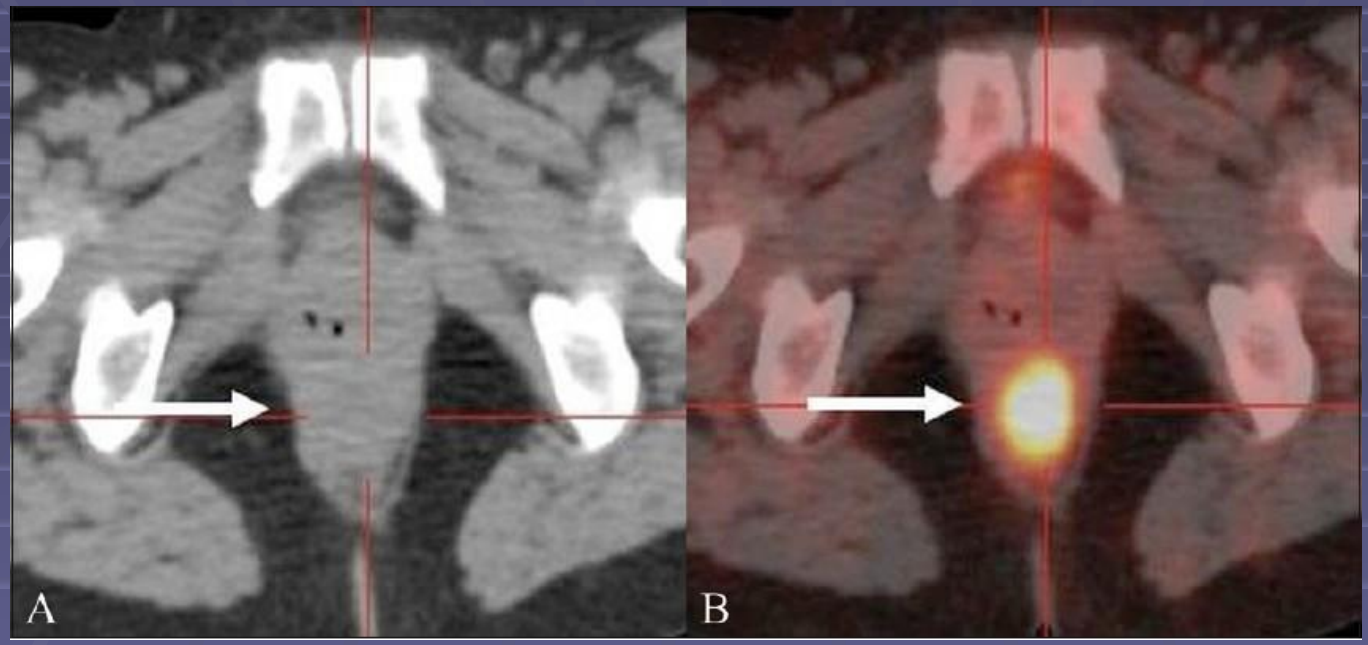


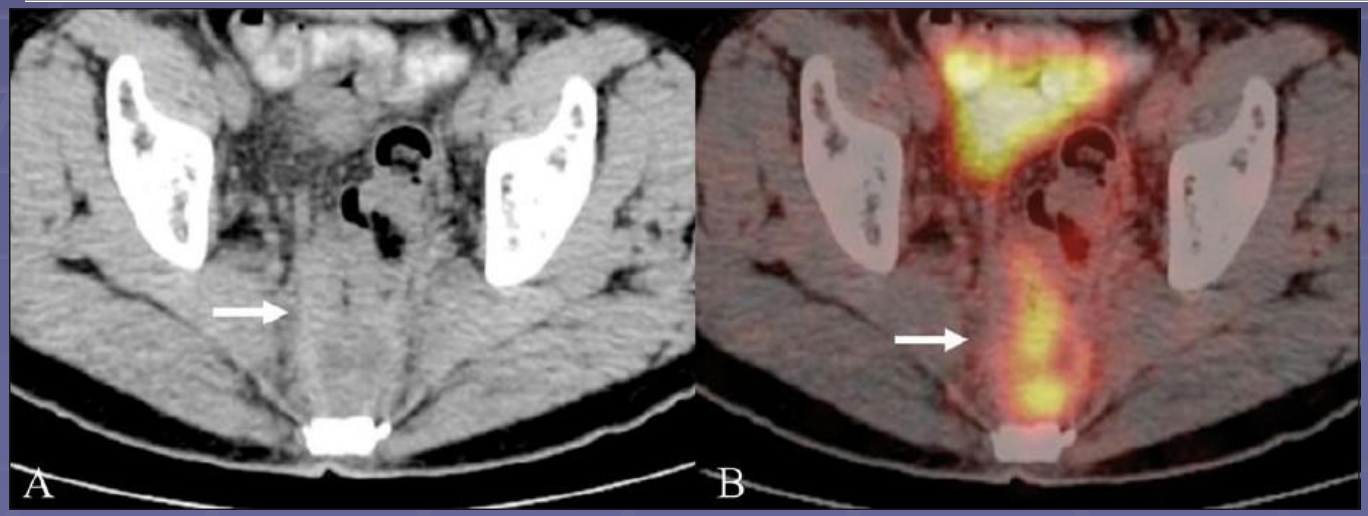




Recurrent rectal cancer

Recurrent rectal cancer (presacral)





Impact of PET on Lymphoma Management

- Impact on staging: 44% of the patients
- Impact on management: >60% of the patients.

Lymphoma Staging and Restaging

- HD: PET was found to be 86% sensitive and 96% specific, compared with 81% sensitivity and 41% specificity of CT.
- NHL: the sensitivity and specificity for CT were the same as for patients with HD, whereas PET was found to be 89% sensitive and 100% specific for the presence of disease.

Nodal Sites

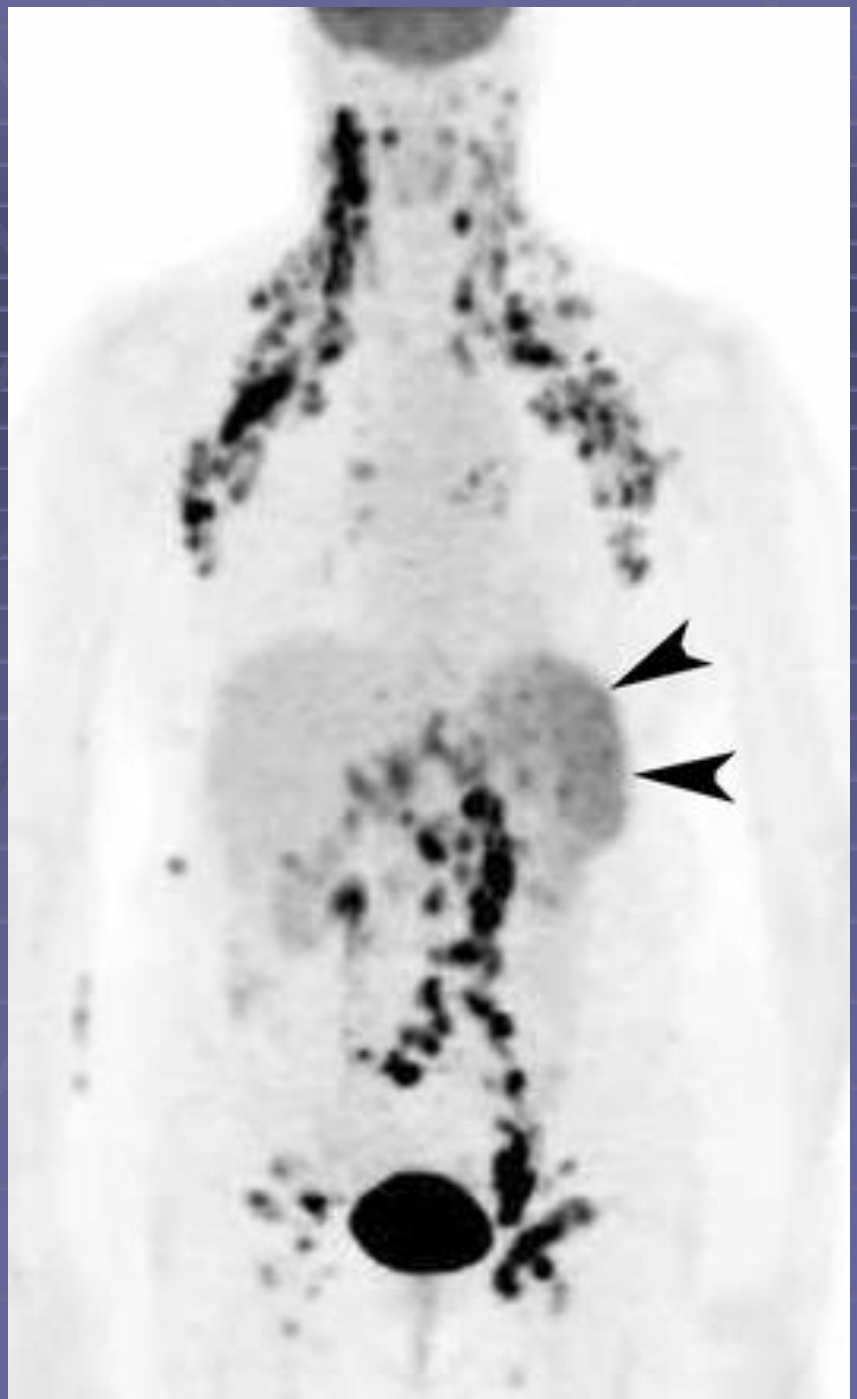
- Discordant interpretations between PET and CT images were almost always resolved in favor of the PET interpretation when confirmation was obtained.
- The identification of additional sites of disease resulted in an increase in disease stage in more than half of the patients.

Extranodal Sites

- PET has been found to be accurate for identification of disease in multiple sites in the abdomen.

Restaging of Lymphoma

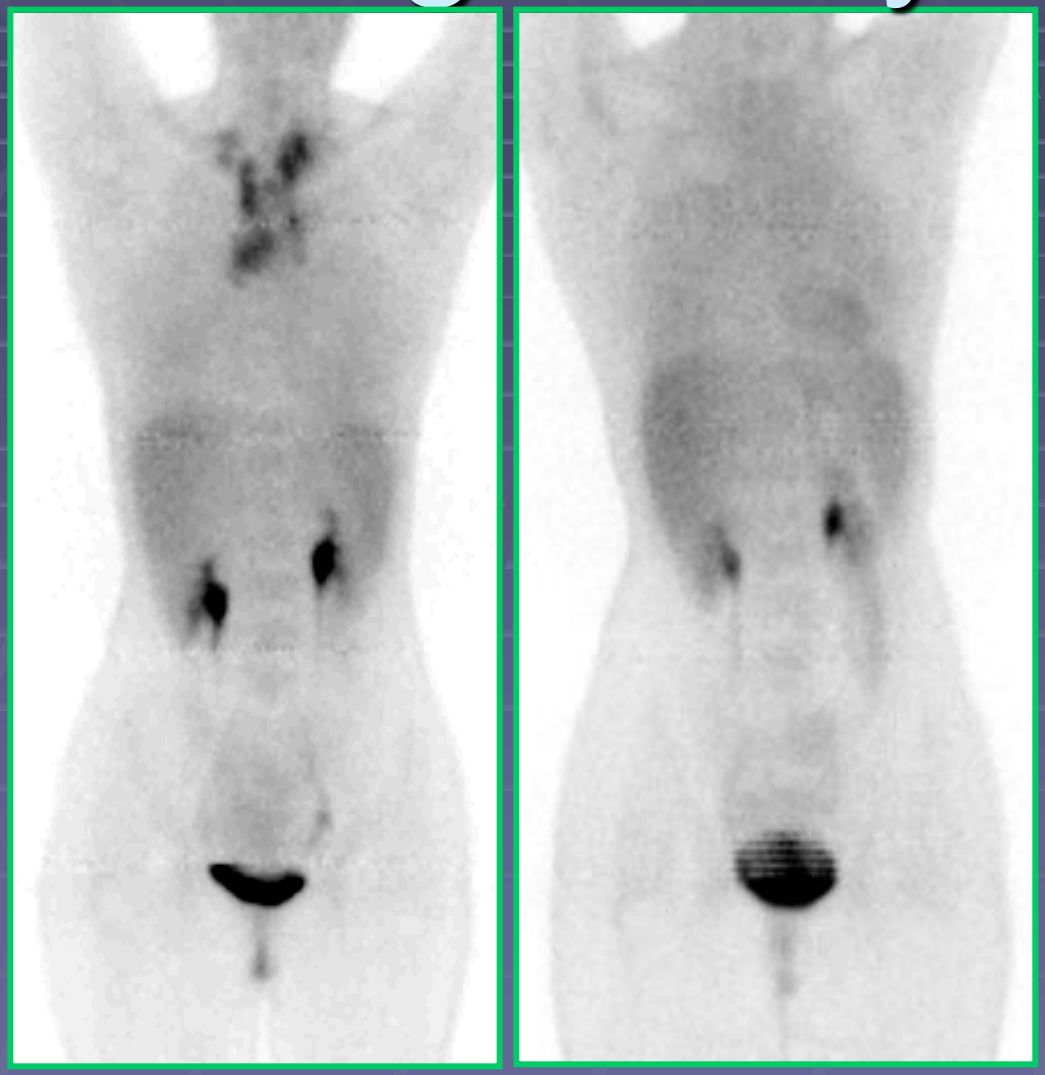
- Positive PET after the end of therapy in HD and NHL patients is a strong predictor of relapse (100% of cases in 2 years).
- A negative PET study is also an excellent predictor of good prognosis.
- The diagnostic accuracy of PET to assess the presence of residual disease after therapy is superior to that of CT.



- Staging for T-cell lymphoma.

- 52 yr Male with Hodgkin's Lymphoma
- Negative CT of the abdomen
- Interval increase in mediastinal adenopathy on CT
- FDG-PET: NED

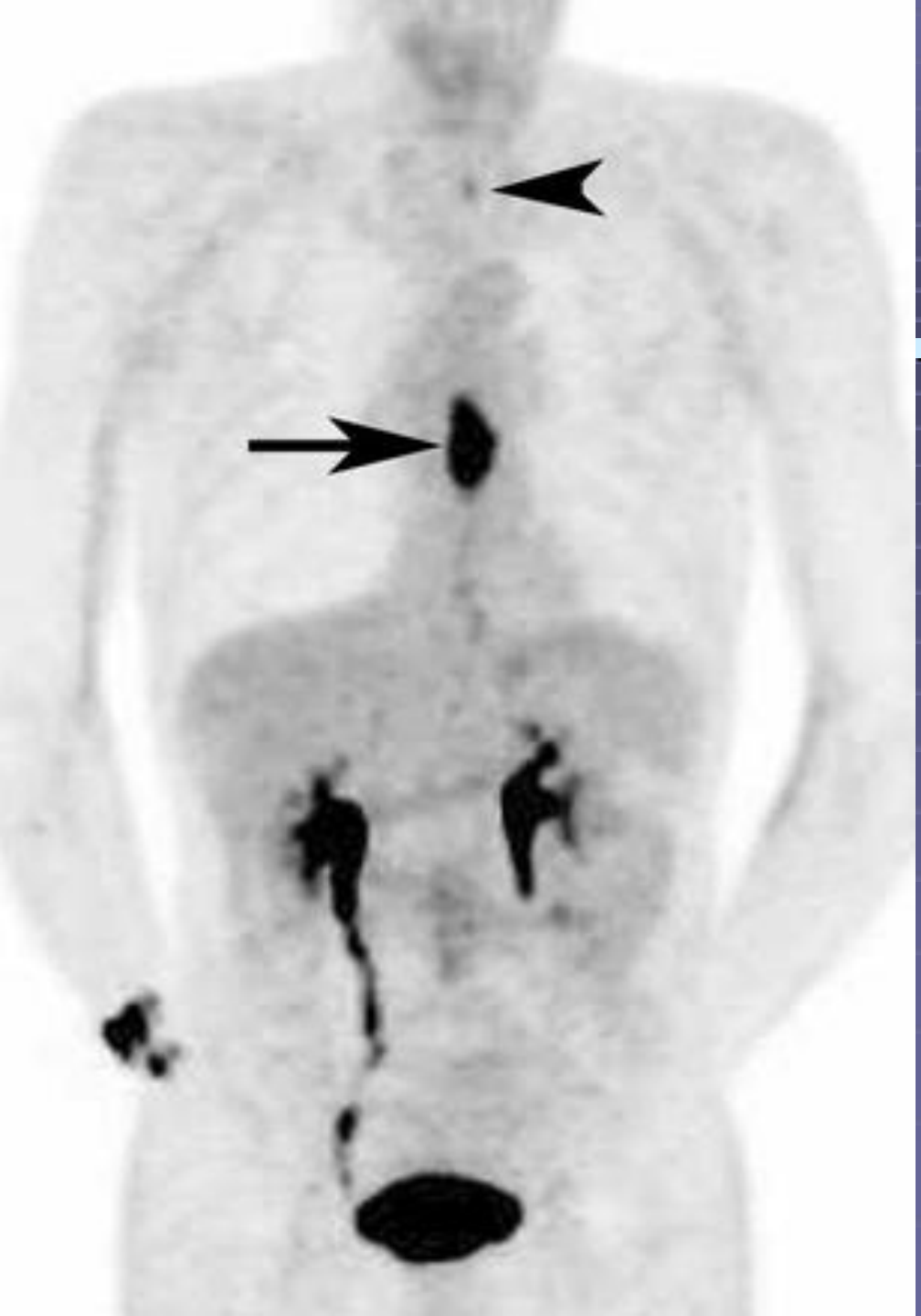
Hodgkin's Lymphoma



- Initial Scan (left) SUV = 8.34
- Positive CT
- Month 1-3 ChemoRx
- Month 7 - Ga and - PET

Staging and Restaging of Esophageal Cancer

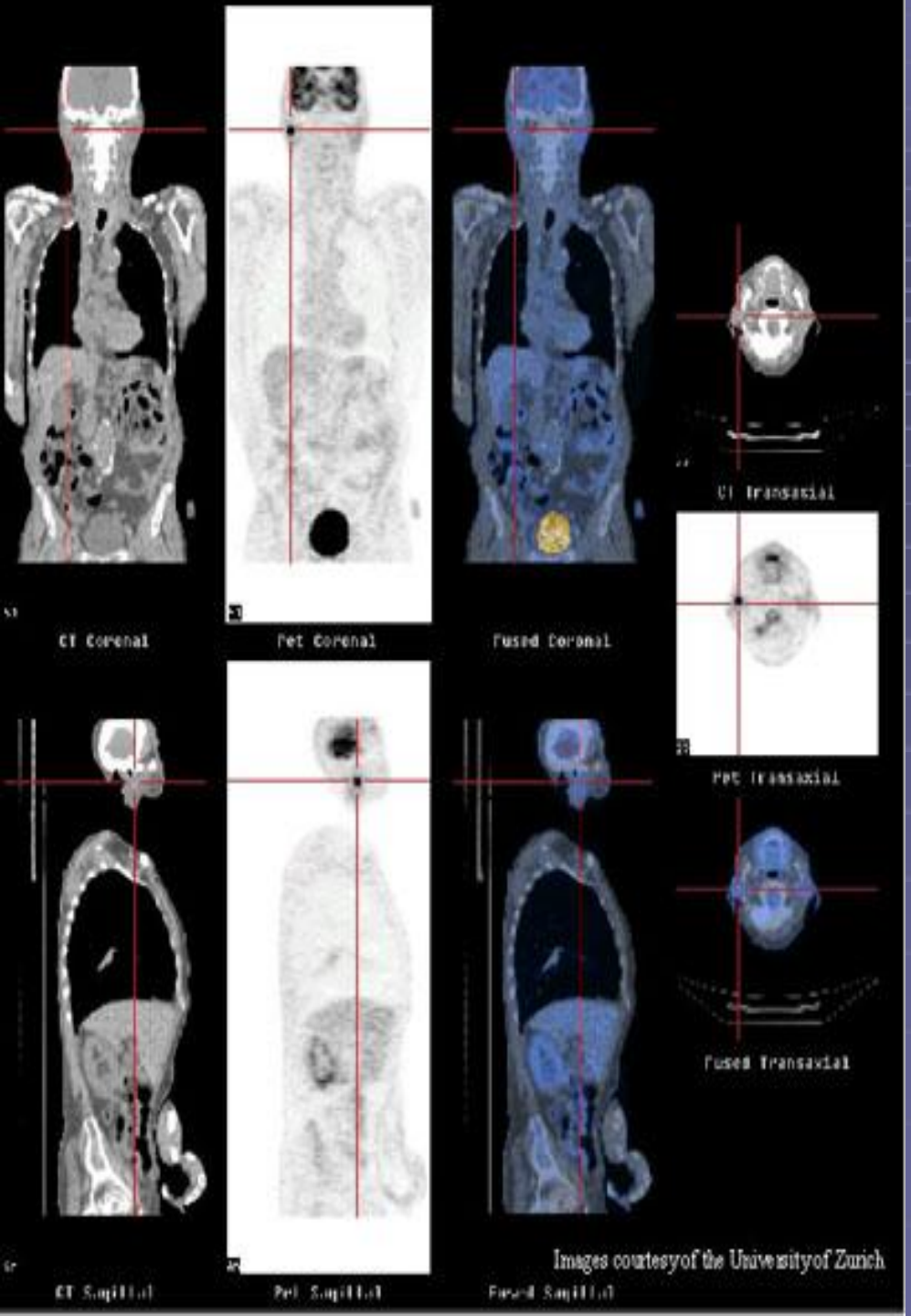
- Distant metastasis: PET was 95% sensitive and 80% specific, compared with CT, which was 79% sensitive and 70% specific.



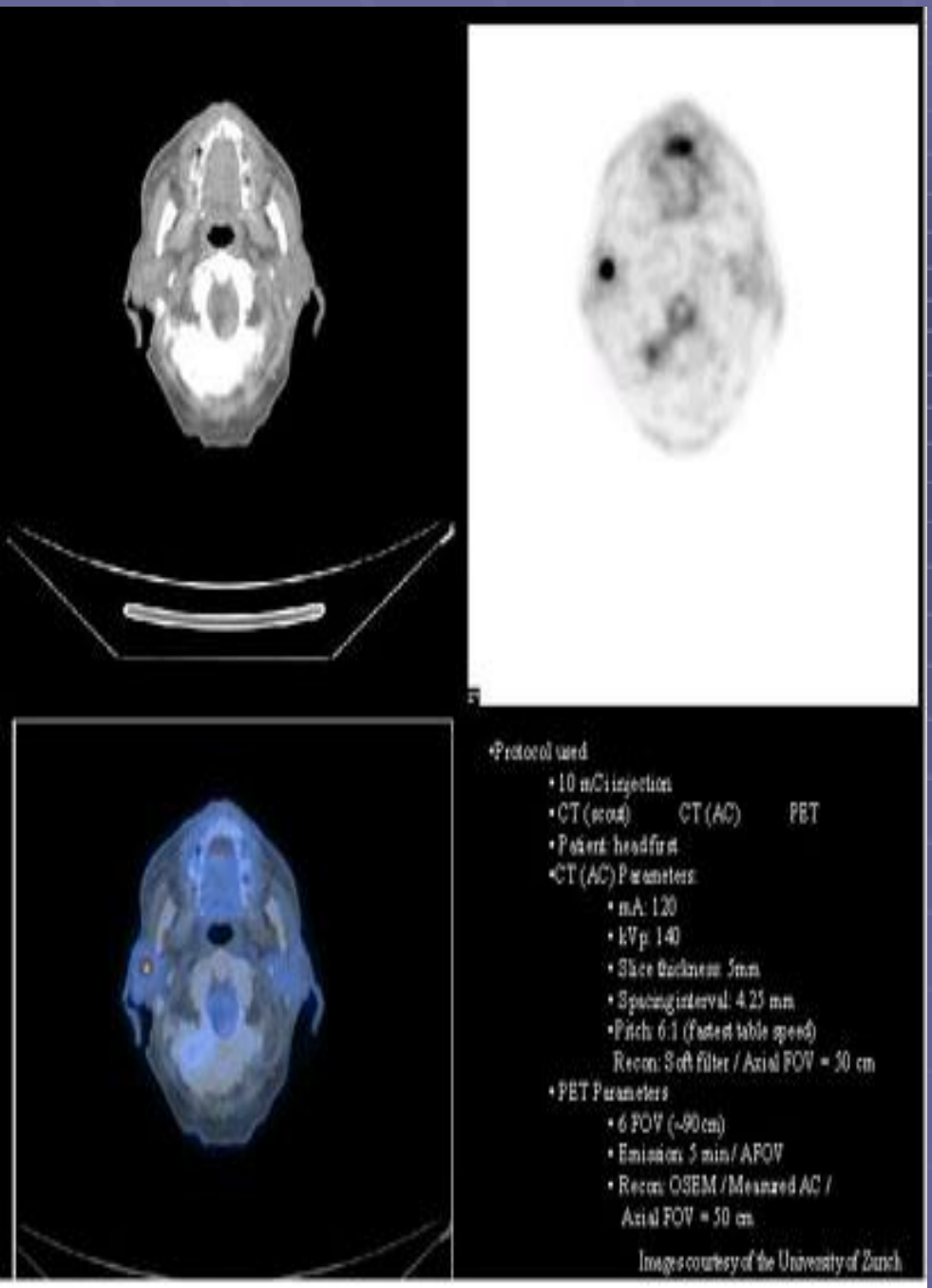
- Metastatic esophageal cancer

Staging and re-staging of Head and Neck Cancer

- PET is more sensitive and specific for cervical nodal disease than is diagnostic CT.
- PET is more accurate for detection of recurrent tumor than is diagnostic CT, MR imaging, or a combination of both (post-surgical/radiotherapy).



- Restaging of Head and neck cancer.



- PET CT demonstrates the tumor with extension over the midline anterior with destruction of the laryngeal cartilage and invasion of the soft tissue.

Breast Cancer Staging

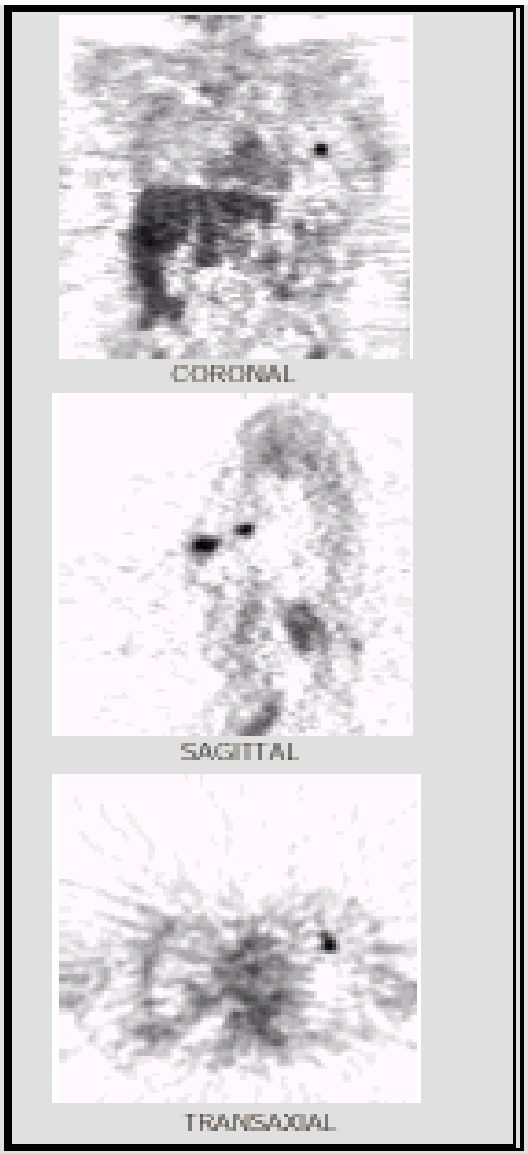
- Compared with CT, PET is more sensitive and specific for osseous and hepatic metastases and equally sensitive and specific for pulmonary metastases.

Breast Cancer Restaging

- PET is useful for demonstration of both locally recurrent disease and distant metastases and appears to be superior to conventional imaging in this regard.

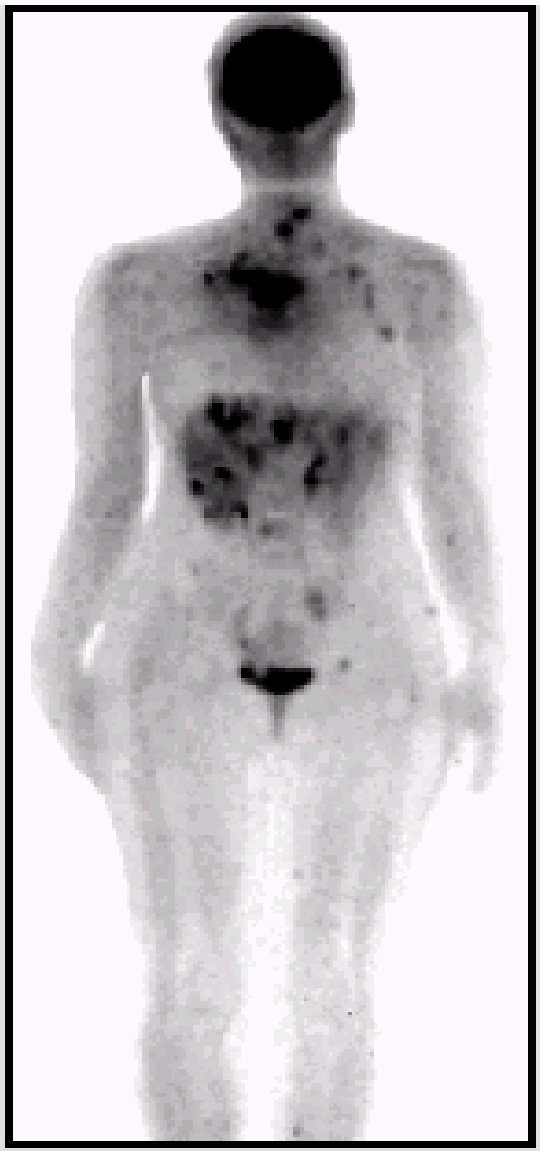
Clinical Example 1

Stage II primary with axillary involvement



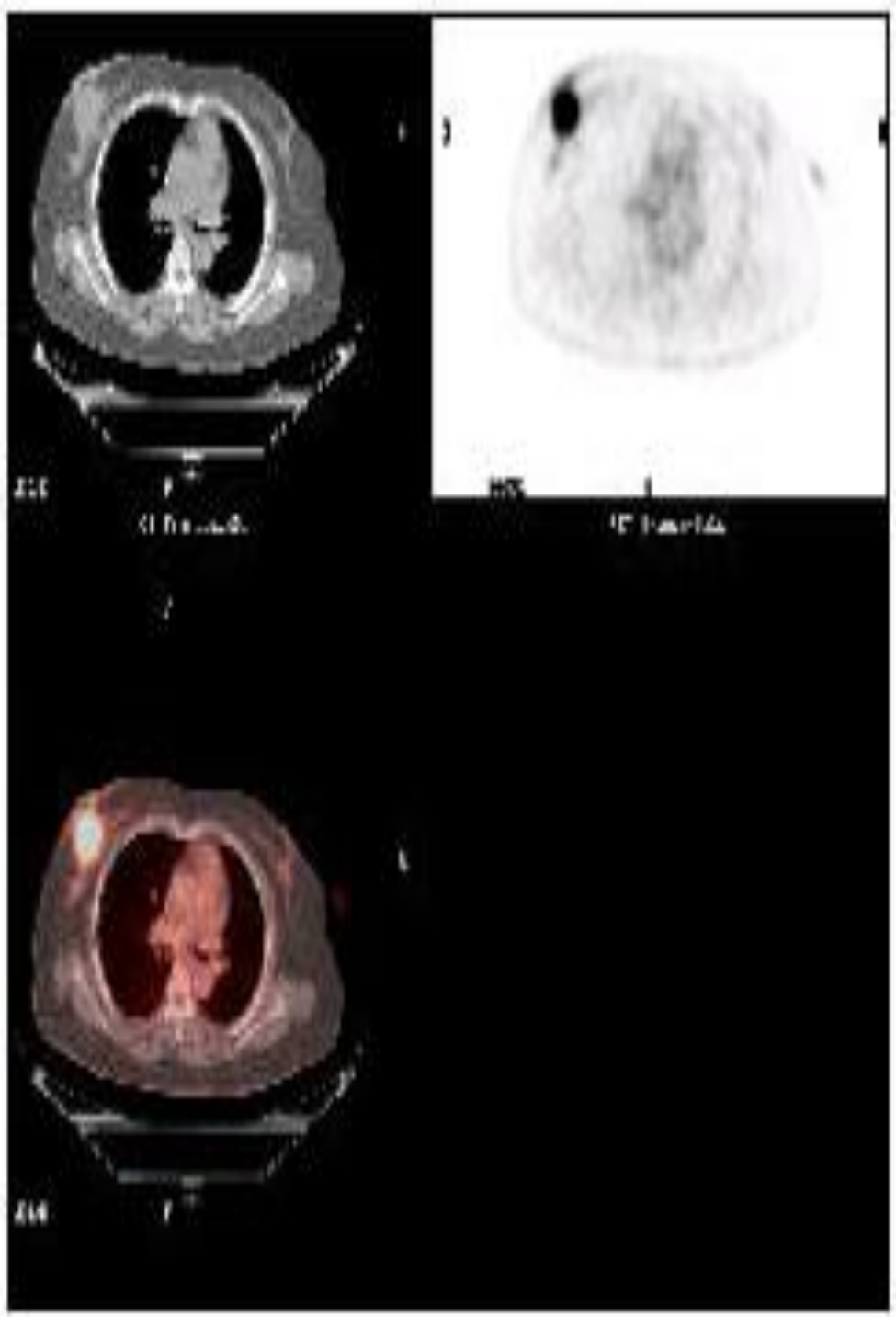
Clinical Example 2

Two hypermetabolic sites consistent with breast carcinoma



Clinical Example 3

Recurrent disease with extensive metastatic involvement



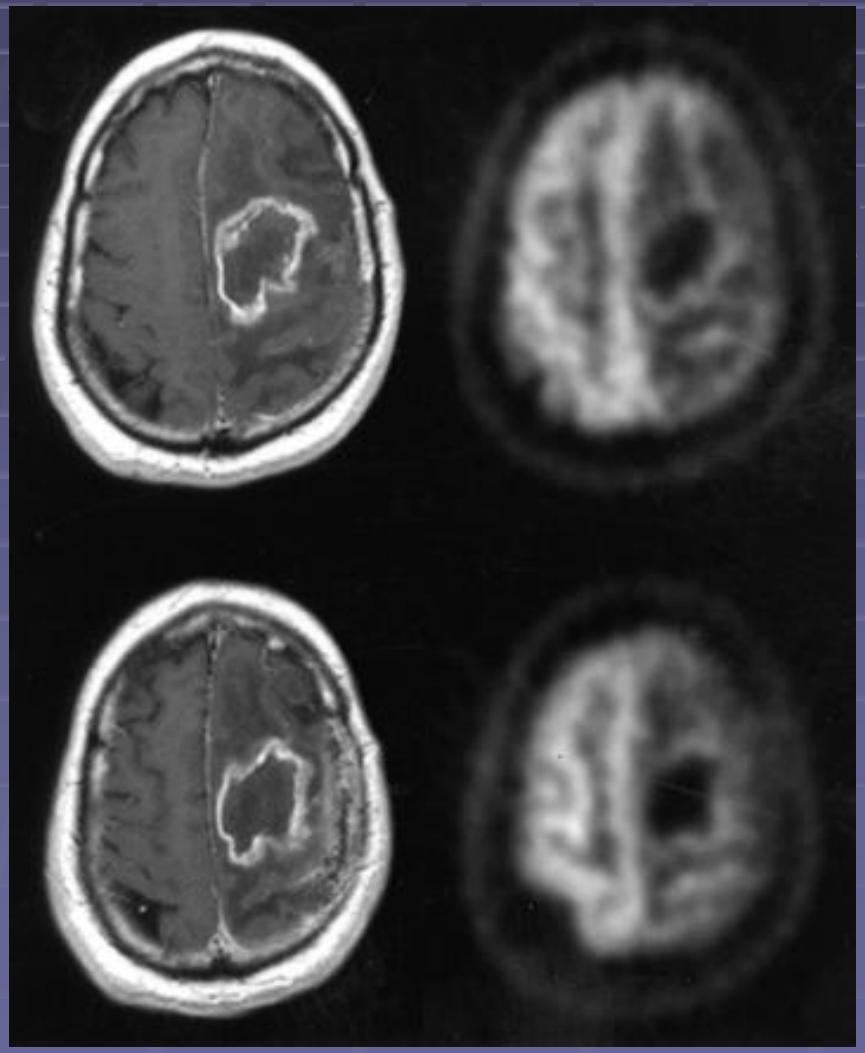
- Breast cancer

Unknown Primary Tumor

- PET imaged unknown primary tumors in about *one third of all patients* investigated.

Brain Tumors

- PET can differentiate scar or necrosis from persistent or recurrent tumor after surgery, chemotherapy or radiotherapy.



An F-18 FDG brain tumor study from a dedicated PET scanner.

MRI: enhancement

PET: Negative

MRI shows a rim-enhancing lesion in the right hemisphere. FDG-PET reveals a hypermetabolic rim (red arrow) consistent with high-grade astrocytoma. Note that such regions of hypermetabolism can be used as a guide for potential biopsy sites.