What Is Diagnostic Medical Imaging

The technology to extract clinical useful information in the format of images.

The Imaging involves physics, engineering, computer sciences, and biology.

2 Major Medical Imaging Methods

Transmission Radiation

- Conventional X-ray
- Computerized Tomography
- Magnetic Resonance Imaging
- Ultra-Sonography

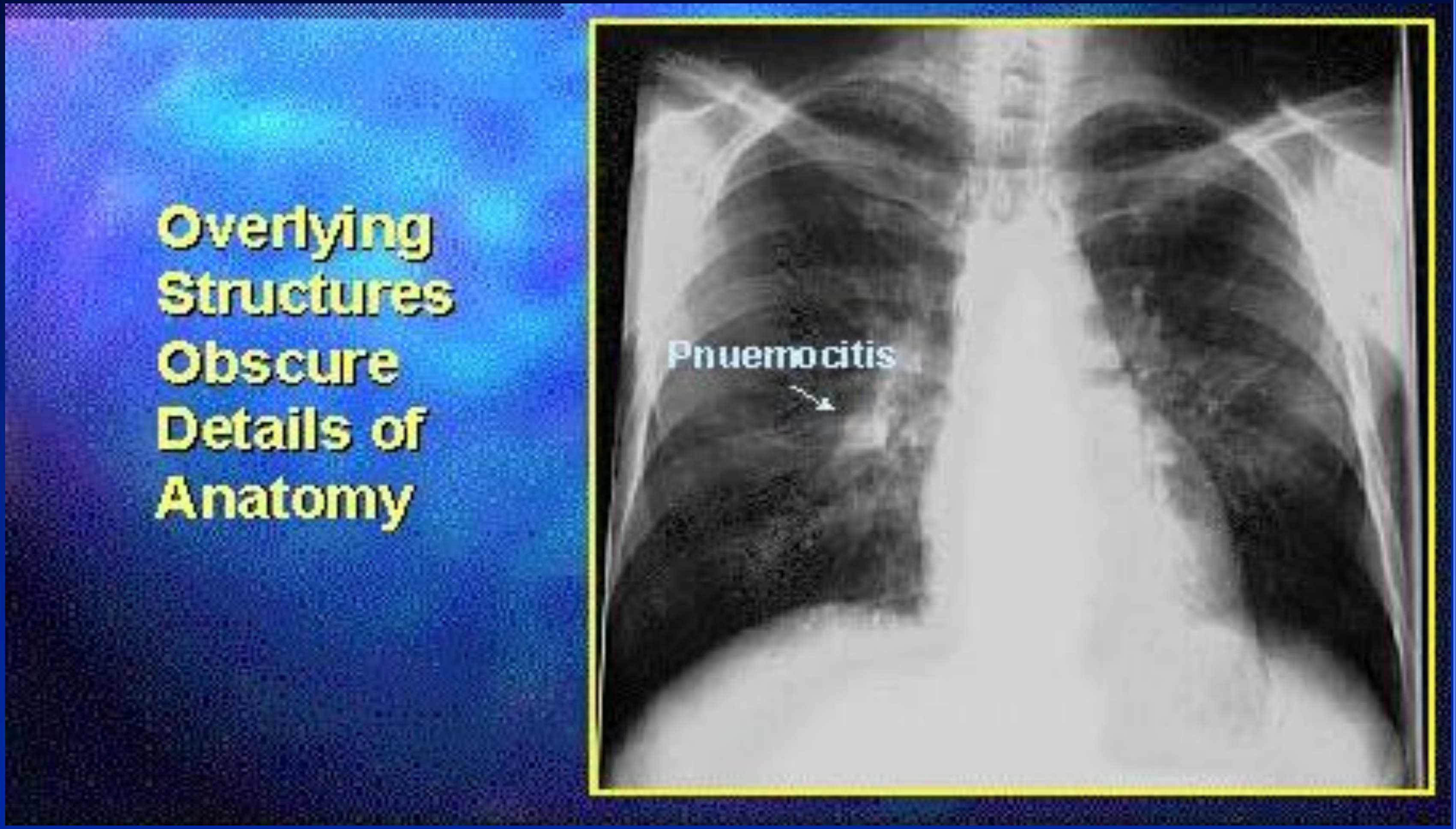
Emission Radiation

- Thermography
- Single Photon Emission tomography
- Positron Emission Tomography

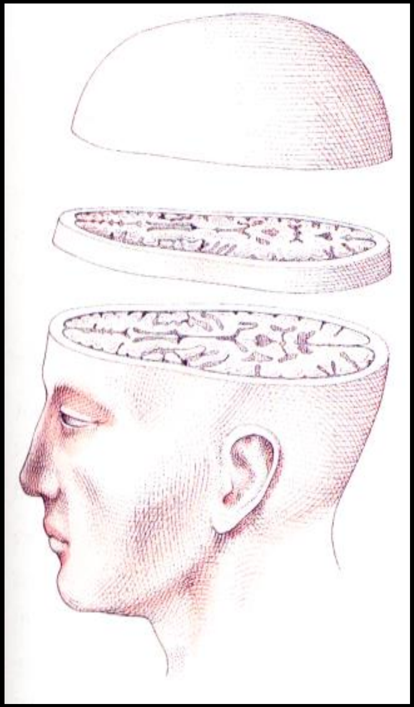
تصویربرداری بر مبنای نوع اطلاعات

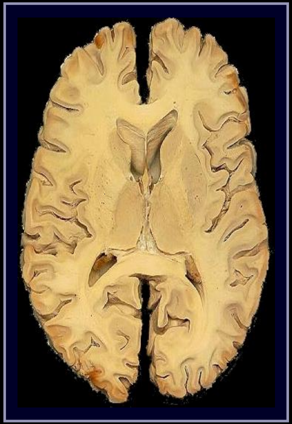
- 1) **تصو**یربرداری اطلاعات آناتومیک
- 2) **تصو**یربرداری اطلاعات فیزیولوژیک
- 3) تصویربرداری اطلاعات مولکولی (تغییرات شیمیائی و **متابولیک**)
- 4) **تصو**یربرداری اطلاعات عملکردی

Anatomical Imaging (Chest x-ray)



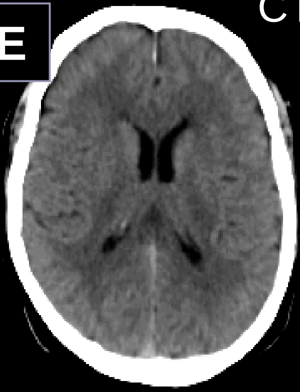
Structural & Functional Imaging



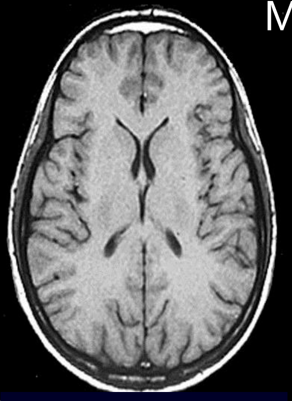


STRUCTURE

CT

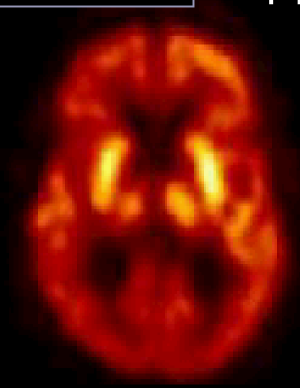


MRI

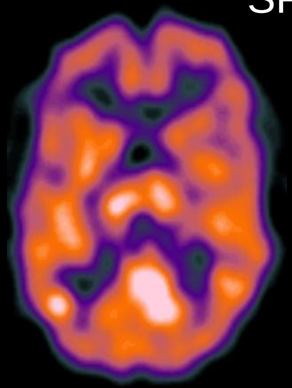


Metabolic & Perfusion

PET

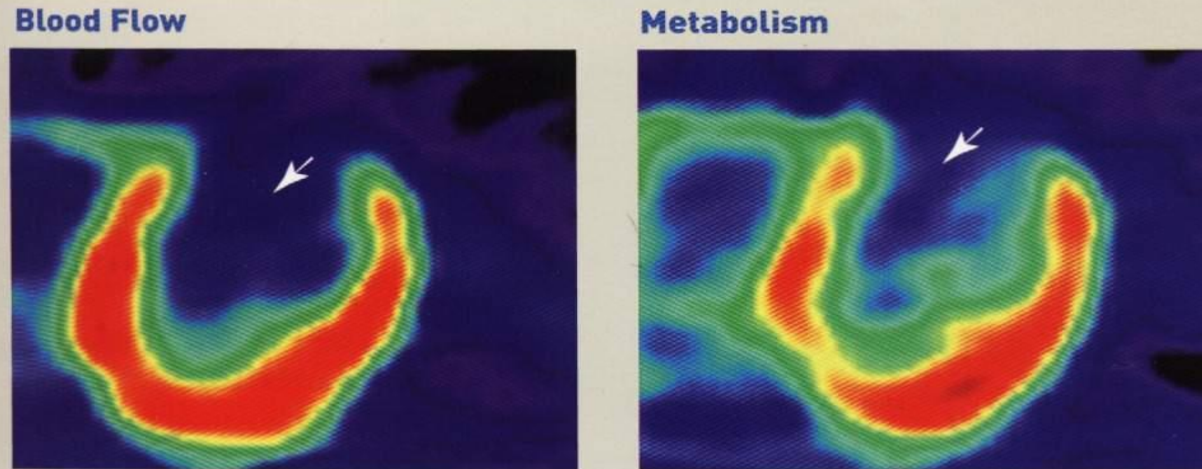


SPECT

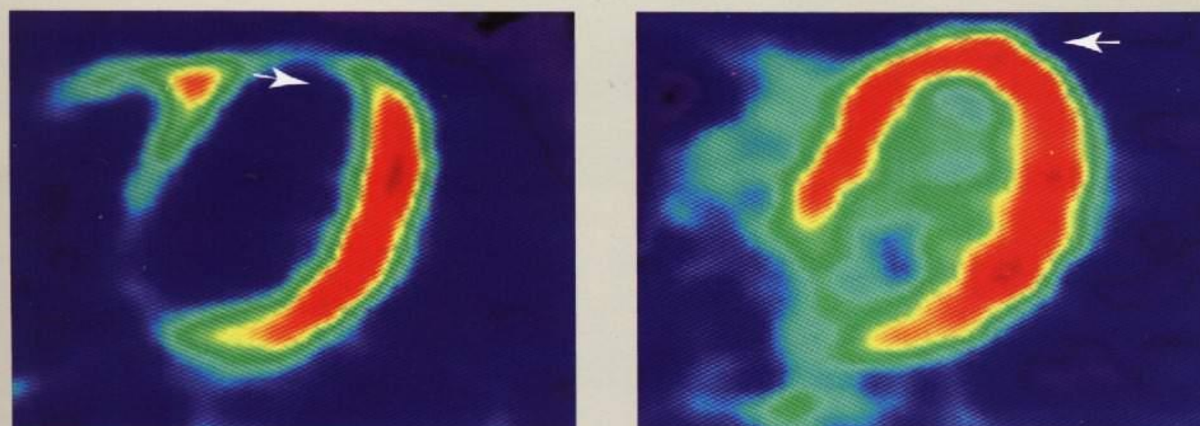


Nuclear Medicine is to physiology as Radiology is to anatomy

Comparison of Physiological and Metabolic Imaging (SPECT/PET)

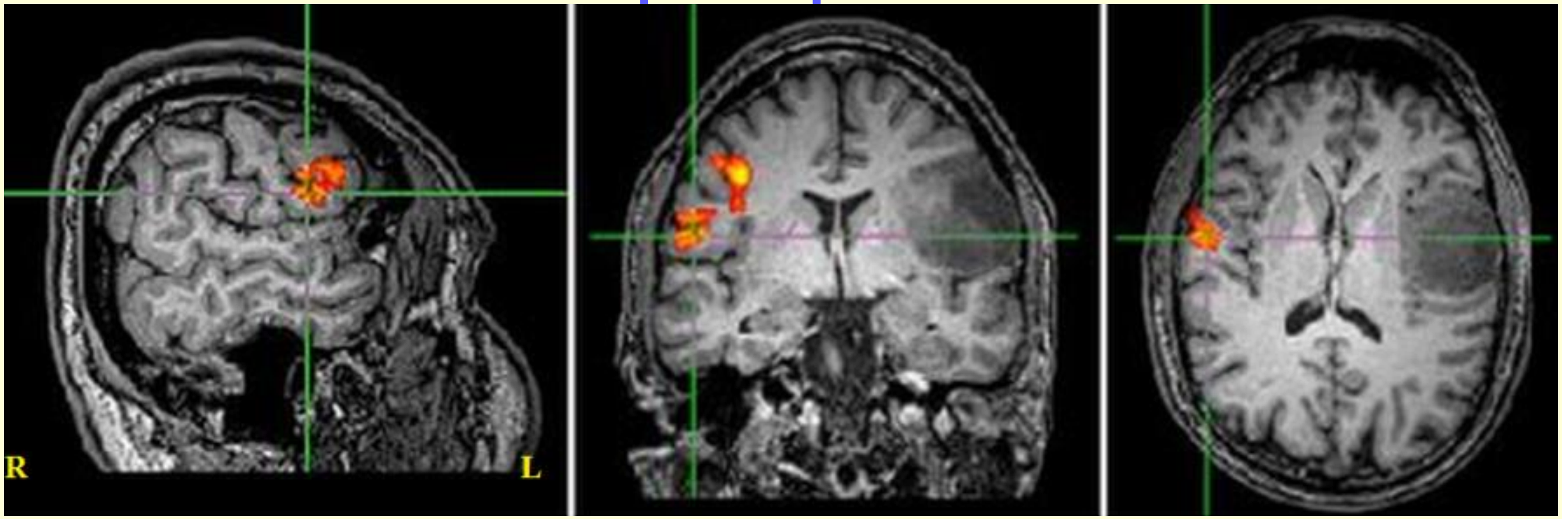


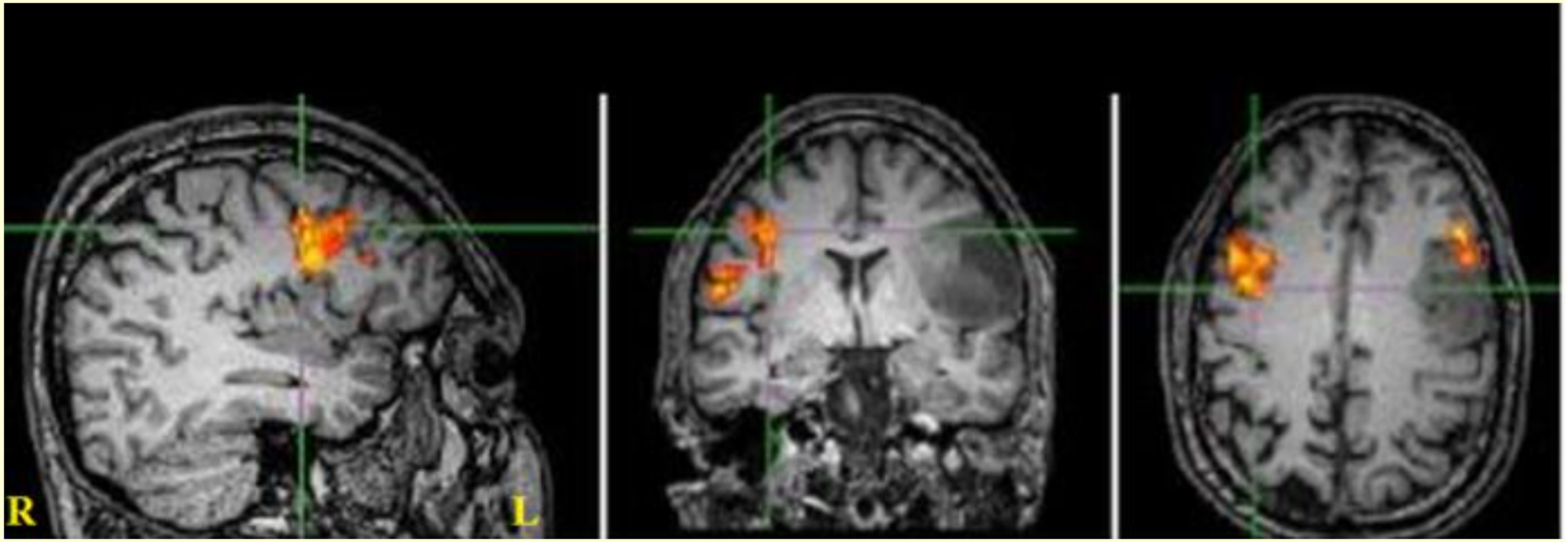
Both blood flow and metabolism are absent in a large area of this patient's heart *(see arrows)*. The absence of metabolism indicates that the tissue is dead, so a cardiac transplantation would be the treatment of choice.



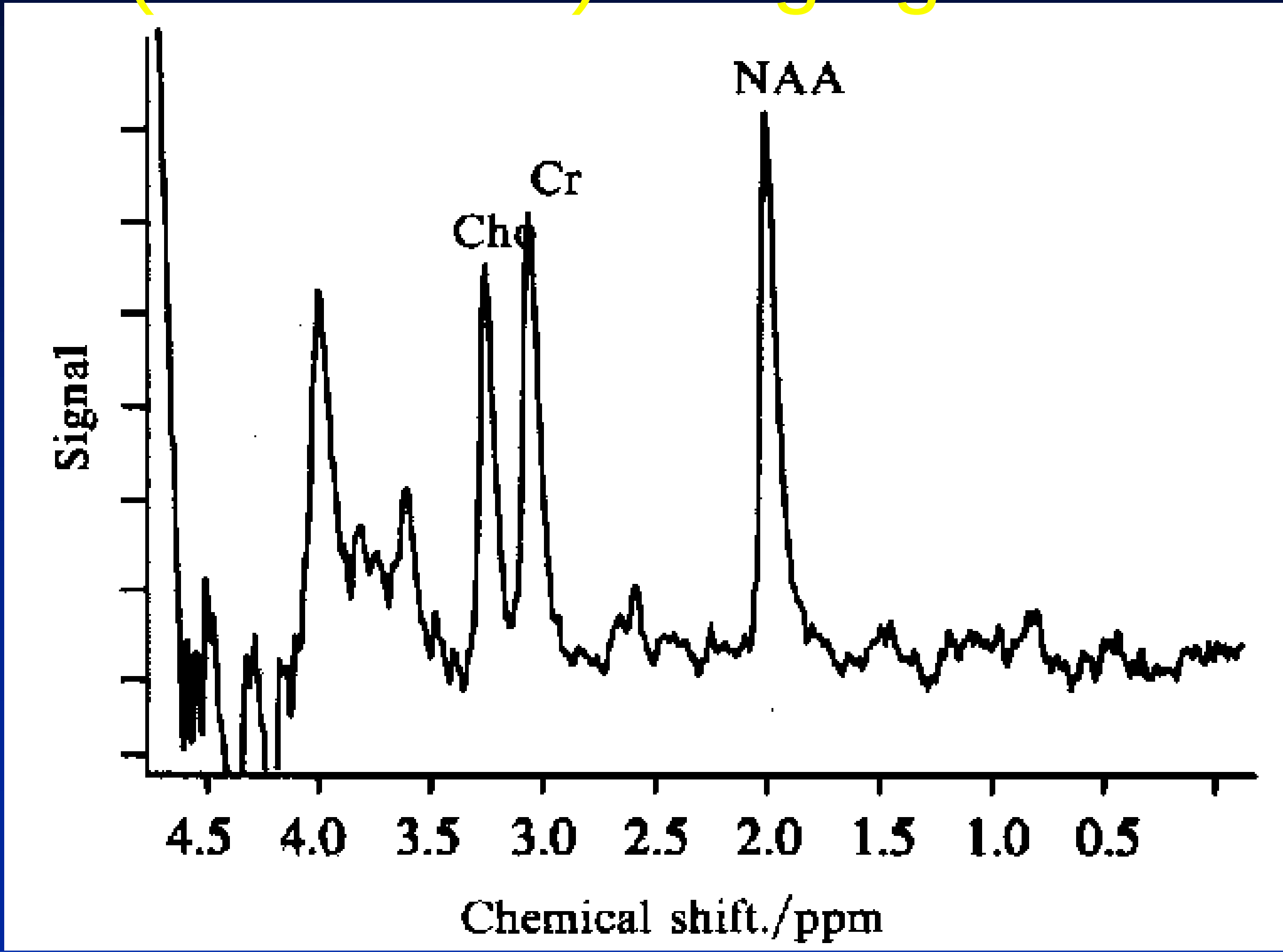
In another patient's heart, blood flow is poor, but metabolism is maintained, indicating the tissue is still alive. A transplant is not necessary for this patient, but bypass surgery would improve the function of the heart.

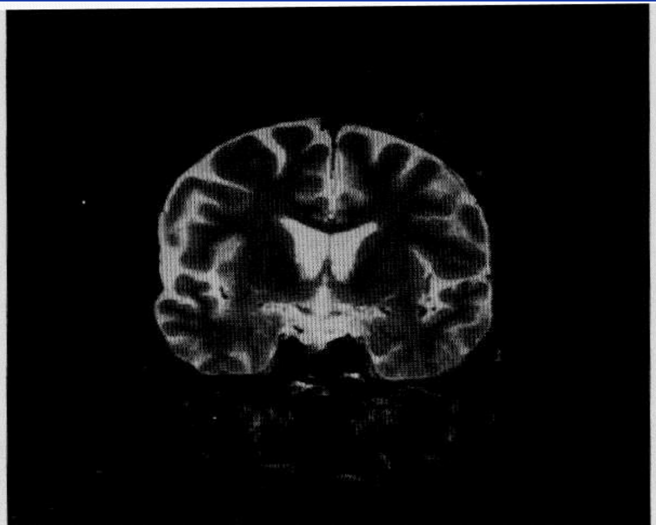
Functional MRI
Language task (WG) on left-handed patient with Temporoparietal mass





Another example of Chemical (Metabolite) imaging: MRS





g. 77-1 Coronal T_2-weighted image (2,200/90).

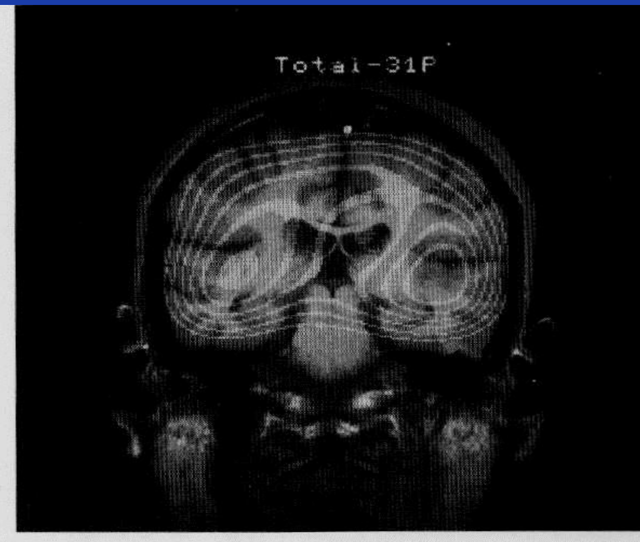
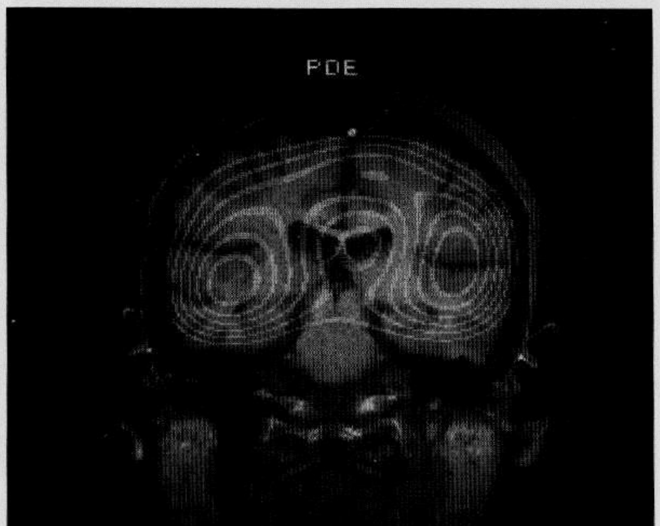


Fig. 77-2 Coronal ^{31}P contour map superimposed or T_1-weighted image (500/15).



g. 77-3 Coronal PDE contour map superimposed on T_1-weighted image (500/15).

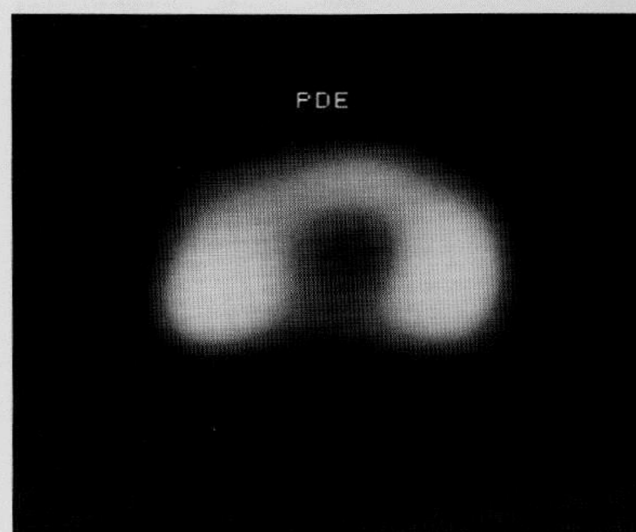


Fig. 77-4 Coronal PDE metabolite image.

Development of Imaging Methods

Two major advances from technologies developed during World War II (1 & 2)

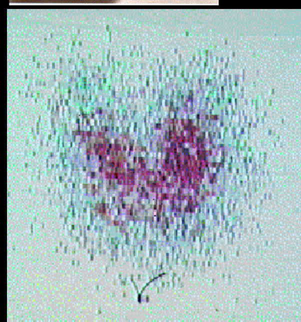
(1) Nuclear Medicine from the availability of radioactive materials from nuclear reactors during late 1940s

(2) Diagnostic ultrasound evolved from the development of SONAR (sound navigation and ranging);

Medical imaging techniques


Discovey of X-rays

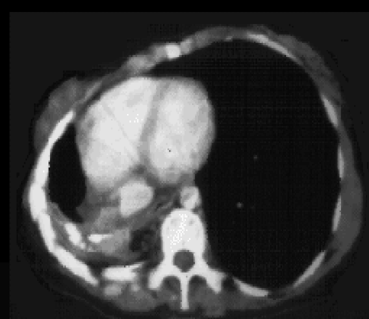
1901: Wilhelm Roentgen received the Nobel Prize for recognition of the extraordinary services he has rendered by the discovery of the remarkable rays subsequently named after him


Radiopharmaceuticals

1943: George de Hevesy received the Nobel Prize for his work on the use of isotopes as tracers in the study of chemical processes

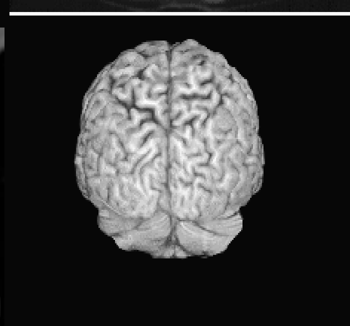





Development of X-ray CT

1979: Hounsfield & Cormack received the Nobel Prize for the development of X-ray computerized tomography (CT)





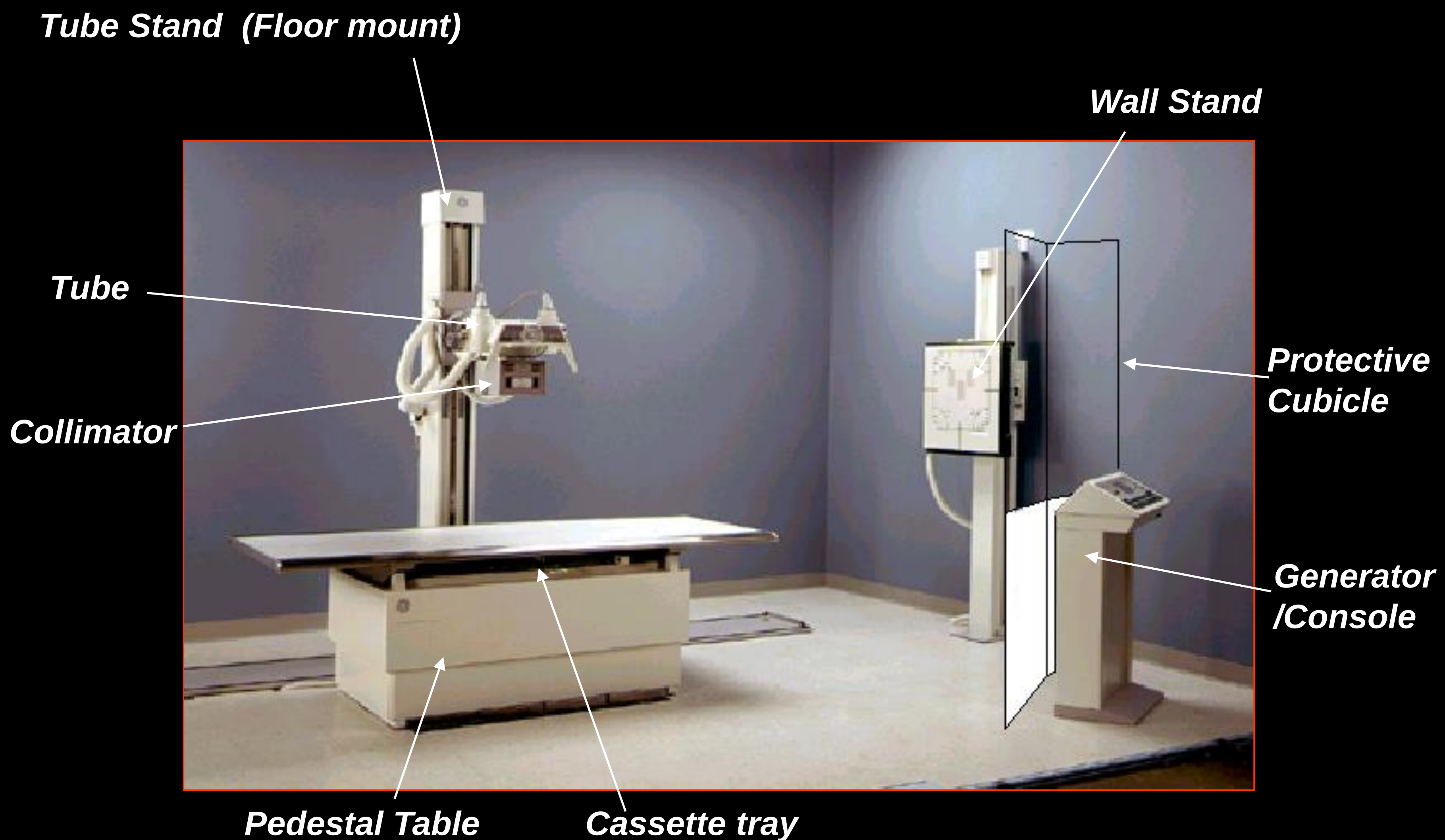

Development of MRI

2003: Lauterbur & Mansfield received the Nobel Prize for their discoveries concerning development of Magnetic Resonance Imaging (MRI)

WHAT DOES PROBE MEANS IN IMAGING ?

MODALITY	*PROBE*	*CHARACTERISTIC*
RADIOLOGY	*X-RAY*	*ELECTRON DENSITY*
MAMMOGRAPHY	*X-RAY*	*ELECTRON DENSITY*
CT	*X-RAY*	*ELECTRON DENSITY*
ANGIOGRAPHY	*X-RAY*	*ELECTRON DENSITY*
MRI	*RF*	*PROTON DENSITY*
SPECT	*GAMMA RAY*	*RADIONUCLIDE DIS.*
PET	*GAMMA RAY*	*RADIONUCLIDE DIS.*
SONOGRAPHY	*ULTRASOUND*	*ACOUSTIC IMPEDANCE*

BASIC RAD ROOM COMPONENTS



Fluoroscopic System

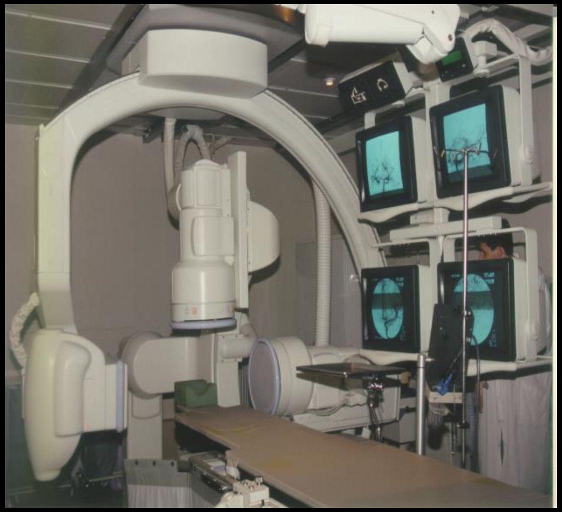
Field of View

Image intensifiers comes in different size, commonly 10, 15, 23, 30, 35 and 40 cm field of view (FOV).

Large IIs are useful for gastrointestinal/ genitourinary work, where it is useful to cover the entire abdomen

For cardiac imaging the 23 cm II is adequate where its smaller size allows tighter positioning.

C-Arm



Cardiac

Cardiovascular

Vascular

Digital Radiology System

<u>Revolution XR/d Digital Radiography</u>

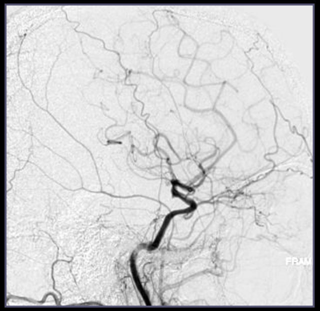
- Digital-Detector size 41cm x 41cm
- Elevating table

<u>Revolution XQ/i Digital Chest System</u>

- Digital-Detector size 41cm x 41cm
- Floor stand with auto-tracking
- ADVANCED RADIOGRAPHY PACKAGE I

Vascular Systems

- **Innova 2000 Digital Cardiology**
- *Digital-Detector 20cm x 20cm*
- *Matrix 1K x 1K x 14 bit*
- *Dynamic Acquisition*
- *Up to 30 Images per Second*
- *Advanced Radiography wip*
- *Package (RIS/HIS/PACS)*

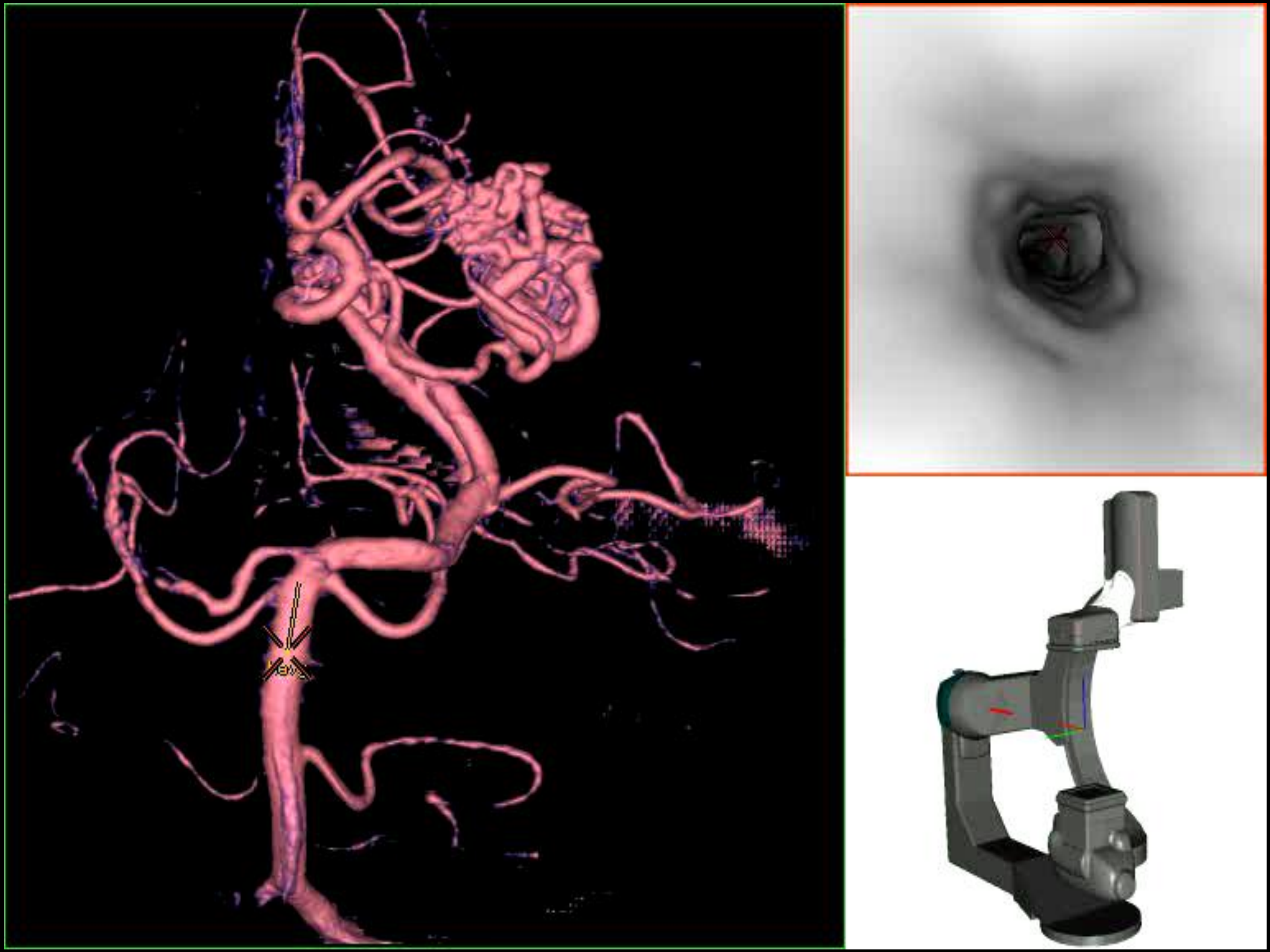


Innova 4100 Digital Vascular / Interventional

Digital-Detector size 41cm x 41cm

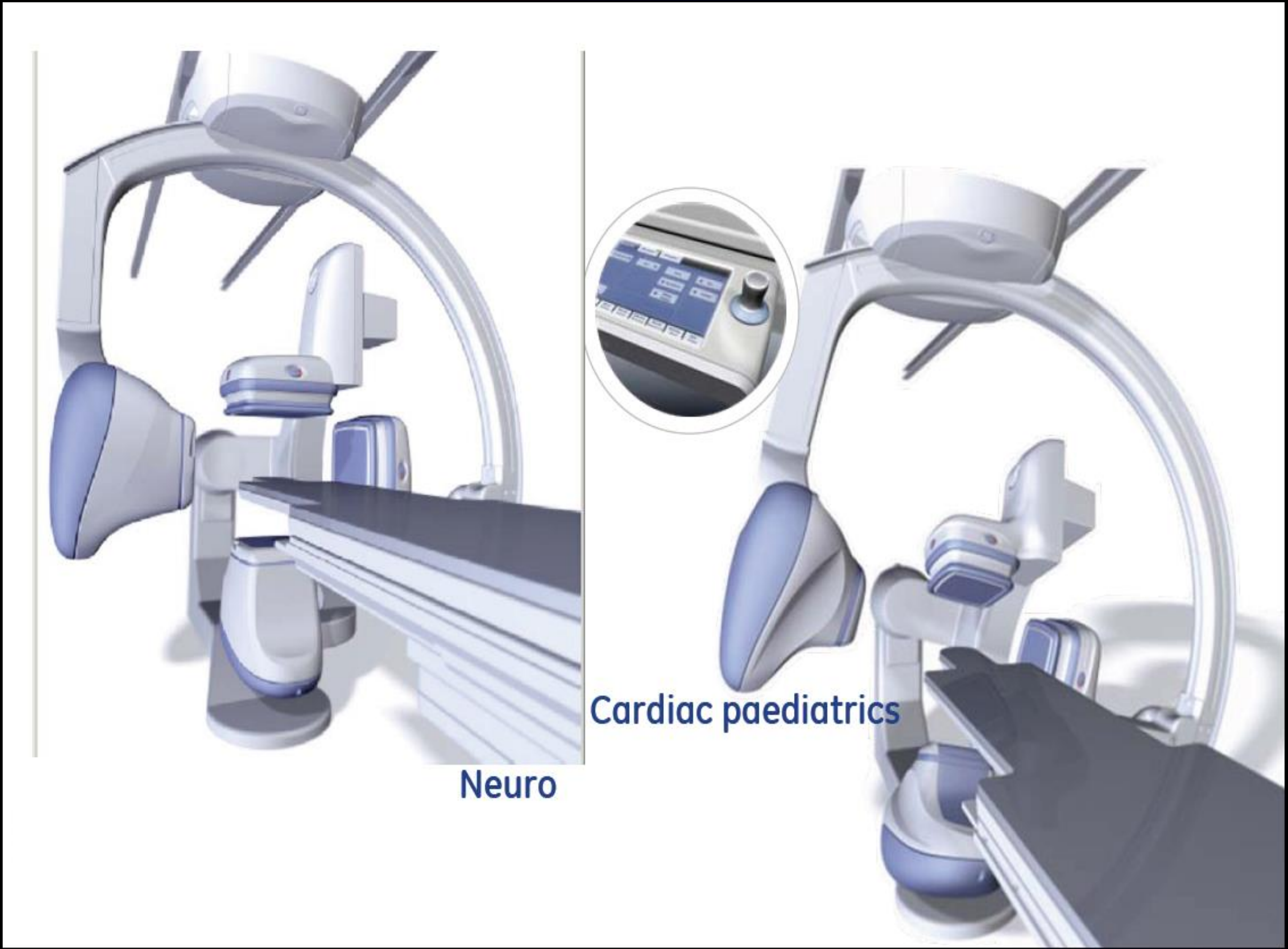
- *Matrix 2K x 2K x 14 bit*
- *Dynamic Acquisition*
- *Up to 30 Images per Second*

Navigation

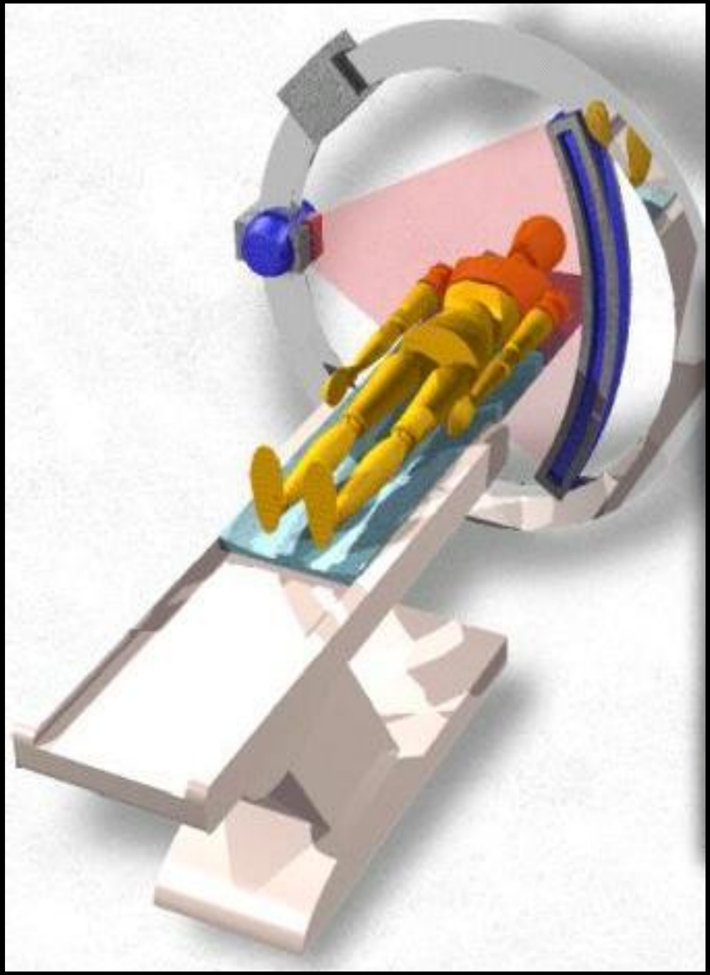


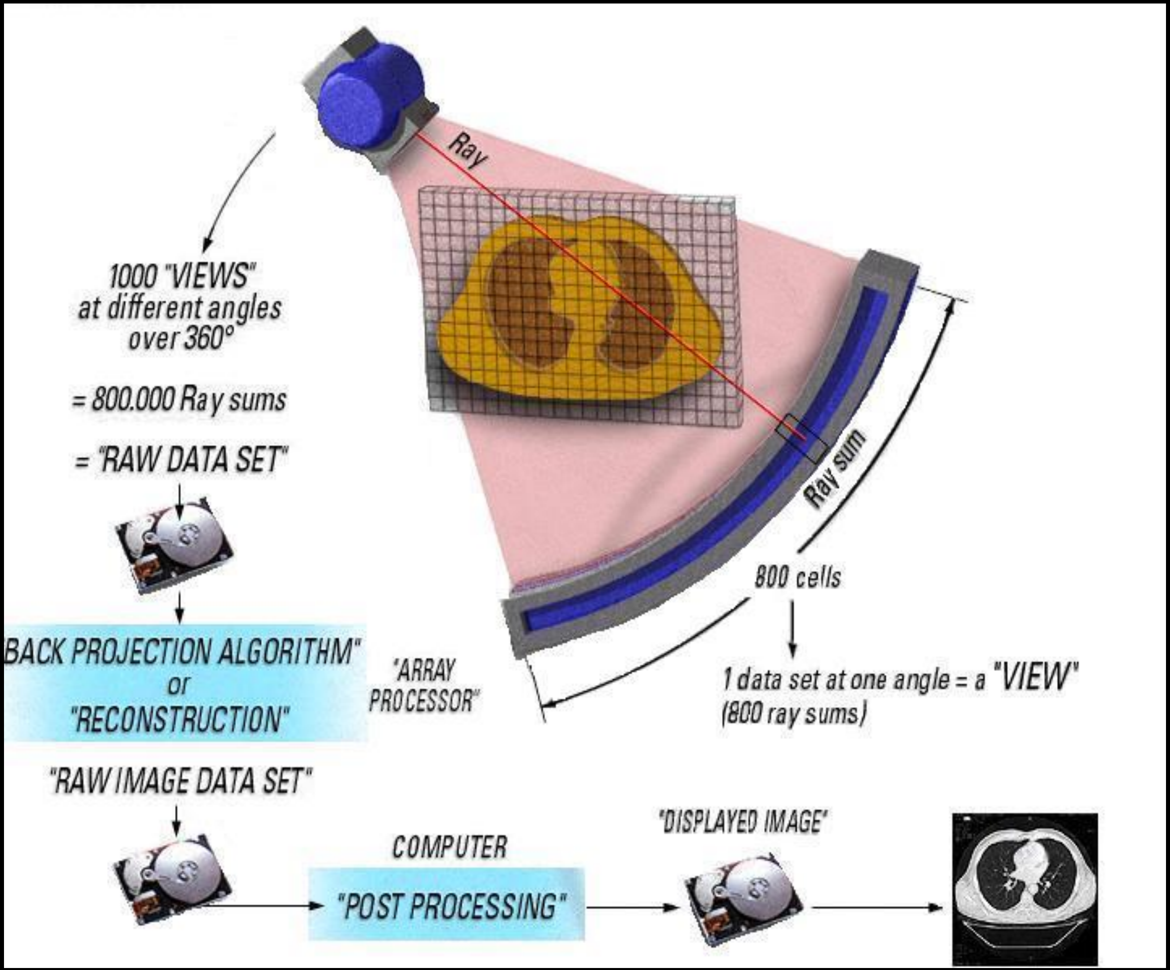
Vascular System

Biplane Systems



CT imaging chain



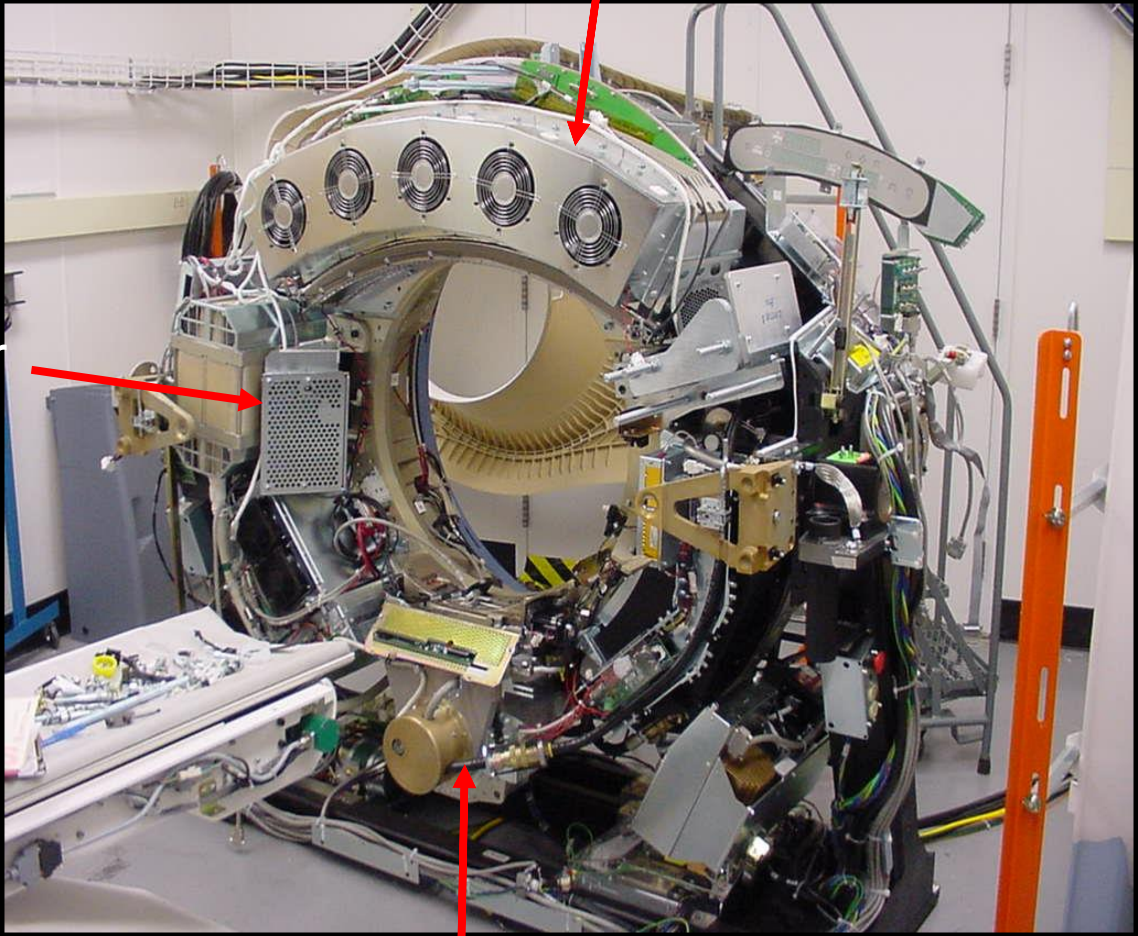


Courtesy: GE Healthcare

Volume CT Hardware?

Detector Bank & On Board comput

Generator



Tube

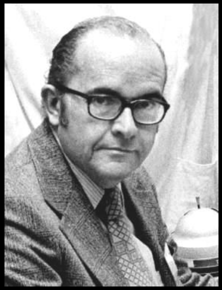
CT timeline

The Big Bang

1895 Röntgen X-rays

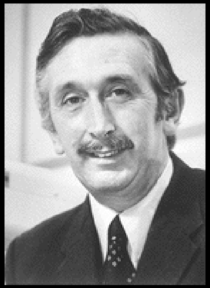
1917 Radon inversion

1961 Oldendorf experimental



1963 Cormack experimental

1972 Hounsfield EMI scanner



1973 Ledley ACTA scanner

1989 spiral CT

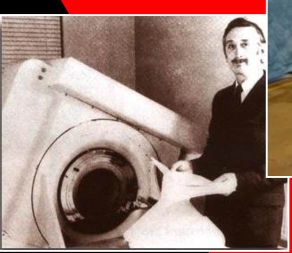
1998 multi-slice CT

2004 VCT

2007 FPCT

CT continuum….

From one slice per rotation
to
One organ per rotation



1972
The first CT Scanner

1980
Third generation

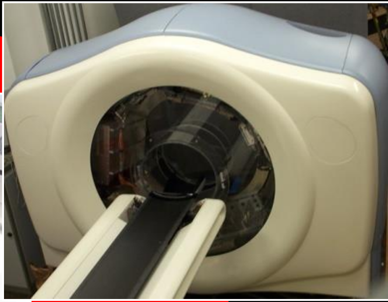
1989
Spiral CT

1998
Multi Slice CT

2002
16 Slice CT

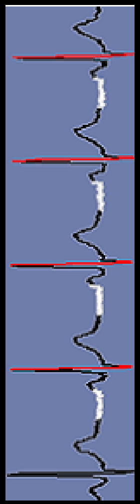
2004
64 Slice CT(VCT)

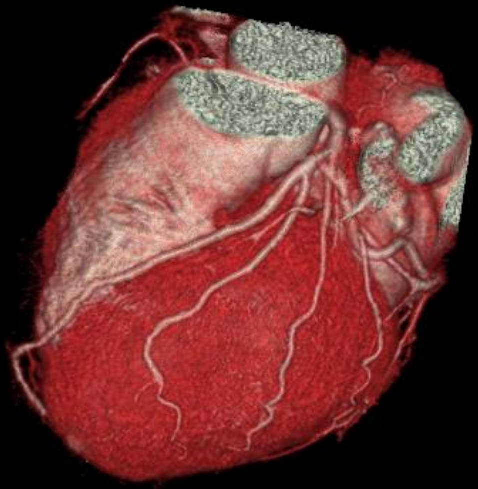
2008
Volume CT with Flat Panel Detector



WIP

What You Get in 5 Heart Beats





5-Beat Cardiac™

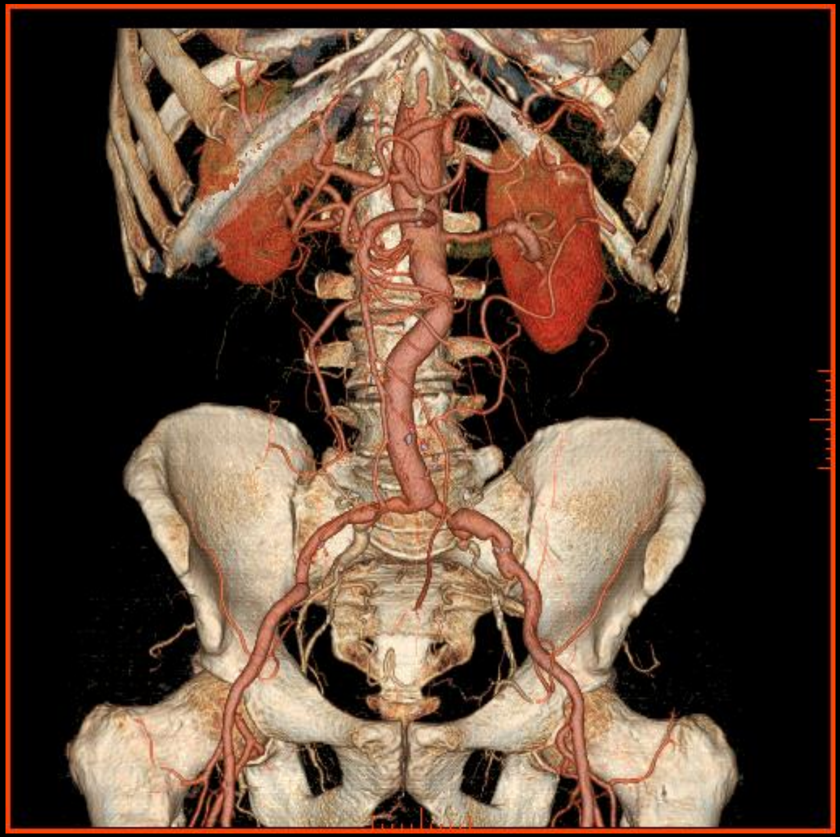
40 mm detector
Pitch ~0.25

12.5 cm in 5 sec

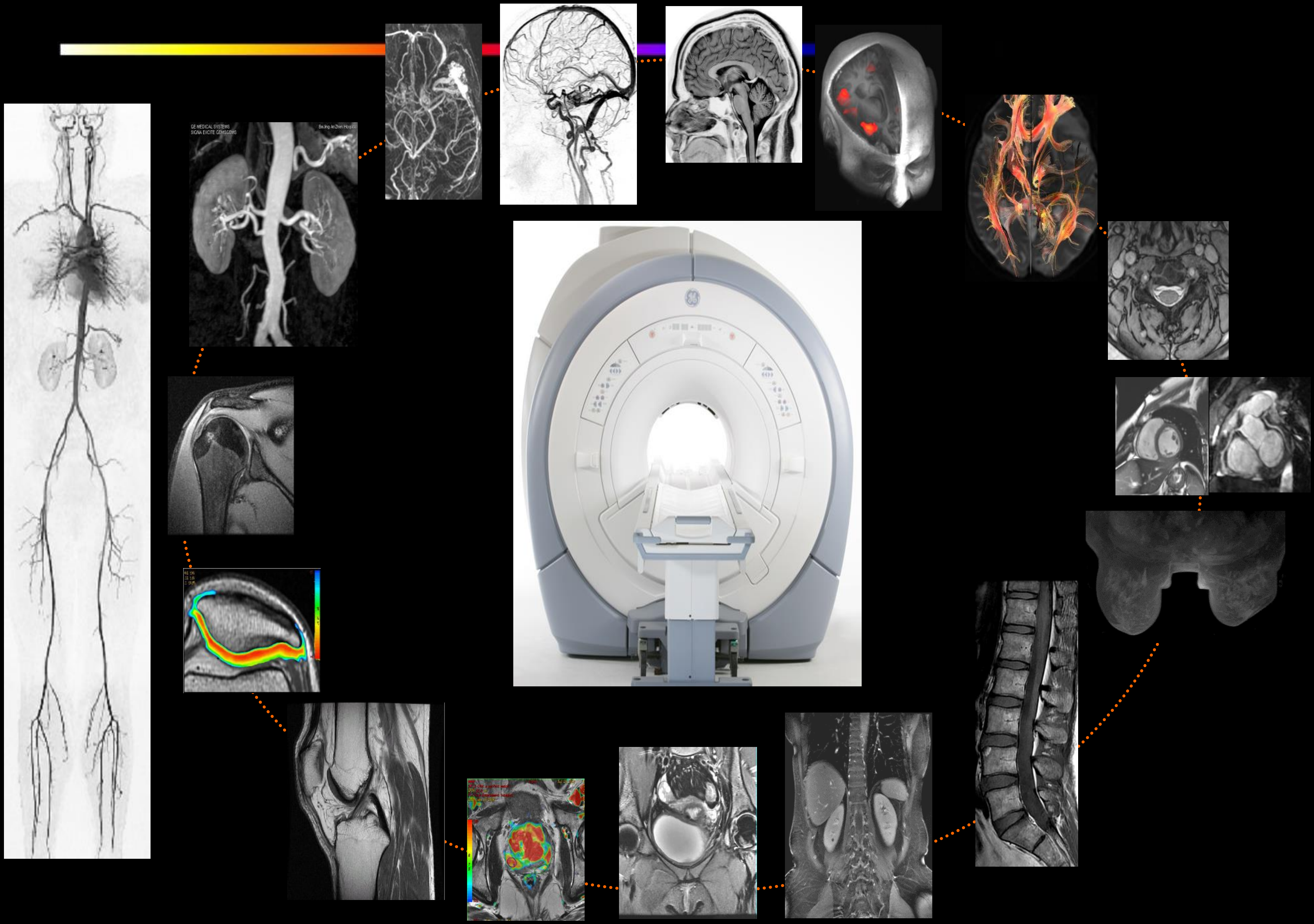
More coverage
Exam reliability
Pure arterial phase
High spatial resolution…

Application of Multi Slice CT

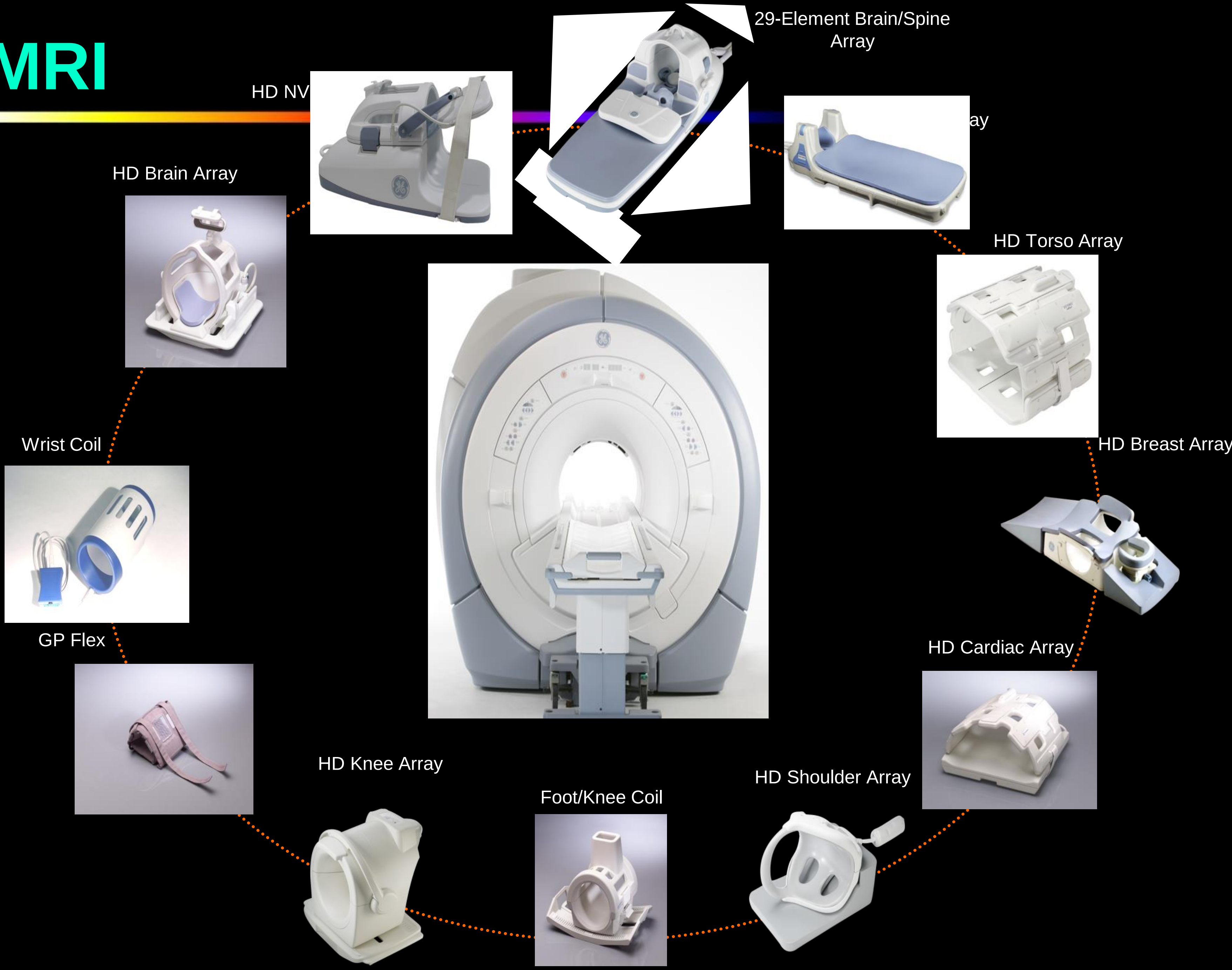
Volume View with Autobone



3.0T MRI– Be Capable across all Procedures



MRI

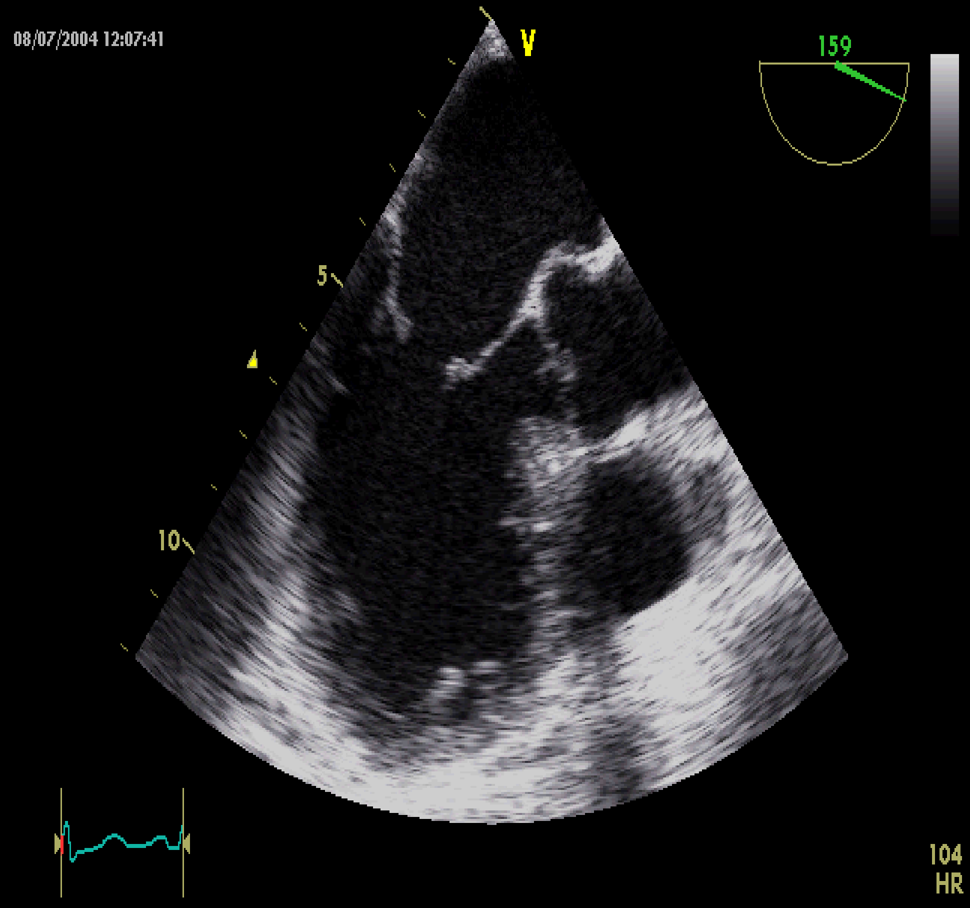


HD NV
29-Element Brain/Spine Array
HD Brain Array
HD Torso Array
Wrist Coil
HD Breast Array
GP Flex
HD Cardiac Array
HD Knee Array
Foot/Knee Coil
HD Shoulder Array

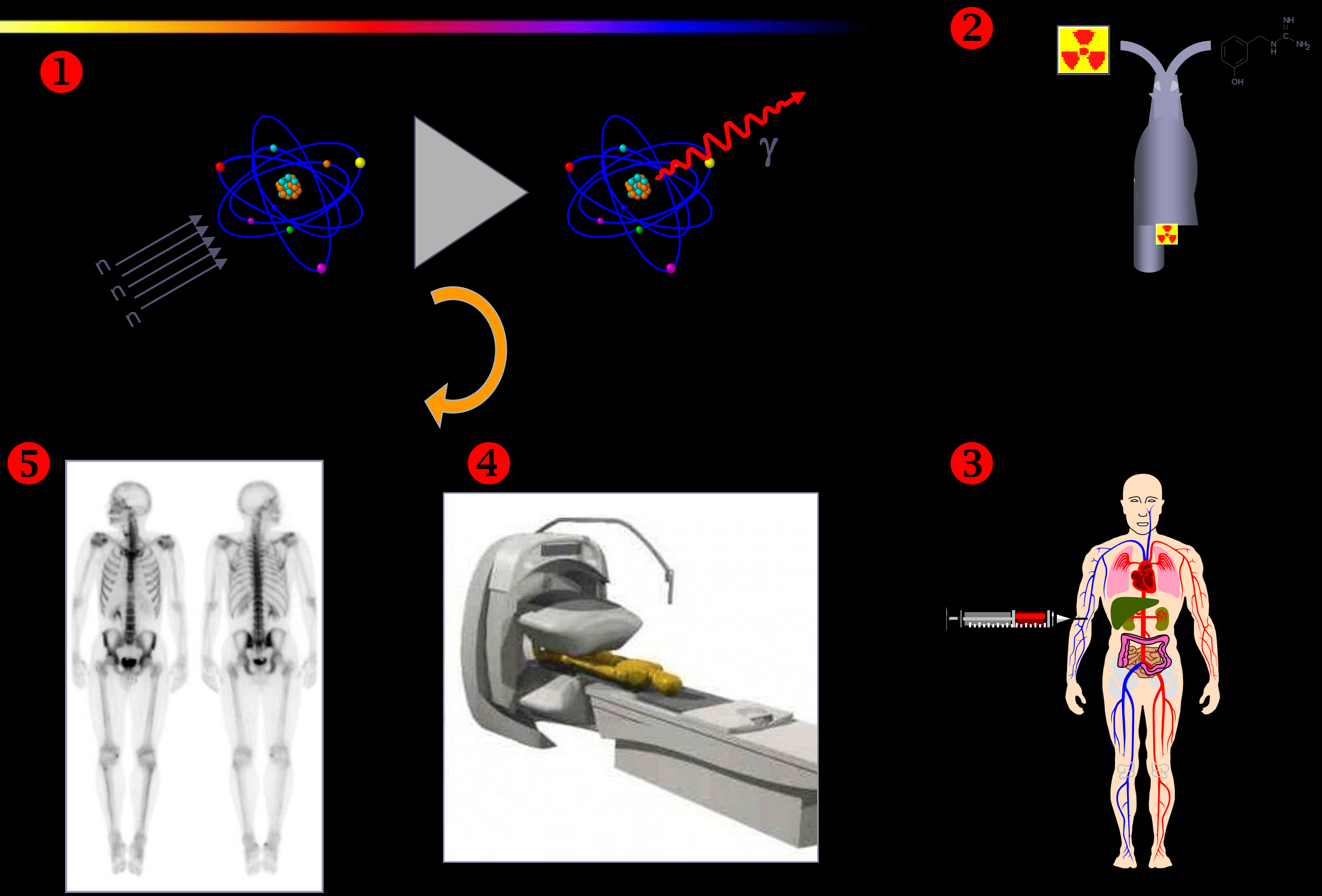
Sonography

Surface 32 weeks“

A New Generation of Cardiovascular Ultrasound



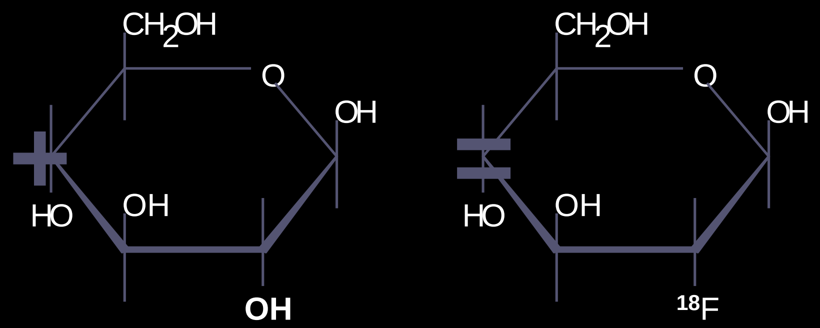
NM and PET Process



Radioisotopes and Radiopharmaceuticals

- **Radioisotope** is the radiation source (radioactive atom)
- **Pharmaceutical** is the vector molecule that targets the organ
- Radioisotope + pharmaceutical = radiopharmaceutical (radiotracer)

^{18}F



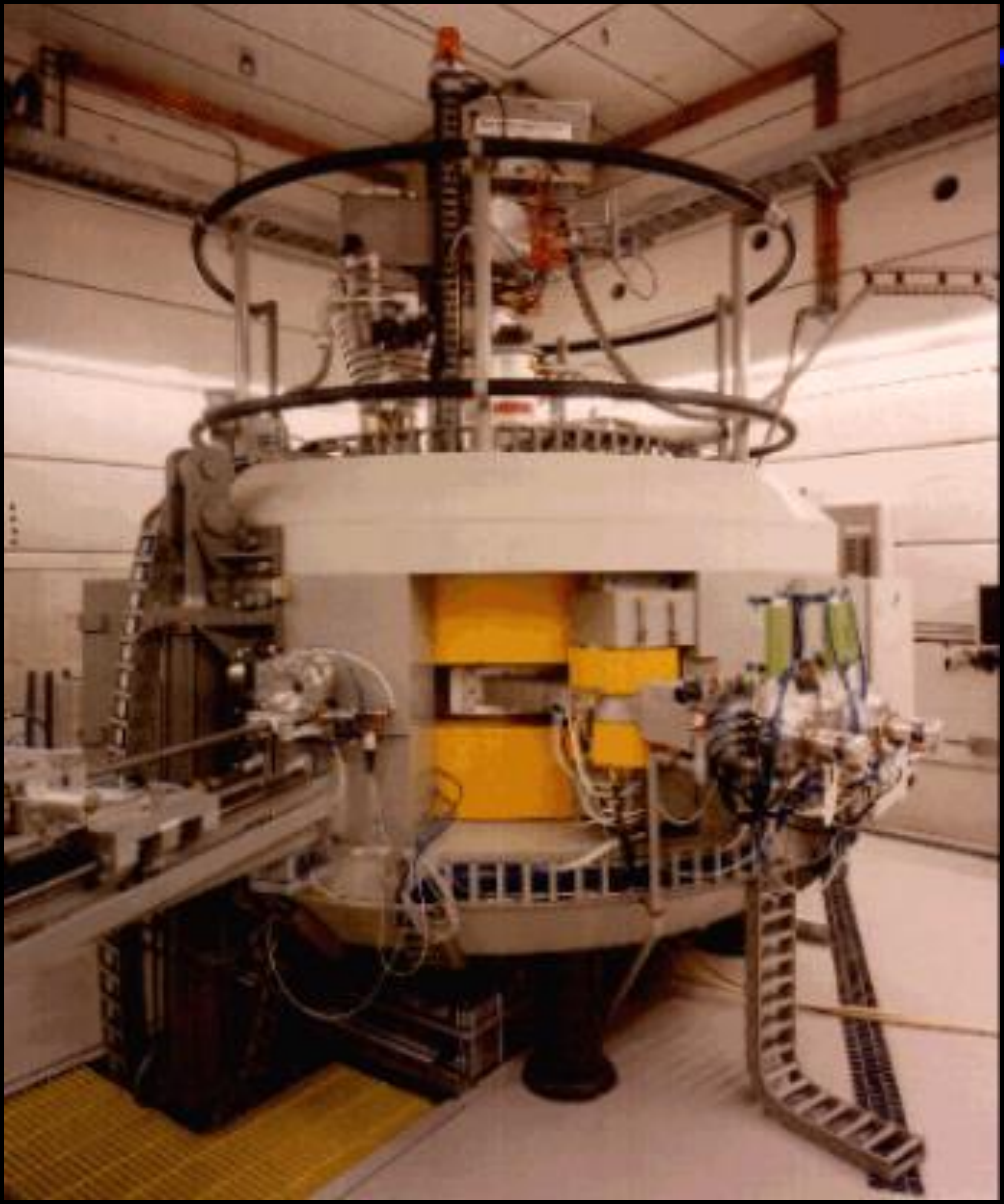
Fluorine-18 + Glucose = ^{18}F-FDG

NM Radioisotopes produced with reactors

Molybdenum-99/Technetium-99m
Bismuth-213
Chromium-51
Cobalt-60
Copper-64
Dysprosium-165
Erbium-169
Iodine-125
Iodine-131
Iridium-192
Iron-59
Lutetium-177
Palladium-103
Phosphorus-32
Potassium-42
Rhenium-186
Rhenium-188
Samarium-153
Selenium-75
Sodium-24
Strontium-89
Xenon-133
Ytterbium-169
Ytterbium-177
Yttrium-90

Radioisotopes of cesium, gold and ruthenium used in

Cyclotron NM Radioisotopes



IBA C30

Cobalt-57 - Used as a marker to estimate organ size and for in-vitro diagnostic kits.

Gallium-67 - Used for tumors imaging and localization of inflammatory lesions (infections)

Yttrium-86 – Convenient PET agent, for use in Oncology

Indium-111 - Used for specialist diagnostic studies, e.g brain studies, infection and colon transit studies.

Iodine-123 beta radiation of I-131.

Iodine 124, early stage evaluation

Krypton-81m (13 sec) from Rubidium-81

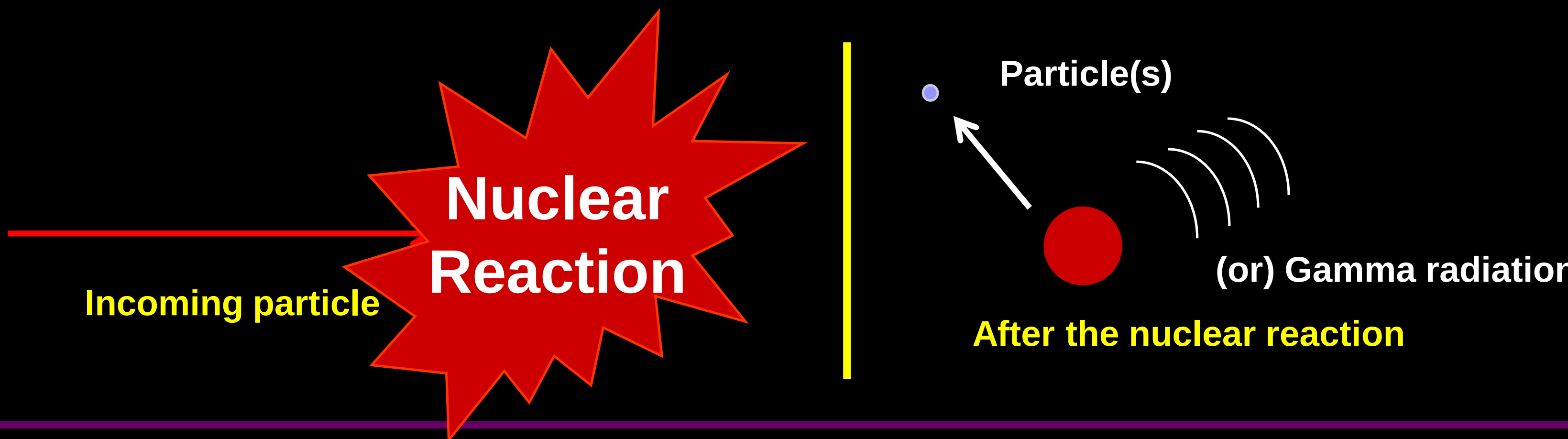
Rubidium-82 (65 h): Convenient PET agent in myocardial perfusion imaging.

Strontium-92 (25 d): Used as the 'parent' in a generator to produce Rb-82.

Thallium-201 - Used for diagnosis of coronary artery disease other heart diseases

Nuclear Reactions : How does it works ?

During a nuclear reaction a target nucleus is bombarded with some particles : the atomic numberZ is changed (adding or removing particles) and the final nucleus is ‘unstable’ i.e. radioactive. A radioactive nucleus always get out energy, in form of particles or EM radiation.



Atomic number for the reacting nucleus

Atomic number for the formed nucleus

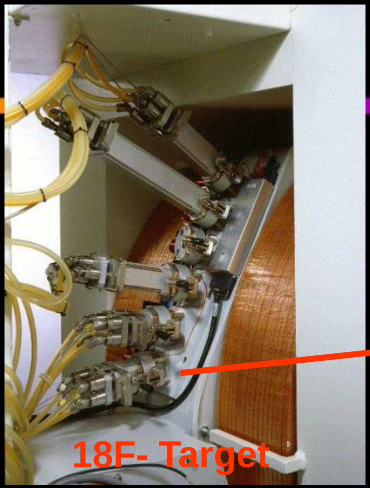
$$^{Z1}A\ (p,n)\ ^{Z2}B$$

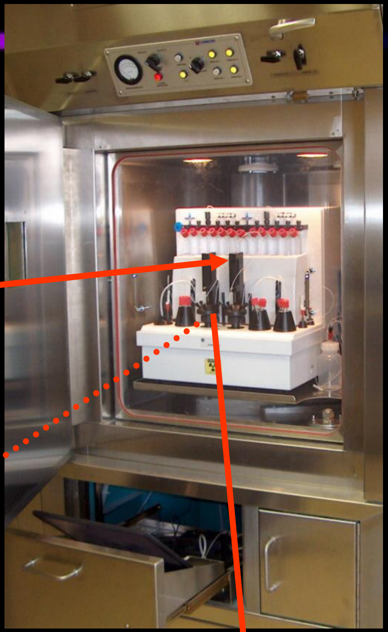
Incoming particle

Expelled particle

FDG Production Cycle

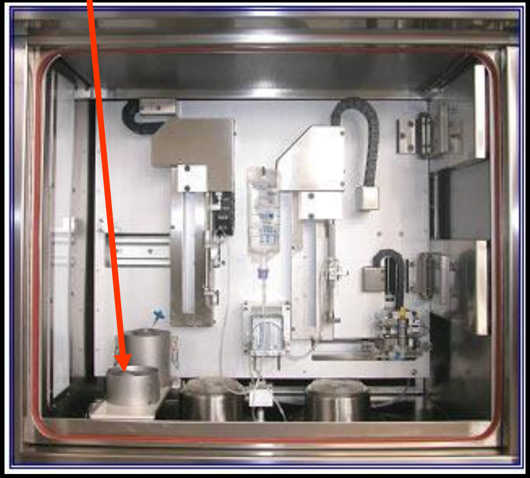
Target Irradiation,
➔ 18F- Production





18F- is automatically transferred in to the synthesis unit
➔FDG Production

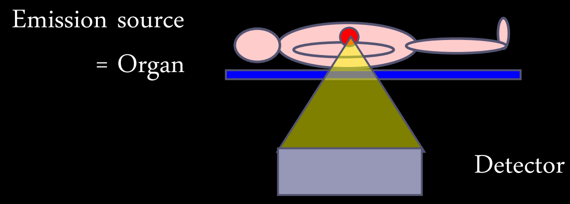
A small amount is moved to the QC Lab to check final Quality of the Product



Finally FDG is transferred to the manual (or automatic) dispenser unit

Why is NM different?

Nuclear Medicine

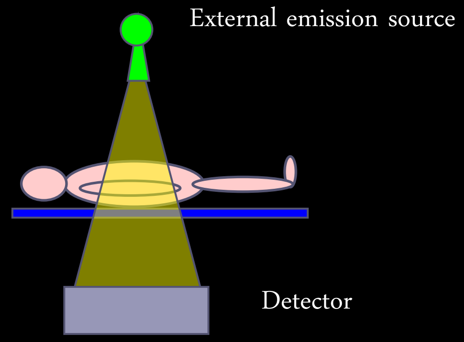


Functional imaging

How does it work?

Other imaging modalities

(X-ray, CT, MR, etc.)



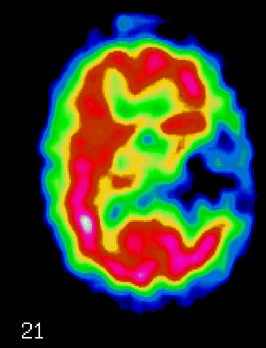
Anatomical imaging

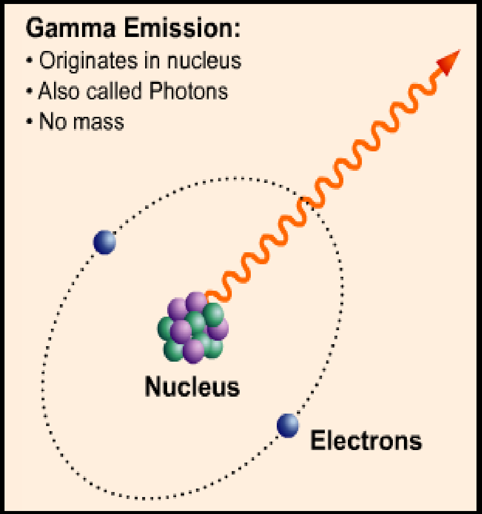
How does it look?

Nuclear Medicine acts as a complement to other modalities, not in replacement.

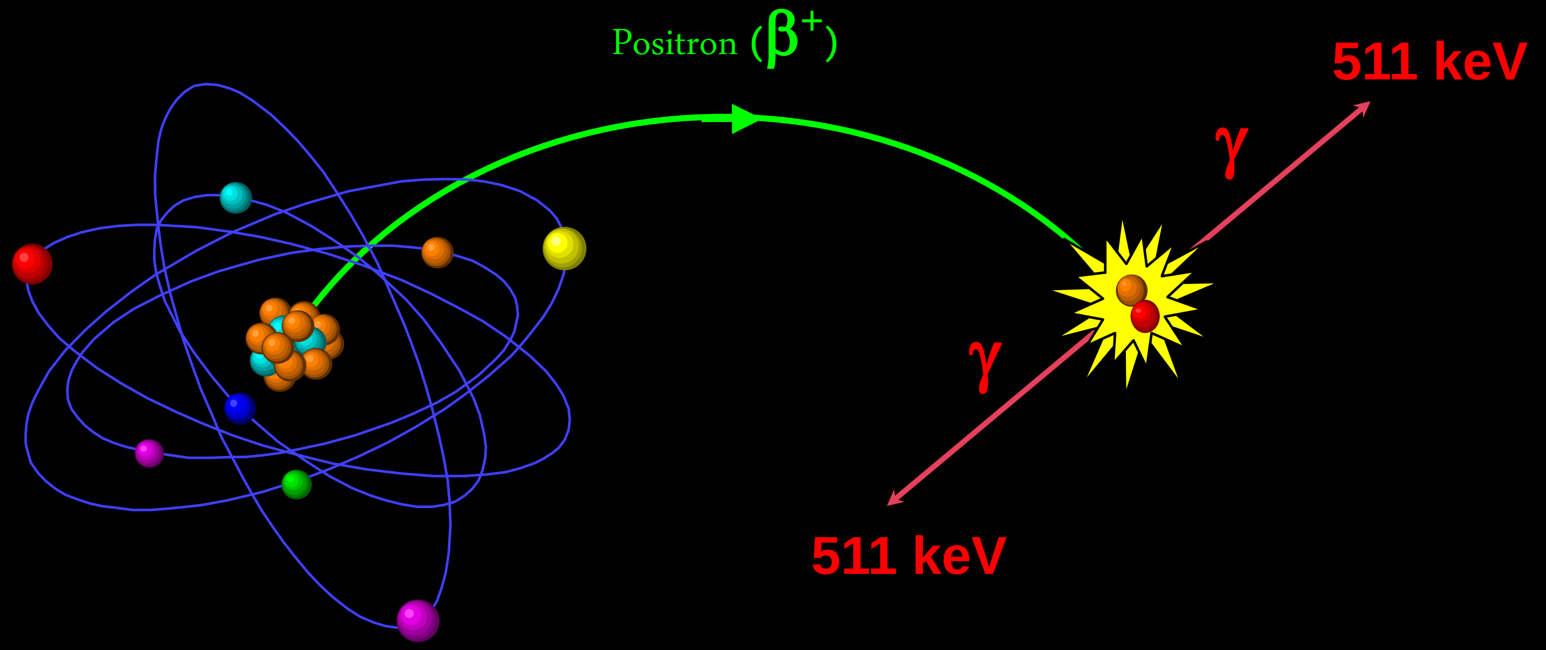
SPECT Physics: Gamma Emission

Gamma rays are of primary interest in functional imaging.





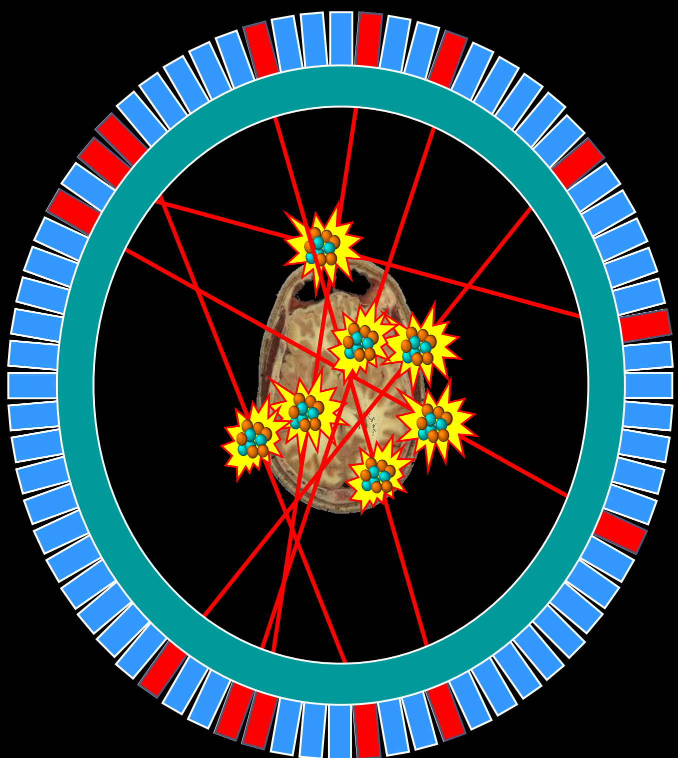
PET Physics: Positron Decay



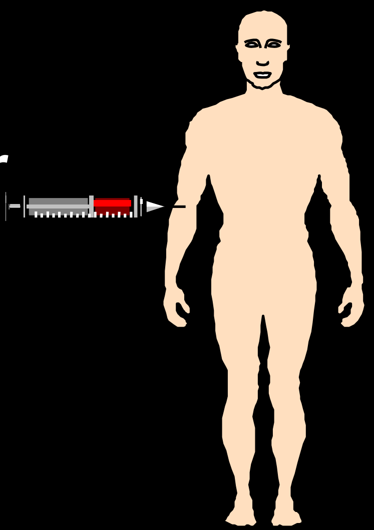
The radioisotope emits a positron.
The positron produced interacts with an electron. A reaction transforms the two particles into two photons of 511 keV emitted in exactly opposite directions.

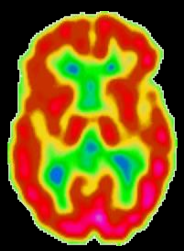
PET data acquisition

Detector ring



Radiotracer injection

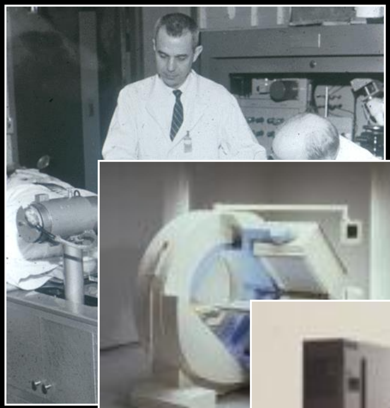




The response lines joining the detector pairs having recorded coincidence events are used for clinical data reconstruction

PET = Positron Emission Tomography

Evolution of PET Instrumentation

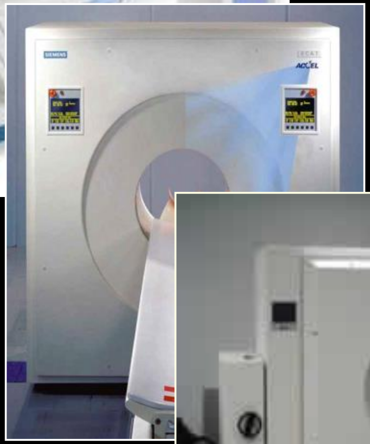


First PET device (1951)
GL Brownell and W Sweet (MGH)

e.cam duet
1” crystal imaging technology

ECAT ART
Partial-ring

Advance Nxi
Full-ring



ECAT ACCEL
LSO technology

ECAT HRRT
Phoswich technology

1st PET device 1952

PET III 1975

ECAT II 1977

NeuroECAT 1978

ECAT 931 1985

EXACT HR+ 1995

HRRT LSO 2000

What are NM & PET used for?

Large number of applications

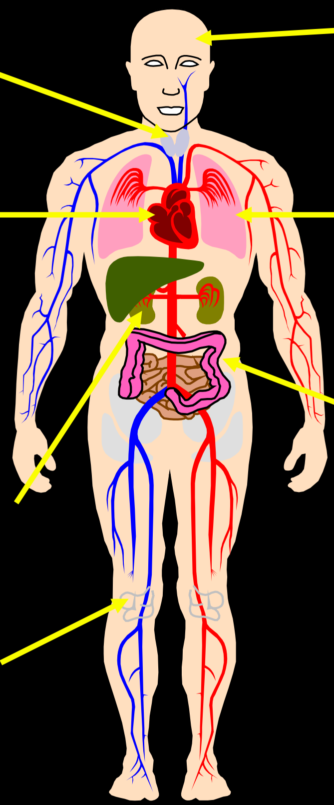
Physiology of many organs can be explored using radiopharma-ceuticals substances.

Thyroid/ Parathyroid malfunction

Coronary artery deseases & Cardiac function evaluation

Renal dysfunction

Bone deseases



Neurology: Dementia and stroke

Polmonary enbolism

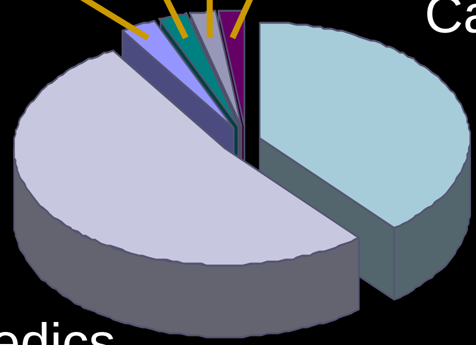
Gatroenterology

Spread of cancer

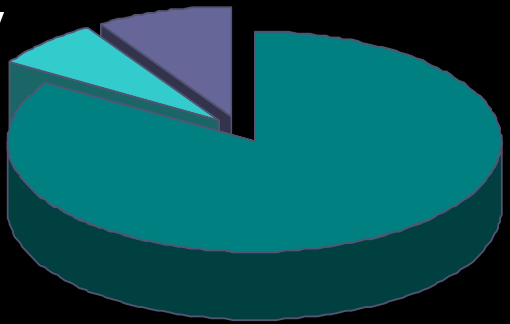
Infection/inflamation

NM Procedures

Single Photon Emission Scintigraphy



PET Imaging

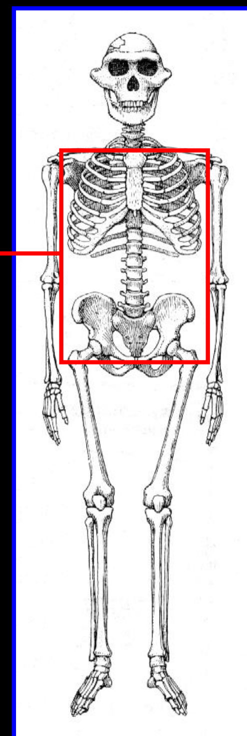


Breakdown of NM/PET procedures in U.S. (year 2000)

Orthopedics

- Bones and joints
- Fracture, infection, inflammation, primary and secondary cancer

^{99m}Tc-MDP bone tomoscintigraphy.
Multiple foci of abnormal tracer uptake on the spine and the pelvis after left iliac crest ablation.

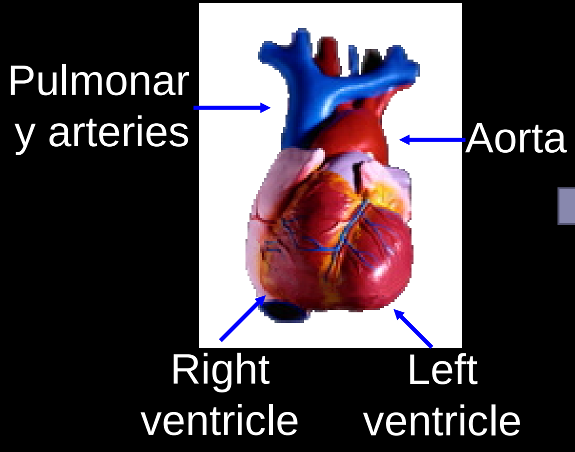


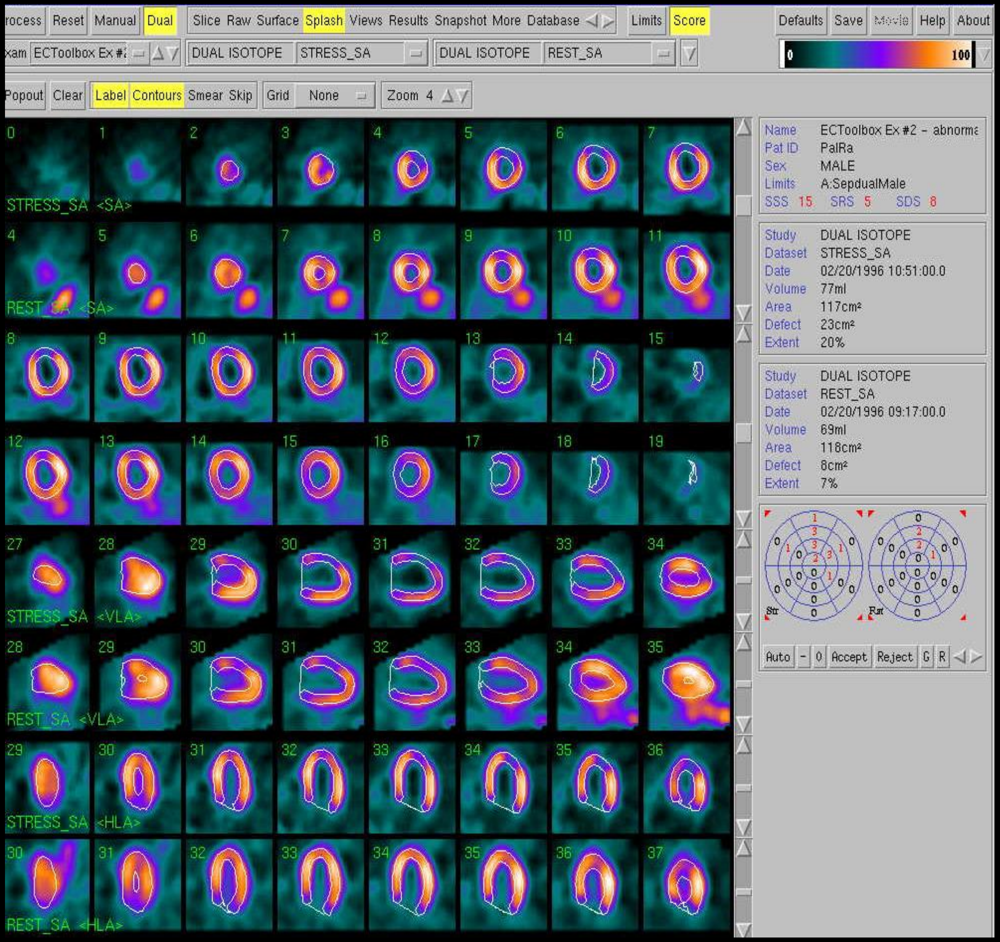
Normal whole-body bone scan (^{99m}Tc-MDP)

NM is irreplaceable in research of bone metastatic spread of cancer

Cardiology

- Cardiac blood pool or tissue imaging
  - Abnormalities, perfusion, metabolism, contractility

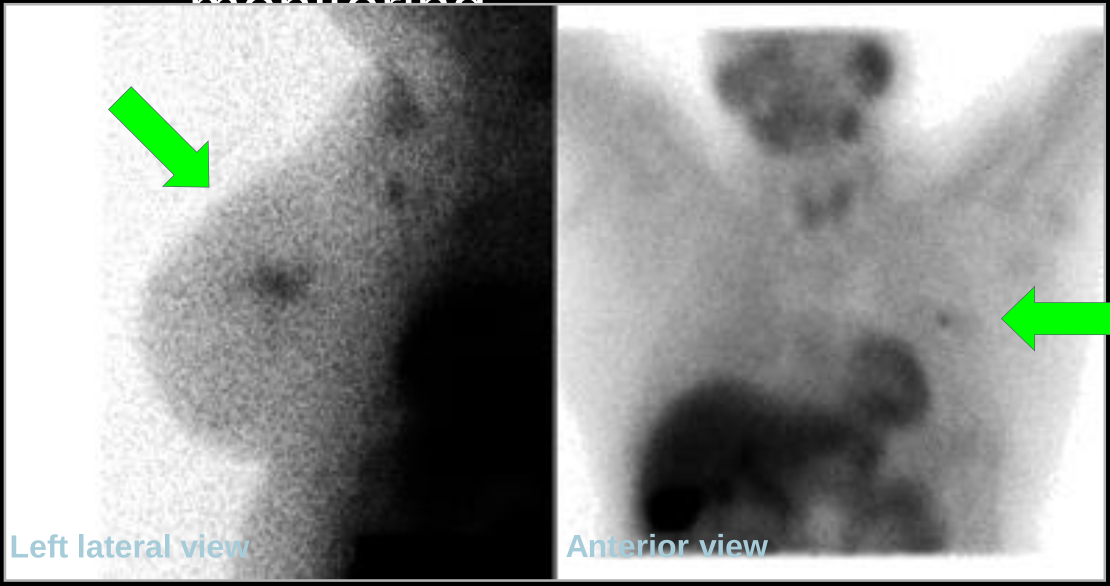




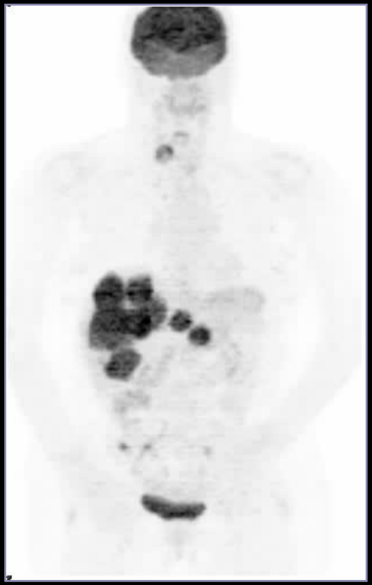
NM is the gold standard for myocardial viability assessment

Oncology

- Primary cancer, secondary cancer (metastases, lymph nodes)
- Detection, localization, characterization and therapy monitoring



Breast cancer on left side (^{99m}Tc-MIBI)



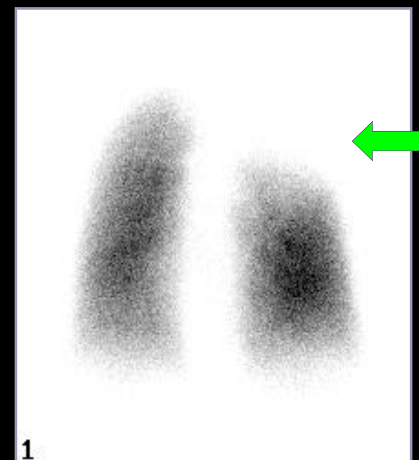
Liver metastases (^{18}F-FDG)

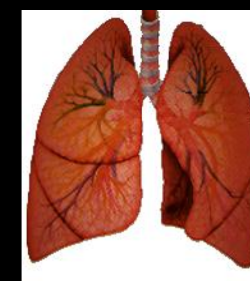
Oncology is the clear driver in PET imaging

Pneumology

- Respiratory system
- Organ abnormality, malfunction, inflammation, infection, cance

Pulmonary embolism demonstrated by the tracer distribution mismatch in the left superior pulmonary lobe





Ventilation
(^{99m}Tc-aerosol)
Anterior view

Perfusion
(^{99m}Tc-MAA)
Anterior view

Right lung

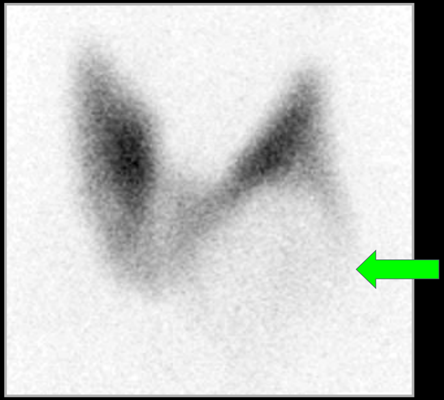
Left lung

NM allows a fast and accurate pulmonary embolism diagnosis

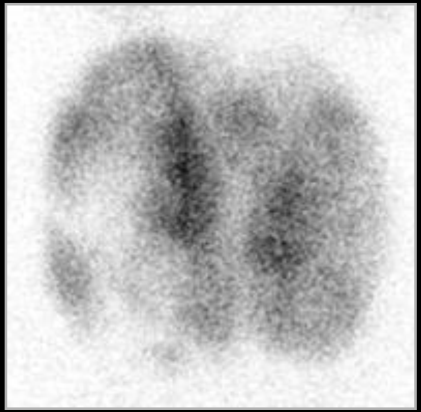
Endocrinology

- Parathyroid glands, thyroid, adrenal and pituitary glands
- Organ abnormality, malfunction, inflammation, infection, cancer

Normal thyroid gland



Cold nodule

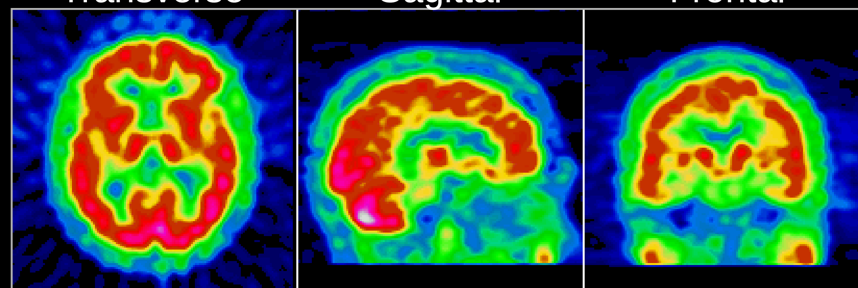


Goiter (enlarged gland)

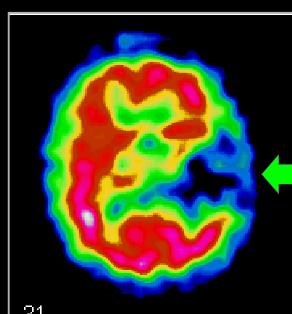
NM is the method of choice for thyroid investigations

Neurology

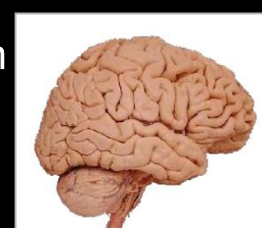
- Central Nervous System
  - Cerebral metabolism, tissue perfusion, infection, inflammation, cancer, cerebrospinal fluid



Normal brain perfusion slices (^{99m}Tc-HMPAO)



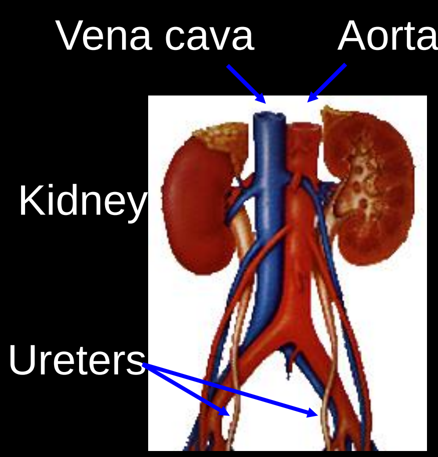
Cerebral stroke: decreased tracer uptake in left temporal lobe.



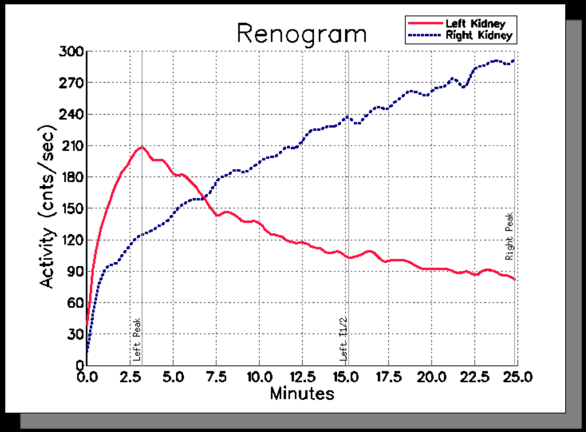
NM findings often precede changes visible on CT or MR

Nephrology

- Genitourinary system
  - Malfunction, inflammation, infection, renovascular hypertension, kidney transplantation



Dynamic renal scan (^{99m}Tc-MAG3).
Abnormal right tracer retention.



Renal time activity curves allow assessment of renal function.
Abnormal right kidney function

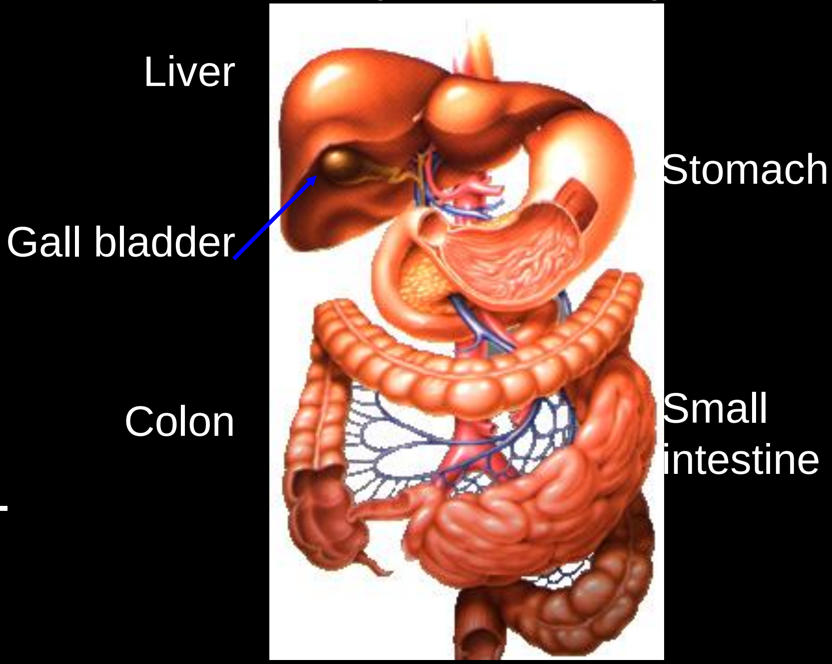
NM exam analyses split left and right functions

Gastroenterology

- Salivary glands, esophagus, stomach, liver, pancreas, colon
- Abnormality, malfunction, inflammation, infection, cancer

Hepatobiliary study (^{99m}Tc-IDA)

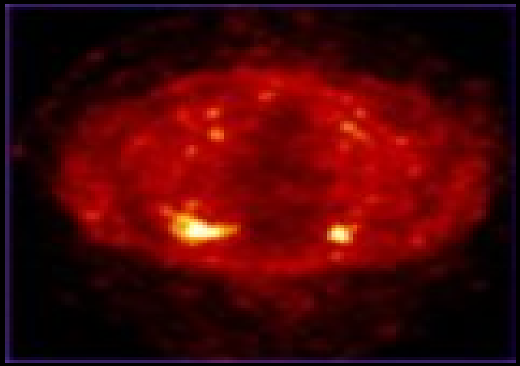
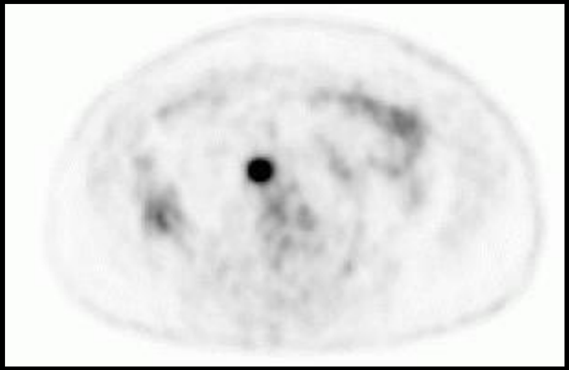
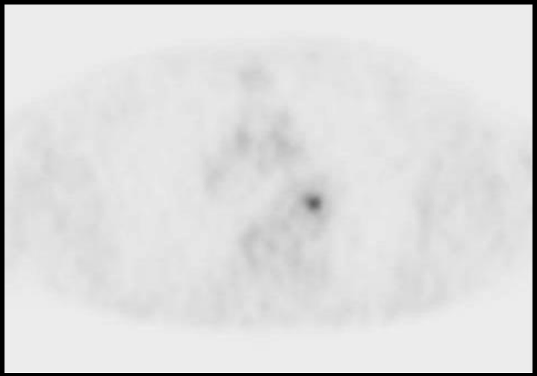
High concentration of tracer in bile duct and gall bladder.



NM is less invasive than other Imaging modalities

Limitation of NM Imaging

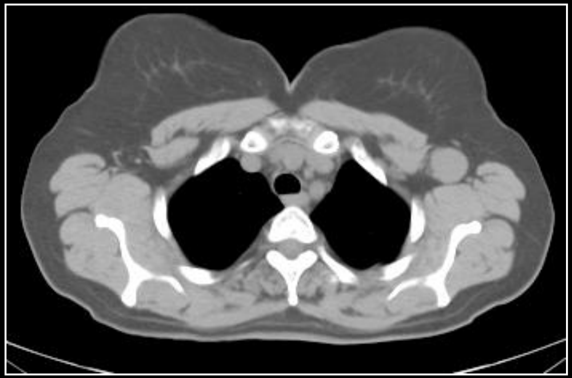
- ***LIMITED SPATIAL RESOLUTION***
- ***POOR SIGNAL TO NOISE RATIO***
- ***POOR UPTAKE TO THE RADIOTRACER IN THE DISEASED CONDITION***

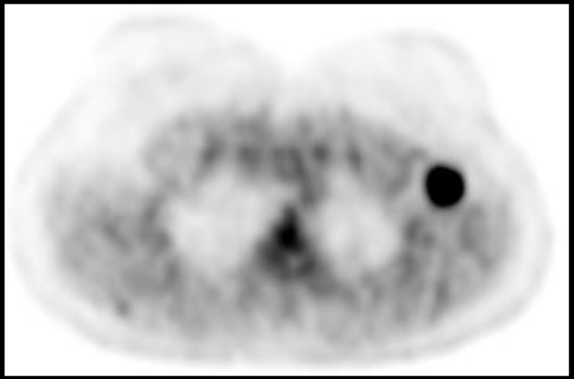
REGISTERATION WITH AN ANATOMICAL IMAGE CAN BE USEFUL……

Fusing Medical imaging techniques

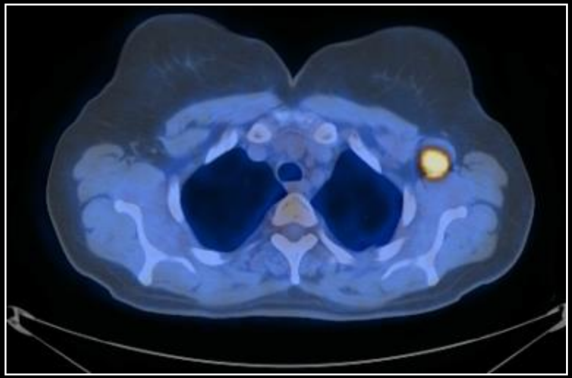
Anatomical



Functional

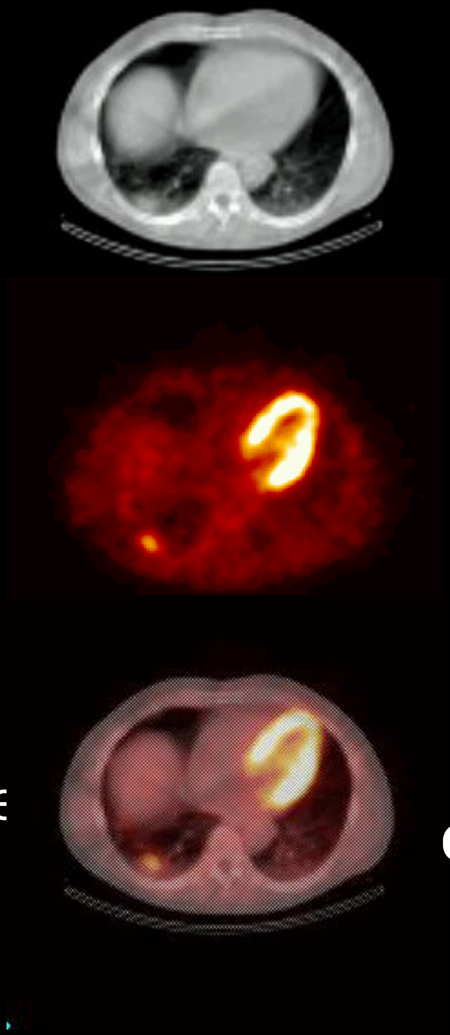


Hybrid



Fusinf Anatomic and Functional Imaging

- Anatomic Imaging
- Functional Imaging
- Complementation of modalitie

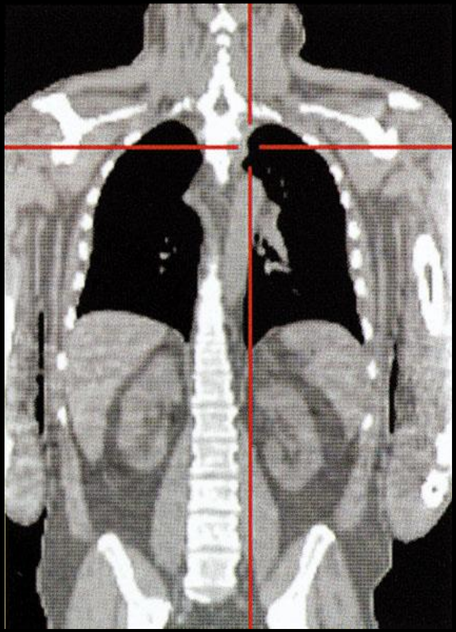


CT

NM

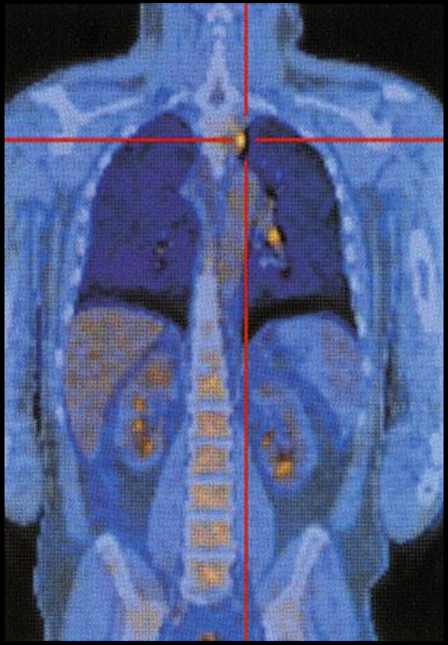
Fusion
CT + NM

Hybrid Imaging



CT Image
« Precise Body Anatomy »

PET Images
« abnormal activity »



PET-CT Images
Abnormal activity and precise localization

Structural Images	Functional Images	Hybrid Images

History of dual-modality imaging

SPECT/CT

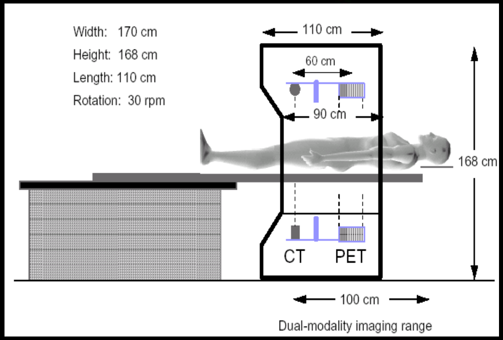
The first prototype SPECT/CT was built by B. Hassegawa in 1990

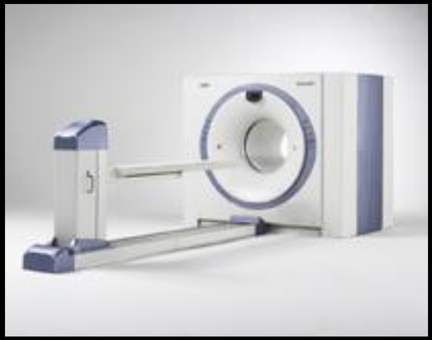
The first commercial SPECT/CT was installed in 1999

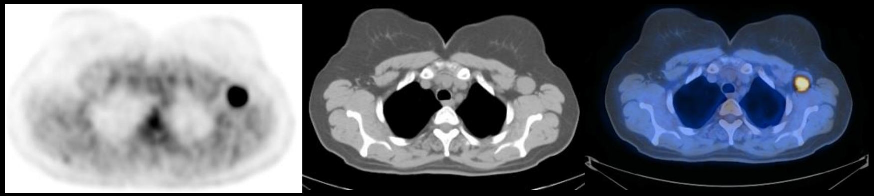
PET/CT

The first prototype system was built by D. W. Townsend in 1998

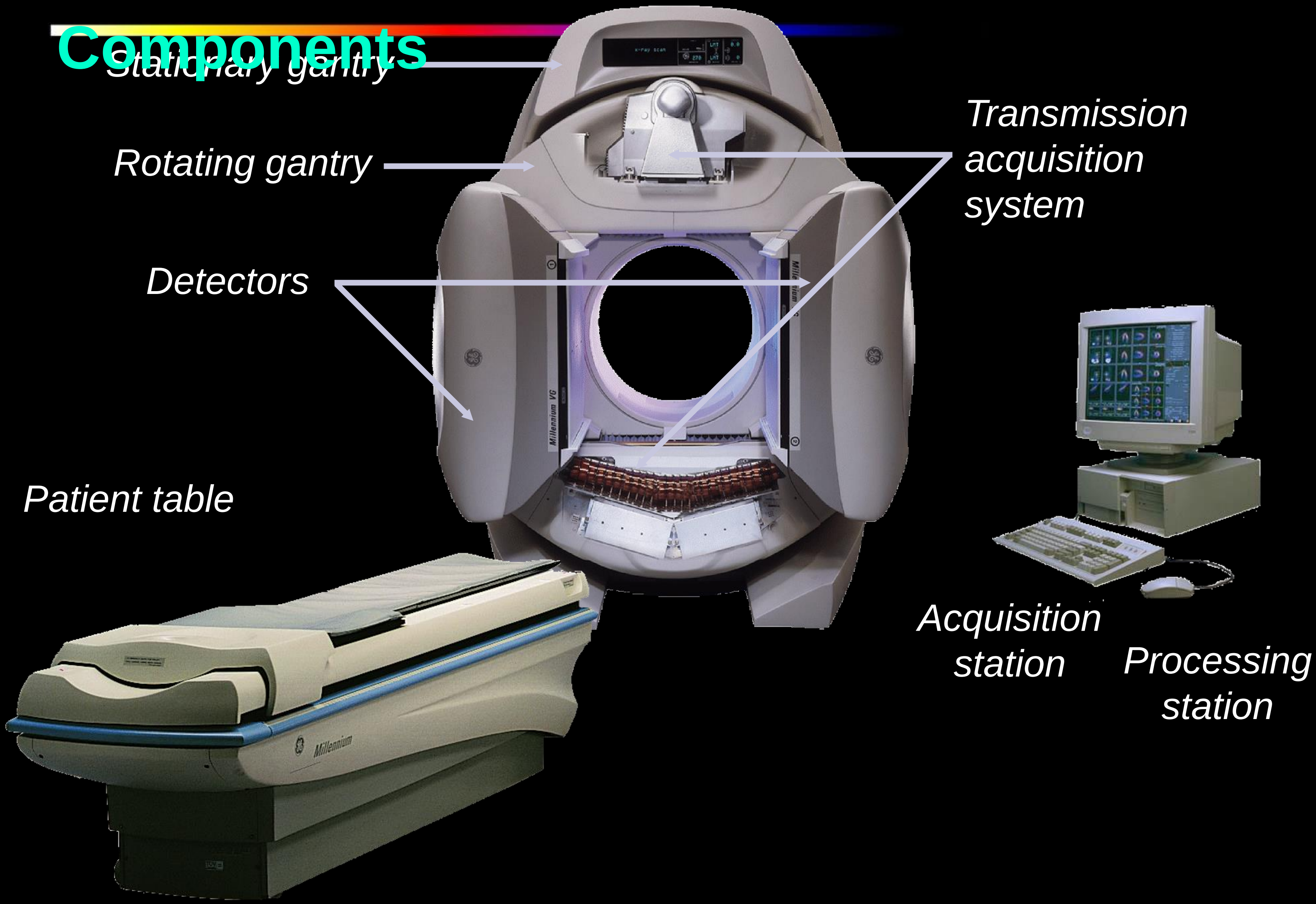
The first commercial PET/CT was installed in 2000







Gamma Camera Components

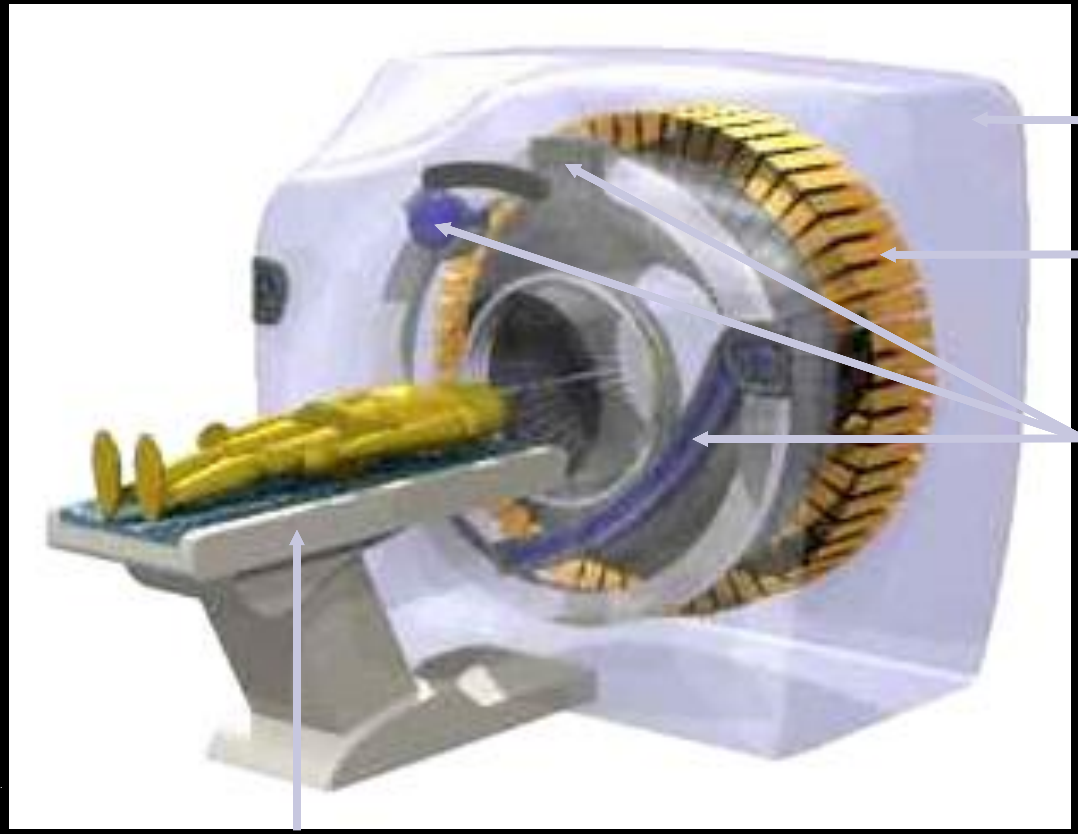


PET Scanner Components

Acquisition and processing station

PET/CT Scanner

Acquisition and processing station



Patient table

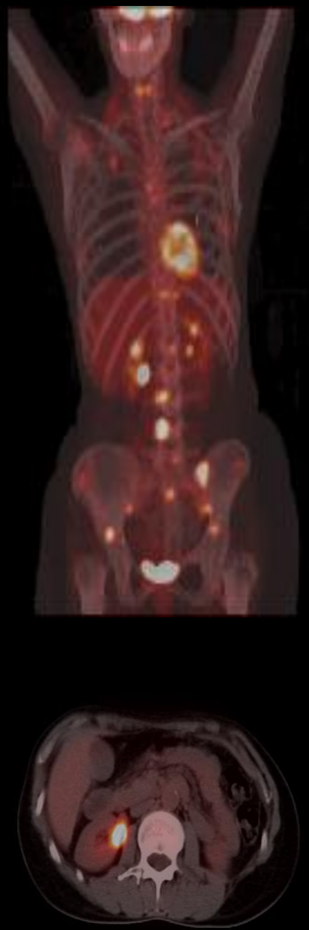
PET/CT Scanner

PET/CT – Image quality

7 minute exam

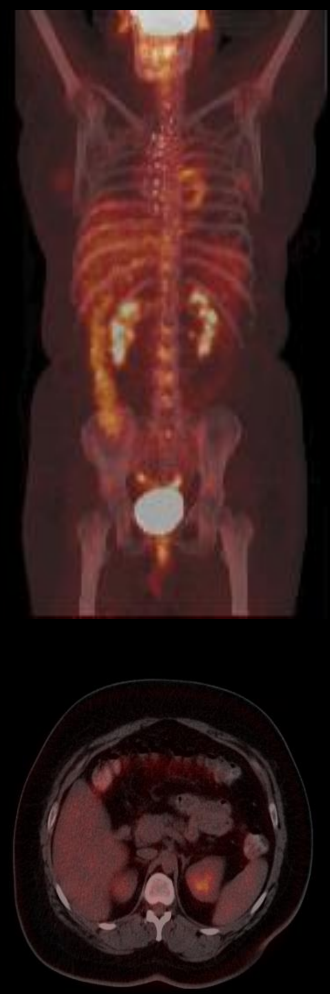
120 lbs – 1 min/bed

12 minute exam



160 lbs - 2 min/bed

17 minute exam



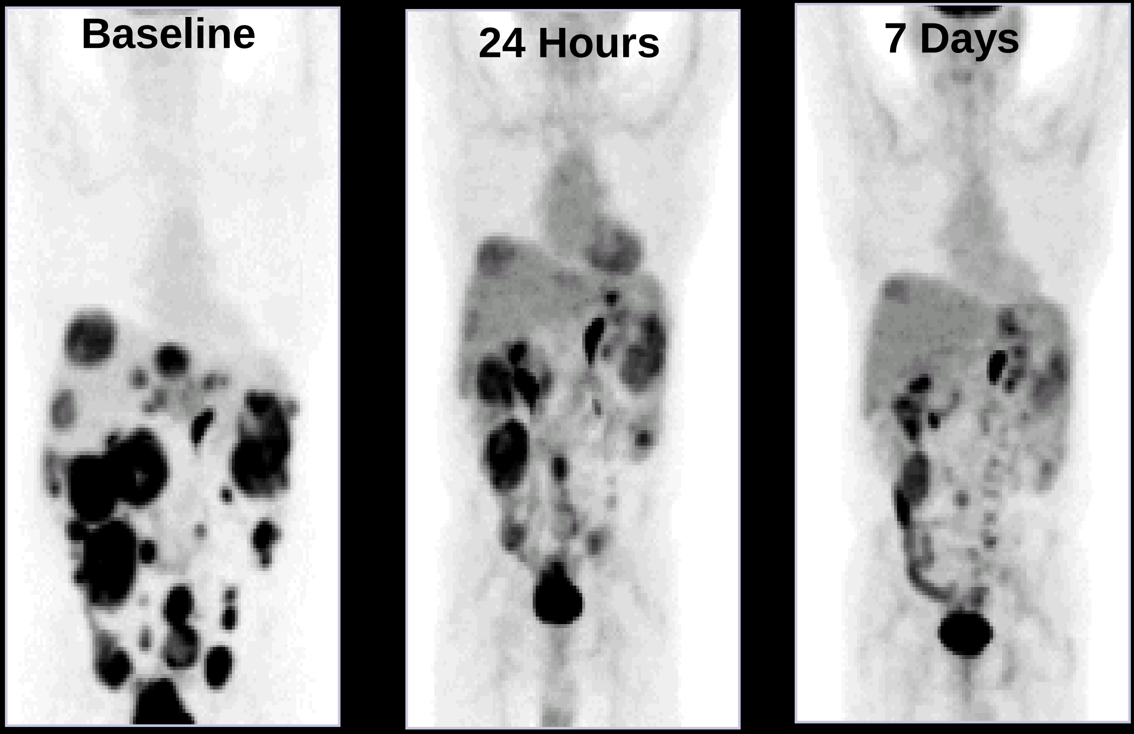
250 lbs - 3 min/bed

Images courtesy of Dr. Johannes Czernin, University of California, Los Angeles

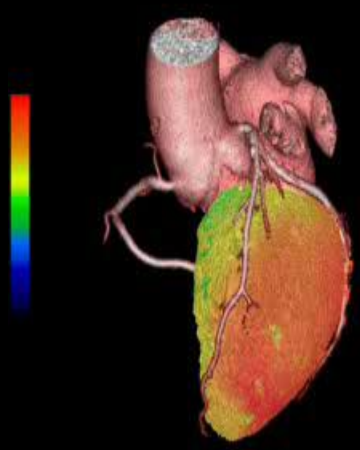
The PET/CT of Choice for Oncology

- Do we Need a High Resolution Scanner?
- Do we Need a High Sensitivity Scanner?
- Do we Need More Slice in CT?
- Do we Need Respiratory Gating?
- Do we Need Especial Software?

Tumor Response Observed Within Days



Clinical Case with Dedicated Cardiac PET/CT



O15 rest perfusion + CTA

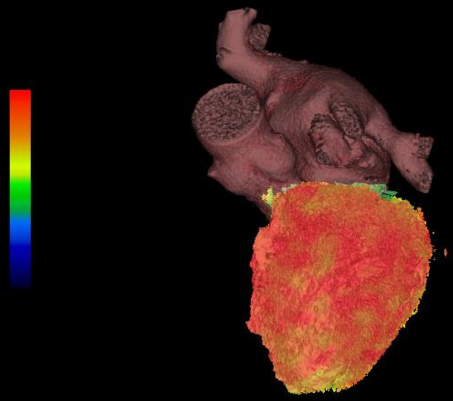
O15 stress perfusion + CTA

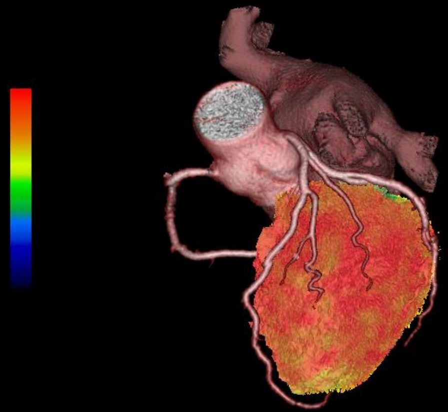
Courtesy Turku PET Center

Oxygen-15

PET Perfusion/CTA

Turku PET Center, Finland





Rubidium-82

PET Perfusion/CTA

Brigham and Women’s