



**Development of Complex Curricula for Molecular Bionics and Infobionics Programs within a consortial\* framework\*\***

Consortium leader

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Consortium members

**SEMMELWEIS UNIVERSITY, DIALOG CAMPUS PUBLISHER**

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\*\*Molekuláris bionika és Infobionika Szakok tananyagának komplex fejlesztése konzorciumi keretben

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# BIOMEDICAL IMAGING

(Orvosbiológiai képalkotás )

# COMPUTED TOMOGRAPHY (CT)

(Számítógépes tomográfia)

**GYÖRGY ERŐSS**

## Tomography

**Tomography** is imaging by sections or sectioning. A device used in tomography is called a **tomograph**, while the image produced is a **tomogram**. The method is used in [medicine](#), [archaeology](#), [biology](#), [geology](#), [materials science](#) and other sciences. In most cases it is based on the mathematical procedure called [tomographic reconstruction](#). There are many different types of tomography, as listed: (Note that the [Greek](#) word *tomos* conveys the meaning of "a section" or "a cutting"). A tomography of several sections of the body is known as a polytomography.

## Conventional medical X-ray tomography:

- a sectional image through a body by moving an X-ray source and the film in opposite directions during the exposure
- structures in the focal plane appear sharper, while structures in other planes appear blurred
- by modifying the direction and extent of the movement, operators can select different focal planes which contain the structures of interest





## Computed tomography (CT)

### Conventional X-Rays

Single projection image  
⇒ superimposed tissues

### Computerized Tomography

Axial image obtained from hundreds of projections

Std. Resolution: 500 - 1200 projections

High Resolution: 900 - 2400 projections

Tissue superposition only within one slice thickness

Measured physical entity: tissue density

Information provided: organ structure

CT density unit:        **1 Hounsfield Unit (HU) = 0.1% density of water**  
                                 **Air (zero density) = -1000 HU; Water = 0 HU**

Precision & validity of CT densities:

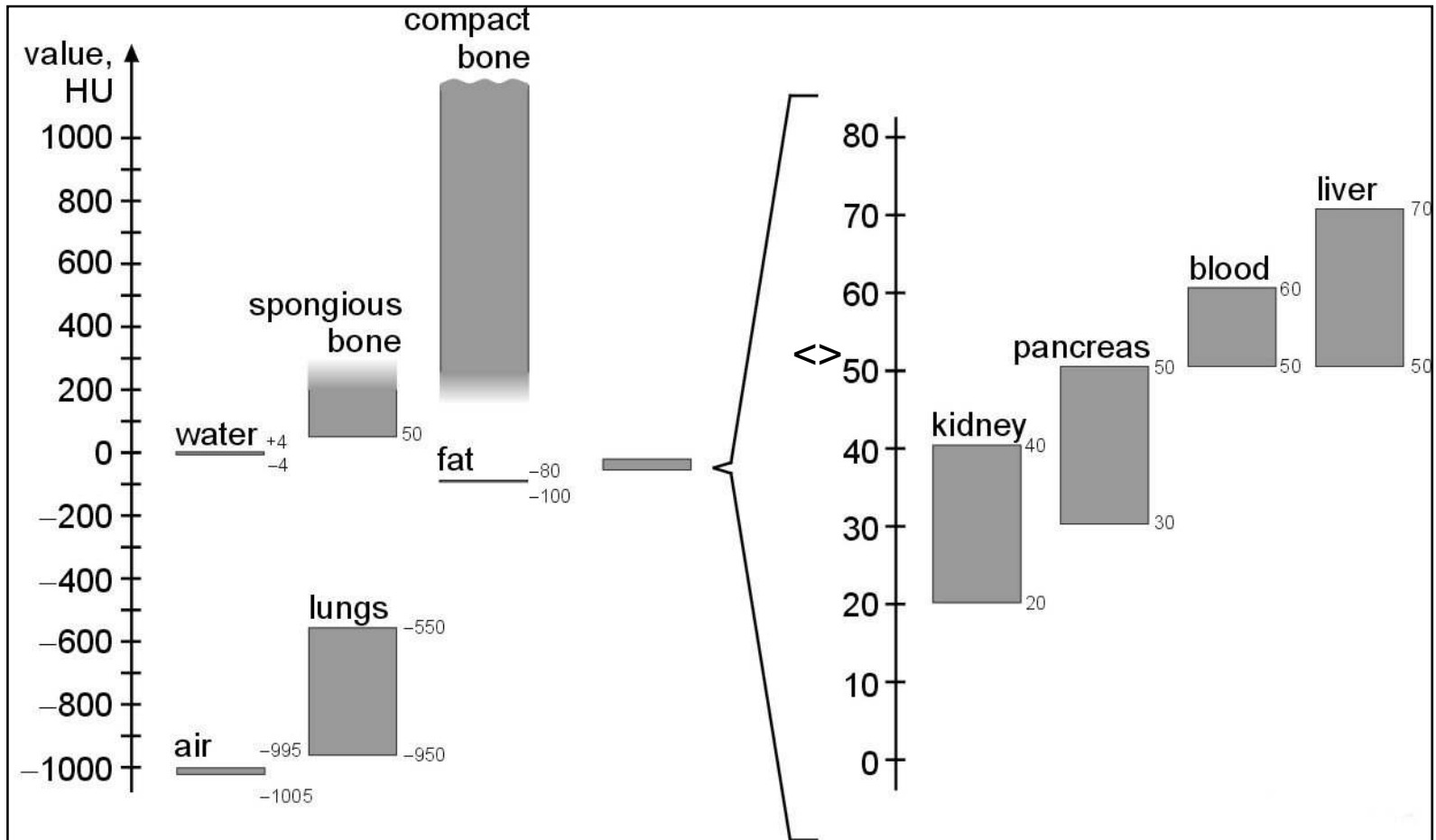
Relative only; CT uses a polychromatic X-ray beam

CT densities are voltage, object size & real density dependent

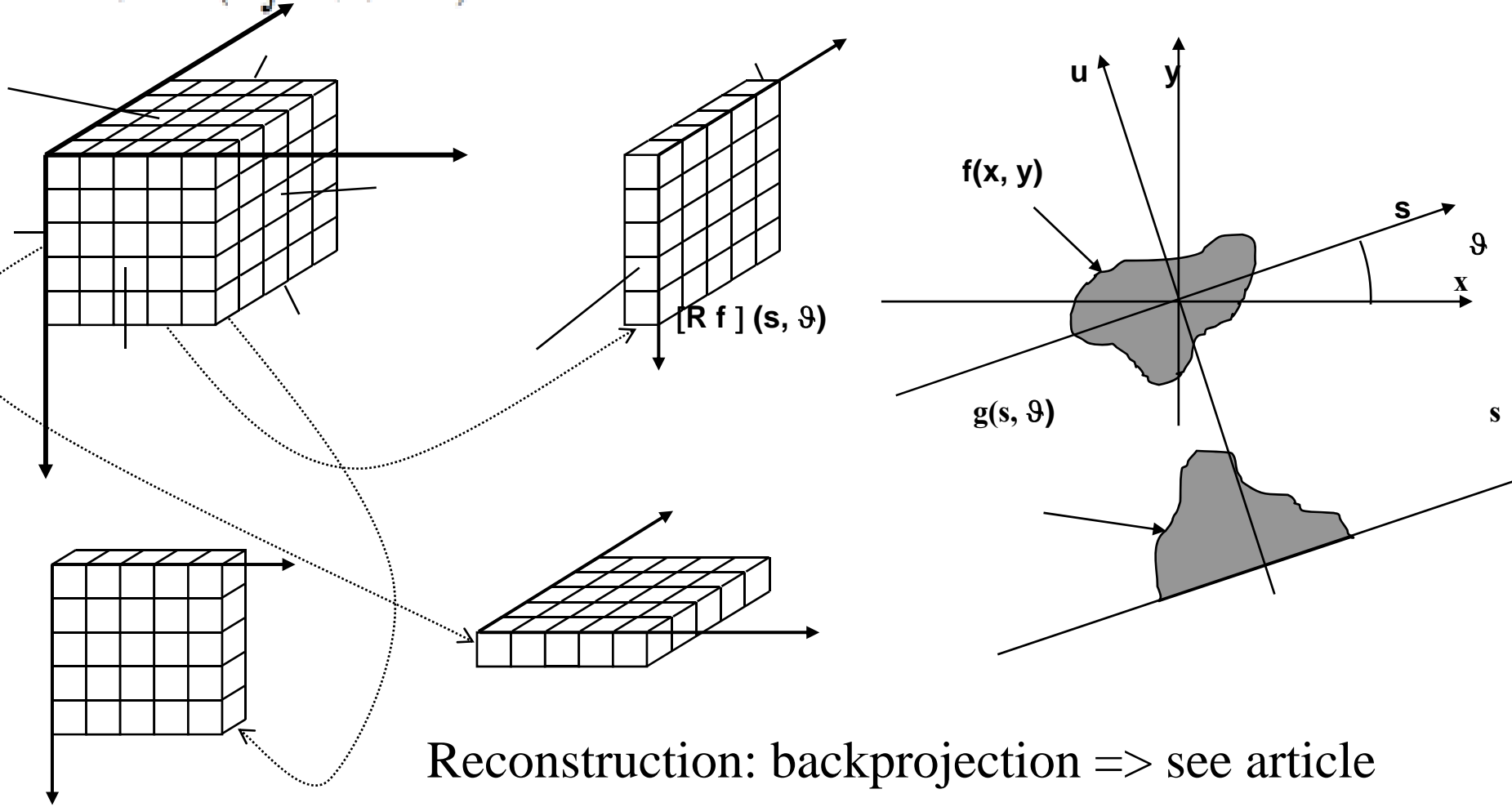
Precise density measurements in CT require dedicated calibrations

## CT Spectrum of densities

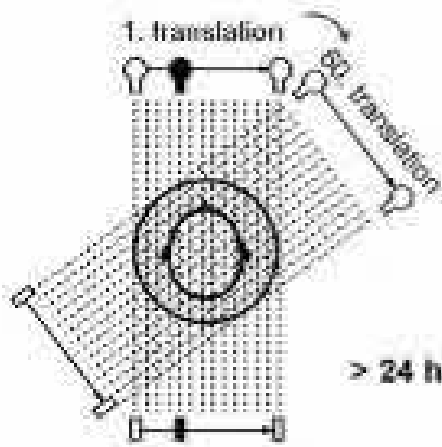
$$HU_{patient} = 1000 \cdot \frac{\mu_{patient} - \mu_{water}}{\mu_{water}}$$



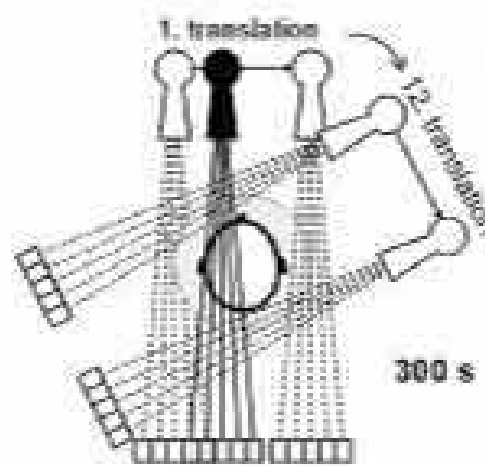
$$I = I_0 \exp\left(-\int \mu(x) \cdot dx\right)$$



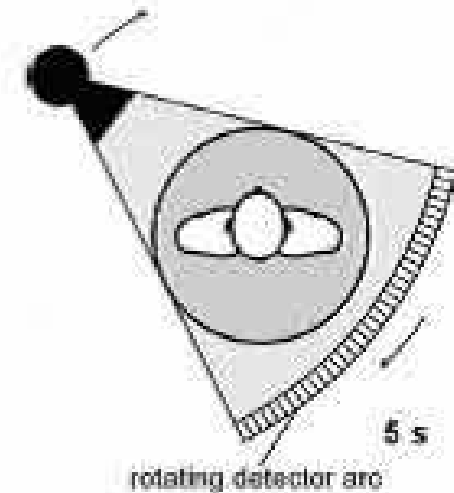
## CT generations



1967 => 1972



1975



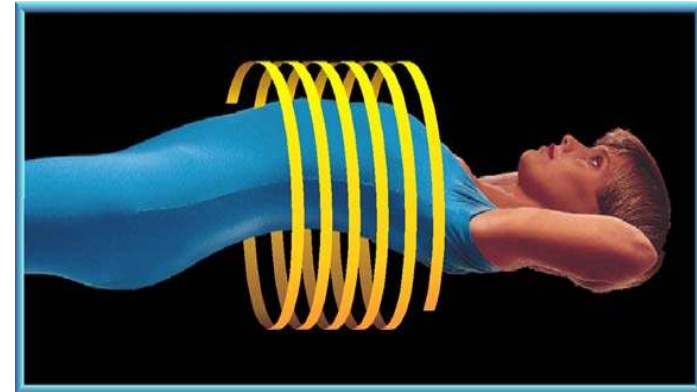
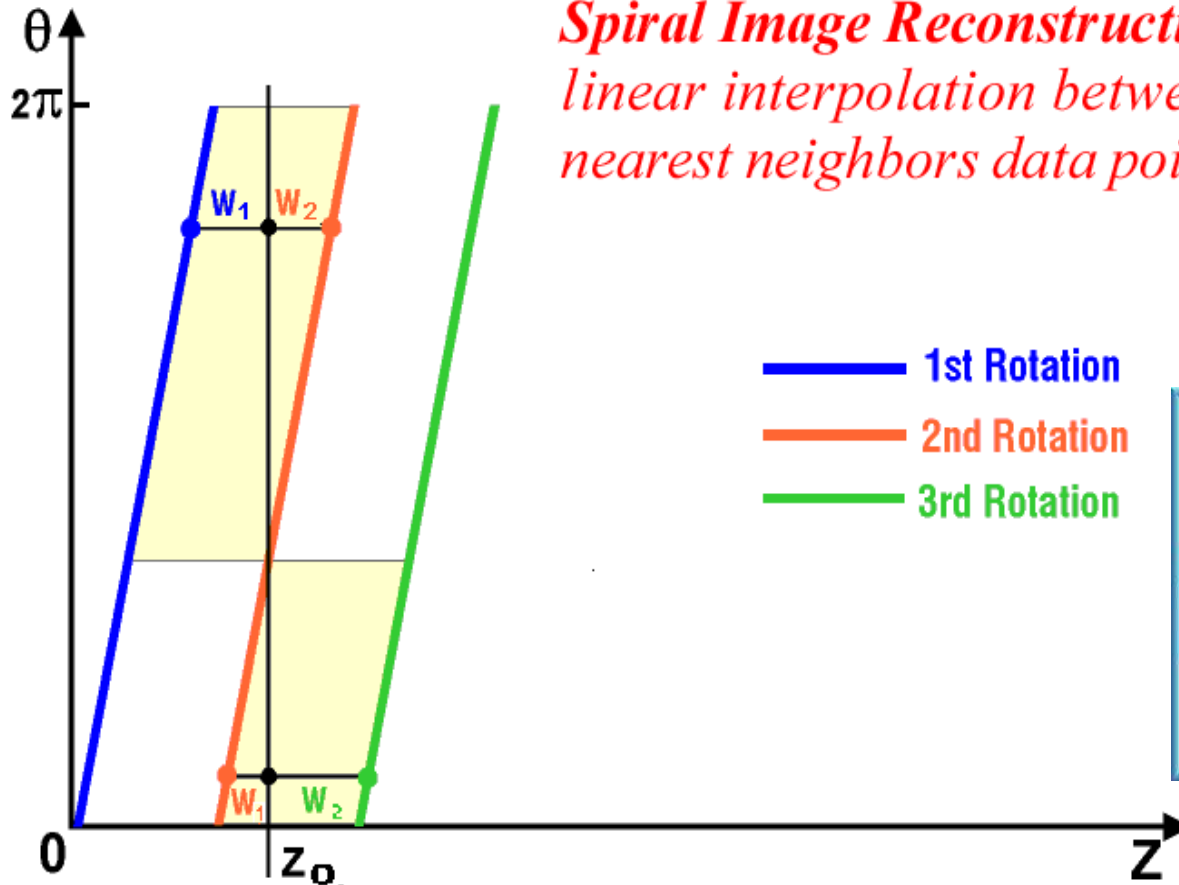
1976

4th generation:  
continuous detector ring



## Spiral scanner

*Spiral Image Reconstruction  
linear interpolation between  
nearest neighbors data points*



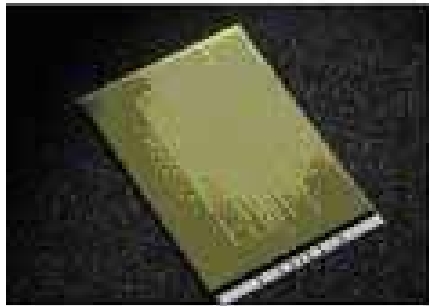
## Factors Determining Low Contrast Resolution

- Detection System: type, design & efficiency
  - » (Xenon or Solid-state)
- X-ray beam filtration: optimal design for beam hardness
- Scan Voltage: lower voltage provides improved low contrast resolution
- Signal-to-Noise Ratio:
  - Proportional to Dose (mAs)
  - Improved when post-collimation is available, protecting the detectors from scattered radiation

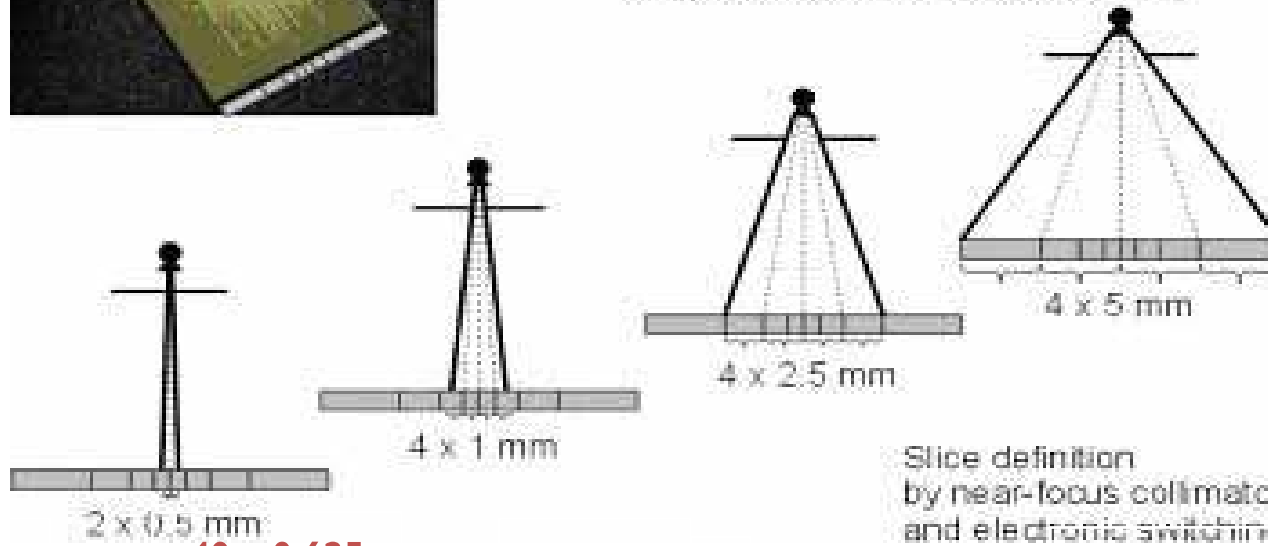
## Factors Determining Spatial Resolution

- Design Parameters:
  - Detector aperture width ( $A_{\text{eff}}$ ) at isocenter
  - Focal spot size ( $s$ )
  - Sampling density ( $\leq A_{\text{eff}}/2$ )
- Reconstruction Algorithm:
  - Filter Modulation Transfer Function
- Display Parameters:
  - Pixel size:  $p = \text{FOV}/(\text{Matrix} * \text{Zoom})$
  - Good Imaging Practice:  $p < \text{image spatial resolution}$

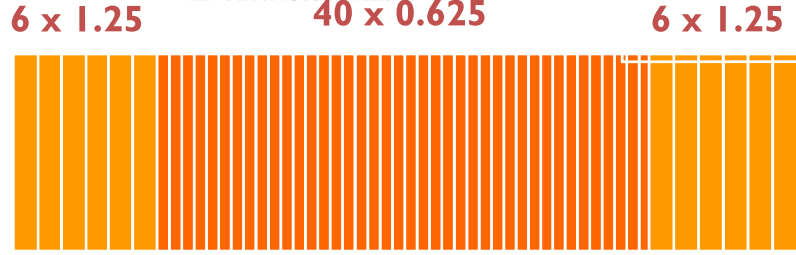
# Biomedical Imaging: Computed Tomography (CT)



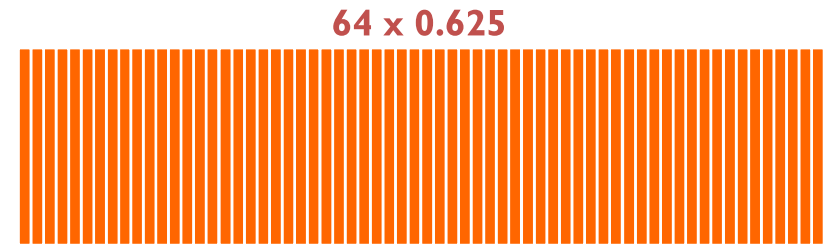
Ultrafast ceramic scintillator (UFC)



Slice definition by near-focus collimators and electronic switching



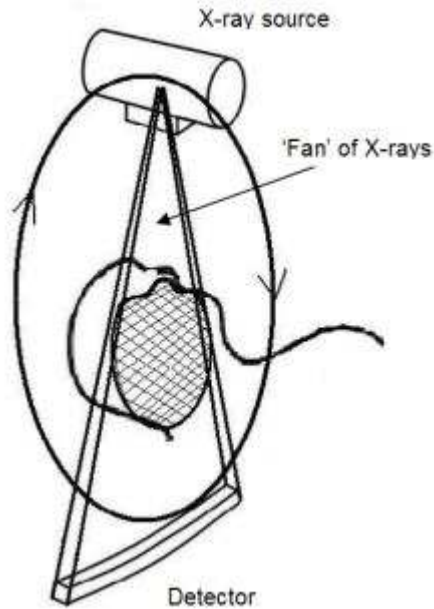
25 mm + 2\*7.5 mm



40 mm

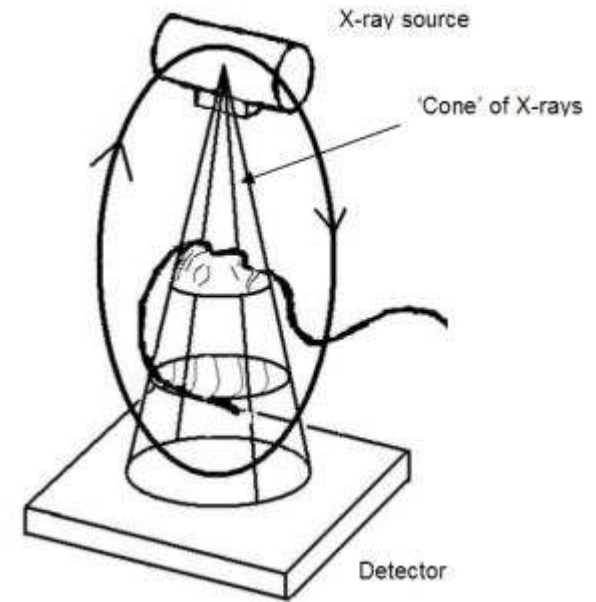
Philips Brilliance 40

## Pencil beam $\Rightarrow$ Fan beam $\Rightarrow$ Cone beam



### 2D Fan Beam Image Reconstruction (1970 – 2001)

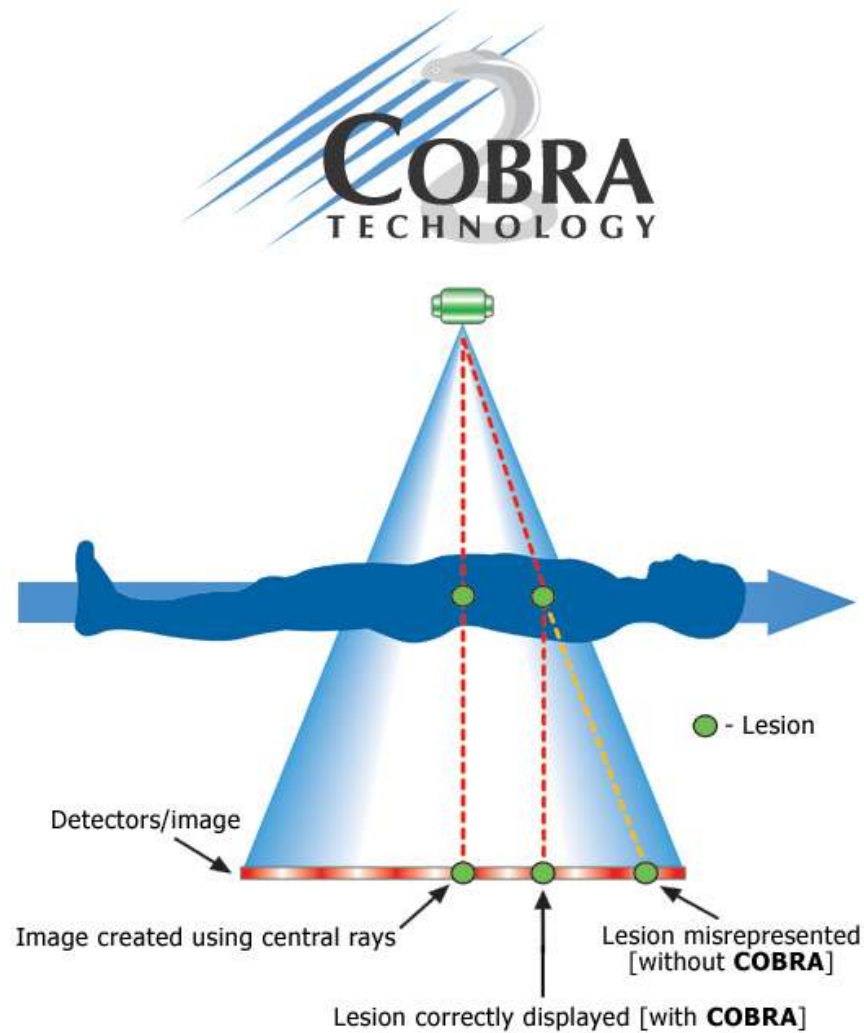
Filtered back-projection into a 2D matrix (Pixels)  
assuming parallel X-ray beams & ignoring the Cone  
Angle



### Cone Beam Reconstruction Algorithm (>2001)

Filtered back-projection into a 3D matrix (Voxels)  
Each Voxel reconstructed individually.  
Only views passing through each individual voxel  
during the acquisition process are back-projected into  
it

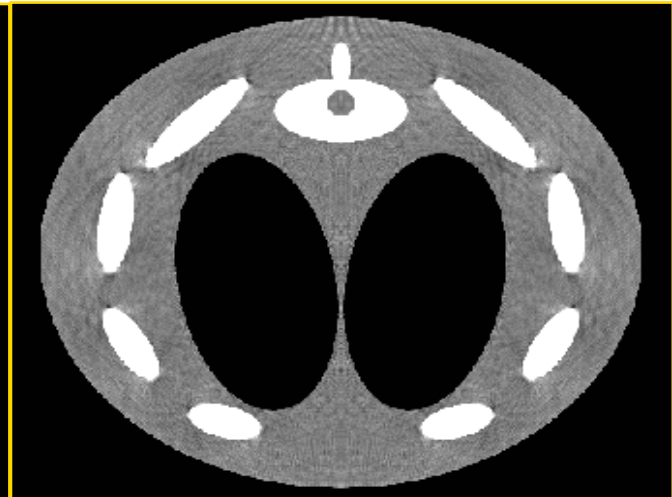
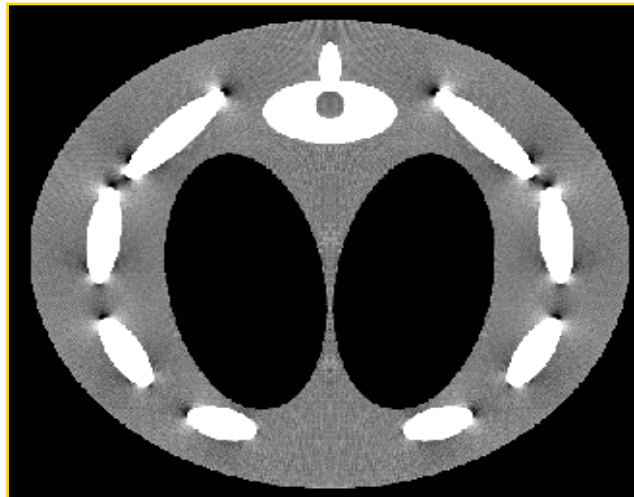
# Biomedical Imaging: Computed Tomography (CT)



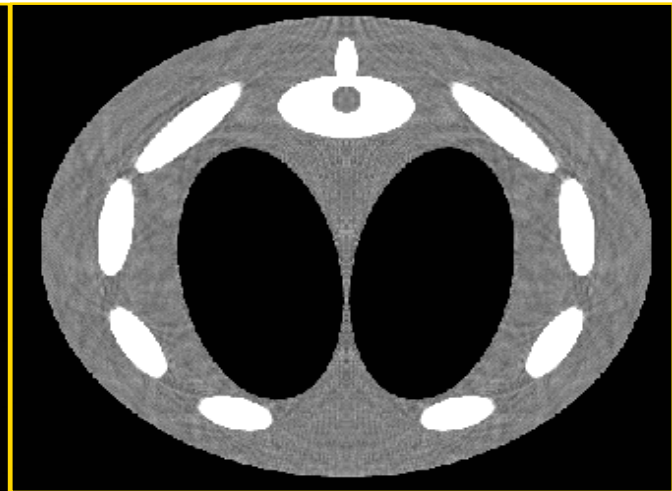
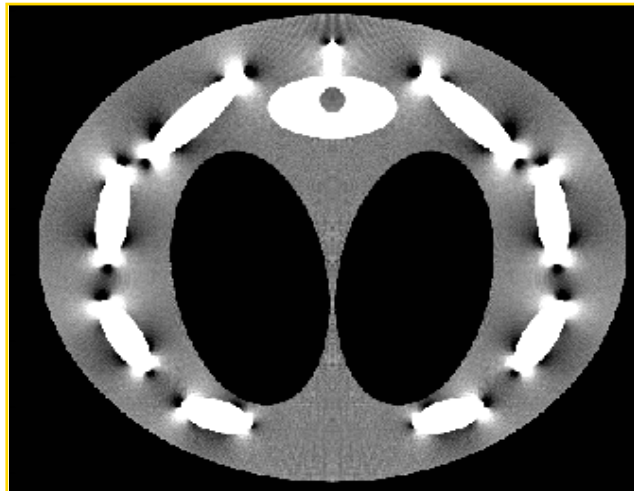
Fan Beam Recon

Cone Beam Recon

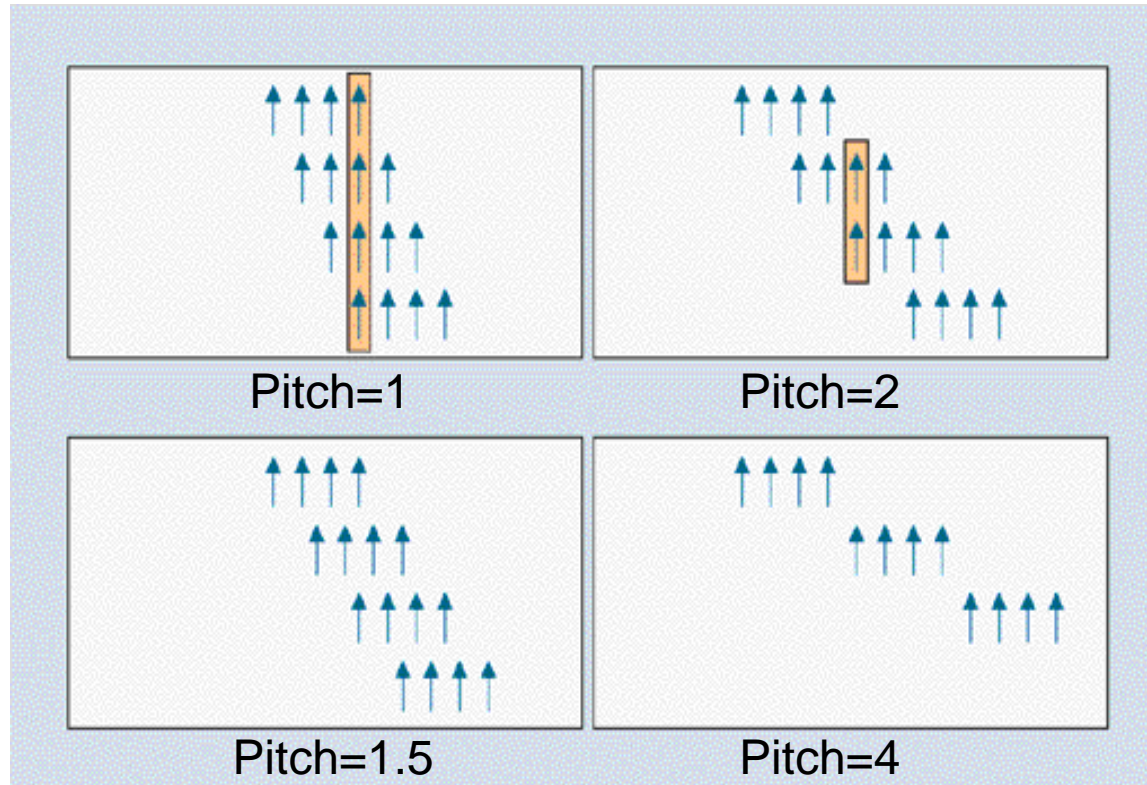
4 mm from  
mid -plane



8 mm from  
mid -plane

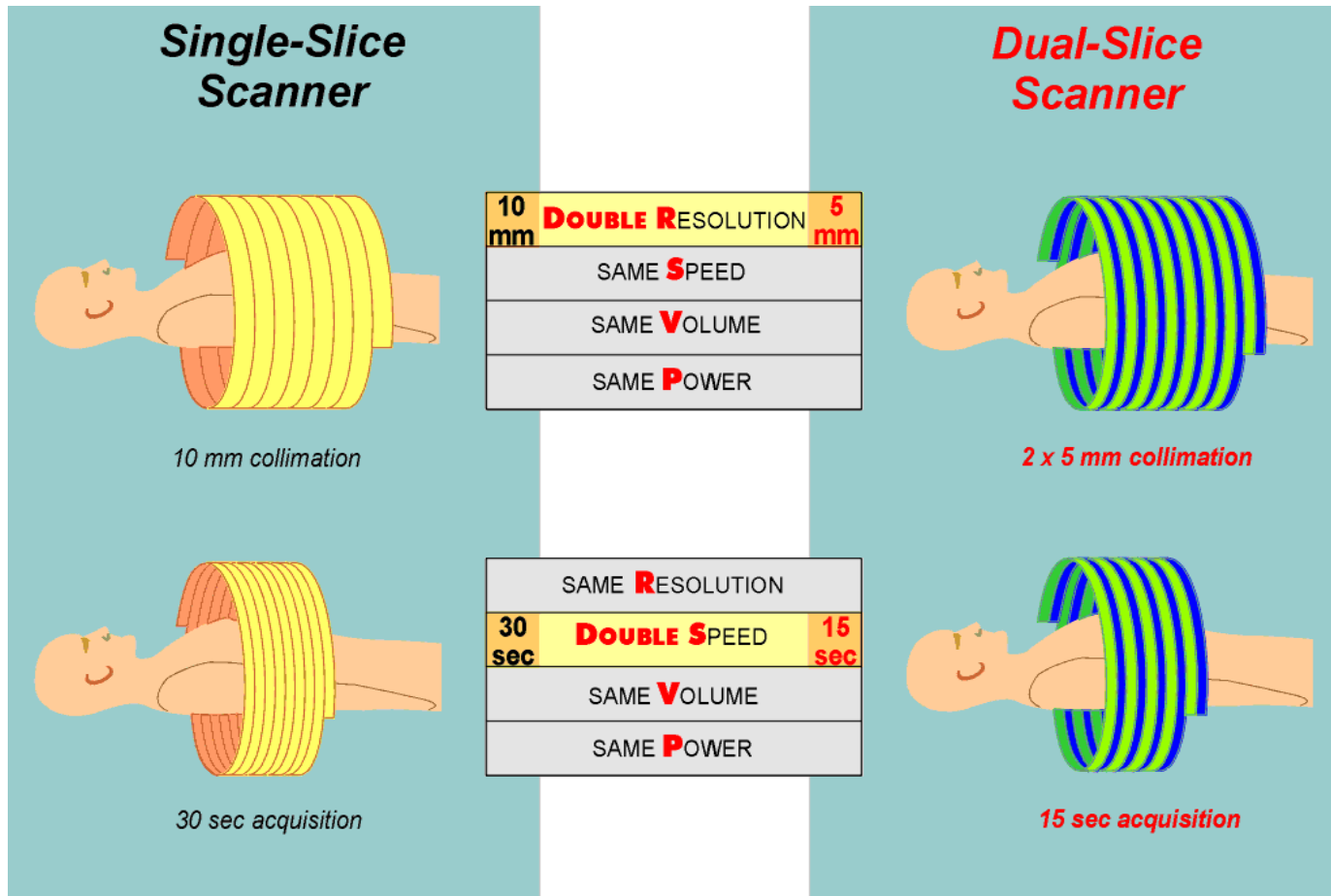


## Speed vs. information => Pitch

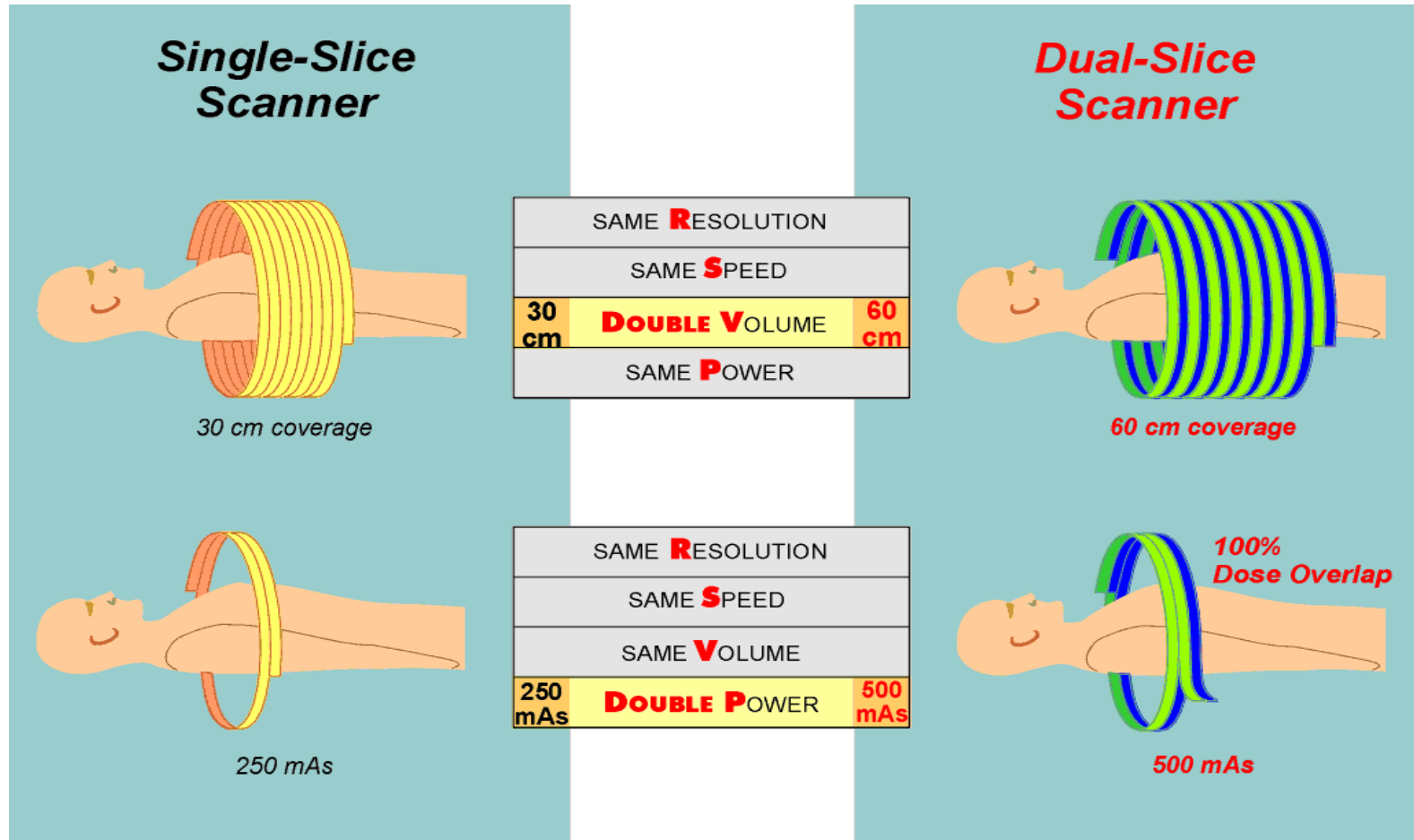


**The pitch** is the ratio of the patient table increment to the total nominal beam width for the CT scan. The pitch factor relates the volume coverage speed to the thinnest sections that can be reconstructed. In spiral CT, dose is always inversely proportional to pitch.

## Multi-Slice RSVP Advantages



## Multi-Slice RSVP Advantages



## Multi-Slice Resolution Advantage

Quad-Slice

Dual-Slice

Single-Slice



4x2.5mm; 2.5cm/sec

2x5.0mm; 2.5cm/sec

10mm; 2.5cm/sec

72 cm coverage; 28 sec; 120kV / 130 mAs

## Multi-Slice Volume Advantage

Quad-Slice

Dual-Slice

Single-Slice



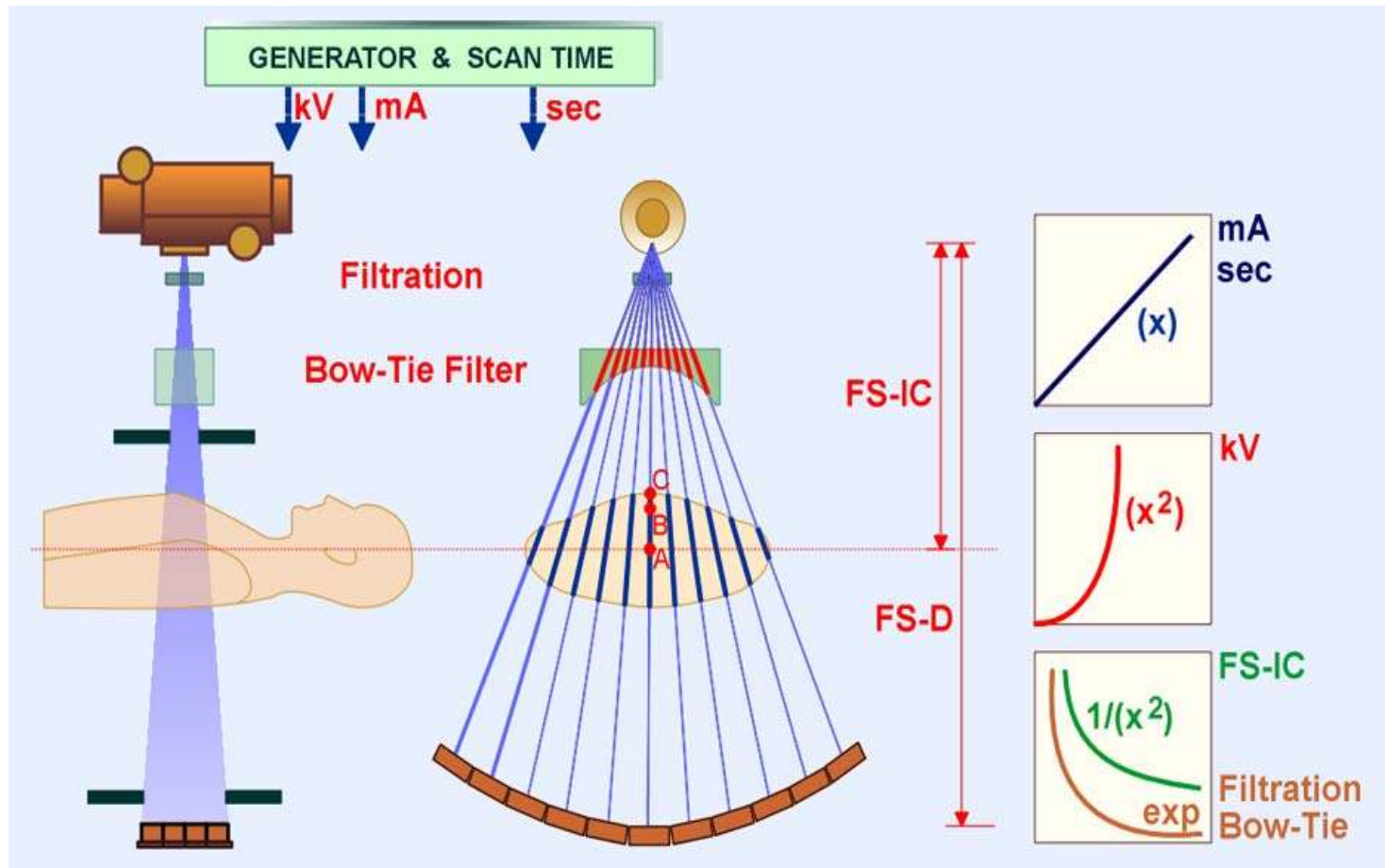
72 cm coverage

36 cm coverage

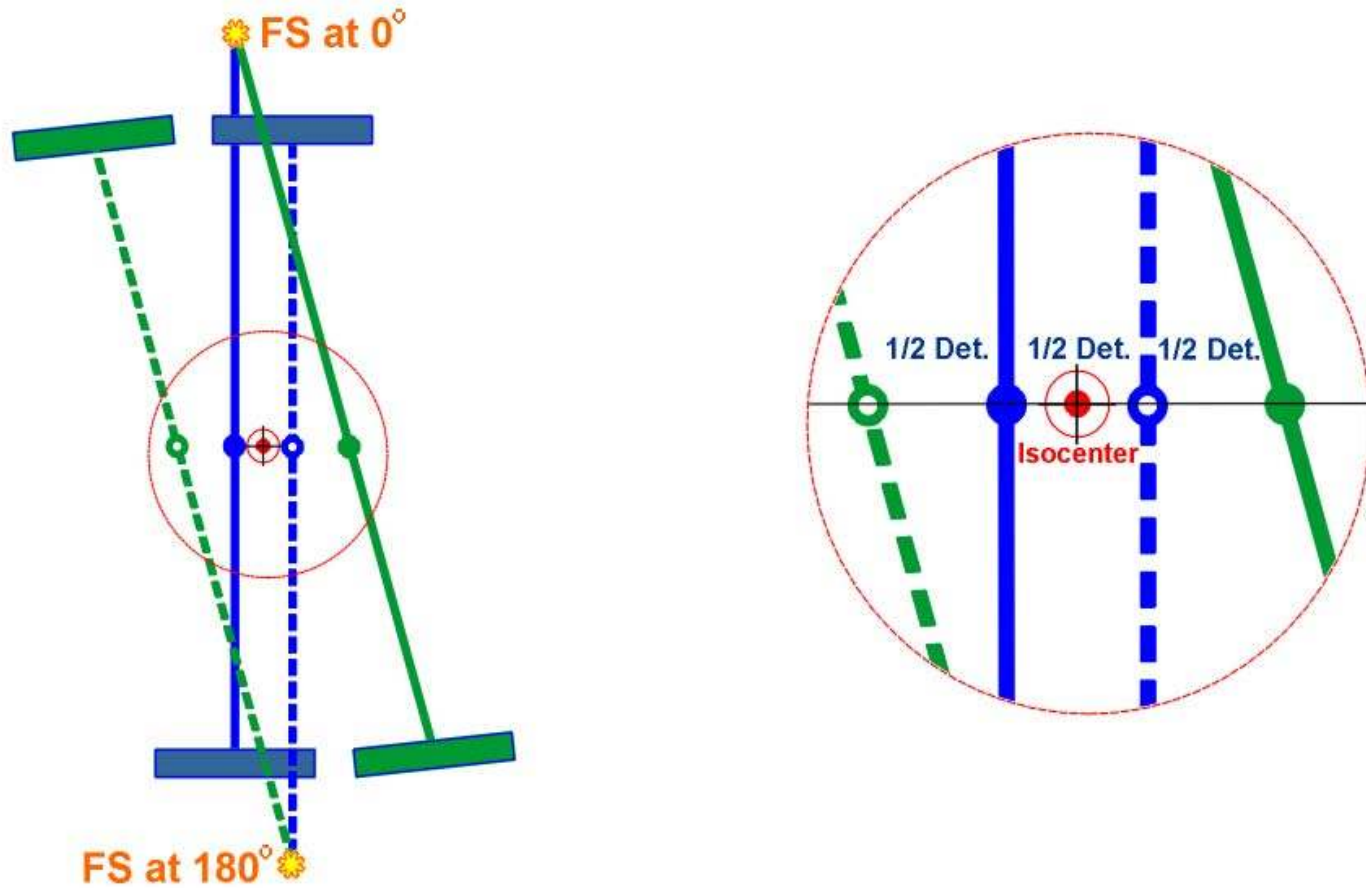
18 cm coverage

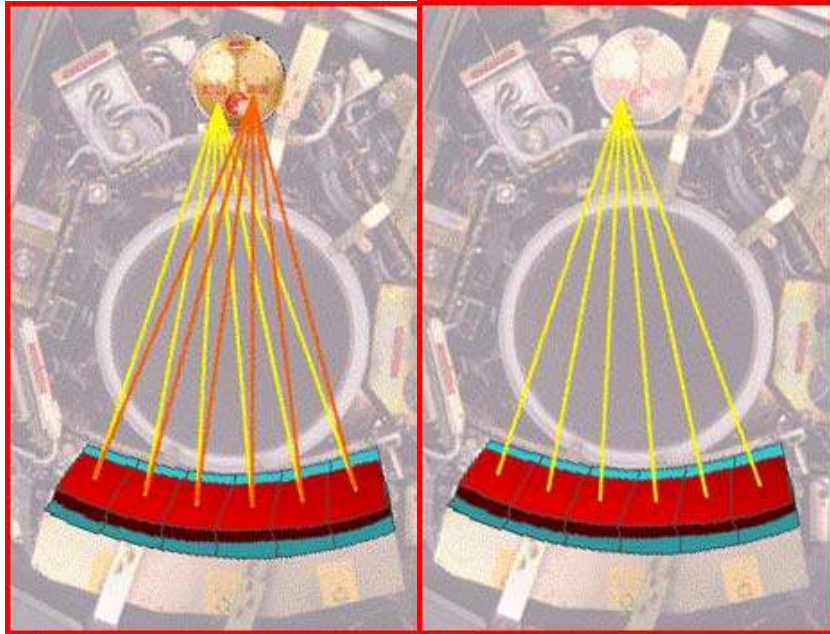
3.2 mm Eff. ST; 28 sec; 120kV / 130mAs

## Patient Dose Path



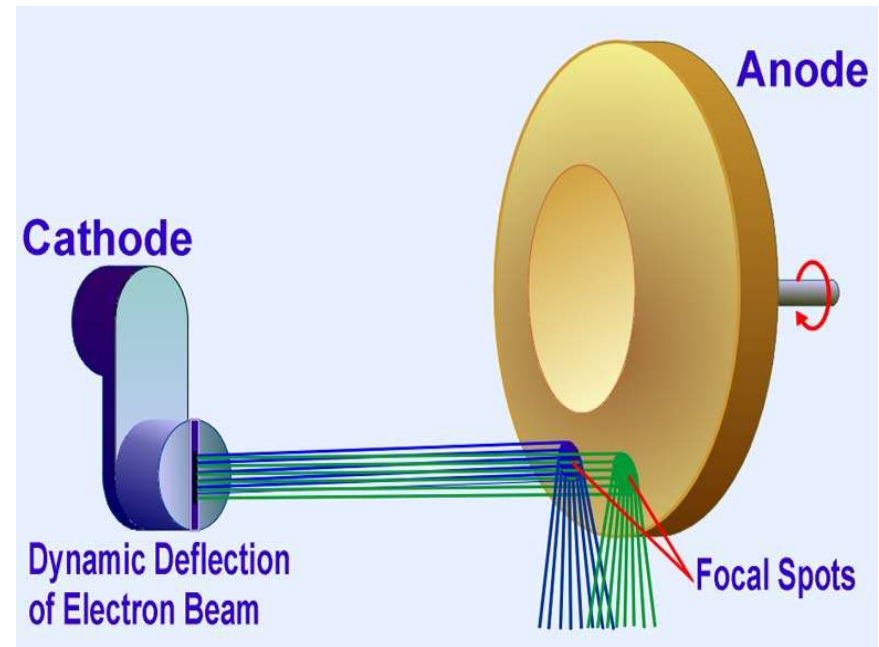
## Quarter detector shift



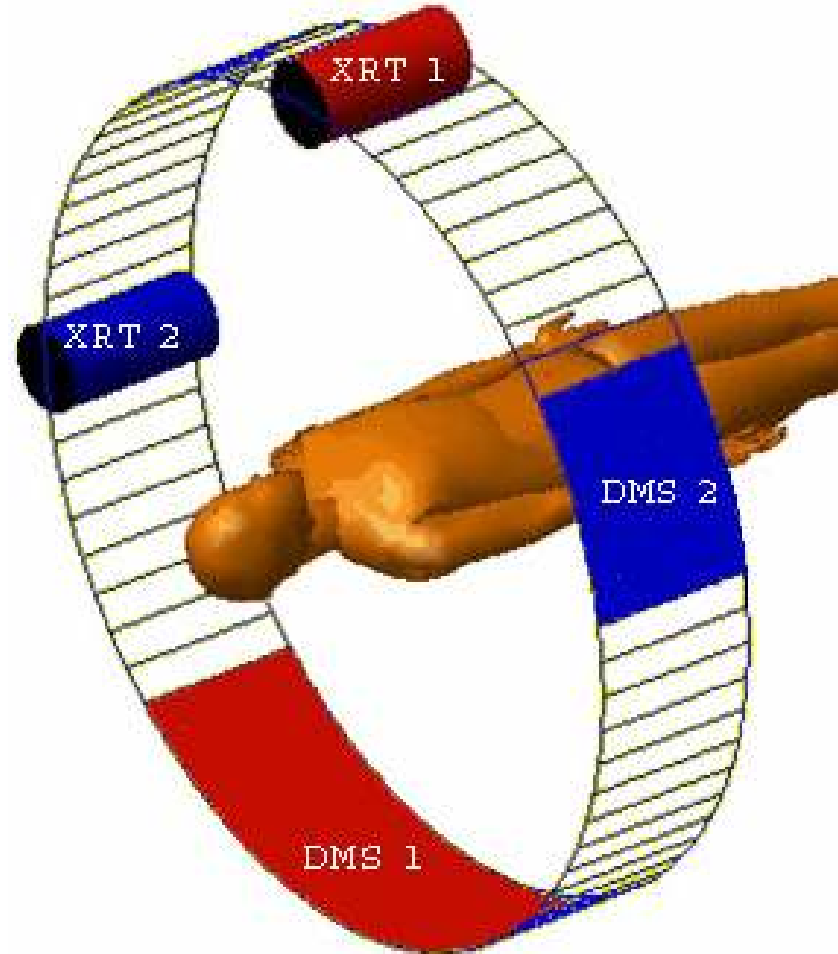
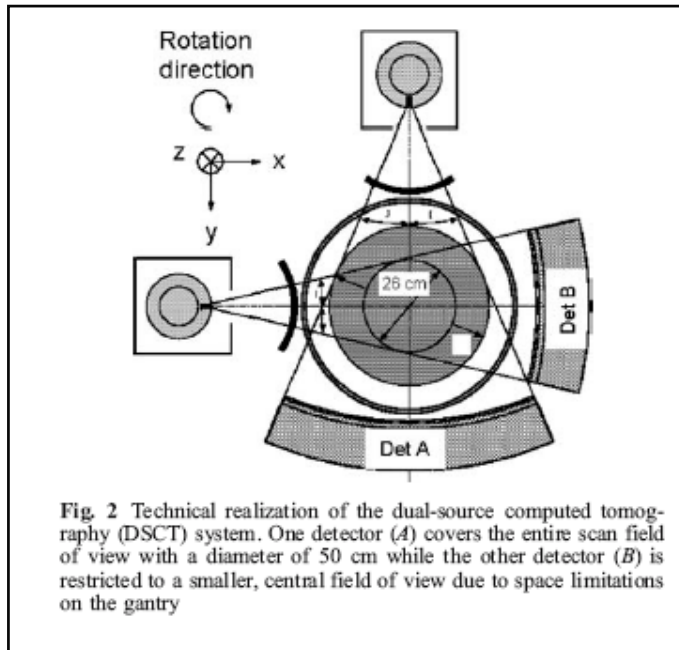


## Dynamic Focal Spot

**Doubles** Ray Density  
and thus  
**Doubles** Spatial Resolution  
with the same number of detectors



## Towards „dual energy” solution



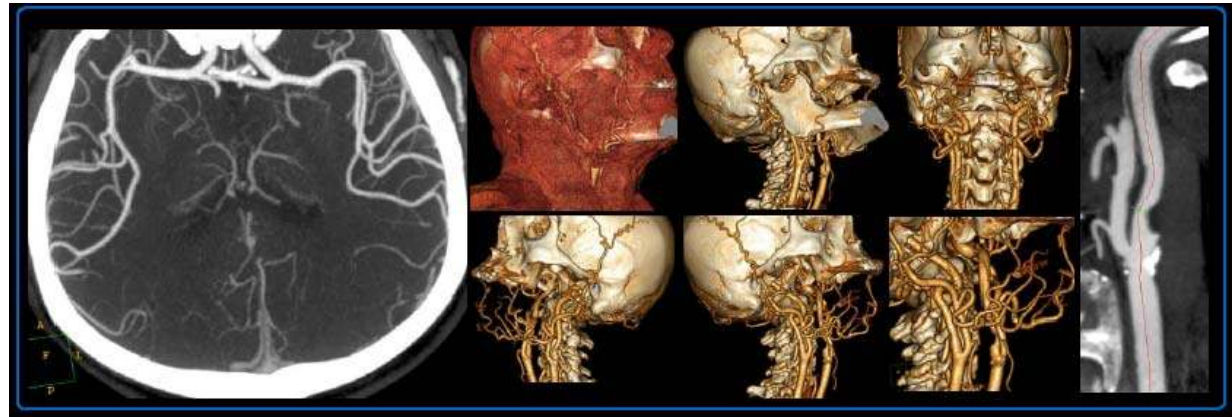
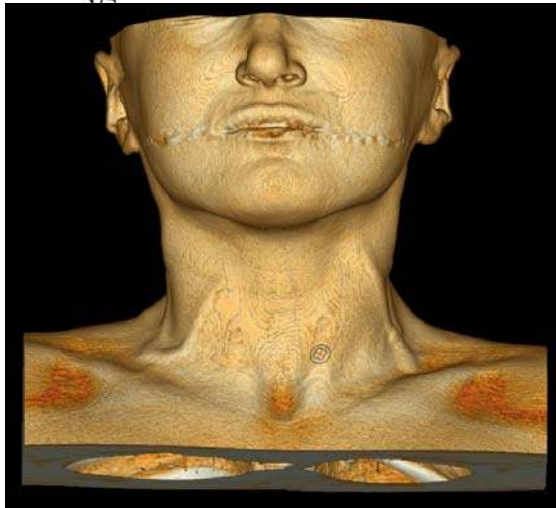
## CT examination room with a 16 slice system



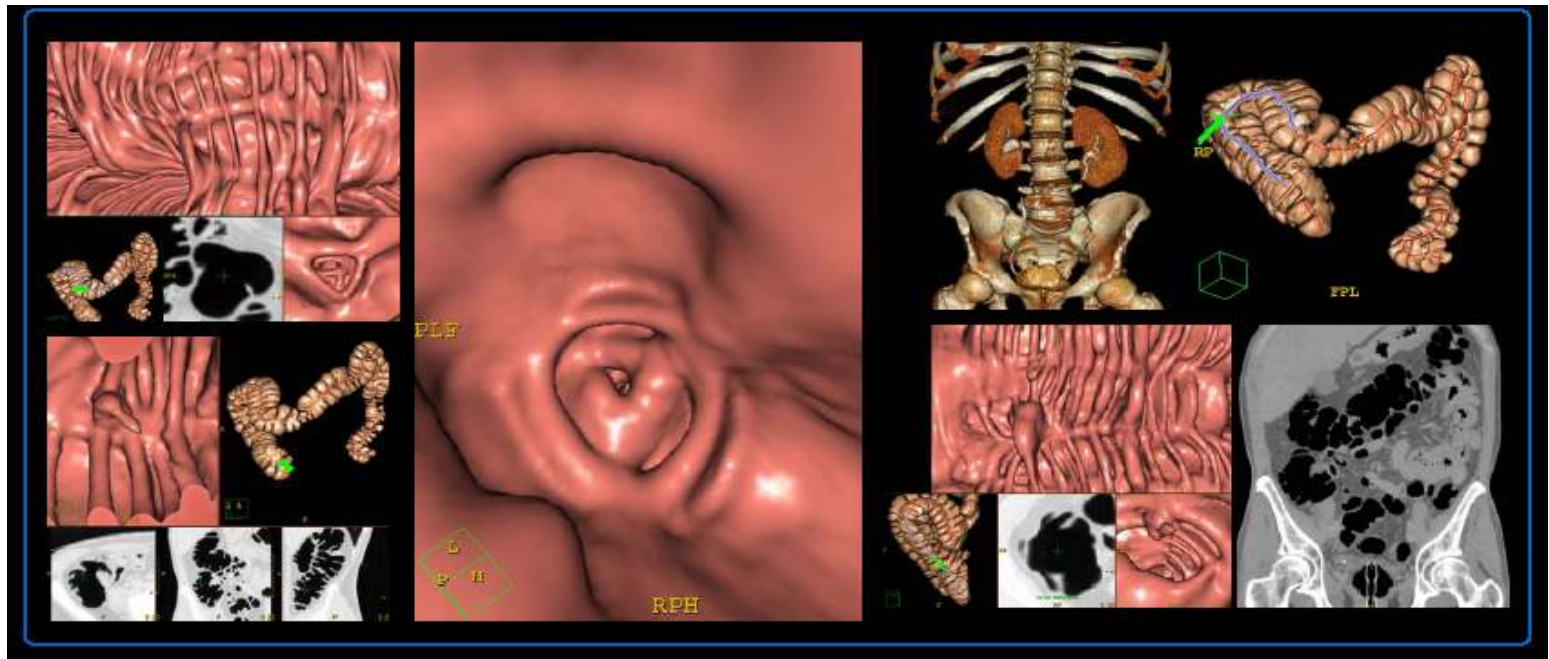
„Anatomy”  
of a CT



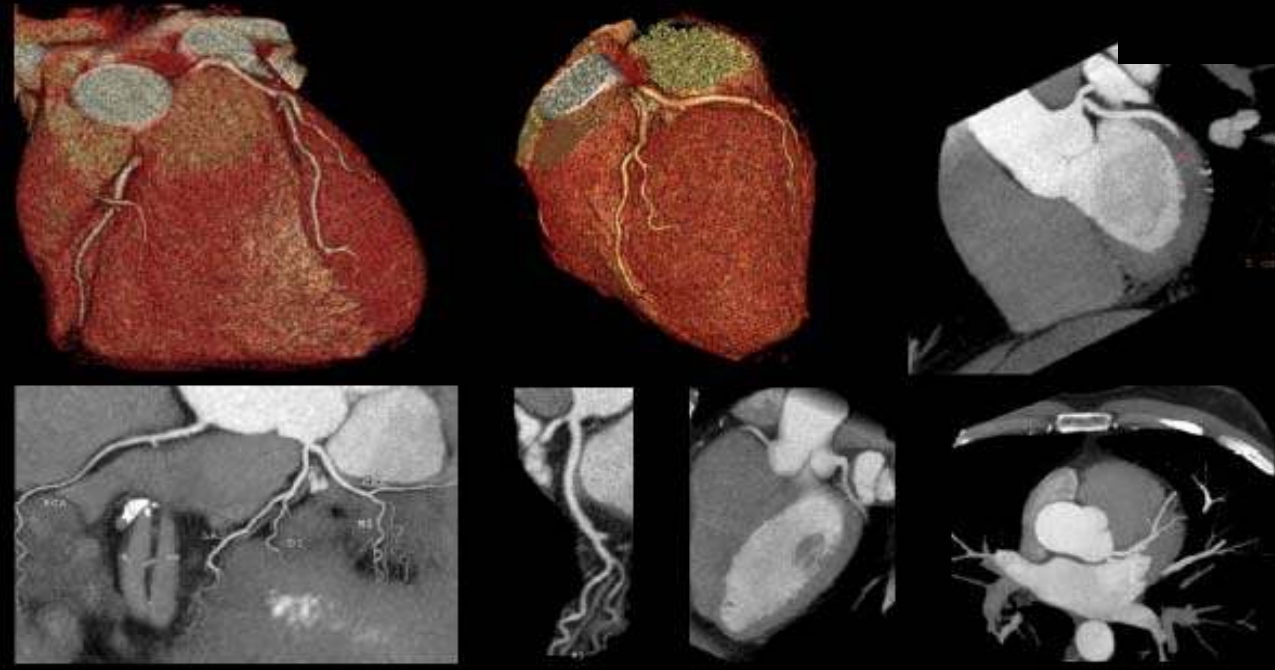
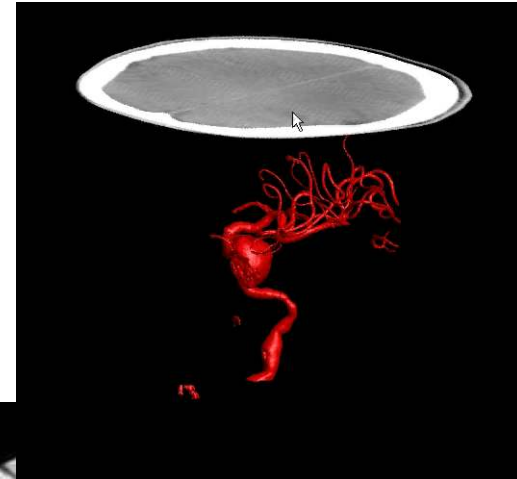
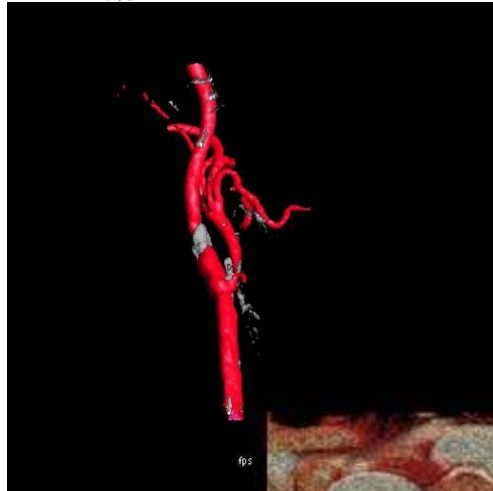
# Biomedical Imaging: Computed Tomography (CT)



## Reconstructed 3D images: virtual colonoscopy

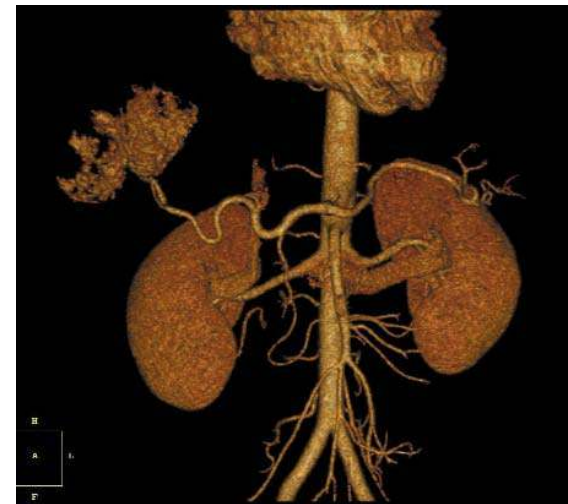
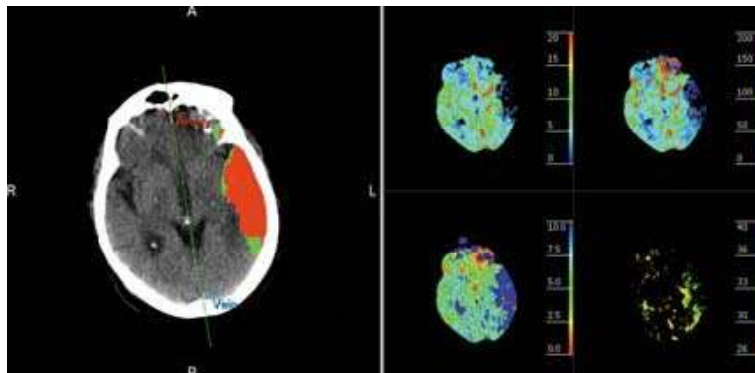


## Reconstructed cardiac and vessel images



## Functional CT images

Functional CT is a imaging method, made possible by fast CT scanners and improved data analysis techniques, to investigate the physiological basis of function and disease in the human body.



## Future of CTs:

- more detector row (128/256/340) / higher coverage
  - => volume CT
  - => specialized CT-s
- detector efficiency / lower dose
- multi-energy detectors

# Biomedical Imaging: Computed Tomography (CT)

## Target Tissue

## Regulatory Limit

Whole Body	12.5 mSv/quarter
Extremities 18,750 mrem/quarter	18.75 mSv/quarter
Skin/Other Organs	75 mSv/quarter
Fetus	5 mSv/gestational period

## Common Radiation Exposures

One Coast to Coast Flight	0.03 mSv
Chest Radiograph, Anterior/Posterior view	0.15 - 0.25 mSv/view
Chest Radiograph, Lateral view	0.5 – 0.65 mSv/view
Screening Mammography (Film/Screen Combination)	0.6 – 1.35 mSv/view

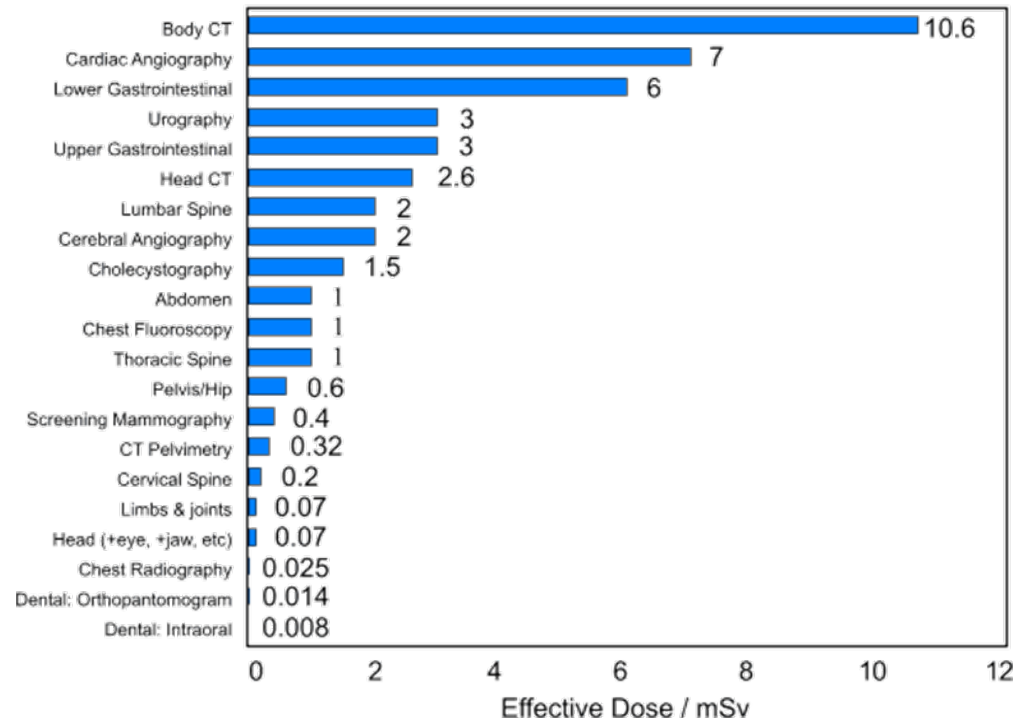
## Significant Radiation Exposures (Acute Doses)

Temporary Blood Count Change (Whole Body or Torso)	250 mSv
Permanent Sterilization in Men (Gonads)	1000 mSv
Permanent Sterilization in Women (Gonads)	2500 mSv
Skin Erythema (Burn)	3000 mSv
Cataract Formation	6000 mSv

## Common units and Conversions:

- $1 \text{ rad} = 0.01 \text{ Gy}$  \*or\*  $100 \text{ rads} = 1 \text{ Gy}$
- $1 \text{ rem} = 0.01 \text{ Sv}$  \*or\*  $1 \text{ Sv} = 100 \text{ rem}$
- $1 \text{ rem} = 1000 \text{ mrem}$  \*or\*  $1 \text{ mrem} = 0.001 \text{ rem}$
- For x-rays:  $1 \text{ rad} = 1 \text{ rem}$  ( $QF = 1$ )

Typical Values of Effective Dose for Various Medical X-rays



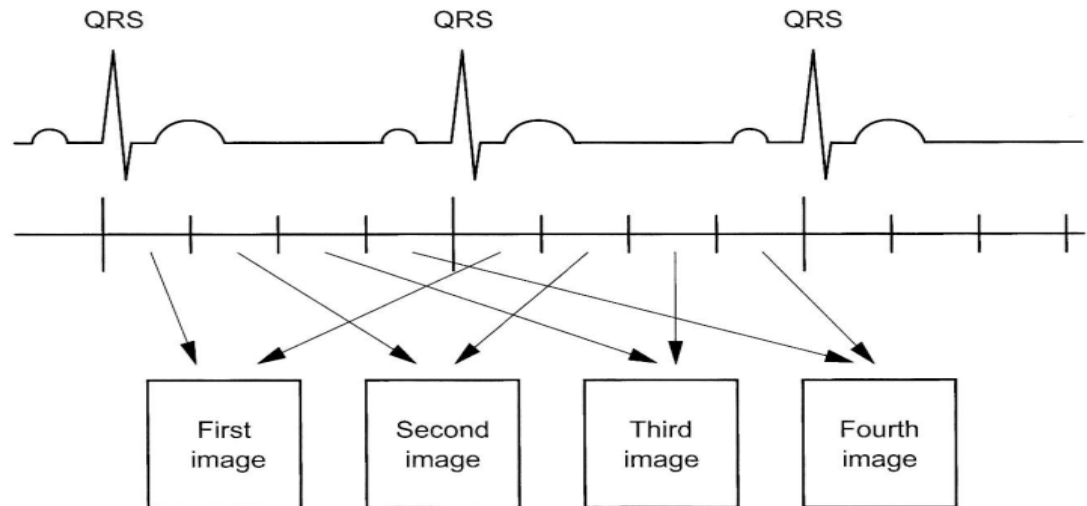
- **Prospective Gating**

Prospective Gating automatically triggers axial multislice scan acquisitions using patient information from the ECG monitor.

- **Retrospective Tagging**

Spiral Retrospective Tagging allows the CT system to acquire a volume of data while the patient's ECG is recorded.

The acquired data is "tagged" and reconstructed retrospectively at any desired phase of the cardiac cycle.



**FIGURE 21-22.** Acquisition of a gated cardiac image sequence. Only four images are shown here. Sixteen to 24 images are typically acquired.