

# **Non-invasive Multislice CT Coronary Angiography**

**Erasmus Medical Center, Rotterdam, The Netherlands**

**Departments of Radiology en Cardiology**

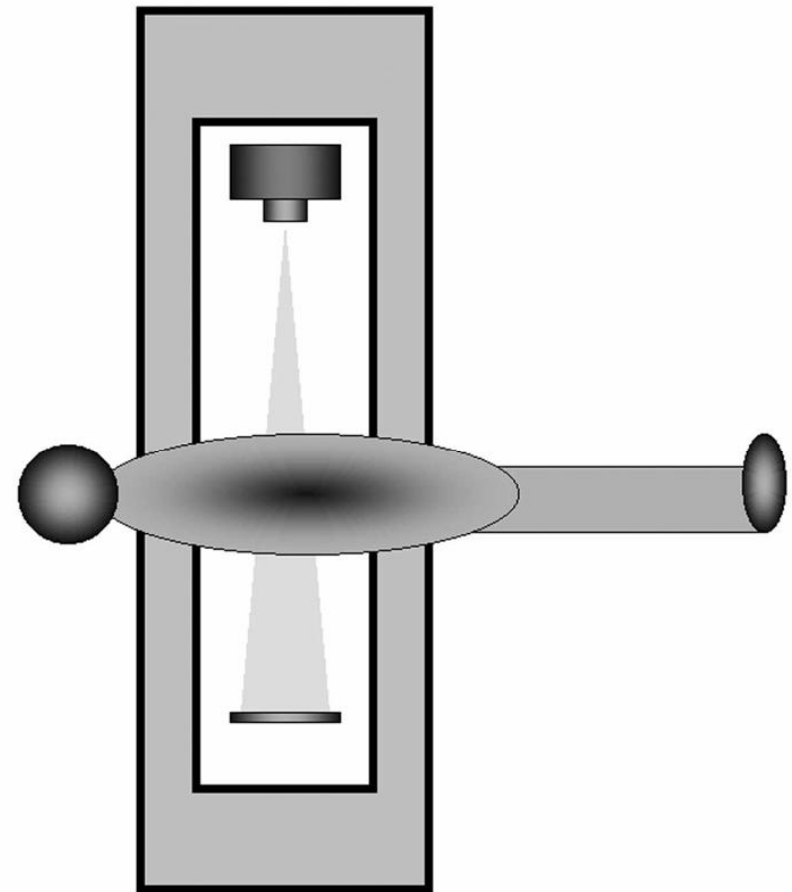
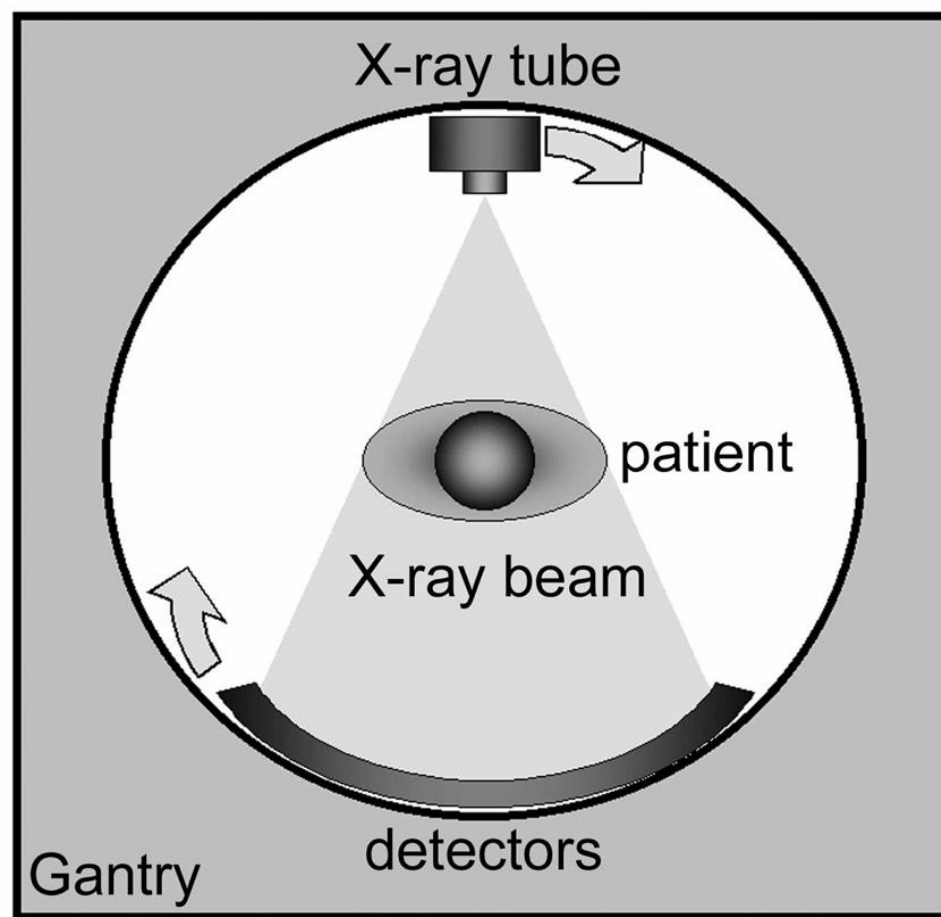
**Nico R Mollet, MD  
Filippo Cademartiri, MD  
Pim J de Feyter, MD**



# **Multislice CT**

## **Basics**

# Data Acquisition



# Data Acquisition

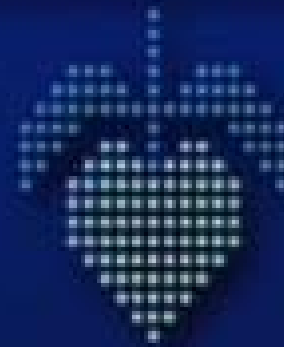


# Data Acquisition

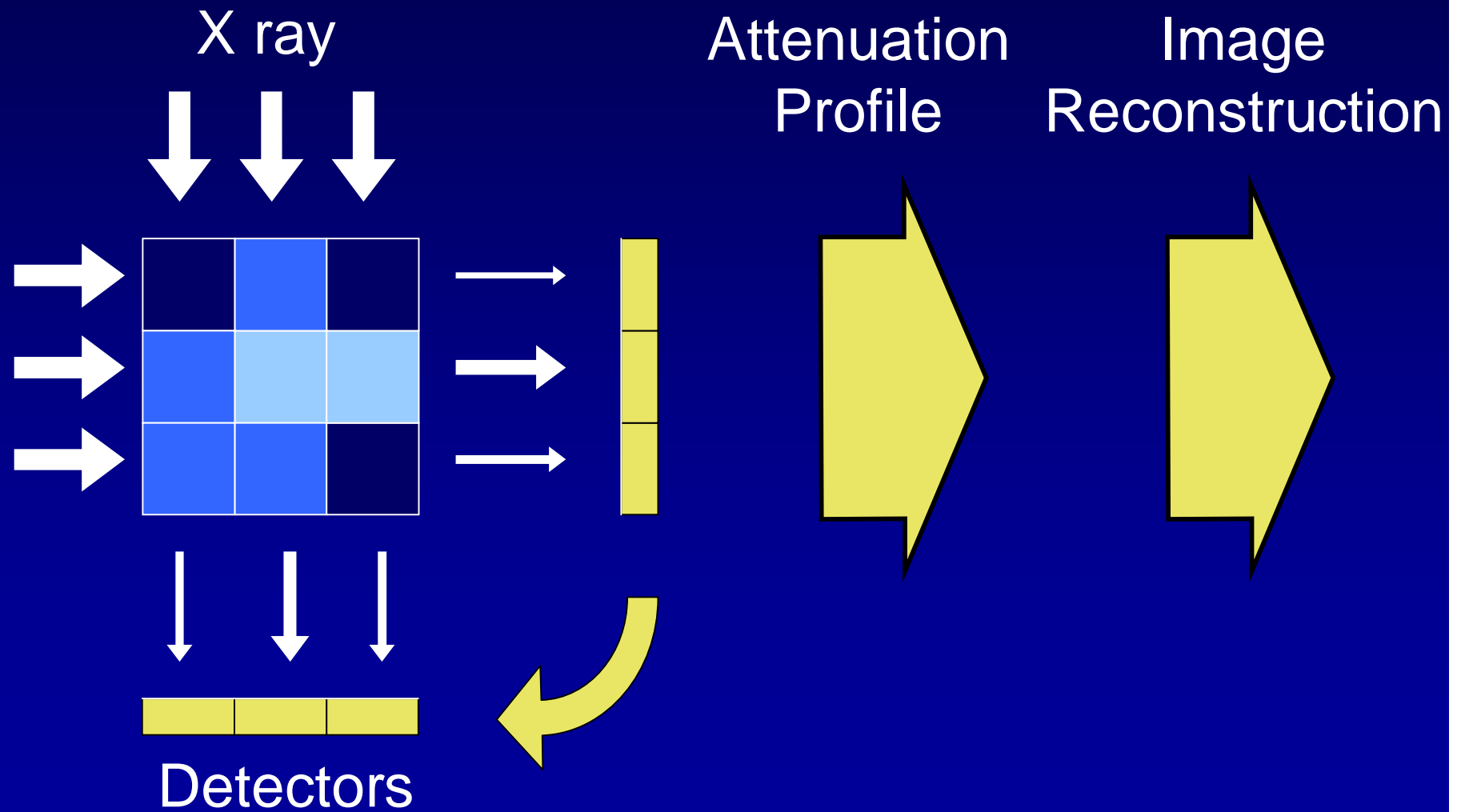
**Erasmus MC**  
University Medical Center Rotterdam



**Thoraxcenter**

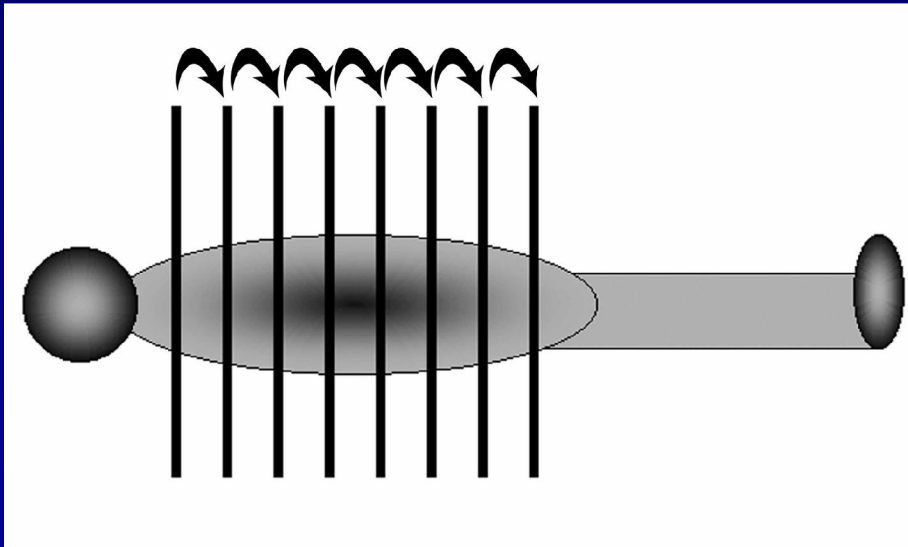


# Data Acquisition



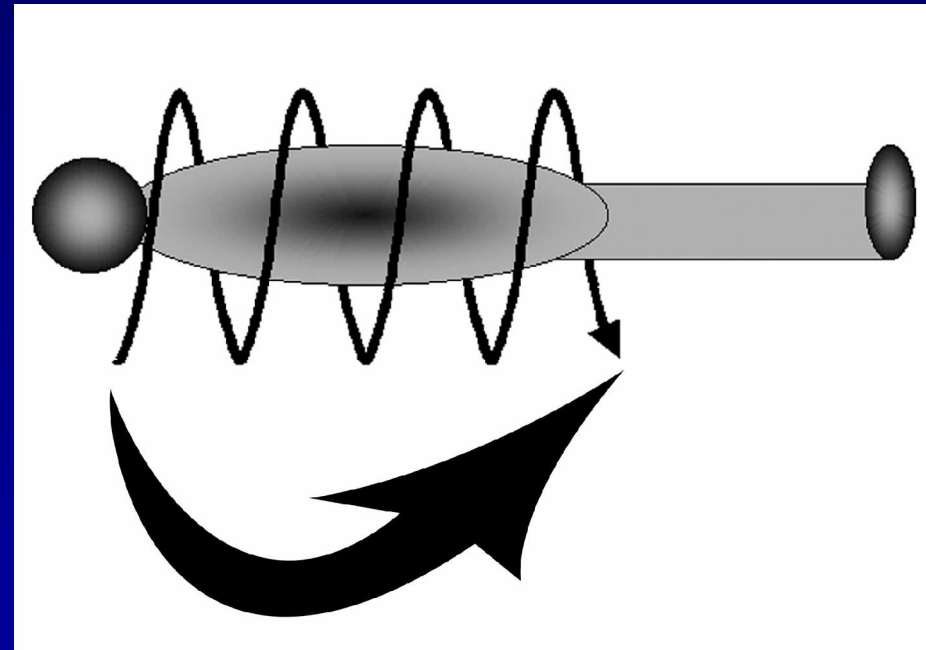
# Data Acquisition

## Sequential CT “Step-and-Shoot”



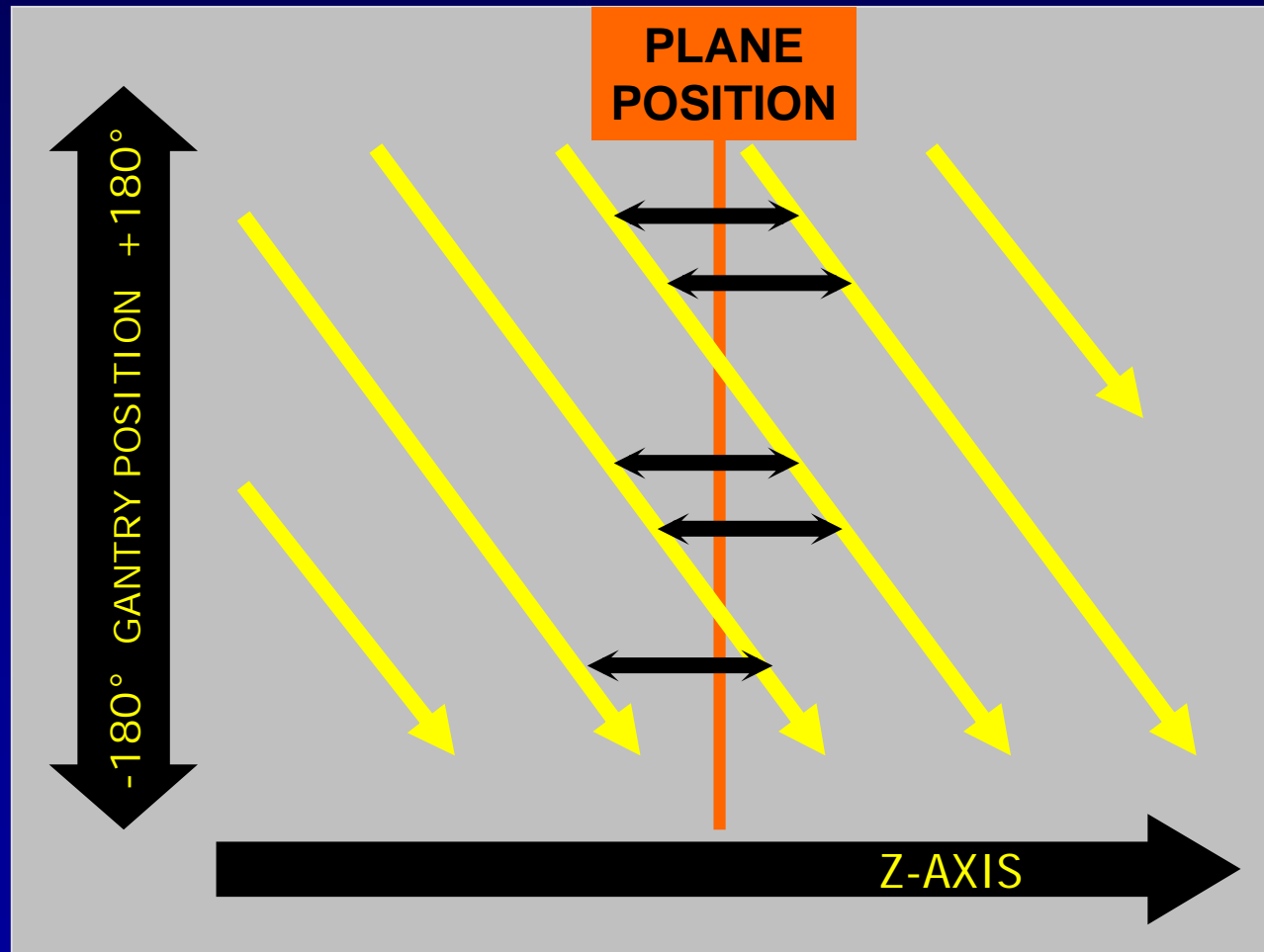
**Axial slices  
obtained**

## Spiral CT



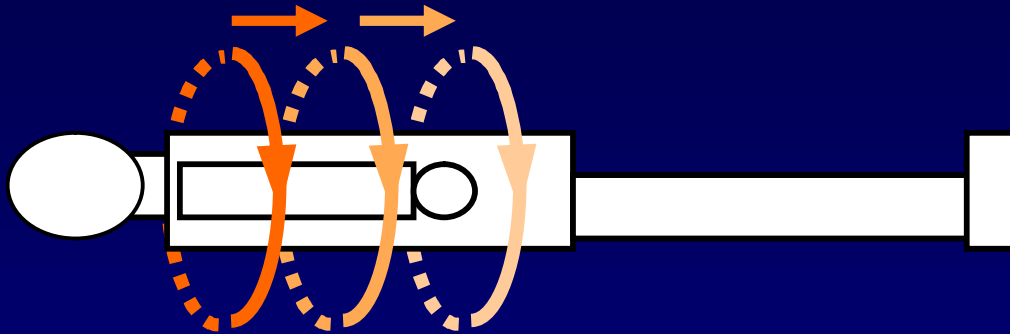
**Axial slices  
reconstructed**

# Image Reconstruction

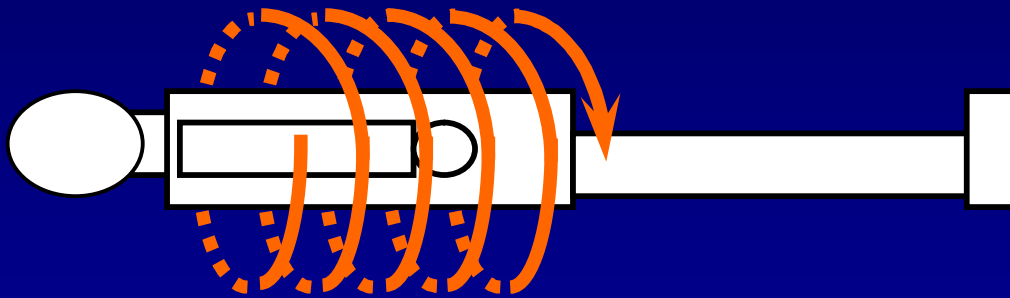




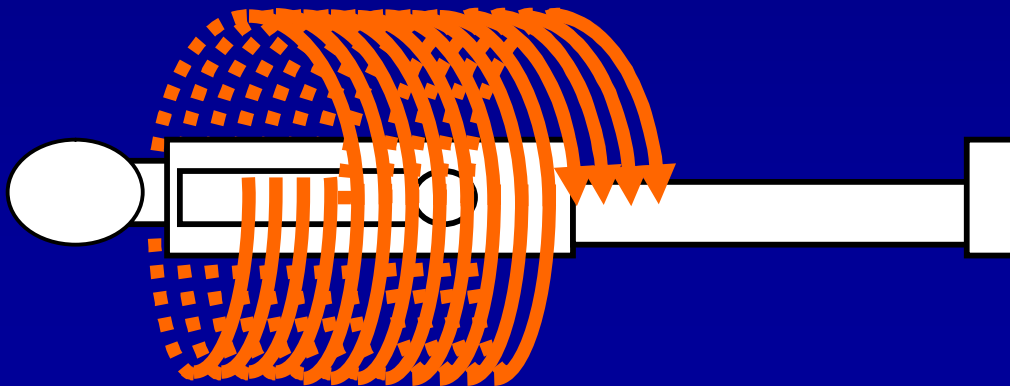
# Evolution in CT



**Conventional  
(Sequential) CT:**  
Axial slices

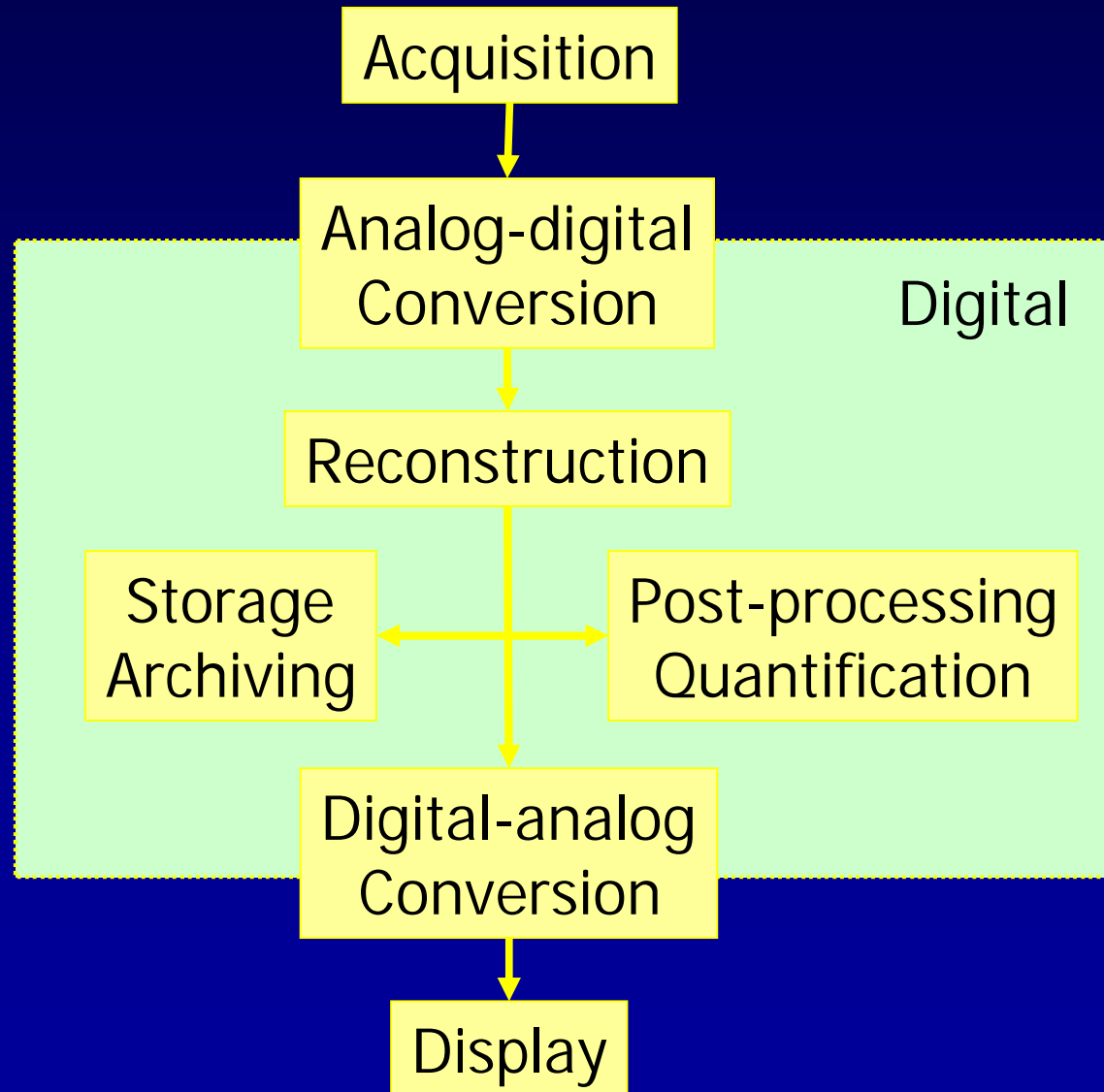


**Spiral CT:**  
Volume scanning:  
Reconstruction of  
axial slices



**Multislice or  
Multidetector Spiral CT:**  
Larger volume in  
less scan-time

# Analog-Digital Conversion



# Digitization



27	47	44	51	58	66	71	75	78	84
69	72	47	61	57	59	69	78	88	98
157	129	107	74	63	69	78	81	83	87
189	141	144	30	36	59	63	81	63	68
188	155	99	16	90	88	86	143	78	62
179	124	47	21	67	102	182	181	143	57
152	77	21	42	65	164	175	177	78	147
107	51	29	49	167	188	182	181	184	173
78	32	30	147	191	191	190	188	190	187
56	23	35	194	188	191	192	190	191	

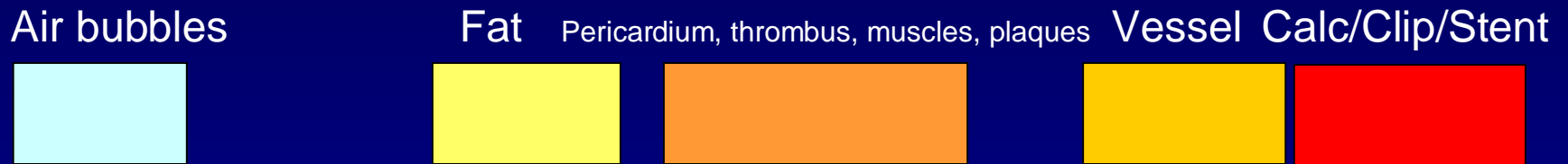
27	47	44	51	58	66	71	75	78	84
69	72	47	61	57	59	69	78	88	98
157	129	107	74	63	69	78	81	83	87
189	141	144	30	36	59	63	81	63	68
188	155	99	16	90	88	86	143	78	62
179	124	47	21	67	102	182	181	143	57
152	77	21	42	65	164	175	177	78	147
107	51	29	49	167	188	182	181	184	173
78	32	30	147	191	191	190	188	190	187
56	23	35	194	188	191	192	190	191	

# CT Density Values: Hounsfield Units

G



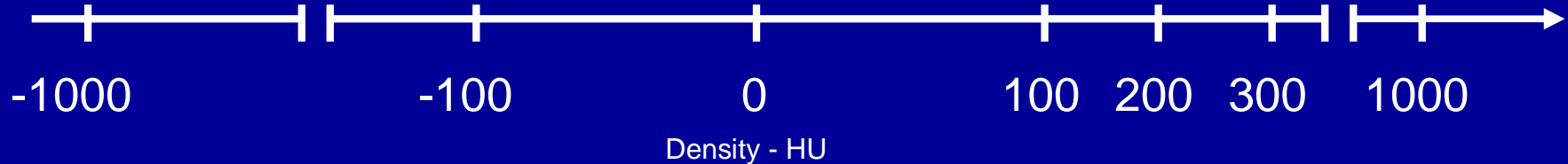
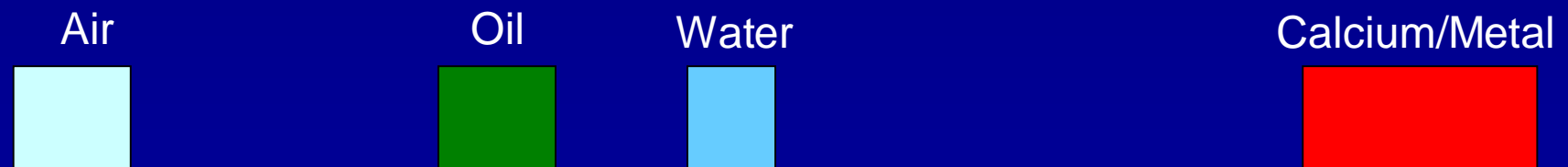
H



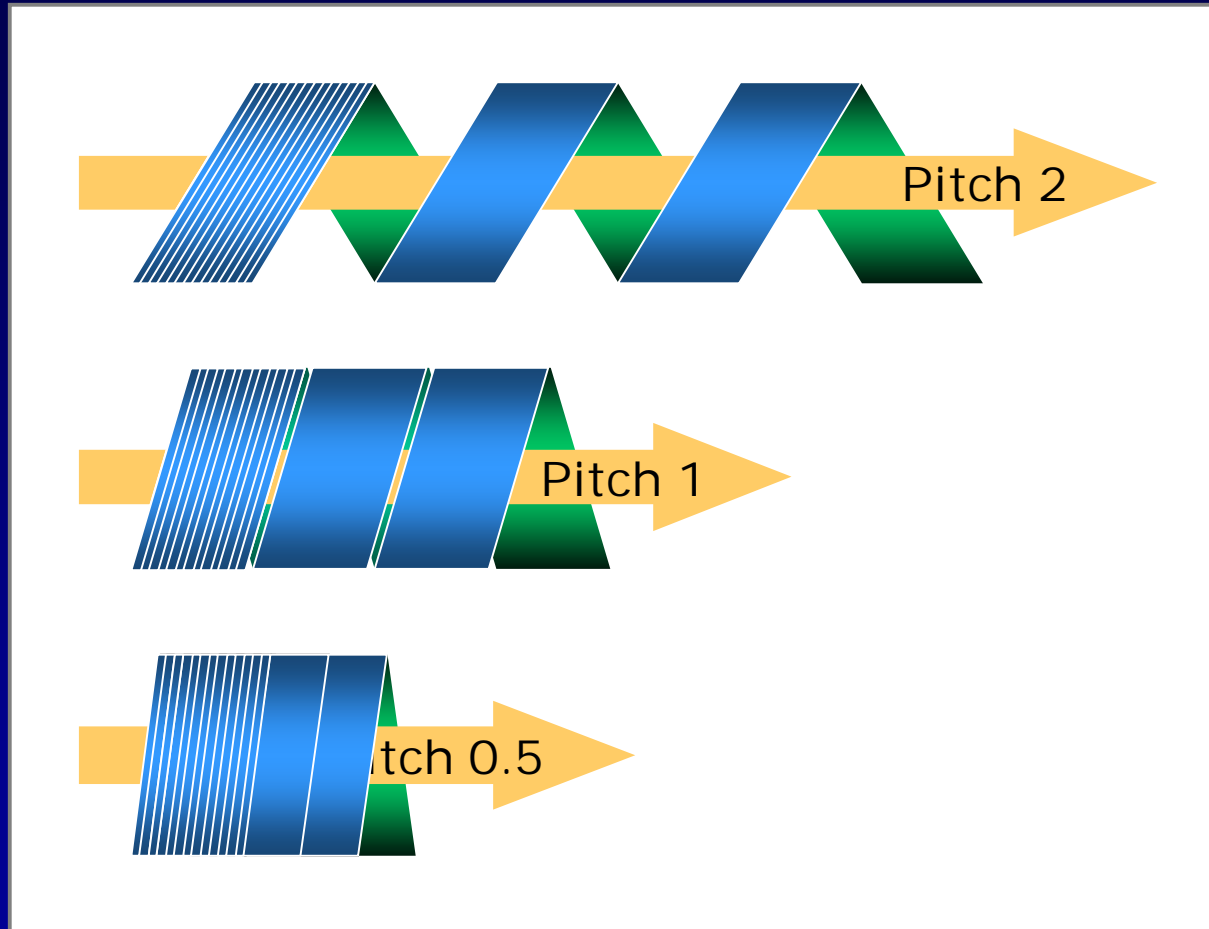
T



R



# Pitch



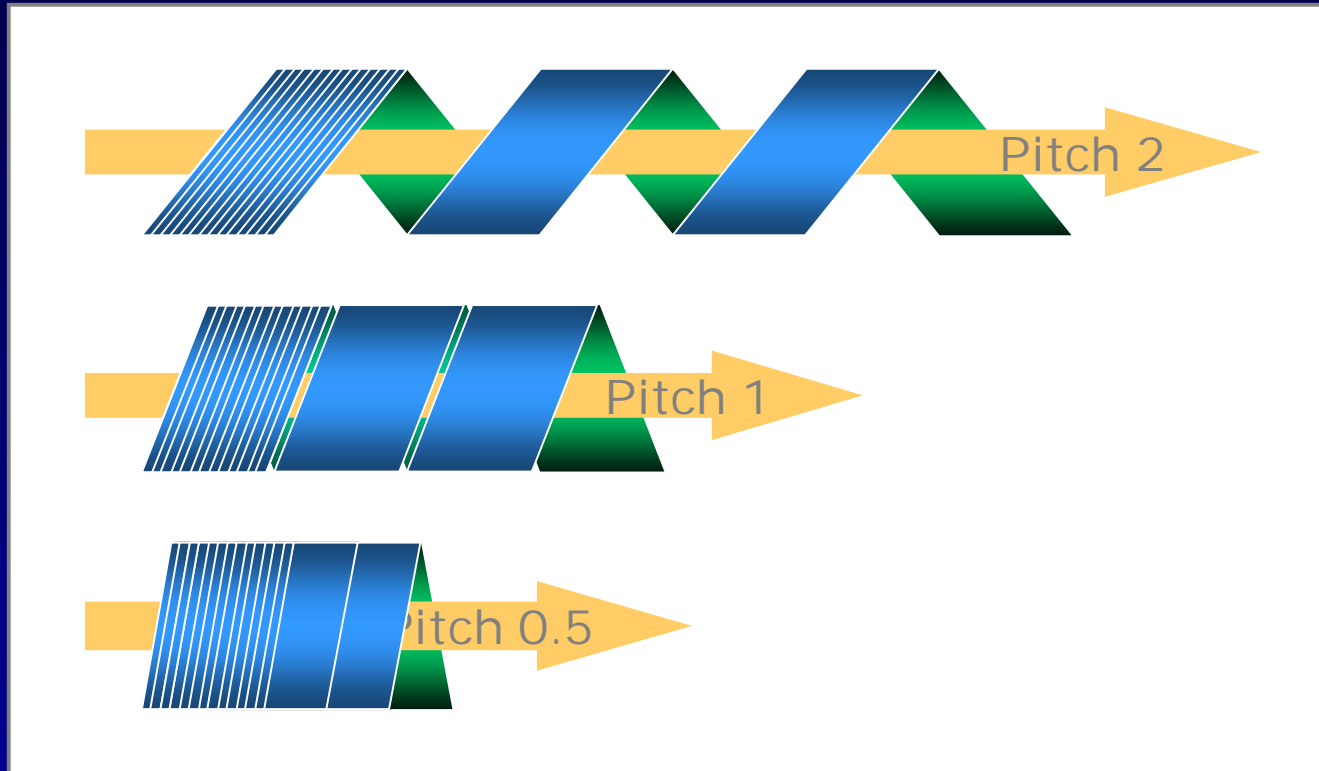
**Pitch:**  
(in Multislice CT)

**Table feed per rotation**  

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**Total width of collimated beam**  
(n detectors x collimation)

# Pitch

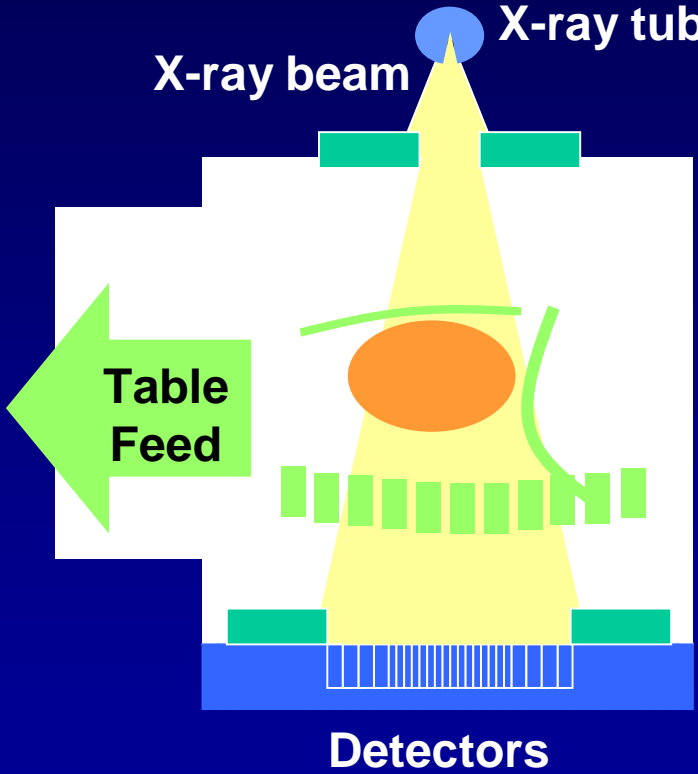


**Pitch >1: Data gaps (interpolation needed)**

**Pitch =1: Contiguous data**

**Pitch <1: Oversampling of a single object  
(e.g pitch 0.2: 5x oversampling)**

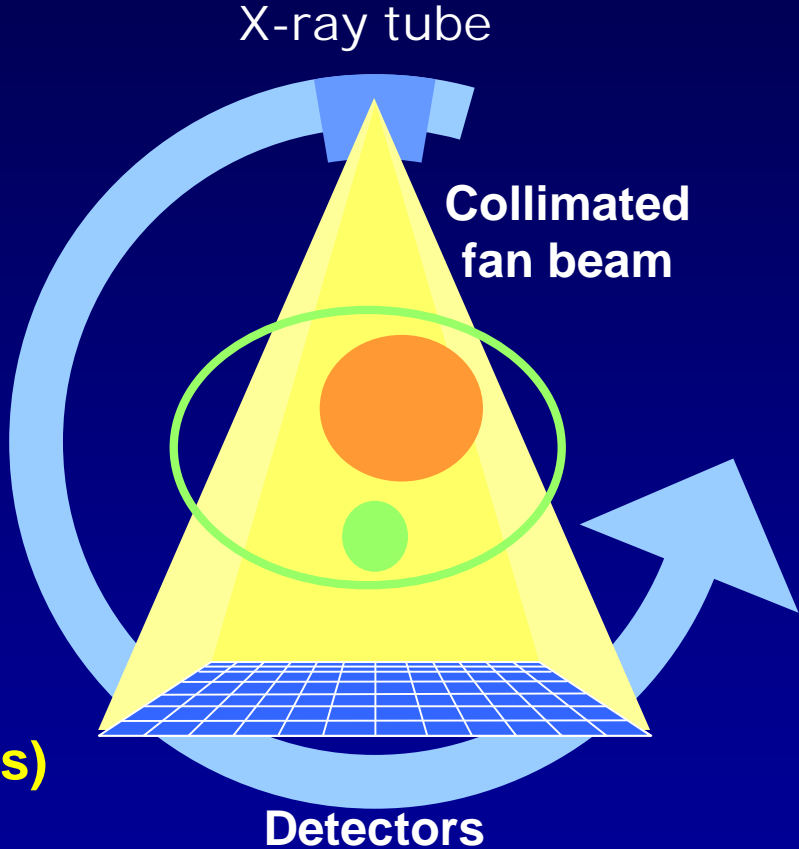
# Collimation



Longitudinal view

**Collimator  
(fan-shaper)**

**Collimator  
(select detectors)**



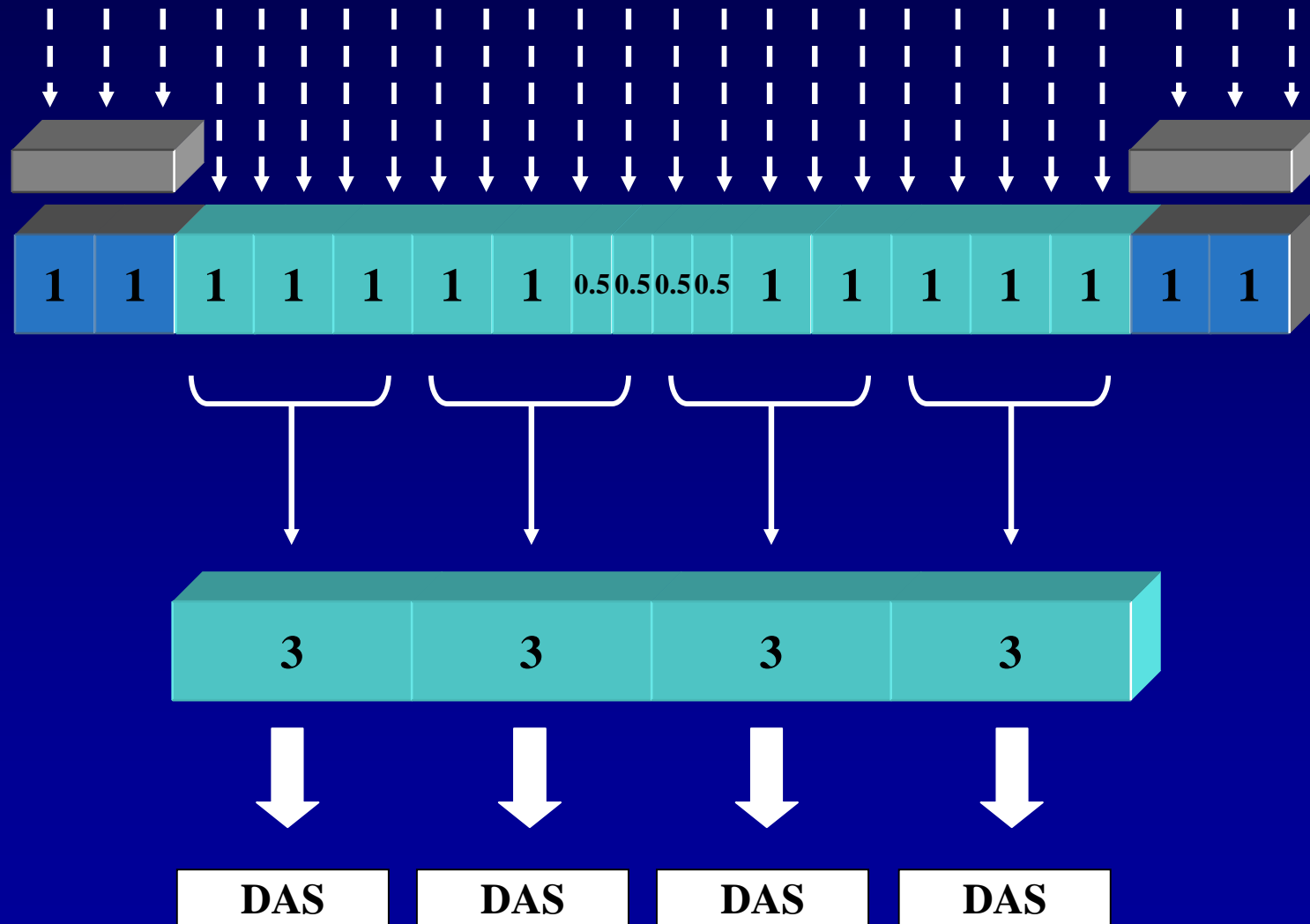
Short axis view

X-ray tube

Collimated  
fan beam

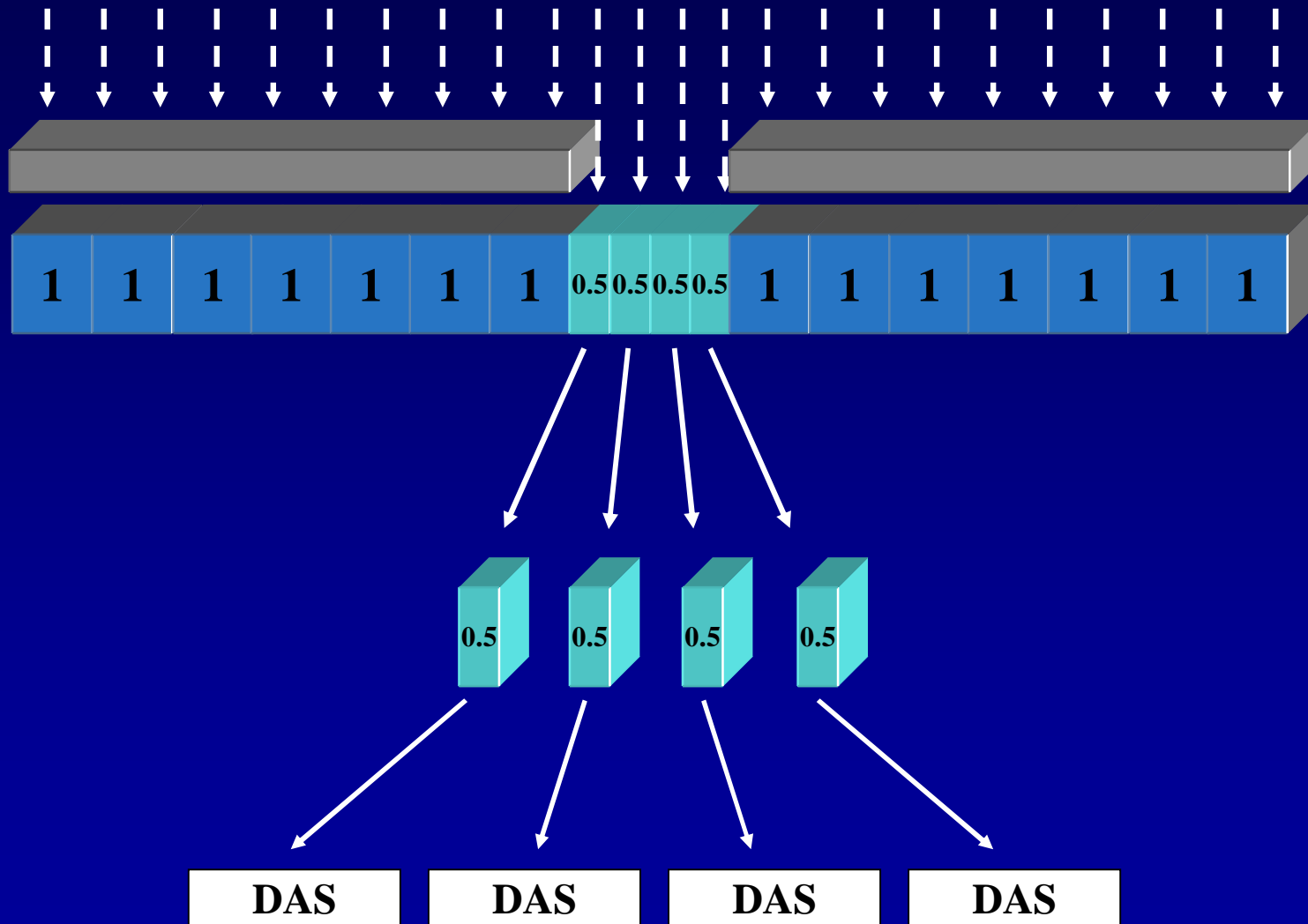
Detectors

# Collimation

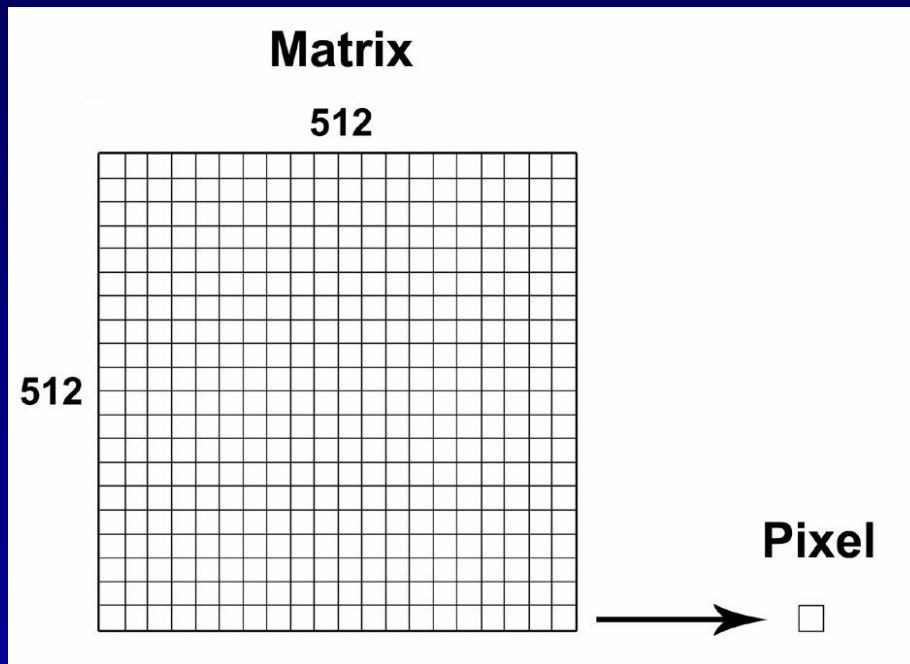




# Collimation

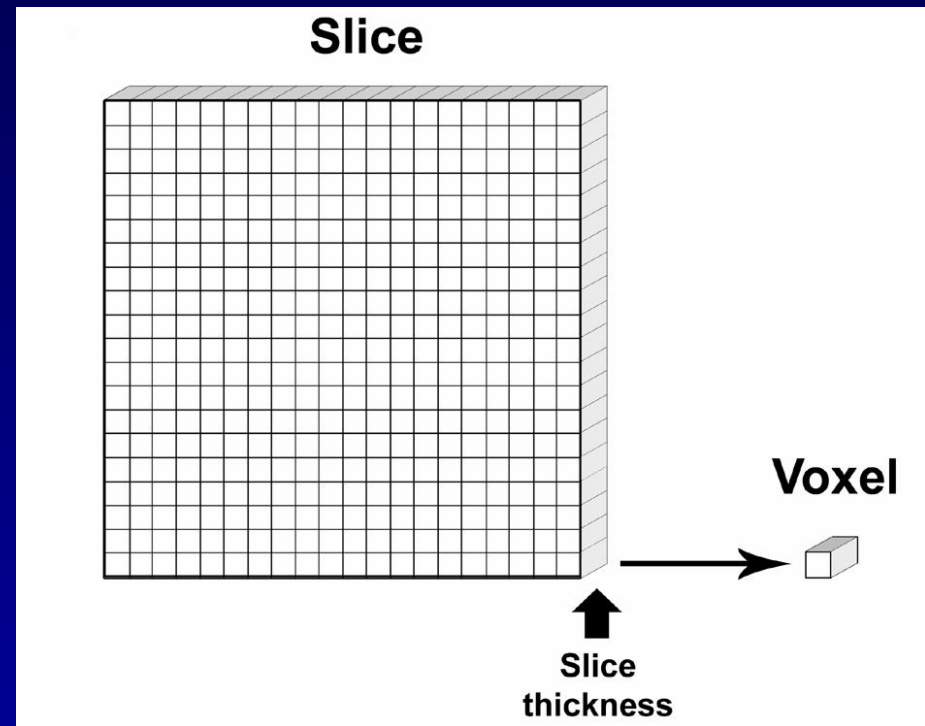


# Matrix & Field of View



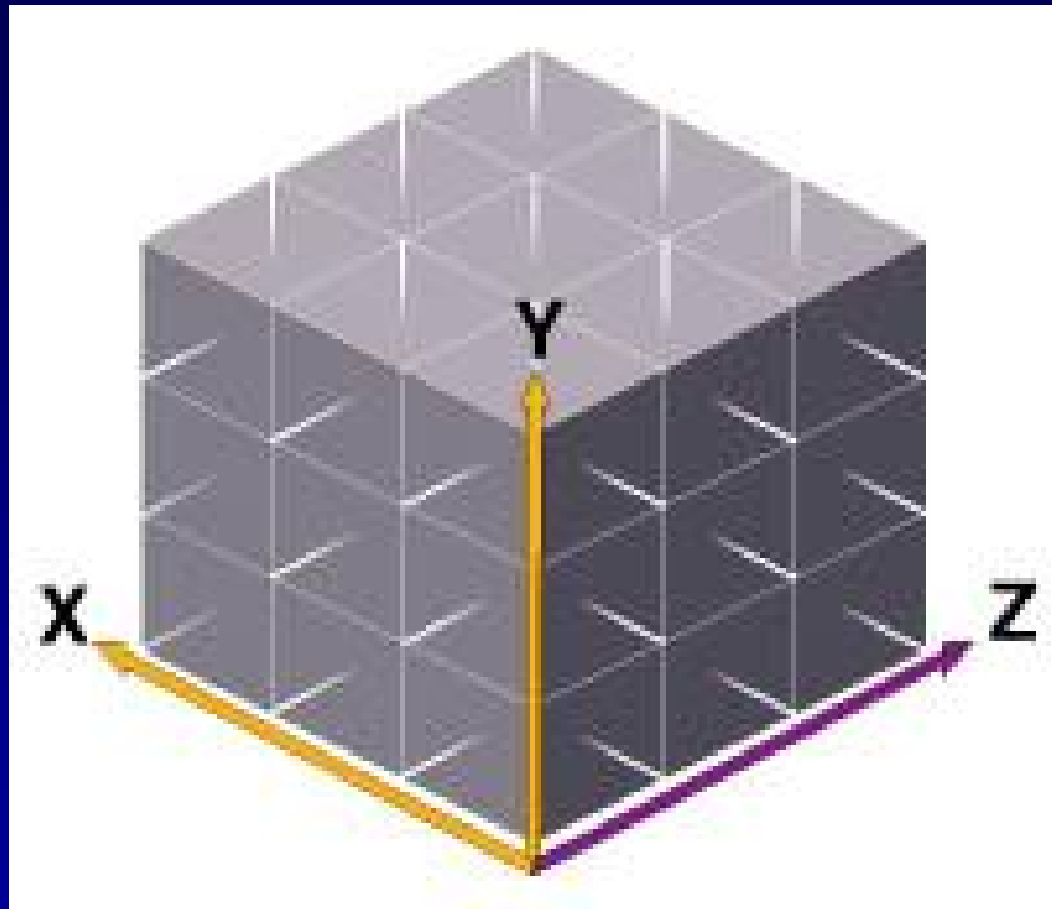
CT matrix: 512 x 512 pixels

$$\text{Pixel size} = \frac{\text{Field of View}}{\text{Matrix size}}$$



CT slice: 512 x 512 voxels

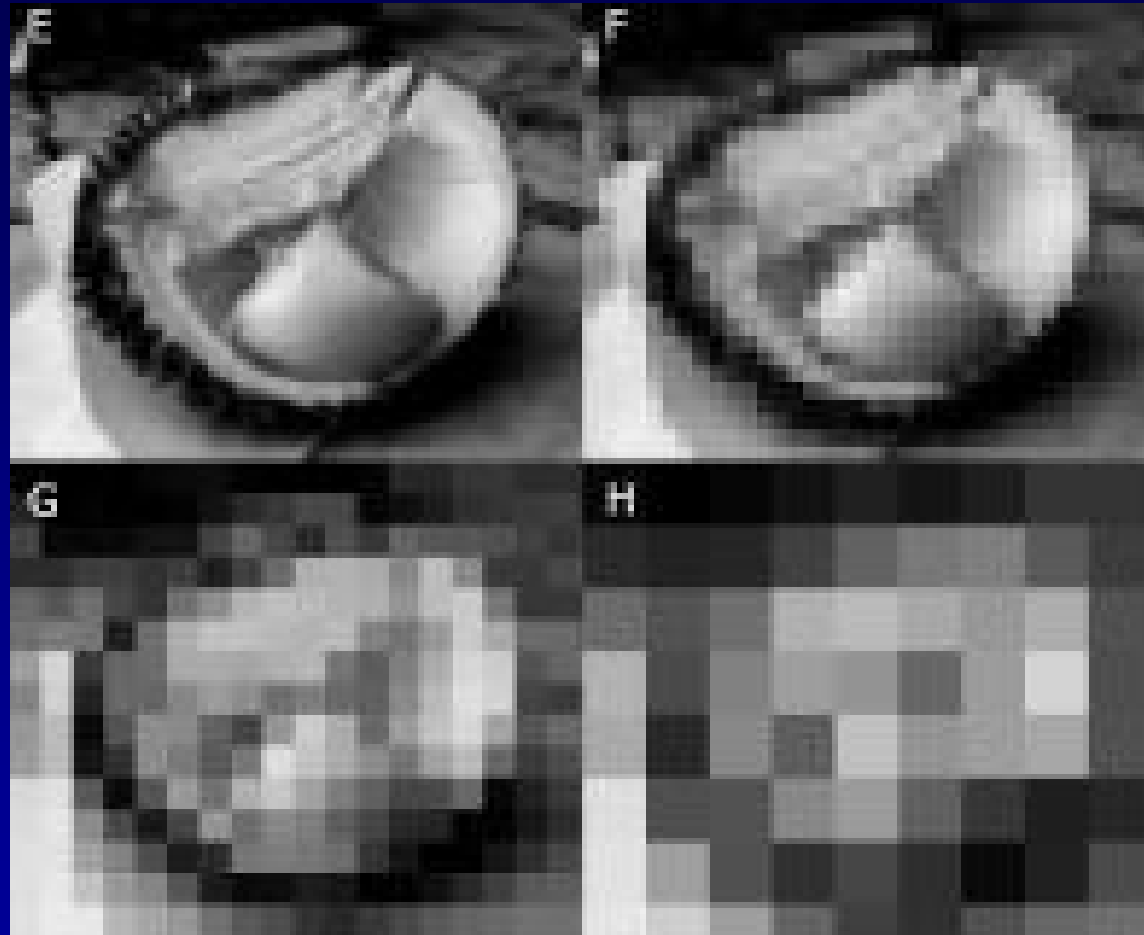
# Voxel Size



**Voxel = “3-dimensional Pixel”**

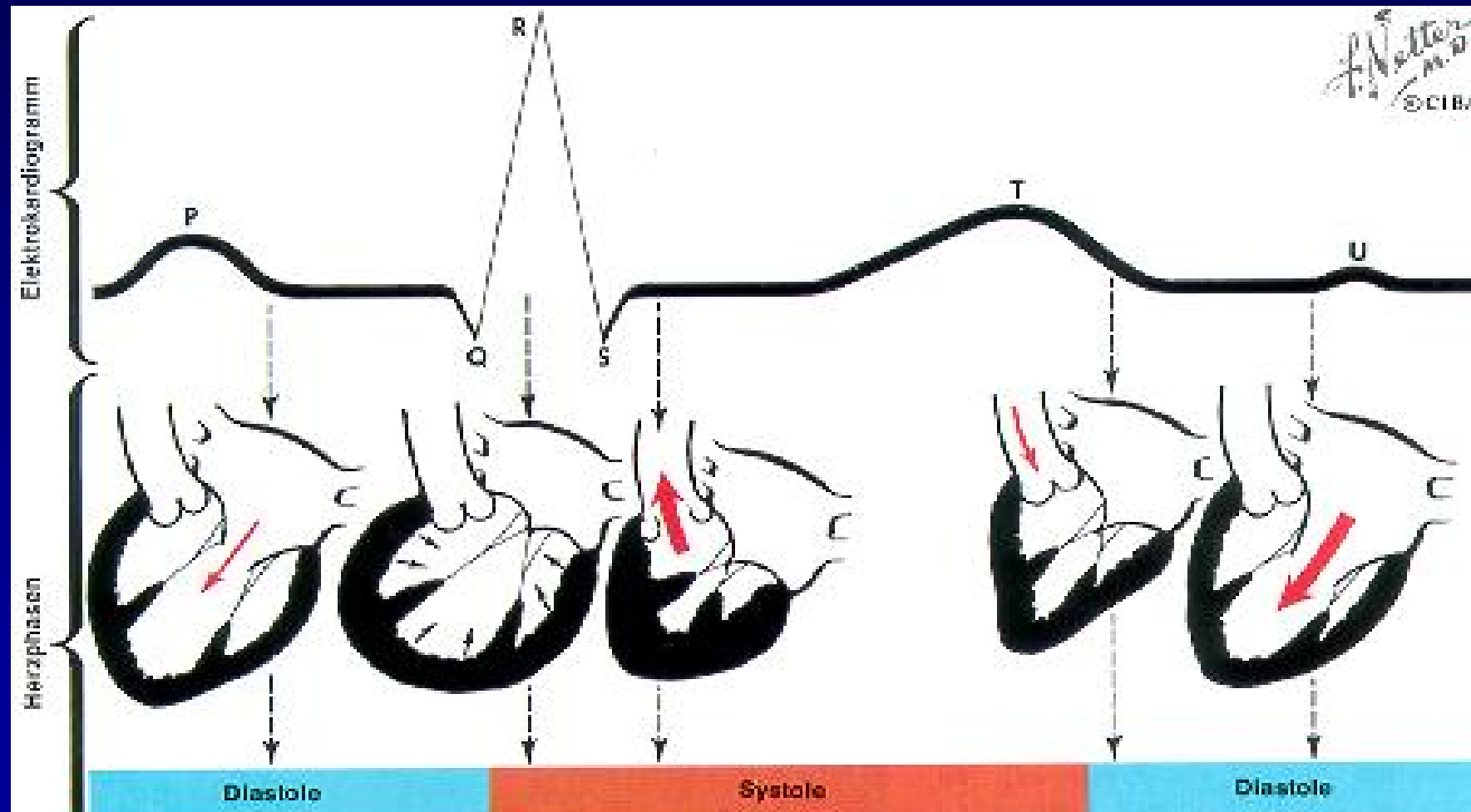
**Isotropic spatial resolution: voxel size equal in x,y,z-axis**

# Spatial Resolution & Partial Voluming

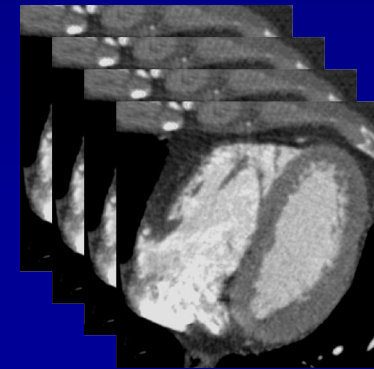
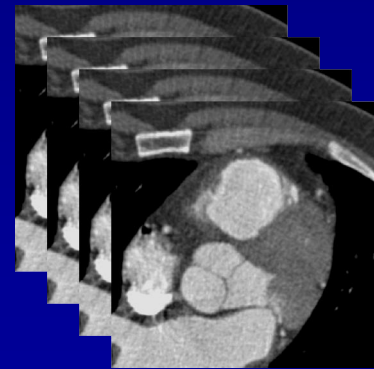
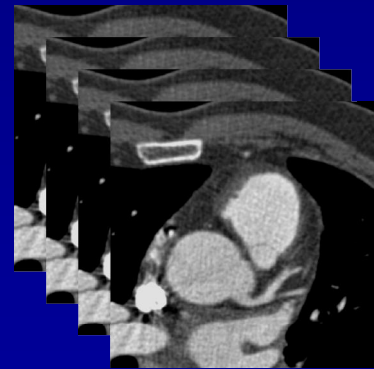
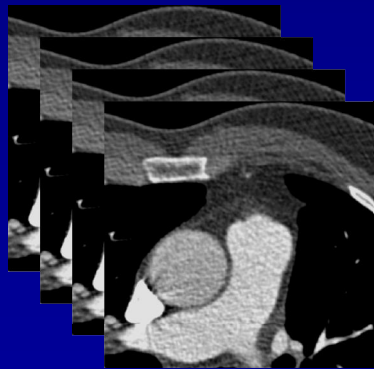
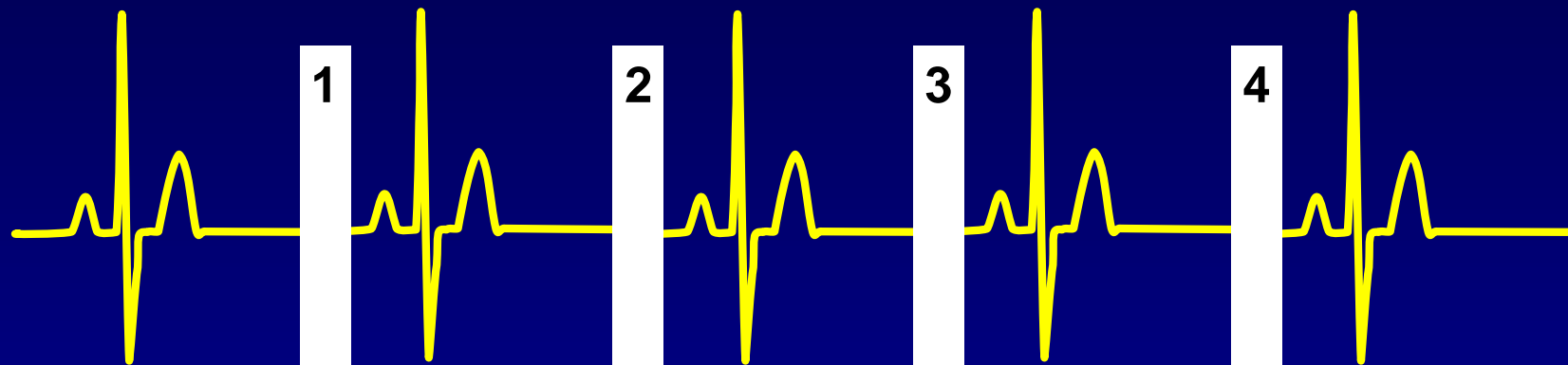


**Averaging of  $>1$  tissue types within 1 voxel resulting in a weighted density value**

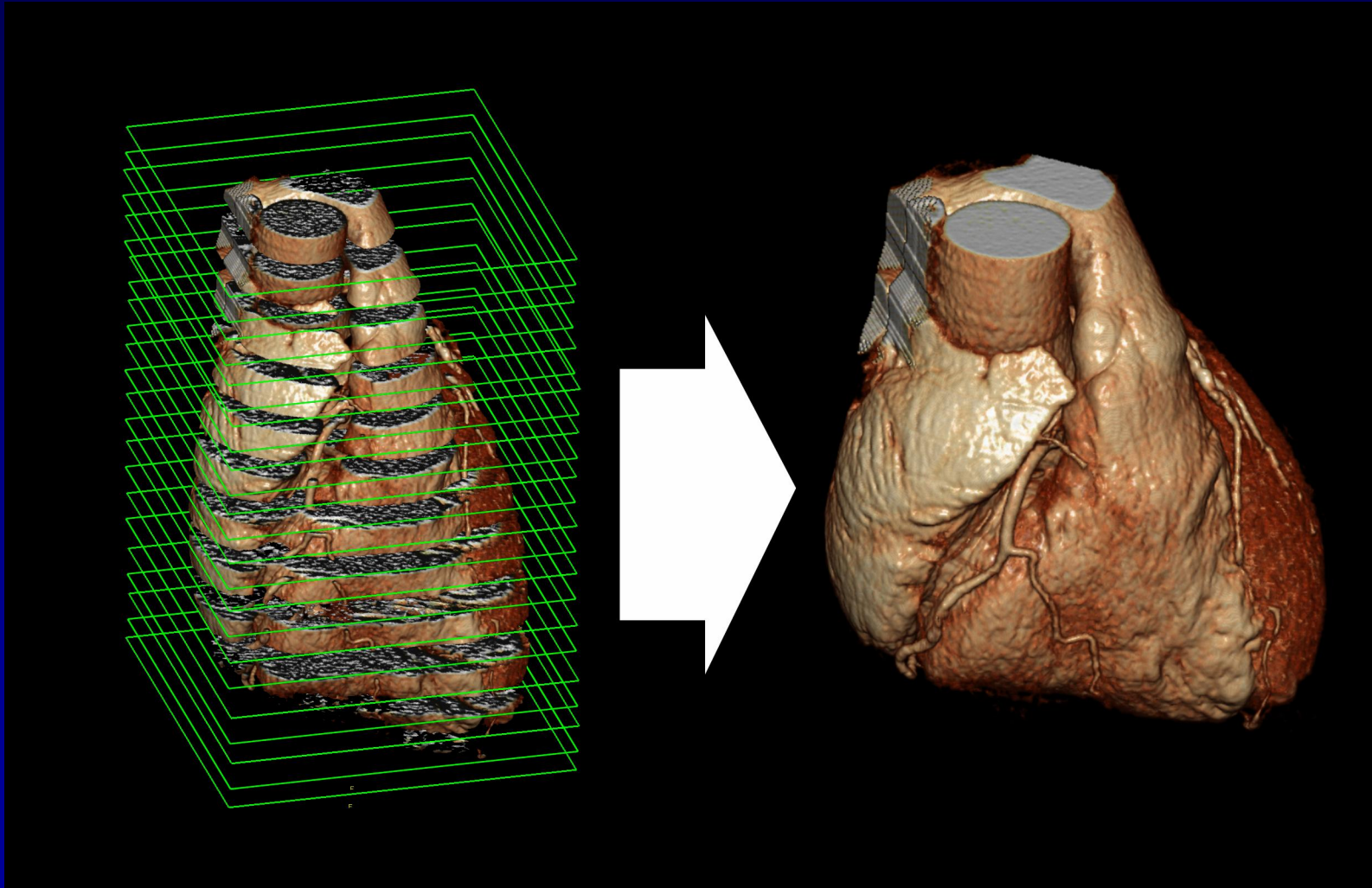
# Synchronization With Cardiac Cycle



# Synchronization With Cardiac Cycle

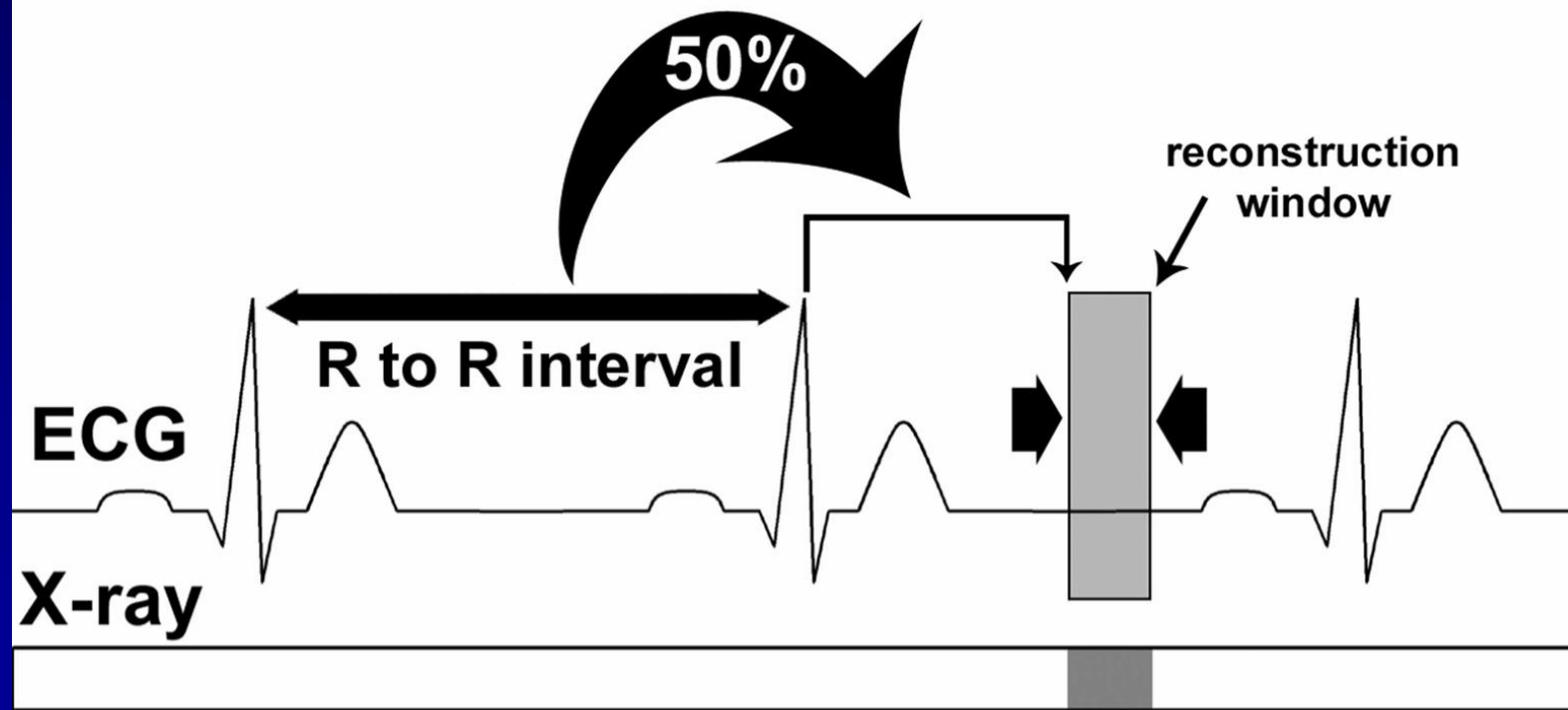


# Synchronization With Cardiac Cycle



# Synchronization With Cardiac Cycle

## Prospective ECG-triggering





# Synchronization With Cardiac Cycle

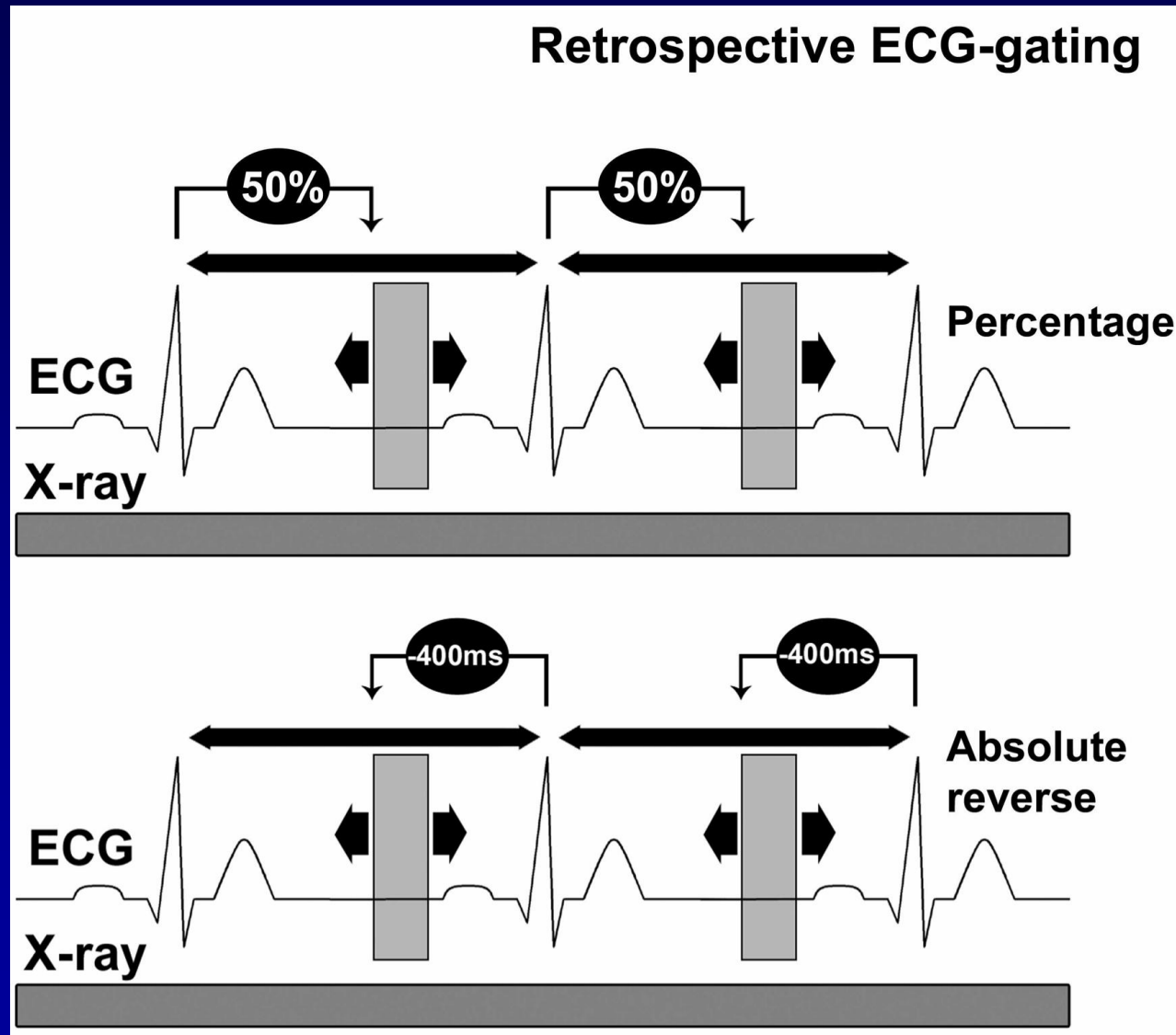
## Prospective ECG Triggering (Sequential)



**ECG signal triggers the acquisition**

**Cardiac phase is pre-defined**

# Synchronization With Cardiac Cycle



# Synchronization With Cardiac Cycle

## Retrospective ECG Gating



ECG signal is recorded while the whole volume is acquired

**Cardiac phase is arbitrary**

# Synchronization With Cardiac Cycle

## Prospective Triggering

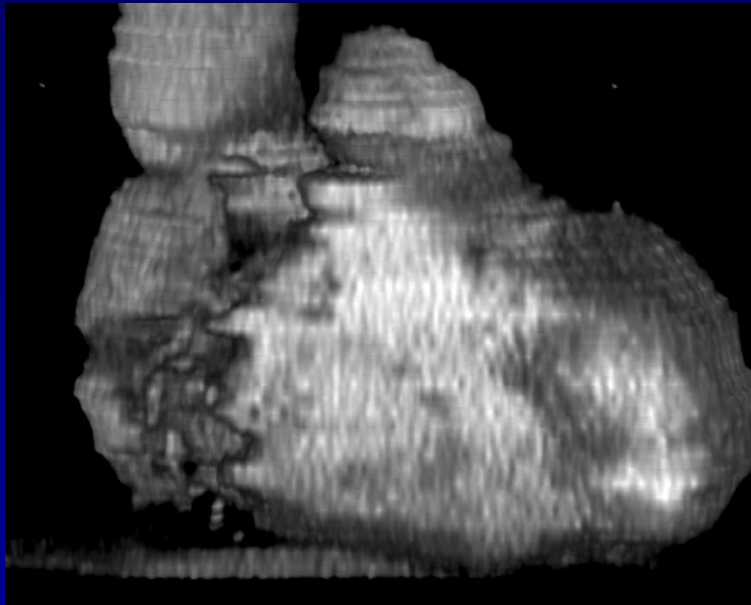
- Sequential Scanning
- Data acquired at a single, predefined phase of the cardiac cycle
- Trigger time is based on estimation of the R-R intervals from previous heart beats
- Sensitive to irregular heart rhythm
- Min. Temporal Resolution - 250ms

## Retrospective Gating

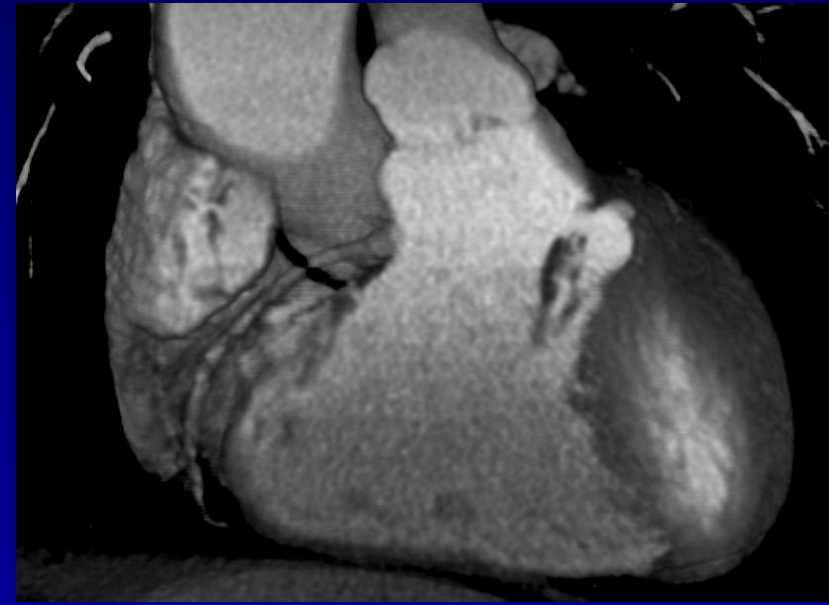
- Spiral Scanning
- Data acquired for the entire cardiac cycle - parallel ECG recording
- True match of the phase reconstruction to the ECG retrospectively
- Less sensitive to irregular heart rhythm
- Min. Temporal Resolution - 125ms

# Synchronization With Cardiac Cycle

Same patient: Irregular Heart Rate



**EBT Sequential Trigger**

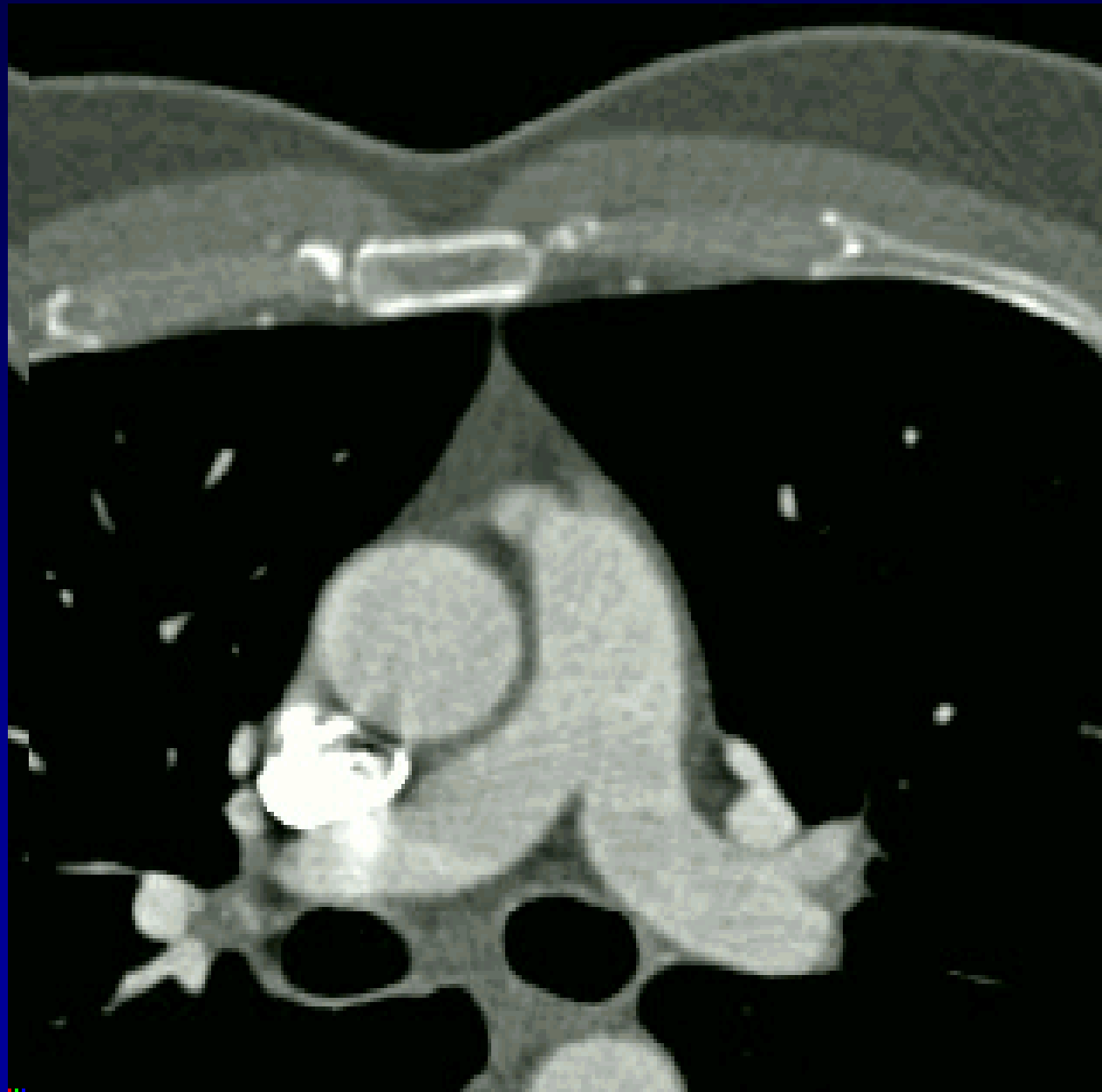


**4-MSCT Spiral Gating**

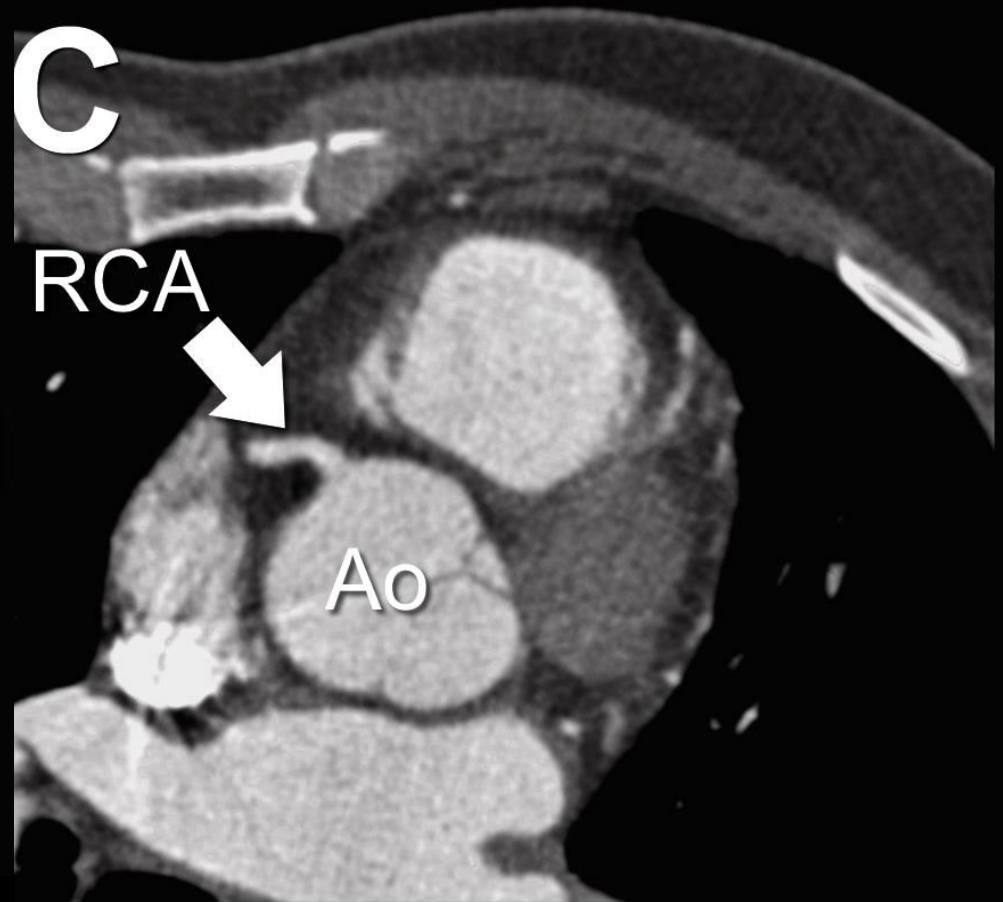
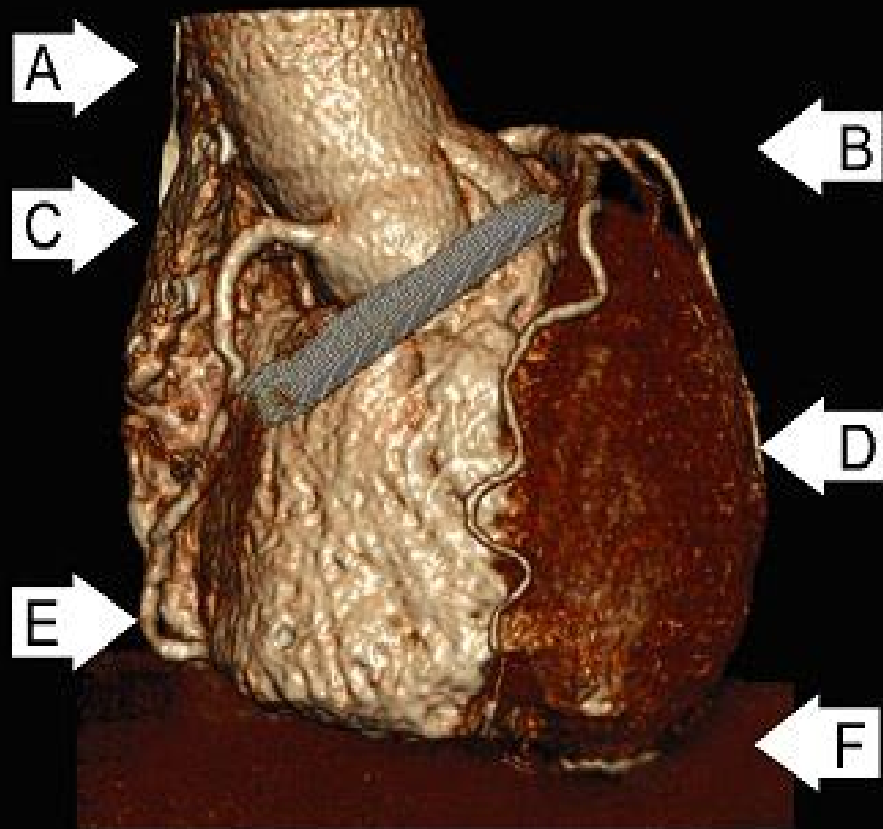
Courtesy of University Clinic of Grosshadern, Munich, Germany

**Multislice CT**  
**Coronary Angiography**  
**Anatomy**

# Tomographic (Axial) Images

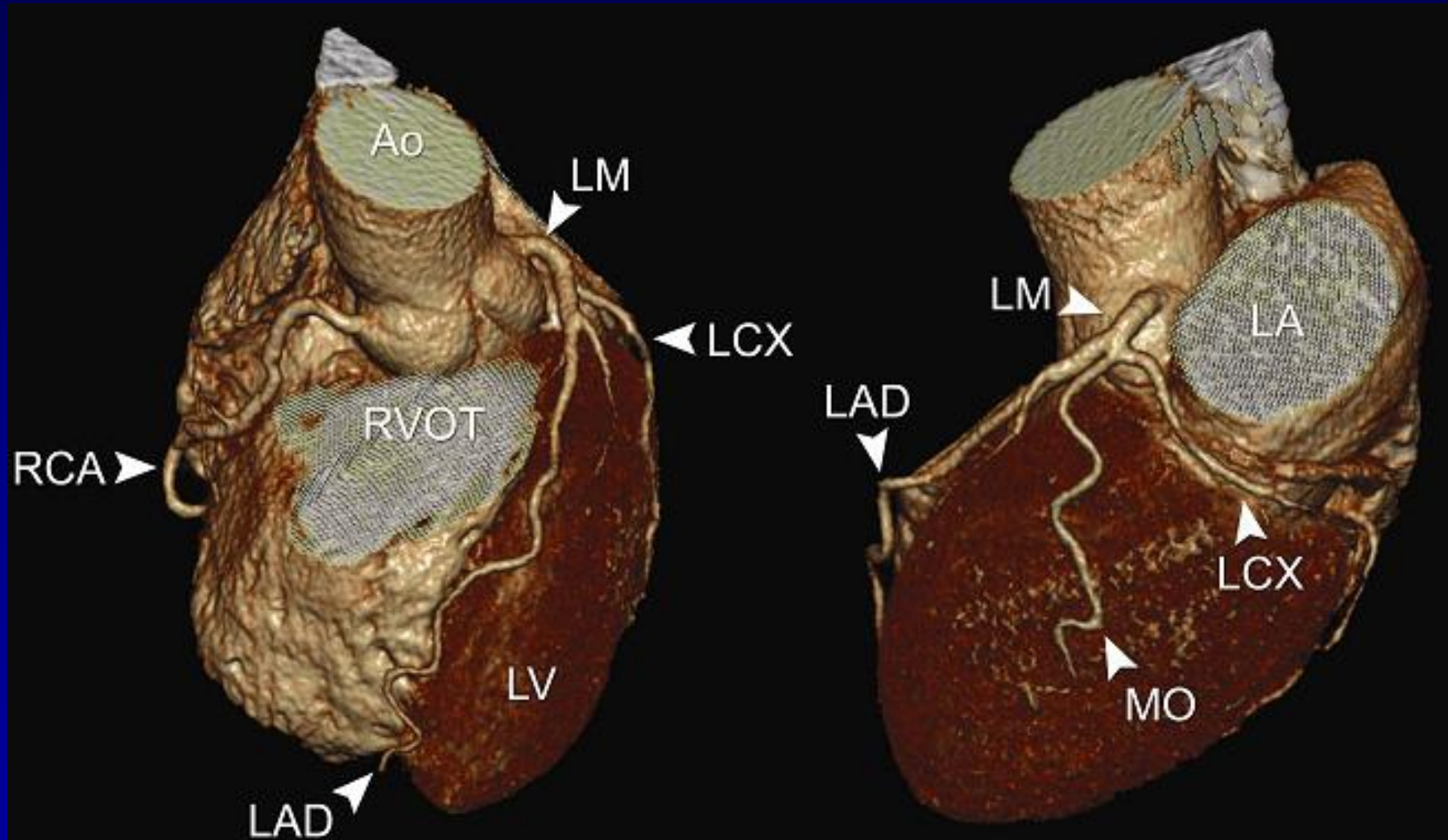


# Tomographic (Axial) Images

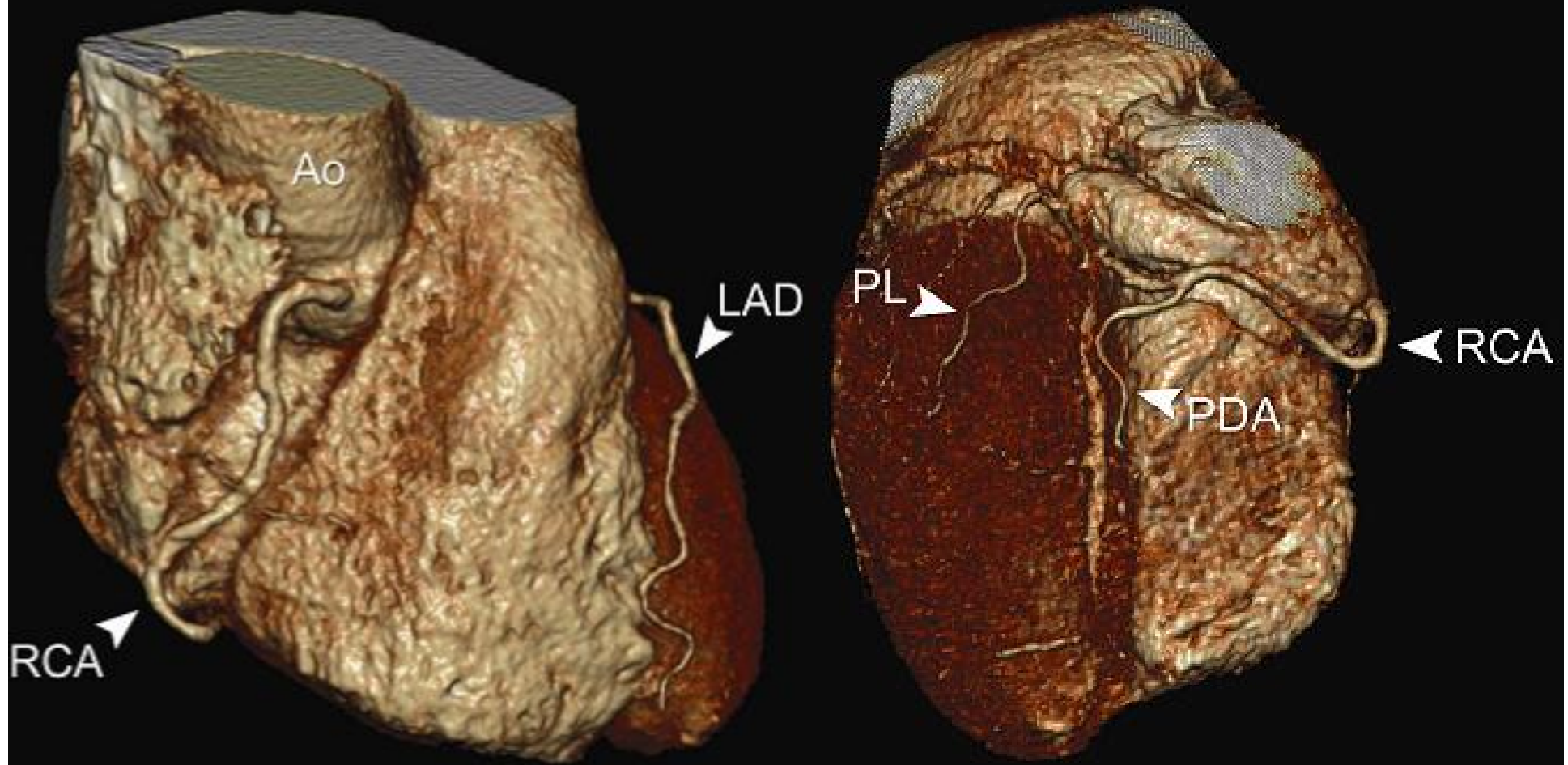




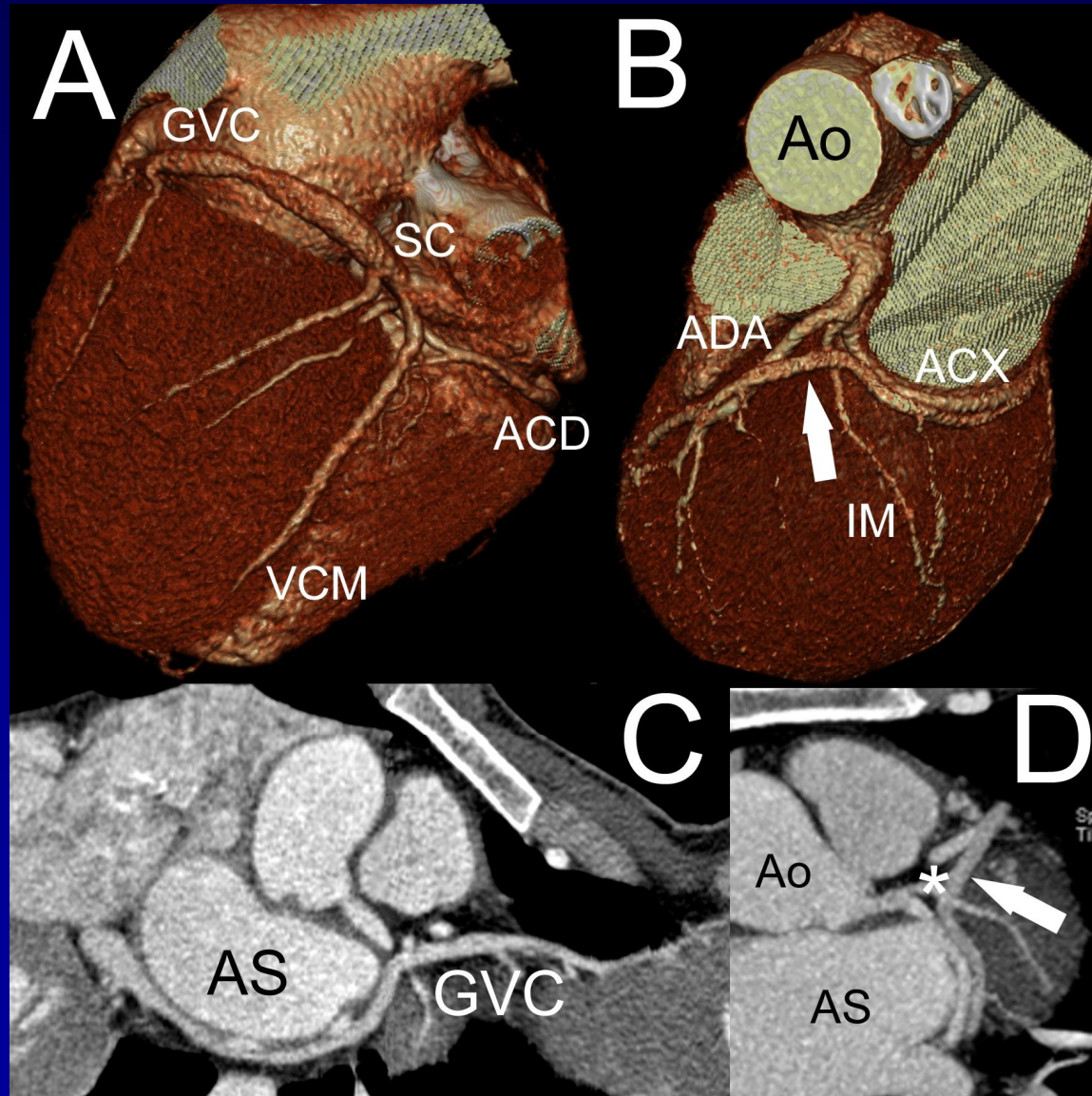
# Left Coronary Artery



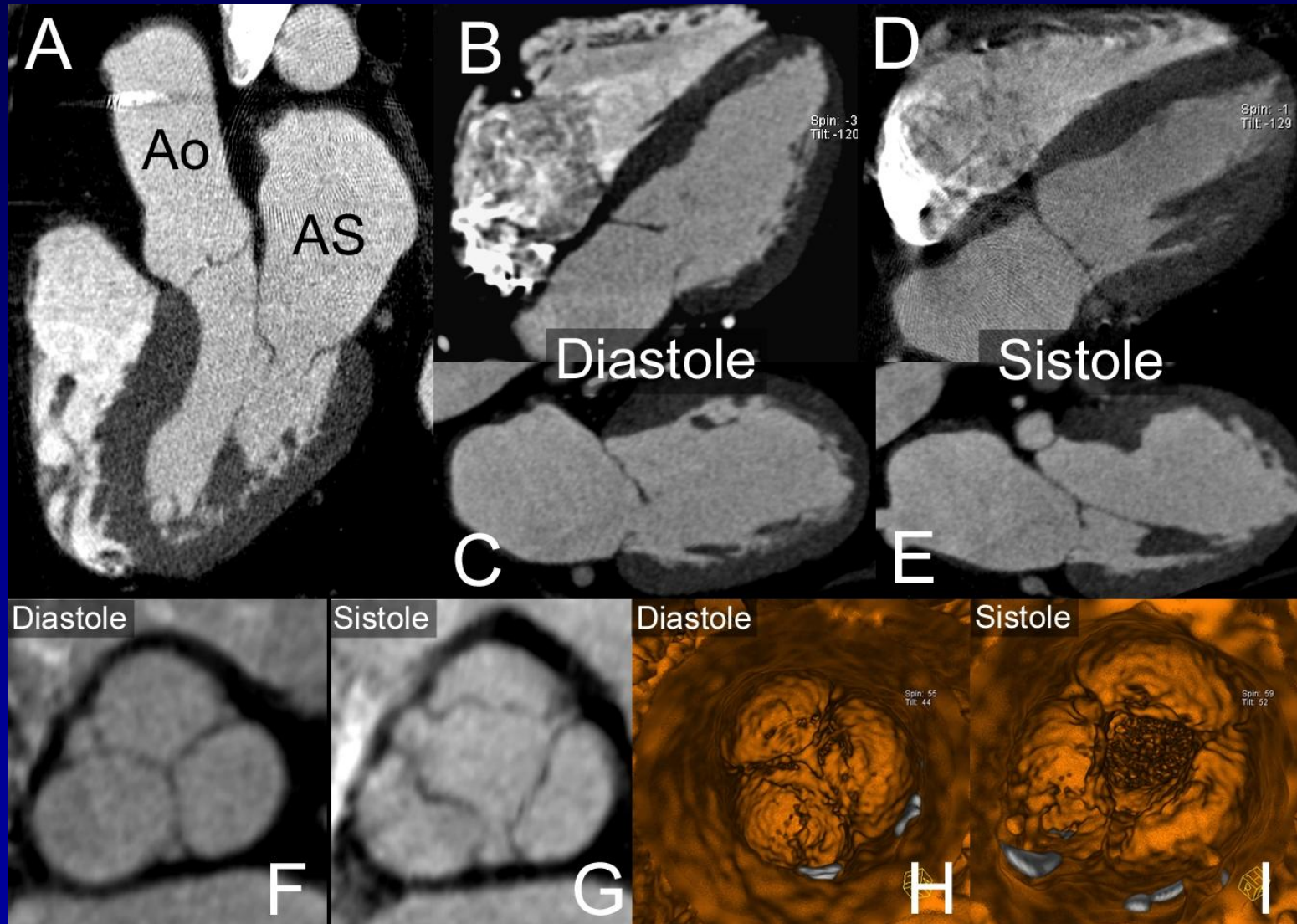
# Right Coronary Artery



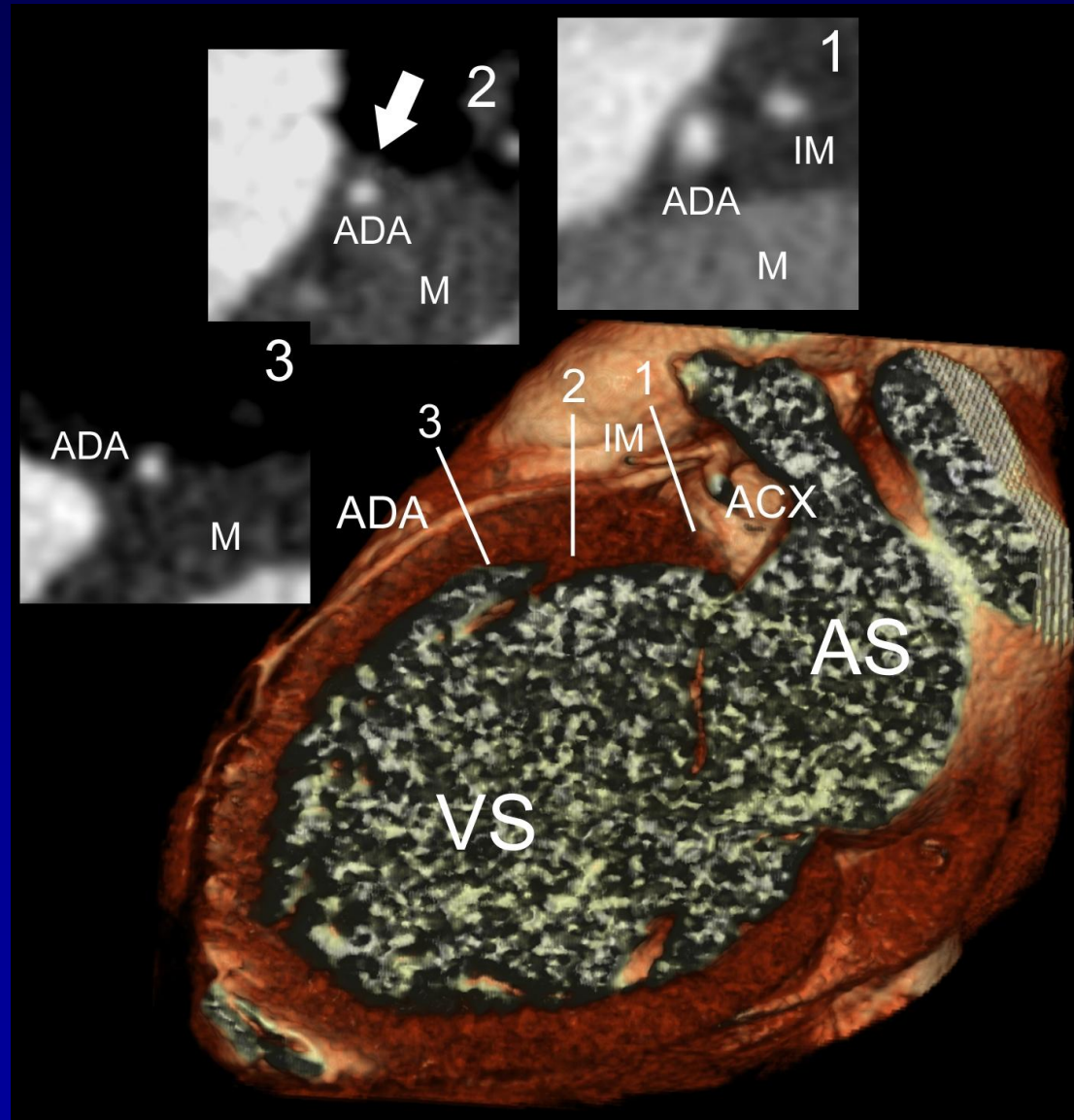
# Venous Anatomy



# Myocardium & Valves

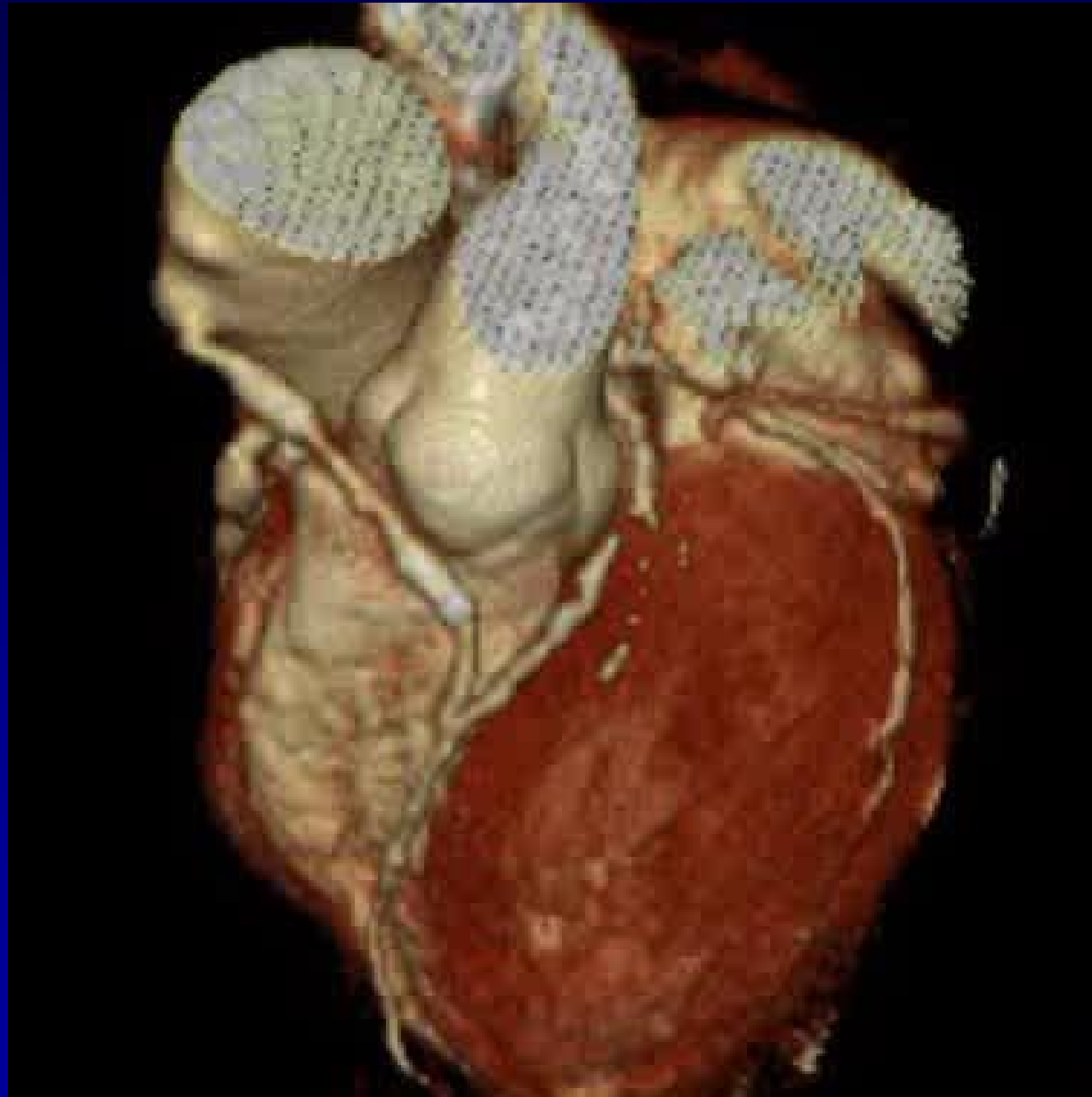


# Anatomical Myocardial Bridging



**Multislice CT**  
**Coronary Angiography**  
**Technique**

# The Aim



# **MSCT Coronary Angiography**

## **Prerequisites**

### **1. HIGH SPATIAL RESOLUTION**

- Depiction of vessel wall and small coronary branches

### **2. HIGH TEMPORAL RESOLUTION**

- Reduce motion artifacts

### **3. FAST COVERAGE**

- Short breath-hold time

### **4. SYNCHRONIZATION WITH CARDIAC CYCLE**

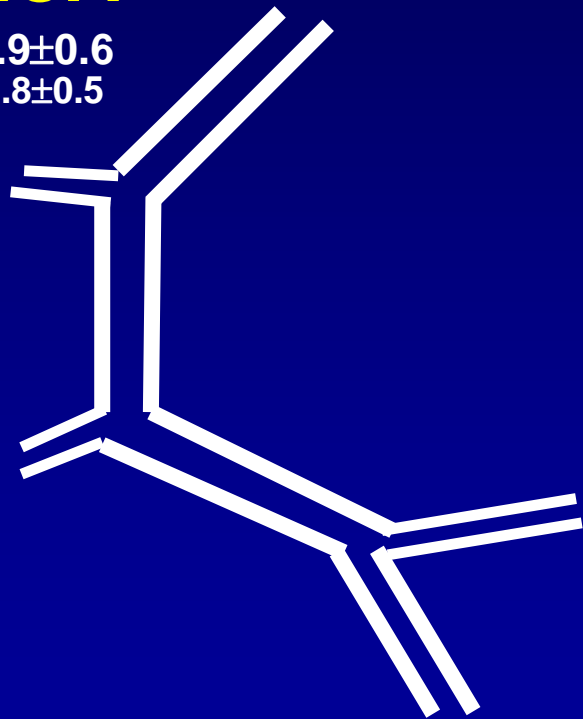
- ECG-gating for end-diastolic and end-systolic imaging



# Spatial Resolution

**RCA**

$3.9 \pm 0.6$   
 $2.8 \pm 0.5$



**LM**  $4.5 \pm 0.5$

**CX**  
 $3.4 \pm 0.5$   
 $4.2 \pm 0.6$



**LAD**

**(prox)**

$3.7 \pm 0.4$

**LAD**

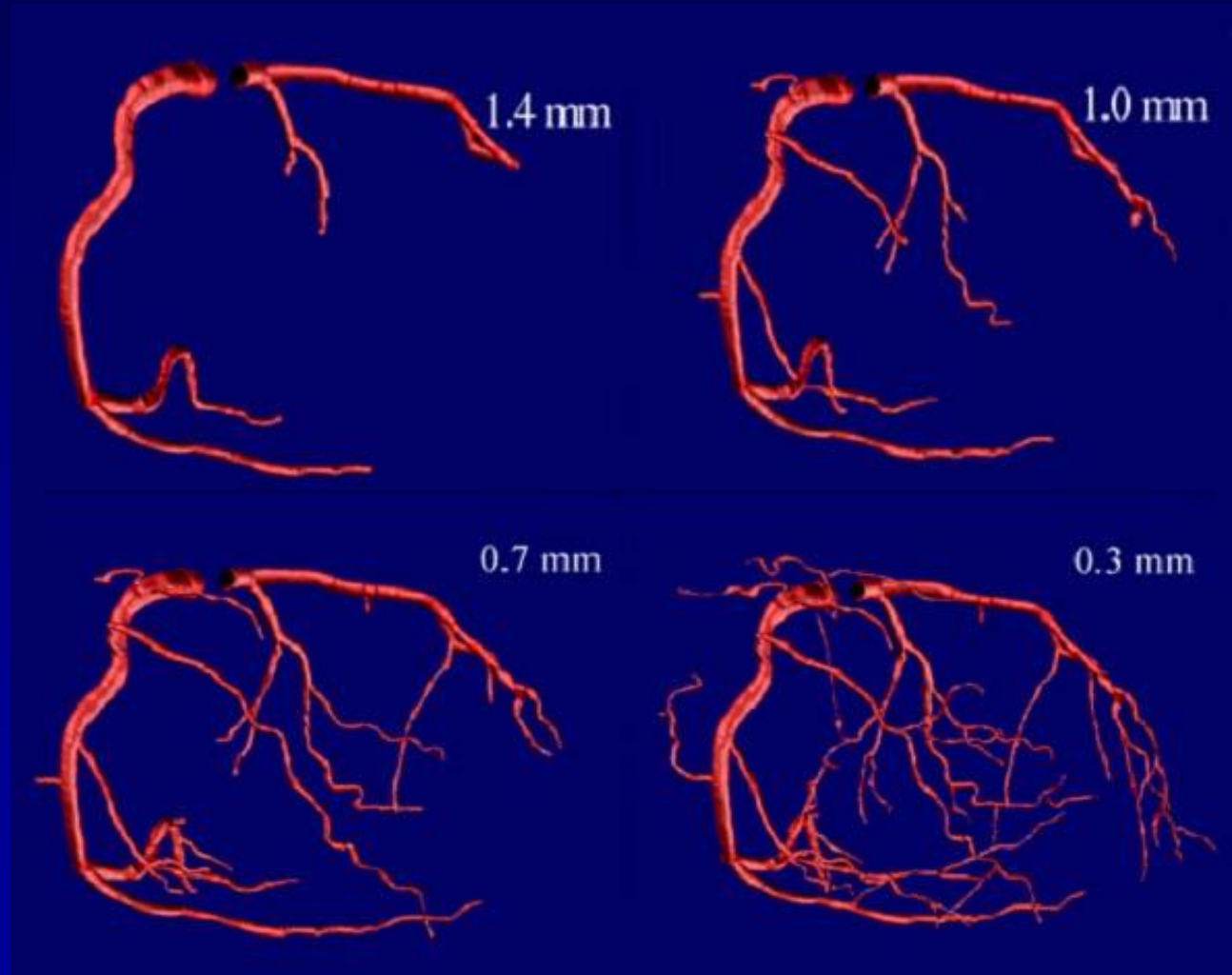
**(dist)**

$1.9 \pm 0.4$

Female : - 9%  
LV hypertrophy : + 17%  
Dilated CMP : + 12%

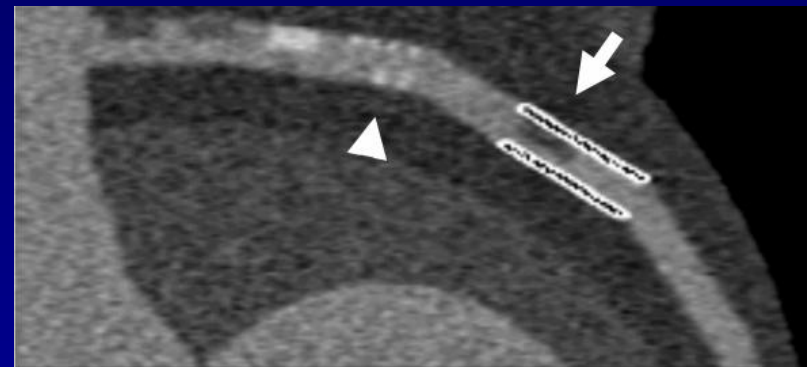
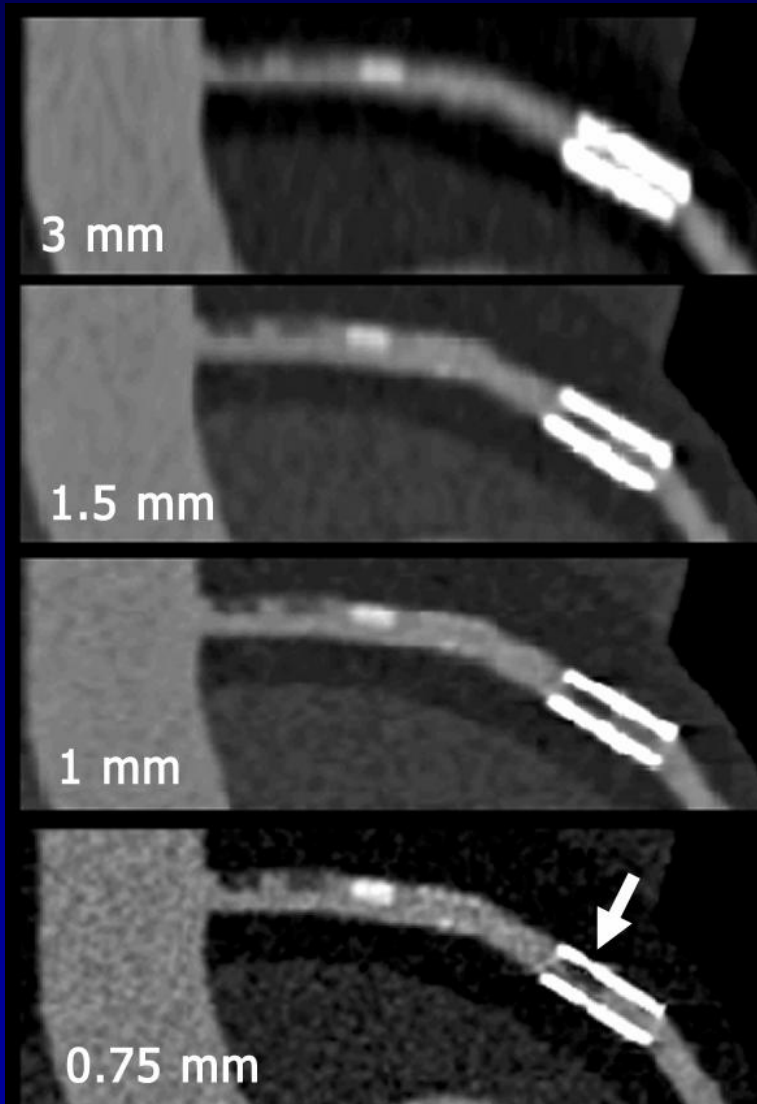
*Dodge JT Jr., Circulation, 1992*

# Spatial Resolution



Courtesy of University Clinic of Grosshadern, Munich, Germany

# Spatial Resolution

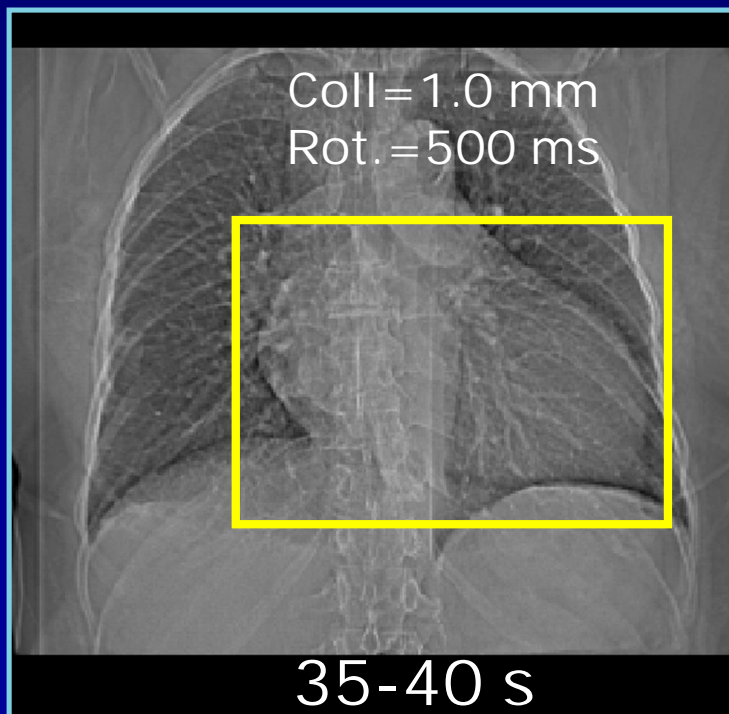


Flat Panel Technology

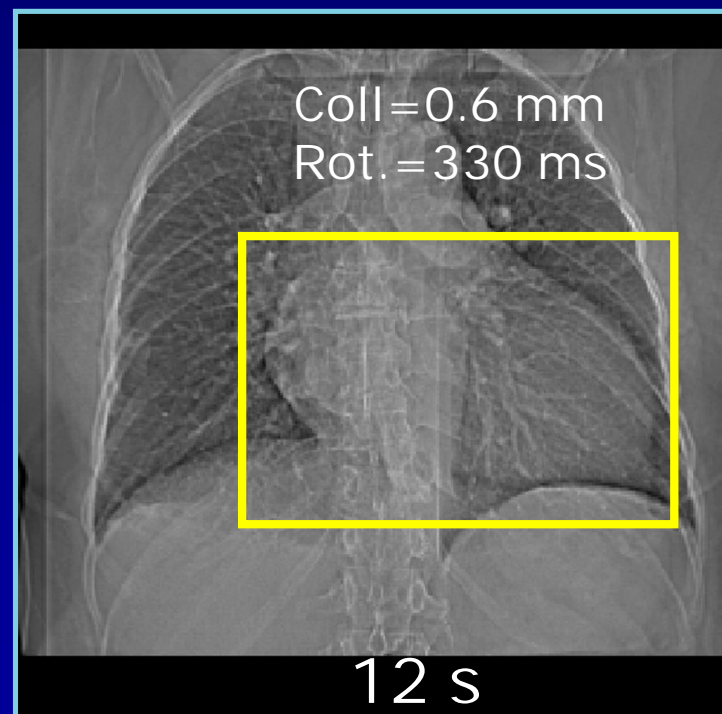
# Fast Coverage

## High resolution MSCT-CA

4-MSCTA

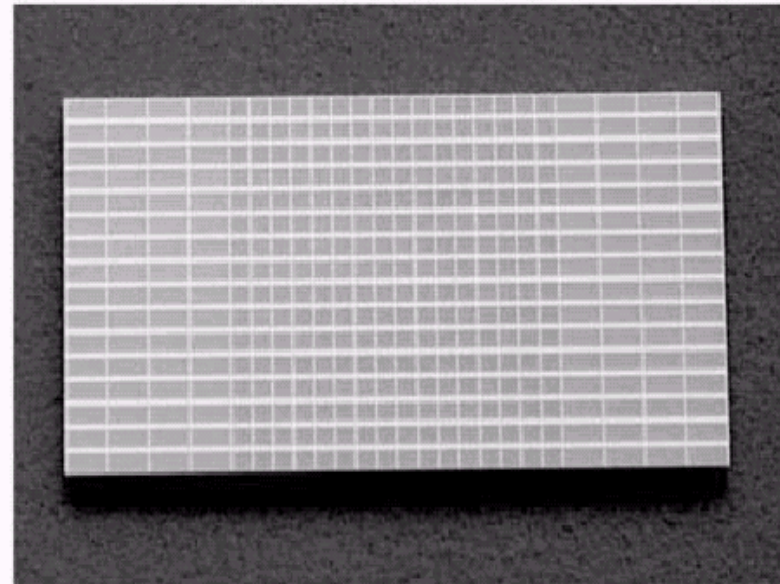
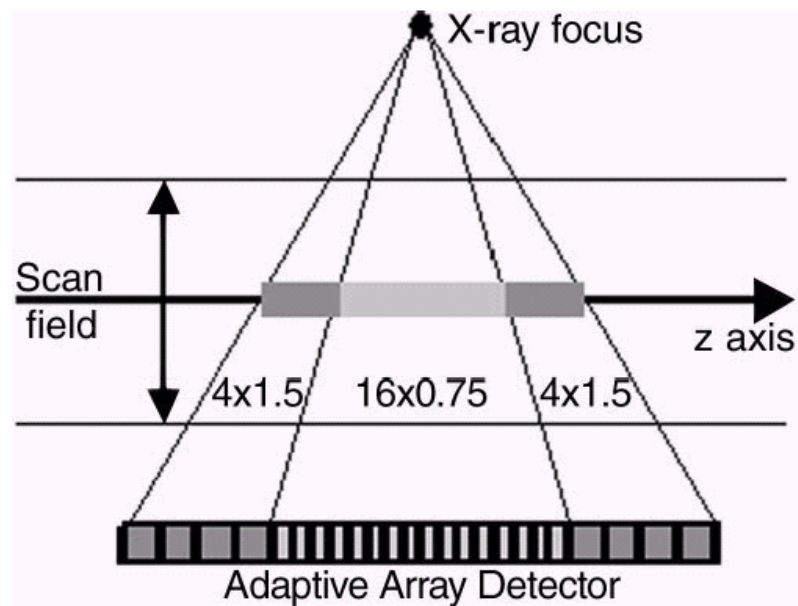


64-MSCTA

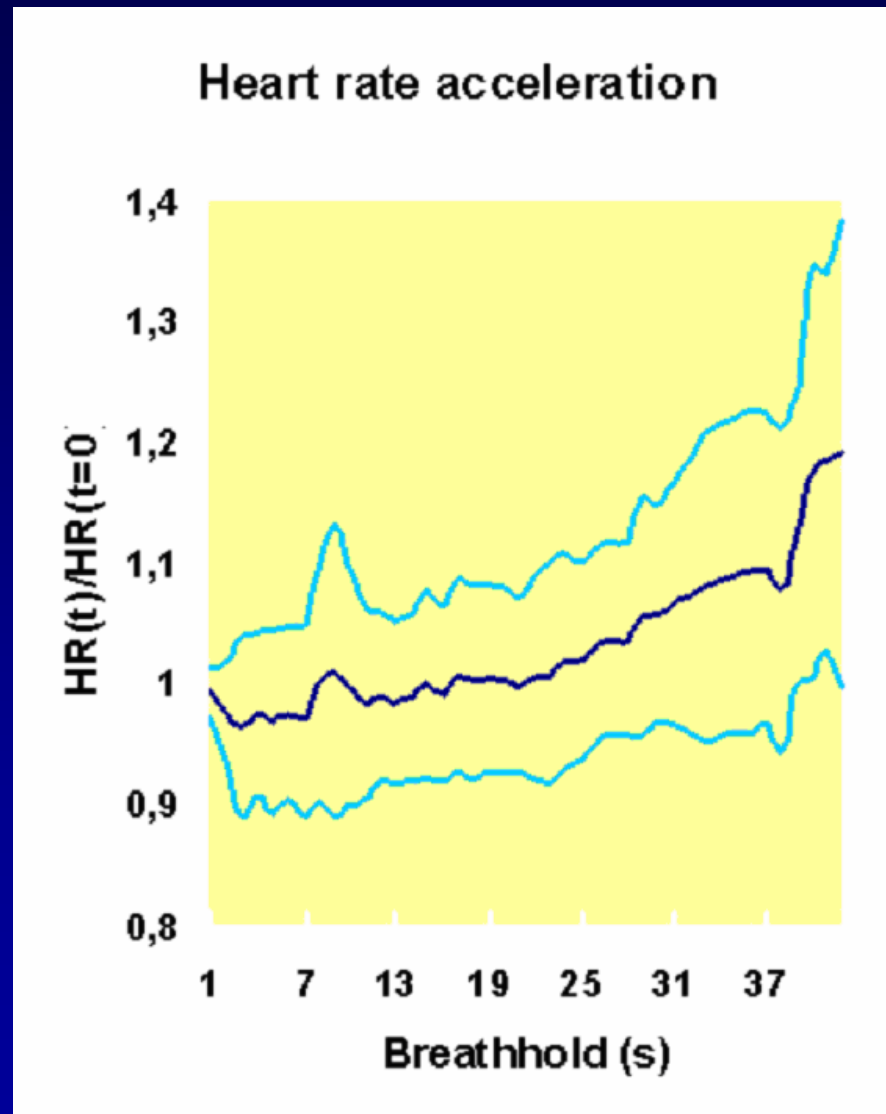


# Fast Coverage

16-slices or more !!!



# Fast Coverage

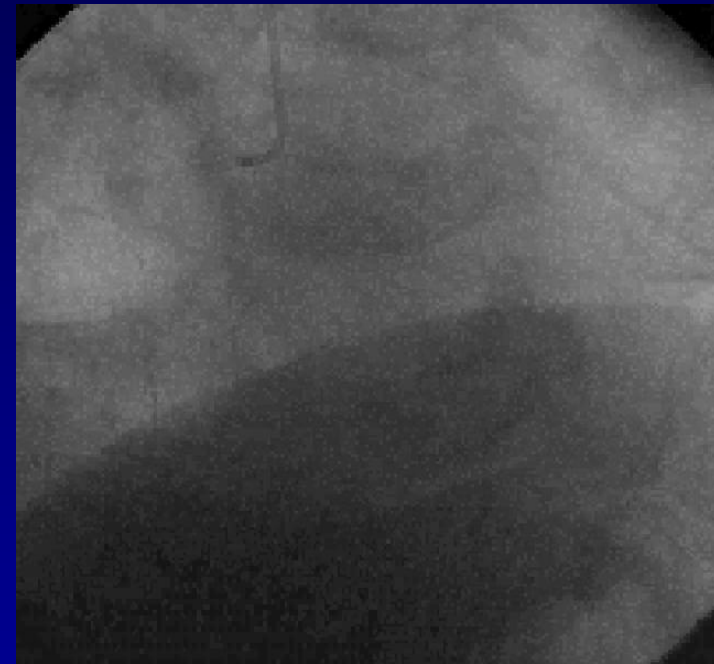


# Coronary Motion



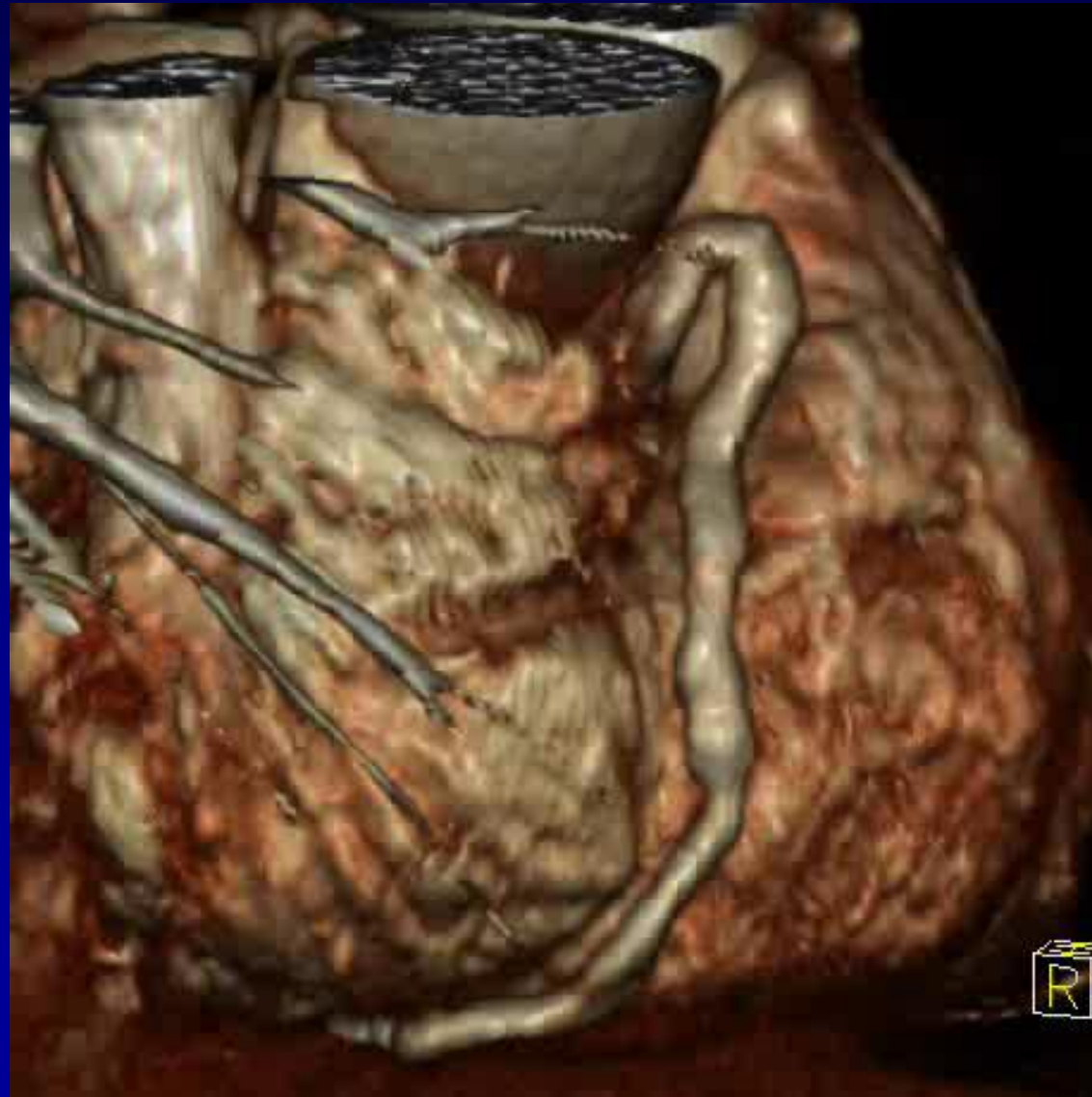
LAD 22.4 mm/s  $\pm$  4.0

CX 48.4 mm/s  $\pm$  15



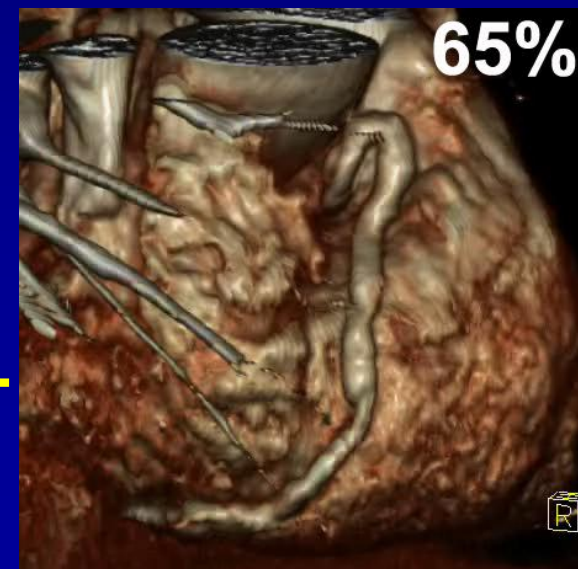
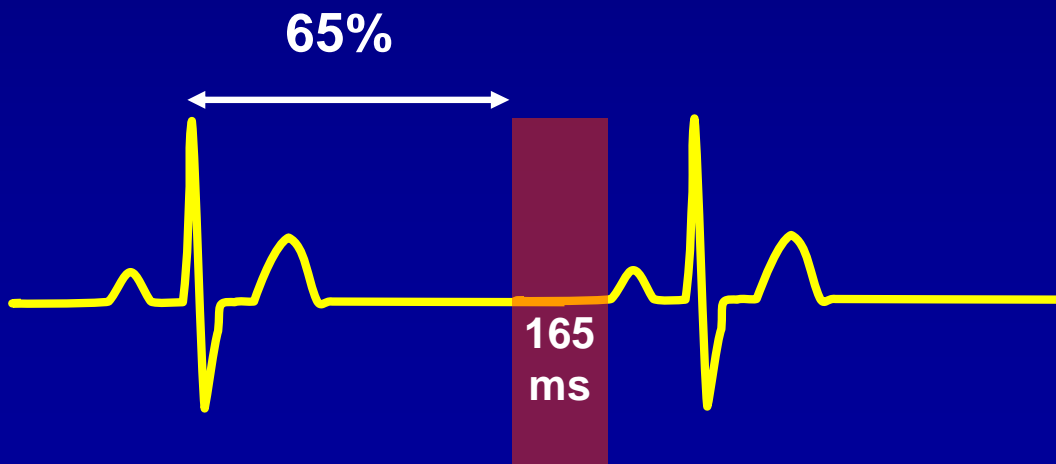
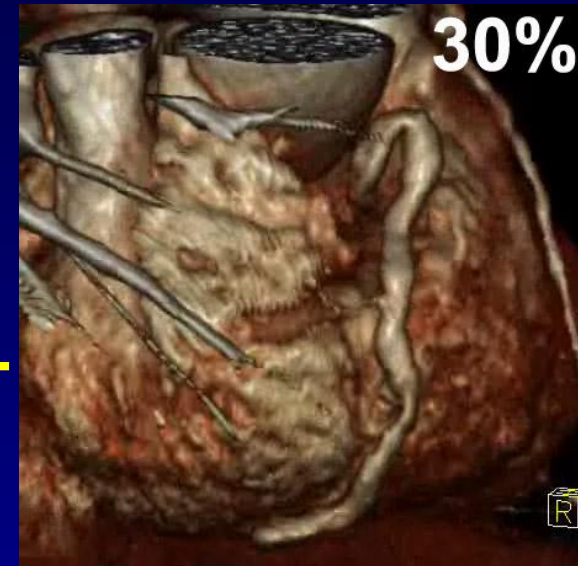
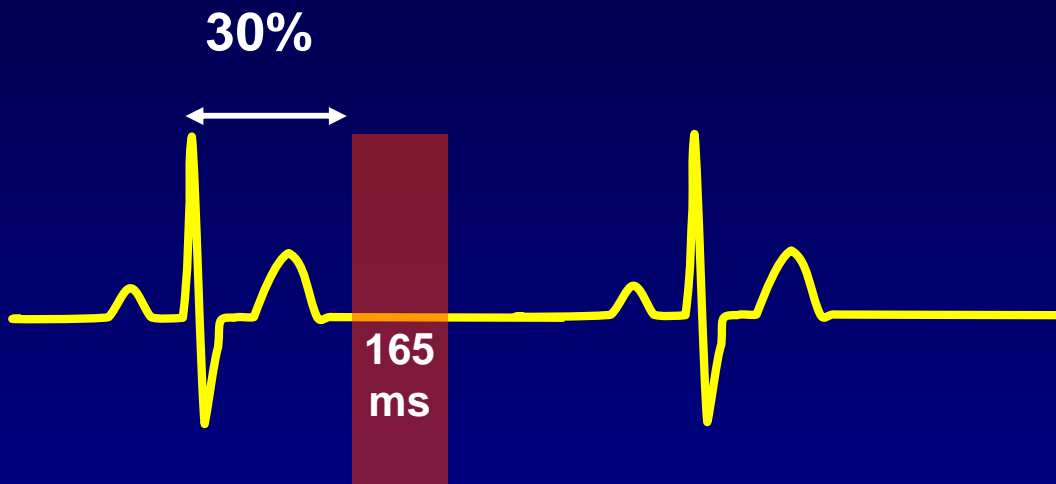
RCA 69.5 mm/s  $\pm$  22.5

# Synchronization with cardiac cycle

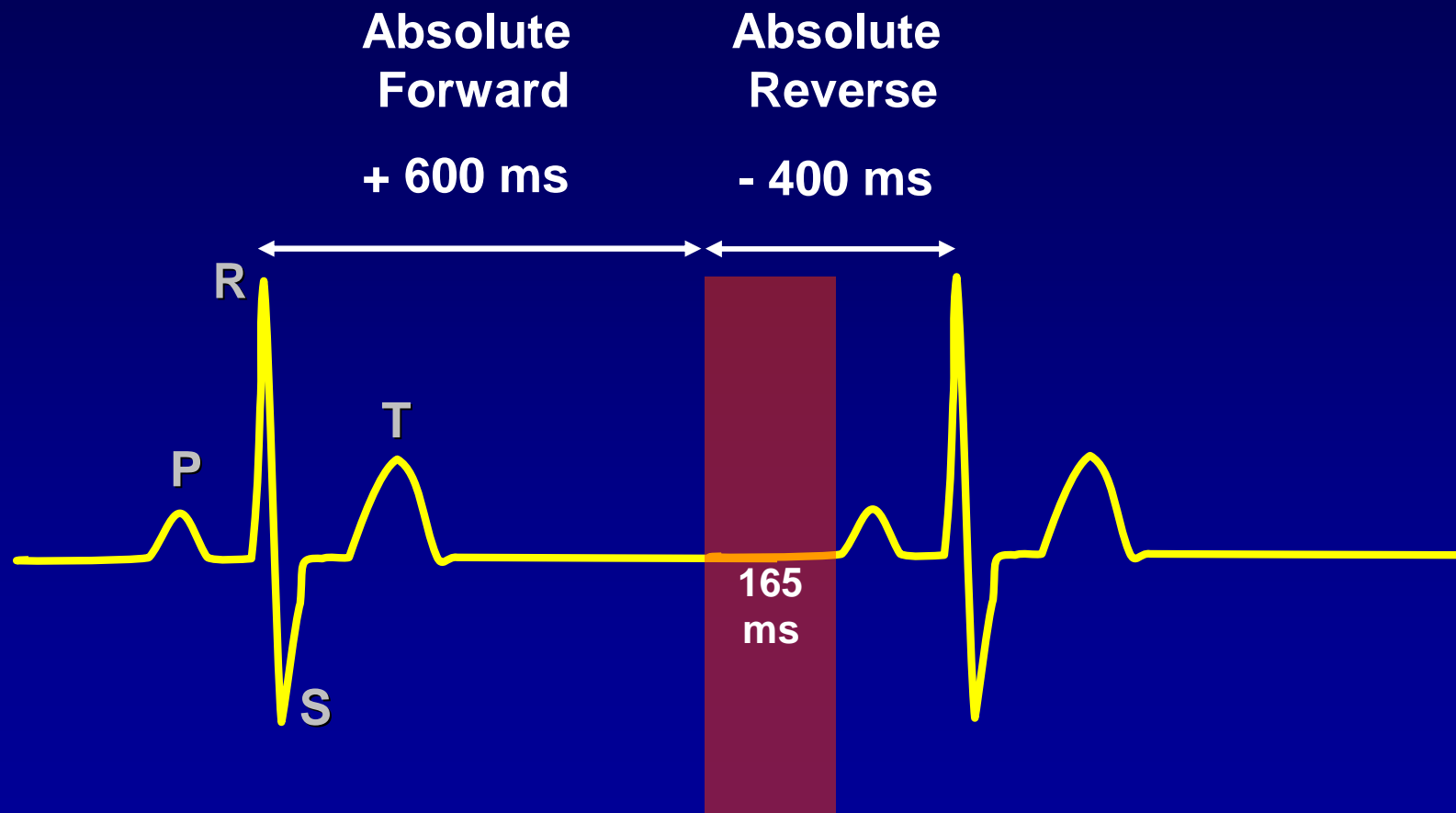




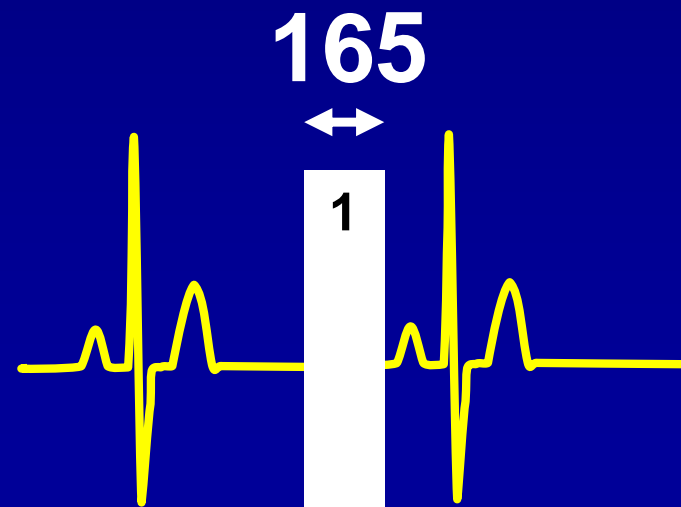
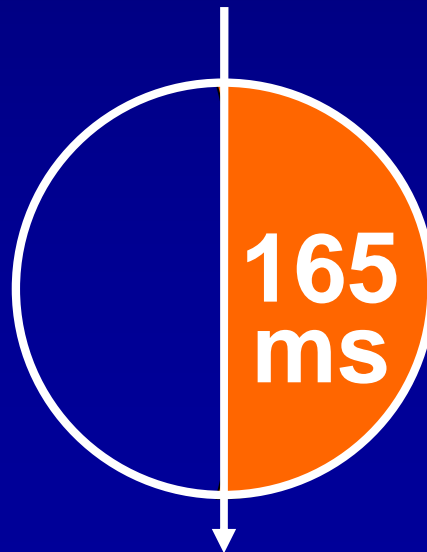
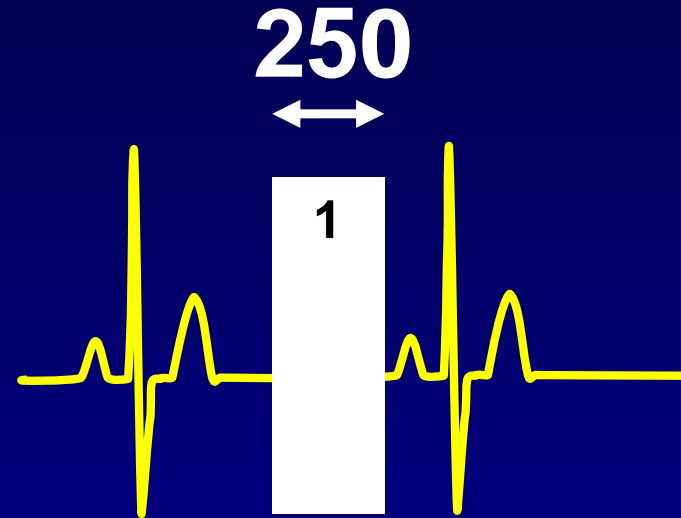
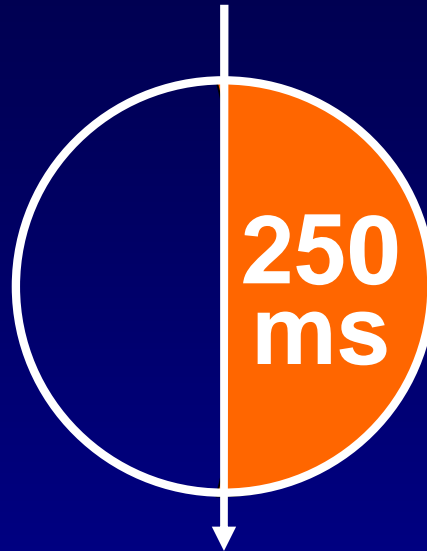
# Synchronization with cardiac cycle



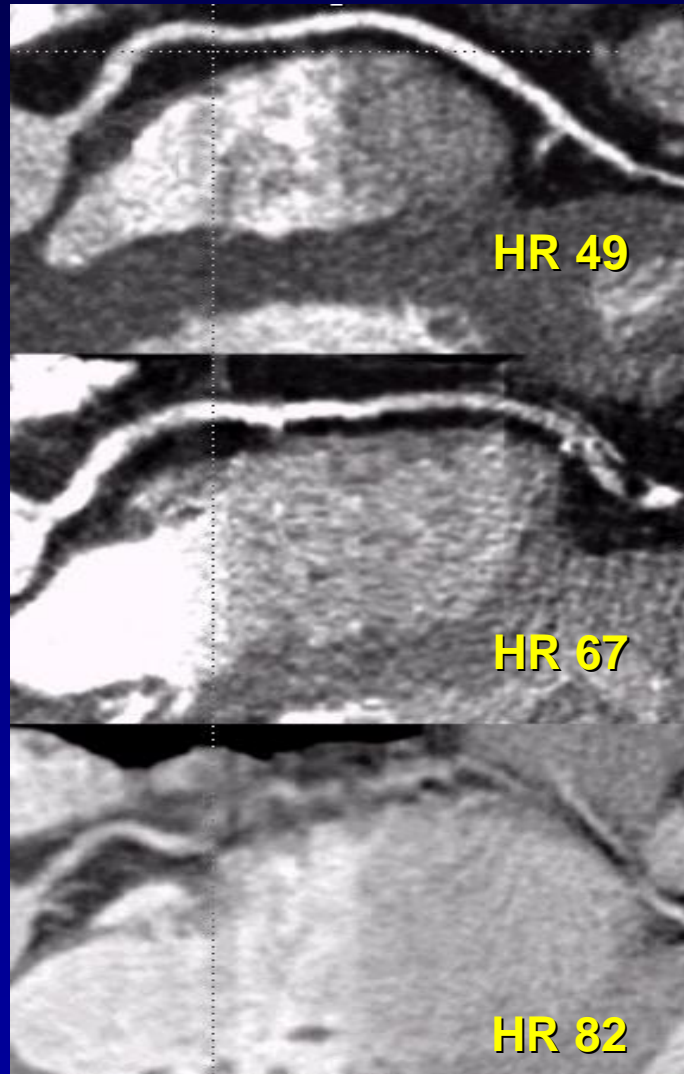
# Synchronization with cardiac cycle



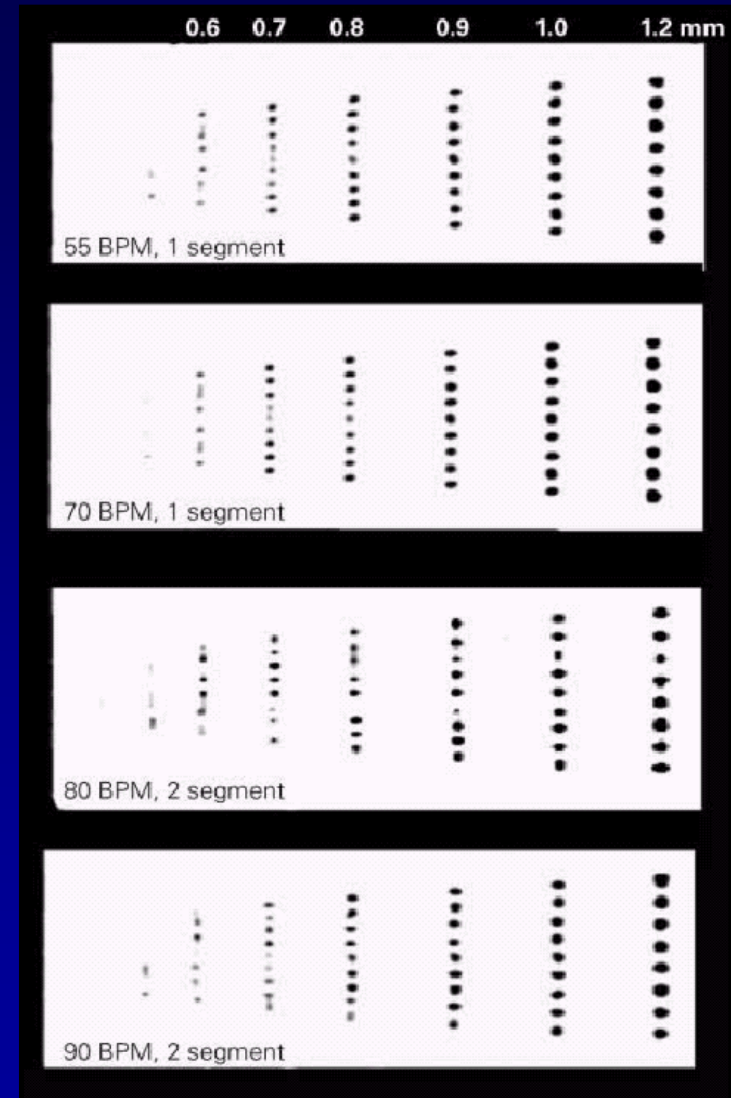
# Temporal Resolution = $\frac{1}{2}$ Rotation Time



# Temporal Resolution



Nieman, Heart '02



Flohr, Herz '03

# Temporal Resolution

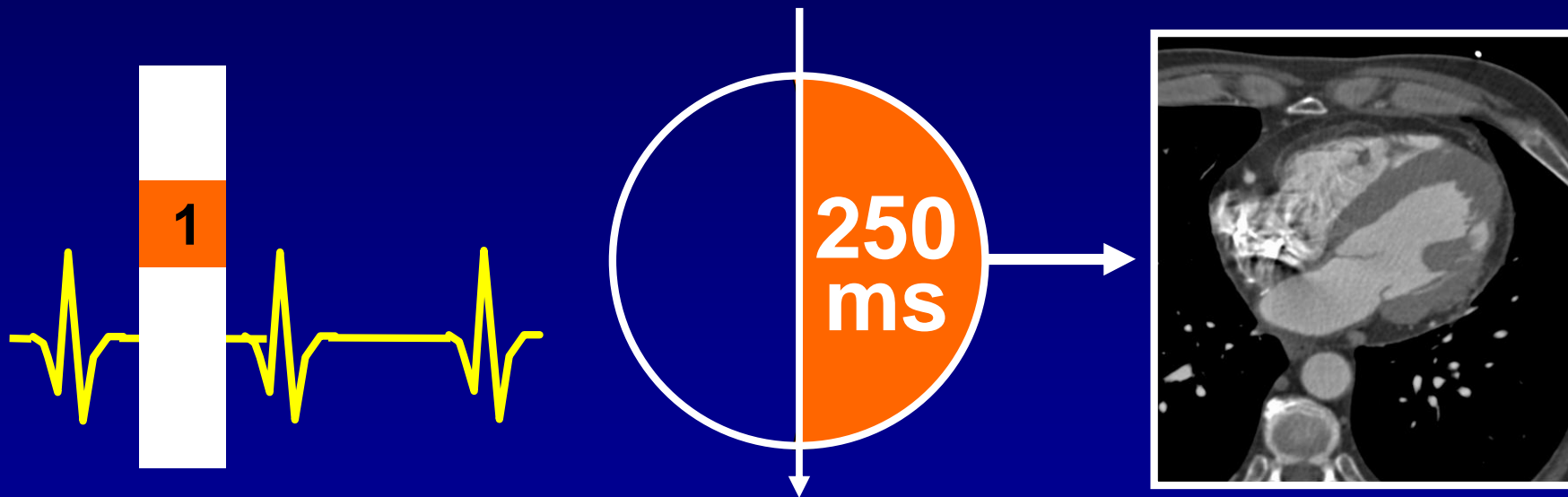
**Single segment**

**vs.**

**Multi-segment  
Image Reconstruction**

# Single segment

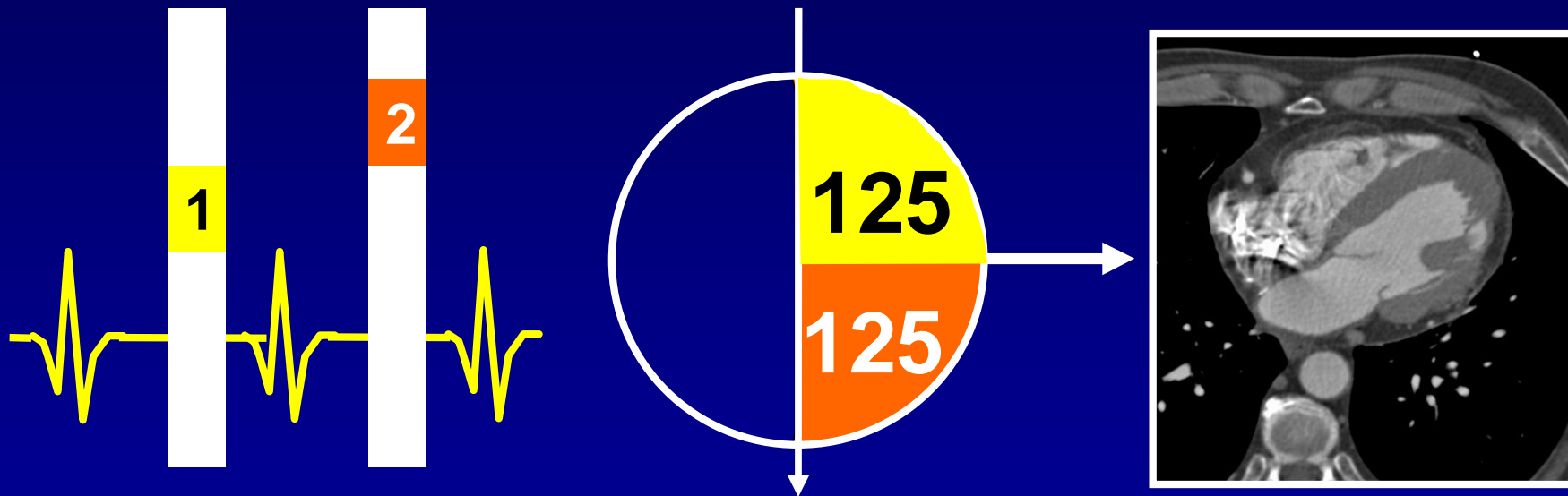
## Data from 1 cardiac cycle



Temporal resolution = 250 ms

# Multi segment

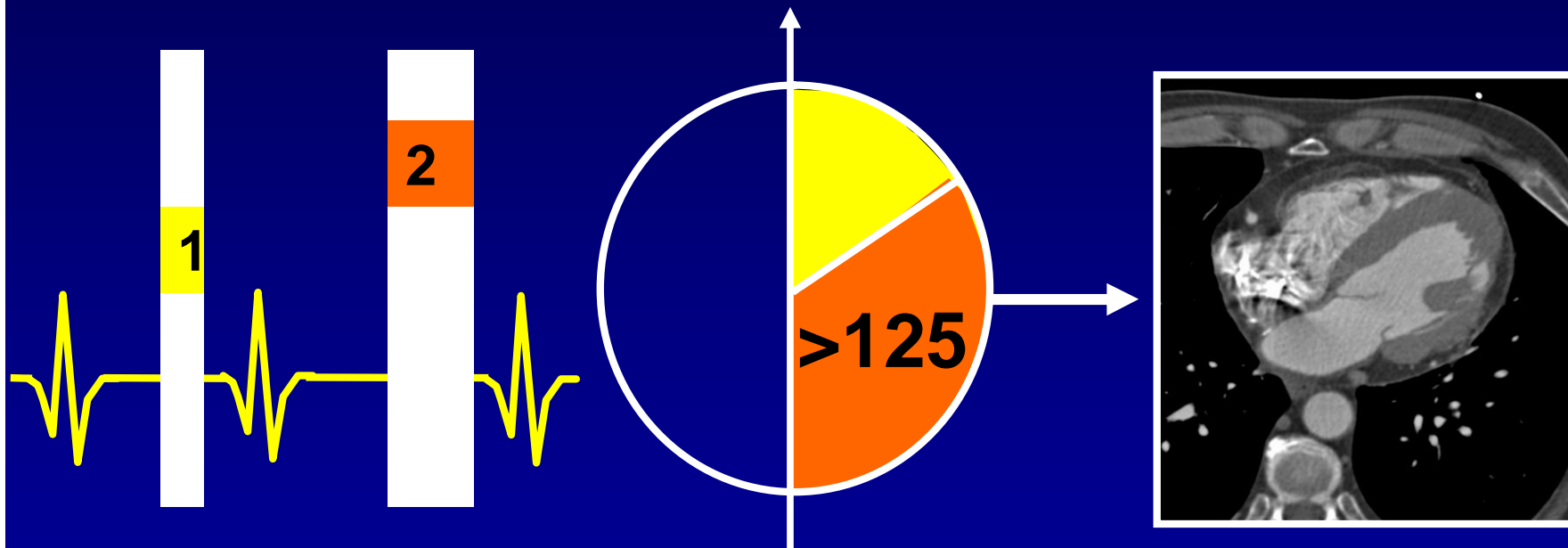
Data from  $\geq 2$  cardiac cycles



Temporal resolution = 125 ms

# Multi segment

Data from  $\geq 2$  cardiac cycles

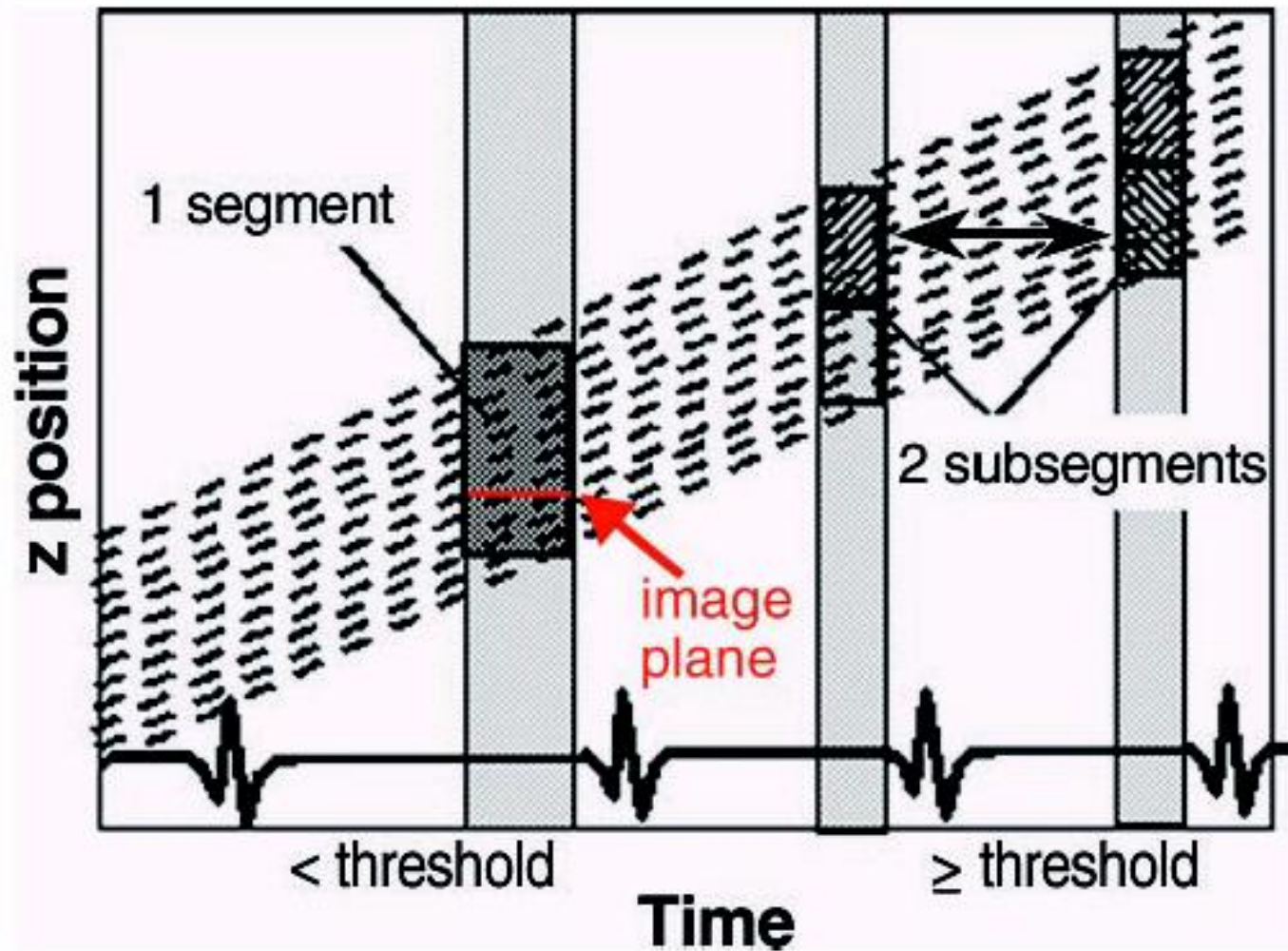


Multi-segment is adaptive

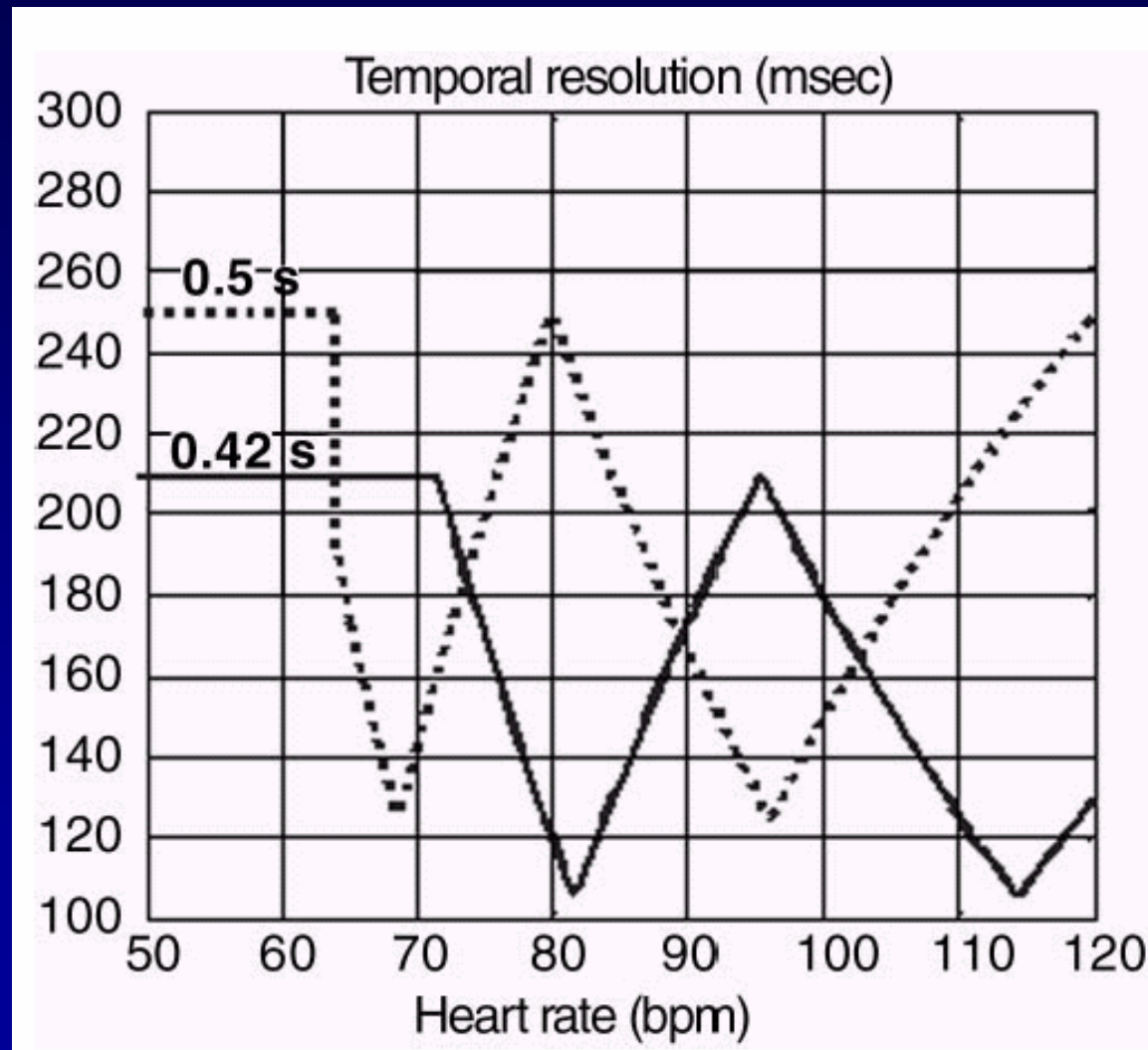


# Multi segment

## Data from $\geq 2$ cardiac cycles

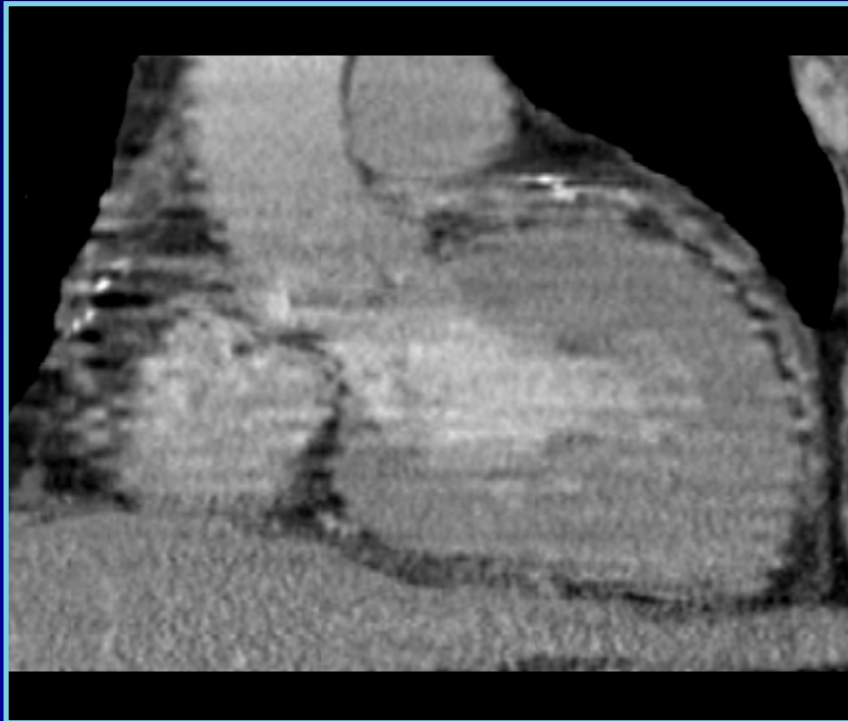


# Multi segment Temporal Resolution



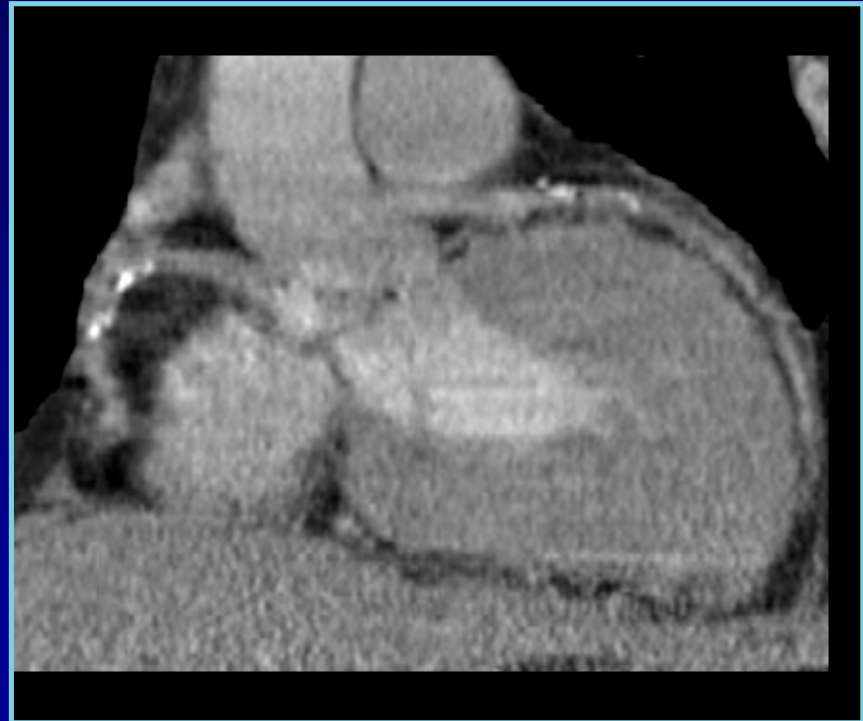
# Temporal Resolution

## Single-segment vs Bi-segment (high HR)



Single Segment Reconstruction

250ms

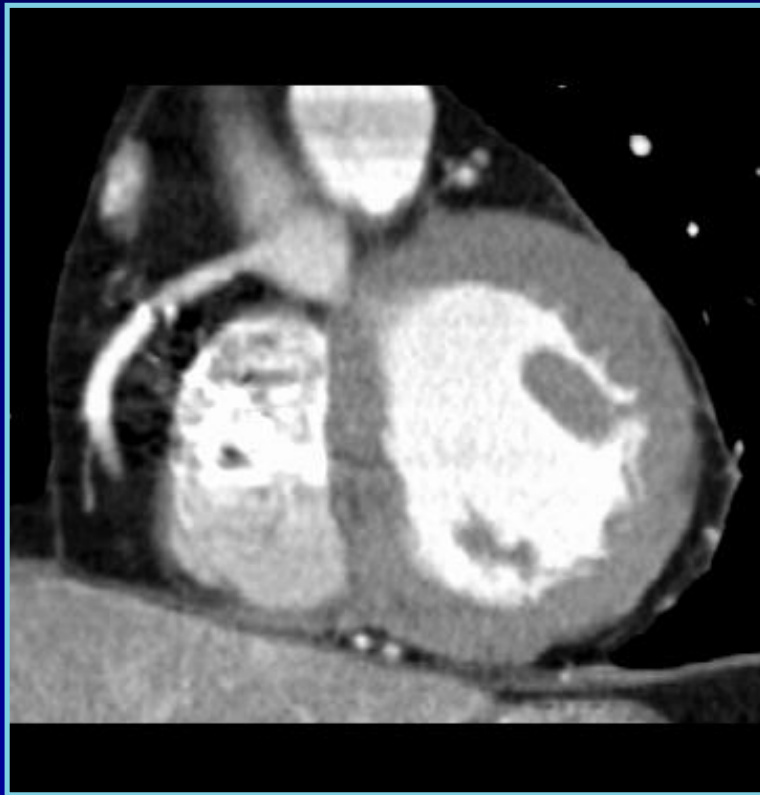


Bi-segment Reconstruction

125msec

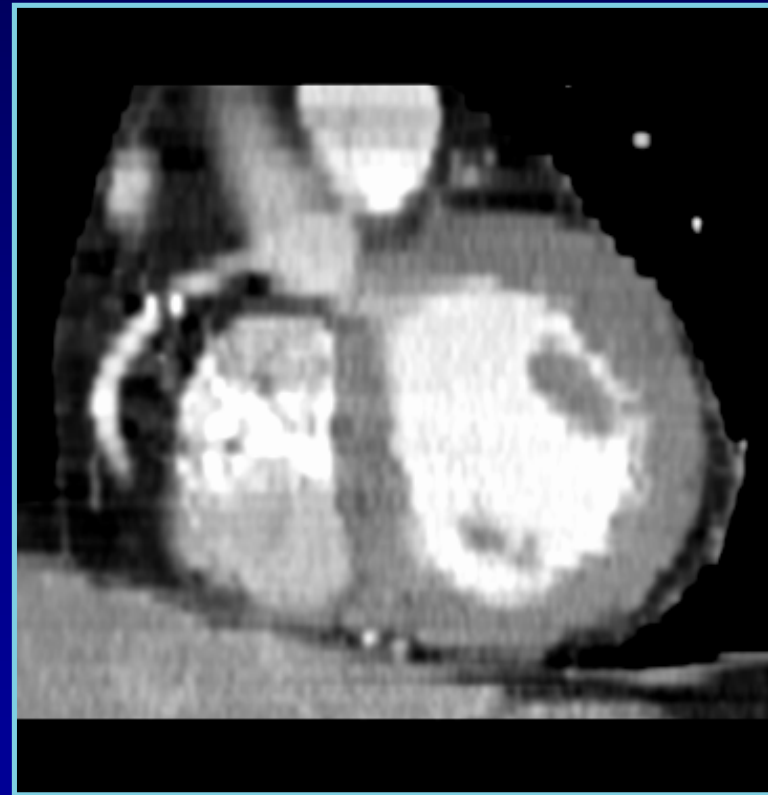
# Temporal Resolution

## Single segment vs Bi-segment (low HR)



Single Segment Reconstruction

250ms



Bisegment Reconstruction

125ms

# **Single vs. Multi- Segment Reconstruction Limitations**

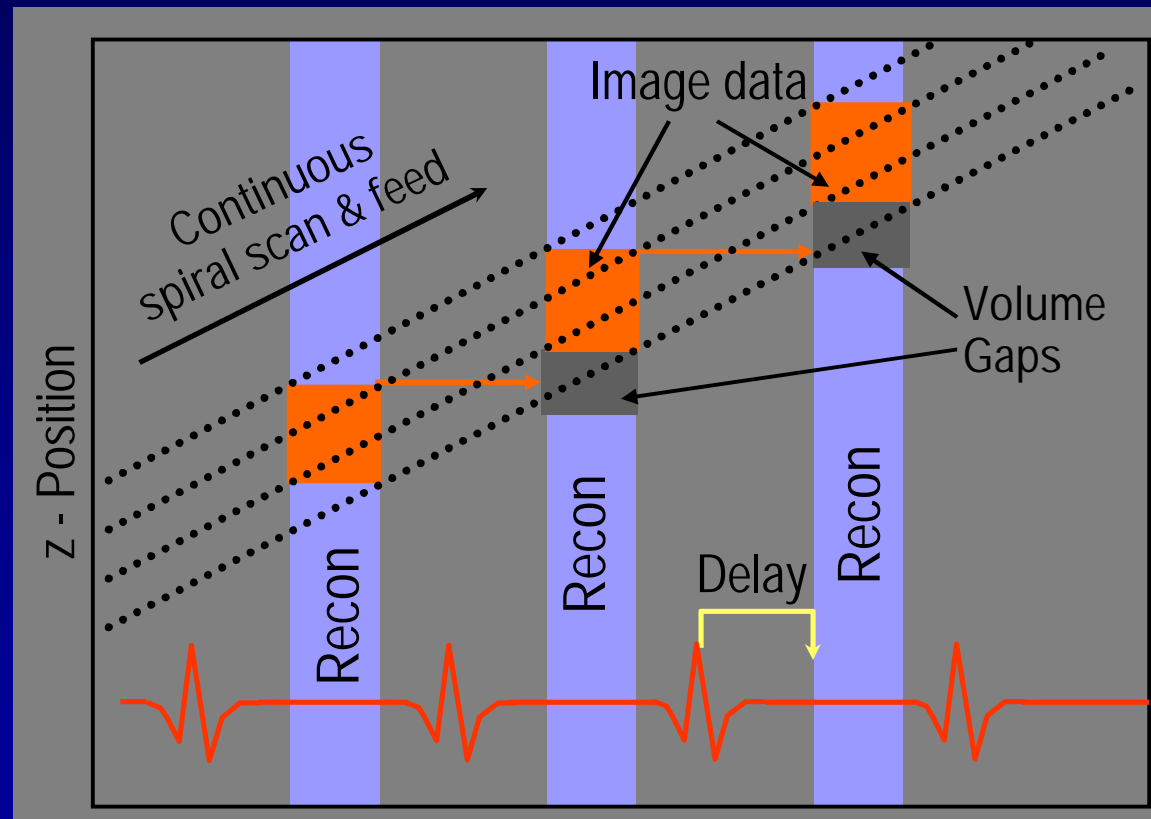
**Multi-segment requires a lower pitch**

**➔ Longer scan and higher dose**

**Multi-segment only feasible in consecutive  
heart beats with equal R-R interval**

**➔ Does not work if small change in R-R**

# Single vs. Multi-Segment Reconstruction Limitations



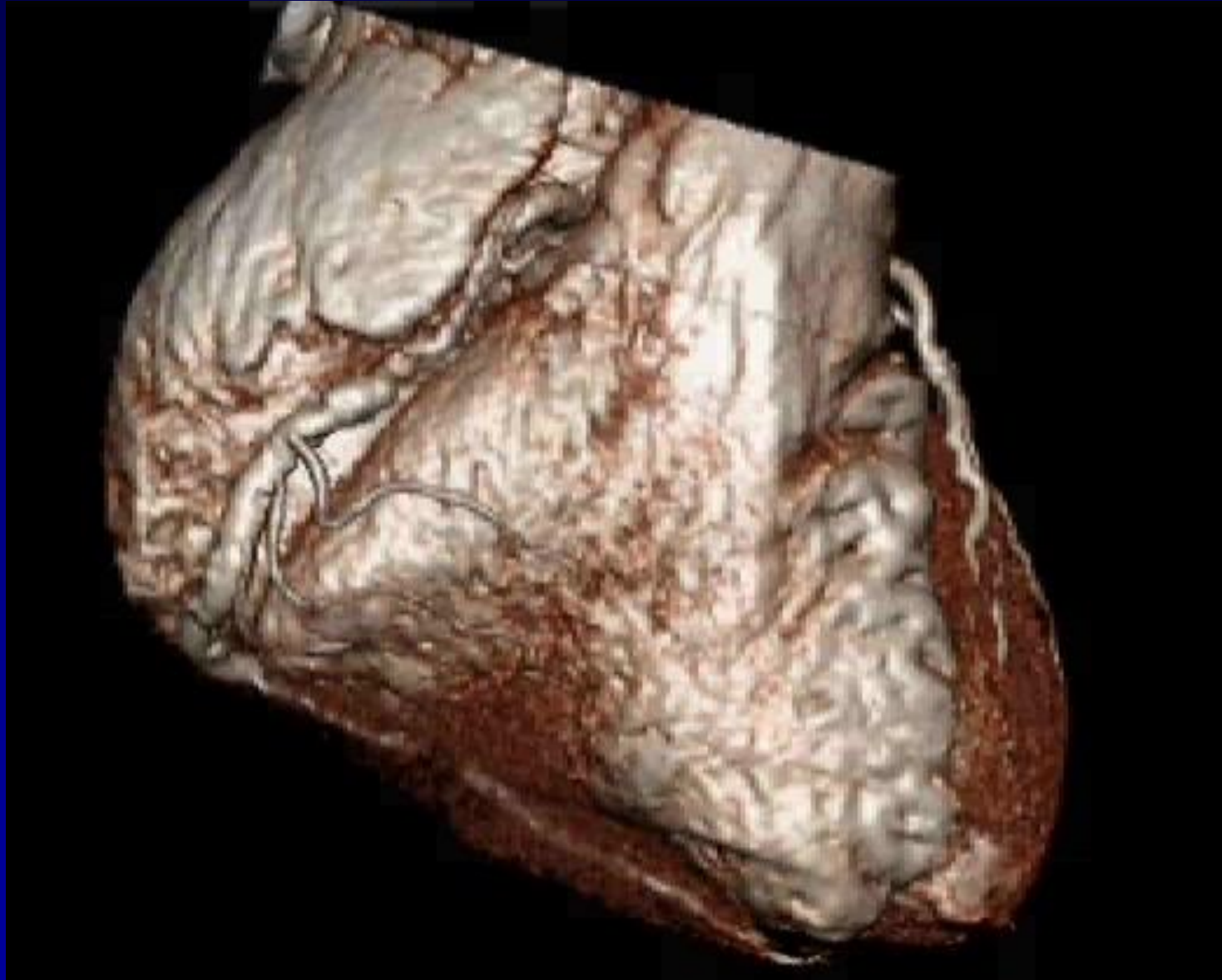
Pitch must be reduced when using >2-segment reconstruction

# **MSCT Coronary Angiography**

## **Prerequisites**

**What do we have ?**

# 64-slice CT coronary angiography





# **MSCT Coronary Angiography**

## **Prerequisites**

### **1. HIGH SPATIAL RESOLUTION (isotropic 0.4 mm<sup>3</sup>)**

- Smaller coronary branches evaluable
- More reliable visualization of in-stent lumen

### **2. HIGH TEMPORAL RESOLUTION**

- Evaluation of entire coronary tree possible in HR < 70 bpm

### **3. FAST COVERAGE**

- Manageable breath-hold for nearly all pts
- Injection of less contrast, higher injection rate  
(80-100 ml @ 5 ml/s)

### **4. SYNCHRONIZATION WITH CARDIAC CYCLE**

- ECG-editing possible in minor heart rhythm irregularities

**Patient Preparation**

**Scan Procedure**

# Patient Preparation



## Phone contact

- Check for indication
- Check for contra-indication
- Check for current medication
- Check for current heart rate

# Patient Preparation

HR > 65bpm



100mg b-blocker

## Contra-indications

- Asthma
- AV block
- Overt Heart Failure

45-60min.



HR check

HR < 65bpm



IV access

# Patient Preparation



**Instructions**



**ECG-leads**

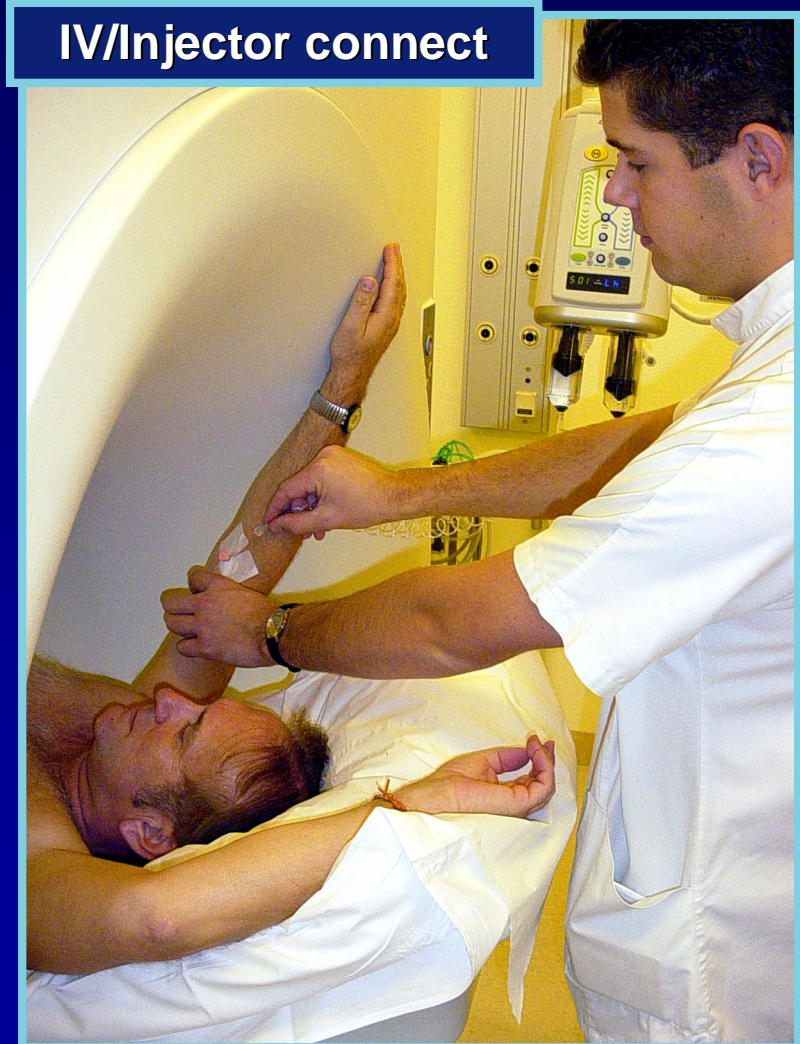


**Breath hold / HR check**

# Patient Preparation



Prepare injector



IV/Injector connect

# Scan Procedure

1 hour

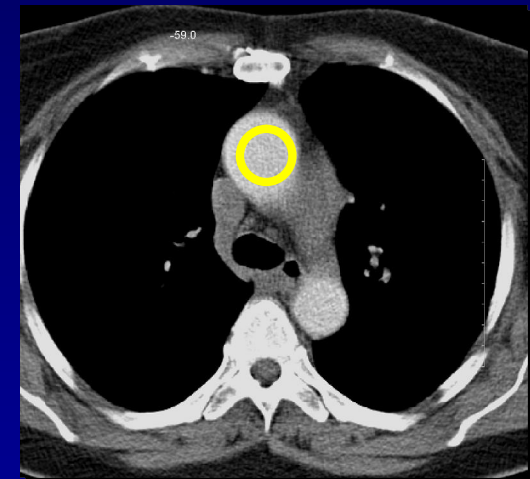
Beta-blocker ( $>70 \text{ min}^{-1}$ )

IV access & ECG leads  
Overview  $\rightarrow$  scan range

Contrast injection  
(CareBolus®)  
100 ml Iomeron 400 @ 5 ml/s

4 sec

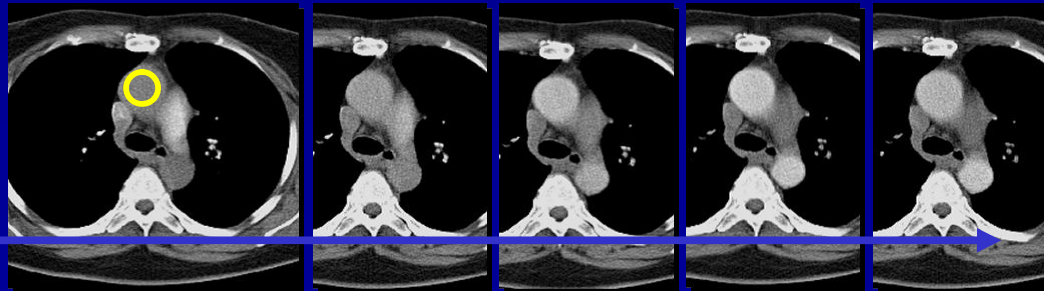
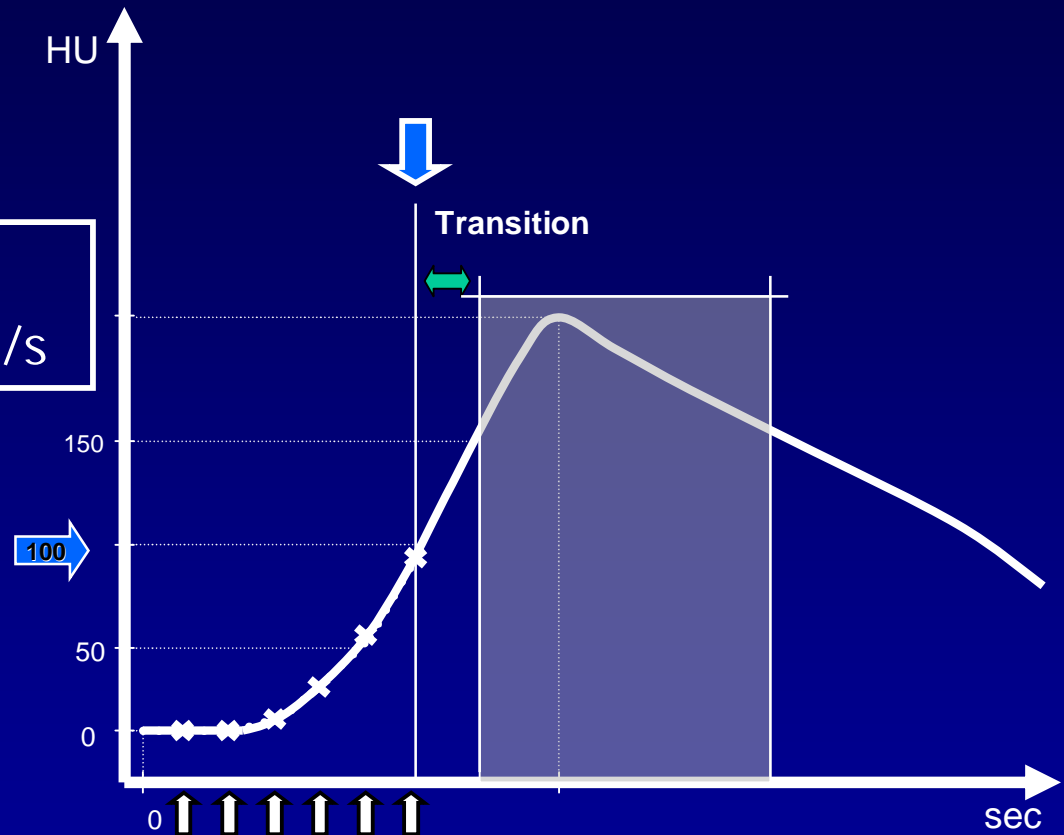
API: Breath hold  $\approx 12\text{s}$



+100 HU

# Scan Procedure: Bolus Tracking

Contrast injection  
100 ml Iomeron 400 @ 5 ml/s





# Scan Protocol

- slices/rotation: 2 x 32 (S16: 16)
- individual detector width: 0.6 mm (S16: 0.75)
- rotation time: 330 (S16: 375 ms)
- table feed: 3.8 mm/rotation (S16: 3.0)
- X-tube voltage: 120 kV
- X-tube current: max. 900 mAs (S16: max. 700)

**Image reconstruction**

**Image processing**

# Image Reconstruction

- retrospective ECG-gating (editing when necessary)
- temporal resolution: 165 ms (single-phase reconstruction)
- effective slice thickness: 0.75 mm
- increment: 0.4 mm
- kernel: medium smooth (b30f) – native coronaries  
sharp (b46f) – in-stent lumen or calcified vessels

# Filtering

**Axial images and VRT's**



**B10f-B30f**

**Measurements, Ca++, Stents**



**B40f-B60f**

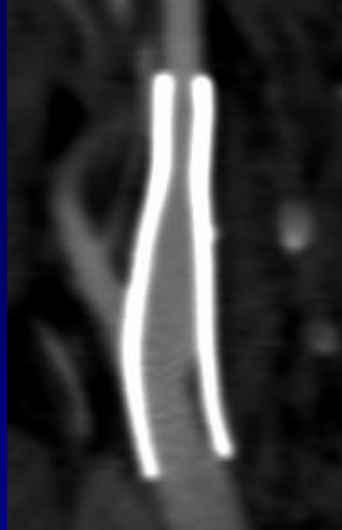
**MPR, MIP and flexible use**



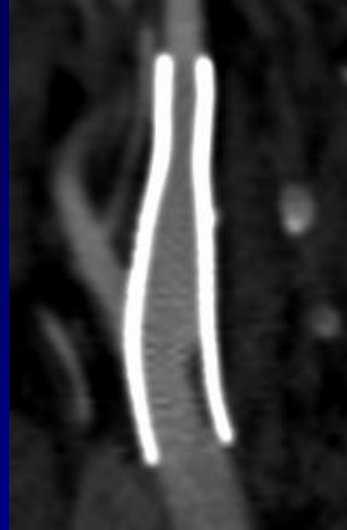
**B30f-B40f**

# Filtering

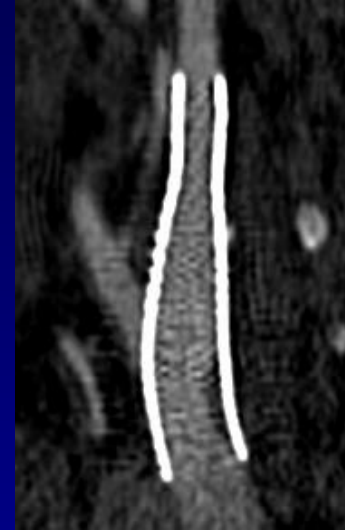
B10f



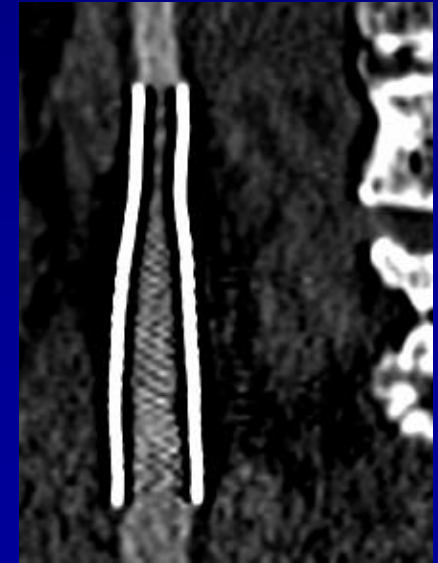
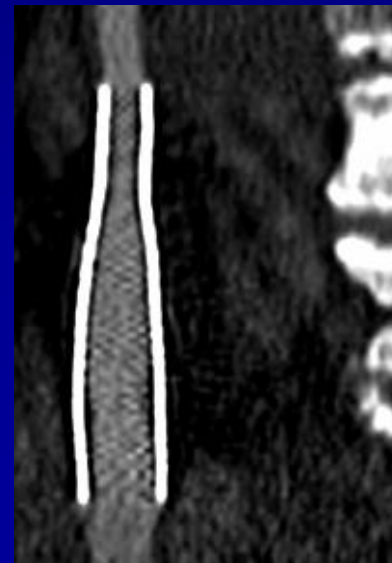
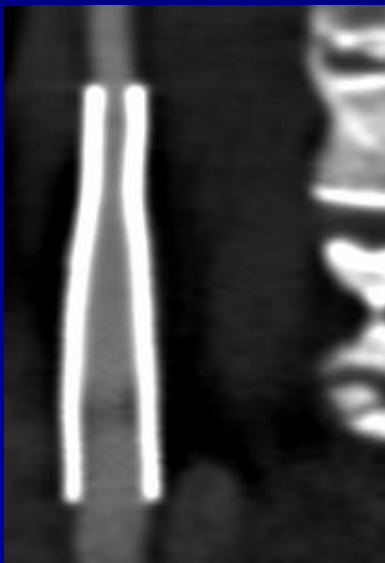
B30f



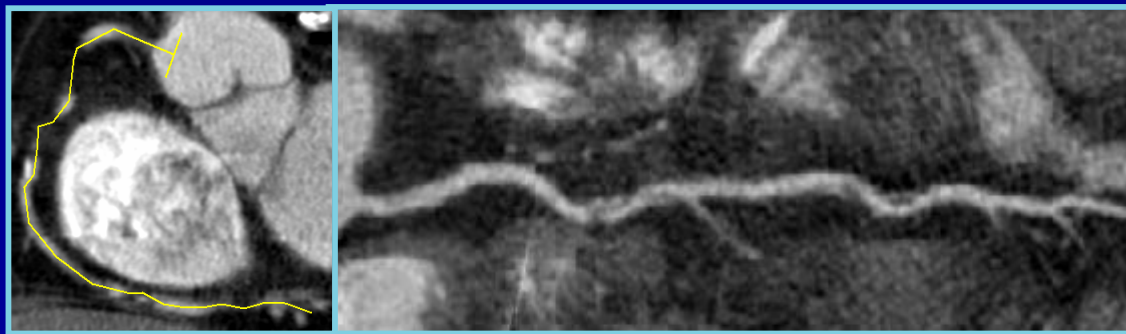
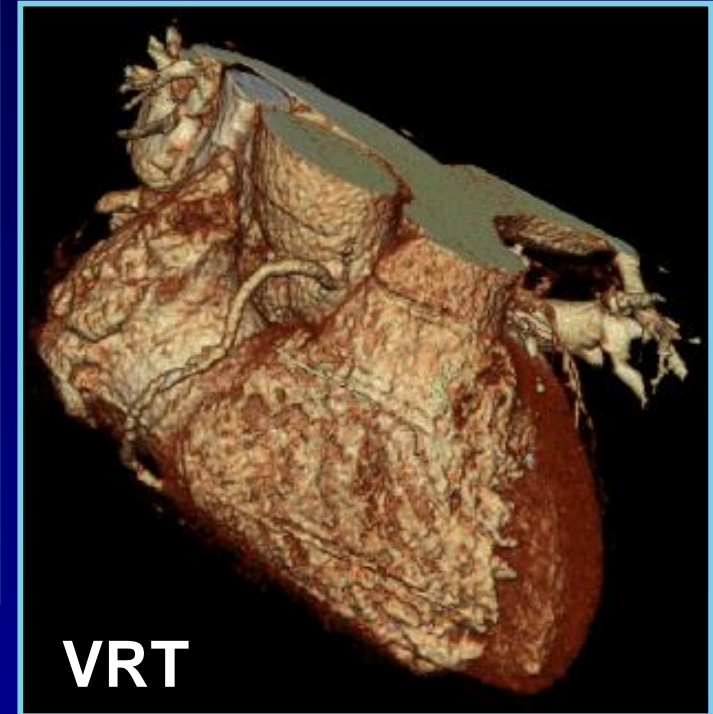
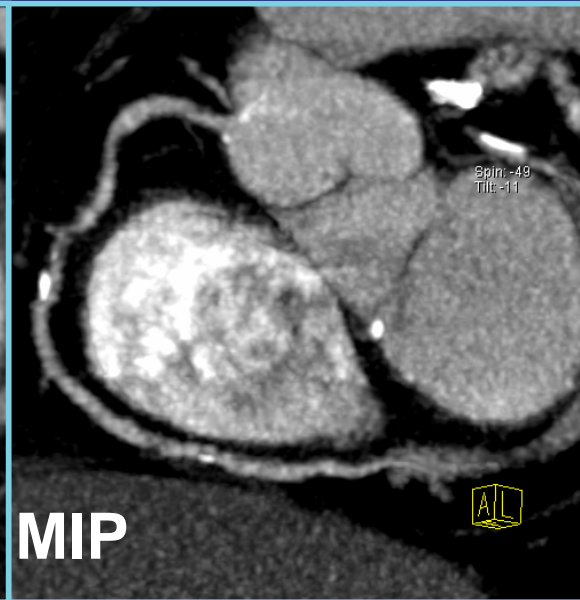
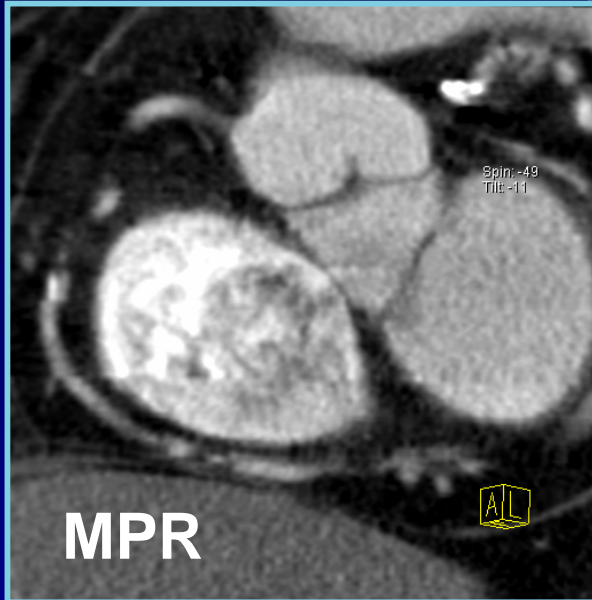
B60f



B80f



# Image Processing



**MPR:** multiplanar reconstructions

**MIP:** maximum intensity projections

**VRT:** volume rendering techniques

# **Limitations & Artefacts**

# Limitations of CT coronary angiography

- **SELECTED PATIENT POPULATION**  
Stable heart rhythm, able to breath hold for 20s,  
<70 bpm (spontaneous/ $\beta$ -blocker induced)
- **X-RAY DOSE**  
Better images and higher spatial resolution requires higher dose
- **HEAVY CALCIFICATIONS**  
Blooming and partial volume artifacts mask the lumen
- **HIGH AND IRREGULAR HEART RATES**  
Motion artefacts and mis-registration
- **OPERATOR DEPENDENCY**  
Time-consuming and variable diagnostic accuracy



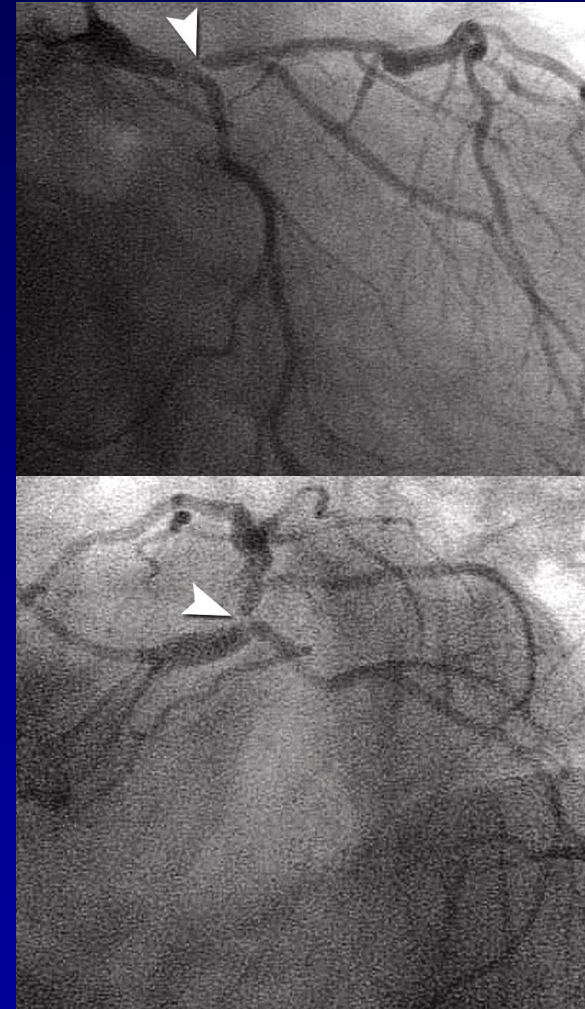
# Operator dependency

	<u>STD</u>	<u>3D</u>
<b>Available:</b>	<b>478</b>	<b>478</b>
<b>Sensitivity:</b>	<b>58 %</b>	<b>96 %</b>
<b>Specificity:</b>	<b>96 %</b>	<b>97 %</b>
<b>PPV:</b>	<b>78 %</b>	<b>87 %</b>
<b>NPV:</b>	<b>91 %</b>	<b>99 %</b>

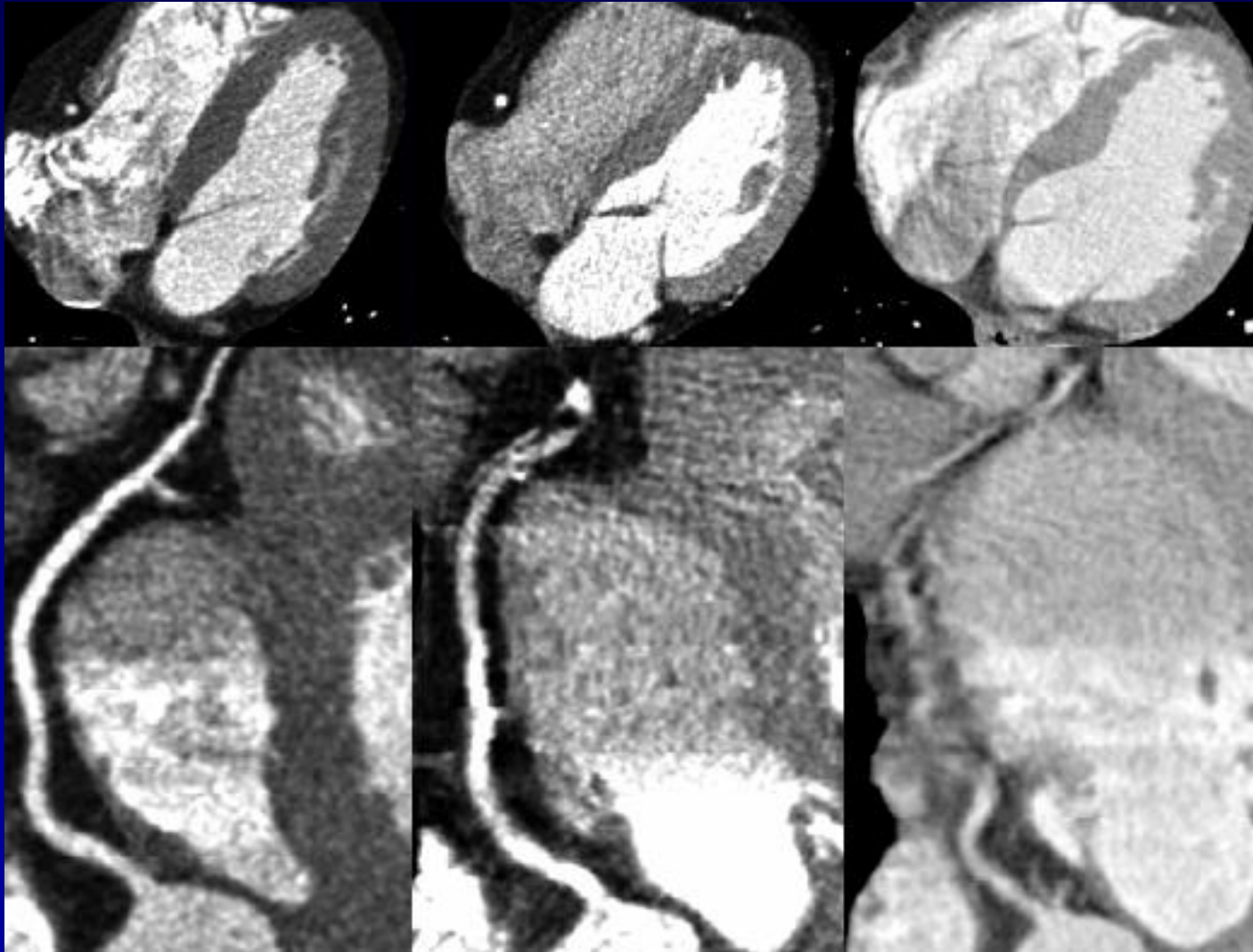
# Severe calcification



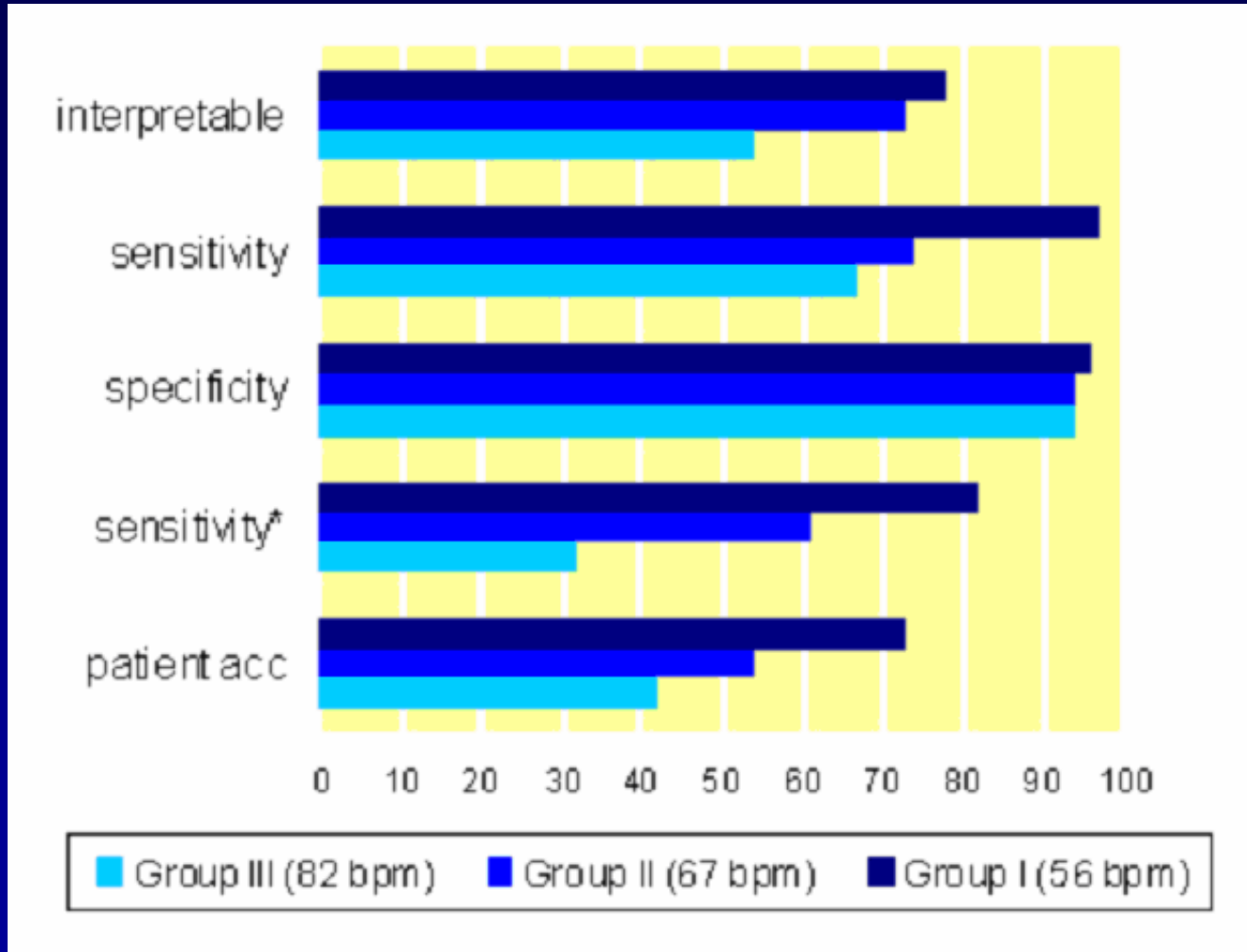
# Severe calcification



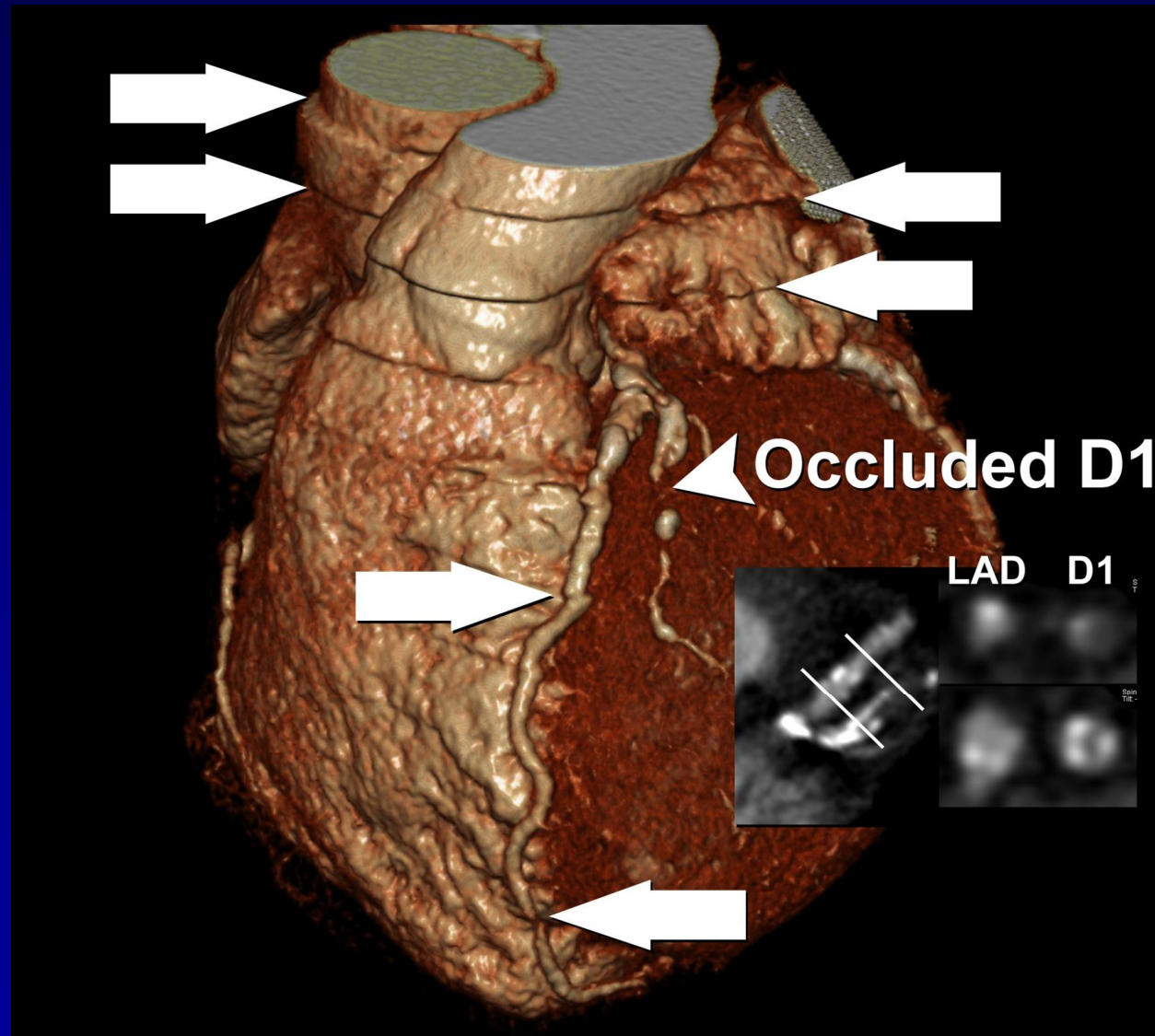
# High heart rates



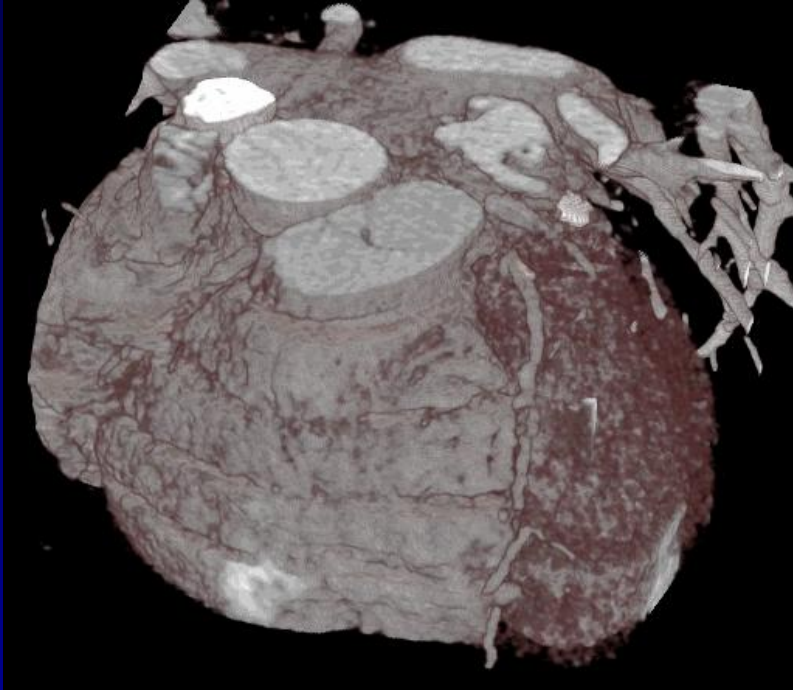
# High heart rates



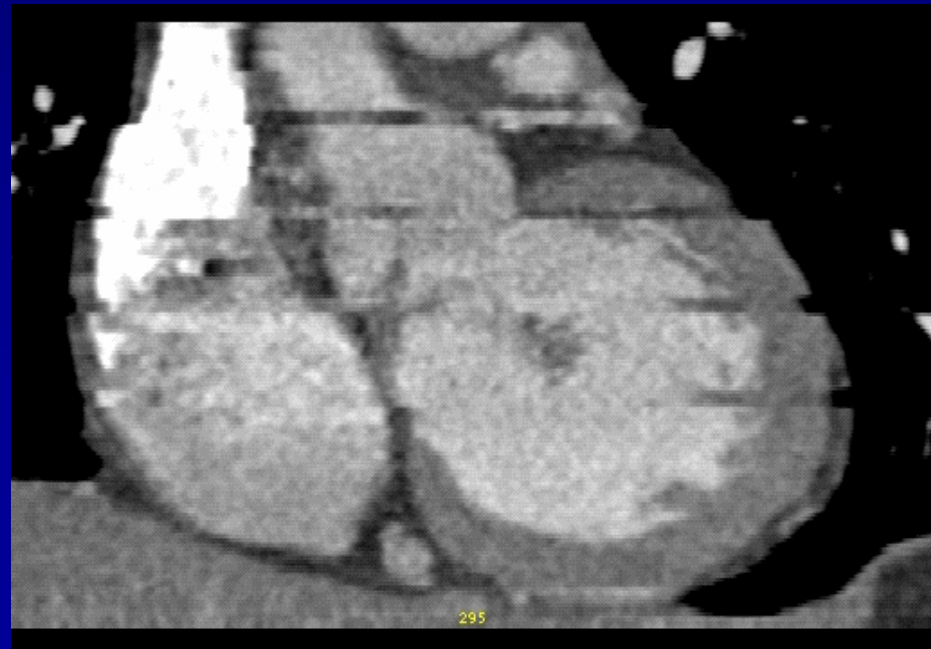
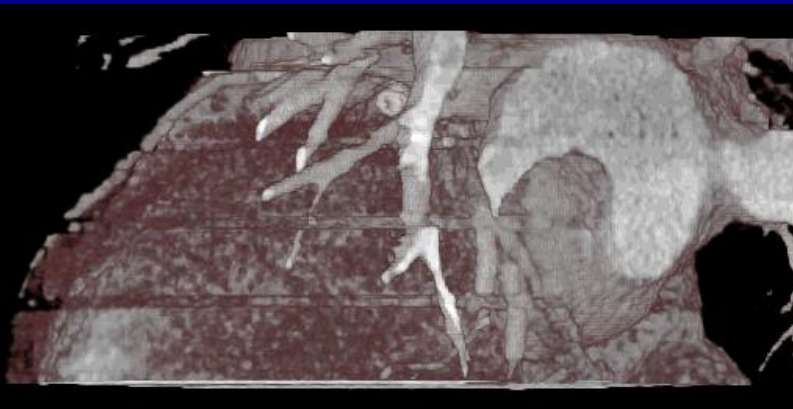
# Respiratory Motion



# Arrhythmia



Premature ventricular contraction  
after each 4-5 normal cycles



# ECG-editing

## Low HR

19-Jun-2003 11:47:00.01  
1.1MA.1  
TOP.1  
SP-81.0

ERASMUS mck32  
Sensation 16  
VA70B  
H-SP

19-Jun-2003 11:47:00.66  
102.1MA.13  
RTD.12  
SP-228.5

ERASMUS mck32  
Sensation 16  
VA70B  
H-SP-CR

HeartView

There are time differences between scanboxes greater than **1.5s**  
Please insert additional syncs.

OK

EMC\_coronaryStd

- Topogram
- CaScoring RT
- Pause
- PreMonitoring
- I.V. Bolus
- Monitoring X
- Cor. CTA RT

Load Cancel Recon

Routine Trigger

Table: Position Height  
-266.5 163.0

0.0° Tilt

19-Jun-2003 11:47:38

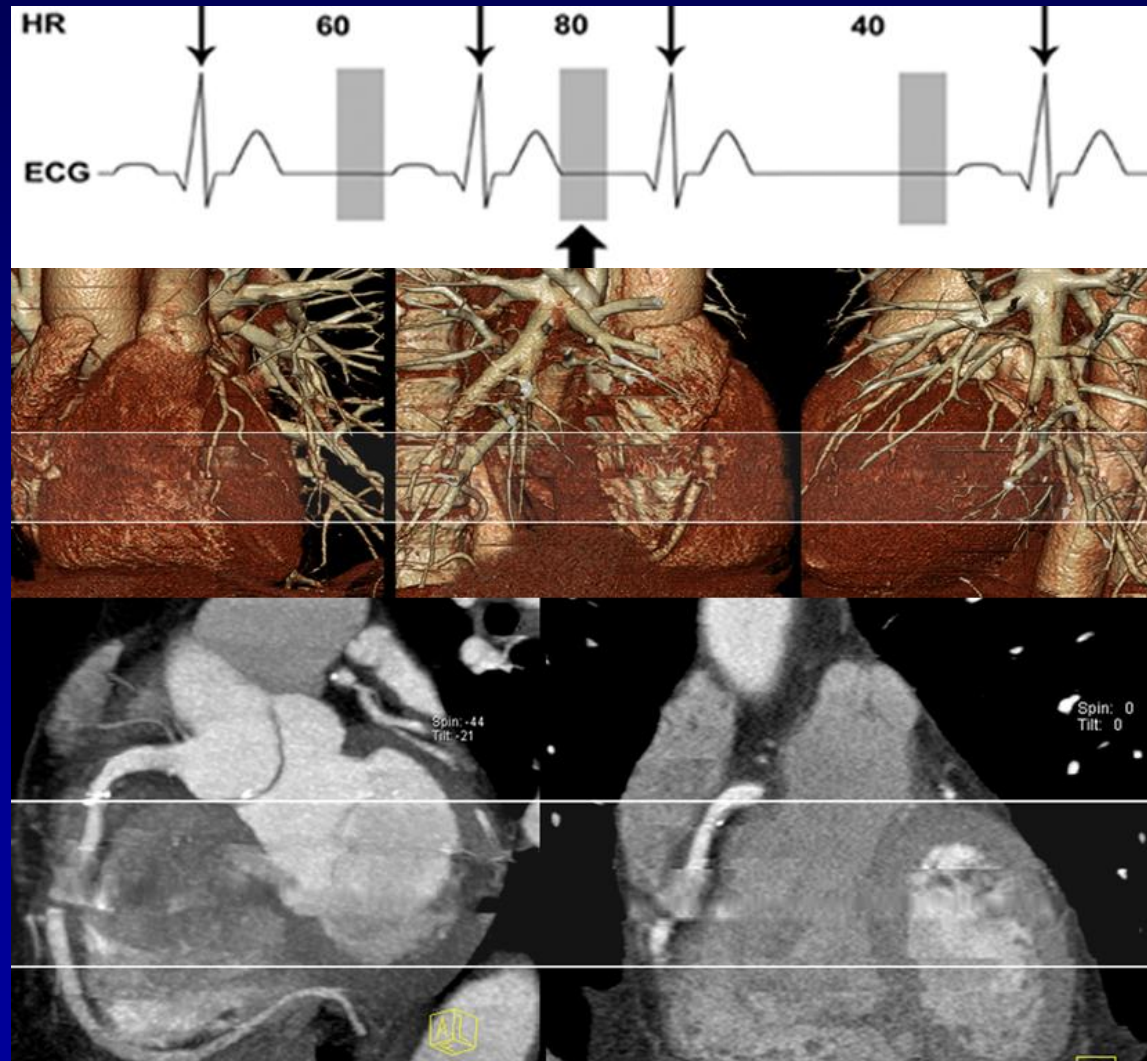
Patient successfully registered.





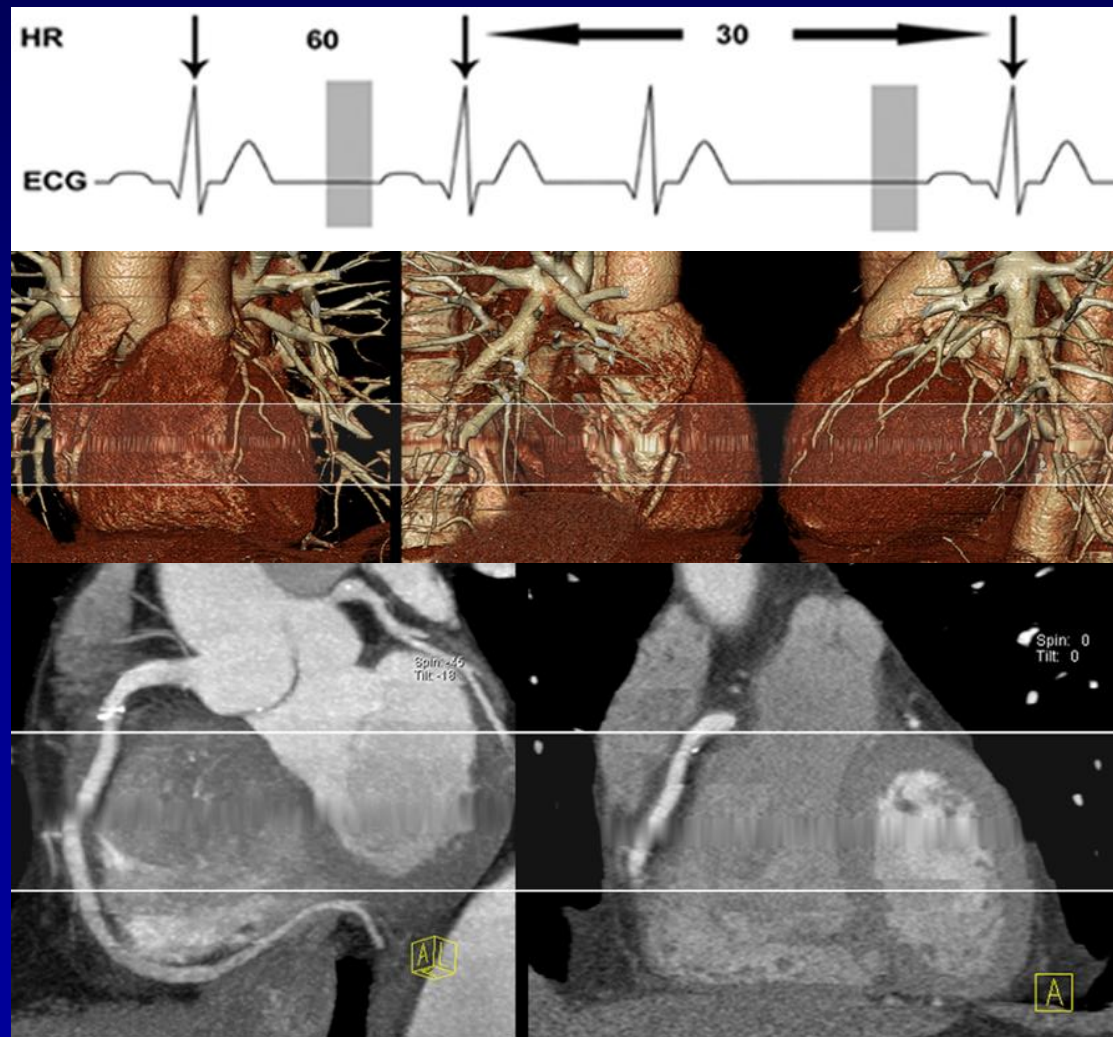
# ECG-editing

## Extra-systole

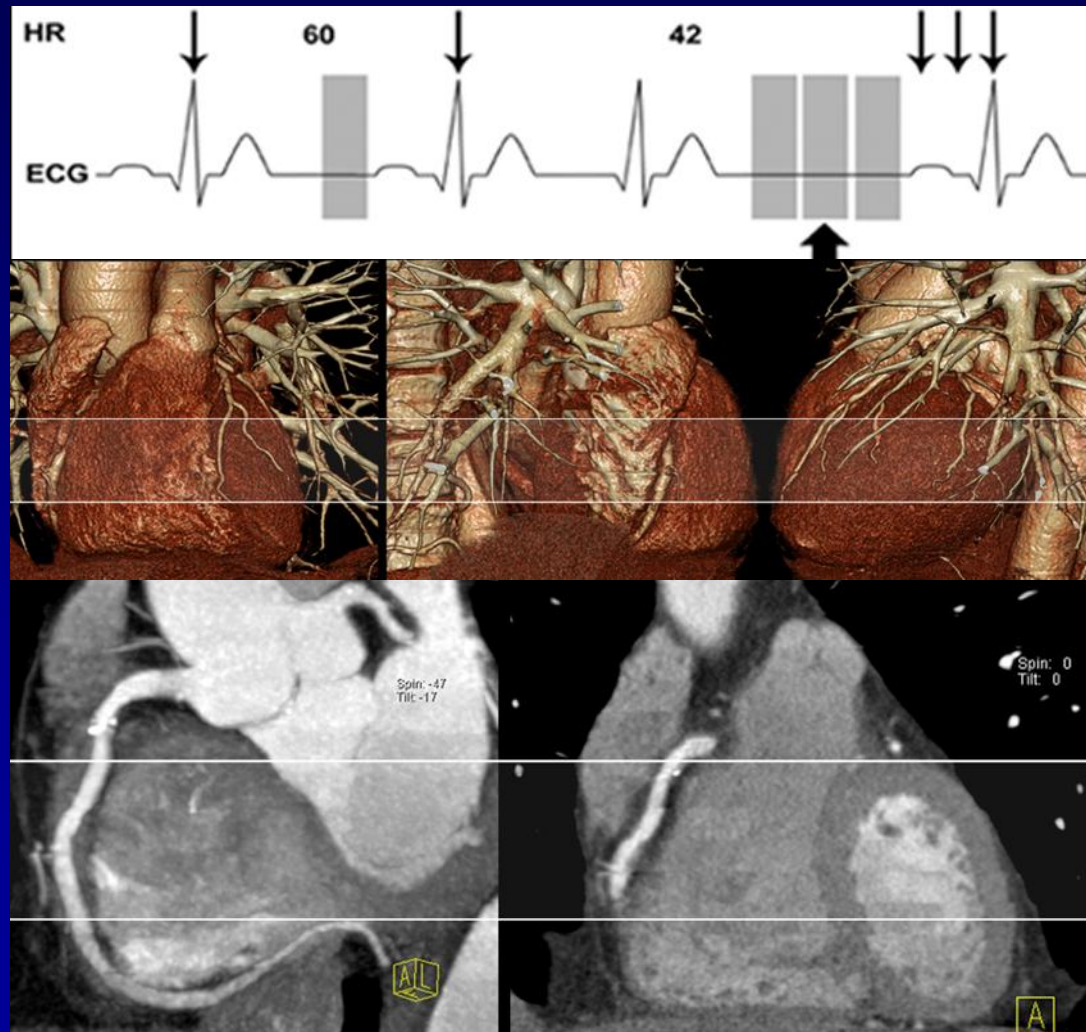


# ECG-editing

## Missing data



# ECG-editing



# ECG-editing: Results

Only patients with mild arrhythmia included

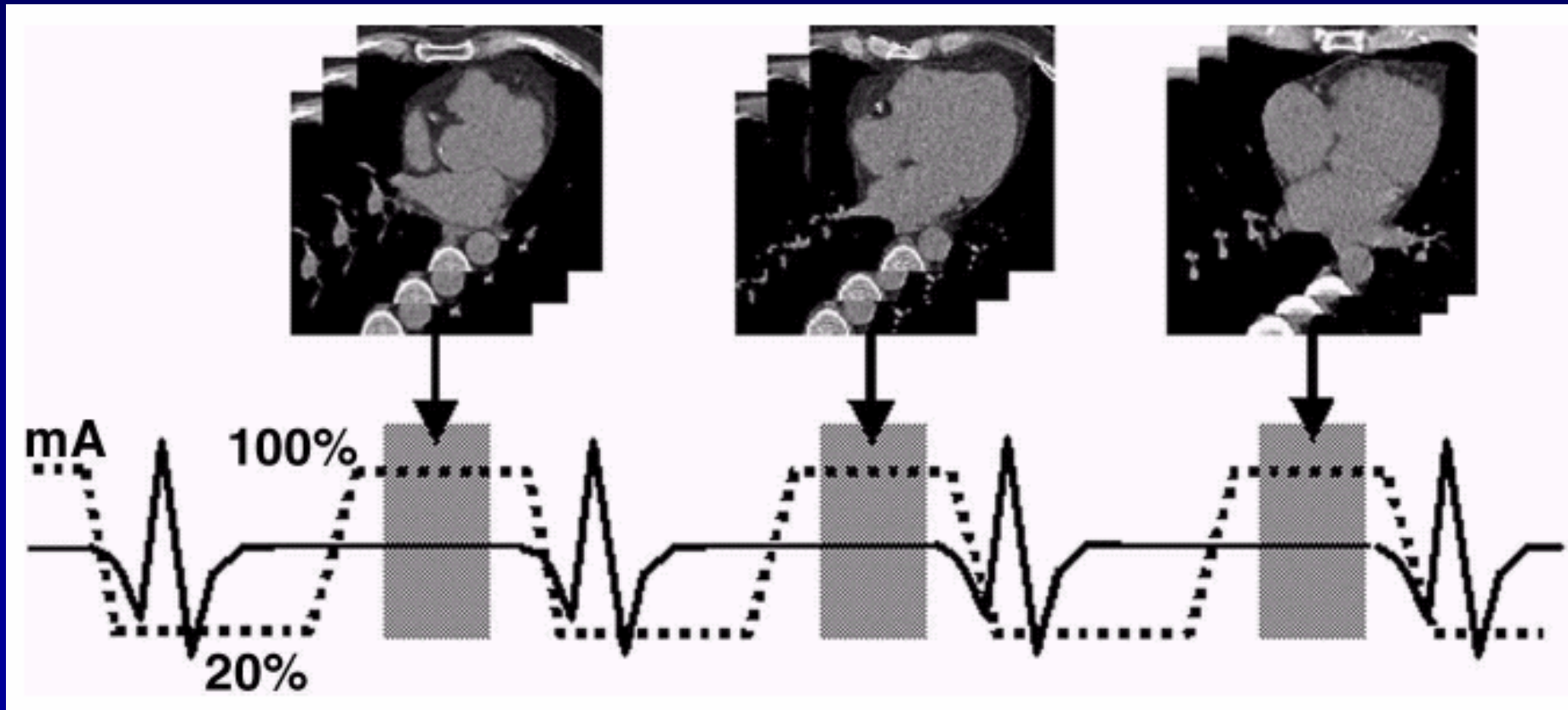
	<u>STD</u>	<u>Edit</u>
Available:	416	416
Sensitivity:	72%	91%
Specificity:	96%	96%
PPV:	87%	87%
NPV:	91%	97%

Cademartiri, AJR (in press)

# Radiation Exposure

# Dose Reduction

## Prospective ECG-tube modulation



# **Dose Reduction**

## **Tube Modulation**

- (+) Reduction up to 50% of dose in low heart rates**
- (-) Less reliable in case of mild arrhythmia**
- (-) Unable to reconstruct datasets during early diastolic phase (low-dose area), but often good time interval for evaluation of the RCA**



# Radiation Exposure Estimations / Calculations

**Values of the Effective Patient Dose for Selected Scanning Protocols**

Parameter	ECG-triggered Ca Scoring		ECG-gated Ca Scoring			ECG-gated Coronary CT Angiography		
	4-section Scanner	16-section Scanner	4-section Scanner	16-section Scanner		4-section Scanner	16-section Scanner	
				12 Sections	16 Sections		12 Sections	16 Sections
Collimation (no. of sections × mm)	4 × 2.5	12 × 1.5	4 × 2.5	12 × 1.5	16 × 1.5	4 × 1	12 × 0.75	16 × 0.75
Range (mm)	120	120	120	120	120	100	100	100
Weighted CT dose index (mGy)	2.74	2.16	10.1	9.54	10.5	36.0	42.0	43.3
Effective patient dose (mSv)								
No ECG pulsing								
Male	0.54	0.45	1.95	1.91	2.16	5.71	6.82	7.1
Female	0.76	0.65	2.79	2.73	3.08	8.49	10.12	10.53
ECG pulsing								
Male	NA*	NA	1.0–1.4	1.0–1.4	1.1–1.5	2.9–4.0	3.4–4.8	3.6–5.0
Female	NA	NA	1.4–2.0	1.4–1.9	1.5–2.	4.2–5.9	5.1–7.1	5.3–7.4

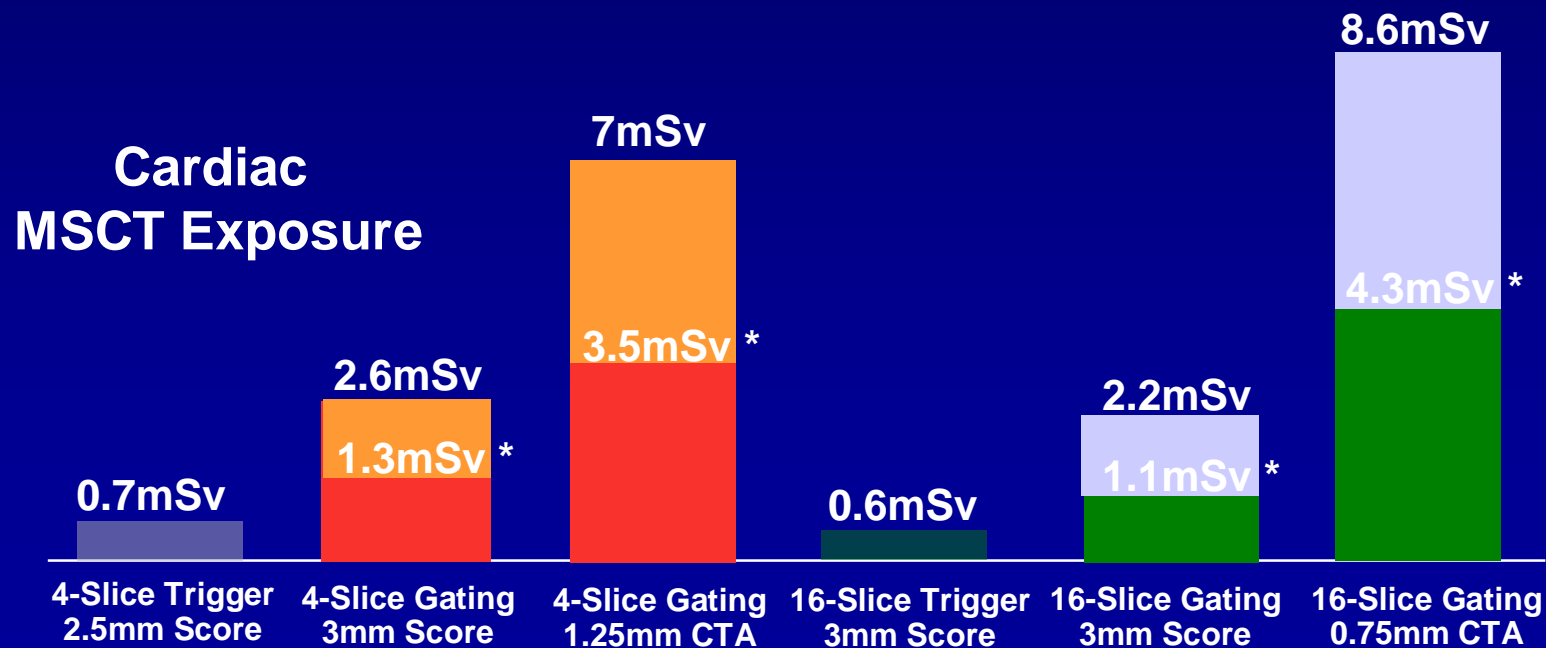
Note.—For the 16-section scanners, either 12 or 16 sections were acquired.

\*NA = not applicable.

# Radiation Exposure Estimations / Calculations

## Exposure Cornerstones:

- Bi-Plane Chest X-Ray:  $\approx 0.1$  mSv
- EBCT Calcium Scoring:  $\approx 0.9$  mSv
- Diagnostic Coronary Angiography:  $\approx 2-6$  mSv
- Natural Background Radiation:  $\approx 2-5$  mSv p.a.



\* ECG-Pulsing

Jakobs, Eur. Radiology '02

# Radiation Exposure Estimations / Calculations

male/female (ECG pulsing)	Ca Seq.	Ca Spiral	CT Angio
Jakobs (Eur Rad'02): est. 4-MSCT 100 mAs 4x2.5mm		2.0 / 2.5 (1.0 / 1.4)	
Hunold (Radiol'03): phantom 1-EBCT63 mAs 1x3 mm 4-MSCT 2-400mAs 4x1 mm	1.0 / 1.3 1.5 / 1.8	3-5 / 4-6	1.5 / 2.0 7-11 / 8-13
Morin (Circ'03): estimations 1-EBCT63 mAs 1x3 mm 4-MSCT 150 mAs 4x1/1.3 mm	0.7 1.0	2.6 - 4.1	1.1 9.3 - 11.3
Trabold (RoFo'03): phantom 16MSCT 300 mAs 12x.8mm		2.9 / 3.6 (1.6)	8.1 / 10.9 (4.3)
Hunold (RSNA'03): phantom			
4MSCT 100/default mAs 4x1mm Siemens		3.0 / 3.6	10.9 / 13.0
4MSCT 100/default mAs 4x1mm GE		4.2 / 5.4	12.3 / 15.7
4MSCT 100/default mAs 4x1mm Philips		2.4 / 3.2	6.3 / 8.2
16MSCT 100/default mAs 16x.6mm GE		5.8 / 6.9	<b>14.1-18.8</b>