

## Technical Principles of ECG-gated CT and Radiation Dose Reduction



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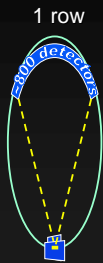
### Technical Principles of ECG-gated CT and Radiation Dose Reduction

#### OBJECTIVE

- review two fundamentals of CT technology
  - detector banks in multidetector (multislice) CT
  - pitch
- prospective and retrospective ECG gating
- explain how heart-rate influences selection of gating technique, ..
- and how this affects radiation exposure

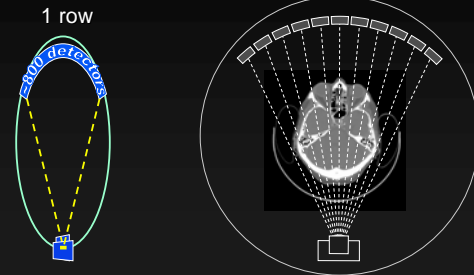
### 3<sup>rd</sup> Generation Computed Tomography

Tube-Fanbeam-detector array rotating around patient



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Tube-Fanbeam-detector array rotating around patient



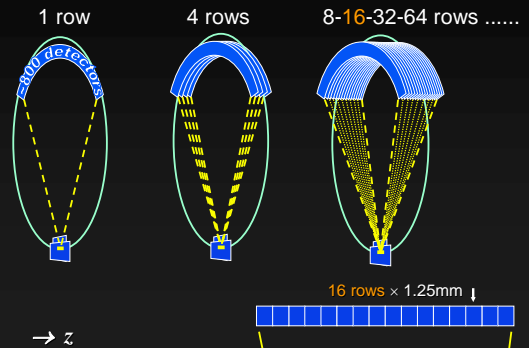
Gantry rotation times (modern scanners): 500ms → 300ms

#### Fastest Gantry Rotation Times for Different Scanners

	gantry rotation time (ms)	(sec)
GE-CT1 (8 row)	500 ms	(0.5s)
GE- CT3 (16-row)	400 ms	(0.4s)
GE-VCT (64-row)	350 ms	(0.35s)
Siemens S 64 (Blake)	330 ms	(0.33s)
Siem. DualSource (SMIC)	330 ms	(0.33s)
Siemens AS+ (SMOC)	300 ms	(0.30s)

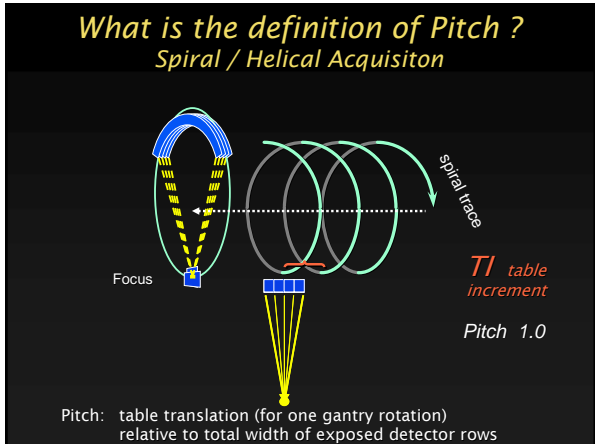
### Multiple Detector Row Systems

Exposed detector-rows



### Examples of Detector Bank Configurations

	detector configuration (rows × thickn.)	total detector bank width (mm)
GE-CT1 (8 row)	8 × 1.25 mm	10 mm
GE-CT3 (16-row)	16 × 1.25 mm	20 mm
GE-VCT (64-row)	64 × 0.625 mm	40 mm
Siemens S 64 (Blake)	32 × 0.6 mm	19.2 mm
Siem. DualSource (SMIC)	32 × 0.6 mm	19.2 mm
Siemens AS+ (SMOC)	64 × 0.6 mm	38.4 mm



### Examples of Detector Bank Configurations

	detector configuration (rows × thickn.)	total detector bank width (mm)	pitch 1.0
GE-CT1 (8 row)	8 × 1.25 mm	10 mm	10mm
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### Examples of Detector Bank Configurations

	detector configuration (rows × thickn.)	total detector bank width (mm)	pitch 1.35
GE-CT1 (8 row)	8 × 1.25 mm	10 mm	13.5mm
GE-CT3 (16-row)	16 × 1.25 mm	20 mm	27mm
GE-VCT (64-row)	64 × 0.625 mm	40 mm	54mm
Siemens S 64 (Blake)	32 × 0.6 mm	19.2 mm	
Siem. DualSource (SMIC)	32 × 0.6 mm	19.2 mm	
Siemens AS+ (SMOC)	64 × 0.6 mm	38.4 mm	

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### CT and Cardiac Motion

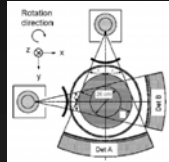
**Problem:**

- fast Motion !!!
- Cardiac cycle ~ 1 s (1000 ms)
- Ideal temporal resolution: <50 msec

Coronary Angiography (Catheter angiography)  
RAO of right coronary artery

### What is Temporal Resolution in CT?

- time it takes to acquire all x-ray projections needed to reconstruct one CT image
- Half-scan reconstruction needs only projections from ~ 180° gantry rotation  
*temporal resol.  $\cong 1/2$  gantry rotation time*
- With two x-ray tube/detector systems *temporal resol.  $\cong 1/4$  gantry rotation time*



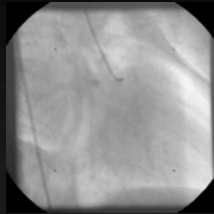
### Temporal Resolution (2009)

	Gantry Rotation (ms)	~Temporal Resolution (ms)	
GE - VCT (CT2)	350	175 ms	
Siemens S 64 (Blake)	330	165 ms	
Siemens AS+ (SMOC)	300	150 ms	
Siem. DualSource (SMIC)	330	85 ms	
GE - HD750 (SMIC)	350	175 ms	Jun 28
Siem. FLASH (SMIC/SMOC)	280	75 ms	Oct '09

### CT and Cardiac Motion

#### Solution:

- (a) scan much faster
- (b) synchronize scan (or reconstruction) with EKG signal
- (a) + (b)



Coronary Angiography (Catheter angiography)

RAO of right coronary artery

### CT and Cardiac Motion

#### Solution:

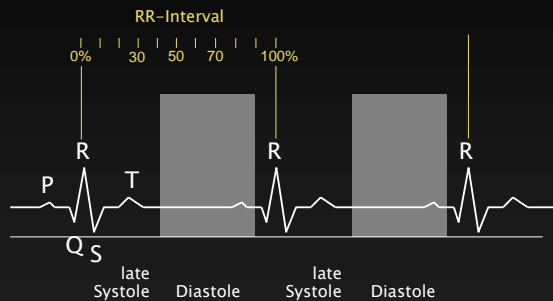
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ECG-gated 64-channel CTA

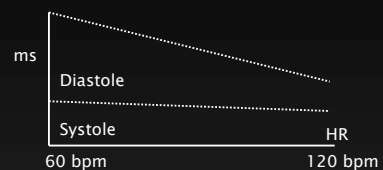
### Cardiac CT basics

#### Elektrokardiogramm



### Cardiac CT basics

#### Heart rate vs duration of diastole/systole



Low heart rate (~60): best images in Diastole  
 Medium heart rate (~70): best images Diastole or Systole  
 Higher heart rates (~80): best images in Systole

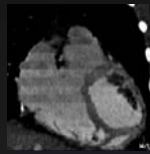
**ECG synchronized CT**  
(coronary CTA, gated chest)

- **Prospective triggering (step and shoot)**
  - every other R-peak triggers (80-175ms) scan
  - no (minimal) radiation dose overlap
  - NEEDS slow and STABLE heart rate
- **Retrospective gating (low pitch helical)**
  - redundant helical data acquisition (pitch ~0.2)
  - coregistration of ECG
  - selecting only projection samples which fall into desired phase of cardiac cycle
- **Prospectively triggered high-pitch helical**
  - dual source only

**ECG - Triggering**

4 x 2.5mm sequential every 2<sup>nd</sup> RR

heart in 15s

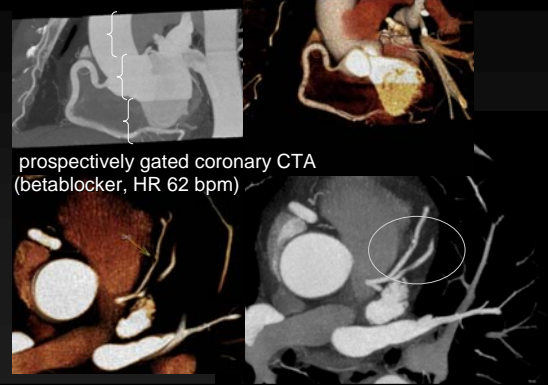


**Prospective Triggering for Coronary CTA**

- **step-and-shoot (every other heart beat)**
  - 3 scans (~12cm): 5 heartbeats → ~5 sec
  - 4 scans (~16cm): 7 heartbeats → ~7 sec
- acquisition as fast as helical
- substantially less radiation dose (as low as 2-3 mSv) \*
- need low and steady heart rate !! (≤60 bpm; ±5)
- no dynamic information (no 4D)

\* Earls (2008) Radiology 246  
Scheffel (2008) Heart 94  
Stolzmann (2008) Radiology 249

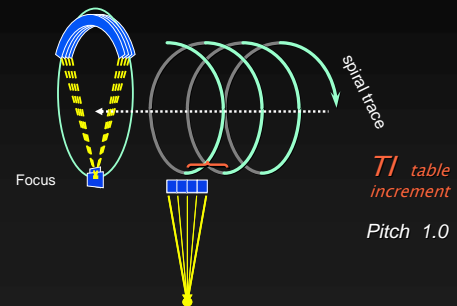
56 yo man with chest pain (ER)

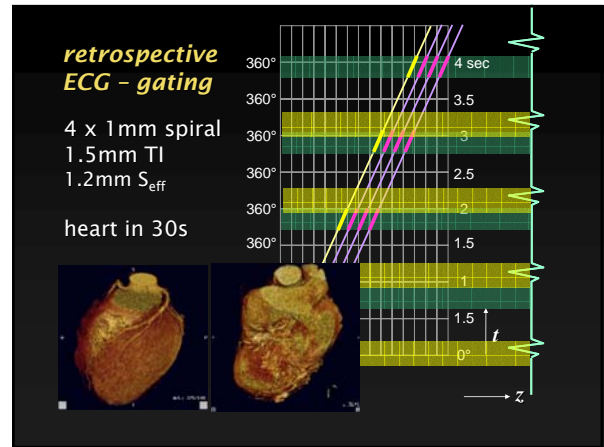
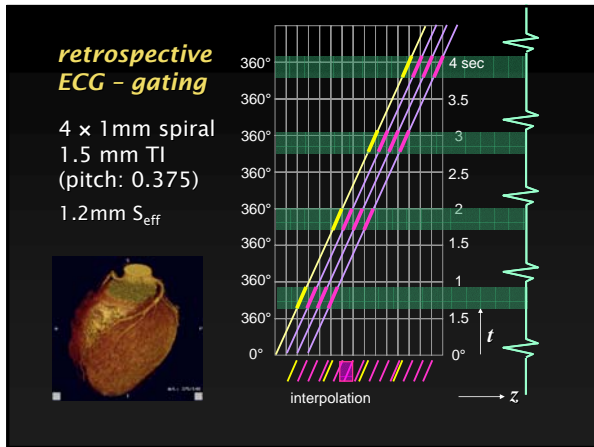
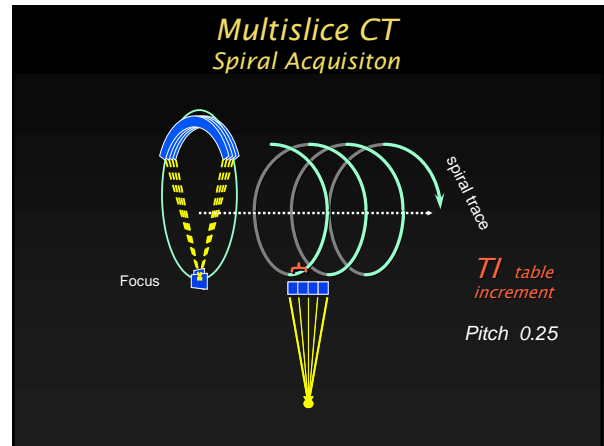
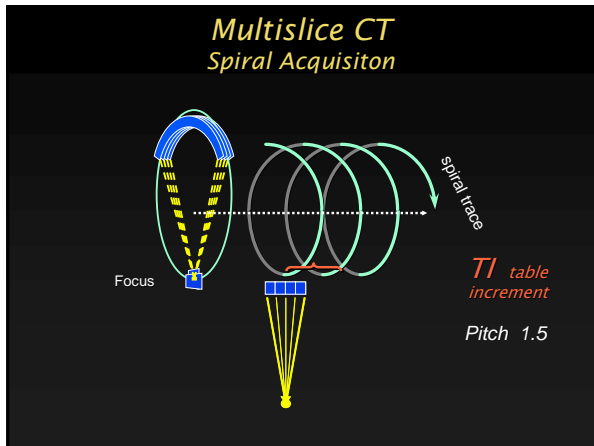


**ECG synchronized CT**  
(coronary CTA, gated chest)

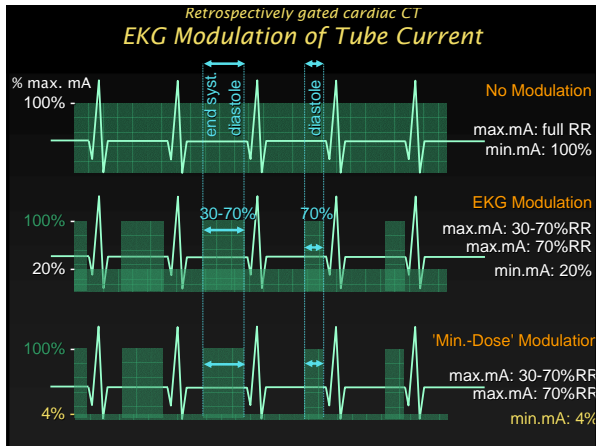
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  - dual source only

**Multislice CT Spiral Acquisition**





- ### ECG synchronized CT (coronary CTA, gated chest)
- Prospective triggering (step and shoot)
    - every other R-peak triggers (80-175ms) scan
    - no (minimal) radiation dose overlap
    - NEEDS slow and STABLE heart rate
  - Retrospective gating (low pitch helical)
    - redundant helical data acquisition (pitch ~0.2)
    - coregistration of ECG
    - selecting only projection samples which fall into desired phase of cardiac cycle
- redundant radiation → increased dose  
→ EKG based tube current modulation



**Lowest Dose Coronary Protocol(s) possible with low heart rates**

**Siemens Scanners**

- retrospective gating (heart rate <65 bpm)
- with 'min-dose' tube current modulation and pulsing window of 70% RR
- (if heart rate > 65bpm, pulsing window 30-70%)

**GE- VCT**

- prospective gating (heart rate ≤60 bpm ±5)
- (if heart rate >60 bpm or irregular, retro-gating)

100 kVp for slim patients (<65kg)

**Radiation Exposure Reduction in Cardiac CT**

Modulation Type	Parameter	Value	Dose (mSv)
Retrospective Gating	no EKG dose modulation	100 %	25 mSv
	EKG mod. 20% mA: 30-70% RR	~ 70 %	
	EKG mod. 20% mA: 70% RR	~ 50 %	
	EKG mod. 4% mA: 30-70% RR	~ 50 %	
	EKG mod. 4% mA: 70% RR	~ 25 %	
Prospective Gating	prospective std. padding	~ 25 %	3-5 mSv
	100kV		3 mSv
	dose proportional to square of kV; iodine signal incr.; noise increases too;	subtract	
	120→100kV: -30% dose (at same mA)	- 30%	

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**CLINICAL CASE EXAMPLES**

**MinDose 30 0%**  
**42.13 mGy (592 mGy\*cm) [10mSv]**

54 yom

5'11" (180cm)  
185 lbs (84kg)  
2.04 BSA

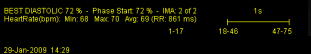
100 atenolol  
HR 69

*MinDose 30 0%*  
**42.13 mGy (592 mGy\*cm) [10mSv]**

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100 atenolol  
 HR 69



Scan	kV	mAs / ref.	CTDIvol mGy	DLP mGy*cm	TI s	cSL mm
Patient Position F-SP						
Topogram AP	1	120 35 mA			5.3	0.6
DS CaScSeq	20	120 189 / 200	10.93	157	0.2	3.0
Last scan no.	9					
TestBolus	10	120 40	55.73	20	0.5	5.0
Last scan no.	34					
Coronary CTA	35D	120 214 / 438	42.13	592	0.33	0.6

CTDI (CT Dose index): mGy (milligray)  
 DLP (dose length product): mGy × cm

*MinDose 30 0%*  
**42.13 mGy (592 mGy\*cm) [10mSv]**

Total mAs 8152 Total DLP 777 mGy\*cm

Scan	kV	mAs / ref.	CTDIvol mGy	DLP mGy*cm
Patient Position F-SP				
Topogram AP	1	120 35 mA		
DS CaScSeq	20	120 189 / 200	10.93	157
Last scan no.	9			
TestBolus	10	120 40	55.73	28
Last scan no.	34			
Coronary CTA	35D	120 214 / 438	42.13	592


CTDI (CT Dose index): mGy (milligray)  
 DLP (dose length product): mGy × cm

*prospective gating: 24.84 mGy*  
**(338 mGy\*cm) [5.75mSv]**


59 yo man

6'1" (190cm)  
 185 lbs (86 kg)  
 BSA 2.11

HR: 50 bpm



*prospective gating: 24.84 mGy*  
**(338 mGy\*cm) [5.75mSv]**




**CLINICAL CASE**

56 yo physician

5'6" (168cm)  
 133 lbs (60kg)  
 1.68 BSA

HR: 48 bpm




Scan	kV	mAs / ref.	CTDIvol mGy	DLP mGy*cm	TI s	cSL mm
Patient Position F-SP						
Topogram AP	1	120 35 mA			5.3	0.6
CA CaScSeq	20	120 48 / 230	11.13	238	0.33	1.2
TestBolus	27	100 40	33.38	17	0.5	5.0
Last scan no.	27					
Coronary CTA	28D	100 68 / 350	11.49	192	0.33	0.6

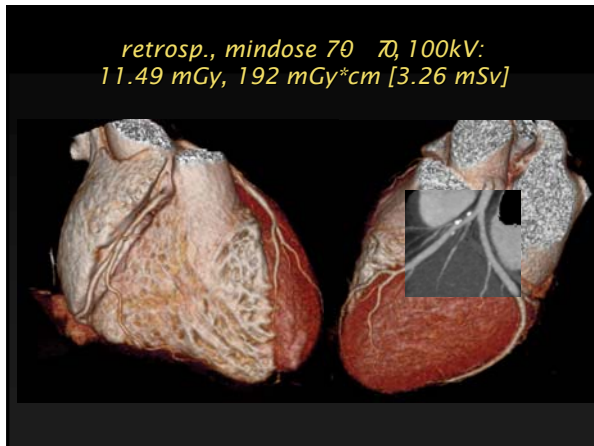
*retrosp., mindose 70 70, 100kV:*  
**11.49 mGy, 192 mGy\*cm [3.26 mSv]**

56 yo physician

5'6" (168cm)  
 133 lbs (60kg)  
 1.68 BSA

HR: 48 bpm





Scan Type	kV	mAs/ ref.	CTDI (mGy)	DLP (mGy*cm)	mSv
no pulsing	120	438	110.60	1593	~27
mindose 30-70	120	214/438	42.13	592	~10
mindose 70-70	120	119/438	26.19	426	~7.2
mindose 70-70	100	68/350	11.49	192	~3.3
prospective	120	385/400	24.48	338	~5.7
XXL	120	438	61.61	890	~15
gated chest30-70	100	203/438	27.01	667	~11

- Practical Dose Reduction Strategies in Cardiac CT*  
**SUMMARY**
- very effective dose-reduction strategies for cardiac CT available
  - slightly different on different scanners
    - prospective: GE-VCT, Siemens AS+
    - retrospective mindose: Dual Source)
  - individually tailored to
    - patient size
    - heart rate
    - clinical indication

