Recent Advancement of Cardiac CT

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* Disclosure: grant support from Philips Medical Systems

Non-Invasive Coronary Angiography

Potential Utility of MDCT

- Utilization:
  - 2 Million catheterizations in 2000
  - 340% increase from 1980 to 2000
- Increasing cost:
  - $11,232 in 1993 per procedure
  - $16,838 in 2000*
- High number of unnecessary procedures†:
  - 40% of women
  - 20-25% of men
- Small but definable risk:
  - 2% major complications (JCA Guidelines, 1999)
- 3-5% patients presenting with CP to ED develop MI

**Agency for Healthcare Research and Quality, Healthcare Cost and Utilization Project, HCUPnet, Washington, DC, 2000.*

†Kugelmass AD. J Am Coll Cardiol 2001;37:497A.

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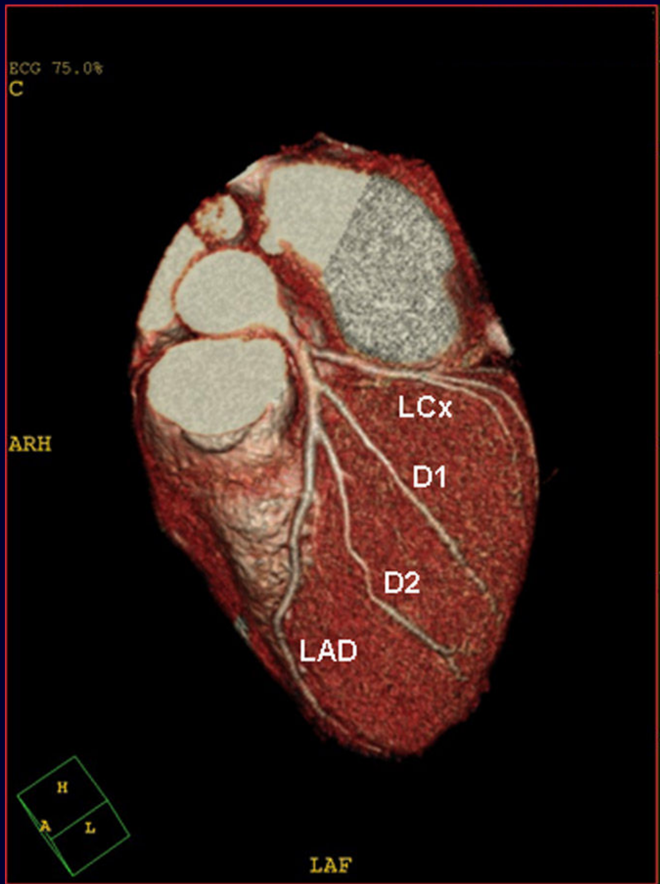
Limitations of the Standard of Care

- Invasive coronary angiography cannot be performed in all patients at risk
- Stress testing has insufficient accuracy:
  - 1) To establish or exclude CAD as the cause of chest pain
  - 2) To establish or exclude CAD in the asymptomatic patient at risk

Multi-Detector CT

Imaging Coronary Arteries



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MDCT-CA vs Cath

Per-Segment Analysis (16r)

Author (year)	No. Subjects	No. Segments	Sens (%)	Spec (%)	NPV (%)	PPV (%)
Hoffman (2005)	103	1384	95	98	99	87
Kuettner (2005)	72	936	82	98	97	87
Mollet (2005)	51	610	95	98	99	87
Mollet (2004)	128	1384	92	95	98	79
Martuscelli (2004)						90
Kuettner (2004)	58	763	72	97	97	72
Ropers (2003)	77	308	92	93	97	79
Nieman (2002)	58	231	95	86	97	80
Dewey (2004)	34	136	88	91	95	88

***5-25 % excluded segments**

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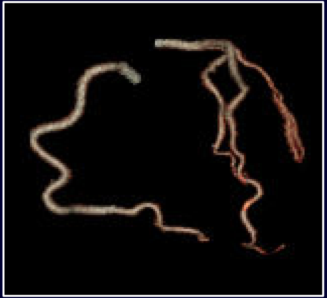
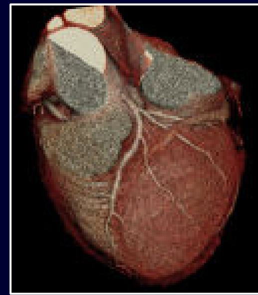
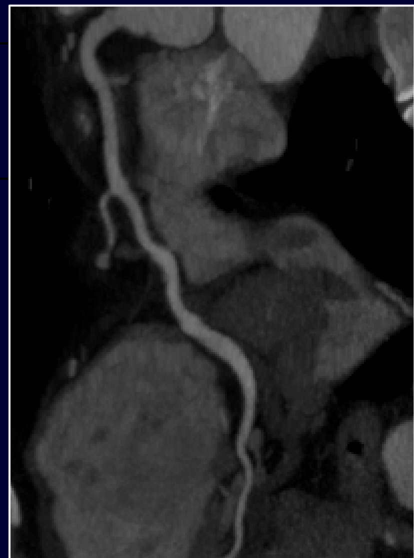


Images from the: CATSCAN Trial



Coronary Assessment by Computed Tomographic Scanning and Catheter Angiography: A Multi-Center Trial



Cleveland Clinic Foundation, Cleveland Mario Garcia [PI]
Washington Hospital Center, Washington DC Augusto Pichard
St. Elizabeth's Hospital, Boston Jeff Mendel
Vanderbilt University, Nashville Ronald Arildsen
University of Maryland Medical Center, Baltimore Charles White
Ochsner Clinic Foundation, New Orleans John Reilly
Rambam Hospital, Israel Eddie Gershin
University Medical Center, Utrecht Matthias Prokop
St. Mary's Hospital, London Andrew Wright
Klinik München-Pasing, Germany Ralph Haberl
Teikyo University Hospital, Japan Shigeru Suzuki
Universitätsklinikum Ulm, Germany Martin Hoffman [CT Core Lab]

Garcia et al, JAMA 2006;296:4003-11

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CATSCAN TRIAL

Demographics

- 238 patients enrolled
- Symptoms
  - Typical angina 137 (58%)
  - Atypical angina 60 (25%)
  - Non-anginal CP 40 (17%)
- Clinical Stratum
  - Intermediate 116 (49%)
  - High 122 (51%)
- Stress test within a year 154/193
  - Positive 118/154
  - Equivocal 19/154

*Patients with at least one vessel with >50% stenosis: 39%

Garcia et al, JAMA 2006;296:4003-11

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CATSCAN TRIAL

Table 2. Accuracy Parameters for Segment-Based and Patient-Based Detection of More Than 50% Coronary Stenosis

	All Segments for Analysis With Nonevaluable Segments "Positive" (n = 1629)	Segments for Analysis Only (n = 1157)*	All Patients for Analysis and Patients With Nonevaluable Segments "Positive" (n = 187)	Patients for Analysis Only (n = 187)†
Stenoses by conventional angiography, No.	89	65	59	59
Stenoses by MDCT, No.	623	151	117	73
False-positive, No.	544	96	58	29
False-negative, No.	10	10	1	15
Sensitivity, % (95% CI)	89 (82-95)	85 (76-96)	98 (95-100)	75 (63-86)
Specificity, % (95% CI)	65 (62-67)	91 (90-92)	54 (45-63)	77 (70-85)
Positive predictive value, % (95% CI)	13 (10-15)	36 (29-44)	50 (41-59)	60 (49-72)
Negative predictive value, % (95% CI)	99 (98-100)	99 (98-100)	99 (96-100)	87 (81-93)
P value for site‡		.25		.10

Abbreviations: CI, confidence interval; MDCT, multidetector computed tomography.
*Excludes 472 (29%) of 1629 segments considered nonevaluable.
†Excludes nonevaluable segments in the counts of stenosis by MDCT.
‡Calculated by bivariate logistic model used to test for variance in accuracy parameters among different participating sites.

Garcia et al, JAMA 2006;296:4003-11

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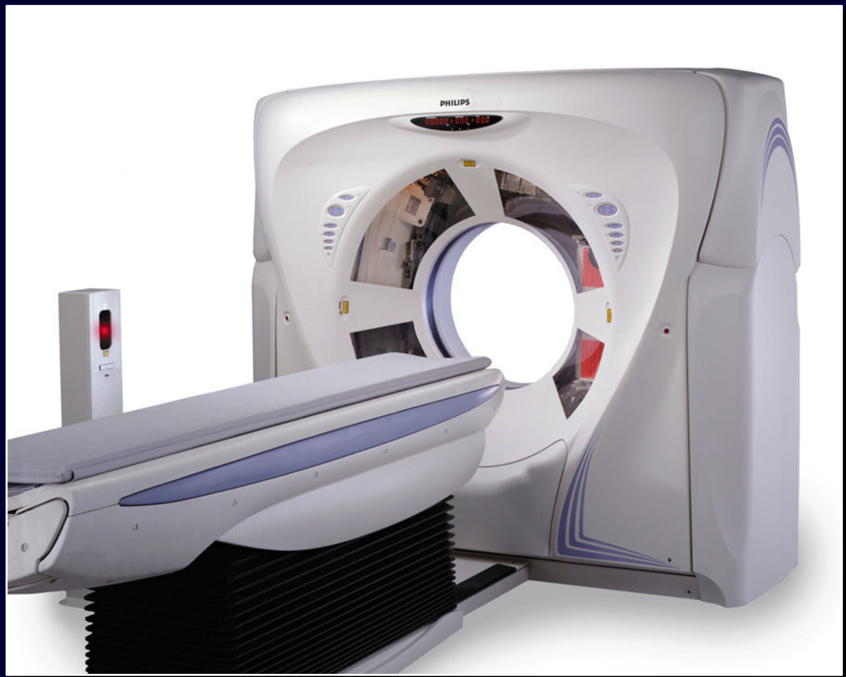
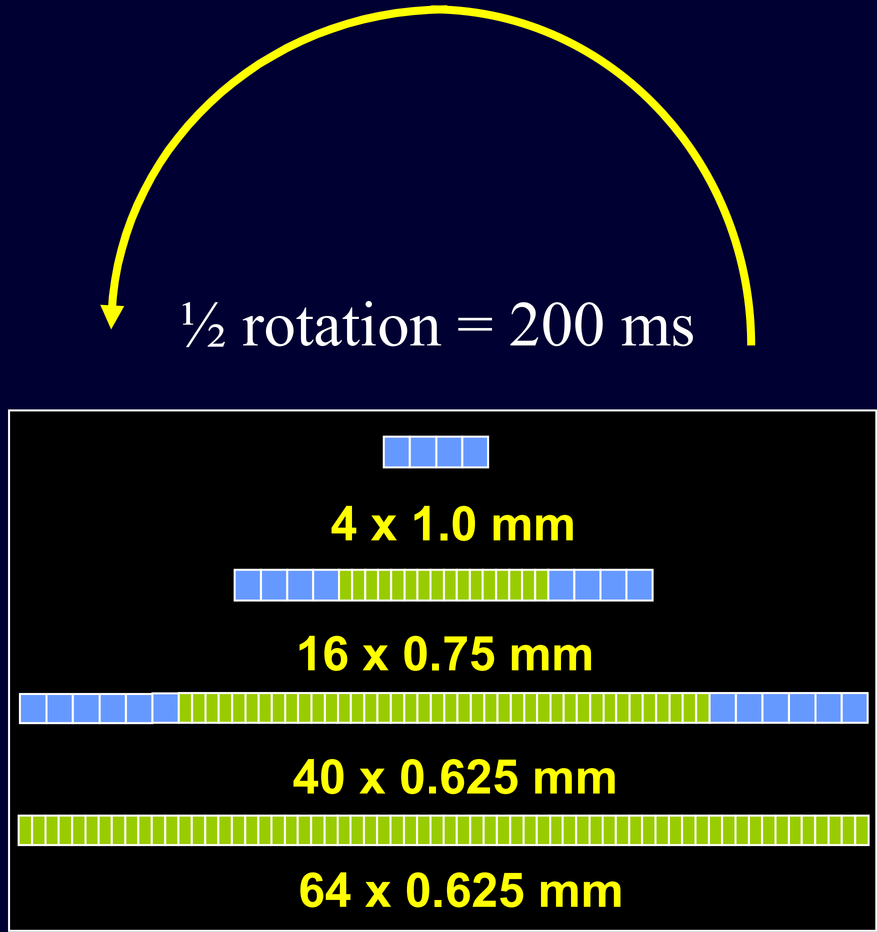
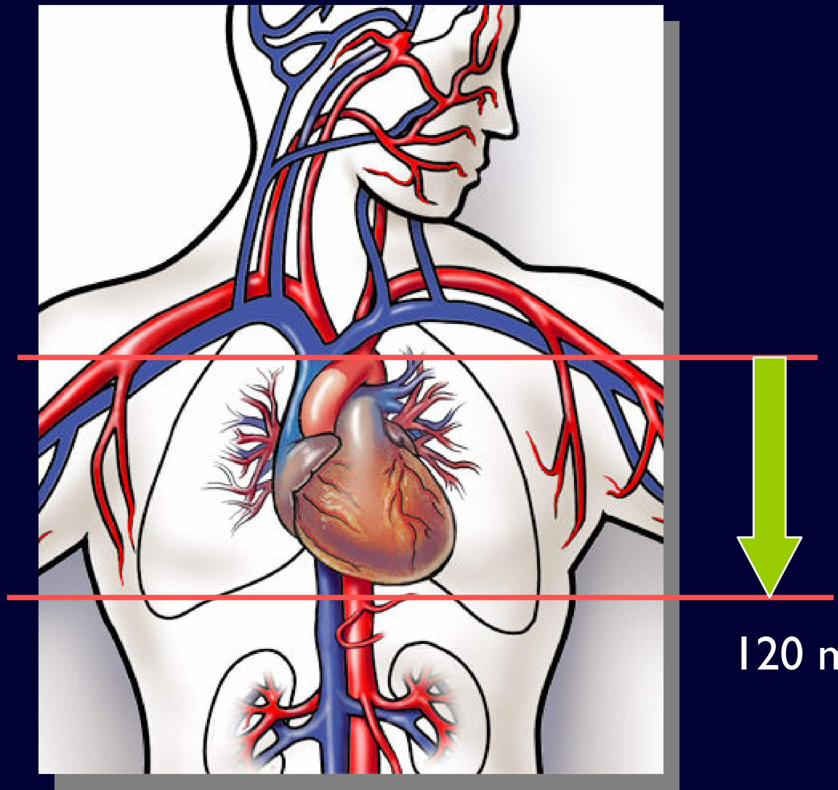
Vascular and Cardiac Imaging

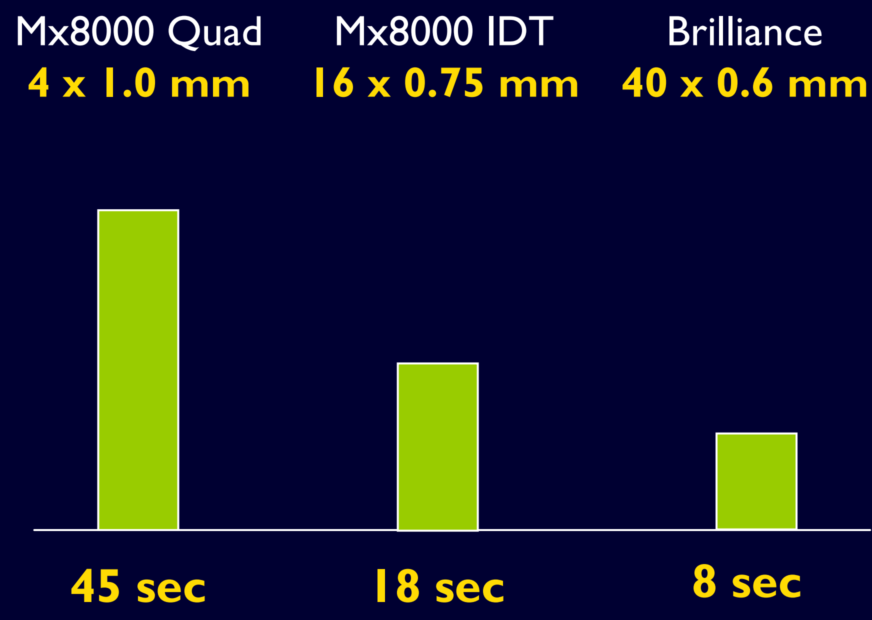
Multi-Detector CT





Coverage and Breath-hold





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Results with high-detector MDCT-CA

Per-patient Analysis (64-r)

Author (year)	No. Subjects	Sens (%)	Spec (%)	NPV (%)	PPV (%)
Mollet (2005)	51	100	92	100	97
Leschka (2005)	53	100	100	100	100
Ropers (2006)	82	96	91	98	83
Raff (2004)	70	95	90	93	93

Current limitations of CTA

• Limited Spatial Resolution	0.5-0.6mm
• Limited Temporal Resolution	200-250ms
• X-ray dose limitation	10-20mSv
• Arrhythmias	6-8beats
• Limited quantification and functional information	

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Overestimation of calcified plaque volume

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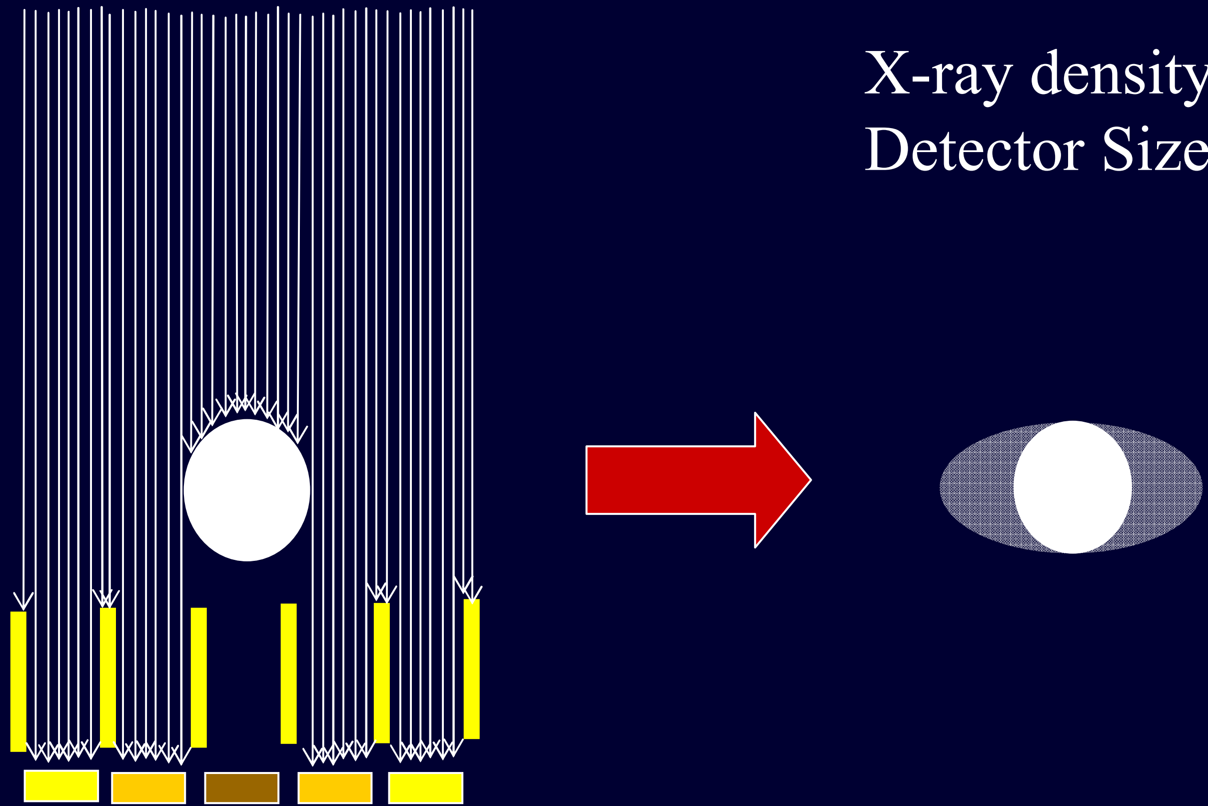
Factors that Limit Resolution

X-ray density
Detector Size



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Limitations of CT Coronary Angiography

High CACS

- 60 non-selected patients with suspected CAD
- MDCT 12 × 0.75 mm CTA
- 2 excluded due to VT and breathing artifacts
- All (n=58): Sens 97%, Spec 77%
- CACS < 1000 (n=46): Sens 98%, Spec 98%

Kuettner, JACC 2004;44:1230

Improving Spatial Resolution

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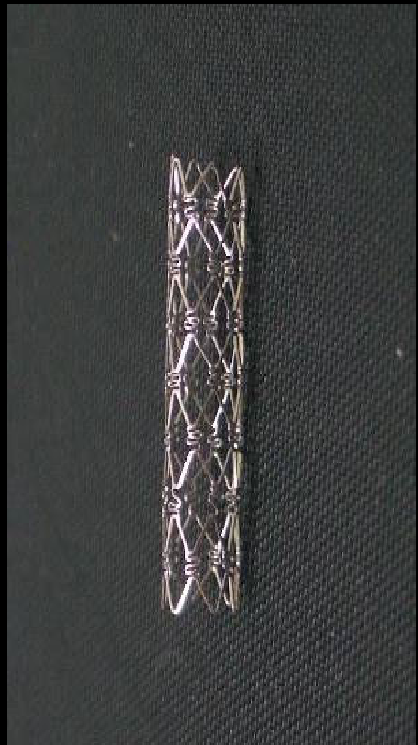
Reduction of Stent Artifacts
z-Sharp Technology



Bx Velocity

3x18mm

Resolution <0.4mm with z-Sharp

*Courtesy of Siemens Medical Solutions

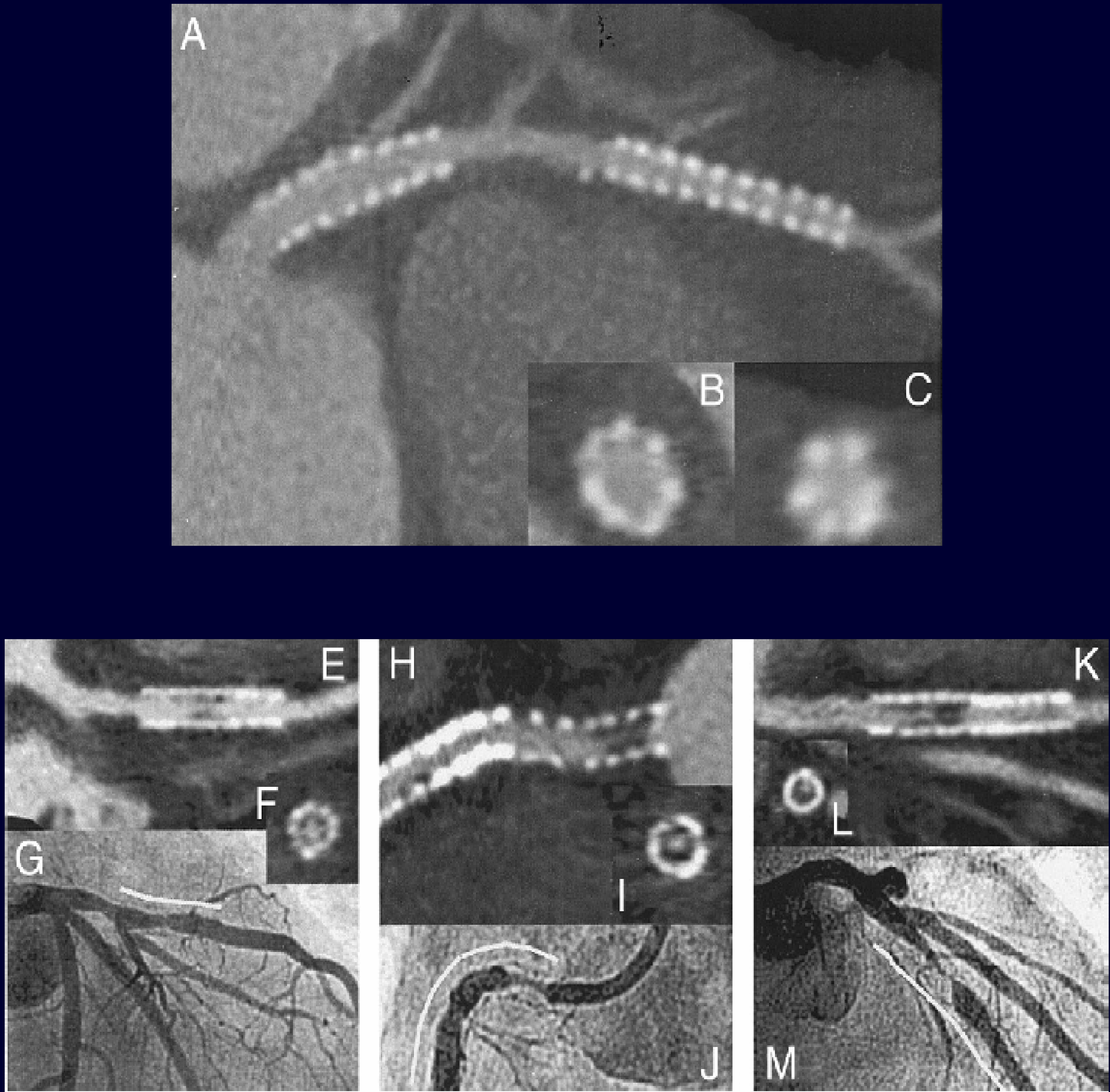
Diagnostic Accuracy of Coronary In-Stent Restenosis Using 64-Slice Computed Tomography

Comparison With Invasive Coronary Angiography

Mariko Ehara, MD, Masato Kawai, RT, Jean-François Surmely, MD, Tetsuo Matsubara, MD, Mitsuyasu Terashima, MD, Etsuo Tsuchikane, MD, Yoshihisa Kinoshita, MD, Tatsuya Ito, MD, Yoshihiro Takeda, MD, Kenya Nasu, MD, Nobuyoshi Tanaka, MD, Akira Murata, MD, Hiroshi Fujita, MD, Koyo Sato, MD, Atsuko Kodama, MD, Osamu Katoh, MD, Takahiko Suzuki, MD

Toyohashi, Japan

- 81 consecutive patients from single institution
- PPV 63%, NPV 99%
- Only 10% stents <3 mm



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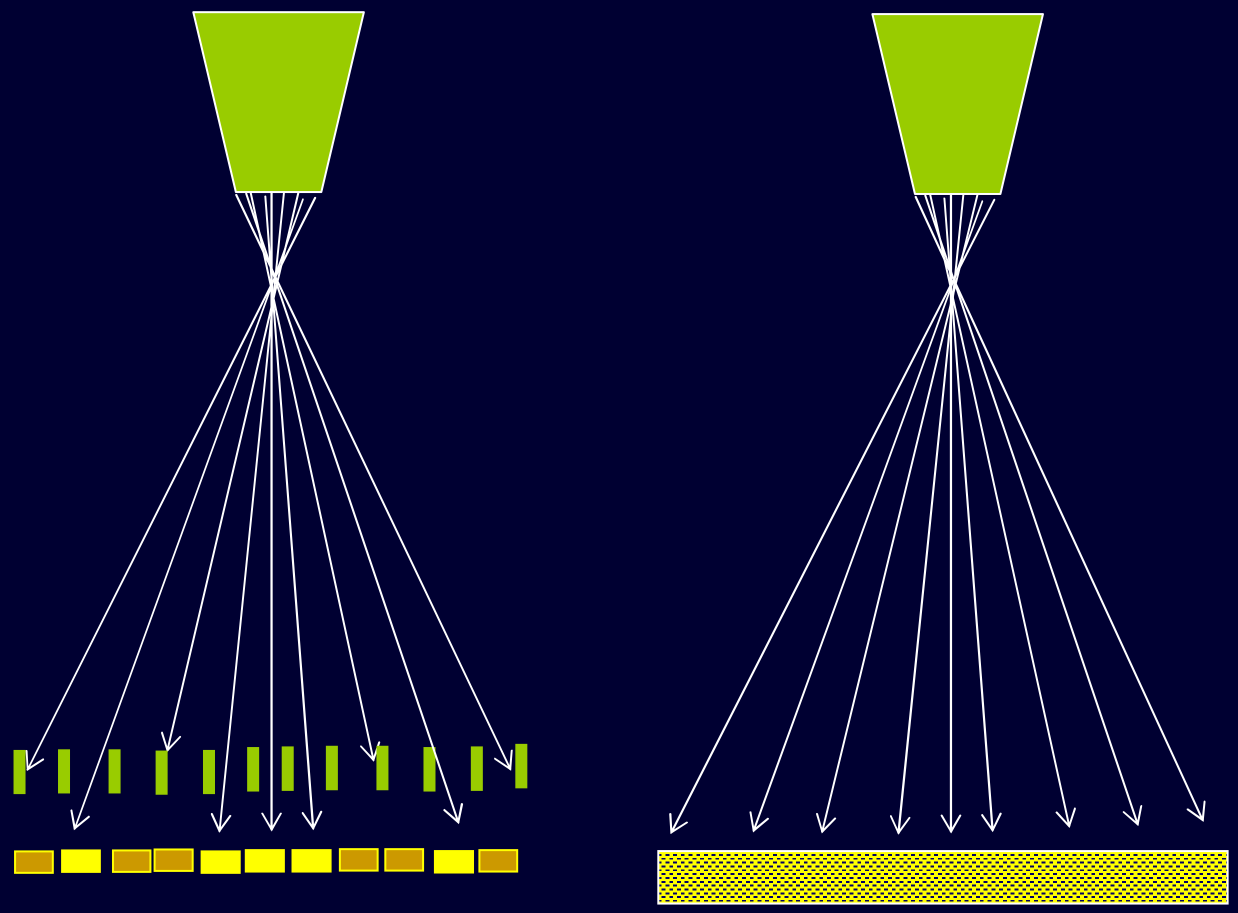
Future Directions: Flat Pannel Technology



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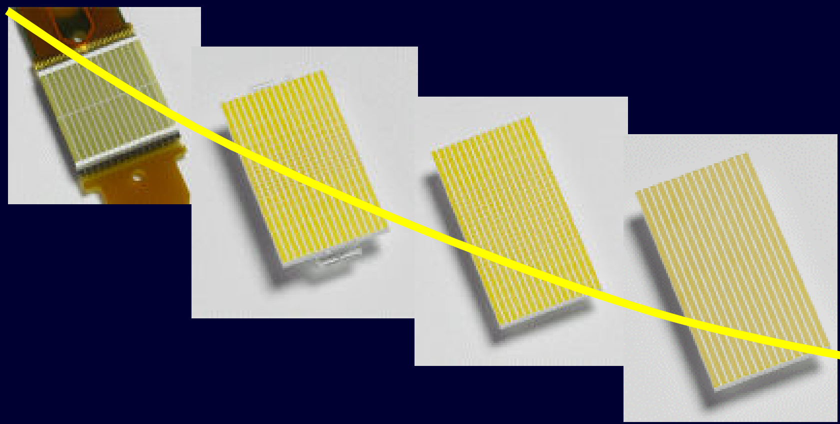
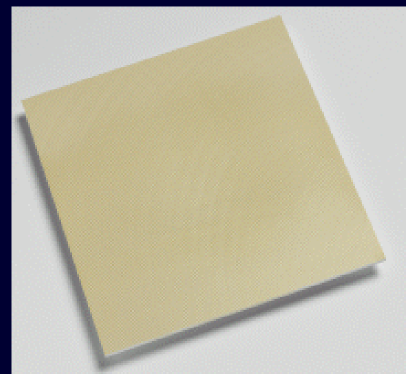
Improving Spatial Resolution

UFC multi-slice (sub-millimeter)

2 … 6 … 64 … ?? … Area detector



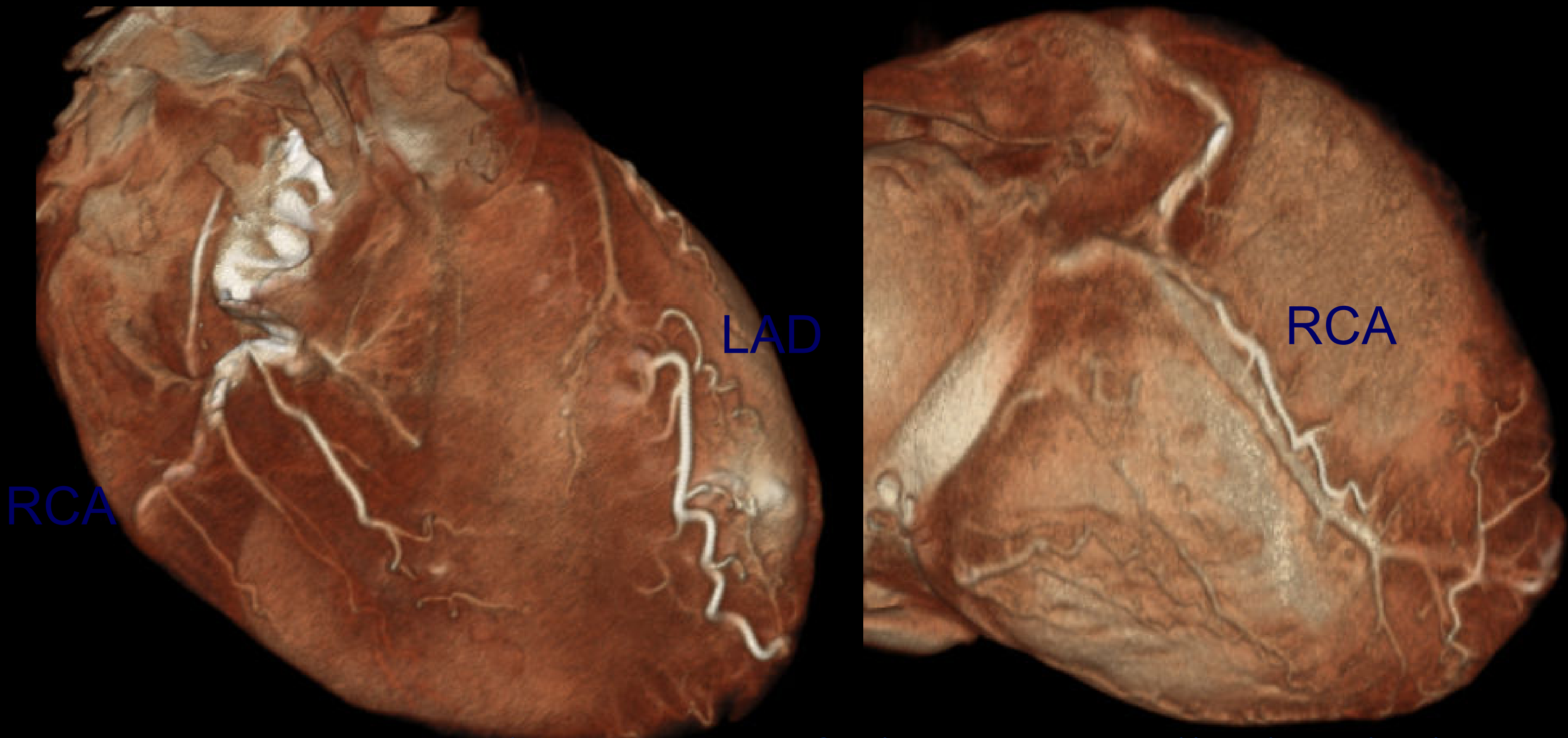


flat panel

*Courtesy of Siemens Medical Solutions

Improving Spatial Resolution
Flat Panel Technology

- Spatial resolution 0.25 x 0.25 x 0.25 mm^3, z-coverage 18 cm
- Human heart specimen with contrast filled vessels



*Courtesy of Siemens Medical Solutions

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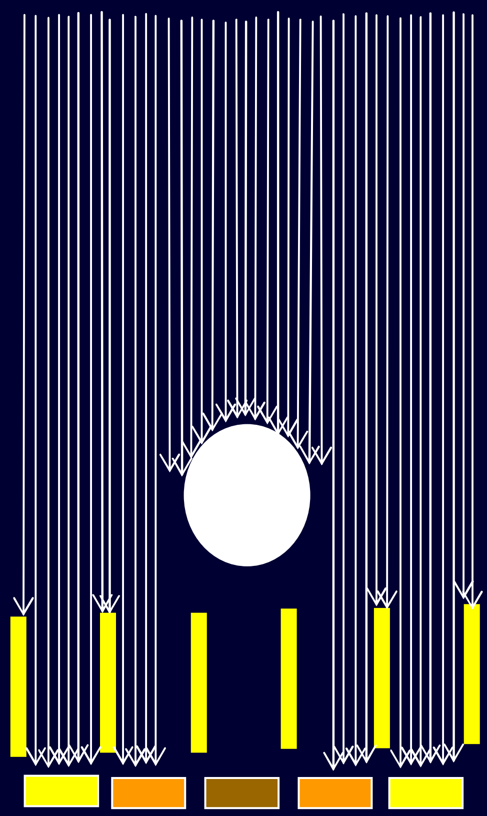
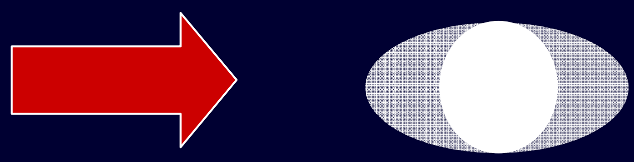
Improving Spatial Resolution



X-ray density
Detector Size
Gantry rotational speed



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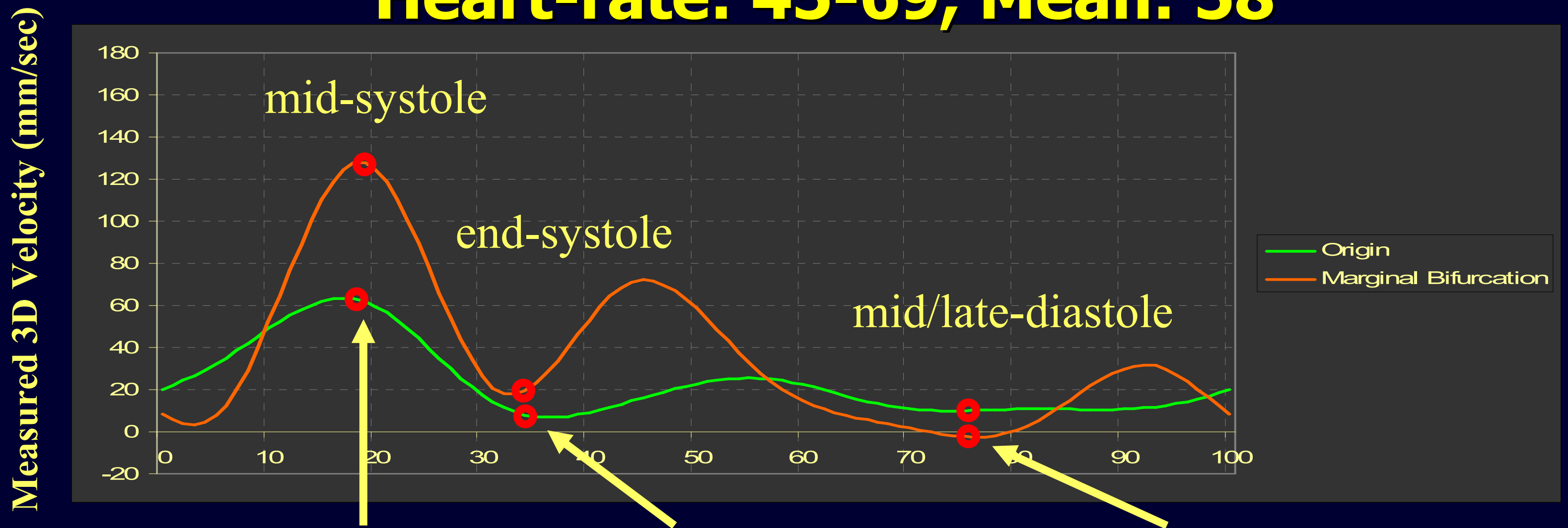
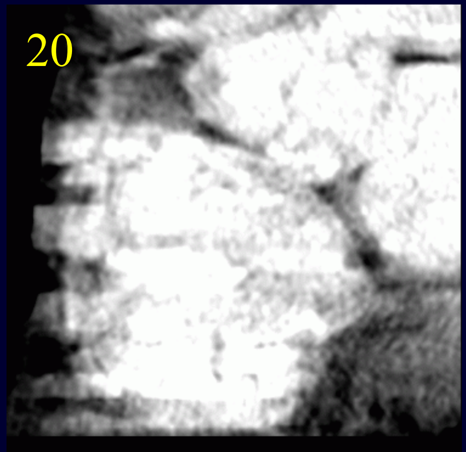
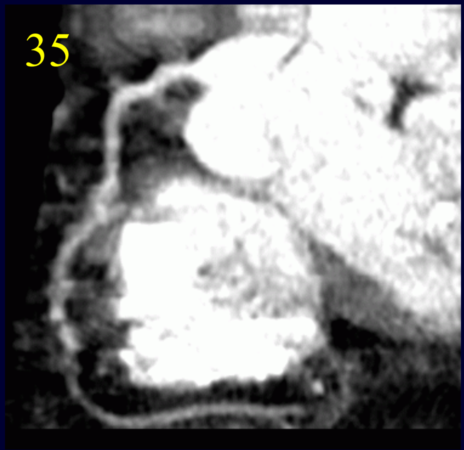
Improving Temporal Resolution

Heart-rate: 45-69, Mean: 58





peak velocity



end systole

mid/late diastole

Direction of scan

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Improving Temporal Resolution

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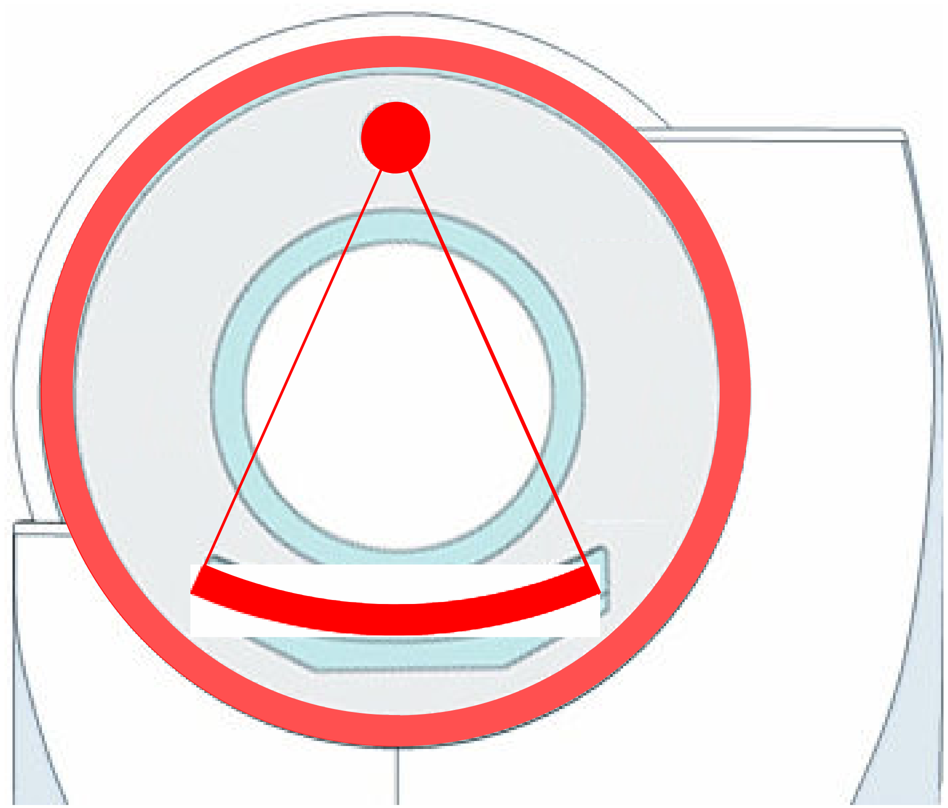
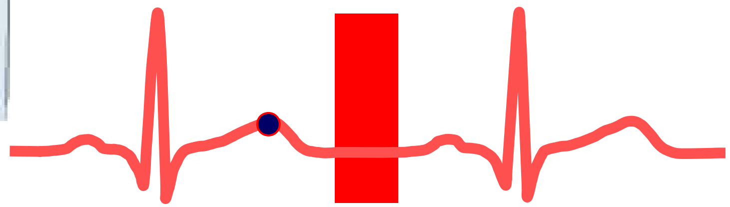
Single source CT

Temporal resolution of maximum 165 ms

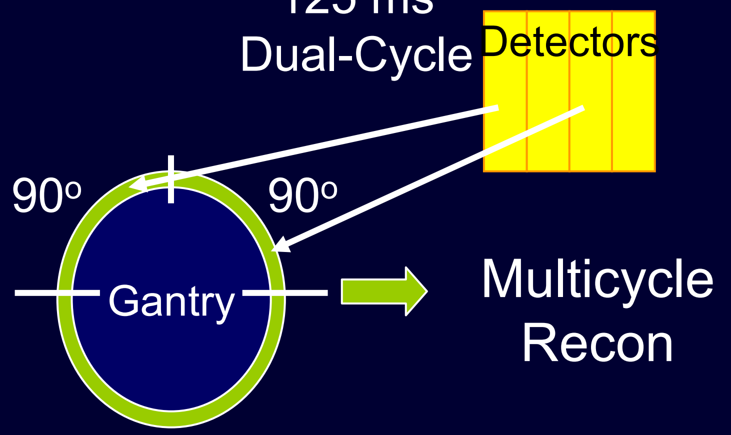


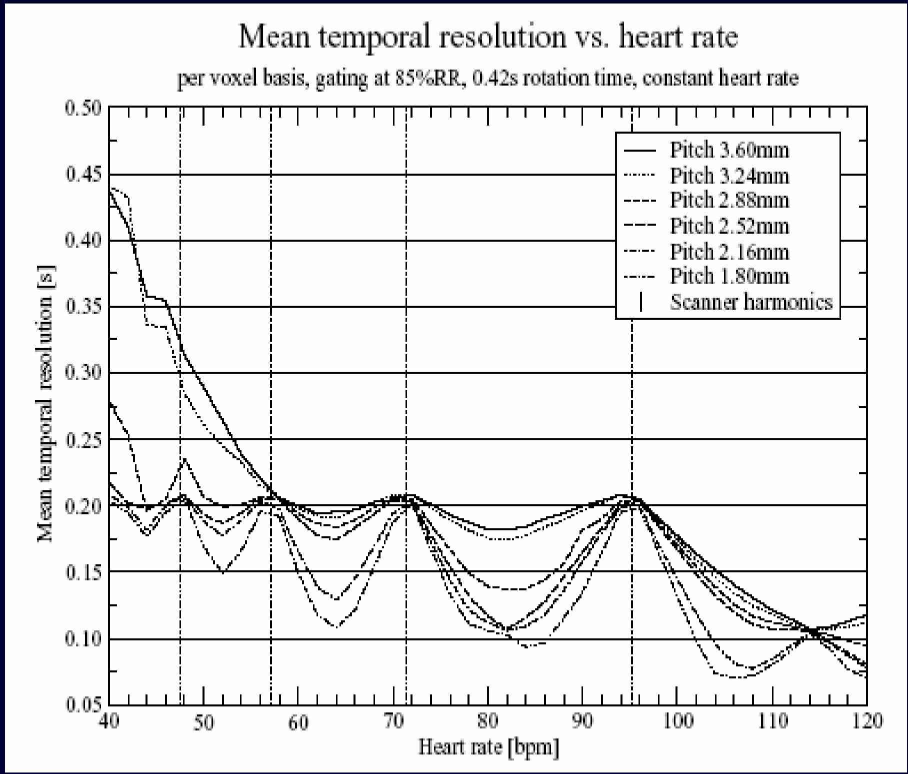


$$\text{Temp. Resolution} = \frac{\text{Rotation Time}}{2} = \mathbf{165\ ms}$$

*Courtesy of Siemens Medical Solutions

Improving Temporal Resolution
Multi-Cycle Reconstruction





Temporal Resolution = f(gantry rotation time, angle)

Manzke, Med Phys 2003;30:3072

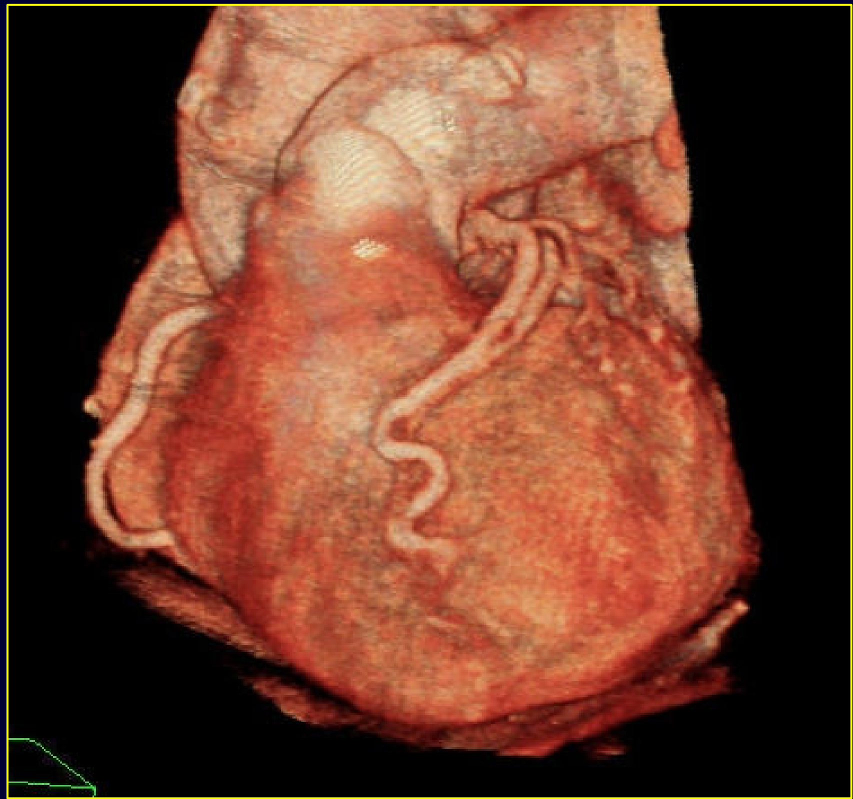
*Courtesy of Philips Medical Systems

Evaluation of Transplant CAD

Table 1. Diagnostic Accuracy of Multidetector Computed Tomographic Angiography to Detect >50% Coronary Obstruction

	Segments	Vessels	Patients
True-positive	43	29	15
True-negative	703	119	29
False-positive	10	10	8
False-negative	7	1	1
Sensitivity*	86% (75–96)	97% (89–100)	94% (79–100)
Specificity*	99% (98–100)	92% (87–97)	79% (64–93)
Positive predictive value*	81% (70–92)	74% (59–88)	65% (44–86)
Negative predictive value*	99% (98–100)	99% (97–100)	97% (89–100)

*Percentages (95% confidence intervals).



Heart rate: 98, Subject nr. 13

Sigurdsson, J Am Coll Cardiol 2006;48;772

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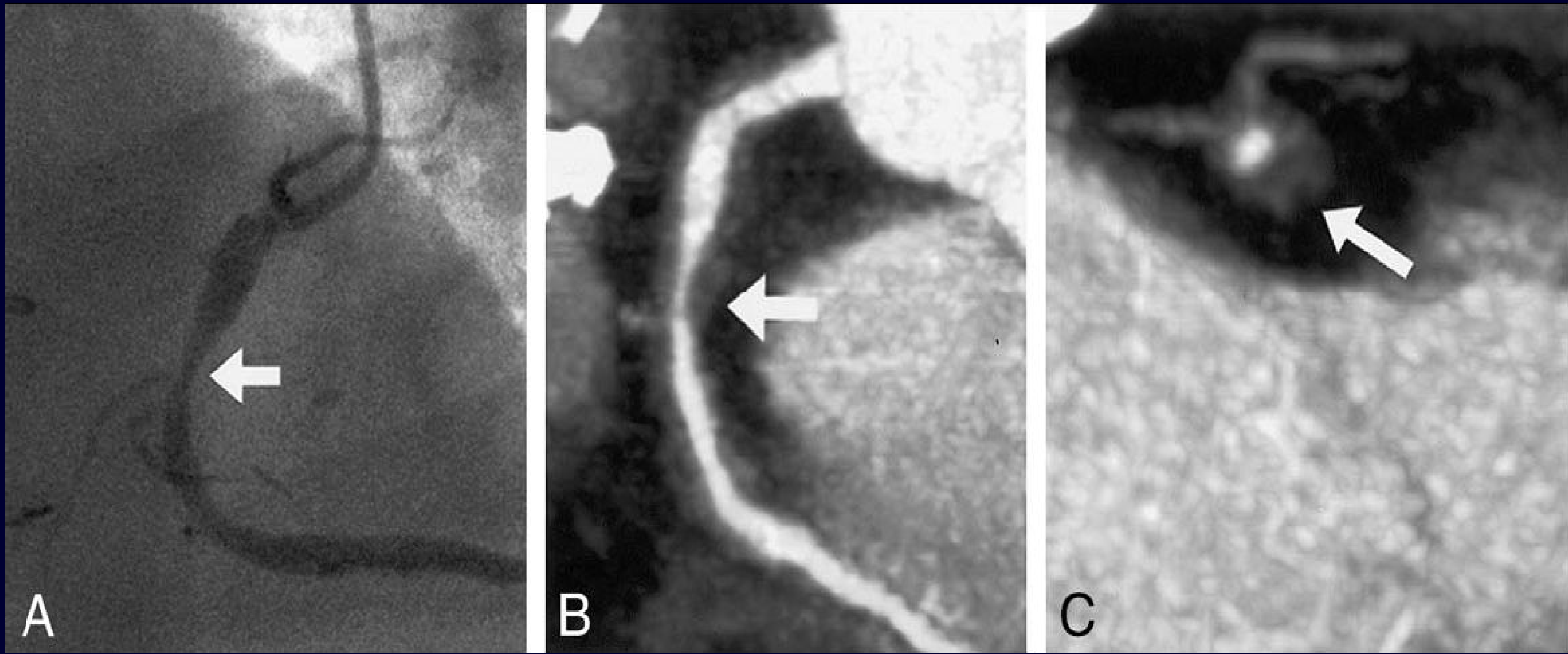
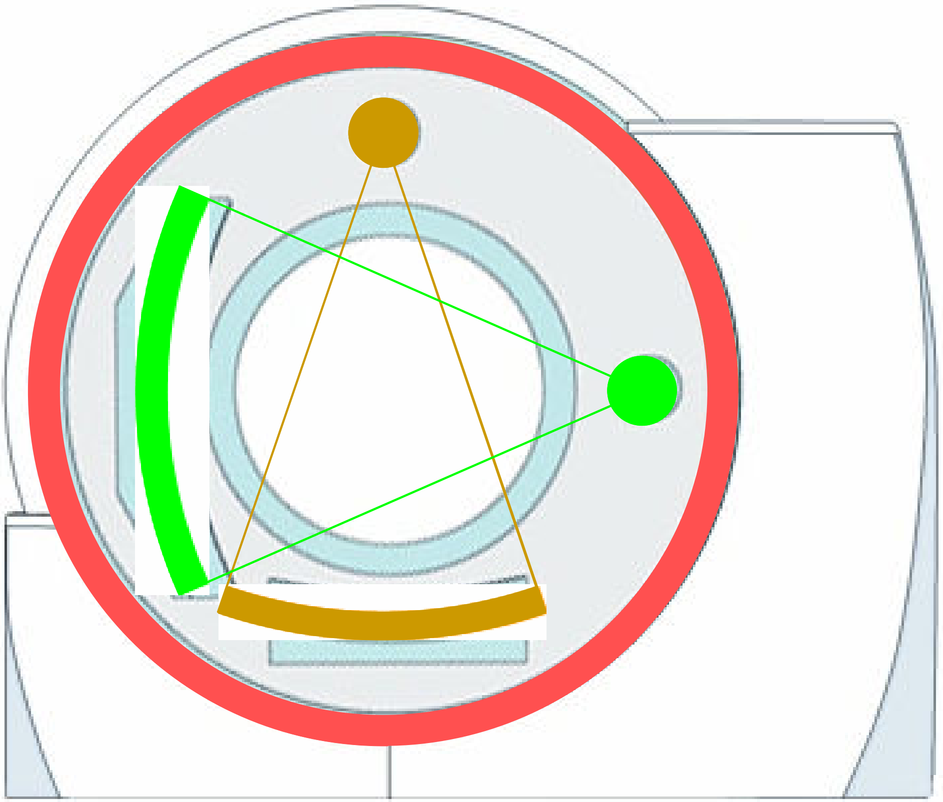
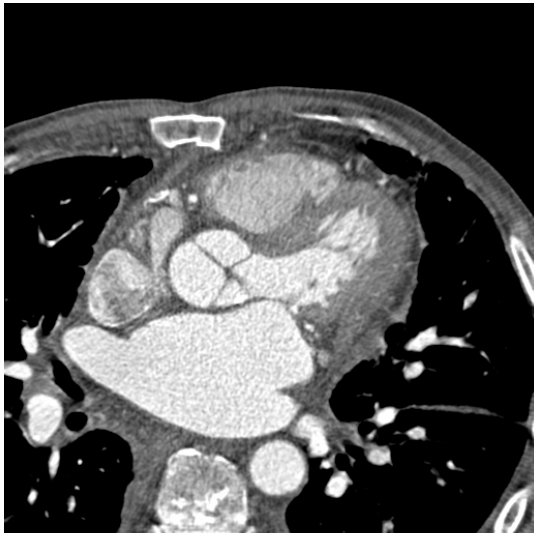
Evaluation of Transplant CAD

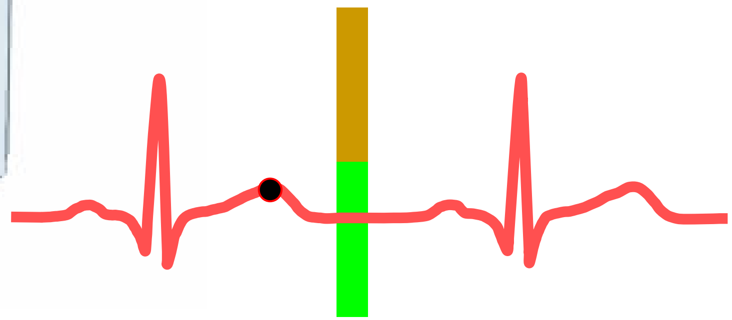


Sigurdsson, J Am Coll Cardiol 2006; August

Dual Source CT: Two X-ray sources and two detectors at the same time







$$\text{Temp. Resolution} = \frac{\text{Rotation Time}}{4} = \mathbf{83\ ms}$$

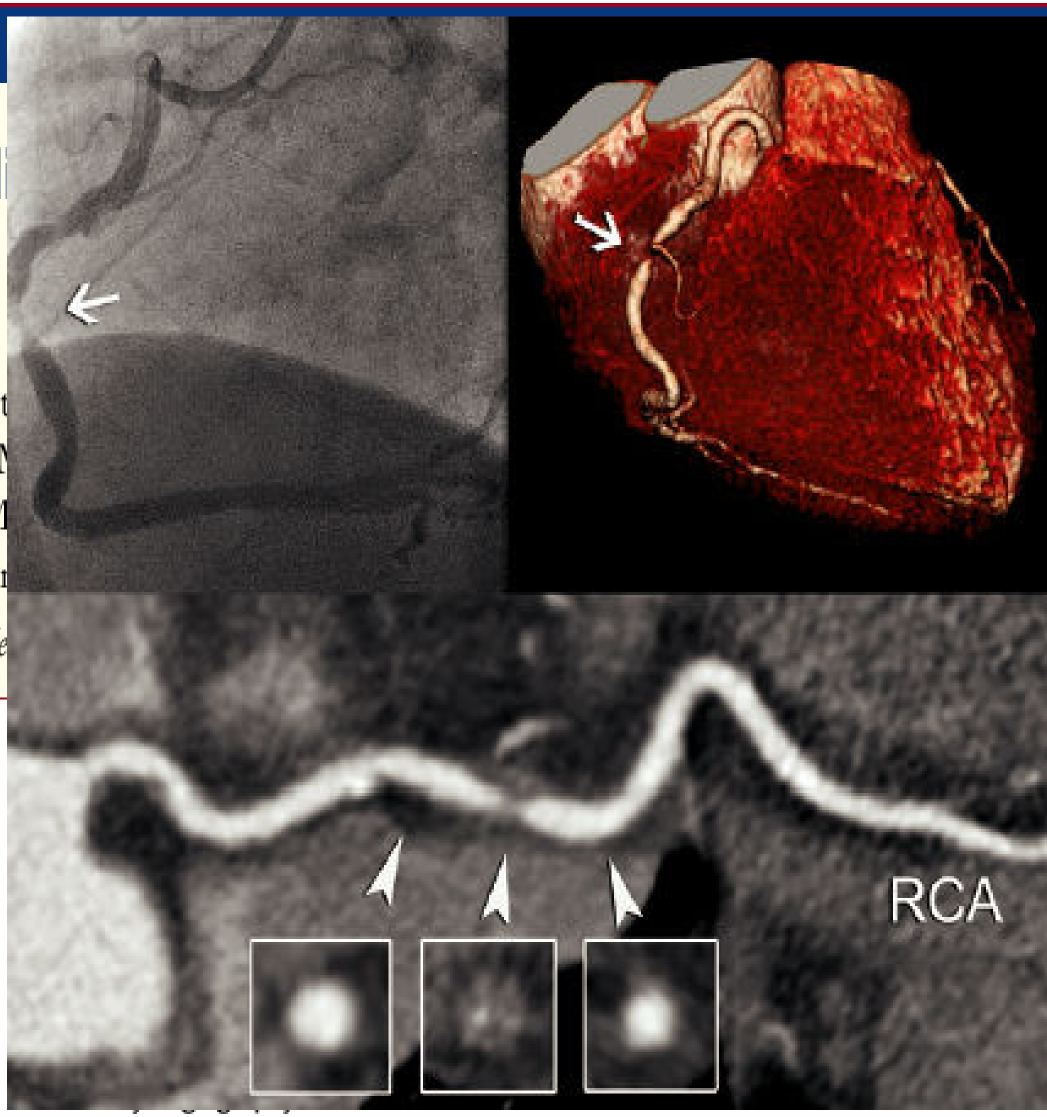
*Courtesy of Siemens Medical Solutions

Journal of the American College of Cardiology
Published by Elsevier Inc.
Vol. 50, No. 8, 2007
ISSN 0735-1097/07/$32.00
doi:10.1016/j.jacc.2007.04.068

Cardiac Imaging

Reliable Hi
Computed

Annick C. Weust … HD,*†
Masato Otsuka, M … erto Malago, MD,†
Niels van Pelt, M … ,*†
Gabriel P. Krestin …
Rotterdam, the Ne…



Objectives … eed dual-source computed … etection of significant coro-

Background … puted tomography scan-

Methods … 61 ± 11 years) with atypi- … scheduled for conventional … 11 beats/min. Quantitative coronary angiography was used as the standard of reference. Irrespective of image quality or vessel size, all segments were included for analysis.

PPV=75%
NPV=99%

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Limitations of MDCT

Estimating Risk of Cancer Associated With Radiation Exposure From 64-Slice Computed Tomography Coronary Angiography

Andrew J. Einstein, MD, PhD
Milena J. Henzlova, MD, PhD
Sanjay Rajagopalan, MD

Context Computed tomography coronary angiography (CTCA) has become a common diagnostic test, yet there are little data on its associated cancer risk. The recent Biological Effects of Ionizing Radiation (BEIR) VII Phase 2 report provides a framework for estimating lifetime attributable risk (LAR) of cancer incidence associated with ra-

JAMA 2007;298(3):317-23

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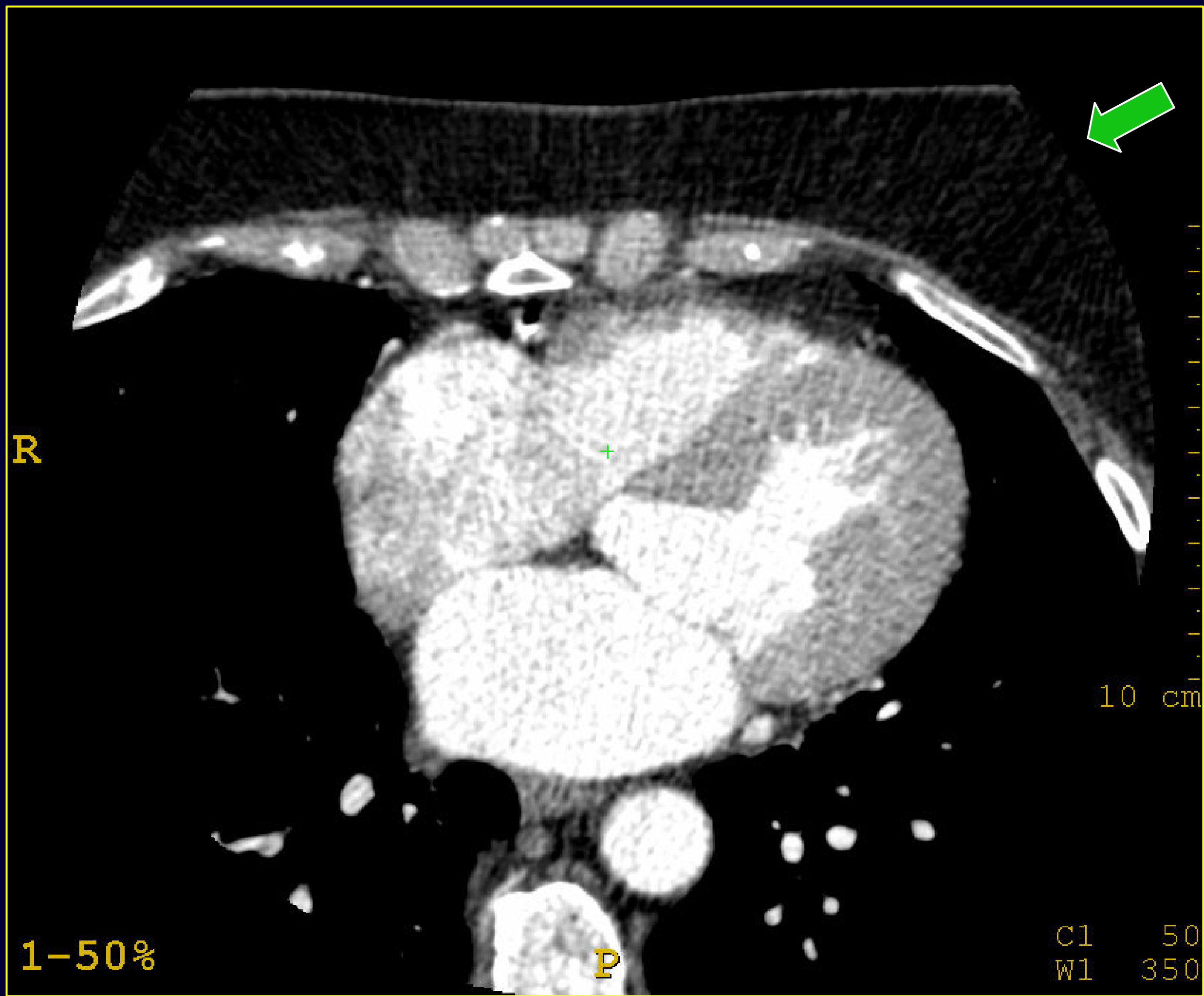
Diagnostic Procedure	Typical effective dose (mSv)	Equivalent period of natural background radiation*	Risk of fatal cancer/exam**
Natural background	**~3 (1.5-7.5)**	**1 year**	
Limbs and joints (except hips)	< 0.01	< 1.5 days	1 in a few million
Teeth (panoramic)	0.01	< 1.5 days	1 in 2 million
Chest (single PA film)	0.02	3 days	1 in a million
Transatlantic flight	0.03	4.5 days	1 in 700 000
Transatlantic Concorde flight	0.06	9 days	1 in 350 000
Cervical spine (neck)	0.08	2 weeks	1 in 200 000
Lung ventilation (81mKr)	0.1*	2.4 weeks	1 in 200 000
Hip	0.3	7 weeks	1 in 67 000
Thoracic spine or abdomen	0.7	4 months	1 in 30 000
Lung perfusion (99mTc)	1	6 months	1 in 20 000
Kidney (99mTc)	1	6 months	1 in 200 000
Thyroid (99mTc)	1	6 months	1 in 200 000
Barium swallow	1.5	8 months	1 in 13 000
CT head	2	1 year	1 in 10 000
IVU (kidneys and bladder)	2.5	14 months	1 in 8000
Bone (99mTc)	4	2.3 years	1 in 5000
Dynamic cardiac (99mTc)	6	2.7 years	1 in 3300
16-slice cardiac CTA	**6-8**		
Barium enema	7	3.2 years	1 in 3000
CT abdomen/pelvis	10	4.5 years	1 in 2000
40-slice cardiac CTA	**10-12**		
Myocardial perfusion (201Tl)	18	8 years	1 in 1100
64-slice cardiac CTA	**15-25**		

* the risk of death by exposure to 0.1 mSv is the same as that of smoking one cigarette or drinking half a bottle of wine.

X-ray attenuation



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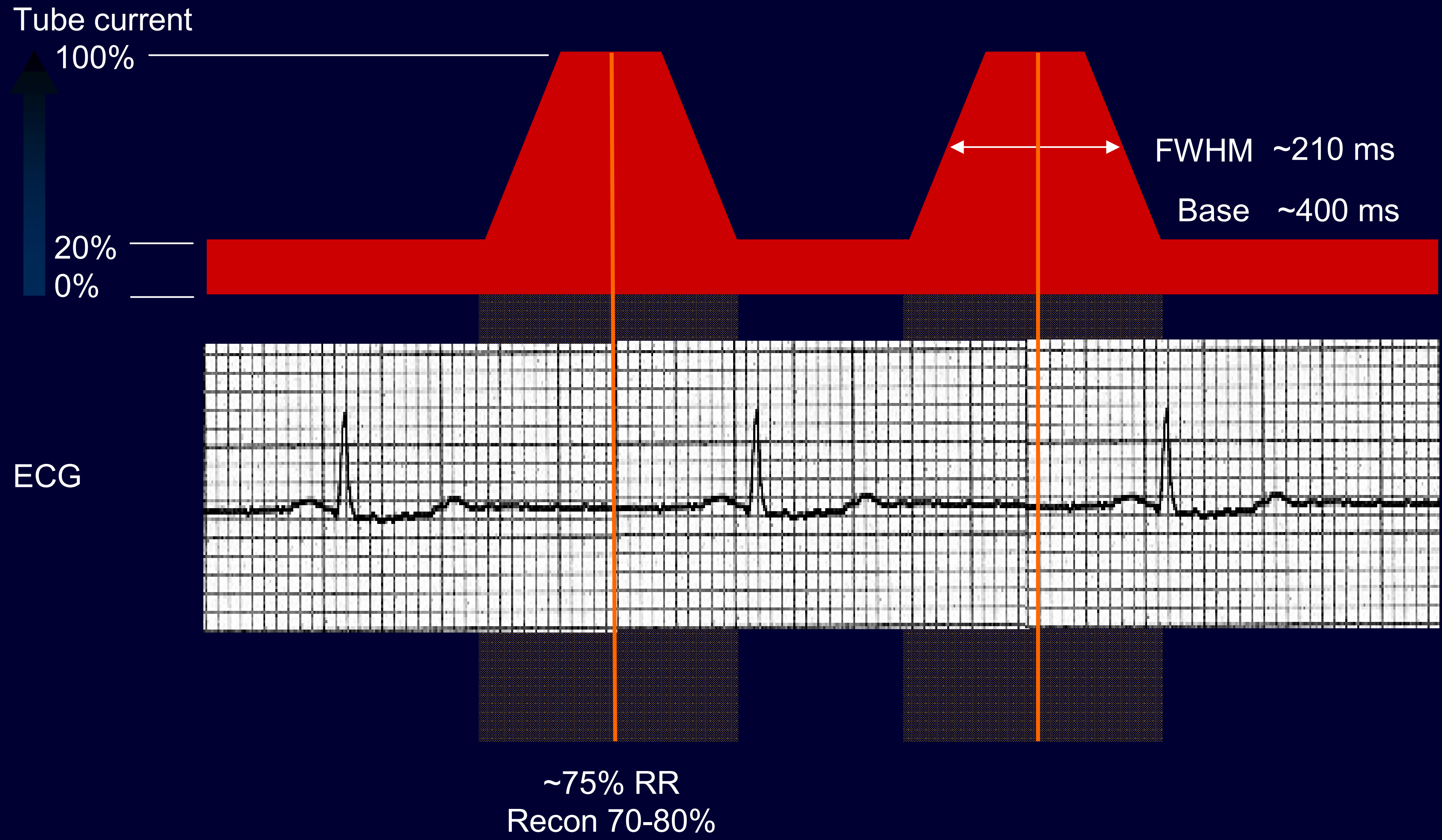
Improving X-ray Dose Efficiency

Prospective tube current dose modulation



Improving X-ray dose efficiency

	Non-modulated	Modulated 50-75%	Modulated 75%
400 Mas	9.5 mSv	8 mSv	6mSv
500 Mas	11.8 mSv	9.9 mSv	7.5 mSv
600 Mas	14.2 mSv	11.1 mSv	9.0 mSv
700 Mas	17.0 mSv	14.0 mSv	10.8 mSv
800 Mas	19.4 mSv	16.0 mSv	11.8 mSv
900 Mas	21.9 mSv	18.1 mSv	13.3 mSv

* Based on 145 mm coverage (15 sec acquisition), using a 40 detector scanner

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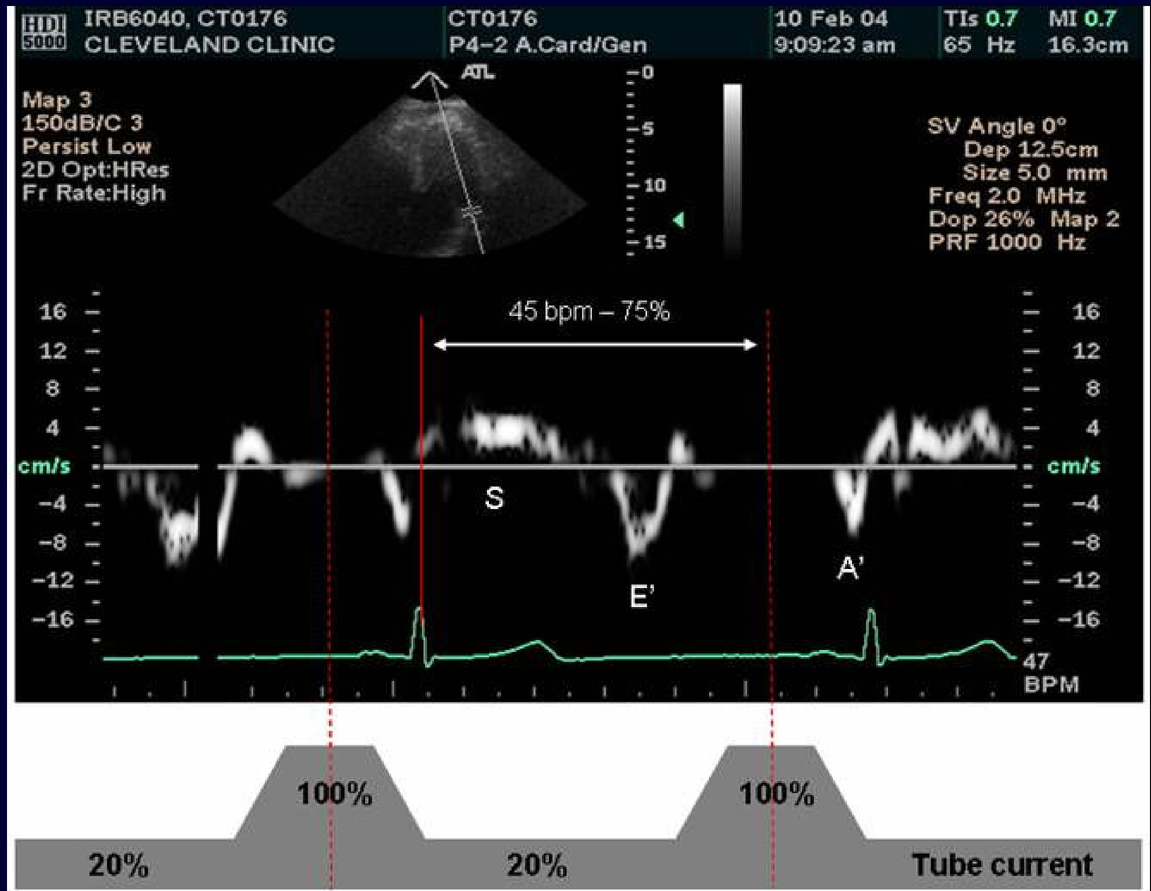
Determining "motionless" phase
Tissue Doppler Echocardiography



Hesse, Am J Cardiol, 2006

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Tissue Doppler Imaging Guided Prospective Tube Current Modulation in Cardiac MDCT

- 94 patients enrolled
- 25 patients with dose-modulated studies
  - 296 segments > 1.5 mm analyzed
  - 8 (3%) not analyzable
  - Sensitivity 92%
  - Specificity 94%
  - PPV 65%
  - NPV 99%
- Correlation between QCA and MDCT:
  - $r = 0.70$, $p < 0.001$

Hesse, Am J Cardiol, 2006

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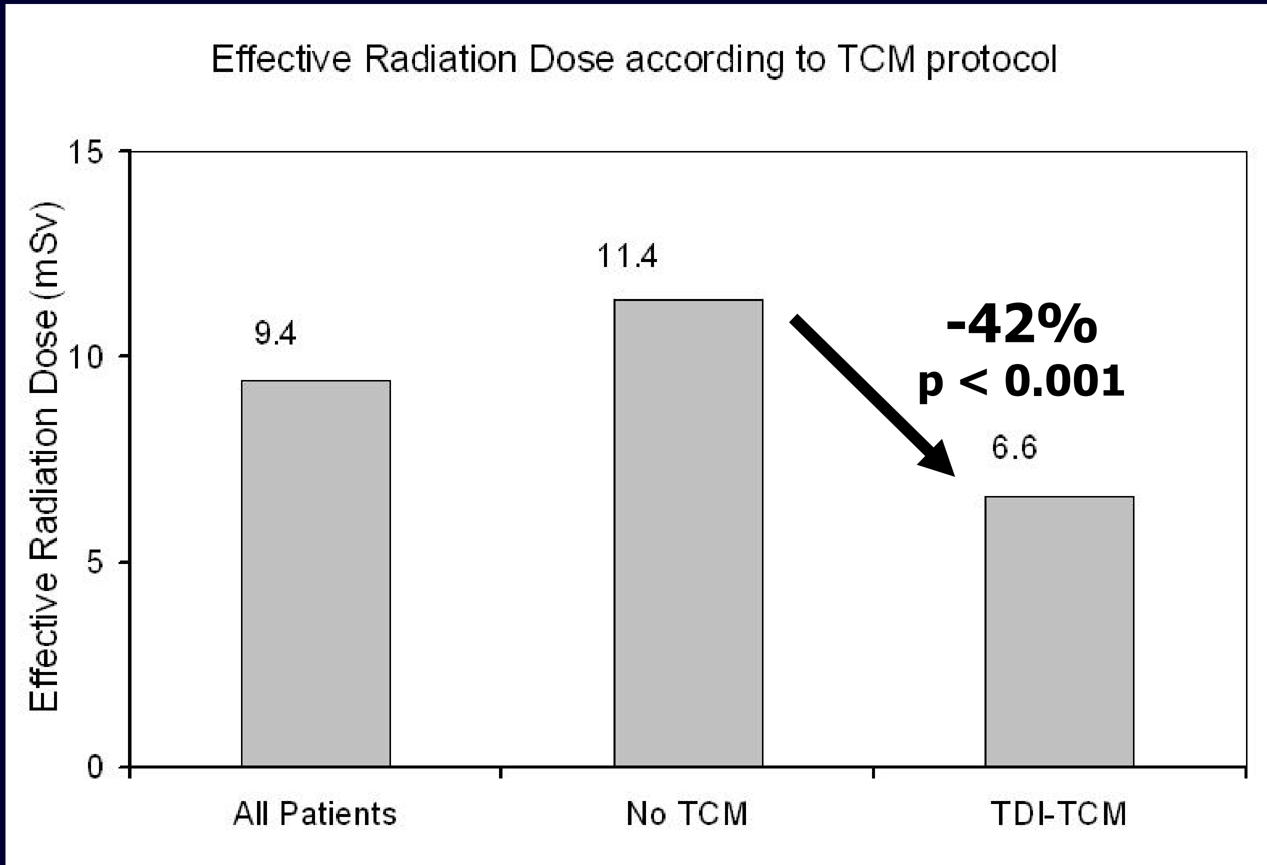
Determining "motionless" phase
Tissue Doppler Echocardiography



Hesse, Am J Cardiol, 2006

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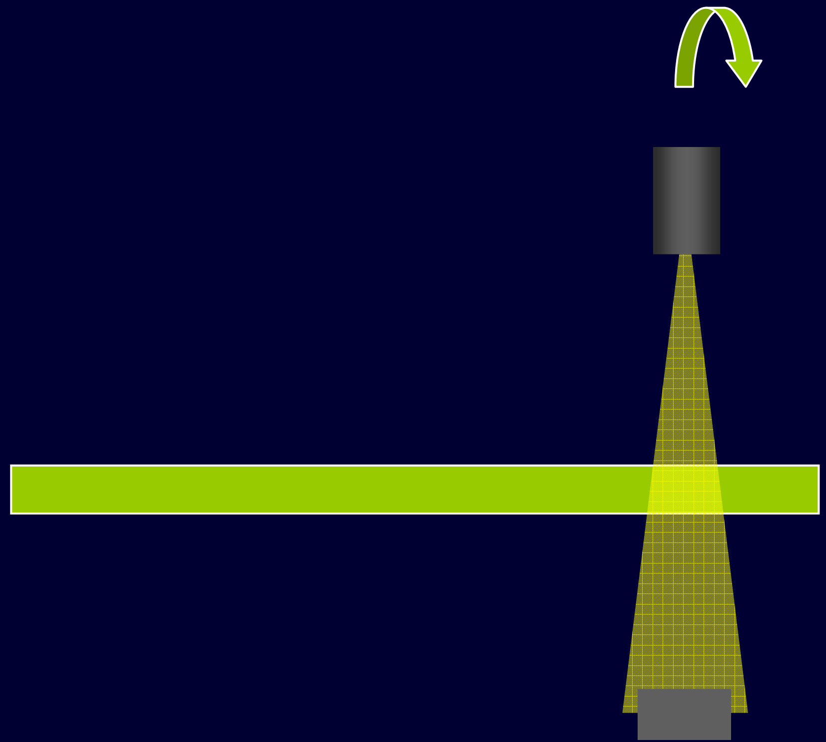
Retrospective Gated Imaging



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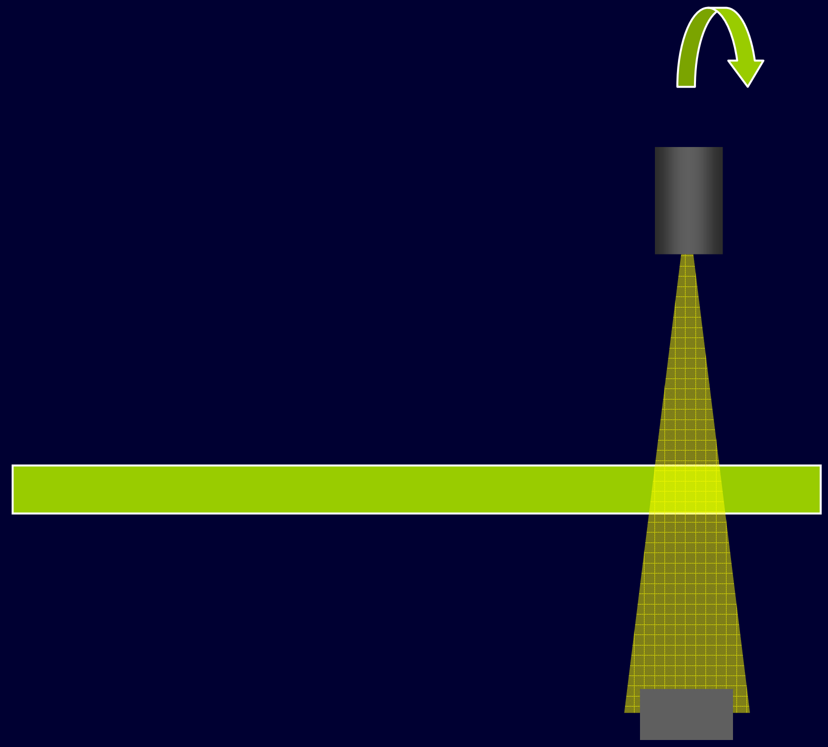
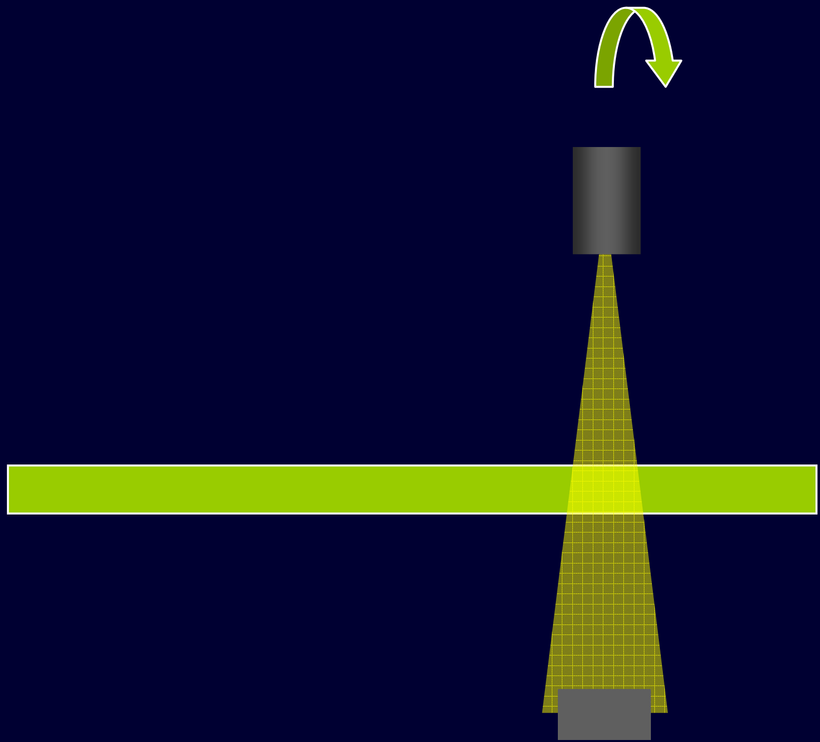
Prospective Gated Imaging



Prospective Gated Imaging



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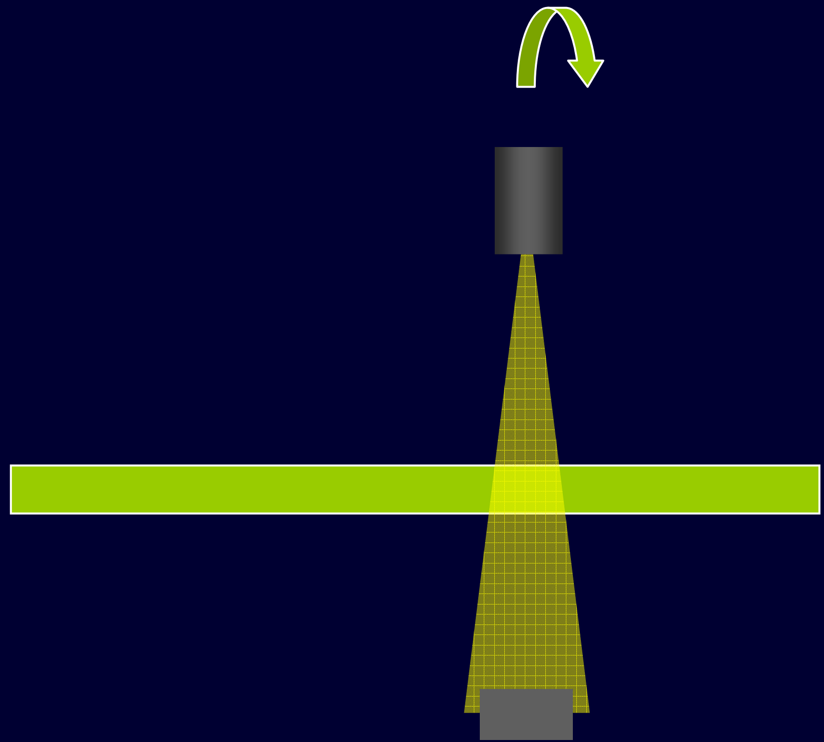
Prospective Gated Imaging



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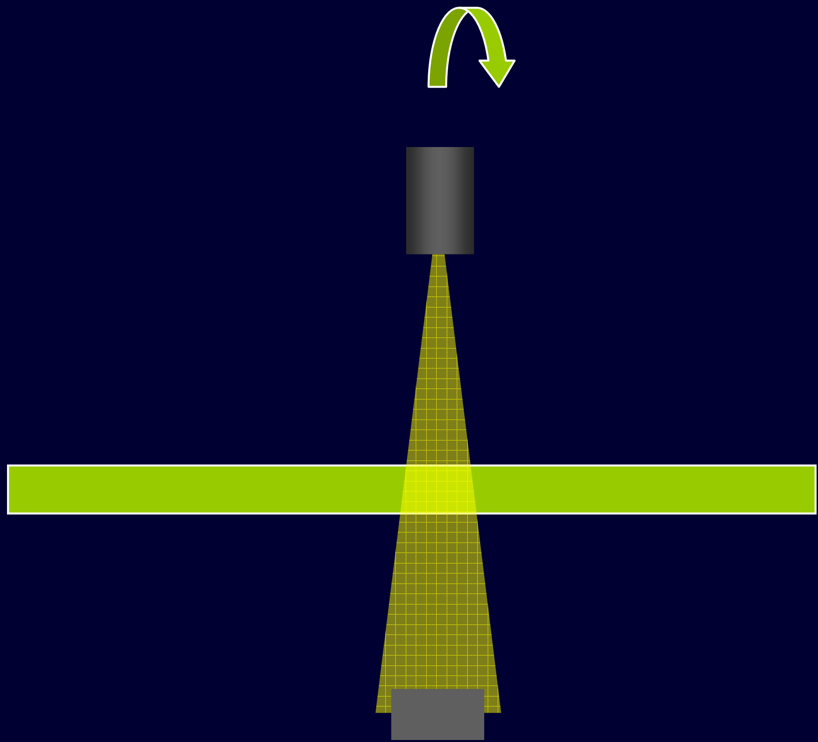
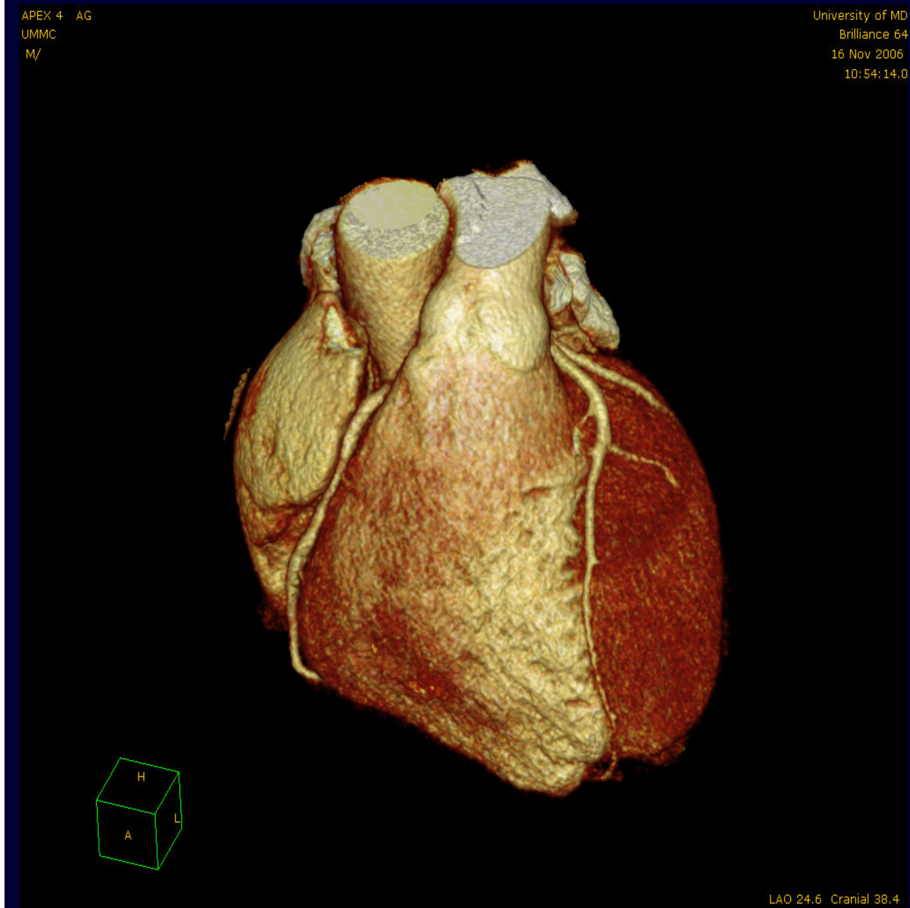
Prospective Gated Imaging



MG/07

Prospective Gated Imaging



Dose 1-3 mSv

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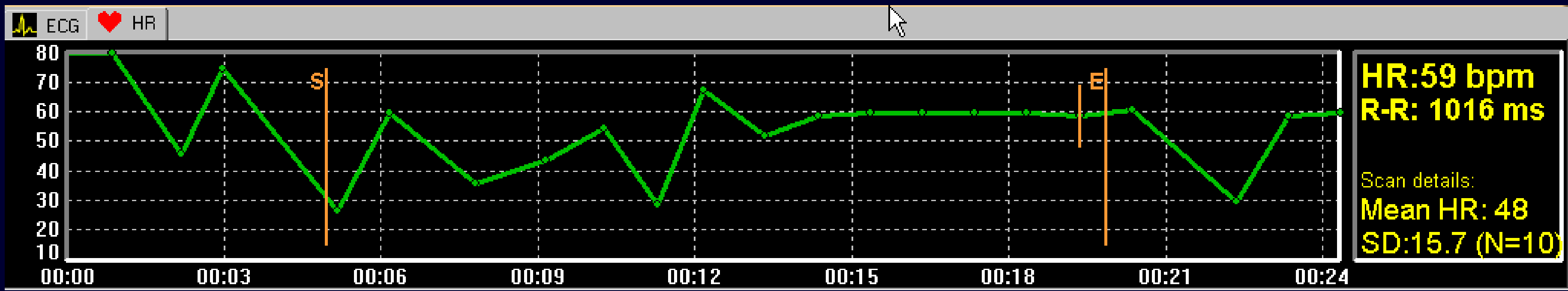
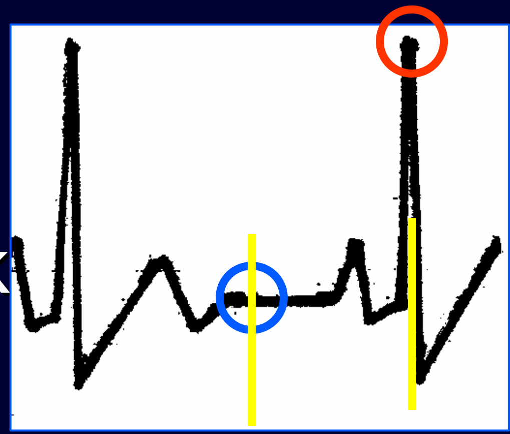
Improving Arrhythmia Artifacts

Heart Rate variations

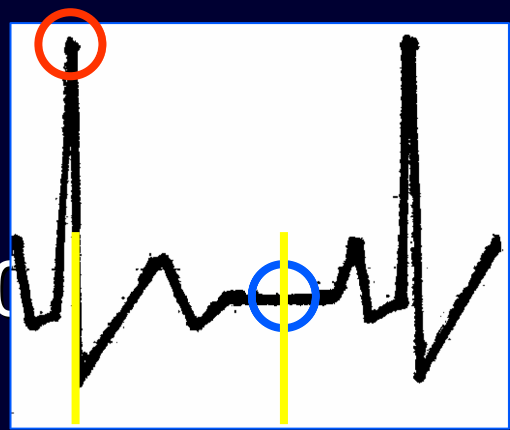


Common Phase Selection Methods
ECG gating

- Fixed time offset
  - Example: 500 ms before R peak
  - Window centered at -500 ms



- Percentage of R-R interval
  - Example: 60% of R-R interval
  - For 60 bpm, R-R interval = 1000
  - Window centered at 600 ms



Delay Algorithm ®

$$delay = RRInterval * PercentageDelay + DelayOffset$$

- Assumes reference heart rate of 72 bpm (common resting heart rate)
- As patient heart rate deviates from 72 bpm, the delay is adjusted so as to identify the ***same physiological*** phase of the cardiac cycle.

"*Algorithm for acquiring/reconstructing any phase of the heart cycle in Multislice Cardiac CT,"* S. Chandra, D. Heuscher, M. Vembar, U. Shreter, M. Garcia. Med Physics 2000"

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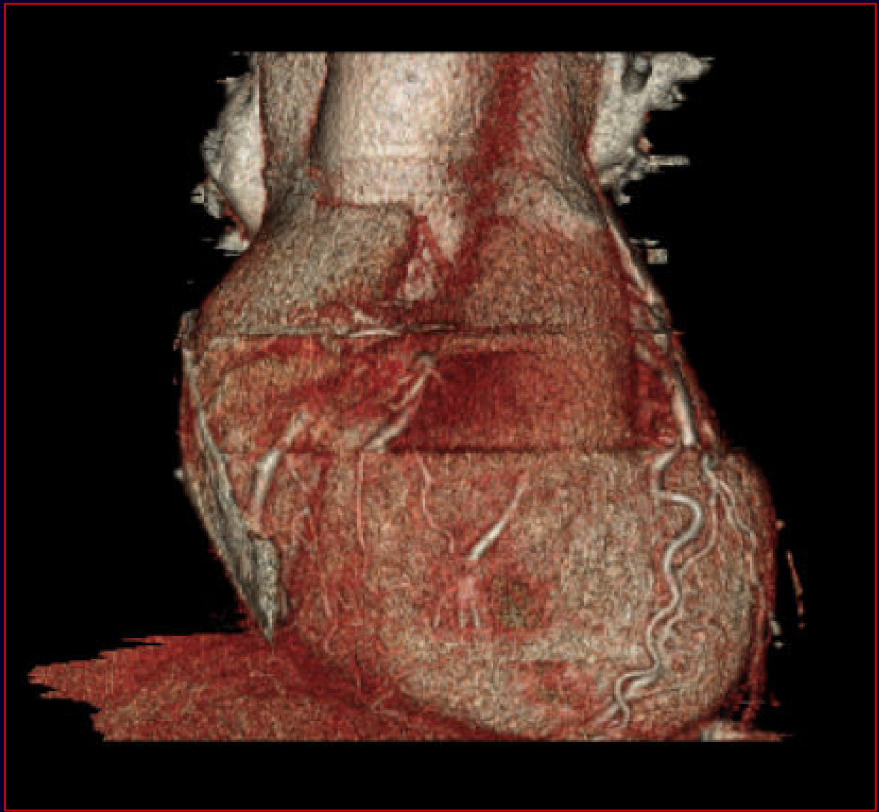
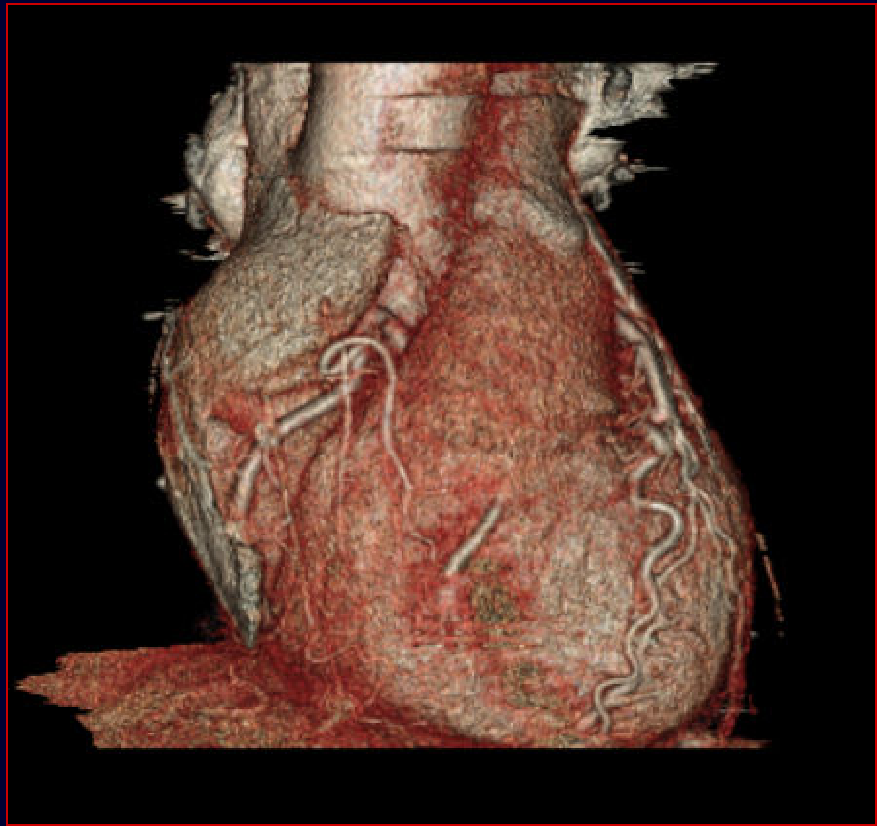


Without correction



With correction

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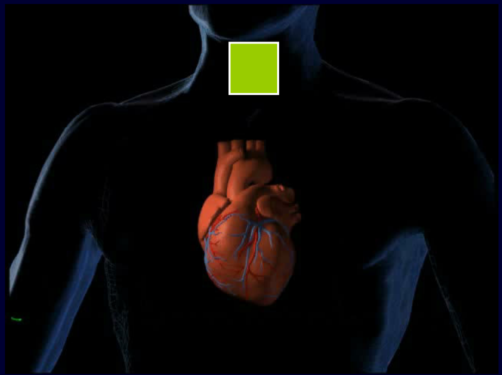
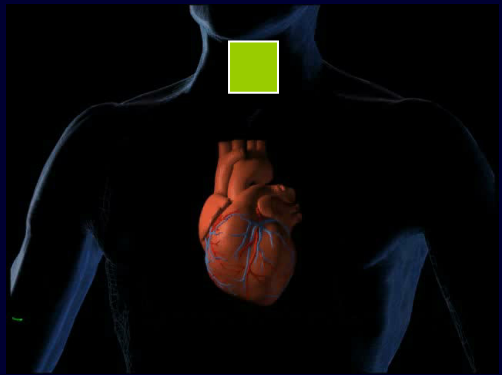
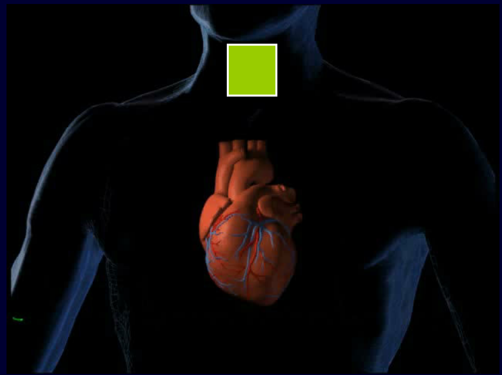
Pitch in MDCT imaging







Intermediate Pitch   Low Pitch   High Pitch

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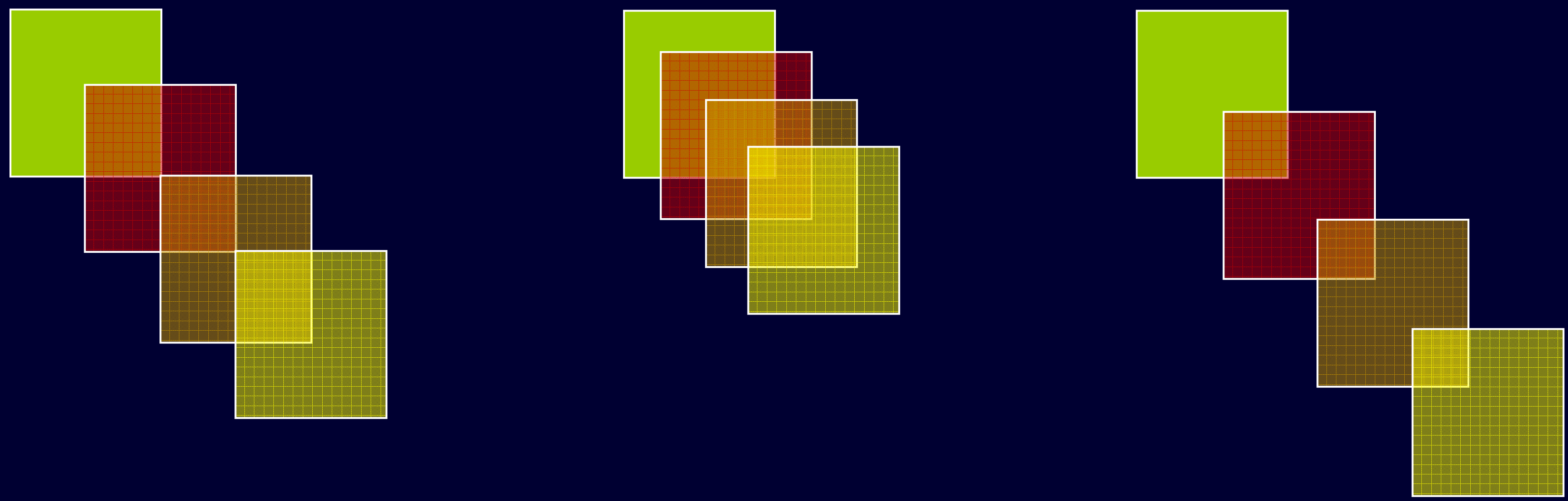
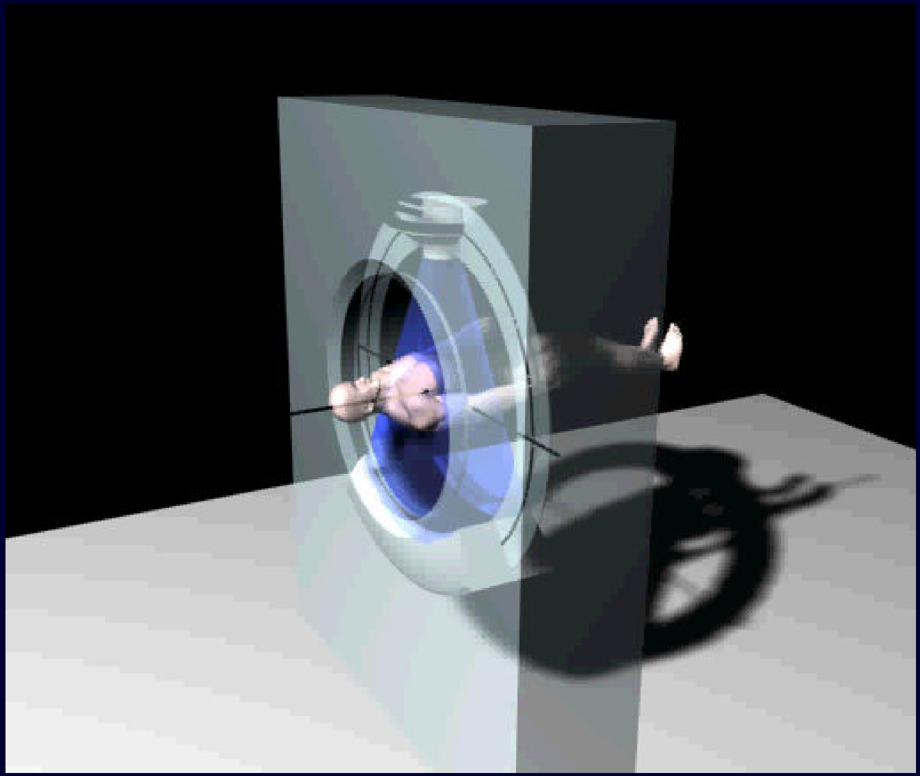
Pitch in MDCT imaging



Intermediate Pitch Low Pitch High Pitch

Future Direction: Full Volume CT



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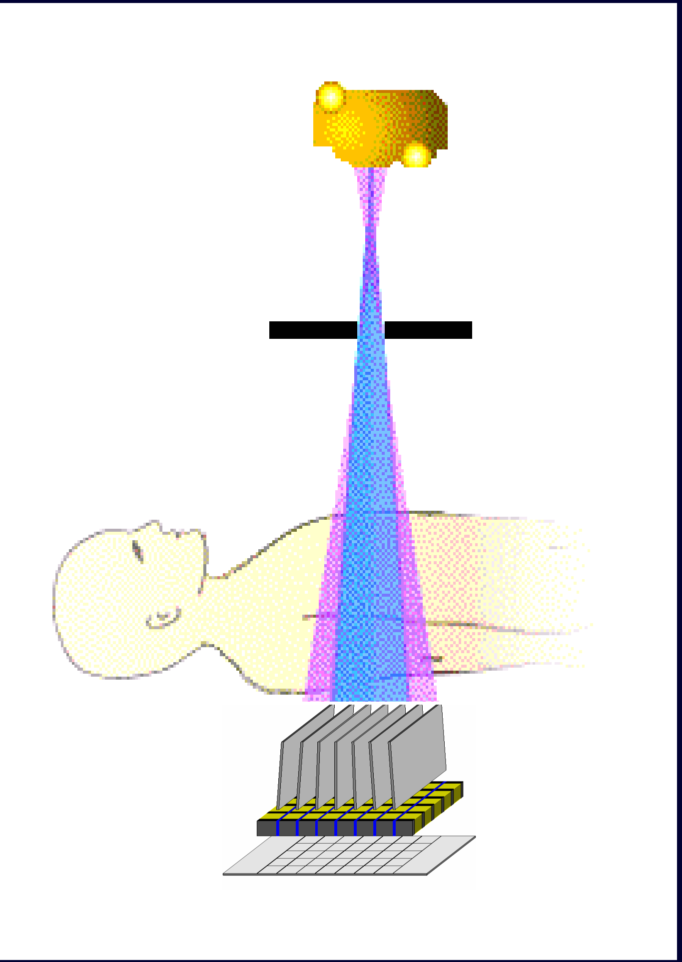
Improving Quantification and Functional Assessment

Tissue Characterization by MDCT



- X-rays are attenuated by tissue
- Attenuation is proportional to tissue density and element composition
- Measured in Hounsfield units (HU)
- Lower attenuation shown as "black", higher attenuation showed as "white"
- Typical mean values:

Air	-1000
Fat	-100
Water	0
Soft Tissue	100
Contrast	300
Calcium	800

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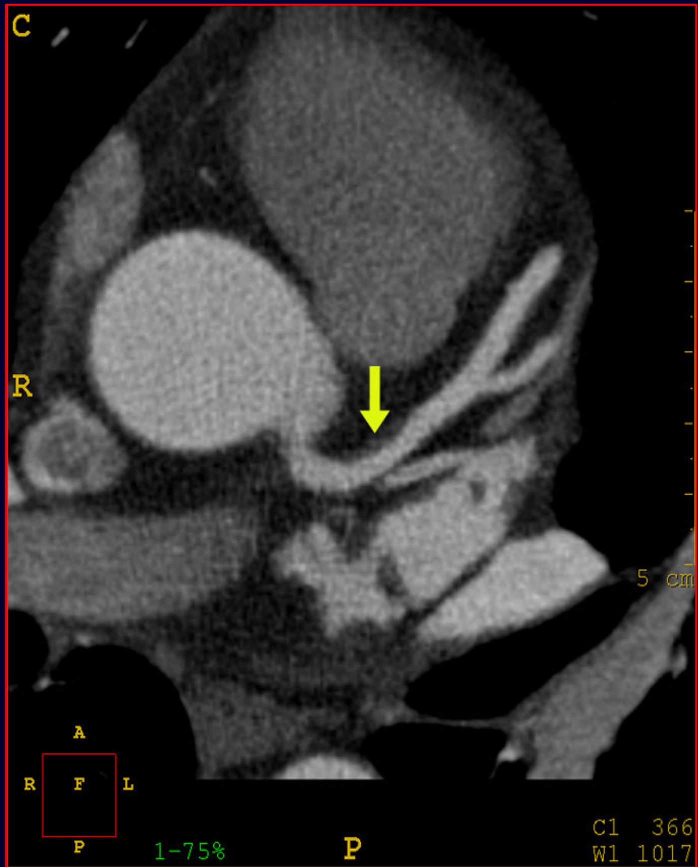
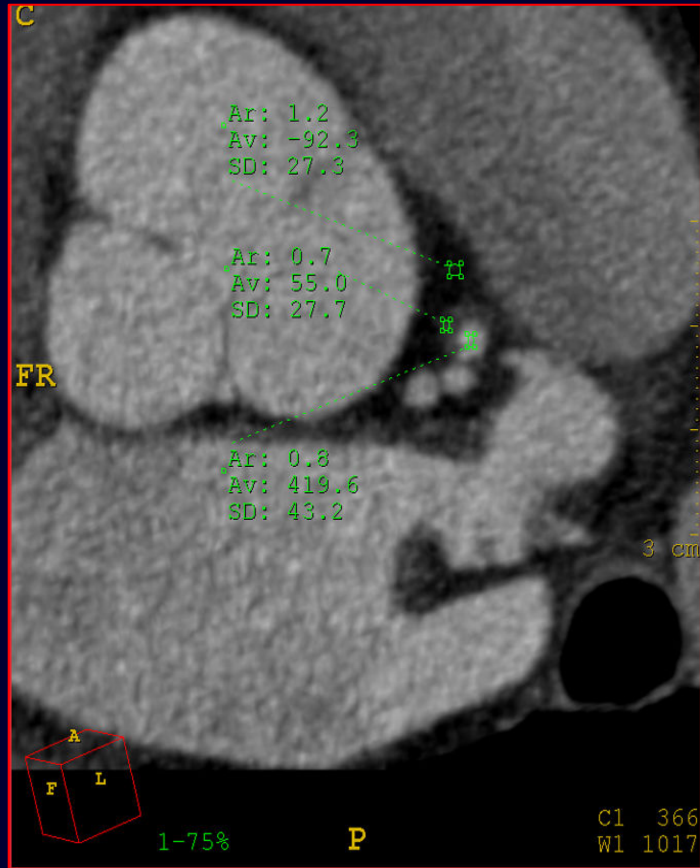
MDCT in CAD-Wall Plaque





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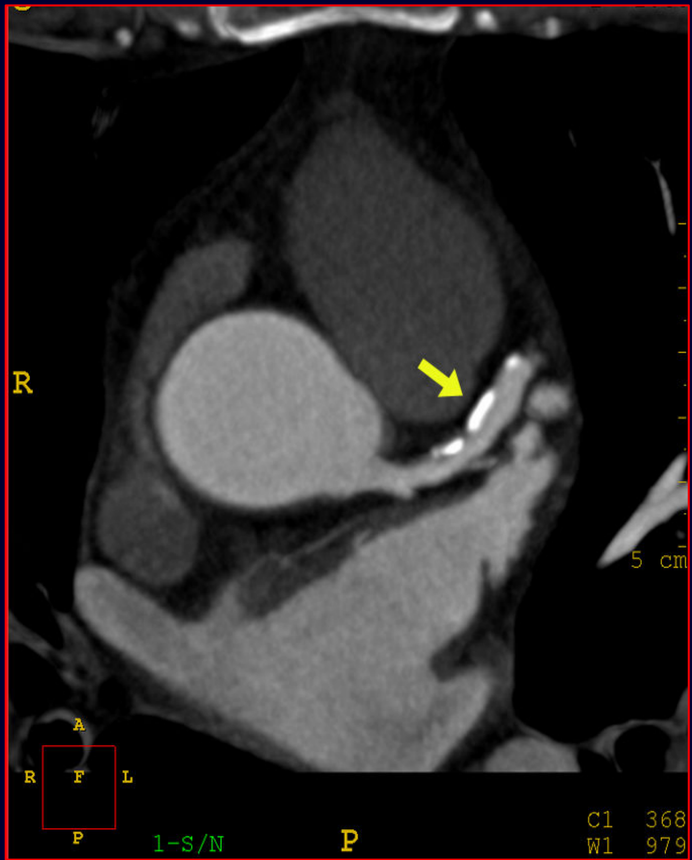
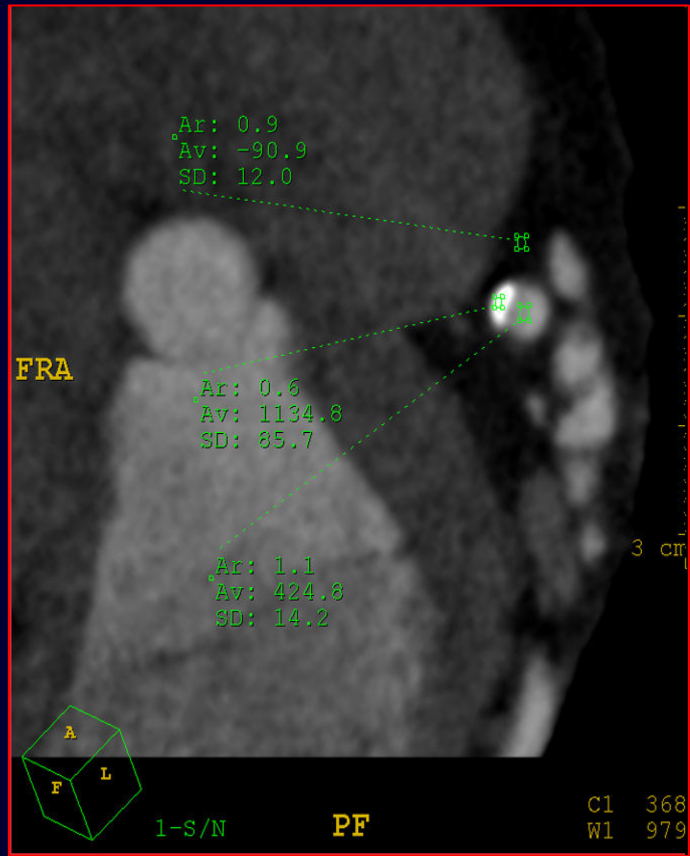
MDCT in CAD-Wall Plaque





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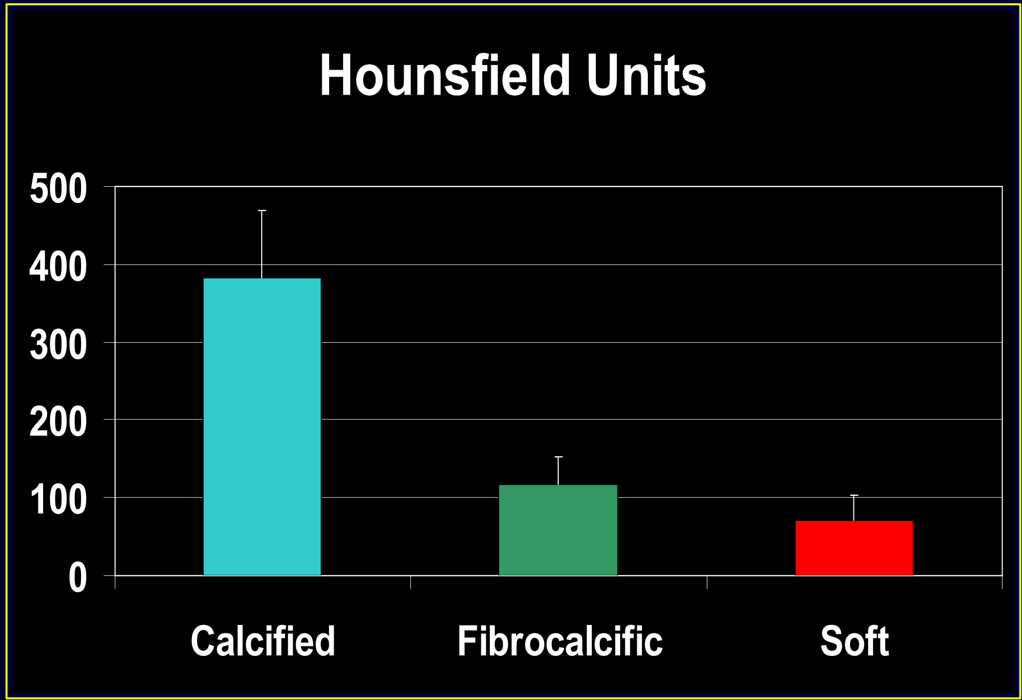
MDCT in CAD-Wall Plaque

Comparison with IVUS

- 40 patients, 194 segments
- 277 plaques
    - 185 Soft
    - 45 fibrocalcific
    - 43 calcific
- Sens 86
- Spec 92



Carrascosa, Am J Cardiol 2006

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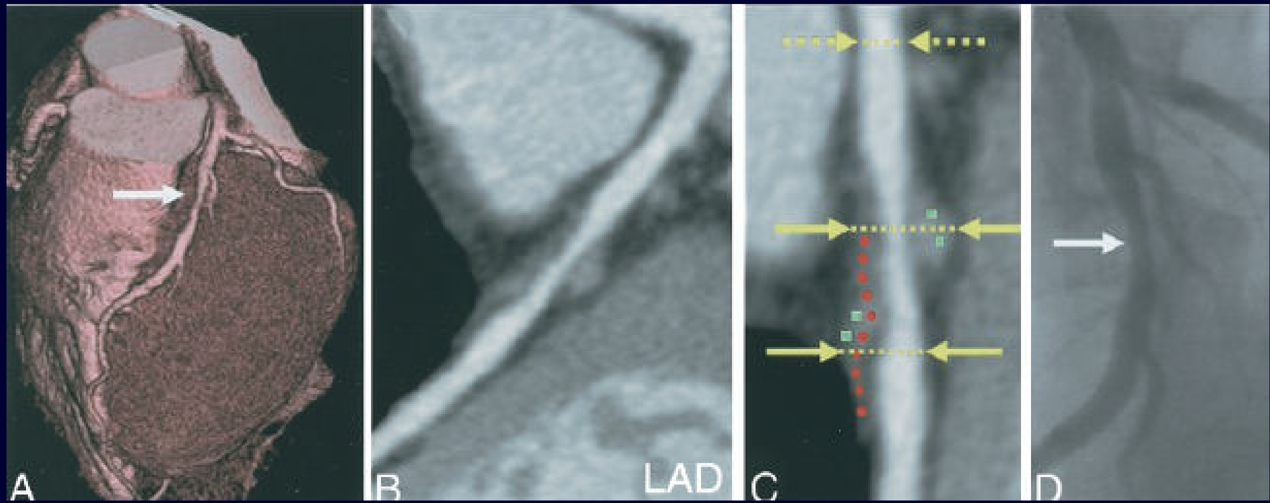

	NCP <30 UH	Large Ca++	Small CA++	+R
ACS	79%	22%	63%	87%
SA	9%	55%	21%	12%
	P < 0.001	P 0.004	P 0.005	P< 0.001

HIGH POSITIVE PREDICTIVE VALUE IF 3 PRESENT

Motoyama et al . JACC 2007

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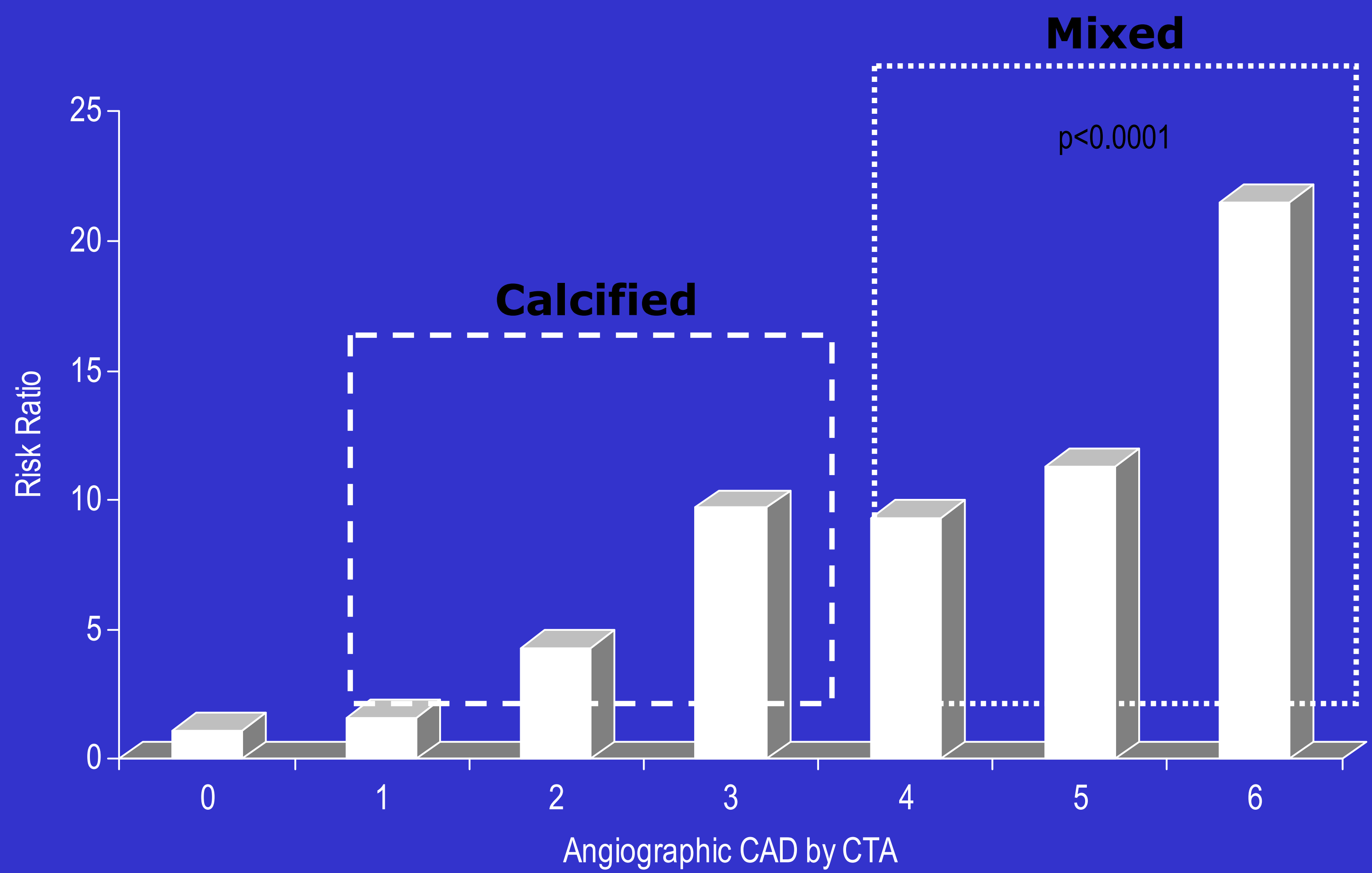
Risk Ratios

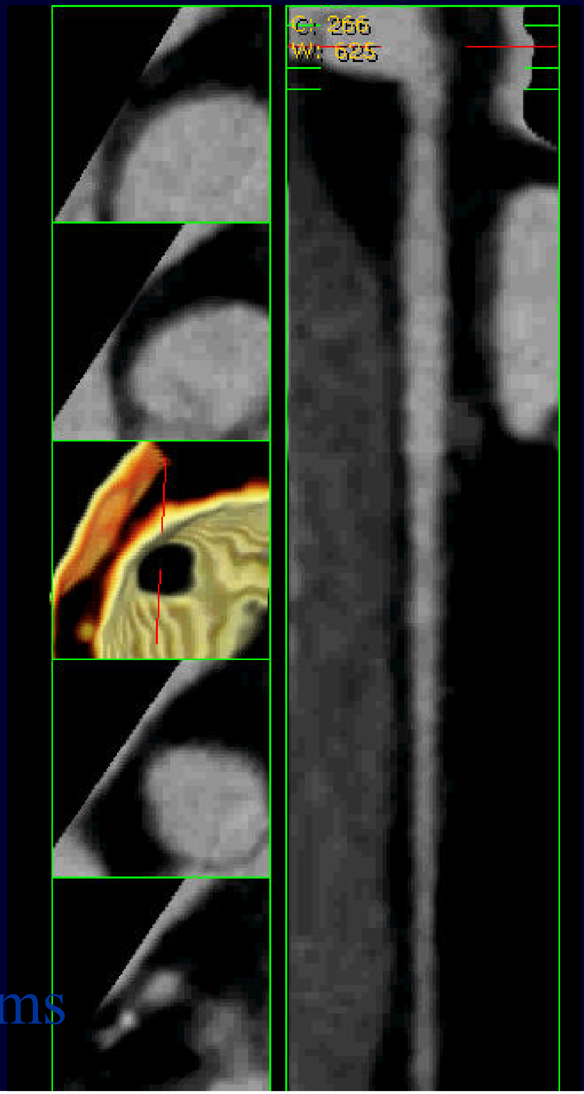


Min, J Am Coll Cardiol 2007

MDCT in CAD-Wall Plaque

Quantification

- Only 3-dimensional with complete volume coverage
- Non-invasive
- Limited spatial resolution
- Prone to motion artifacts
- No quantification standards



*Courtesy of Philips Medical Systems

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MDCT Coronary Plaque Quantification

Differentiation and Plaque Burden Measurement

*Courtesy of Vital Images

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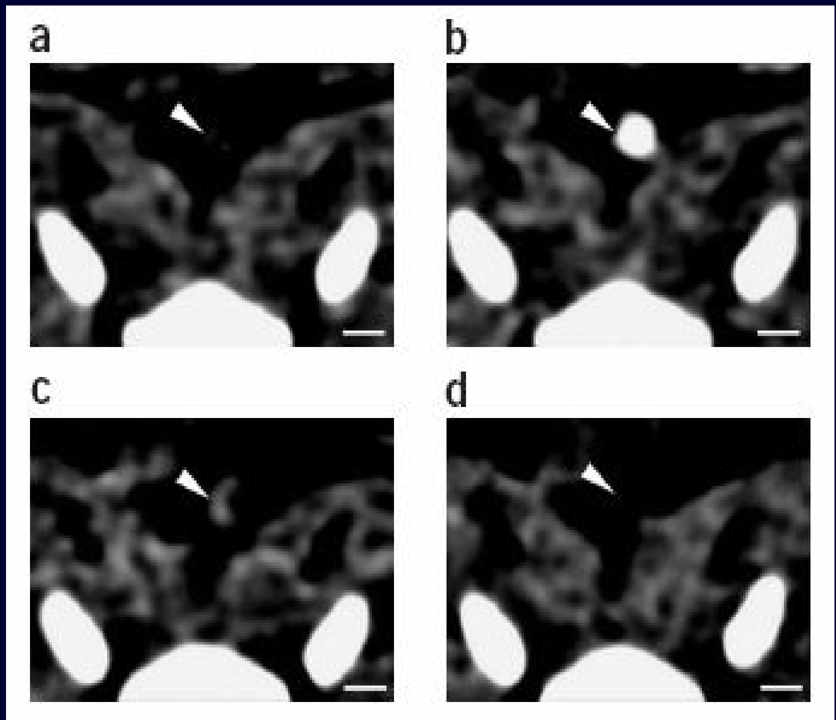
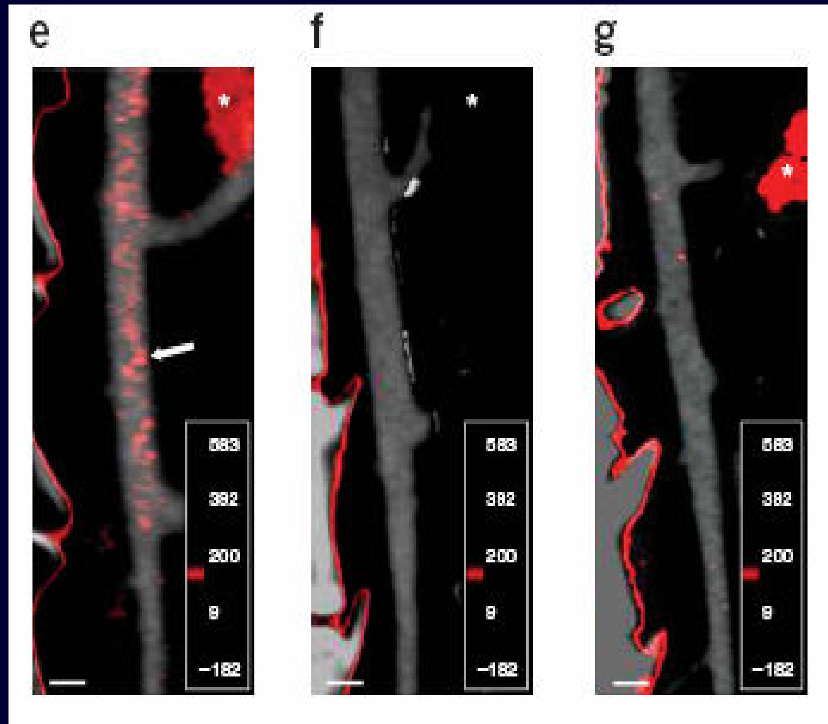
Imaging inflammation in Plaque

NC1177





Hyafil, Nature Medicine 2007;13:636-41

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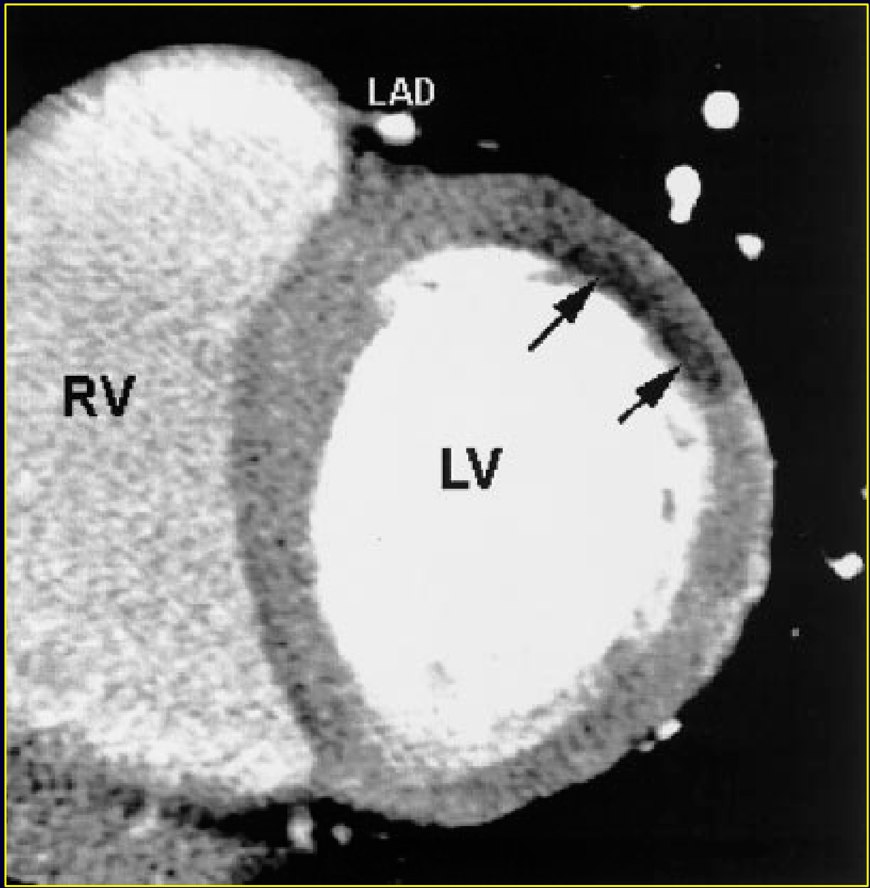
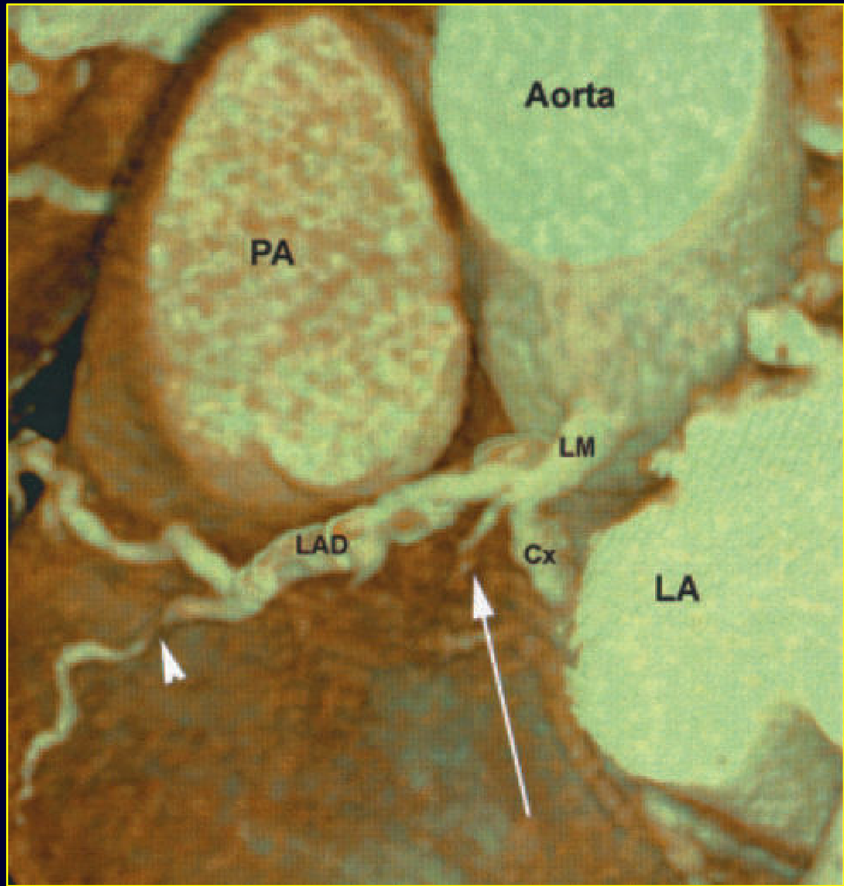
MDCT in Acute Myocardial Infarction

From Perfusion Defect to the Culprit Lesion





Paul, Circulation 2003;108:373

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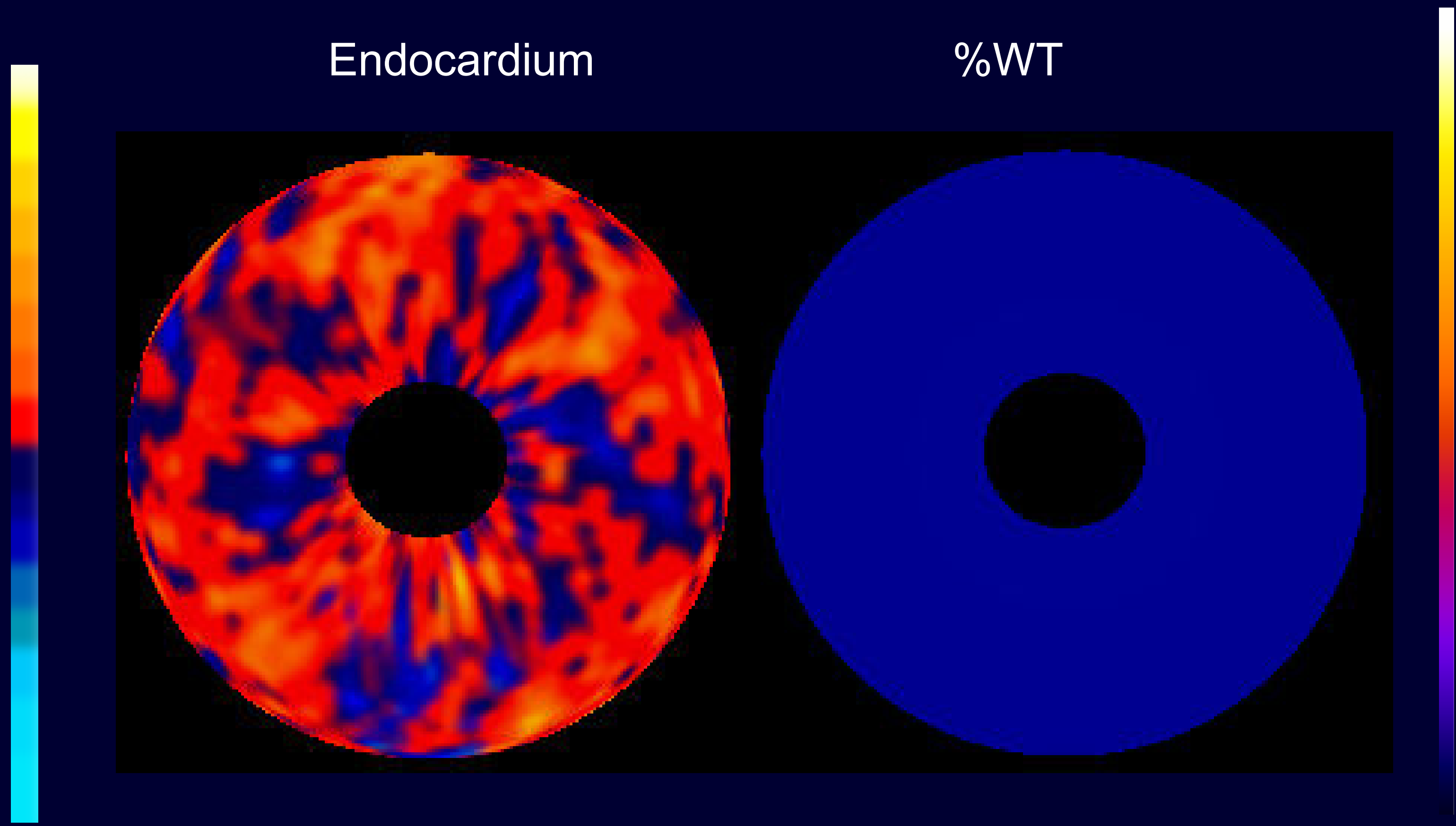
Case 1 (normal coronary artery)

Contrast velocity map



Koyama, in progress

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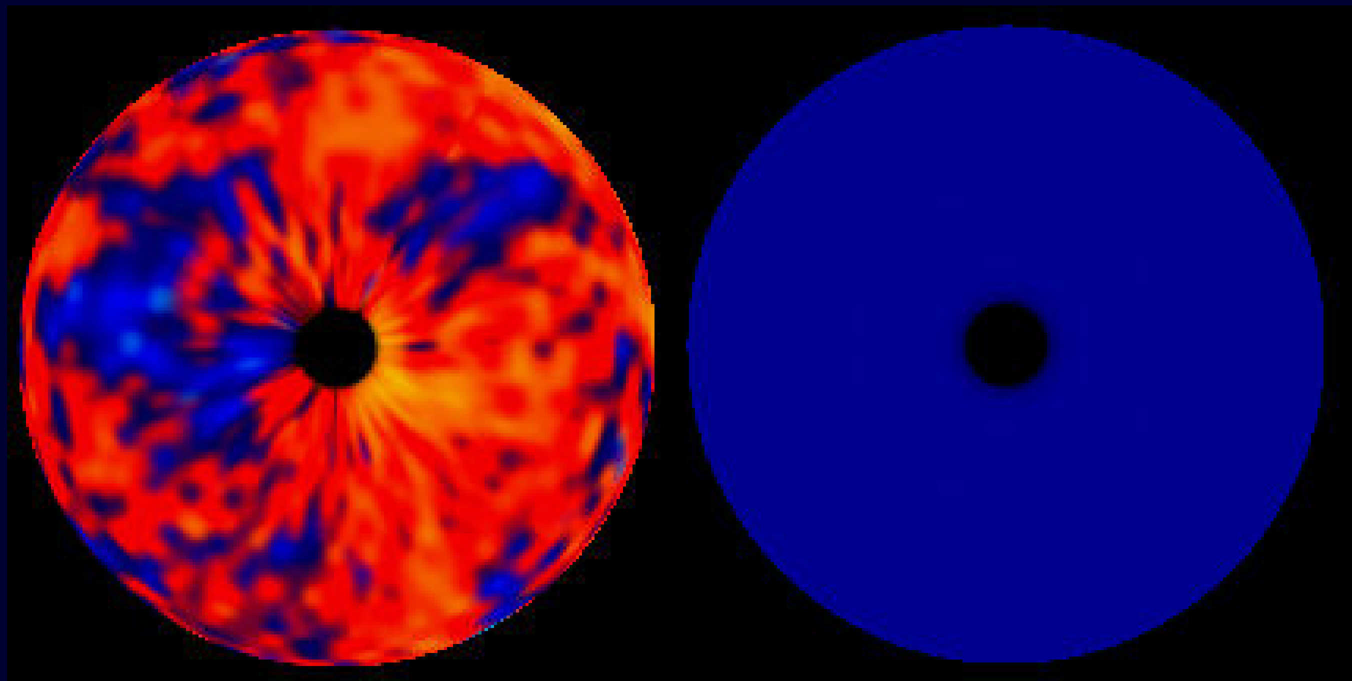
Case 2 (normal coronary artery)

Contrast velocity map

Endocardium %WT



Koyama, in progress

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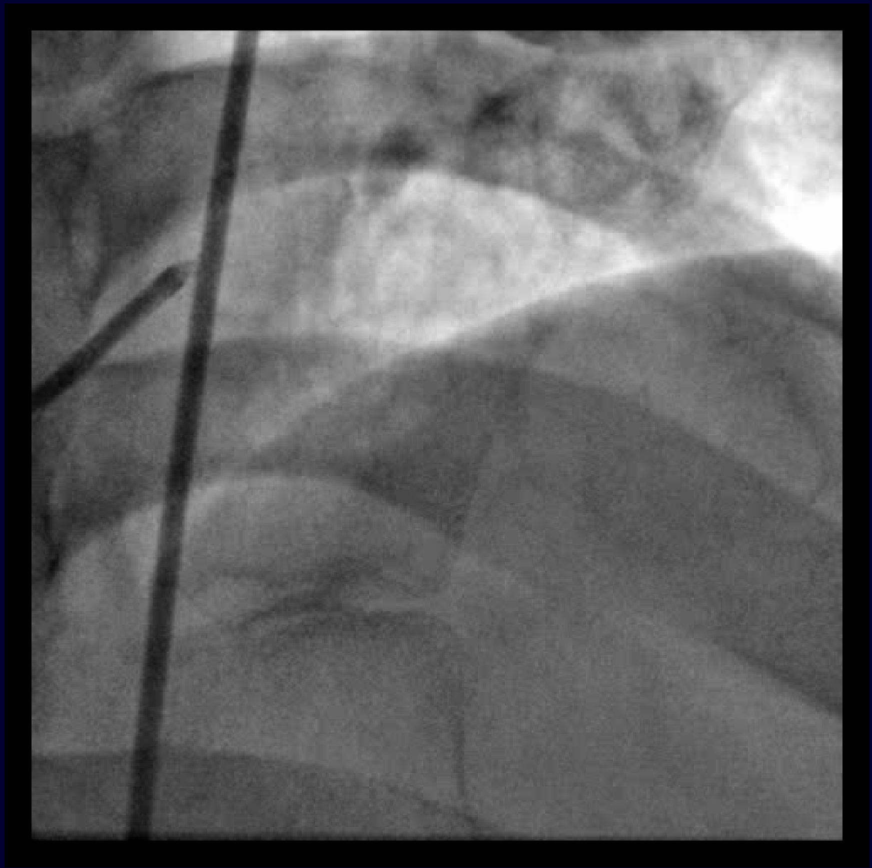
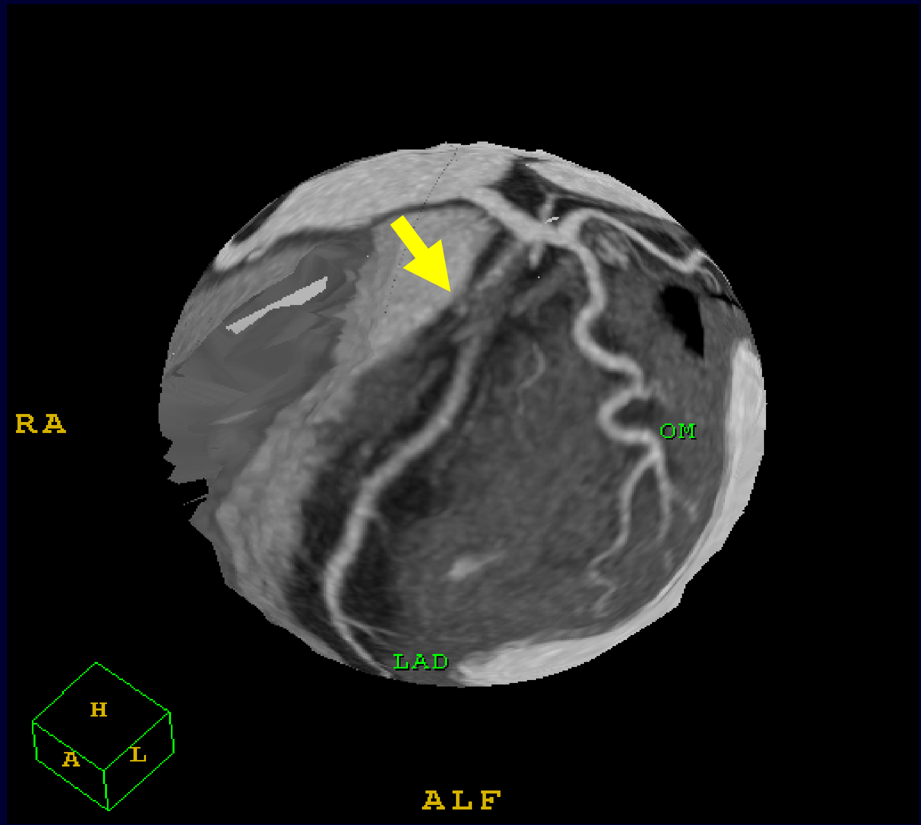
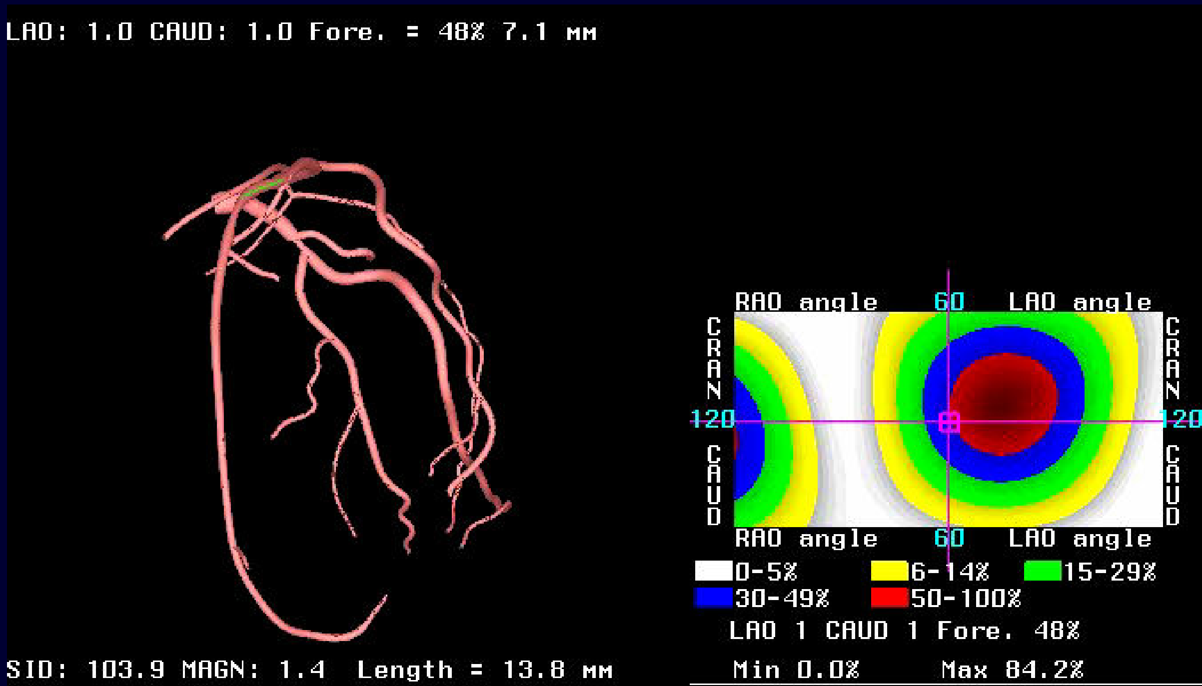
Computer Assistance to Optimize 2-D Projection Images





*Courtesy of Philips Medical Systems

Computer Assistance to Optimize 2-D Projection Images



Chen & Carroll. 3-D reconstruction of coronary artery tree to optimize angiographic visualization. IEEE Transactions on Medical Imaging. Vol 19: April, 2000. Pp 318-336.

*Courtesy of Philips Medical Systems

Future directions in cardiac CTA

- Improved detector technology- 10-20% reduction in dose, improvement in spatial resolution?
- Lower component weight, reduced friction and gravitational forces, multi-tube/detector systems-improvement in temporal resolution
- Improved tube modulation efficiency- 20-30% reduction in dose
- Quantification and functional assessment: "non-calcified" plaque score, automated LV mass, EF, myocardial perfusion, multimodality co-registration, novel contrast agents

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