

# *Characterization of Coronary Atherosclerotic Plaques Using CTA*

*Koen Nieman, MD*



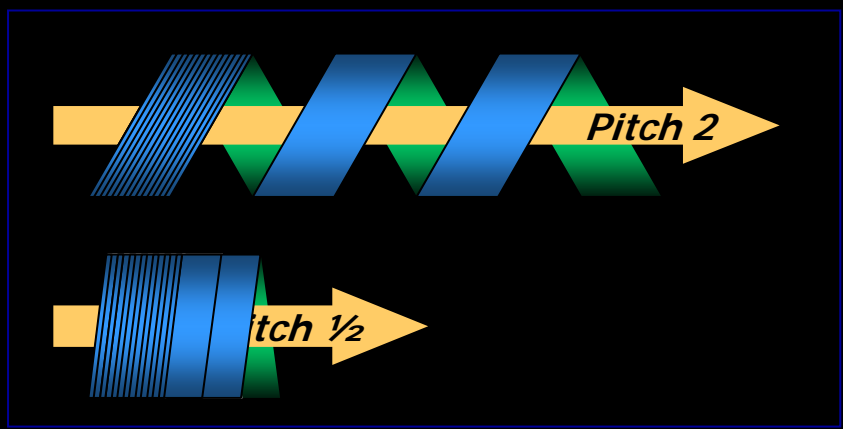
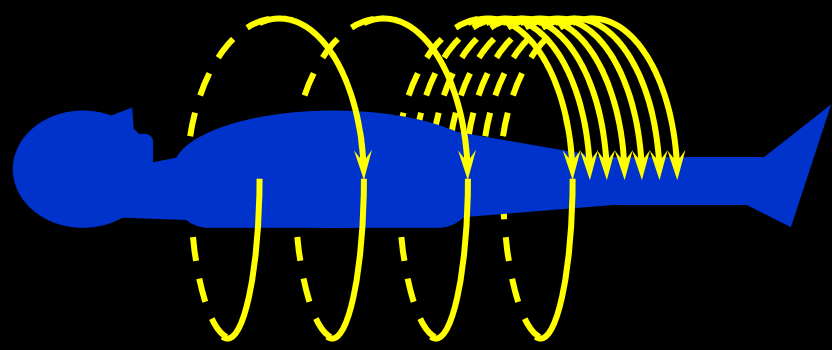
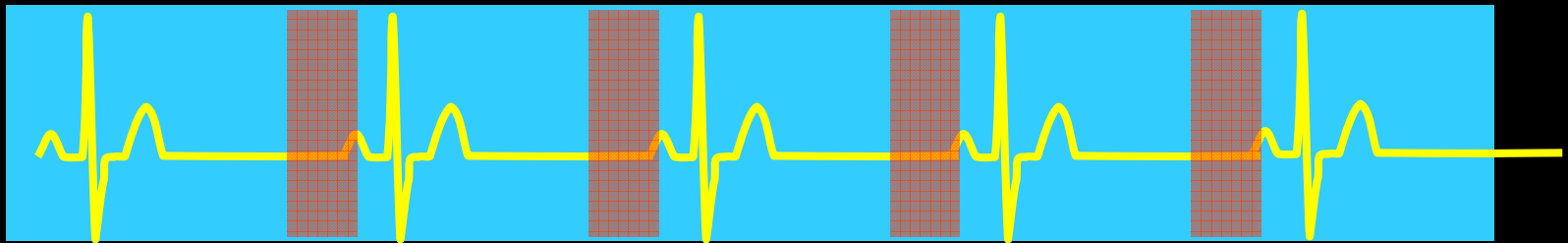
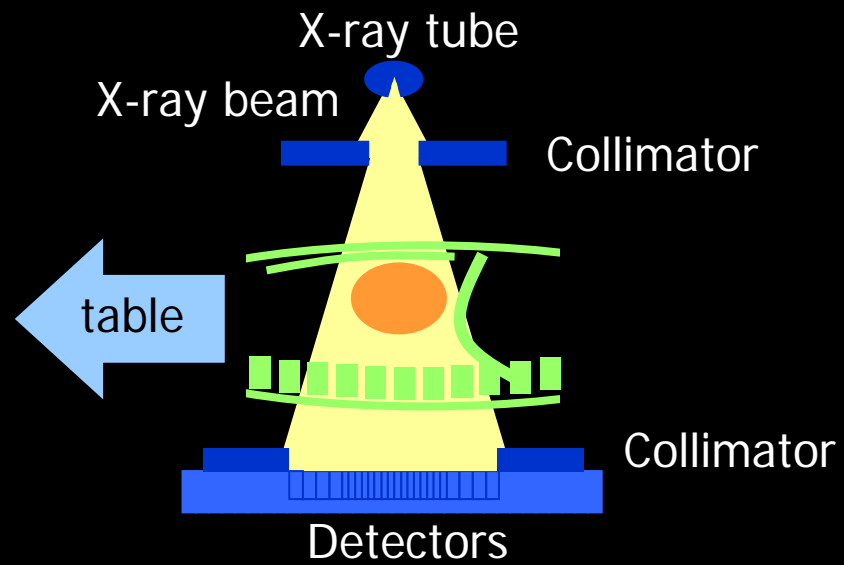
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CIMIT Dept. of Radiology  
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# Non-invasive Plaque Imaging

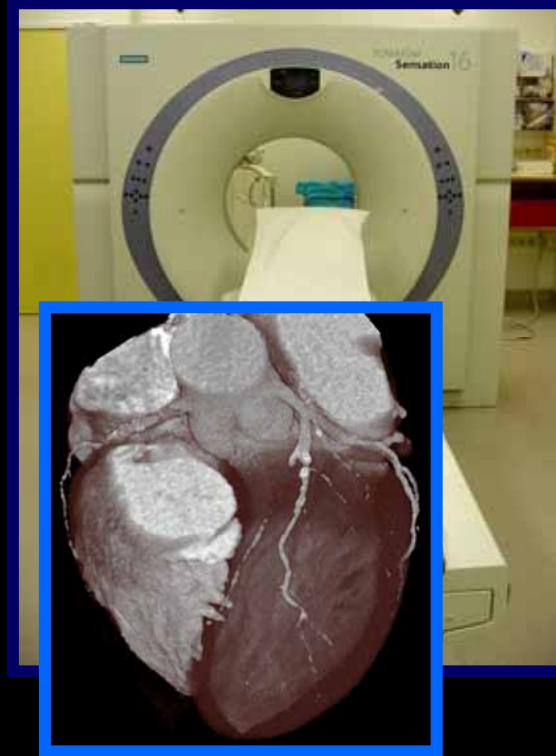
- Practical and economic limitations of widespread use of intra-vascular imaging.
- Applicability of MRI currently limited to non-coronary vessel walls.
- A 10-sec MDCT scan images plaque throughout the coronary artery system.



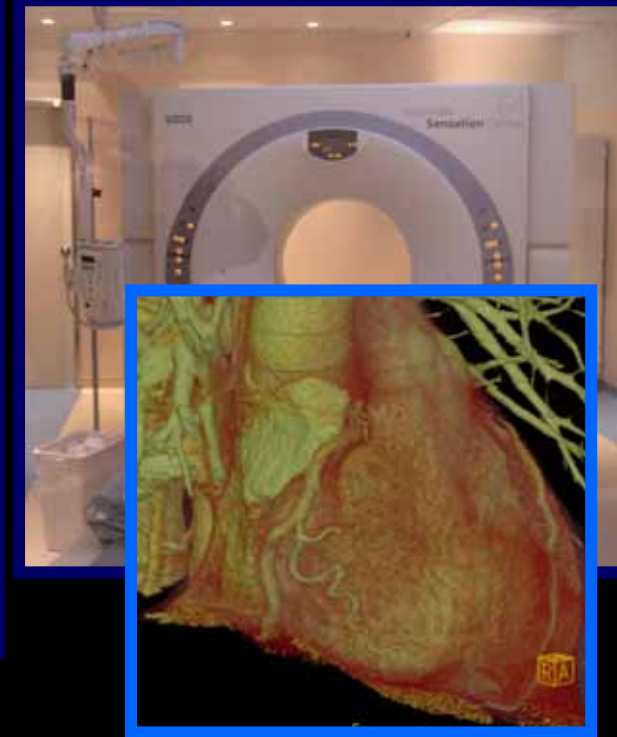
# 4-slice CT → 16-slice CT → 64-slice CT →



4 × 1 mm collimation  
500 ms rotation  
35-40 s scan  
45 min recon time



16 × 0.75 mm  
375 ms rotation  
20 s scan  
3 min recon time



64 × 0.6 mm  
330 ms rotation  
12 s scan  
1 min recon time

CT scanner	N	EXCL	SENS	SPEC	SENS*
4-MSCT (500ms) <sup>1</sup>	31-102	6-32	72-95	84-99	49-93
8-MSCT (500ms) <sup>2</sup>	25	14	90	99	73
16-MSCT (420ms) <sup>3</sup>	33-128	0-17	70-95	86-98	63-95
16-MSCT (375ms) <sup>4</sup>	51+72	0	82-95	98	82-95
64-MSCT (375ms) <sup>5</sup>	67	0	94	97	94
64-MSCT (330ms) <sup>6</sup>	30+37	0-7	93-96	89-95	90-96

<sup>1</sup>Nieman ('01), Achenbach ('01), Knez ('01), Vogl ('01), Kopp ('02), Becker ('02), Giesler ('02), Nieman ('02), Morgan-Hughes ('03), Sato ('03), Kuettner ('04), Dirksen ('05).

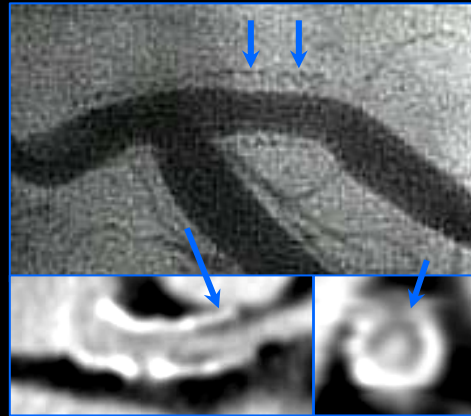
<sup>2</sup>Maruyama ('04).

<sup>3</sup>Nieman ('02), Ropers ('03), Martuscelli ('04), Mollet ('04), Kuettner ('04), Hoffmann ('04), Morgan-Hughes ('05), Schuijf ('05), Moon ('05).

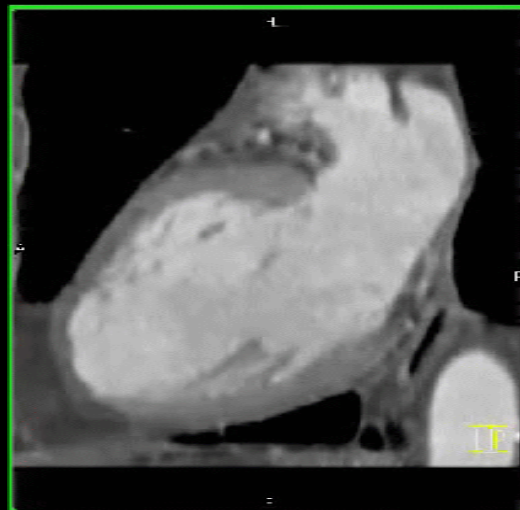
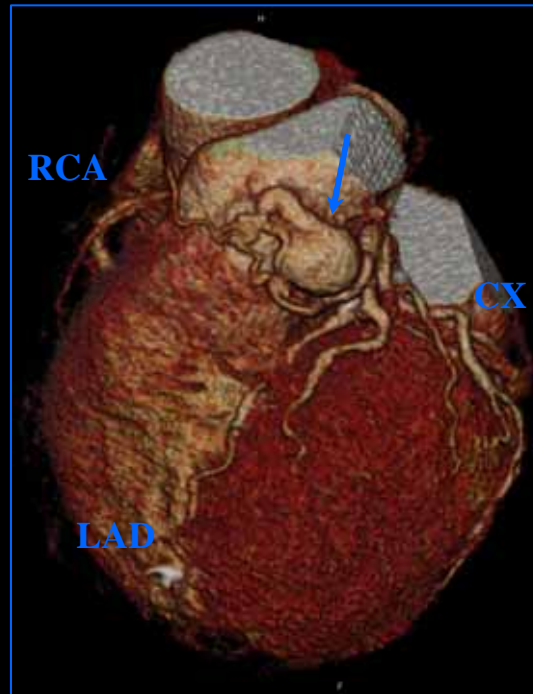
<sup>4</sup>Mollet ('05), Kuettner ('05).

<sup>5</sup>Leschka (EHJ '05-in press).

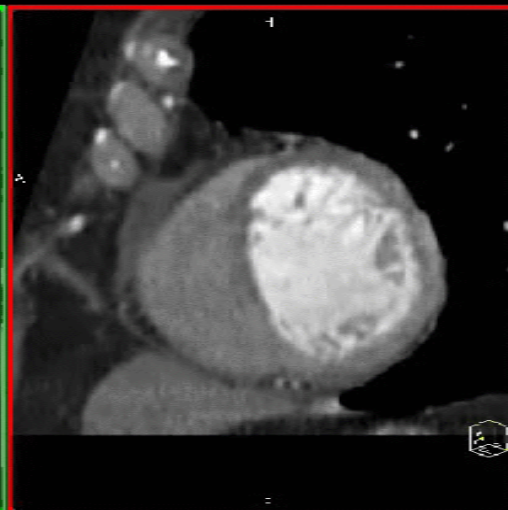
<sup>6</sup>Mollet (ACC '05), Ropers (ACC '05).



**LM-LAD in-stent  
Hyperplasia**



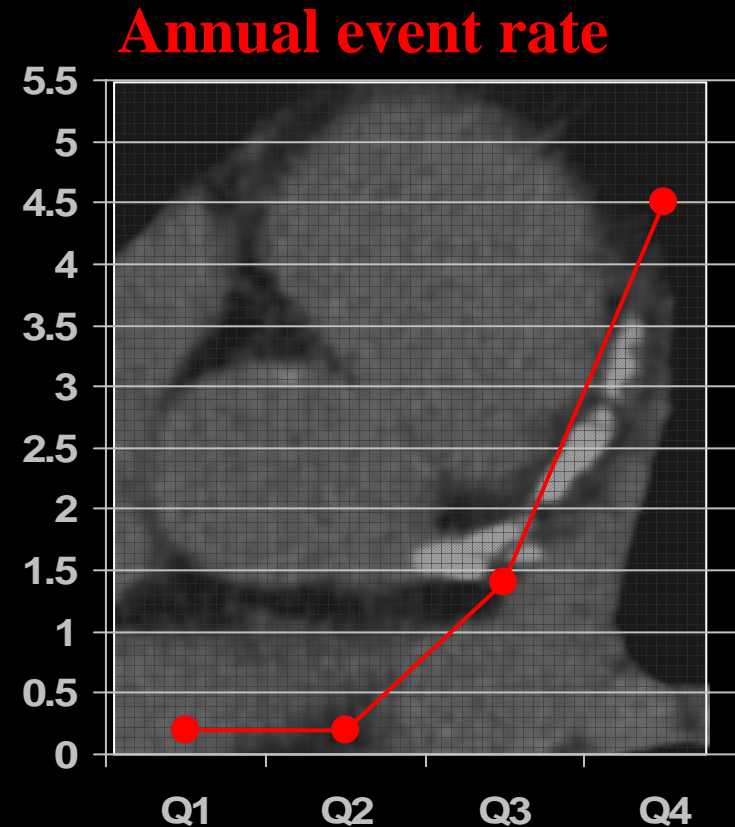
**Anterior Wall Akinesis**



**Transmural Perfusion Defect**

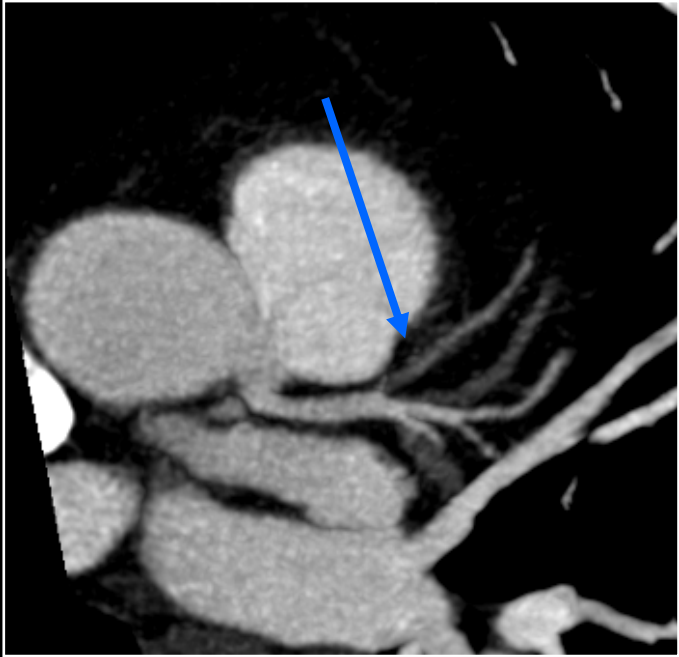
# Coronary Calcium Quantification

- Non-enhanced CT scan
- Calcium = atherosclerosis
- Poor accuracy for stenosis detection
- Incremental value to traditional risk factors for medium to long-term risk
- Considered in individuals at intermediate-risk

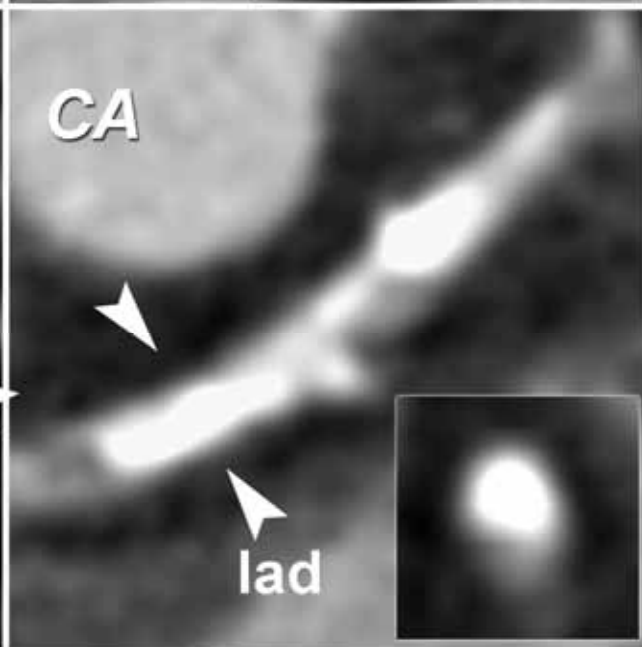
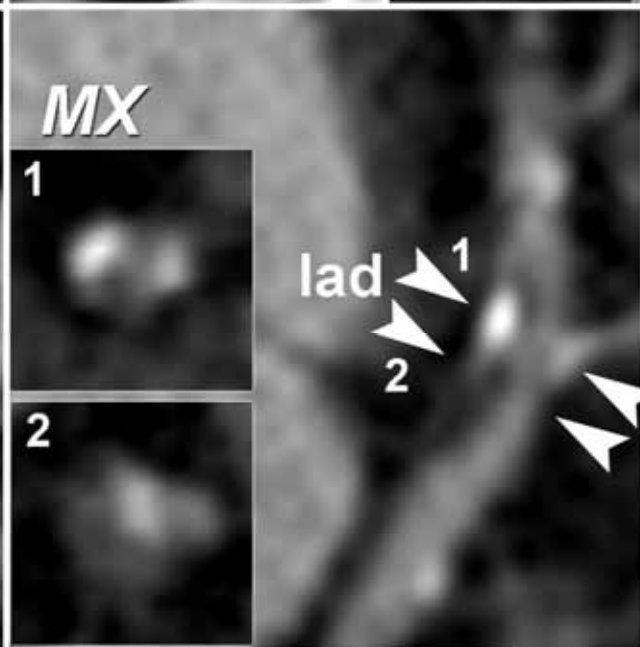
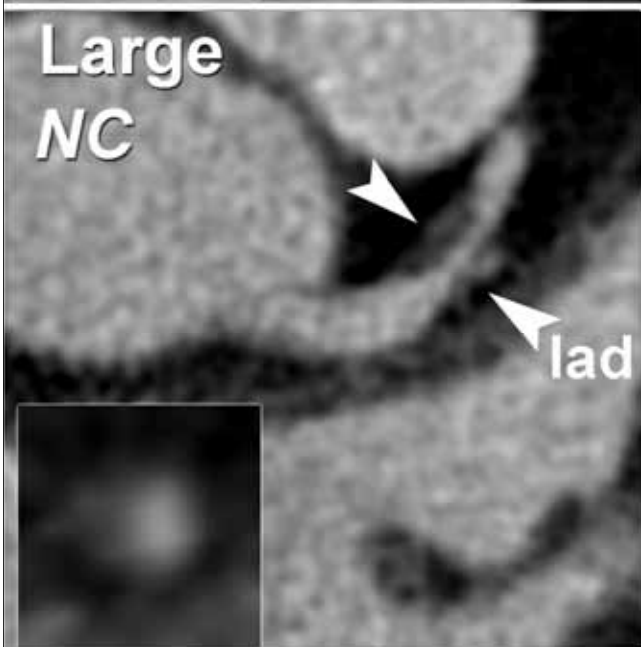
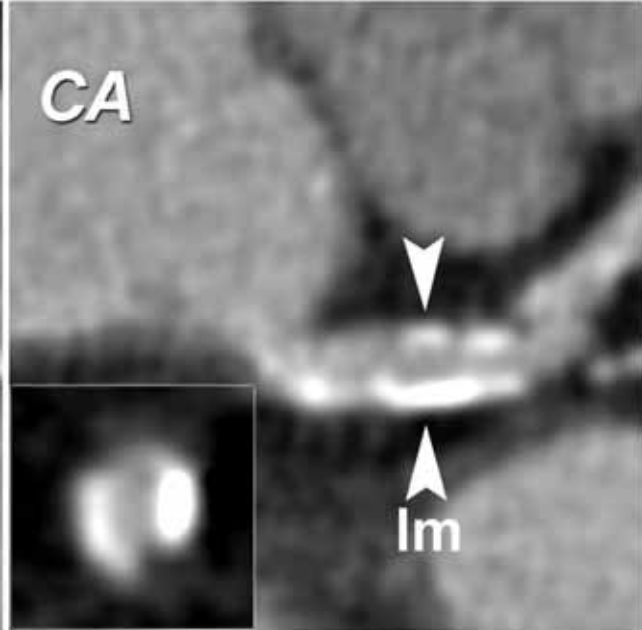
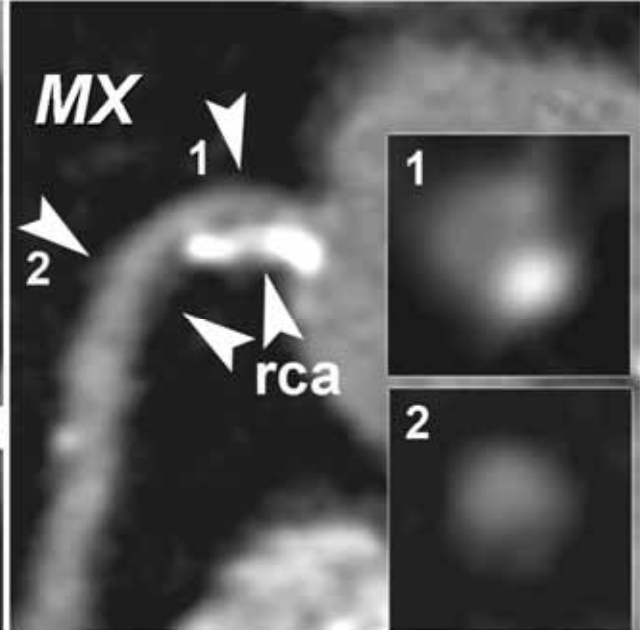
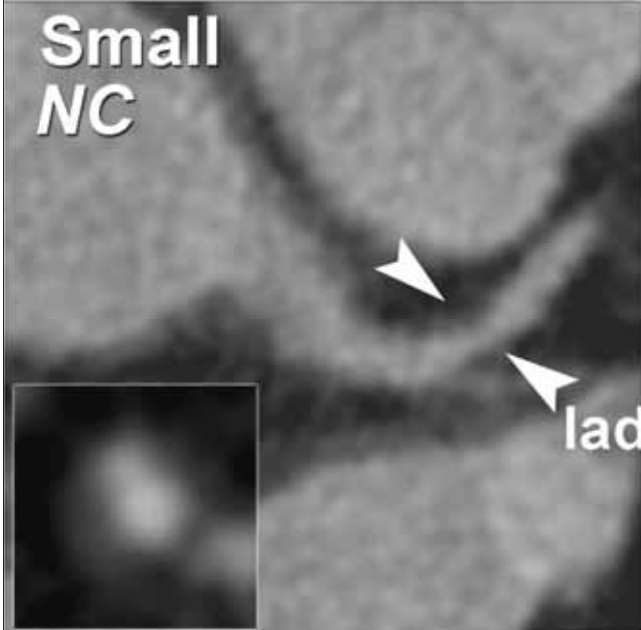


*Raggi et al, AHJ 2001*

# Total Coronary Plaque Burden

- Good prognosis in acute chest pain without calcium.
  - No calcium  $\neq$  no CAD
  - Indirect correlation between calcium and vulnerability
  - Calcified = stabilization?
  - Calcium does not regress
- 
- Non-calcified plaque is more active and dynamic
  - Potentially a better predictor of short-term risk
  - Possible target for intervention monitoring





# Plaque detection by MDCT

*Mollet et al, EHJ 2005 (in press)*

73 patients with chest pain

- 72 male,  $59 \pm 14$  yrs
- HR=57 (38  $\beta$ -block)

$\emptyset > 2$ -mm segments

Plaque per patient

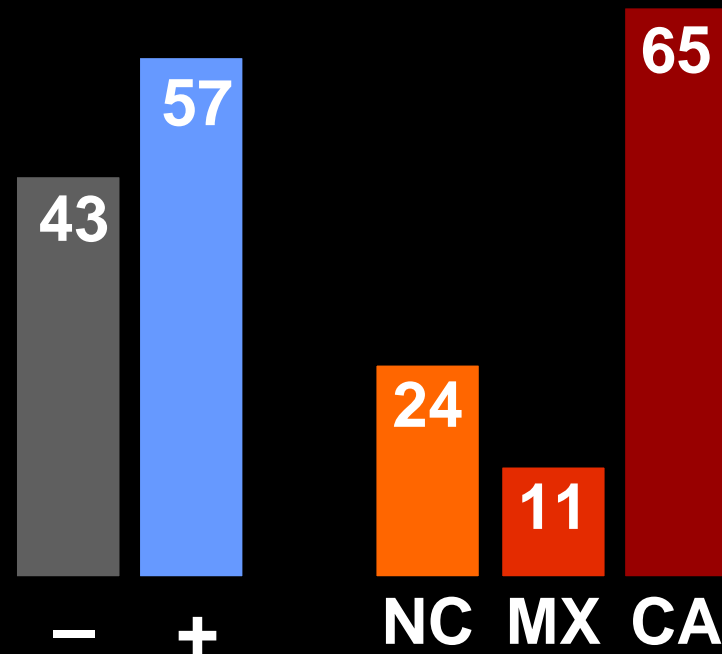
$6.2 \pm 2.9$  segments

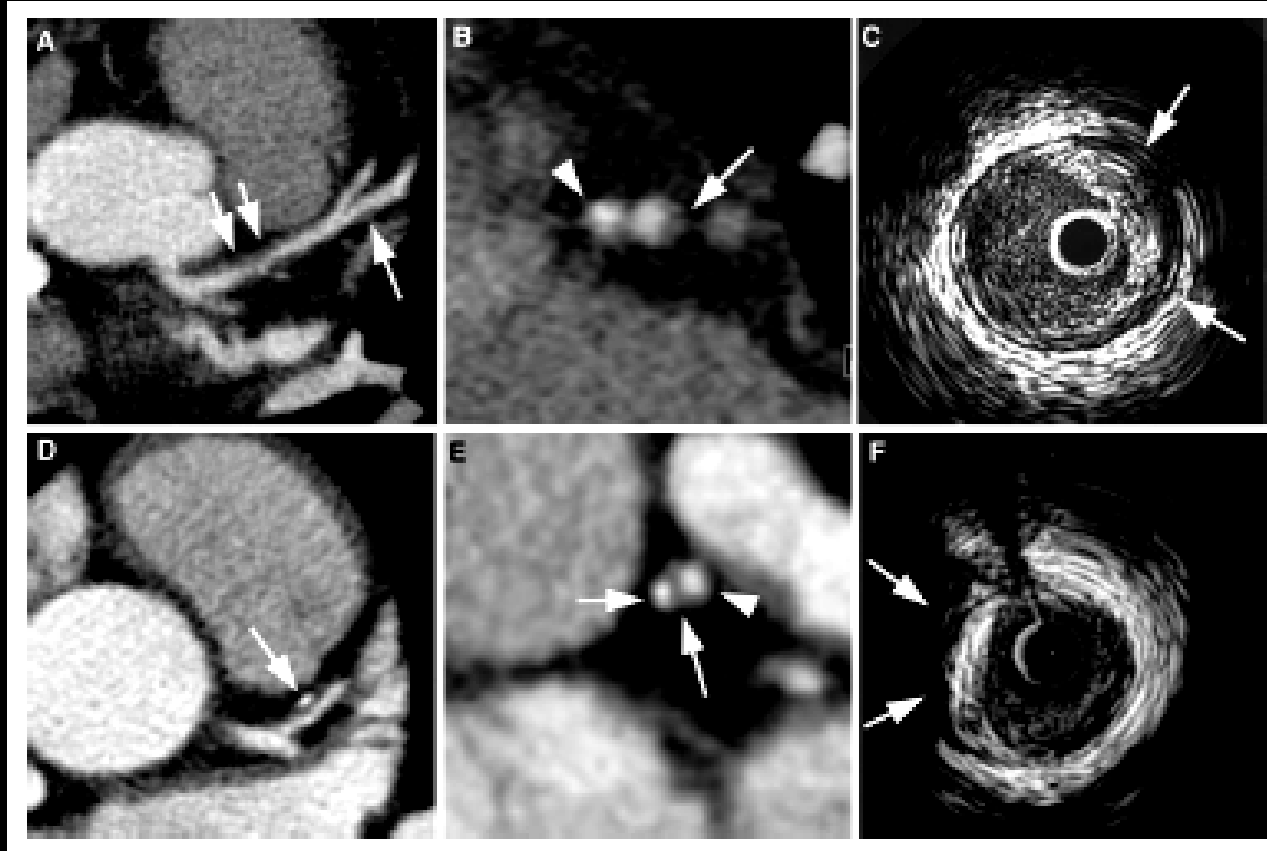
**Frequency**

segments  
w/ plaque

**Contents**

calcium, mix  
non-calcified





IVUS 83 segments:

Sens 82% (41/50)

Spec 86% (29/33)

Calcium dependency:

Sens Ca+ 94% (33/35)

Sens Ca- 53% (8/15)

22 Patients

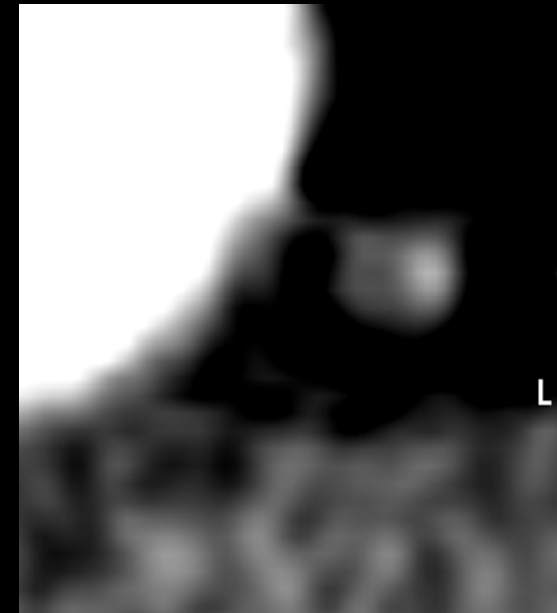
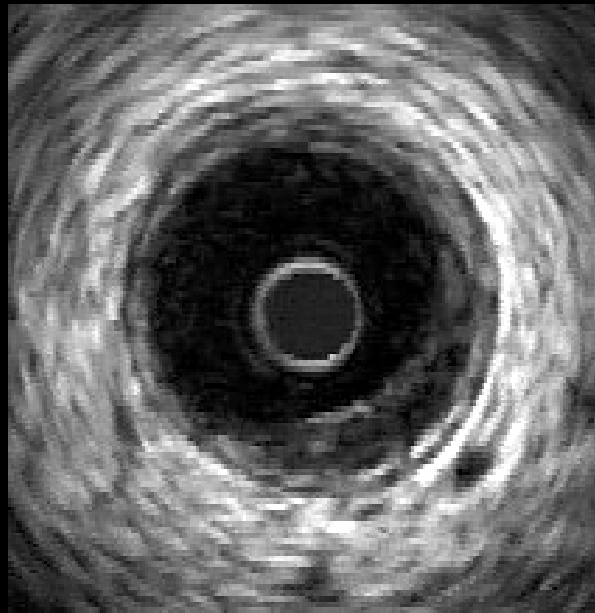
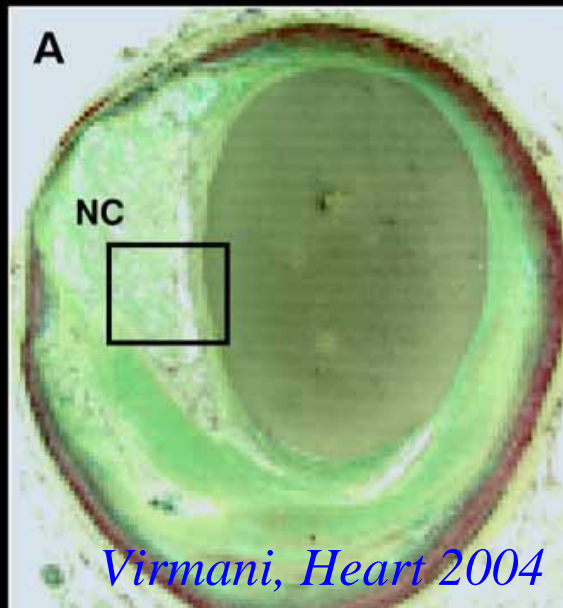
Achenbach et al,  
Circulation 2004

# Culprit Lesions

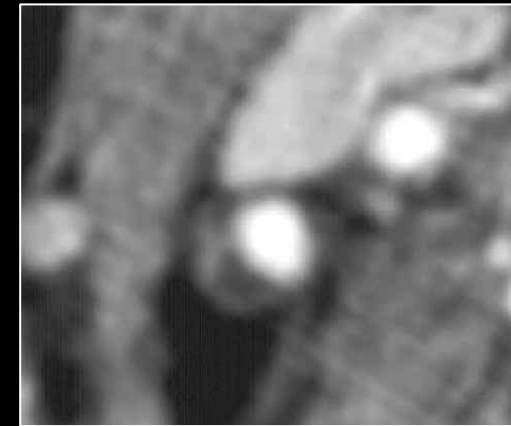
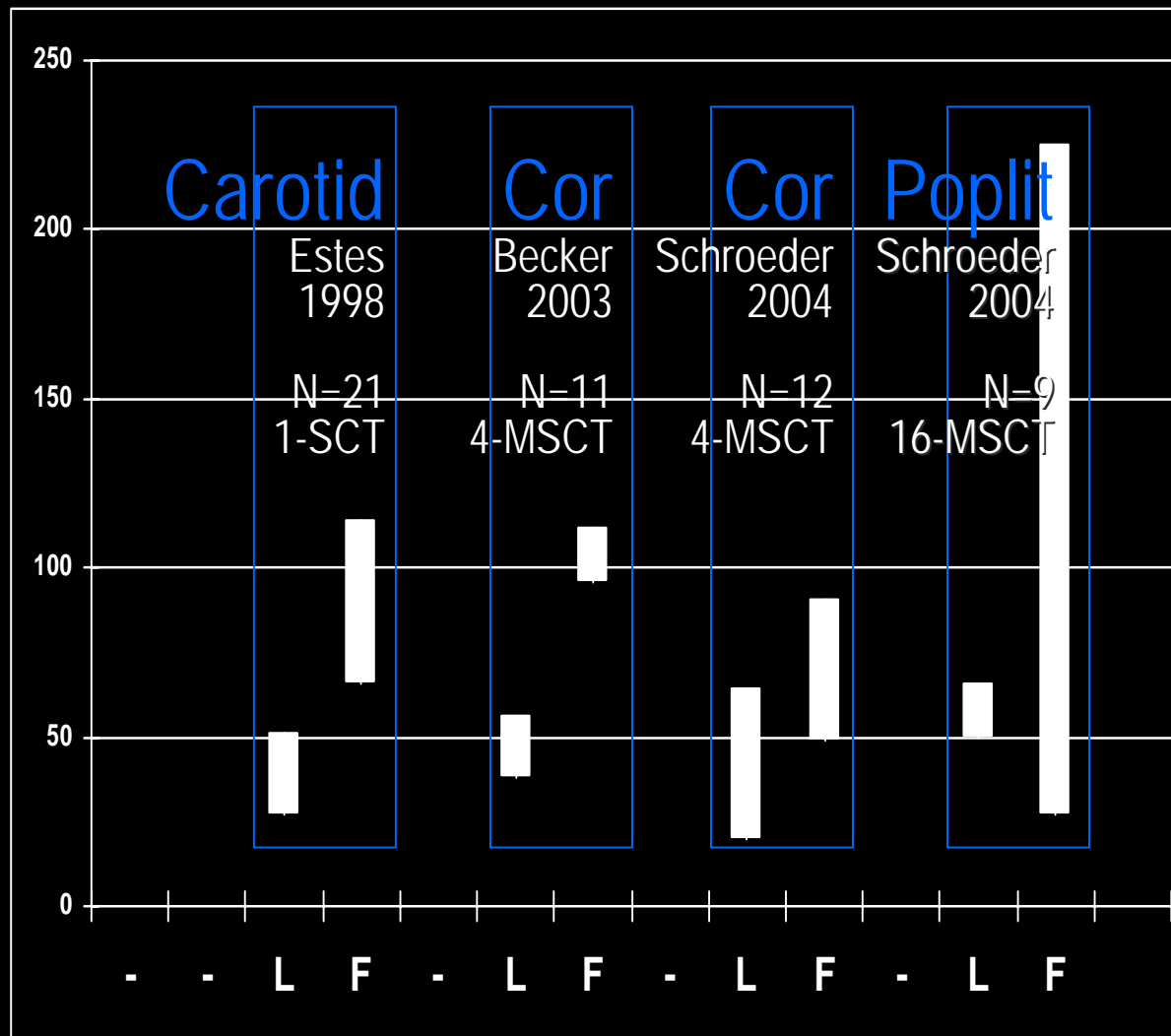
Naghavi et al, Circulation 2003

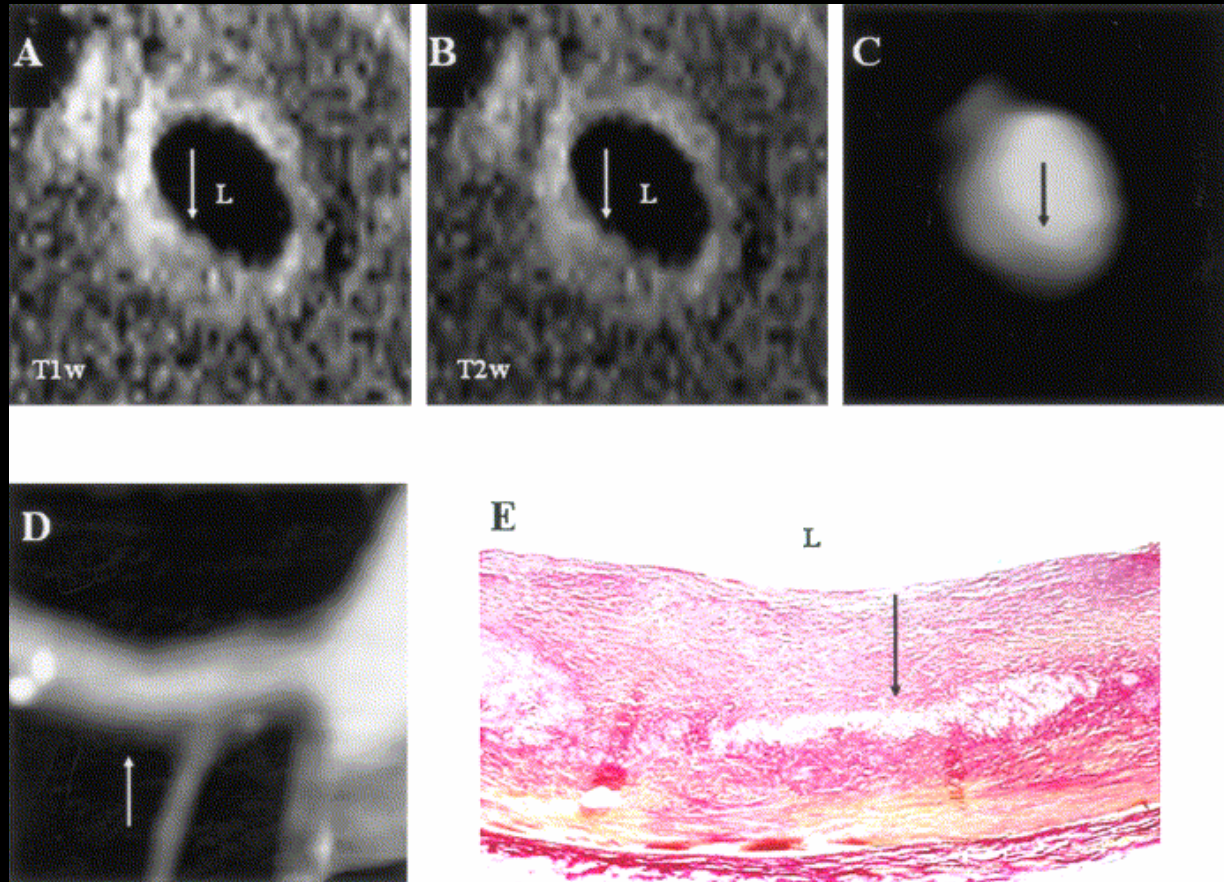
- Large lipid core and thin fibrous cap (TCFA)
  - Inflammation - macrophages
  - Endothelial denudation or fissure
  - >90% Lumen stenosis
- 
- Superficial calcified nodule
  - Glistering yellow surface (angioscopy)
  - Hemorrhage within the plaque
  - Endothelial dysfunction
  - Outward vessel remodeling

# Thin-Cap Fibro-Atheroma (TCFA)



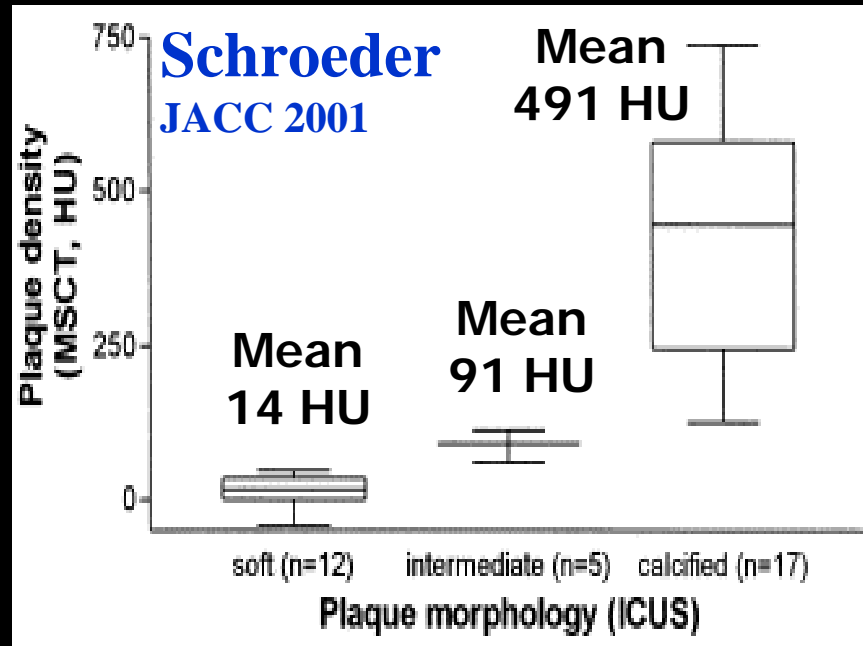
# Non-Cardiac Plaque Morphology





Ex-vivo coronary fibro-atheroma by MR & CT  
Nikolaou et al, 2004, Atherosclerosis 2004

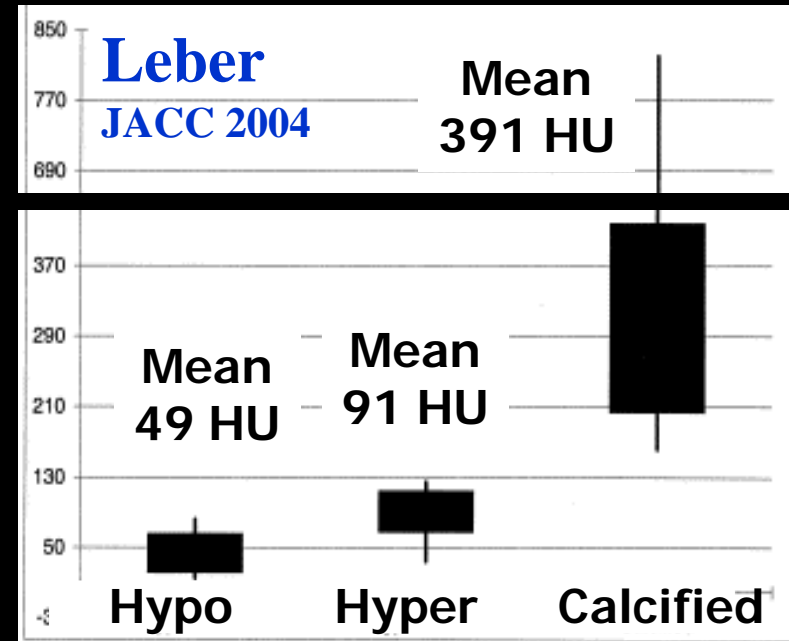
# MSCT versus IVUS plaque



4 × 1 mm, 500 ms rotation

N=15, 34 Plaques

- Soft: -42 - 47 HU
- Intermediate: 61 - 112HU
- Calcified: 126 - 736HU



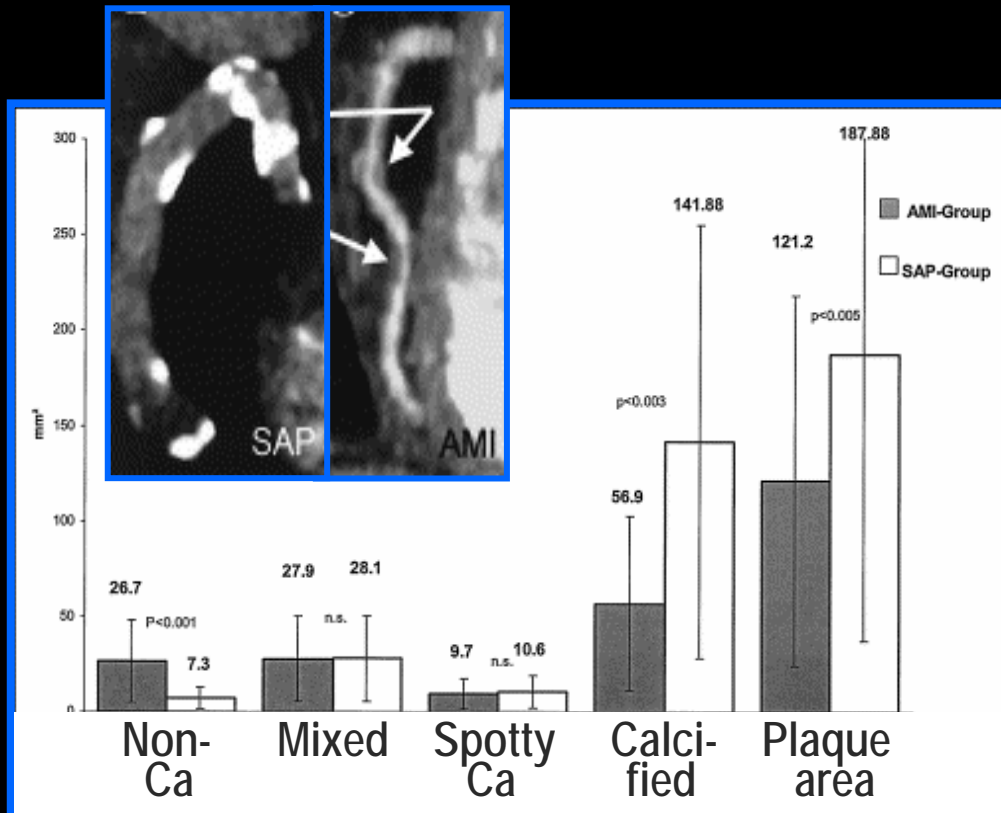
16 × 0.75 mm, 420 ms rotation

N=37, 58 vessels > 350 sections

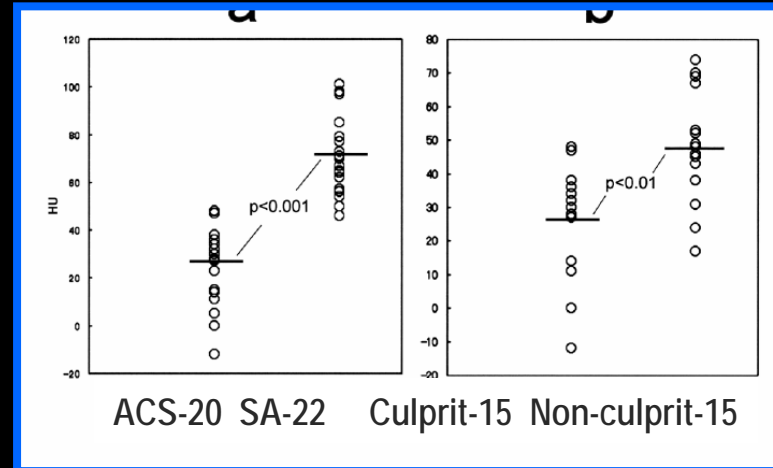
- Soft: 14 - 82 HU
- Intermediate: 34 - 125 HU
- Calcified: 162 - 820 HU



# Imaging Culprit Lesions



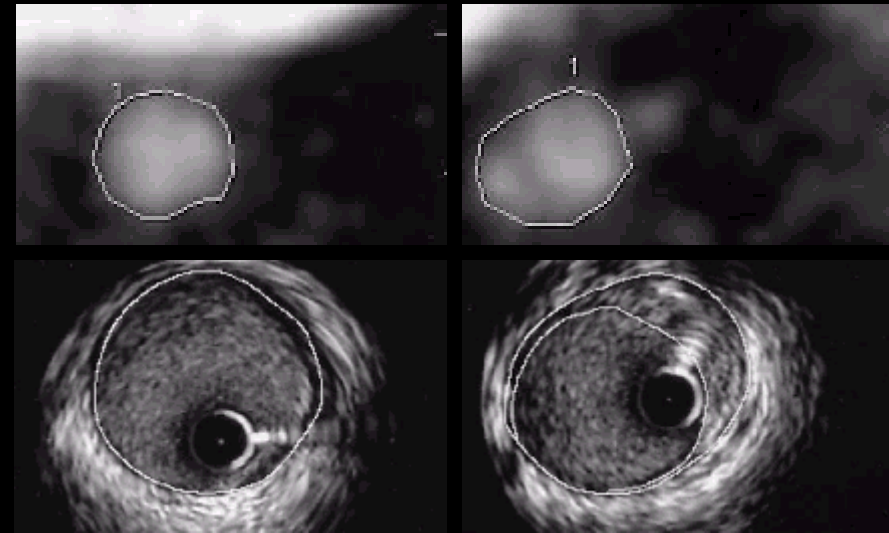
Coronary plaque in patients with myocardial infarction vs stable angina  
 - Leber, AJC 2003



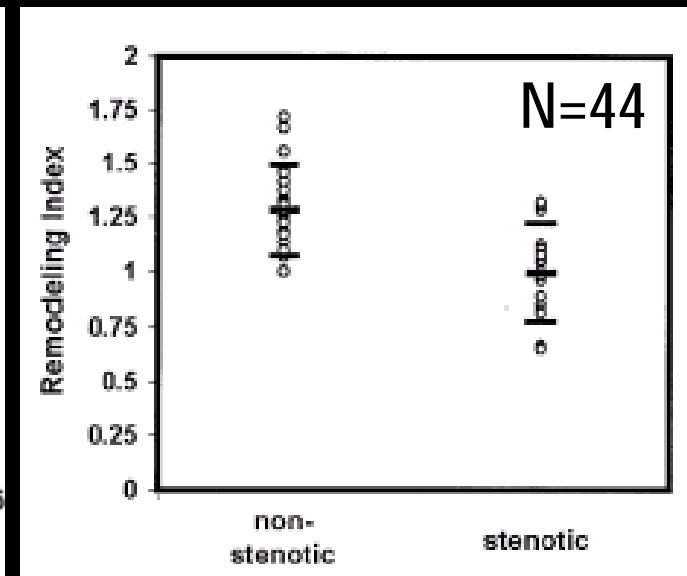
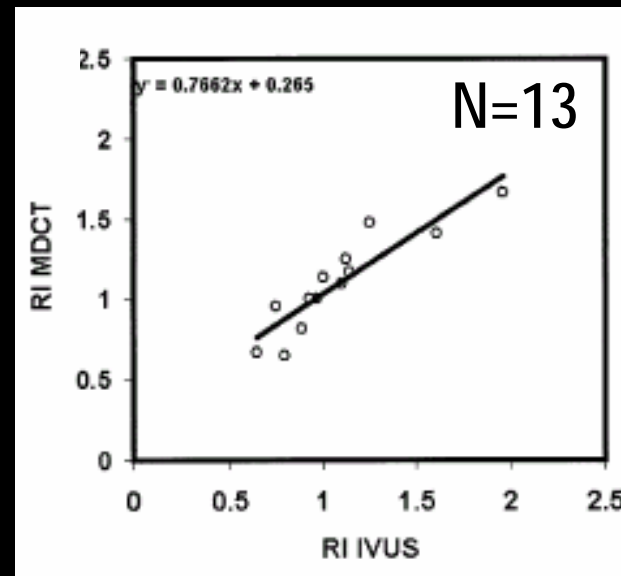
Minimal density (HU):  
 Culprit lesions:  $25 \pm 15$   
 Non-culprit:  $48 \pm 17$   
 Stable lesions:  $71 \pm 16$   
 - Inoue, Circ J 2004

# Outward Remodeling

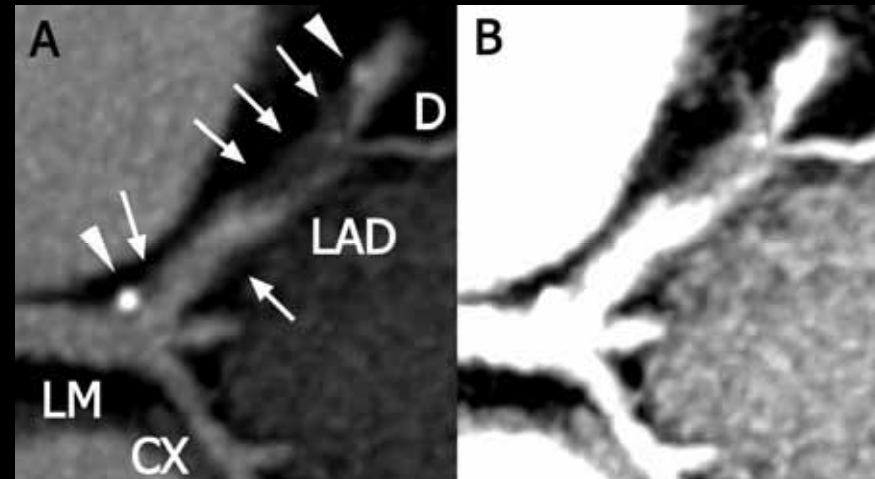
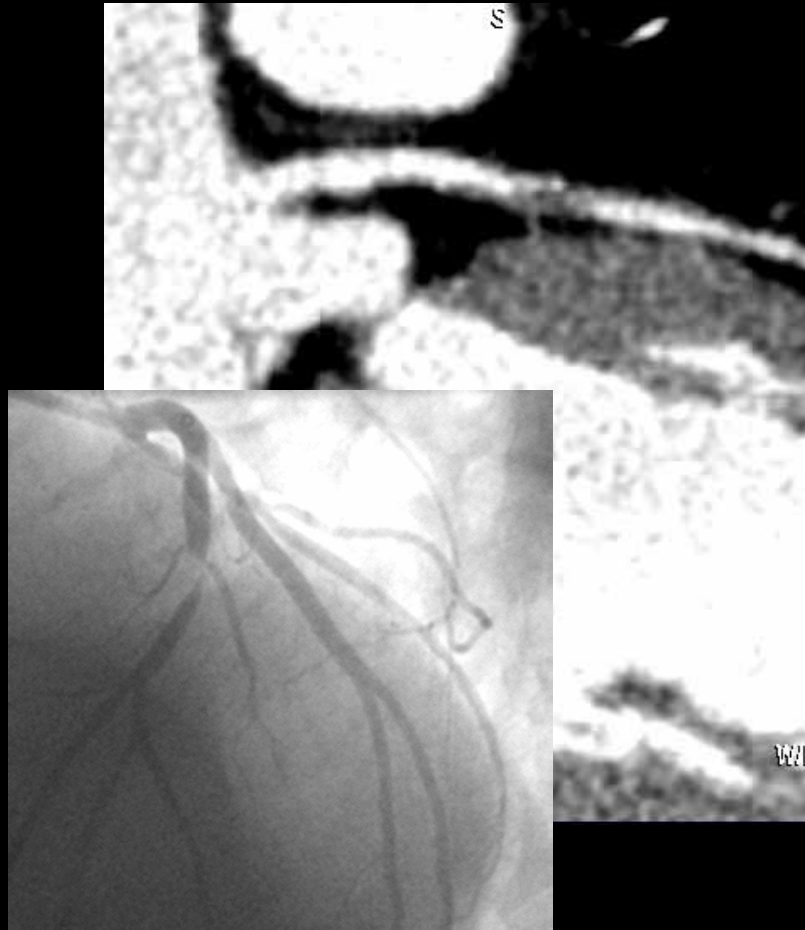
Remodeling index CT and IVUS ( $r^2=0.82$ )



S. Achenbach  
(JACC 2003)



# Culprit Features by MSCT

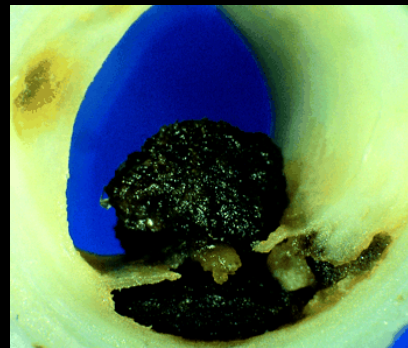


- 1) Severe stenosis
- 2) Lipid-rich plaque material
- 3) Superficial calcified nodule
- 4) Outward vessel remodeling

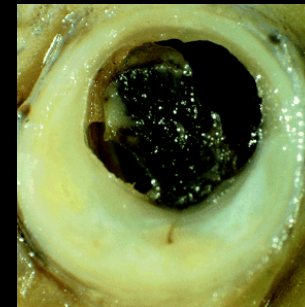
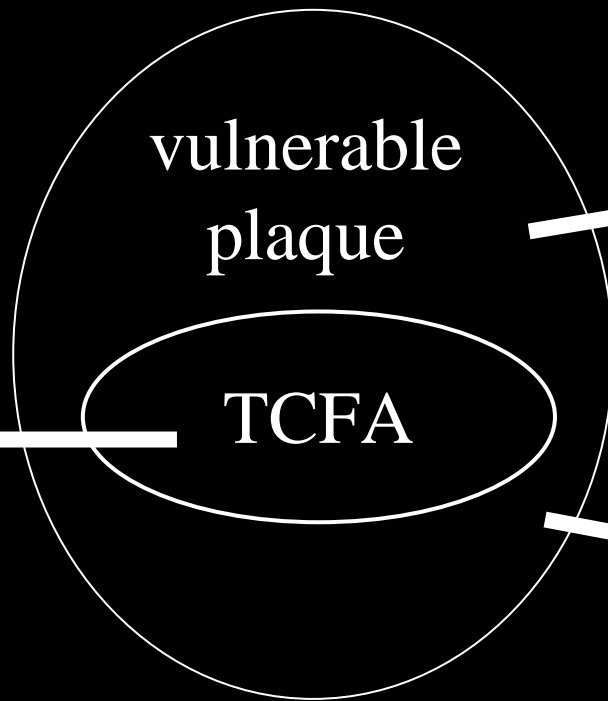
? Macrophages

? Plaque hemorrhage

# The Vulnerable Patient



Classic  
plaque  
rupture  
(70%)



Erosion  
thrombus  
w/o rupture  
(30%)

Spasm  
Infarct  
w/o thrombus

# Pros/cons of MDCT Plaque Imaging

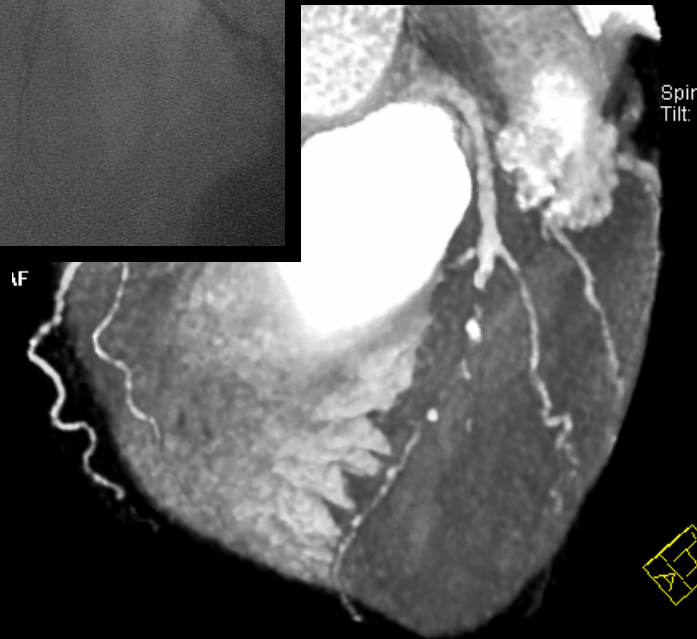
## **Disadvantages:**

- Modest spatial and temporal resolution
- Modest versatility compared to MRI and invasive techniques
- Radiation / contrast

## **Advantages:**

- Non-invasive / low risk
- Short scan time
- Complete coverage
- Comes for free with a coronary angiogram

# PCI Guidance



- 1 - Complete lesion morphology.
- 2 - (Chronic) total occlusions - road map & calcium.
- 3 - Stenting of non-significant “vulnerable” lesions?

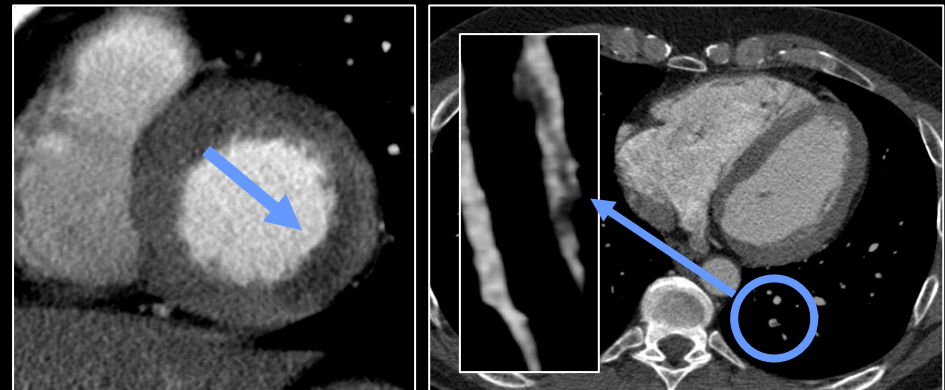
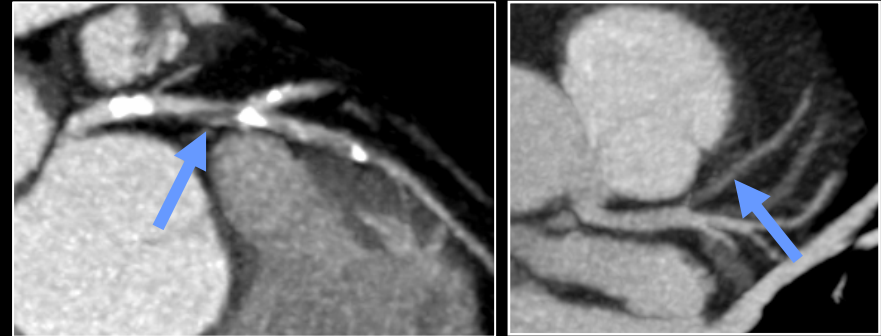
# MDCT and Acute Chest Pain

## Diagnosis

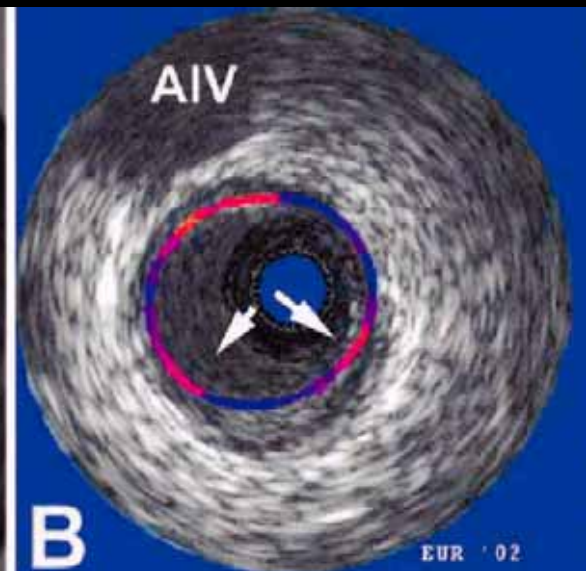
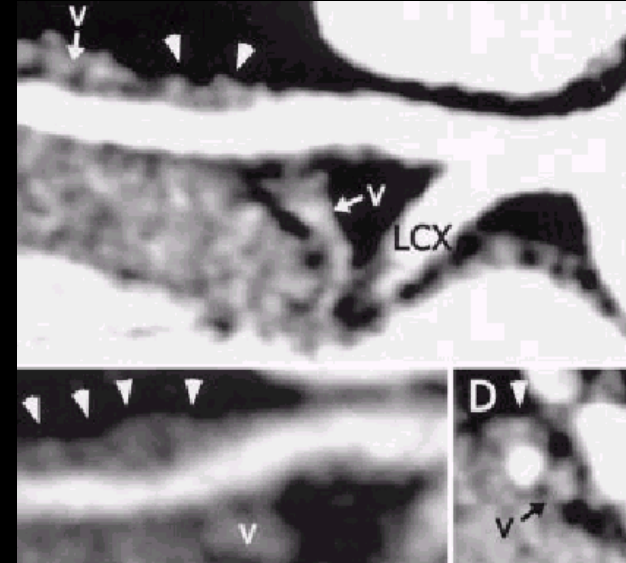
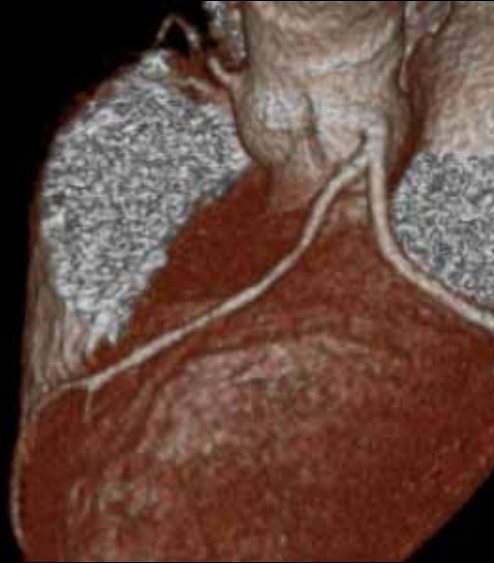
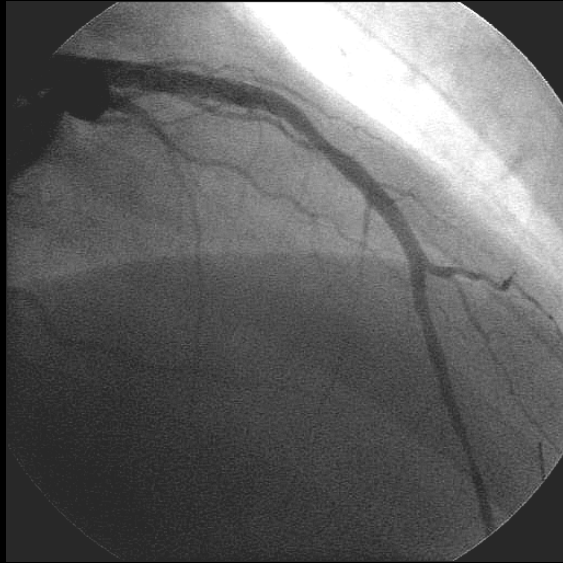
- Coronary obstruction
- Acute perfusion defect
- Wall motion abnormalities
- Alternative diagnosis

## Risk stratification

- Calcium
- Non-calcified plaque
- Chronic myocardial disease
- Global ventricular function



# Road Map for Invasive Imaging



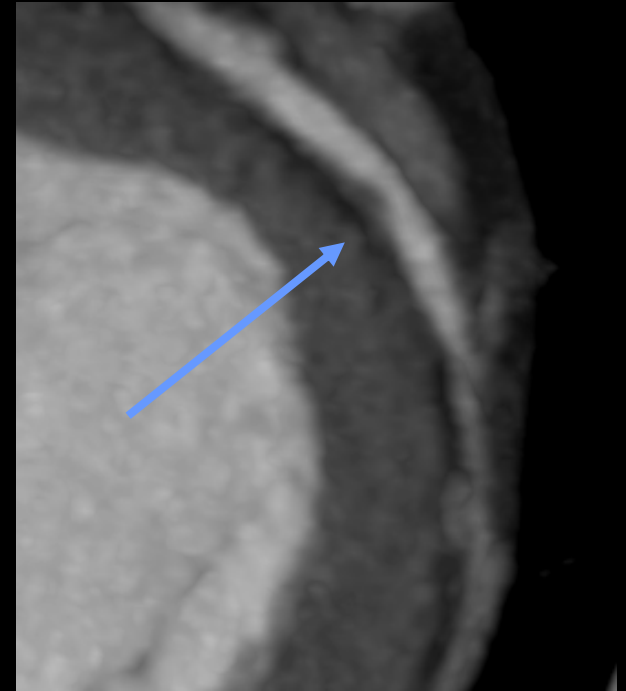
Arampatzis  
Circulation 2003

EUR '02



# Future developments

- Scanner performance:
  - faster, thinner and sharper
- Software development:
  - Automatic detection/evaluation
- Clinical evaluation:
  - CT plaque imaging compared to histology
  - natural course of CT plaque characteristics
  - implementation of CT plaque characterization



# Acknowledgments

## **Erasmus Medical Center Rotterdam Thoraxcenter**

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- Ricardo Cury
- Maros Ferencik
- Suhny Abbara
- Udo Hoffmann
- Ahmed Tawakol
- Ik-Kyung Jang
- James Muller
- Thomas Brady

# Potential Applications

- Risk stratification (without symptoms):
  - added value of non-calcified plaque over calcium.
- Acute coronary syndrome:
  - diagnostic: detection of CAD, thrombus, myocardial perfusion, alternative causes.
  - risk stratification: plaque burden, quality, myocardium.
- Modification of PCI procedures (w/o IVUS):
  - Complete plaque coverage, moderate lesion PCI.
  - Road map for intervascular imaging modalities.

# Plaque section

- Imaging plaque burden: quantification:
  - Calcium: method, value, recent studies, guidelines.
  - Soft plaque assessment - entire coronary artery tree.
- Plaque qualification - stability (MI w/o Ca).
  - CT-able vulnerable plaque features. Limitations.
  - Potential role combined with other tools:
    - guide IVUS, etc. > Akis' case.
    - guide intervention > non-significant lesions, longer stents

# 64-slice CT Angiography

## Mollet, ACC '05

64 × 0.6, 330 ms rotation  
(Siemens Sensation 64)

N=30 (Angio CAD 80%)

HR 58 (BB 75%)

>1.5 mm vessels

Sensitivity 96%

Specificity 89%

Positive PV 85%

Negative PV 97%

## Ropers, ACC '05

64 × 0.6, 375 ms rotation  
(Siemens Sensation 64)

N=37

HR 59 (IV betablocker)

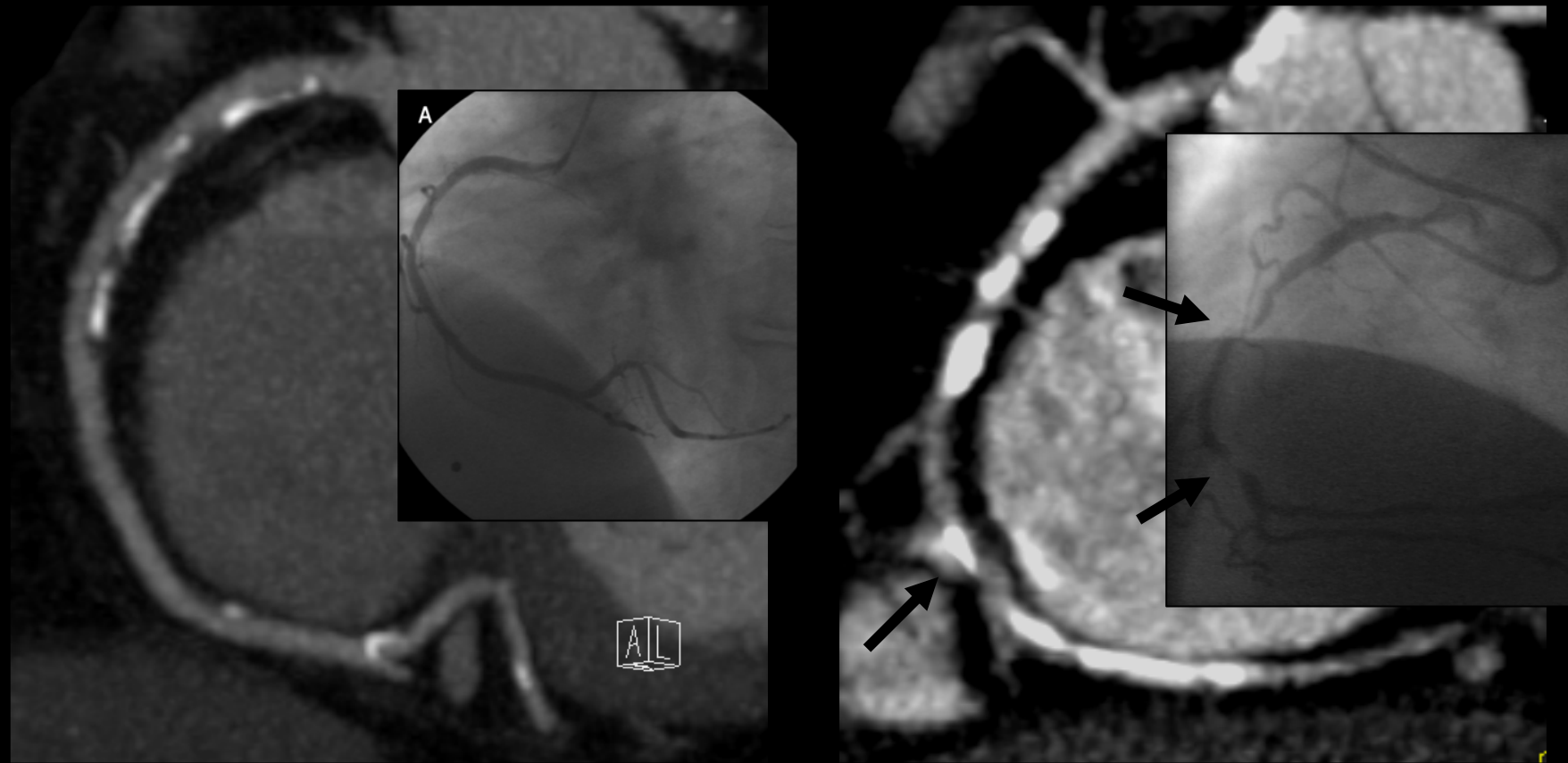
>1.5 mm vessels (7% excl.)

Sensitivity 93%

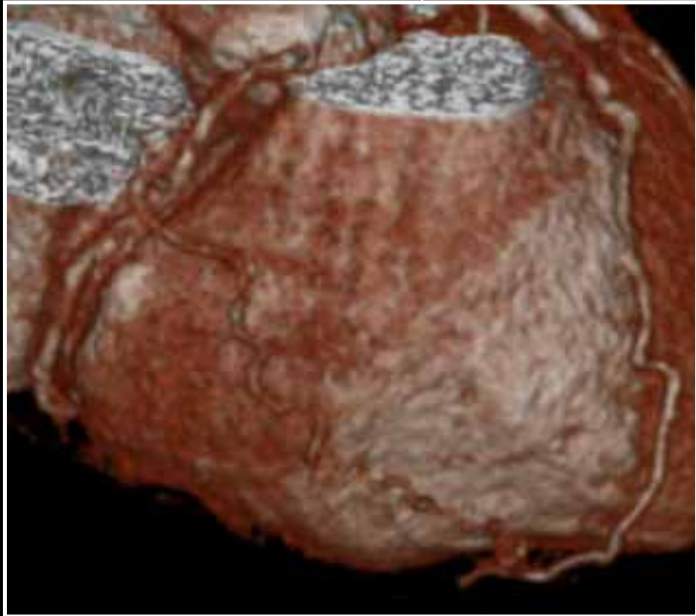
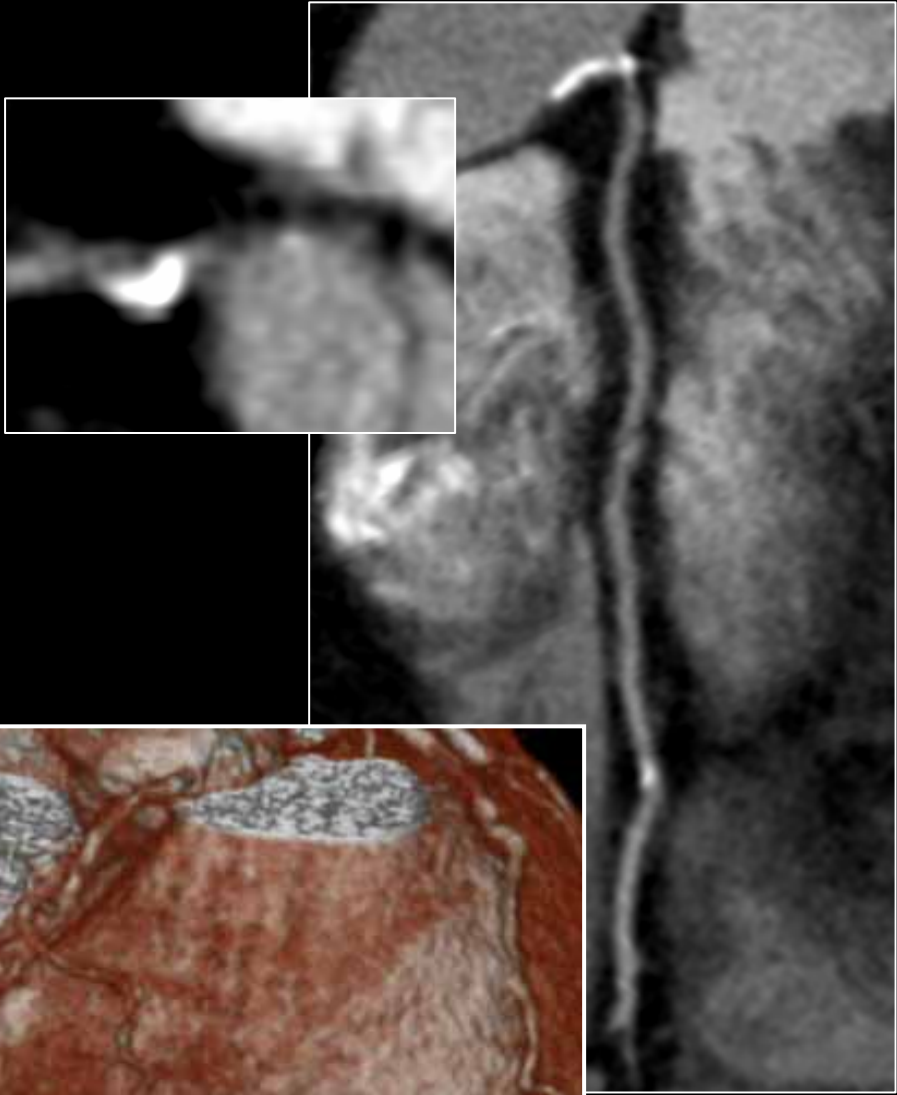
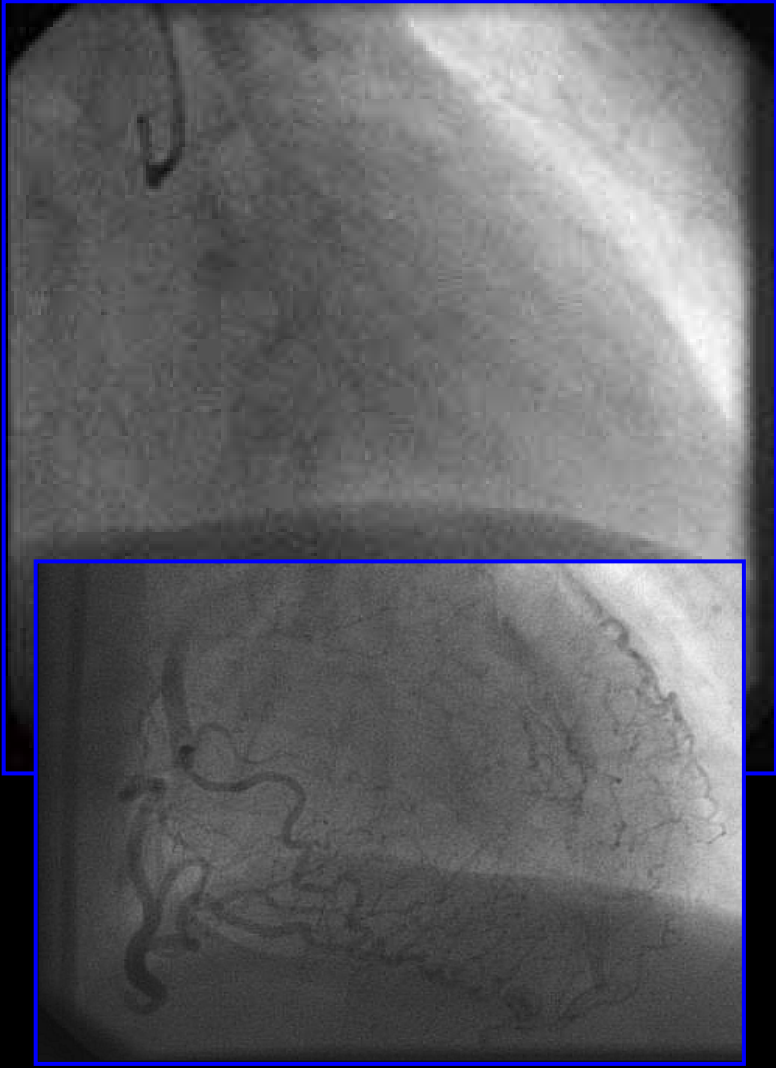
Specificity 95%

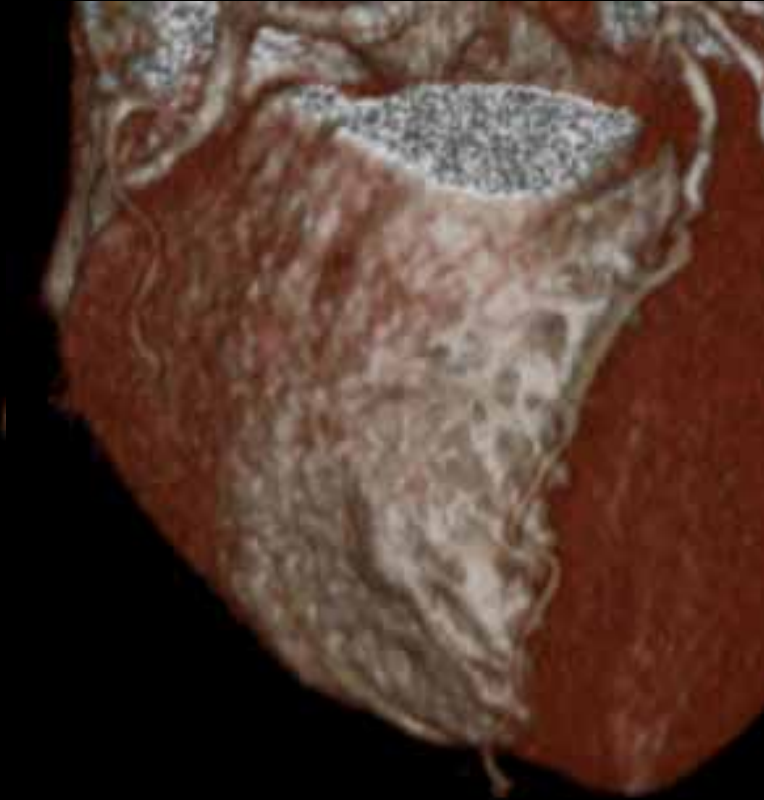
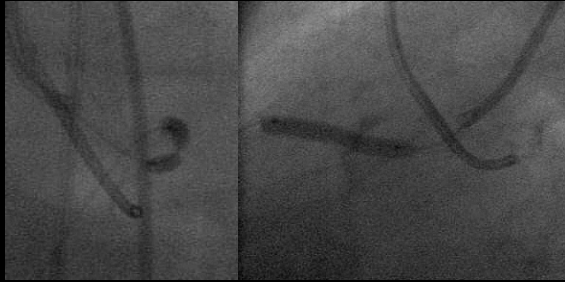
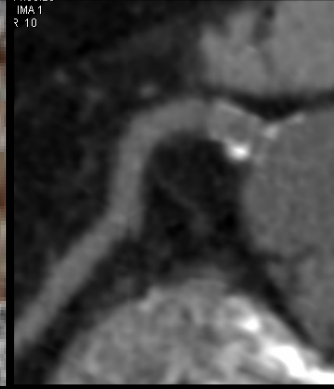
Overall accuracy 89%

# Coronary Calcification



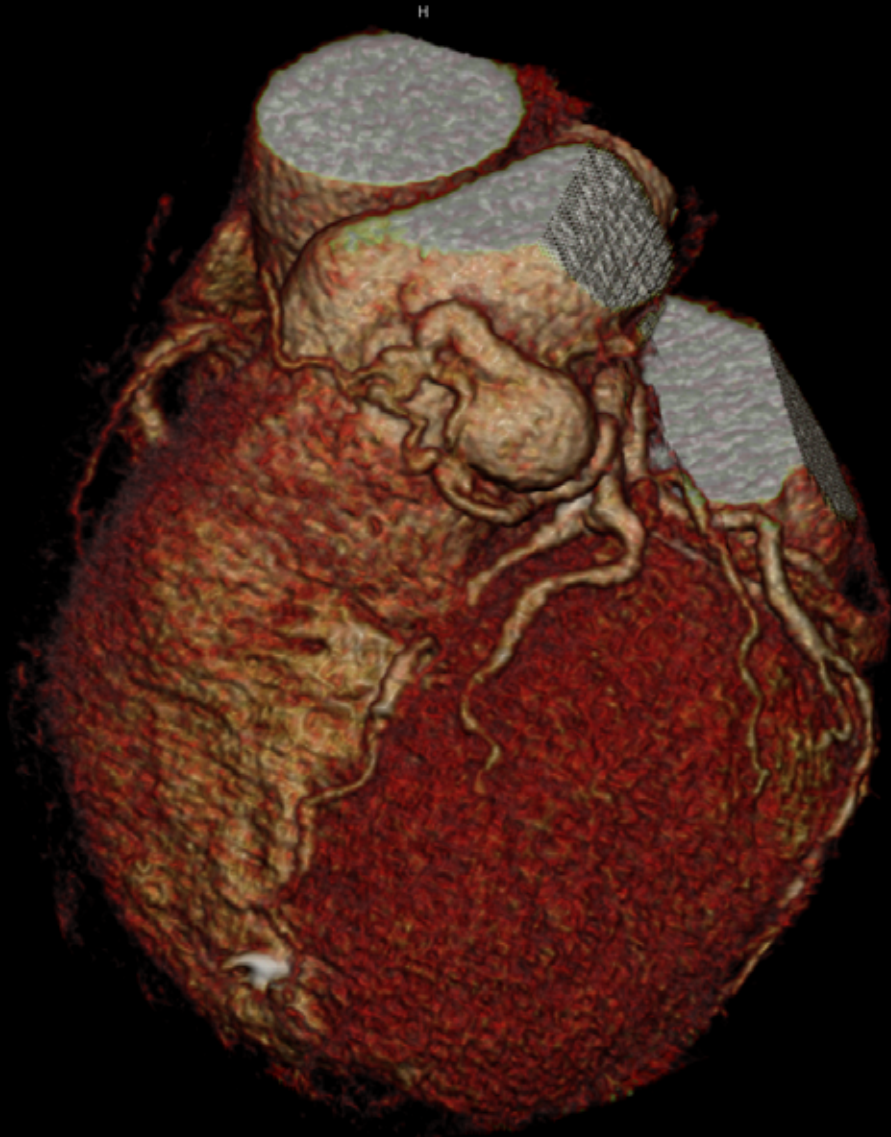
Occlusion proximal RCA  
- collateral filling via LAD



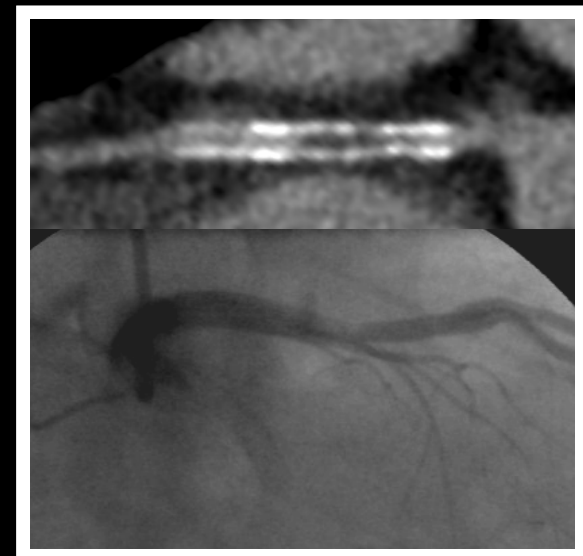
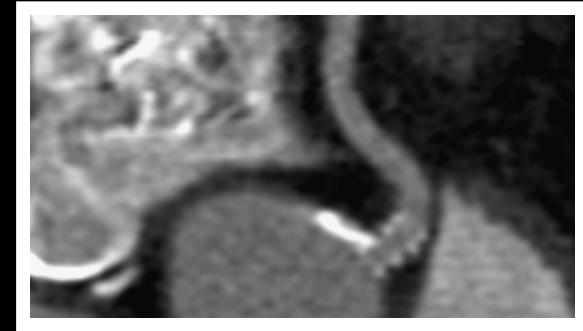
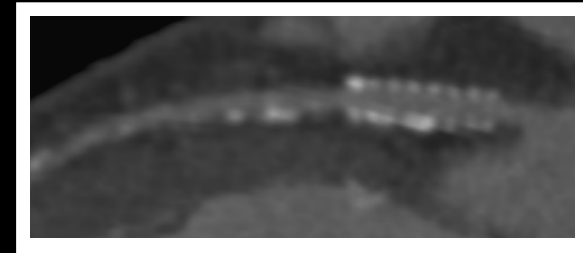




# Vascular Malformation



# Coronary Stents



## **Kuboyama et al, ACC 2005 - 16-MSCT:**

N=92, 176 stents

Sens 97% (30/31)

Eval. 89% (157/176)

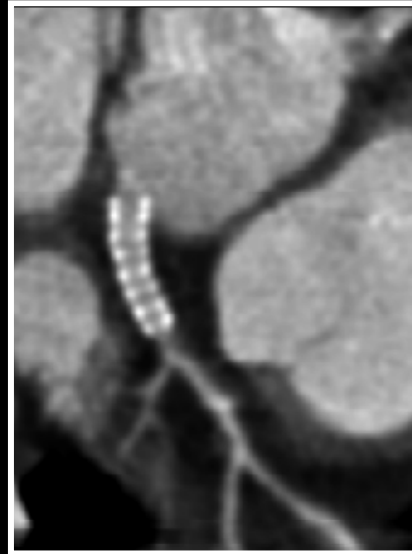
Spec 85% (107/126)

PPV 61% (30/49)

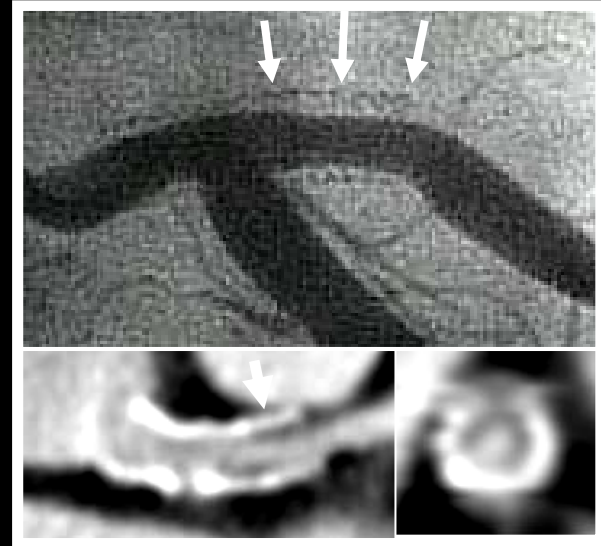
Overall acc 78%

NPV 99% (107/108)

# Follow-up after PCI of the LM



Nieman et al, Circ '02



Mollet et al, Circ '04

**Maupas (ACC '05):** N=135, 16-MSCT FU 6 months:

Assessable 86%

Sensitivity 71%

Positive PV 74%

Specificity 92%

Negative PV 94%

**Van Mieghem (ACC'05):** N=41, 16/64-MSCT FU 6 months:

Assessable 93%

Sensitivity 100%

Positive PV 27%

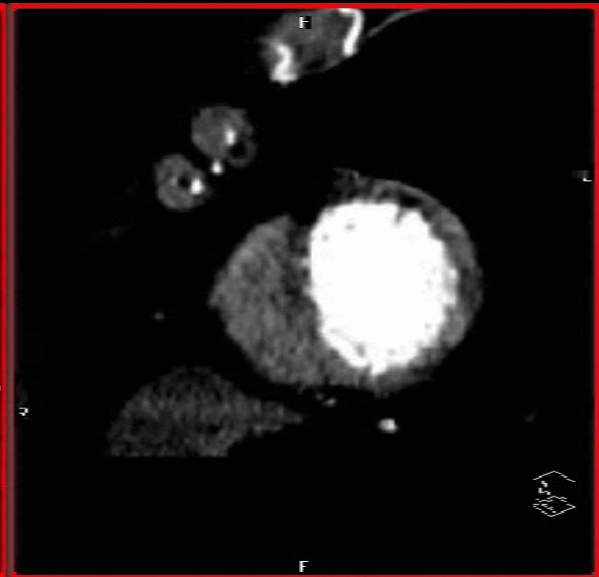
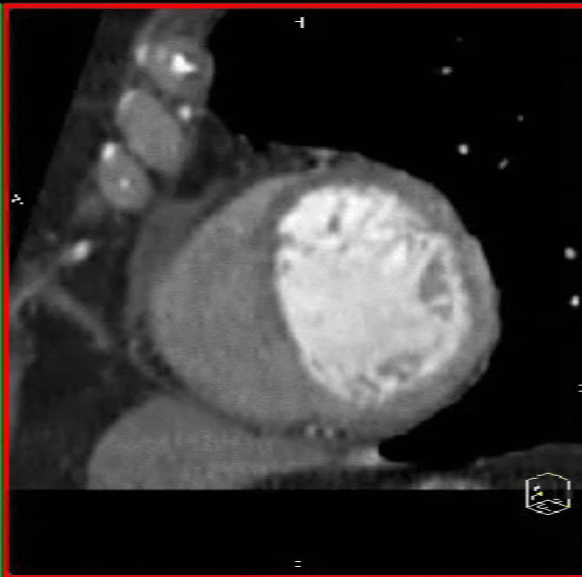
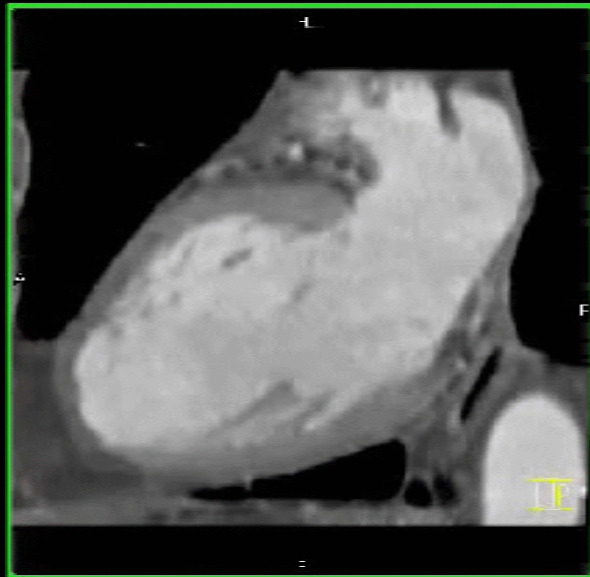
Specificity 77%

Negative PV 100%

# Graft & Stented Grafts



# Transmural Anterior MI



# CT After Myocardial Infarction

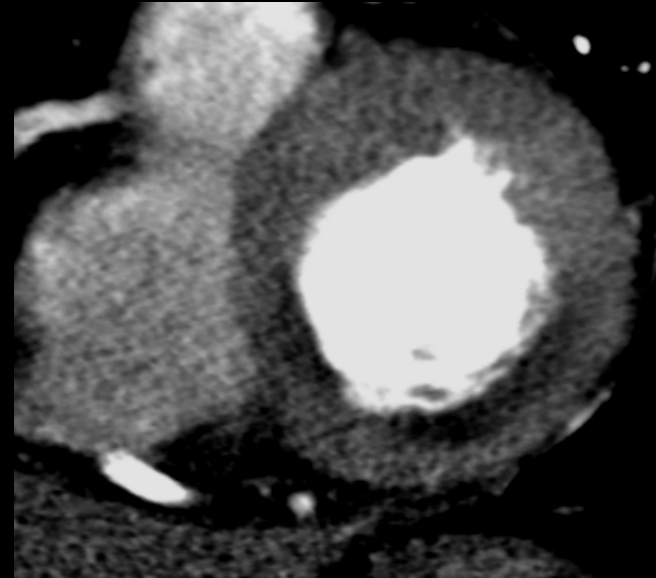
## Post-thrombolysis

### Coronary angiography

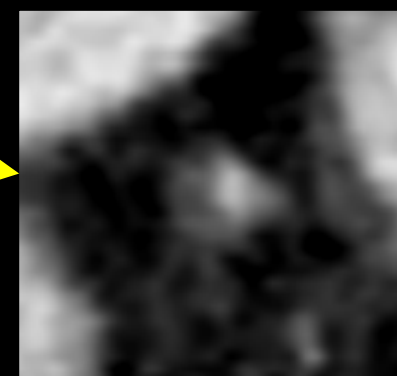
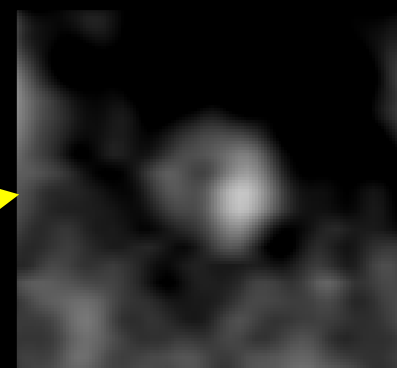
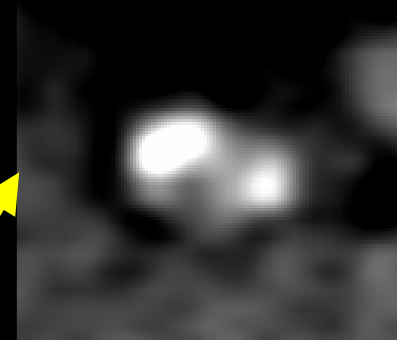
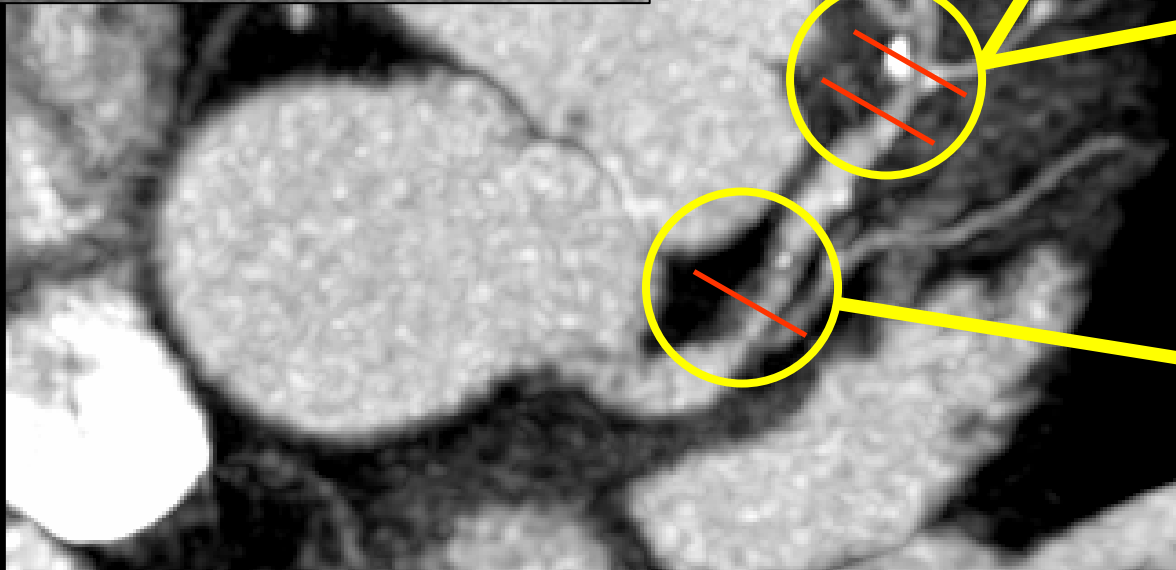
- Patency IRA
- Additional lesions
- Indication angiography

### Infarct imaging

- Localization & quantification
- Ventricular function
- Myocardial viability



# Plaque Detection by CT



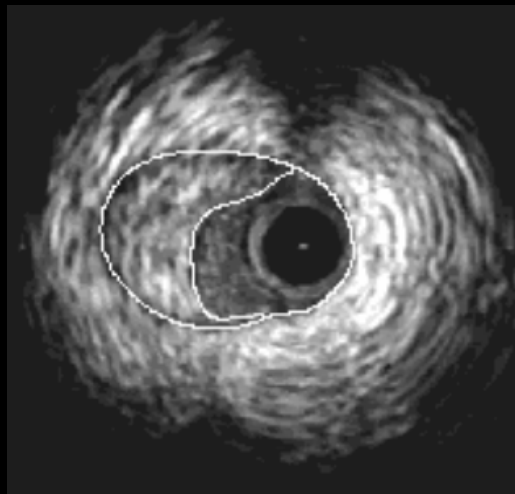
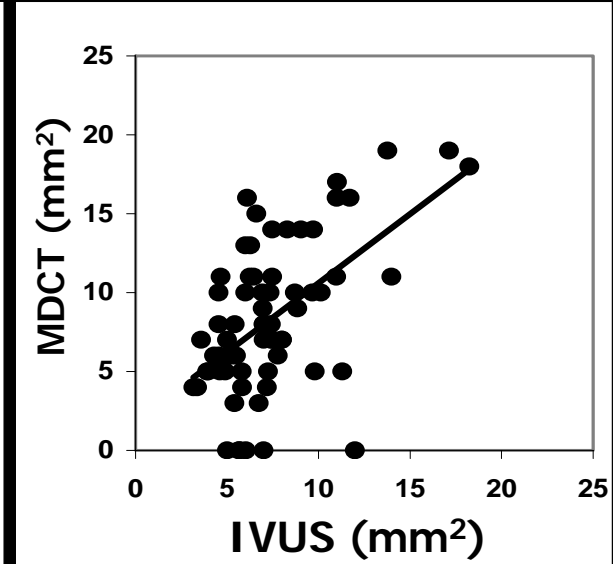
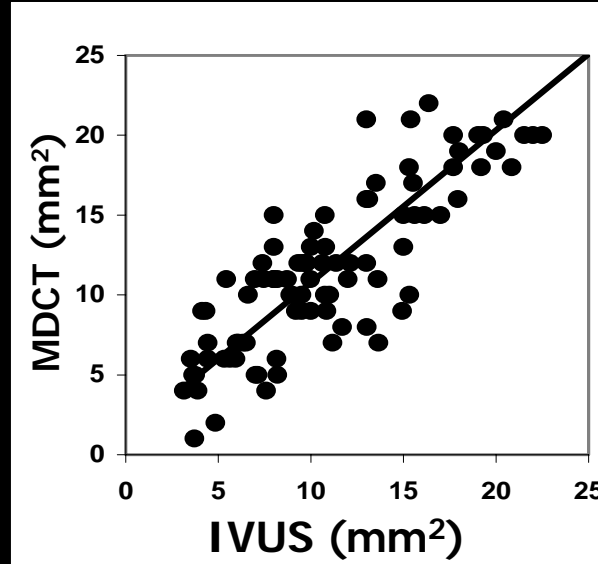
# Incidental *Soft* Plaques

- Risk?
- Therapeutic consequences?
  - Intervention
  - Medical
- Additional diagnostics?
- Need for follow-up?



# Lumen & Plaque Quantification

Moselewski F, Am J Cardiol. 2004



Luminal CSA (100)

CT  $13.6 \pm 8.3 \text{ mm}^2$

US  $12.9 \pm 8.0 \text{ mm}^2$

Mean difference:

$0.6 \pm 3.2 \text{ mm}^2$

( $p = 0.02$ )

Plaque CSA (65)

CT  $8.3 \pm 4.8 \text{ mm}^2$

US  $7.3 \pm 3.1 \text{ mm}^2$

Mean difference:

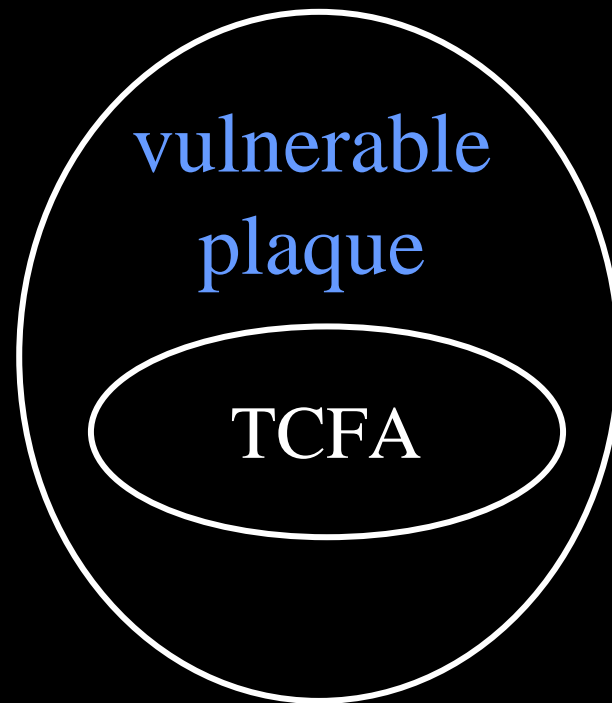
$0.9 \pm 4.0 \text{ mm}^2$

( $p < 0.001$ )

# The Vulnerable Plaque

## Morphology

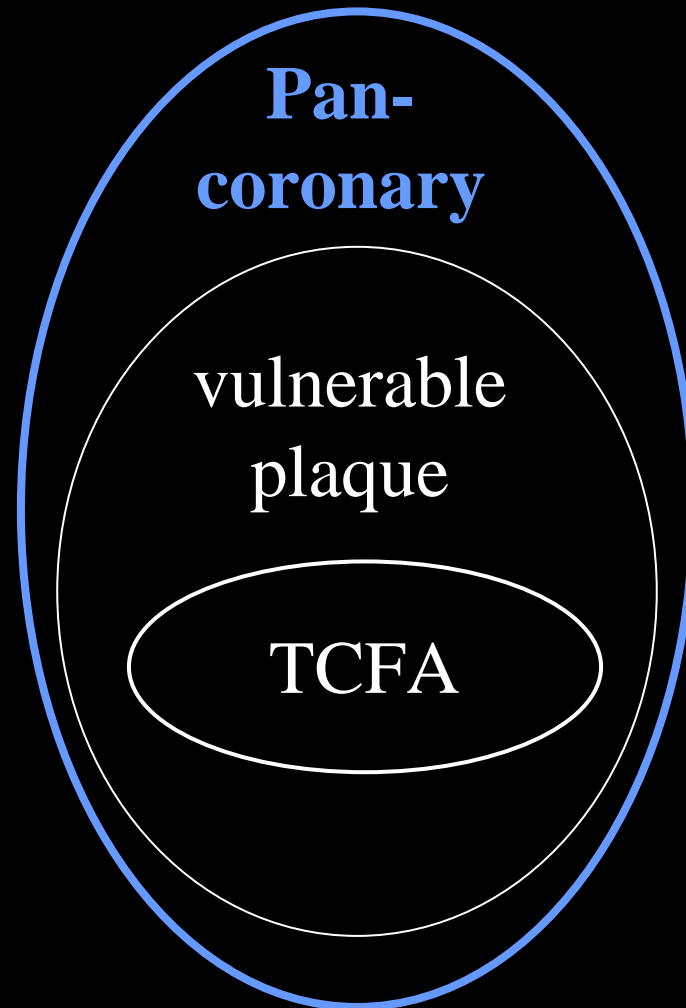
lipid core  
thin cap  
stenosis  
remodeling  
yellow color  
lipid content  
(elasticity)  
calcium  
coronary flow  
(shear stress)



## Function

Inflammation  
Endothelial function  
Endothelial denudation  
Oxidative stress  
Platelet aggregation  
Apoptosis rate  
Angiogenesis  
Matrix digestion (MMP)

# The Vulnerable Patient



## Pan-coronary disease

Multiple ruptures  
Bilateral markers

## Systemic screening

Coronary calcium

Endothelial function  
(vaso-reactivity)

Carotid IMT  
hs-CRP

# The Vulnerable Patient

