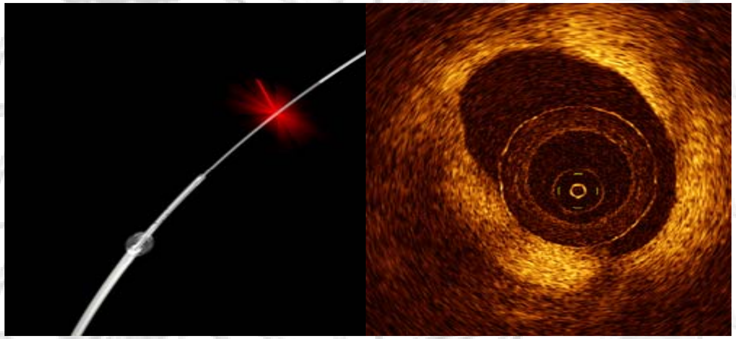
CPIS 2007

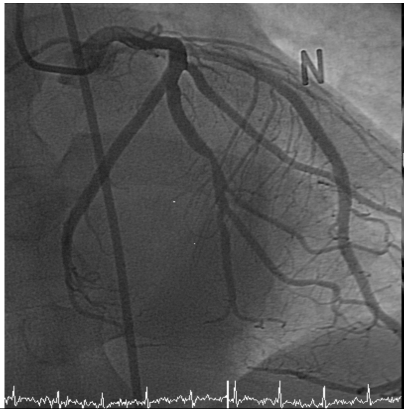
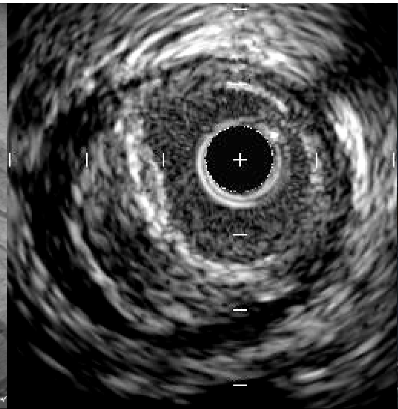
Optical Coherence Tomography "Overview"

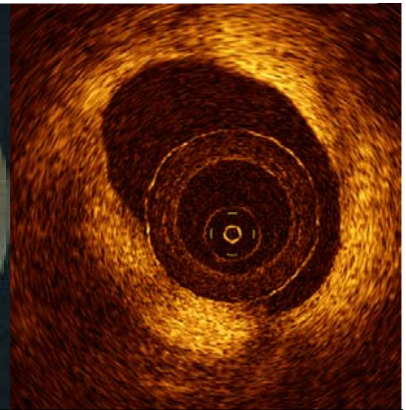


So-Yeon Choi, MD., PhD.
Department of Cardiology
Ajou University School of MedicineSuwon, Korea

Coronary Artery Imaging

The ideal coronary imaging technology would be capable of identifying not only vessel narrowing but also the characteristics of plaque hidden in the vessel walls.



	Angiography	IVUS	Angioscopy	OCT
Resolution (μm)	**100-200**	**80-120**	**10-50**	**10-20**
Probe size (mm)	**n/a**	**0.7**	**0.8**	**0.14**
Type of radiation	**X-ray**	**Ultrasound**	**Visible light**	**Near-IR light**
Other	**Images blood flow**	**Subsurface tomogram**	**Surface imaging only**	**Subsurface tomogram**

What is OCT?

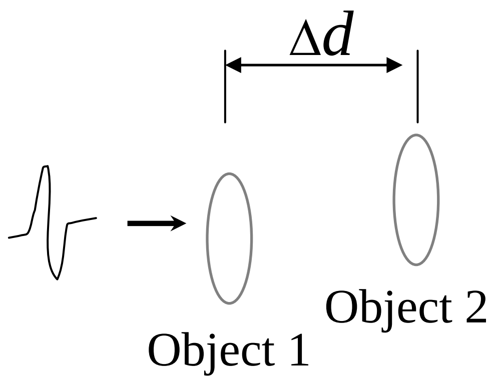
- Optical Coherence Tomography (OCT) is a high-resolution imaging technology that employs near-infrared light (1.3 μM) to probe micrometer-scale structures inside biological tissues.

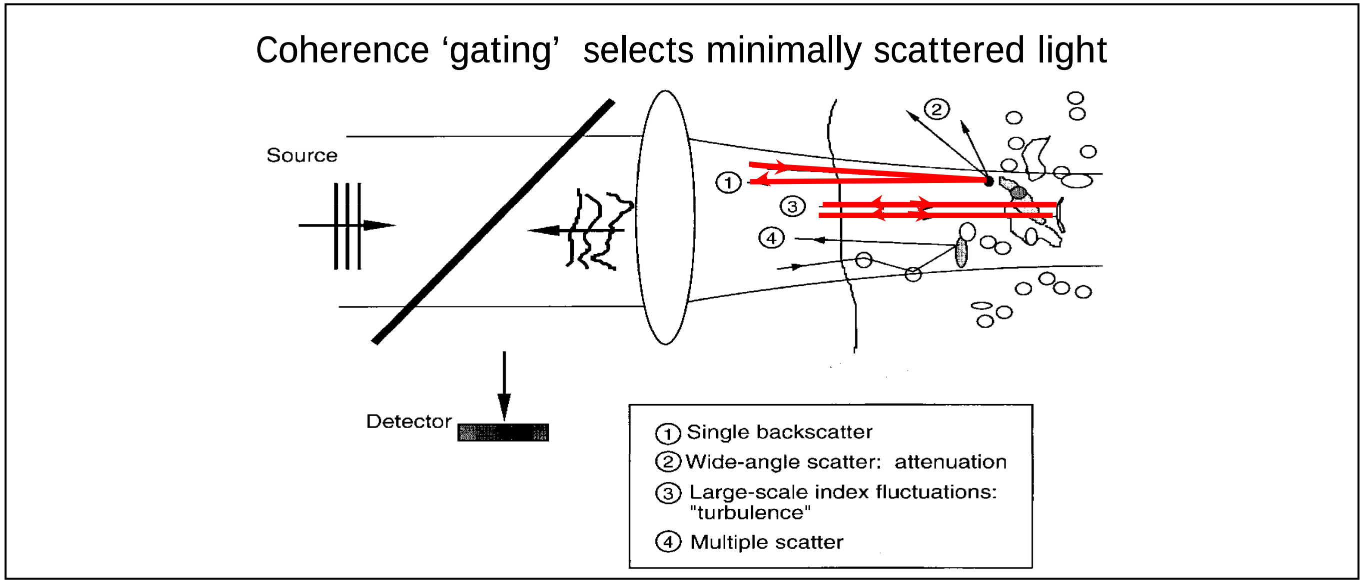
Near-infrared light

- 0.77-3μm, biologically safe
- Property of particle and wave
  - Goes straightly
  - Reflection, refraction, interference, diffraction
  - Doppler effect

What is OCT?

- Analogous to sonar and radar, OCT measures back-reflected optical intensity <u>in terms of “optical echoes”</u>.



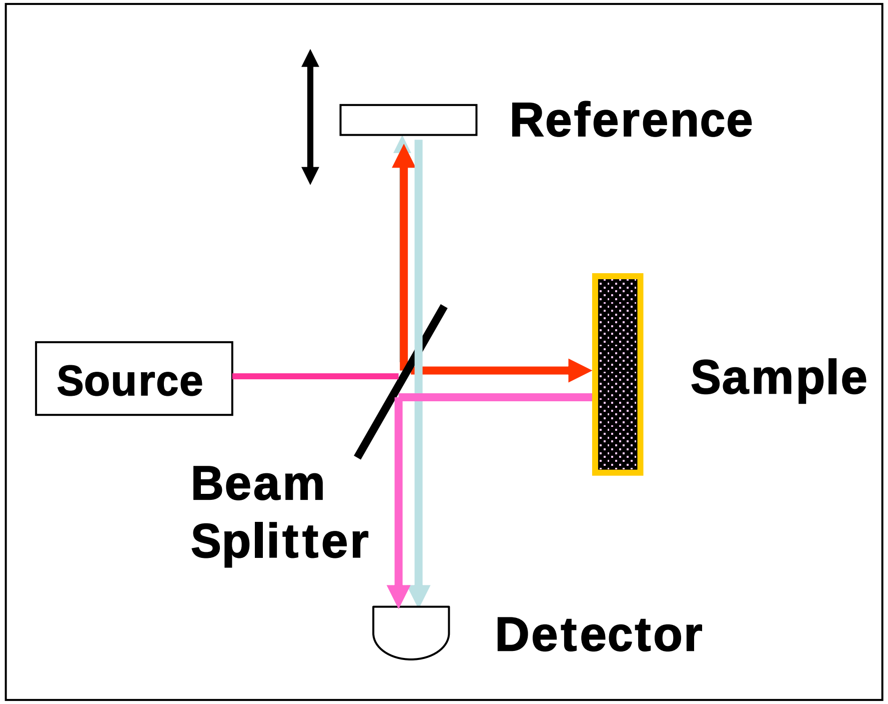


OCT System: Interferometry

To generation of OCT image, the key basic mechanism is interferometry.

- Interferometer splits broadband light from source into reference and sample beams.
- A fraction of the light backscattered from the artery into the interferometer, where it mixes with a reference beam.
- When the back-reflected optical intensity of the two arms is measured and compared, the optical properties of the tissue can be deduced.

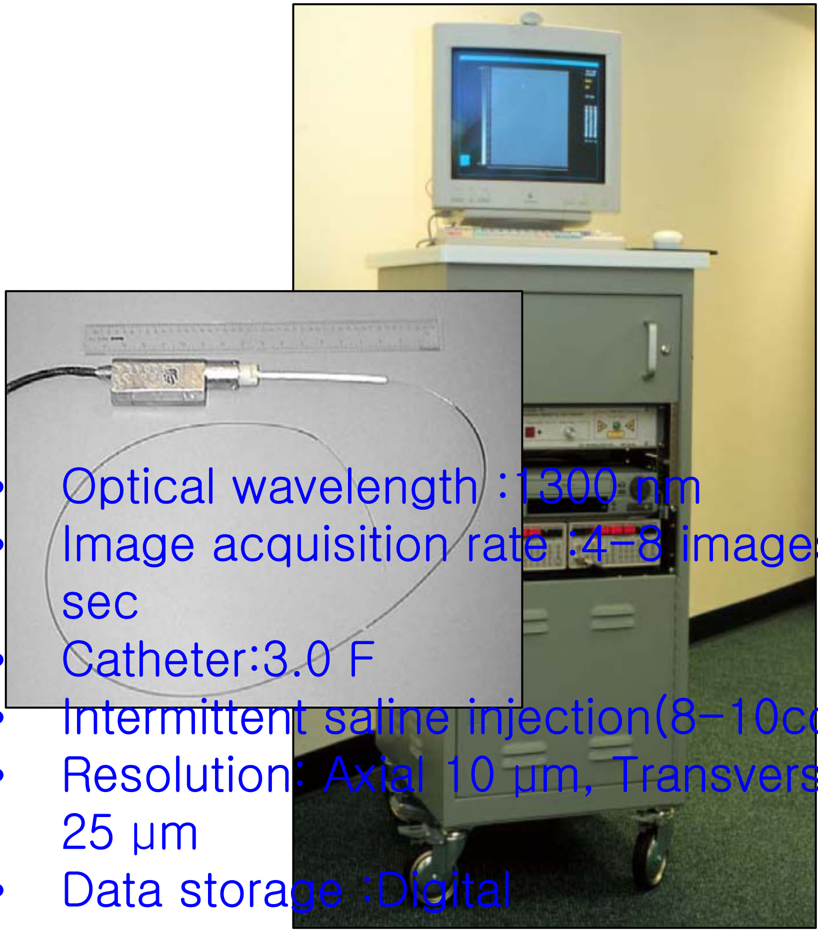
Interferometer Schematic



Brief History of Development of OCT

- 1990-91 : Invention of OCT by Fujimoto (USA), Tanno (Japan)
- 1996 : Exploratory in vitro studies by Brezinski et al in MIT and MGH
- 1996-99 : Validated the superior resolution compared to IVUS by Weissman
  : In vivo imaging in animal (rabbit) by Fujimoto
- 2000 : First published clinical studies by Jang, Bouma, Tearney, Park et al. US, Korea
- 2002- : Commercialization phase
  : Clinical trials began by Grube, Serruys, William, Suzuki
- 2003 : CE-approved on Oct
- 2006- : KFDA approved on Nov
  : FDA and MHLW will approved

OCT Imaging Systems



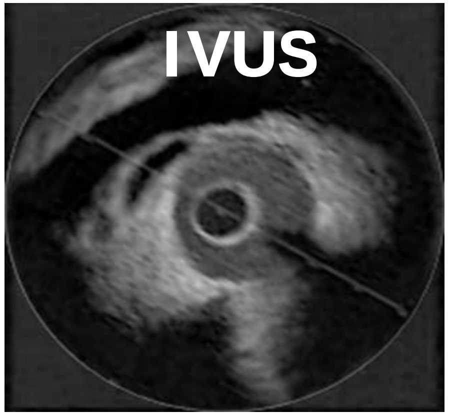
- Optical wavelength :1300 nm
- Image acquisition rate :4-8 images / sec
- Catheter:3.0 F
- Intermittent saline injection(8-10cc)
- Resolution: Axial 10 μm, Transverse 25 μm
- Data storage :Digital

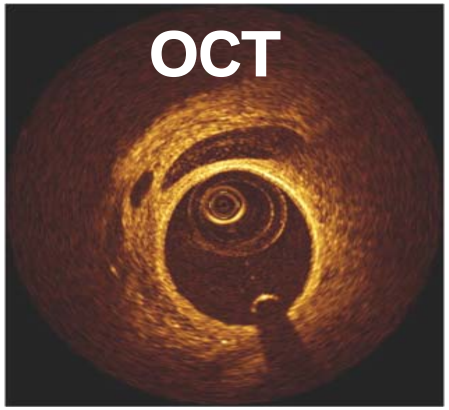
MGH OCT system

- Optical wavelength :1280-1350 nm
- Image acquisition rate : 15 images / sec
- Catheter:4.0 F, Image wire: 1.4F
- Balloon occlusion with continuous saline injection 0.5 ml/s
- Resolution: Radial 15μm
- Data storage :Digital

LightLab system

Comparison of IVUS and OCT



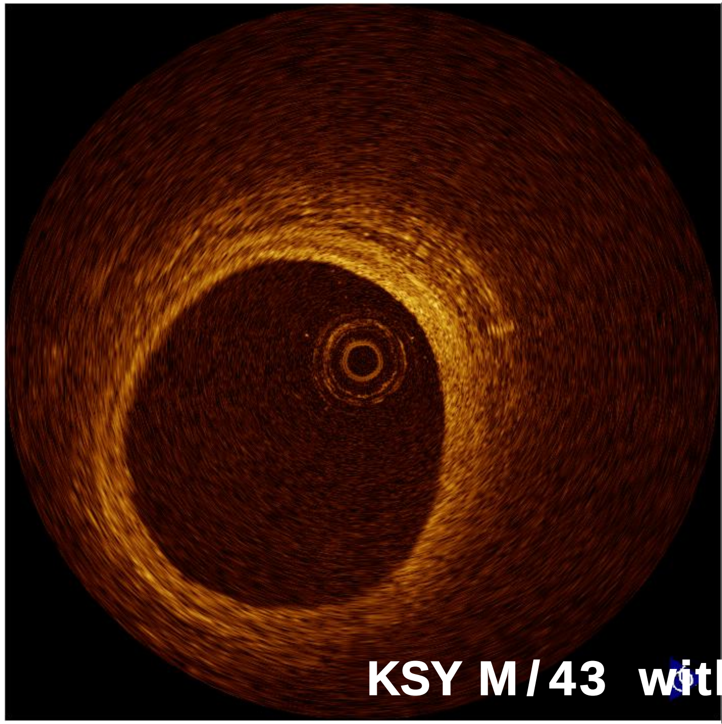


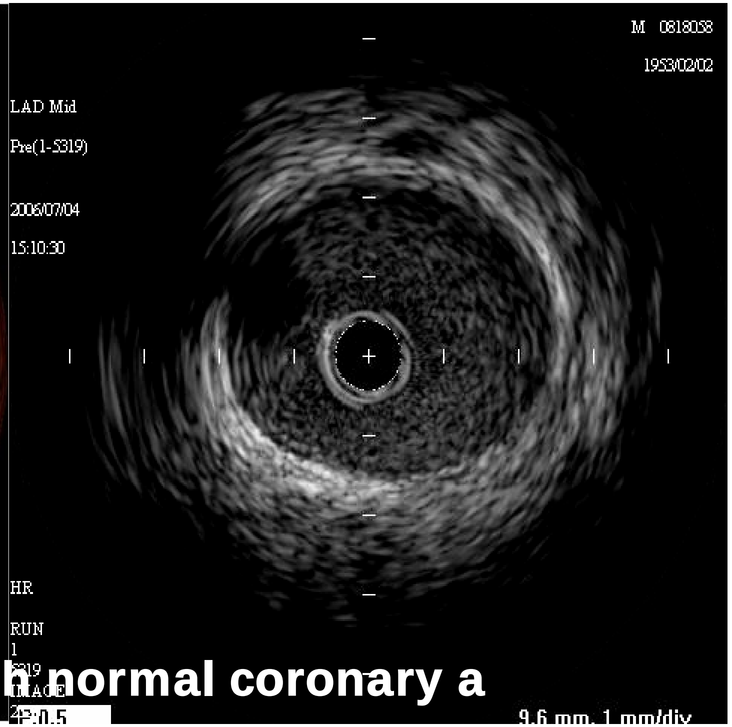
		IVUS	OCT
Resolution	*(axial)*	100 - 150 mm	10 - 20 mm
	(lateral)	150 - 300 mm	25 - 40 mm
Size of imaging core		0.8 mm	0.4 mm
Dynamic range		40 - 60 dB	90 - 100 dB
Frame rate		30 frames/s	15 frames/s
Scan area		10 - 15 mm	7.0 mm
Max. depth of penetration		4 - 8 mm	1 – 1.5 mm
		Blood clearing not required	Requires blood clearing

Normal Vessel Image by OCT

Evaluation of Normal Structure

Comparison with IVUS



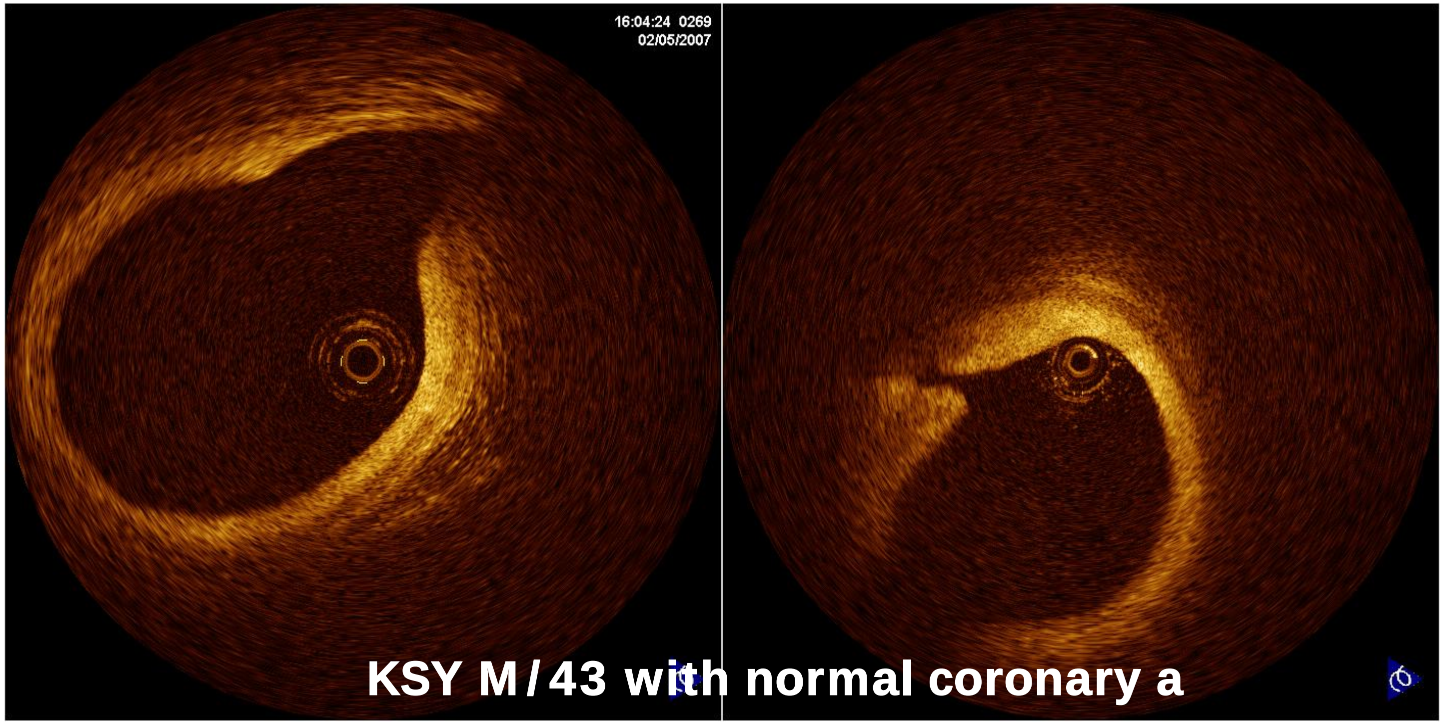


KSY M/43 with normal coronary a

Normal Vessel Image by OCT

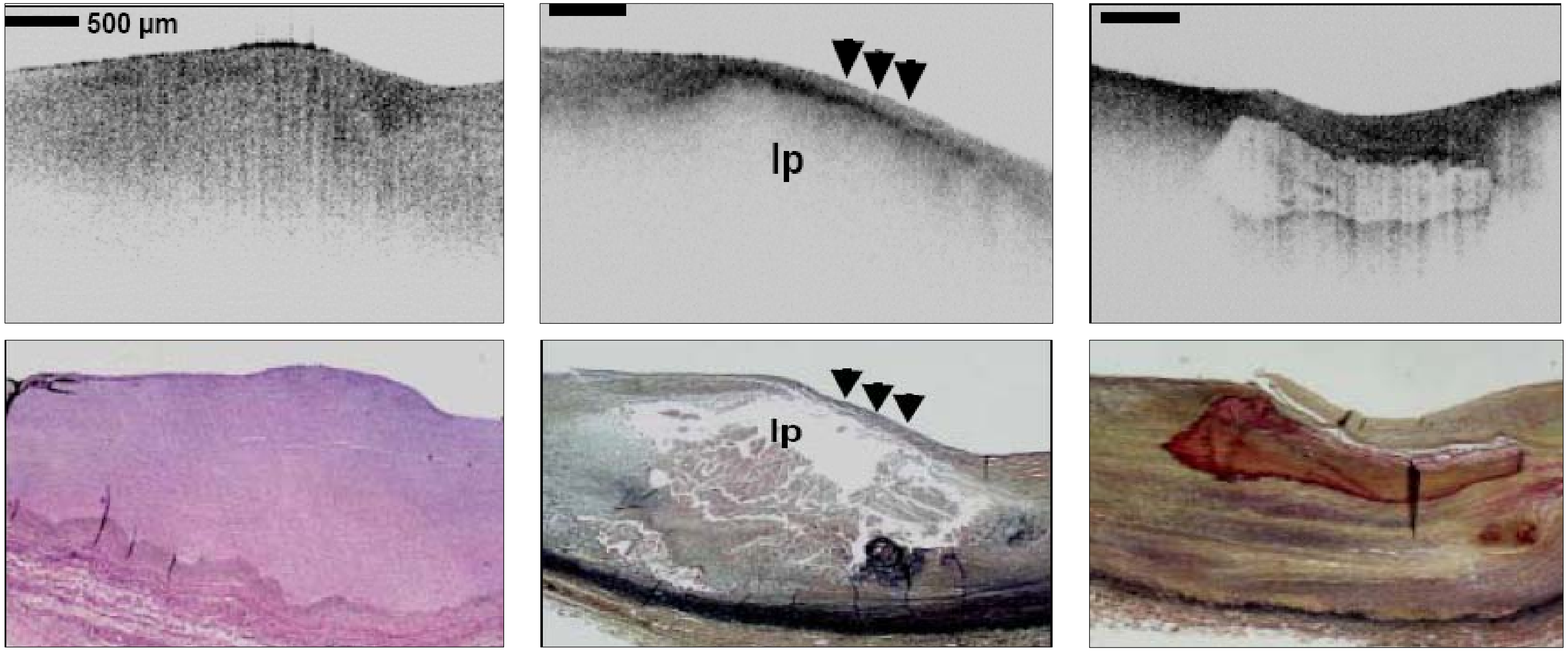
Evaluation of Normal Structure

LAD-first diagonal br | LAD-small septal br



Plaque Characterization by OCT
Ex Vivo Study

Fibrous | **Lipid-rich** | **Calcified**



Homogenous Signal-rich | **Echolucent Diffuse border** | **Echolucent Sharp border**

Presented by IK Jang in 2002 TCT

Plaque Characterization by OCT
Ex Vivo Study

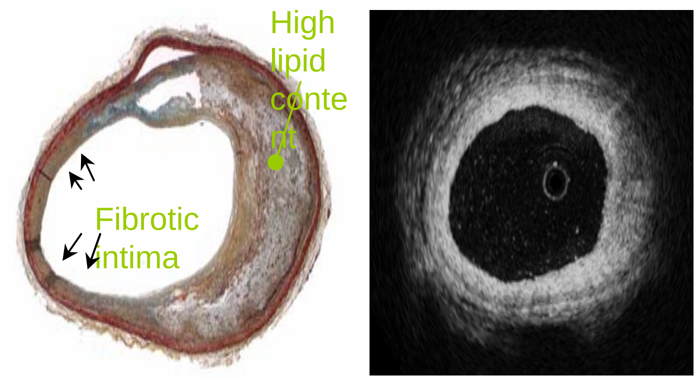
	Sensitivity	Specificity	Positive predictive value	Negative predictive value
Fibrous	0.87	0.97	0.88	0.96
Calcific	0.95	0.1	0.1	0.95
Lipid pool	0.92	0.94	0.81	0.97

Accuracy Statistics: Interobserver k=0.88, Intraobserver k=0.91

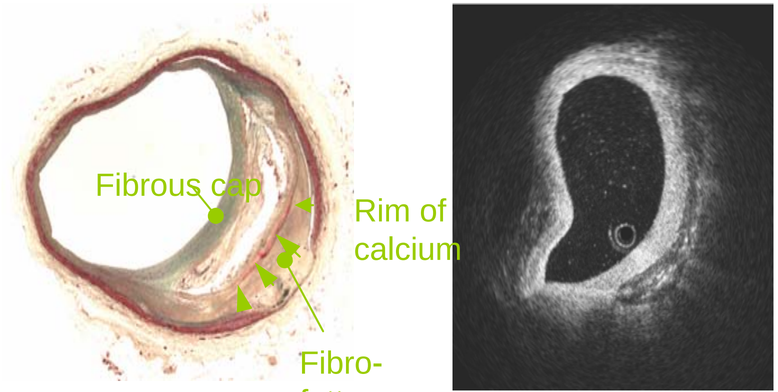
H Yabushita, IK Jang, et al. Circulation. 2002;106:1640-45

Plaque Characterization by OCT
Ex Vivo Study

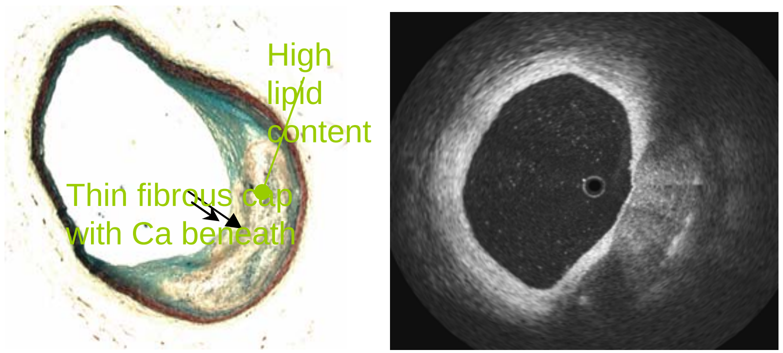
Thick-capped Fibroatheroma



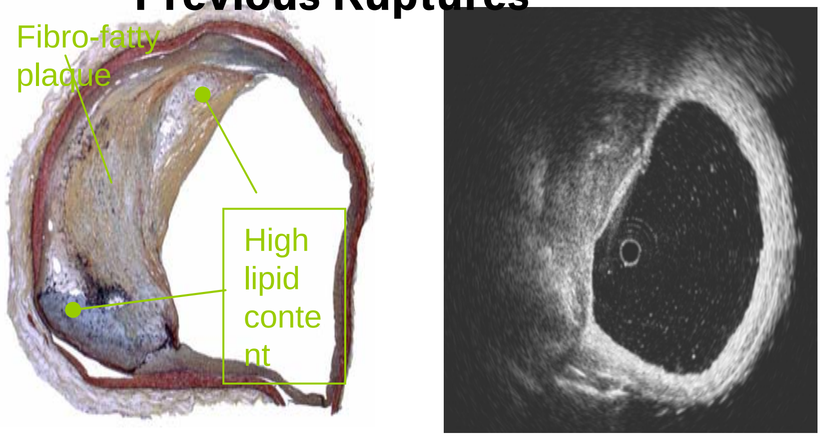
Calcified Lesion



Thin-capped Fibroatheroma



Mixed-composition Plaque
Previous Ruptures



Histology courtesy of E. Mont and R. Virmani

Plaque Characterization by OCT
In Vivo Experience

Fibrous

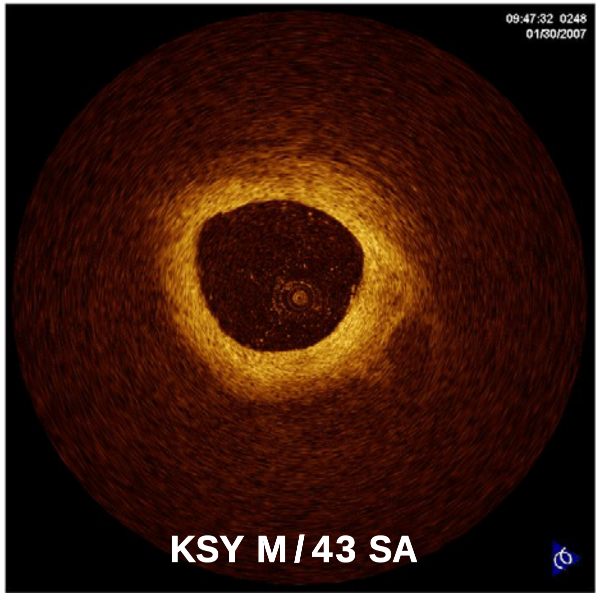
- High reflectivity
- Homogenous
- Finely textured

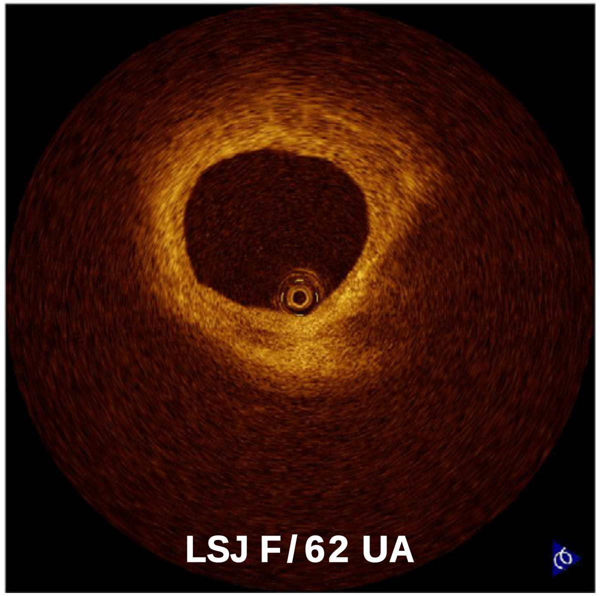
Lipid-rich

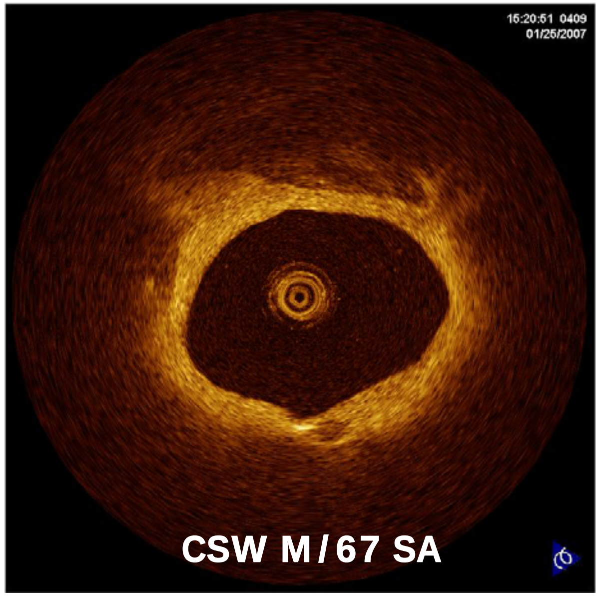
- Low reflectivity
- Homogenous
- Diffuse margins

Calcified

- Low reflectivity
- Inhomogeneous
- Sharp margins
- Isolated, strong reflections in dark background







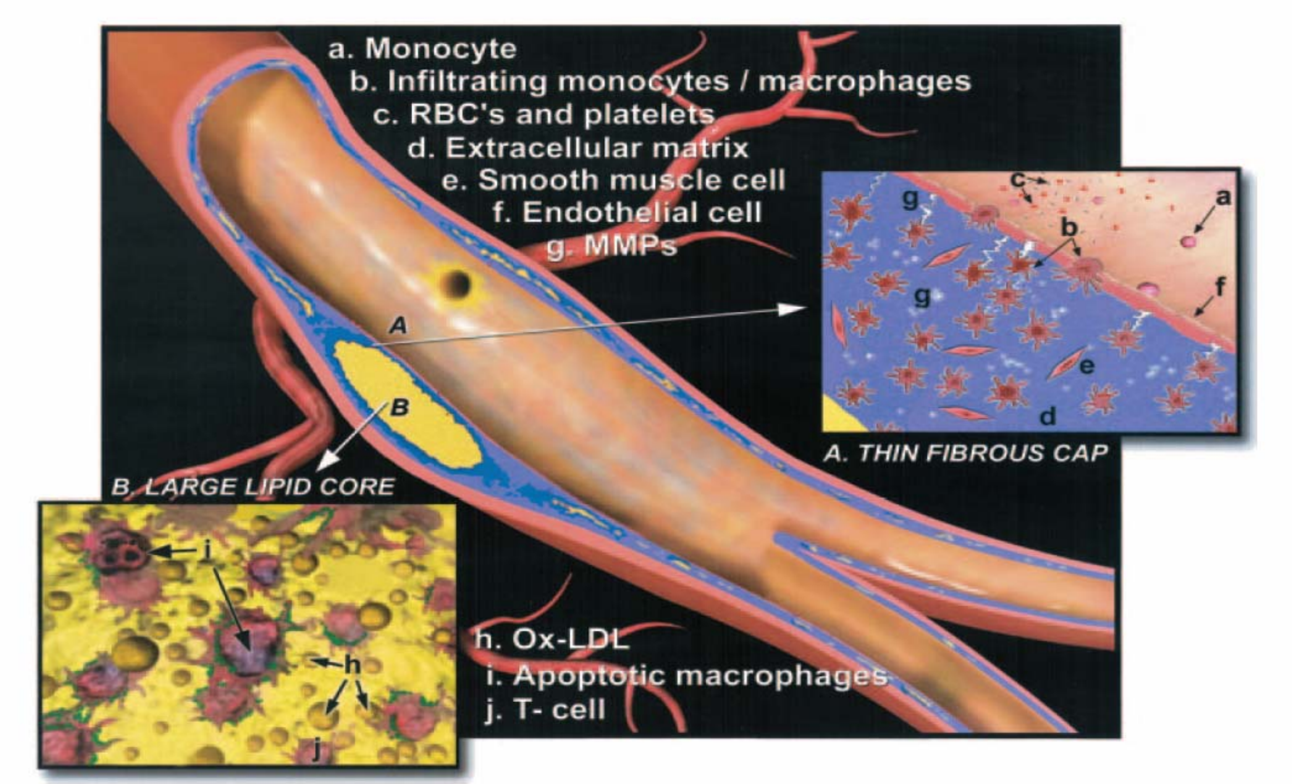
Potential Applications of OCT

- Vulnerable Plaque

- Therapeutic Guidance

- Evaluation of Therapeutic Results

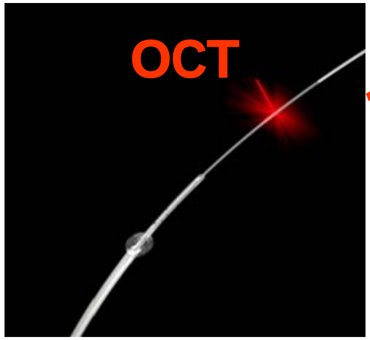
Characteristics of Vulnerable Plaque



The most common type of vulnerable plaque characterized by thin fibrous cap, extensive macrophage infiltration, paucity of smooth muscle cells, and large lipid core, without significant luminal narrowing.

Criteria for Defining Vulnerable Plaque

Based on the autopsy study



Major criteria

- Active inflammation (monocyte/macrophage and T-cell infiltration)
- Thin cap with large lipid core
- Endothelial denudation with superficial platelet aggregation
- Fissured plaque
- Stenosis 90%

Minor criteria

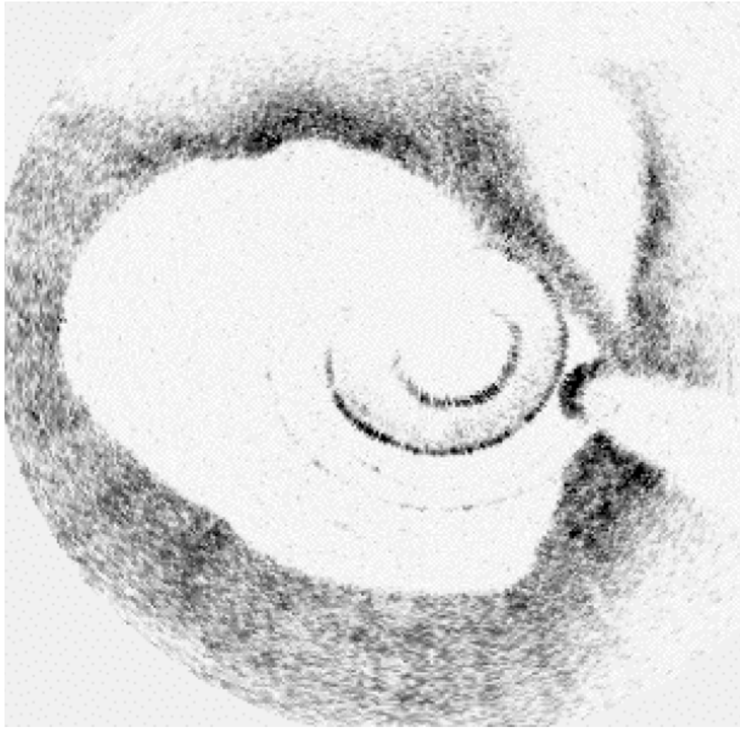
- Superficial calcified nodule
- Glistening yellow
- Intraplaque hemorrhage
- Endothelial dysfunction
- Outward (positive) remodeling

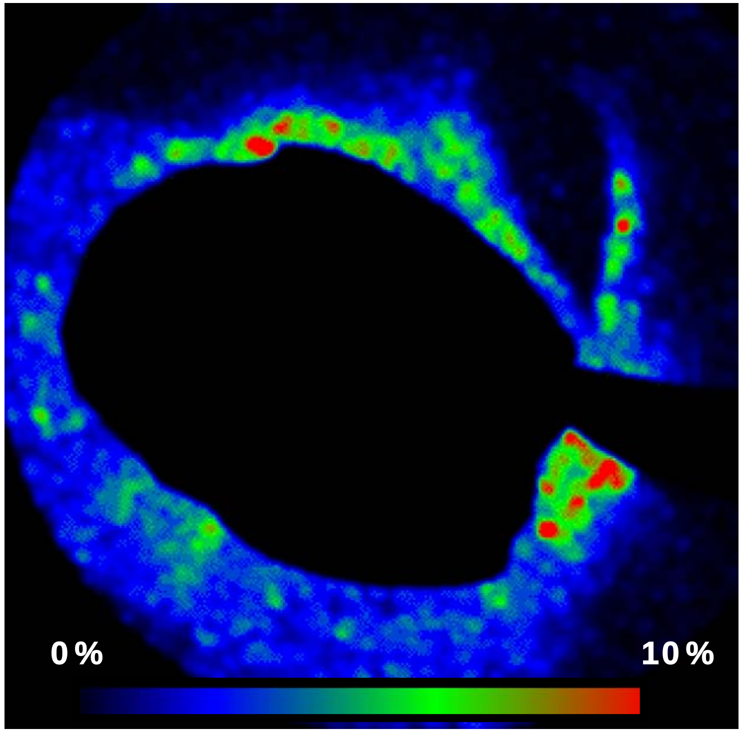
Circulation. 2003;108:1664-1672

Detection of VP in OCT
Macrophage Accumulation

There was a high degree of positive correlation between OCT and histological measurements of fibrous MQ density r=0.84, p<0.0001.

OCT Image **MQ Density**





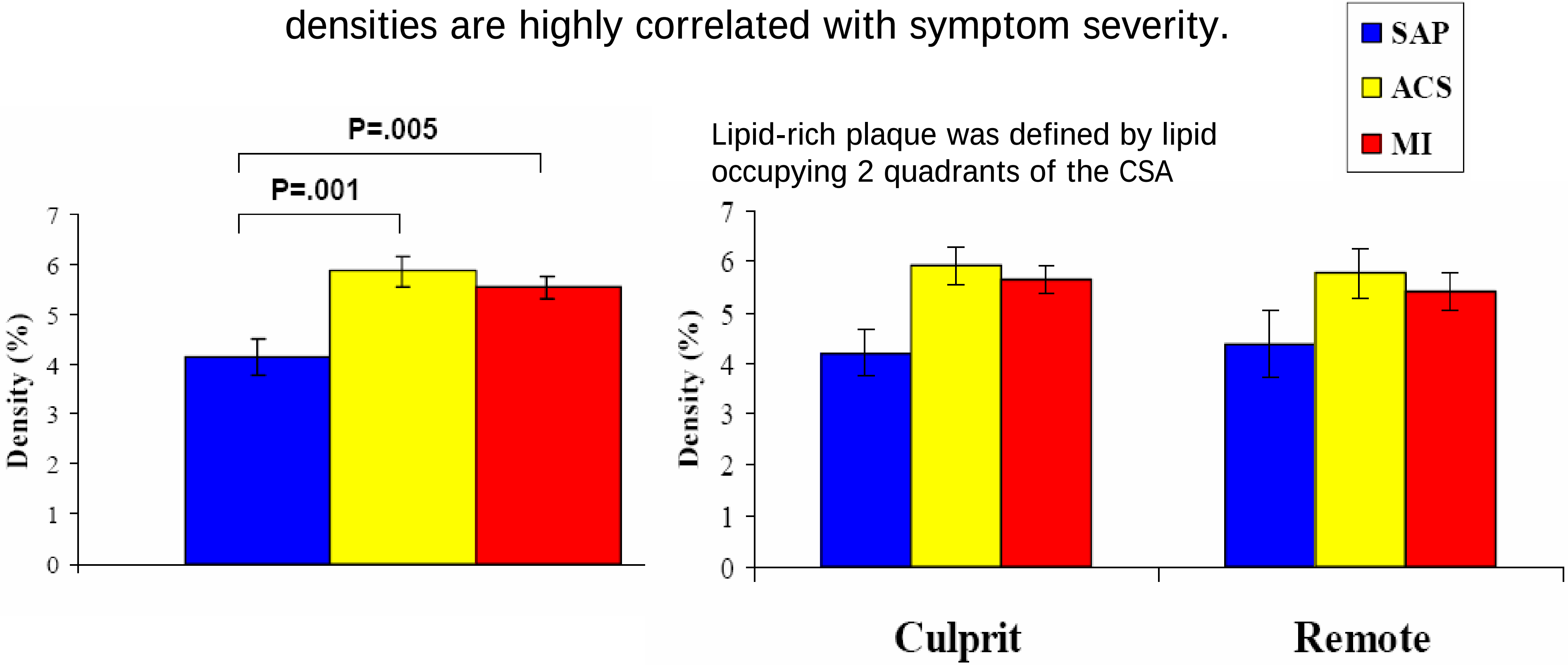
GJ Tearney, et al. Circulation 2003;107:113-9
Briain D. MacNeill, et al. J Am Coll Cardiol 2004;44:972–9

Detection of VP in OCT
Macrophage Accumulation

119 lipid rich plaques in 49 patients
49 AMI; 46 ACS; 24 SAP

The increases in both multi-focal and focal macrophage densities are highly correlated with symptom severity.

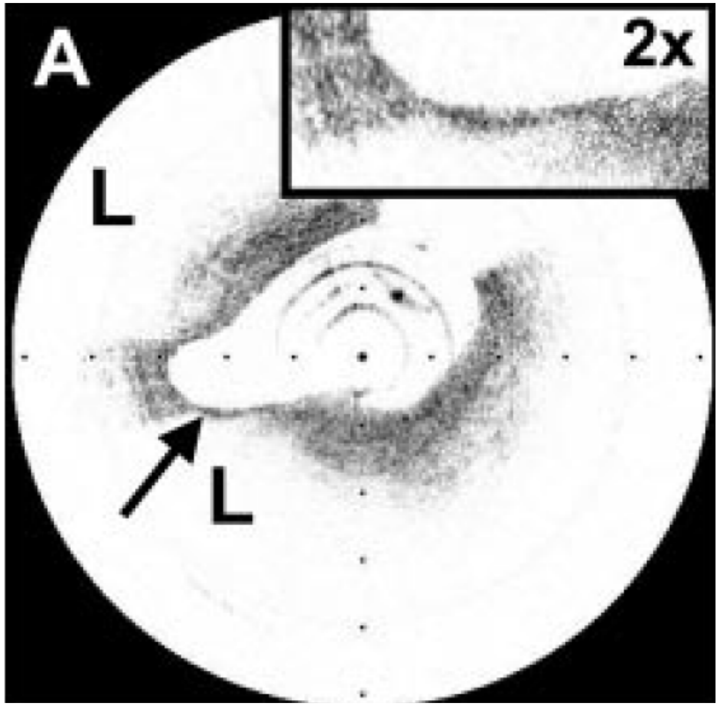
Lipid-rich plaque was defined by lipid occupying 2 quadrants of the CSA



Briain D. MacNeill, et al. J Am Coll Cardiol 2004;44:972–9

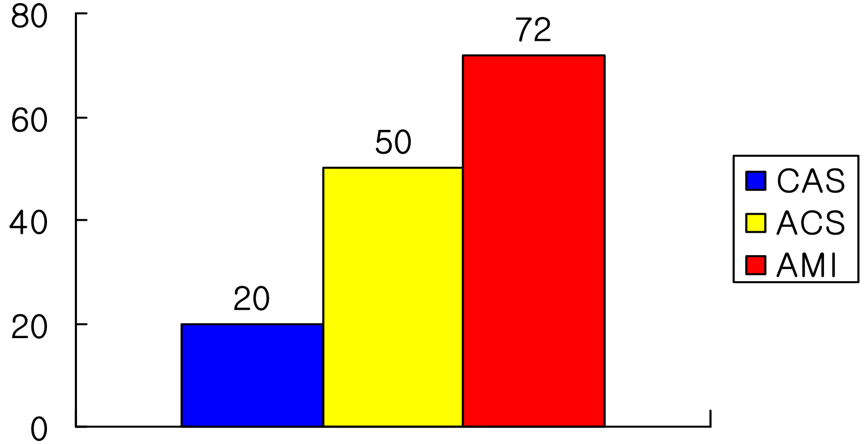
Detection of VP in OCT
Thin Fibrous Cap

57 patients: 20 AMI, 20 ACS, 17 SAP



Thin-cap fibroatheroma was defined by lipid-rich plaque with cap thickness 65 μm

Thin-cap fibroatheroma was more frequently observed in patients with AMI or ACS than SAP.

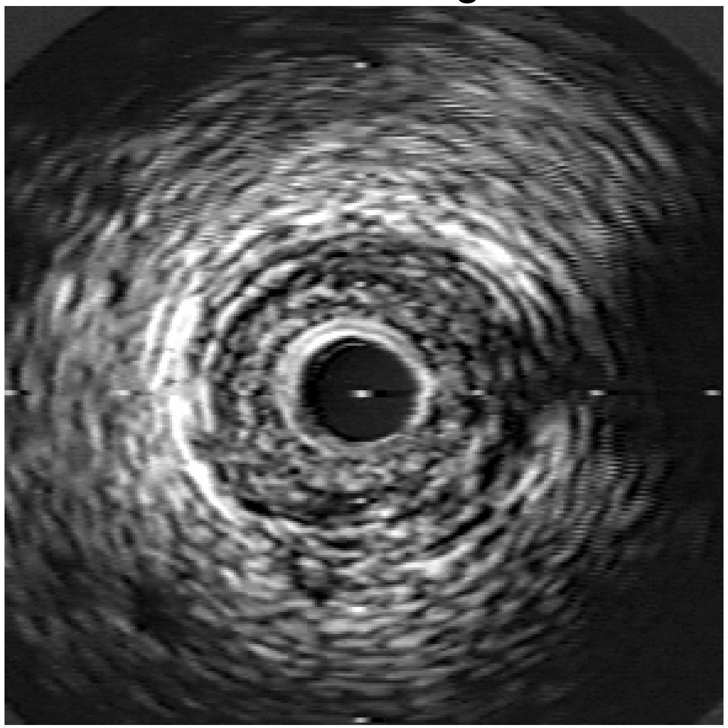


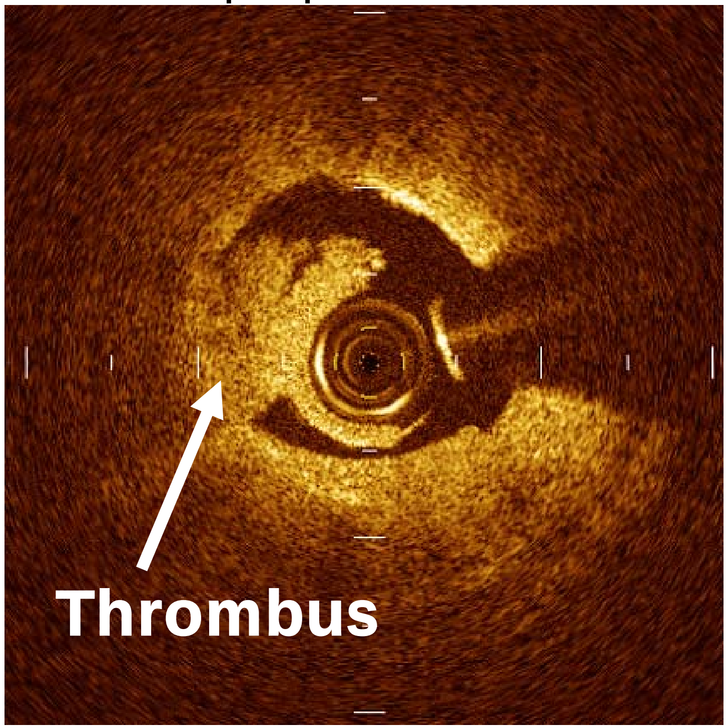
Thin-cap Fibroatheroma

IK Jang, et al. Circulation. 2005;111:1551-5

Detection of VP in OCT
Thrombus

OCT may allow us not only to estimate plaque morphology but also to distinguish thrombus from the plaque.

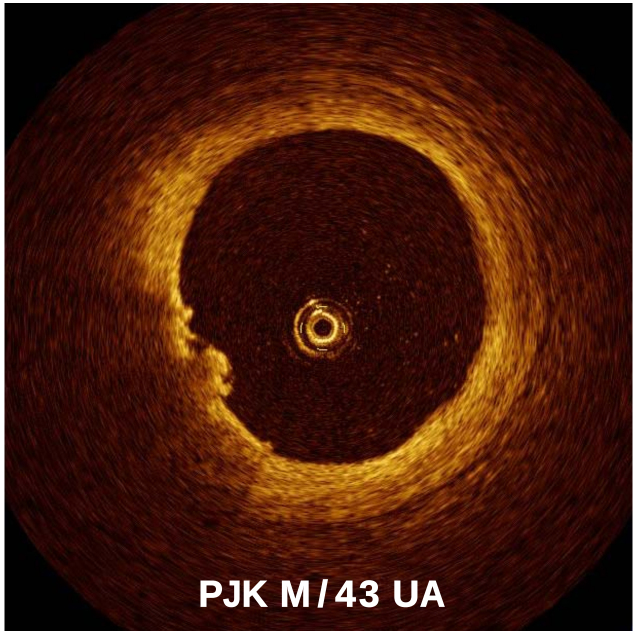




Presented by Dr. Suzuki. Toyohashi Heart Center

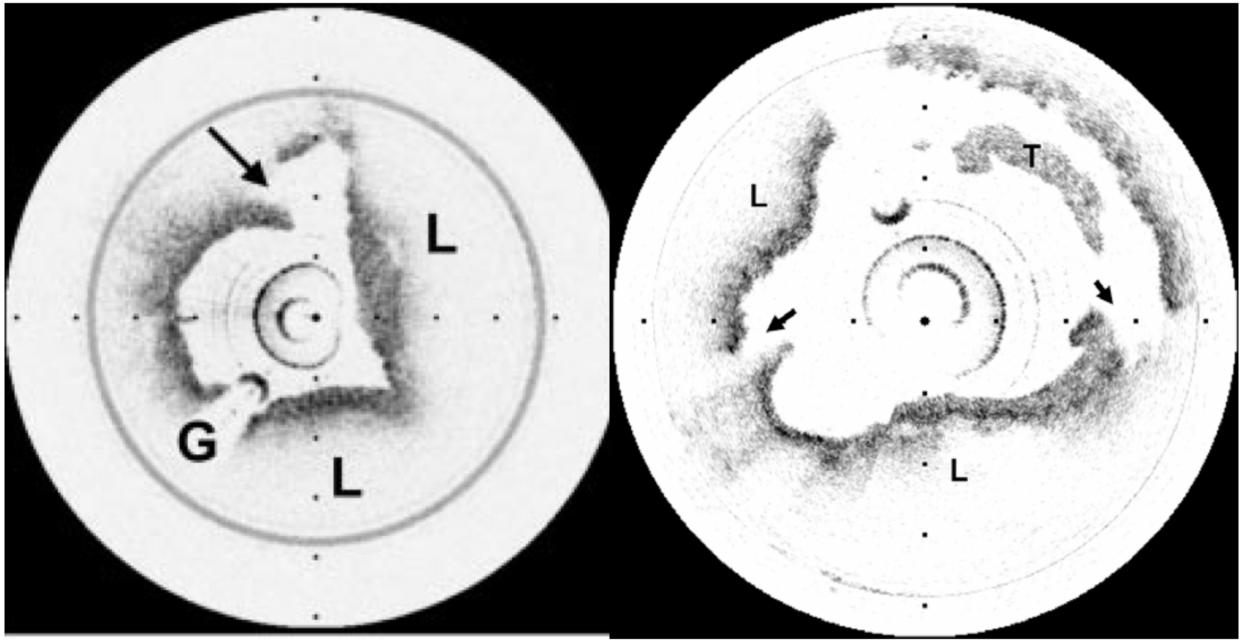
Detection of VP in OCT
Superficial lesion of Plaque

Intimal Tear



In Ajou Hosp.

Plaque rupture



IK Jang, et al. Circulation. 2005;111:1551-5

Imaging Modalities for Detection of VP

Imaging Modality	Resolution	Penetration	Fibrous Cap	Lipid Core	Inflammation	Calcium	Thrombus	Current Status
IVUS	100 μm	Good	+	++	–	+++	+	CS/CA
Angioscopy	UK	Poor	+	++	–	–	+++	CS/CA*
OCT	10 μm	Poor	+++	+++	+	+++	+	CS
Thermography	0.5 mm	Poor	–	–	+++	–	–	CS
Spectroscopy	NA	Poor	+	++	++	++	–	PCS
Intravascular MRI	160 μm	Good	+	++	++	++	+	PCS

NA indicates not applicable; CS, clinical studies; CA, clinically approved for commercial use; CA*, clinically approved commercial use in Japan; PCS, preclinical studies; UK, unknown.

++++=sensitivity>90%; +++=sensitivity 80% to 90%; ++=sensitivity 50% to 80%; [en]=sensitivity <50%.

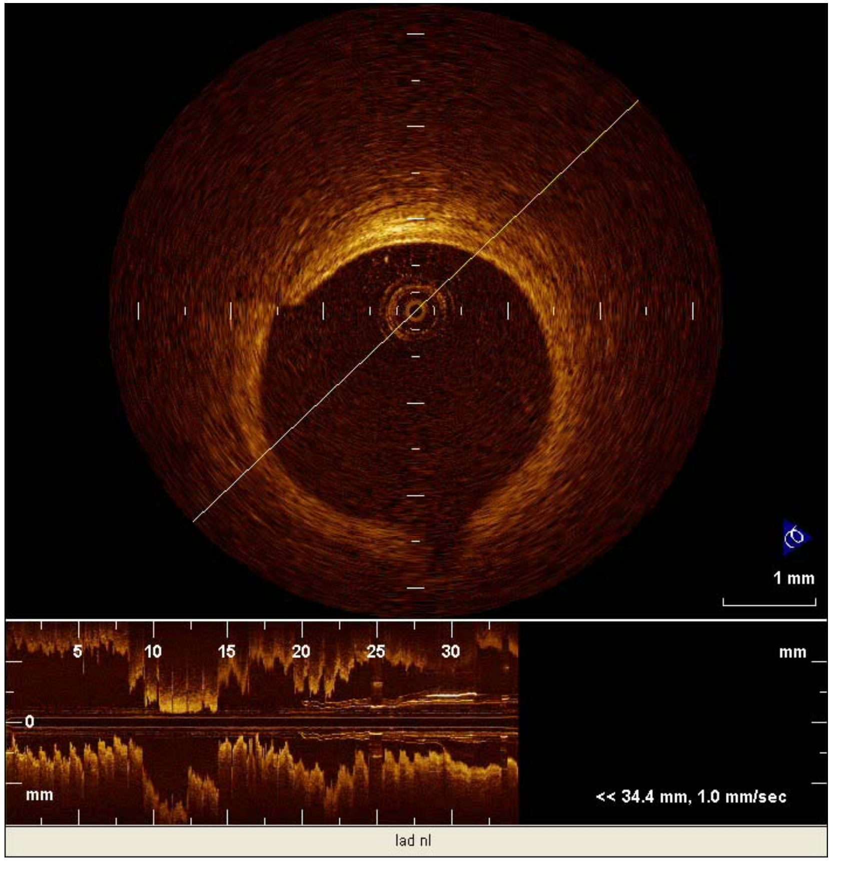
OCT and PCI
As a Tool for PCI

	IVUS	OCT
Preinterventional lesion assessment		
Assessment of severity and clinical impact	☺	😐
Detect Vulnerable Plaque	😐	☺
During intervention		
Device sizing	☺	☹
Decision of strategies for the lesion	☺	😐
Understanding mechanism of intervention	☺	☺
Decision of ending of predecure	☺	☺
Recognition of complications	☺	☺
Serial follow-up		
Understanding for atherosclerosis	☺	☺
Mechanisms, prevention and Tx of restenosis	☺	☺
Assessment for long-term complication	☺	☺

OCT as a Tool for PCI

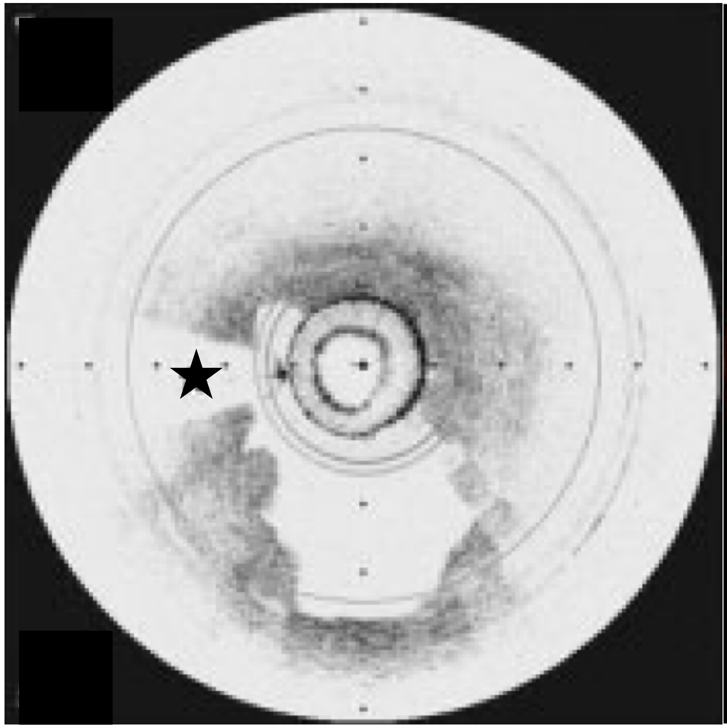
Grey Scale Image for 2D and L-mode

- Lesion assessment
- Device sizing
- Decision of strategies for the lesion
- Understanding mechanism of intervention
- Decision of ending of predecure
- Recognition of complications
- F/U



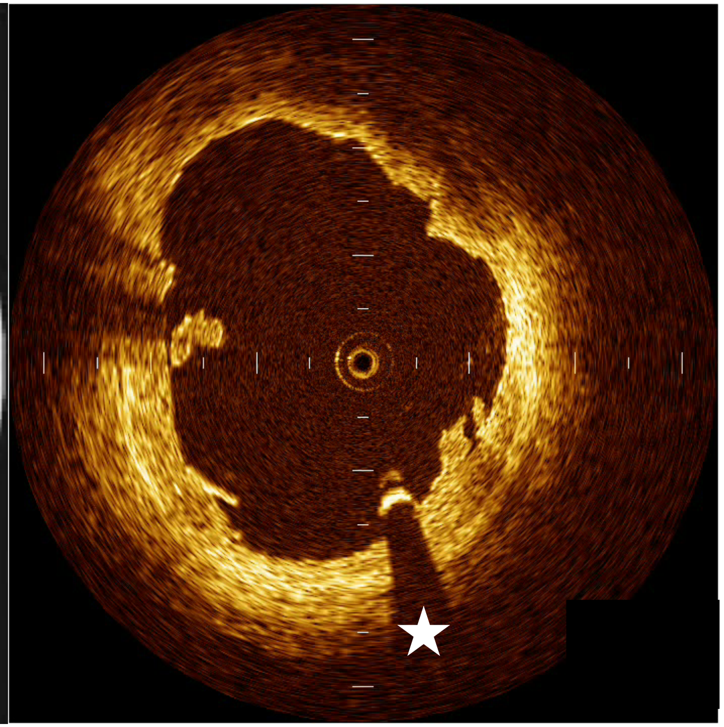
OCT as a Tool for PCI
Understanding PCI Mechanism

After Cutting Balloon



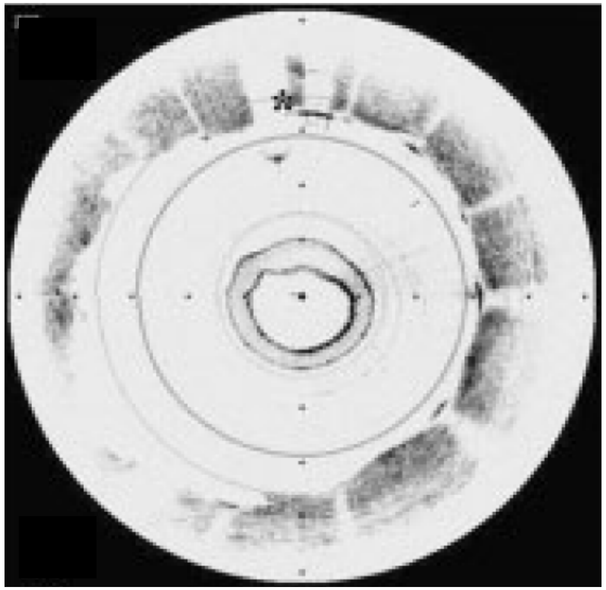
LJ. Diaz-Sandoval, IK Jang et al.
Cath Cardio Interv. 2005:65:492-6

After DCA

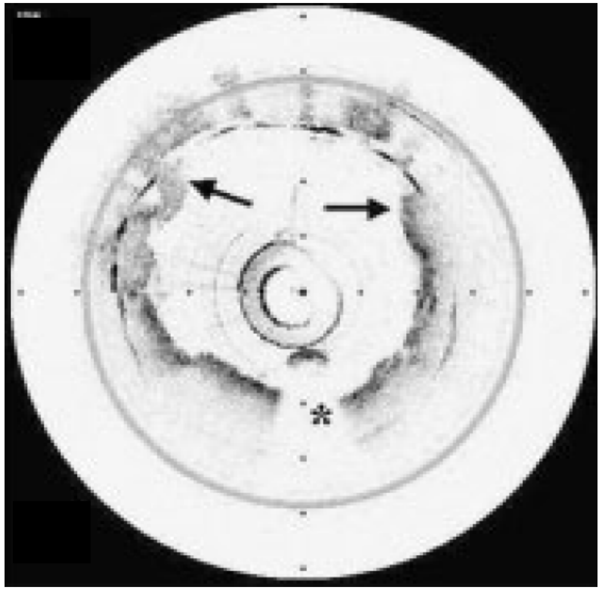


Presented by Suzuki
Toyohashi Heart Center, Japan

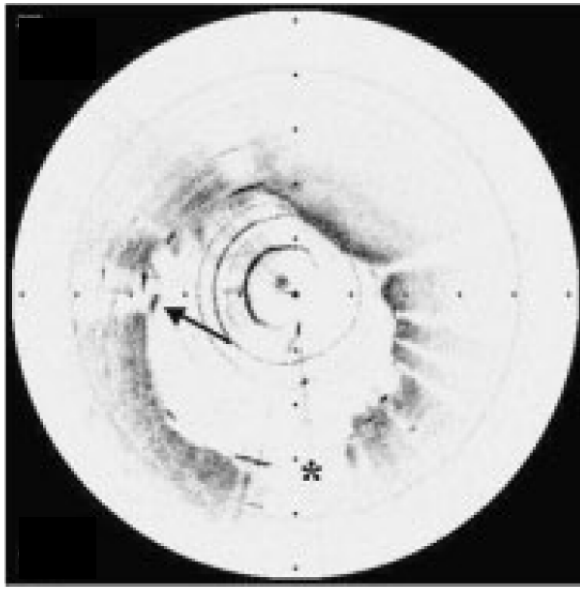
OCT as a Tool for PCI
Evaluation Just After Stenting



Well-apposed stent



Protrusion of thrombus within stent



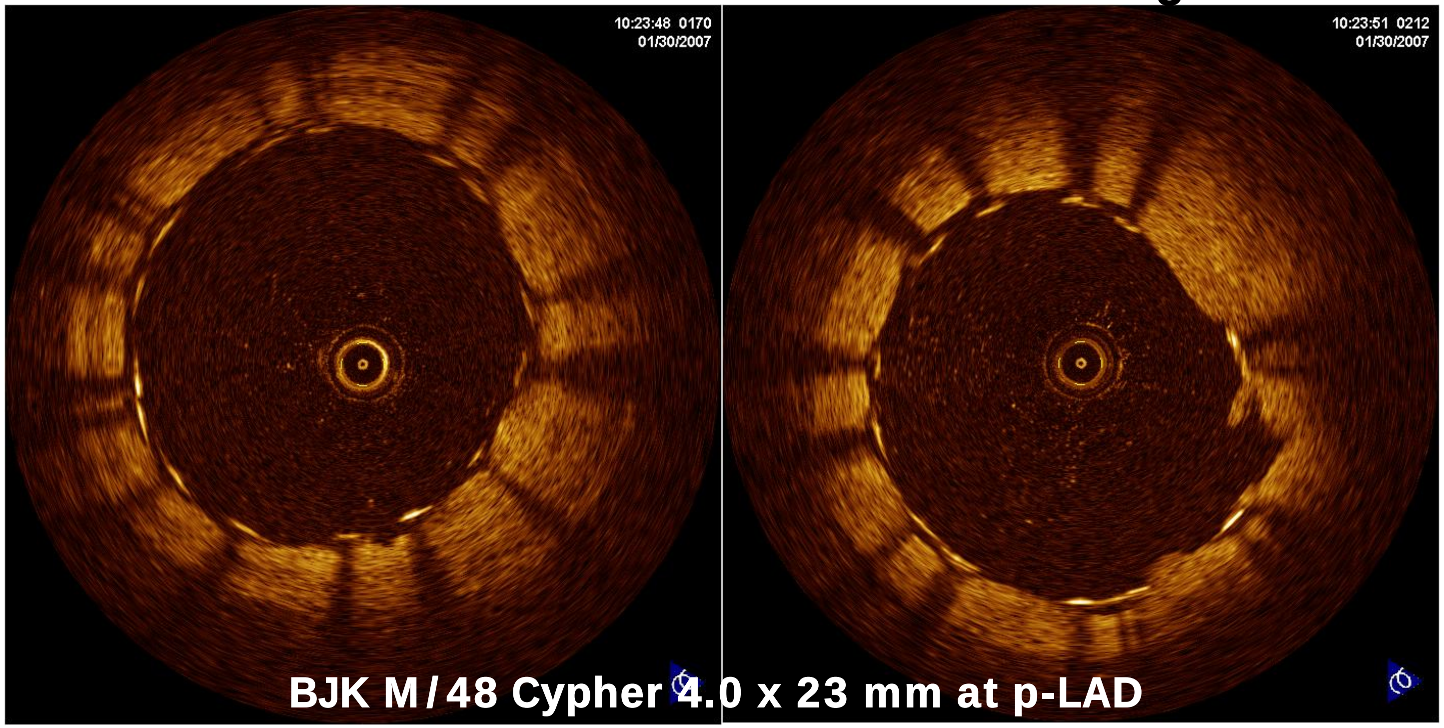
Stent with irregular strut distribution

LJ. Diaz-Sandoval, IK Jang et al. Cath Cardio Interv. 2005:65:492-6

OCT as a Tool for PCI
Evaluation Just After Stenting

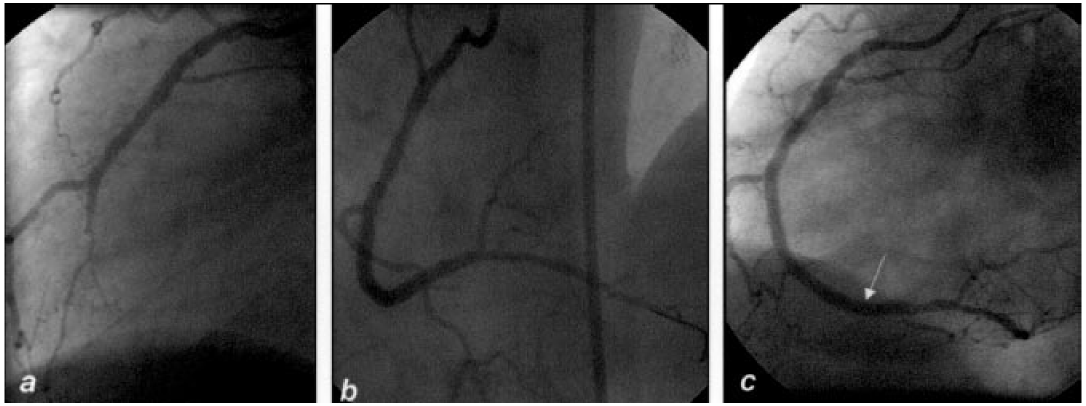
Well-apposed stent

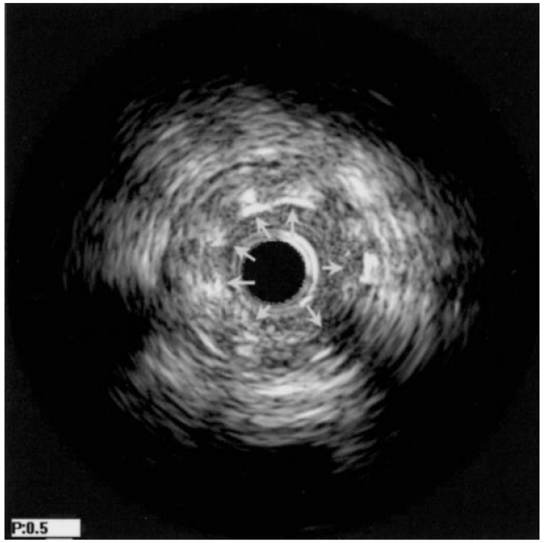
Minor prolapse of plaque after stenting

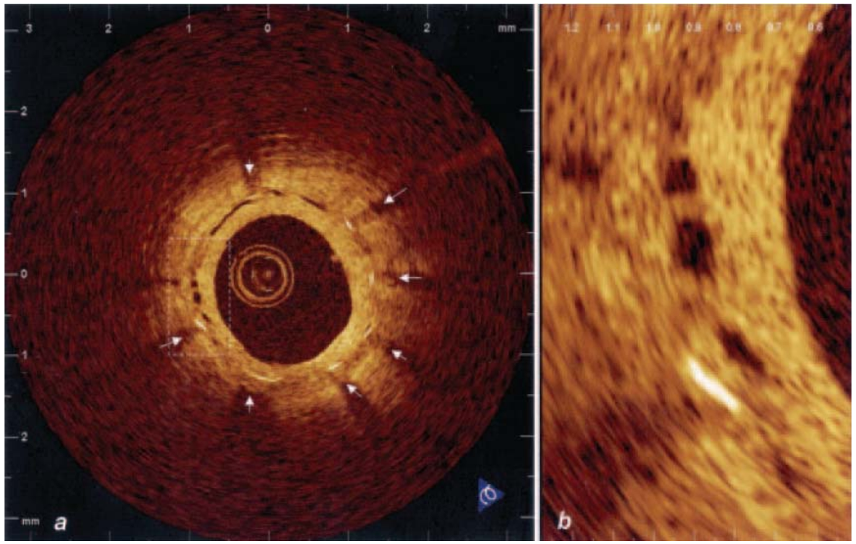


BJK M / 48 Cypher 4.0 x 23 mm at p-LAD

Optical Coherence Tomography Findings at 5-Year Follow-Up After Coronary Stent Implantation



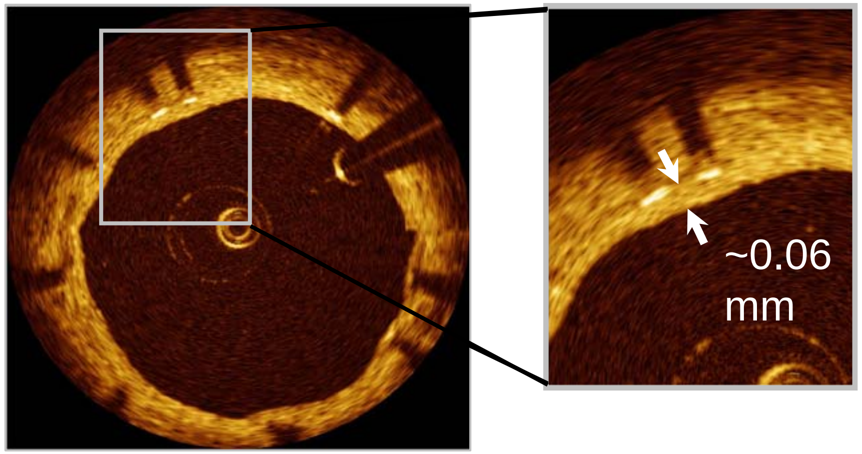




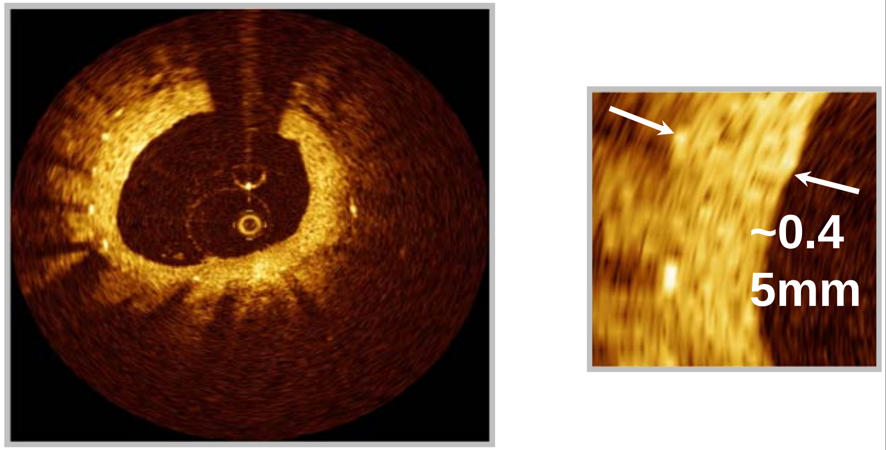
E. Regar, PW. Serruys et al. Circulation. 2005;112:e345-6

Imaging of Stent

Comparison DES vs BMS



Taxus I 19 month F/U
(RCA)

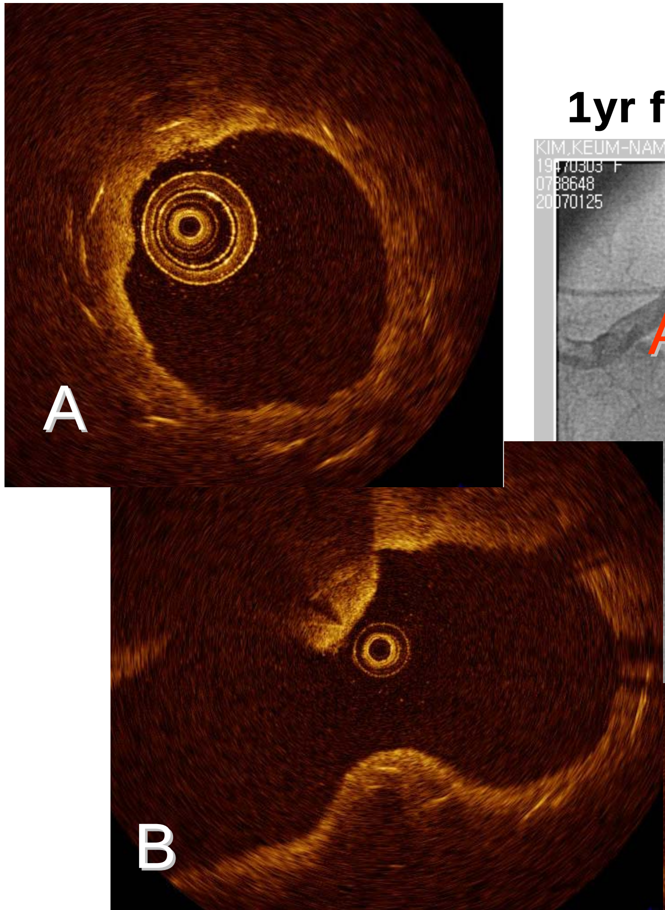


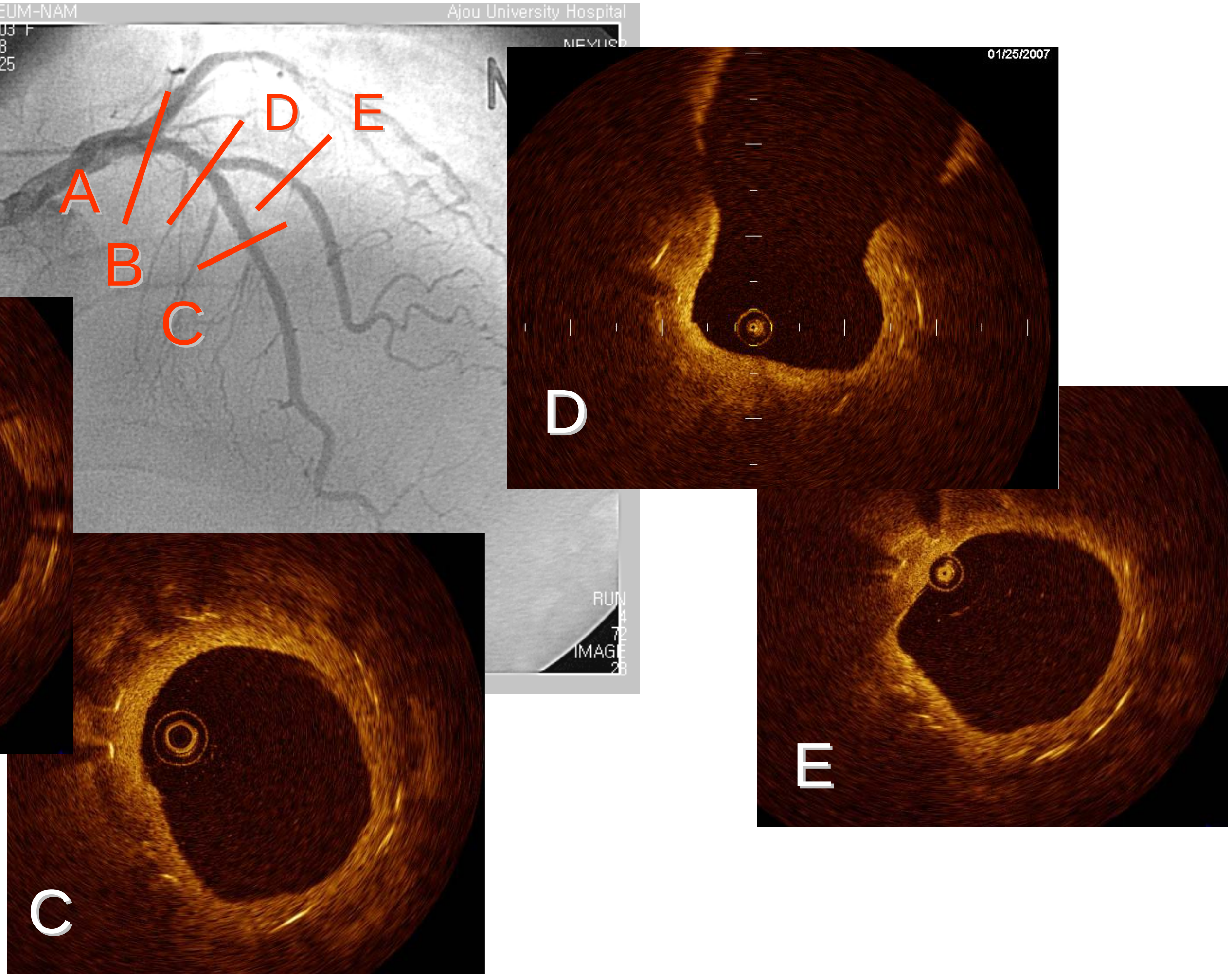
BMS 19 month F/U
(LAD)

By U.Gerckens, E. Grube, Herzzentrum Siegburg, Germany

Imaging of Stent
F/U after Crushing with DESs in Bifurcation

KKN F/61:
1yr f/u for crushing with two Cypher stents at LAD-D1





Limitation of OCT

1. OCT imaging is attenuated by blood and needs to create blood free zone.

   Approaches to overcome this limitation are saline flushes, balloon occlusion, and index matching.

   → Fluid loading and transient ischemia or balloon injury are other problems.

2. Penetration through the arterial wall is in the range of 2–3 mm. The entire plaque cannot be imaged and only superficial anatomic information is obtained.

3. OCT has no functional (physiologic) information like other intraluminal imaging.

Currently Evolving OCT

Toward complete lesion characterization with OCT

The design of delivery catheters with improved blood-clearing efficiency continues to evolve. New platform modality and combine with other modality are also promising.

Morphological	Lesion size Lesion shape % stenosis Cap thickness	Backscatter/ Gray Scale
Biochemical composition	Lipid, collagen, proteoglycans, calcium	Spectroscopy Polarization
Physiological	Flow disturbances CFR, FFR	Doppler
Mechanical	Plaque stiffness	Elastography

Take Home Massages

- OCT could be conducted safely in cath Lab.
- OCT has a high resolution, it could assess the tissue characterization more accurately than IVUS. OCT has a potential benefit to identify vulnerable plaques.
- OCT also provides superficial information of the vessel during and after PCI.
- OCT has major limitations in need of blood clear zone and low penetrating depth.
- Evolving OCT image moves closer to becoming a powerful diagnostic tool that will provide new insights into the etiology and treatment of coronary artery disease.