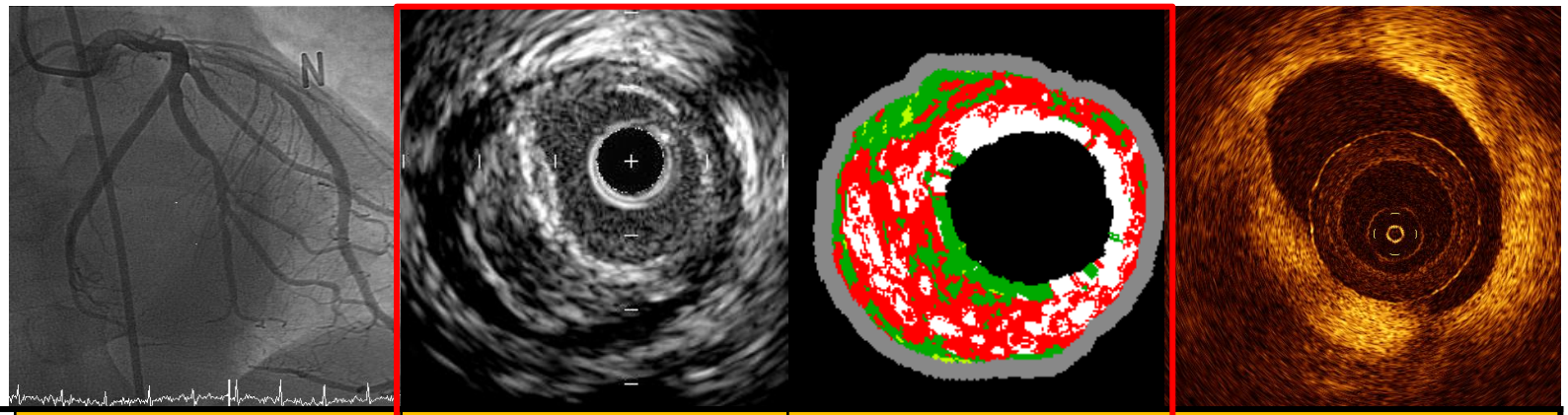
Intravascular Ultrasound and Virtual Histology

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

Imaging for Coronary Artery

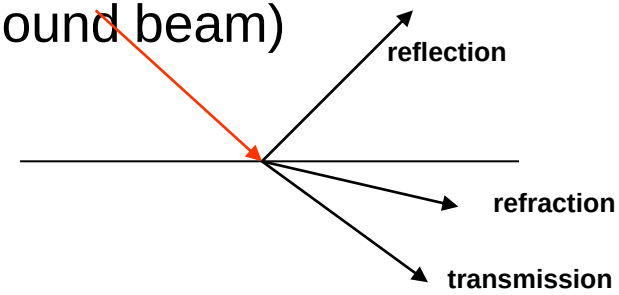


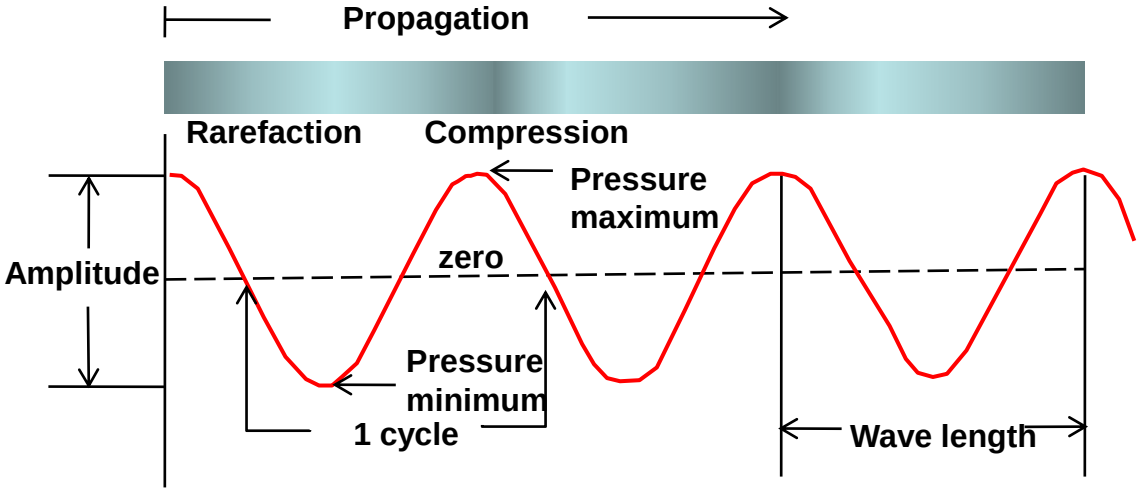
	Angiography	IVUS	Radiofrequency IVUS	OCT
Type of source	X-ray	Ultrasound	Ultrasound	Near-IR light
Resolution (μm)	100-200	80-120	80-120	10-20
Probe size (mm)	n/a	0.7	0.8	0.14
Other	Contrast luminogram	Subsurface tomogram	Subsurface tomogram	Subsurface tomogram

What is Ultrasound?

Ultrasound

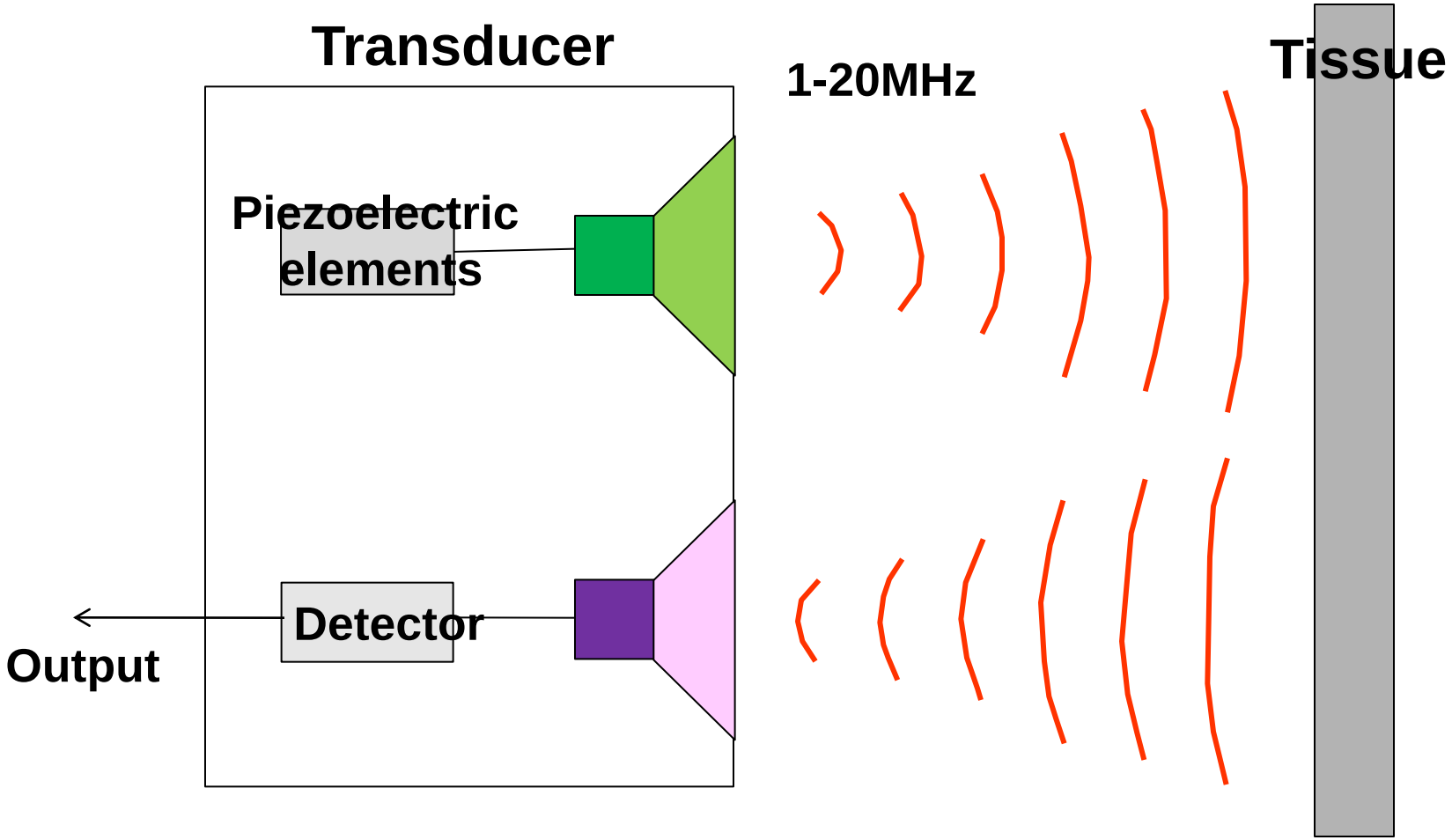
- High-frequency (>20kHz) form of sound
- Property of ultrasound
  - Beamed in a particular direction (ultrasound beam)
  - Reflection, refraction, transmission
  - Attenuation and absorption
  - Scattering





Frequency (f= ν/λ) and Amplitude (intensity)

Ultrasound in Medicine



Catheter of Intravascular Ultrasound

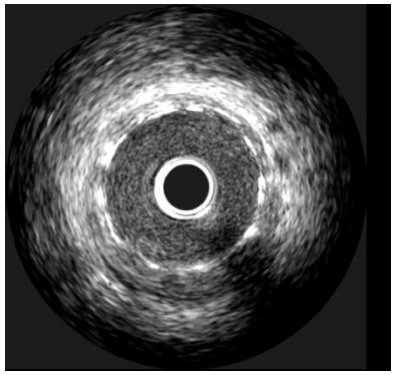
Mechanical vs Synthetic Phased Array

Boston Scientific

Mechanical Transducer

Single transducer rotates on a drive shaft, 1800 rpm

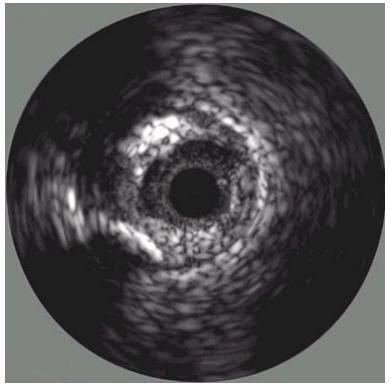
40MHz



Volcano

Synthetic Phased Array / Solid State Transducer

Multiple (64) stationary transducers



20MHz

Planar Image Reconstruction

Mechanical transducer

Shaft rotates at 1800 RPM

256 pulses per rotation

i.e.- one pulse every 1.4°

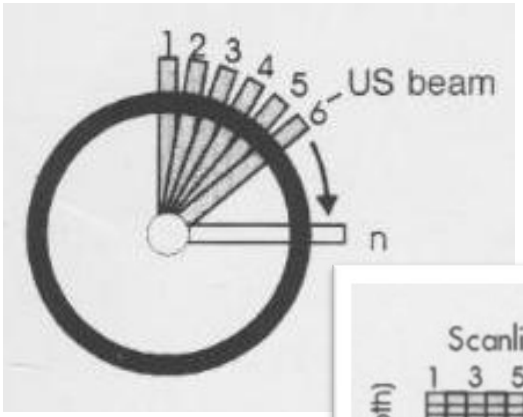
Frame update rate = 30 FPS

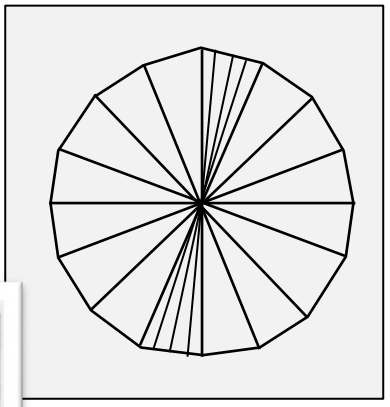
Solid state transducer

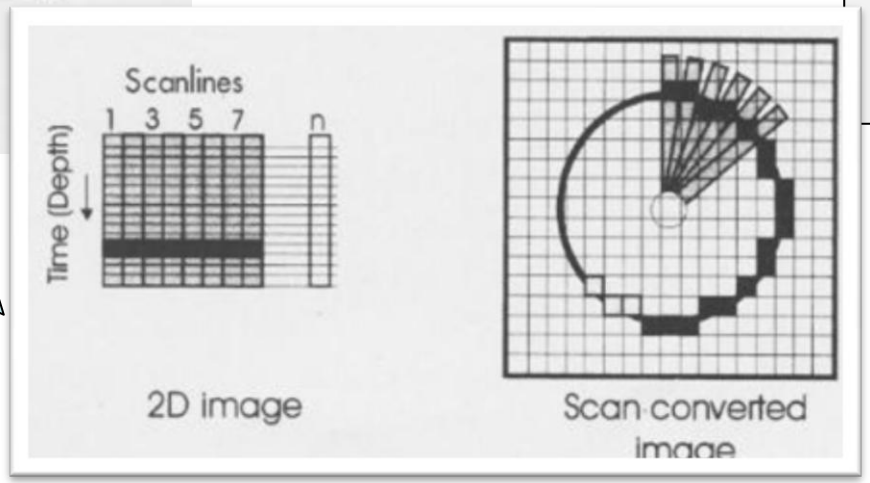
64 phase

64x5.63°=360° planar image

Frame rate = 30 FPS



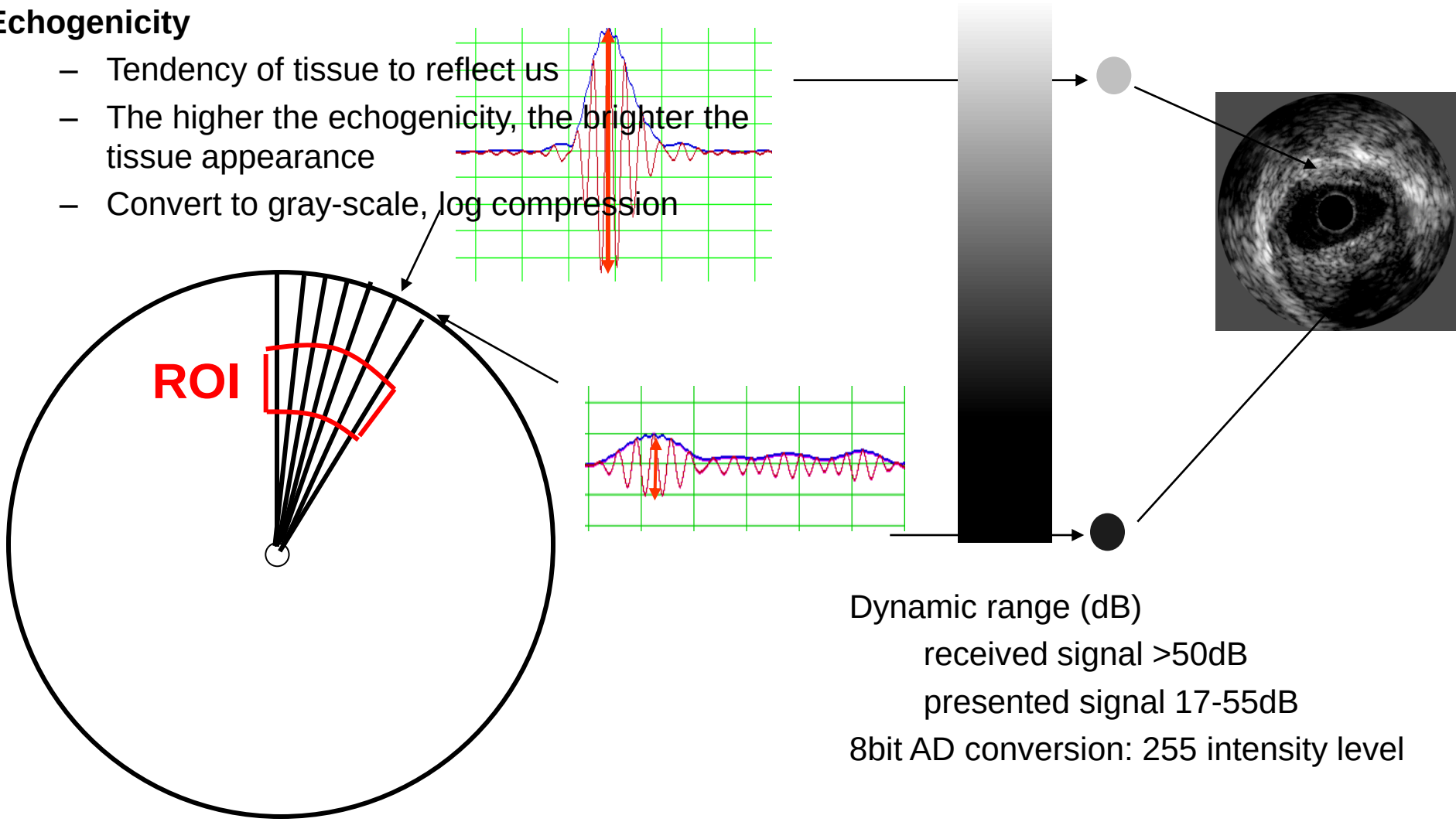




Gray Scale Image

Echogenicity

- Tendency of tissue to reflect us
- The higher the echogenicity, the brighter the tissue appearance
- Convert to gray-scale, log compression



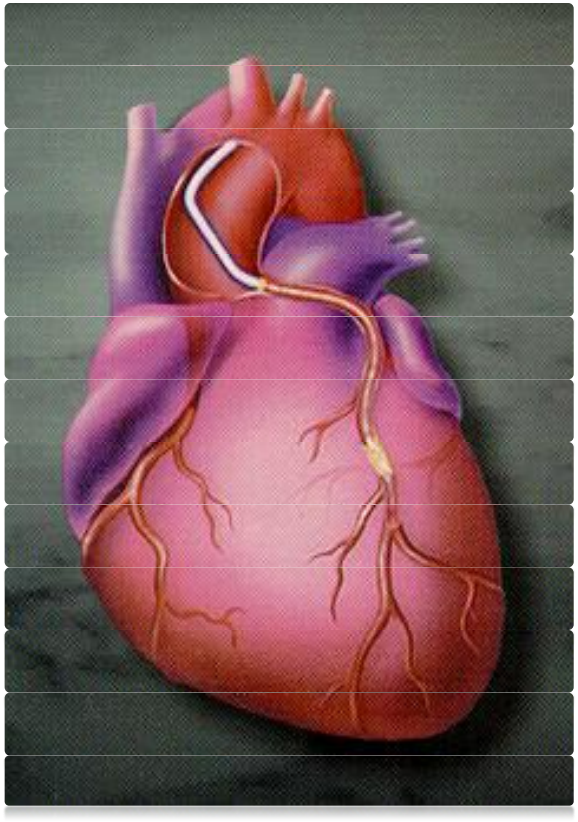
Dynamic range (dB)

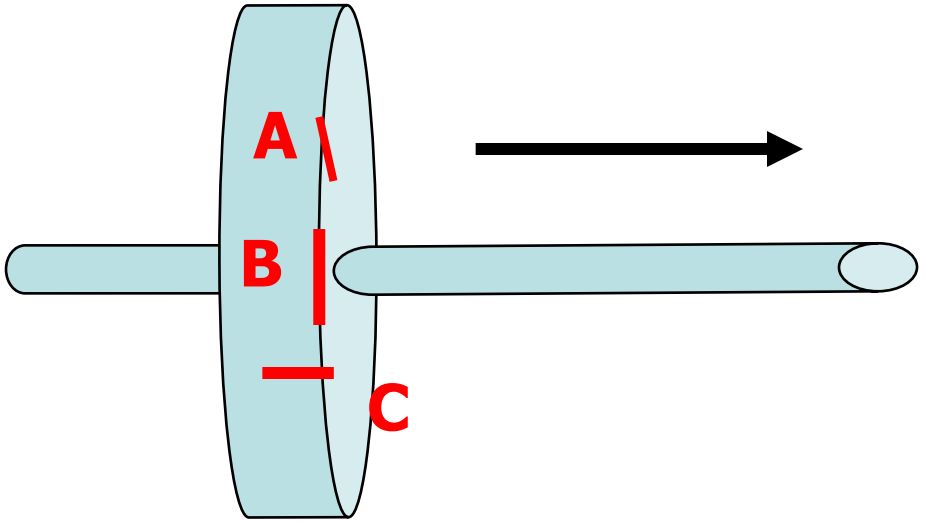
received signal >50dB

presented signal 17-55dB

8bit AD conversion: 255 intensity level

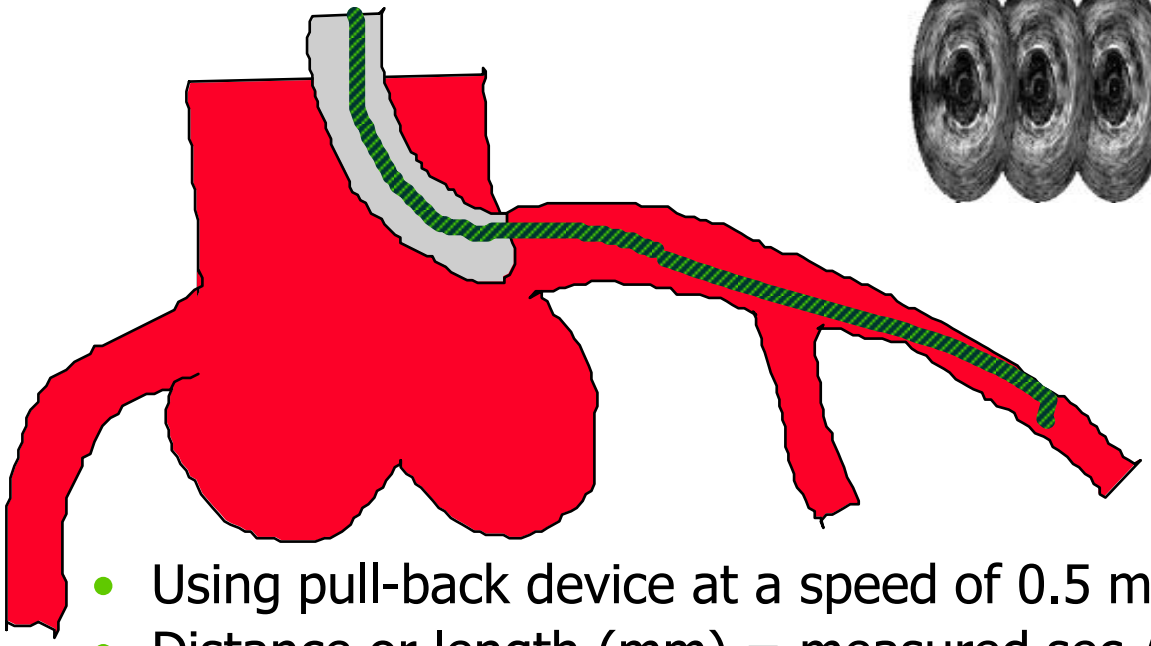
Resolution of the Ultrasound System

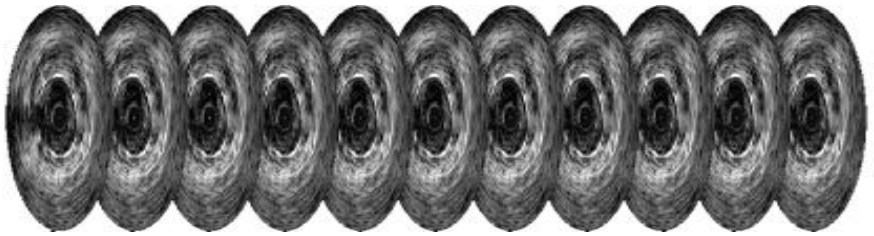




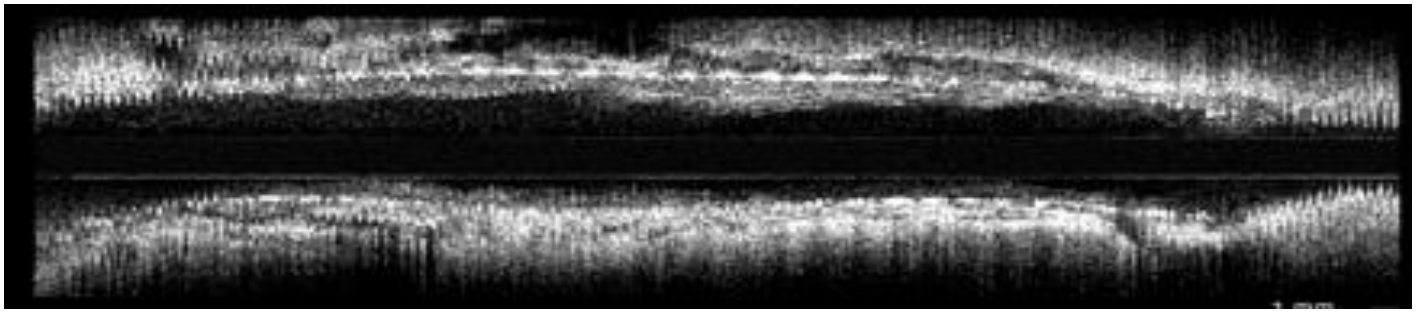
A : Axial resolution = 150 μm
B : Lateral resolution = 250μm
C : Penetration Depth = 10mm

Methods of Taking Longitudinal Image

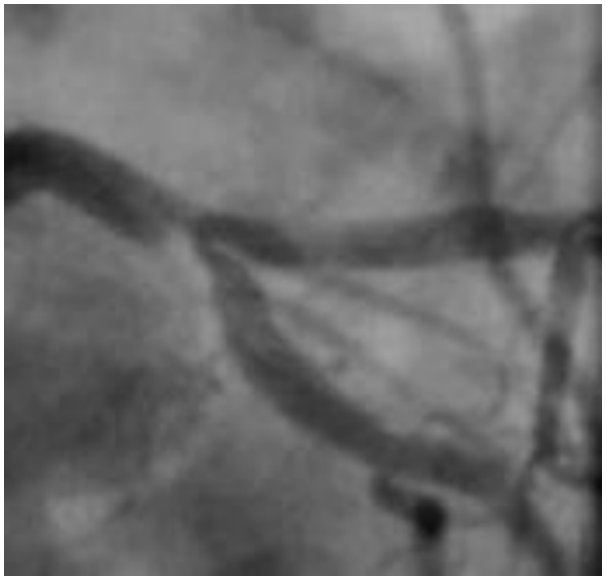




- Using pull-back device at a speed of 0.5 mm/s
- Distance or length (mm) = measured sec / 2

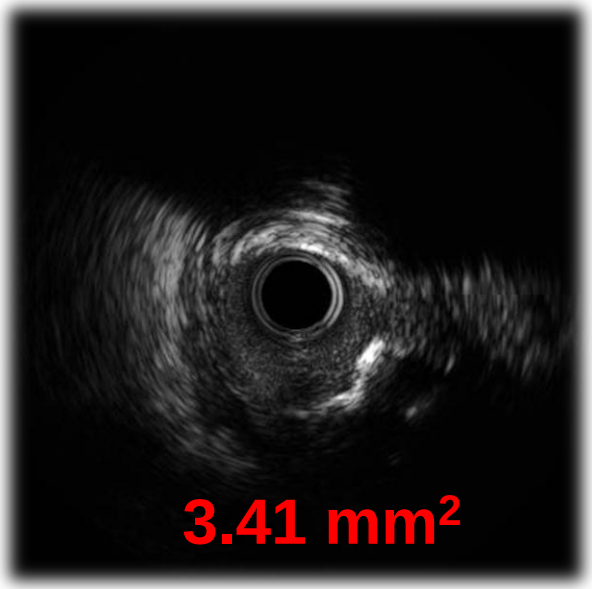


LM disease로 혈관내 초음파를 시행하였다. 양측 혈관에서 측정한 값이 왜 차이를 보이는 것일까?



Lumen Area of LM

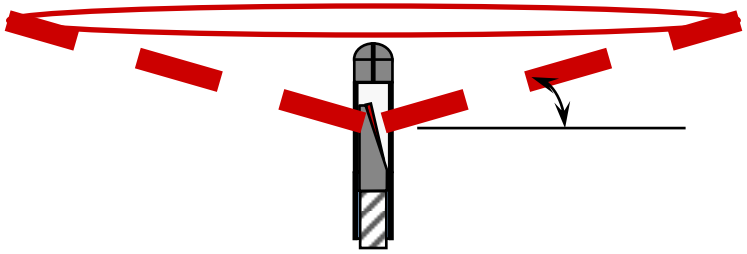
From LAD

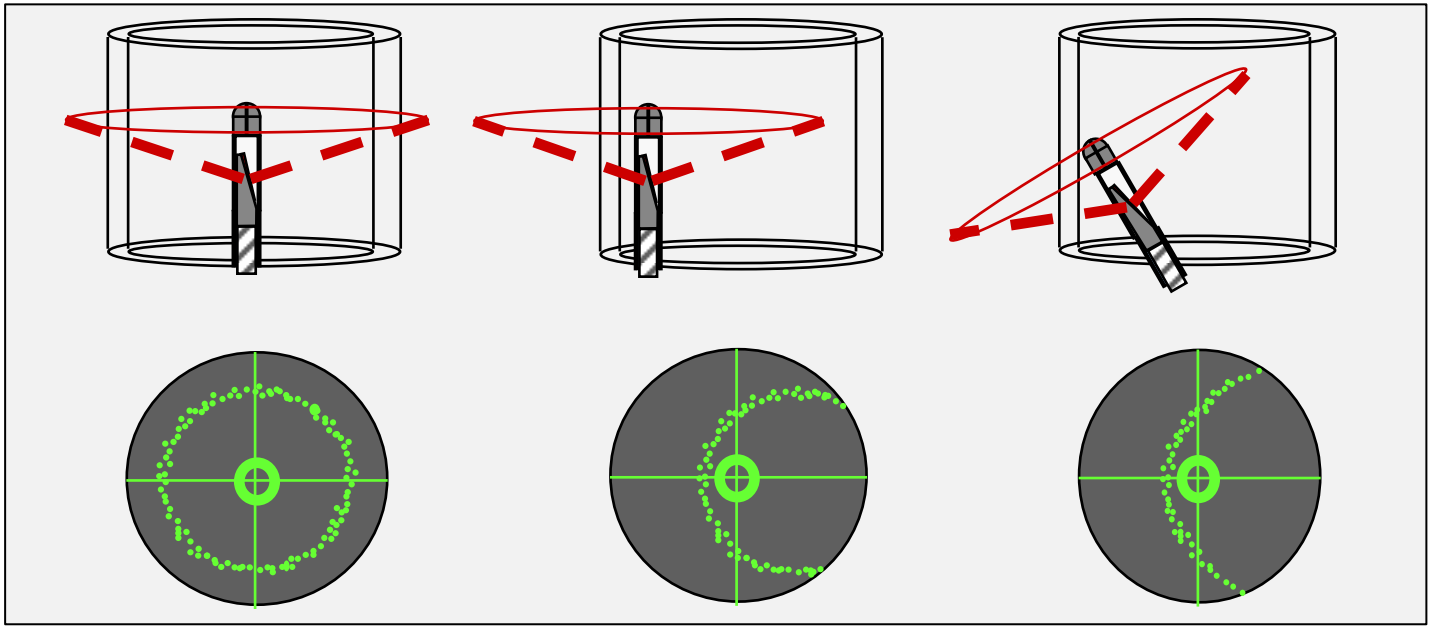


From LCX

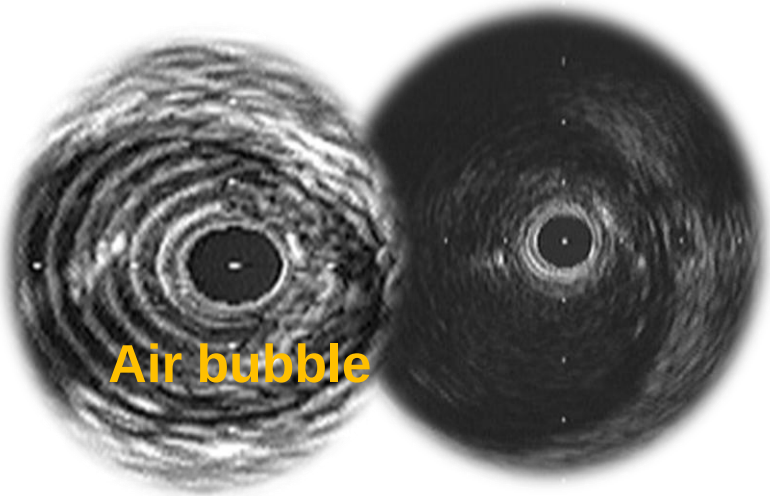
IVUS Image Artifacts: Catheter Alignment

Imaging "Plane" is Actually a Cone (due to angle of transducer placement)





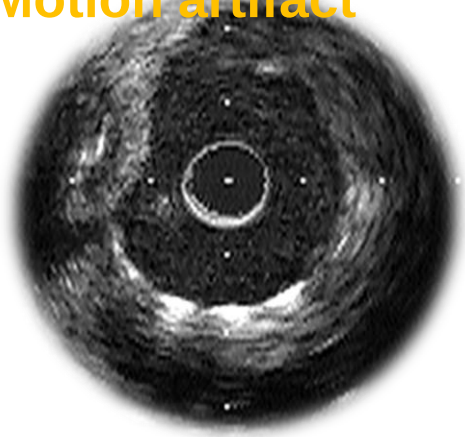
Mechanical type 에서만 관찰되는 IVUS artifact는?



Air bubble

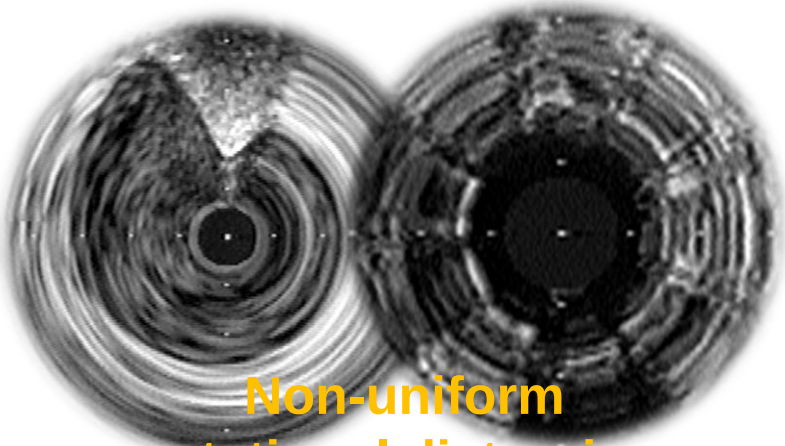
Ring down artifact

Motion artifact



Reverberation

Side robe

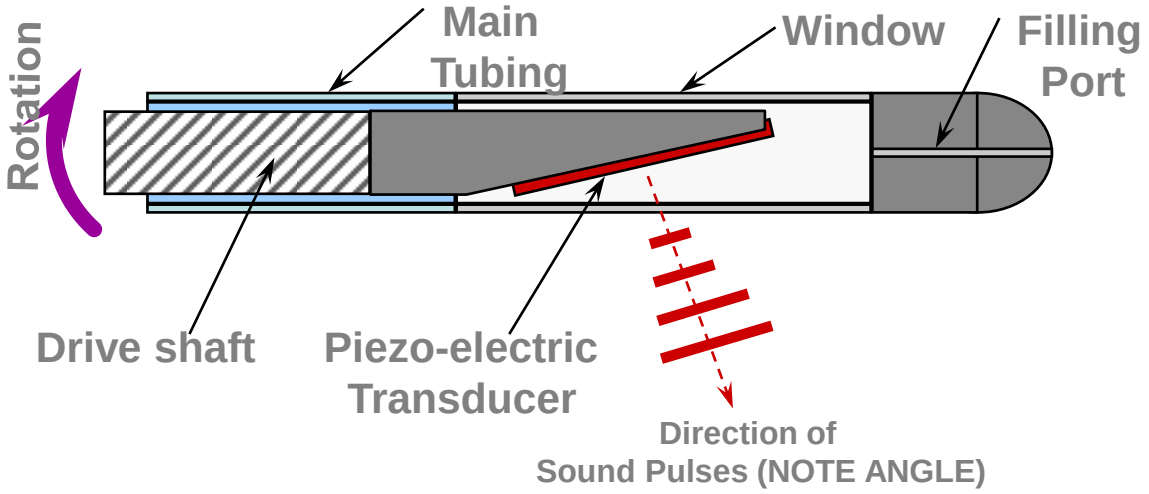


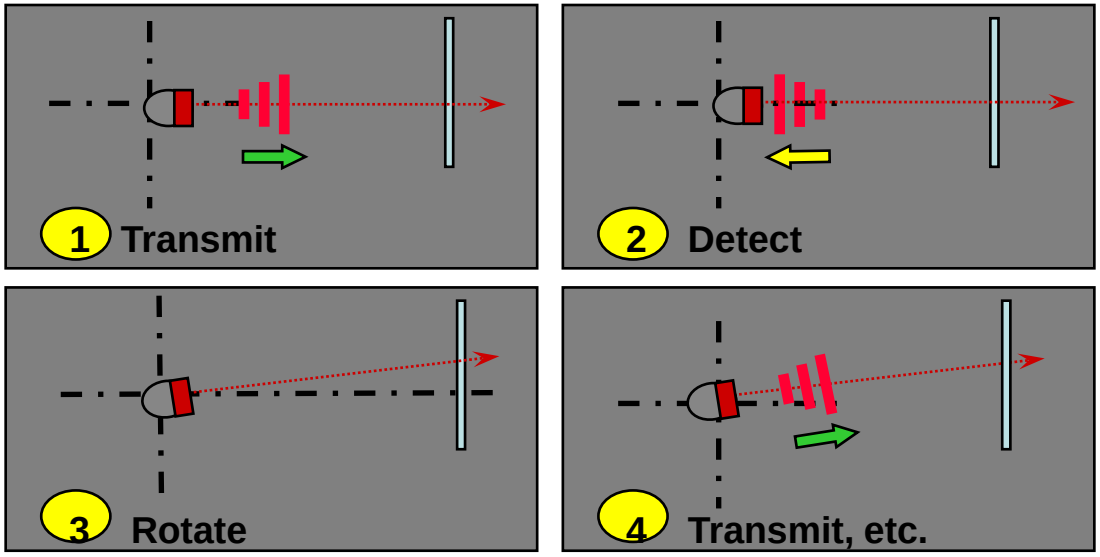
Non-uniform rotational distorsion (NURD)

IVUS Image Artifacts

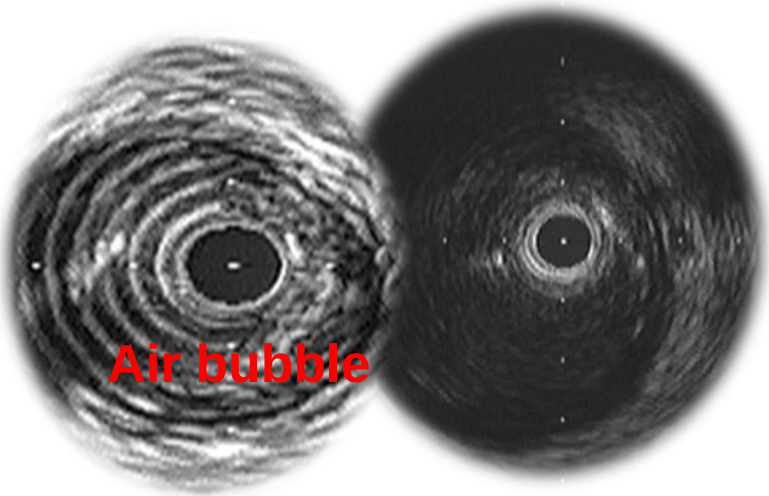
- Ring-down artifact
  - Disorganization of the image closest to the face of the transducer or surface of the catheter
- Guide wire artifact and Acoustic shadowing
- Reverberations
  - Secondary false echoes of the same structure, along the axial path of US beams
  - Common form strong echoreflectors
- Rotation angle artifact
  - Non-uniform rotational distortion (NURD)
  - Unique artifact to mechanical system, geometric distortion due to asymmetric friction,
- Side lobes
  - Extraneous beams of US that are generated from the edges of the individual transducer elements circumferential sweep
  - Prominent when imaging stents or calcium

IVUS Image Artifacts: Mechanical transducer

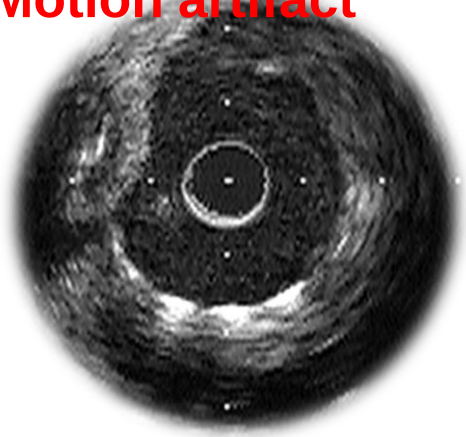


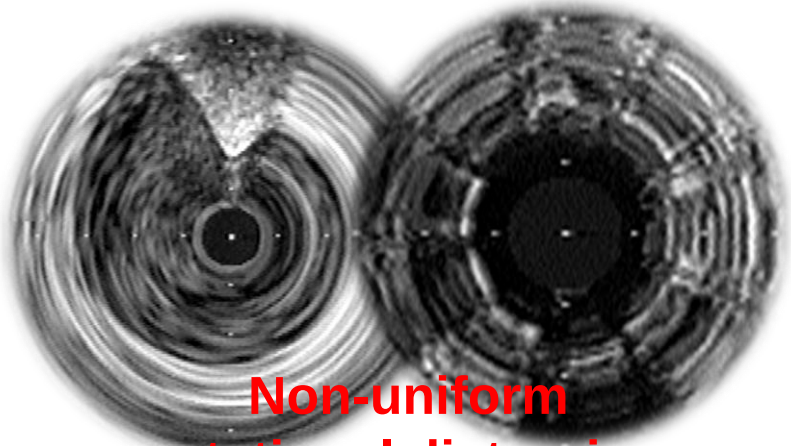


Mechanical type 에서만 관찰되는 IVUS artifact는?



Motion artifact





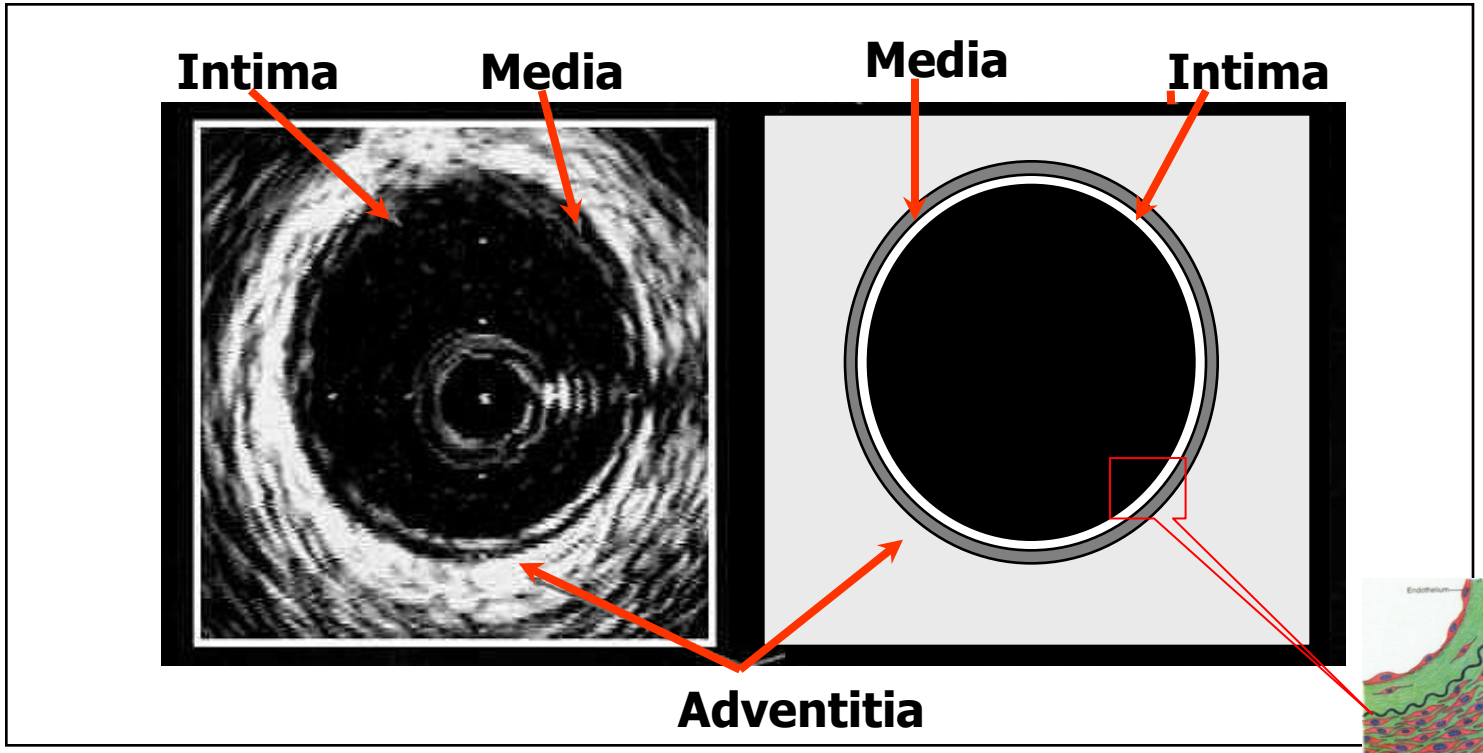
Non-uniform rotational distorsion (NURD)

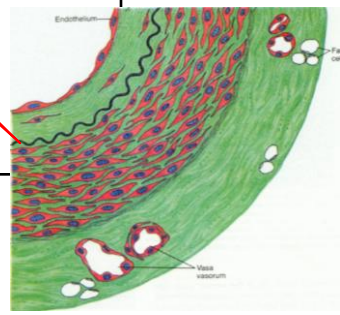
What should we evaluate by using IVUS?

IVUS Parameters

Quantitative			Qalitative	
Lesion	**Reference segement**	**Lesion /reference**	**Plaque morphology**	**Plaque composition**
Length Lumen CSA Vessel CSA Plaque CSA Stent CSA Neointima CSA Lumen symmetry Plaque eccentrisity Plaque burden	Lumen CSA Vessel CSA Plaque burden	Area stenosis Remodeling	Ulceration Fissure Rupture Dissection Hematoma Thrombus	Fibrofatty Fibrous Calcified

Vessel Wall: Three-Layered Appearance





Three Concentric Layers

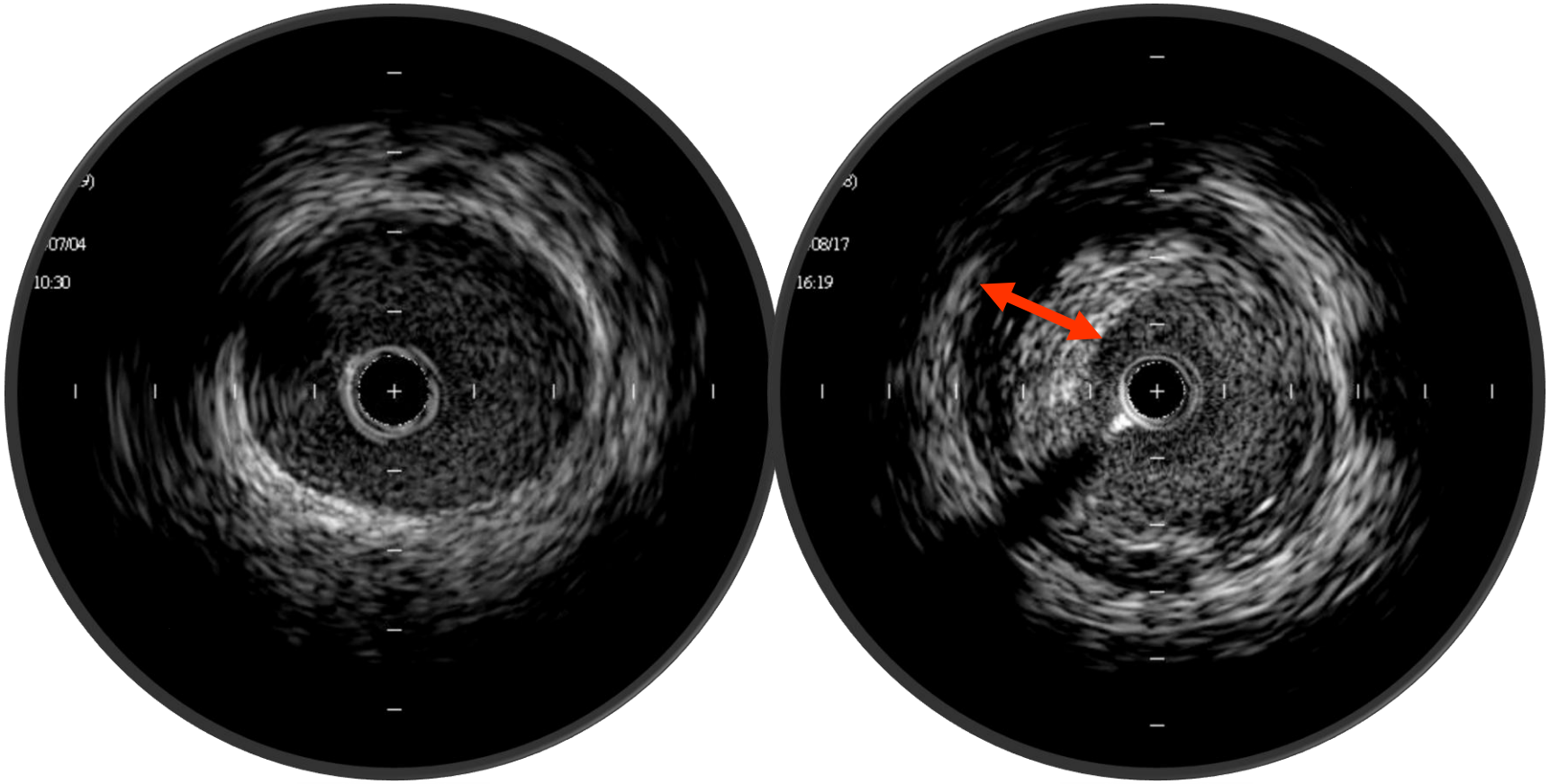
Inner : Intima / IEM (including plaque)→ white

Middle : Media→black

Outer : EEM / Adventita / Periadventitial tissue→white

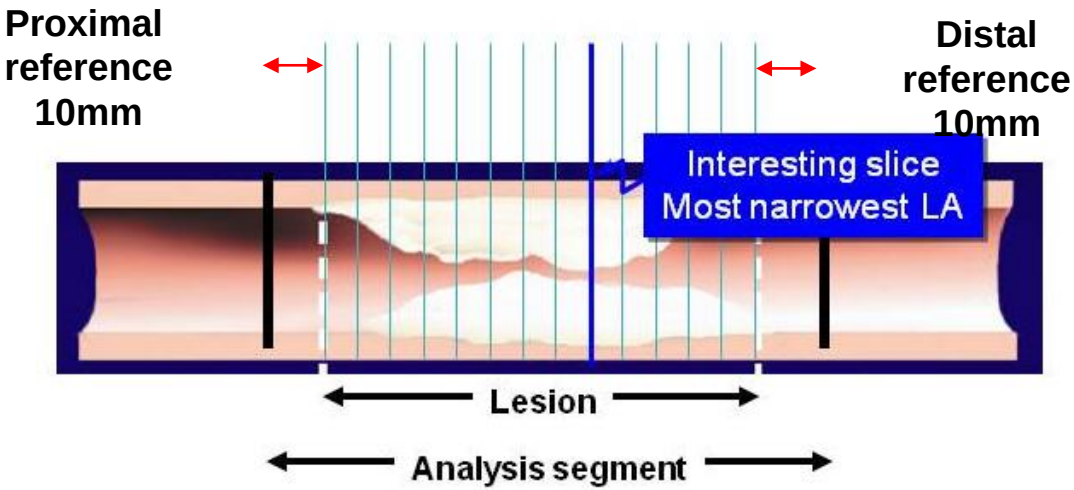
Basic Imaging of IVUS

Normal vs. Diseased



Analysis Length and Volume Data

Using pull-back device at a speed of 0.5 mm/s
Distance or length (mm) = measured sec x 0.5



By using echoPlaque (INDEC) or QCU-CMS (Medis) sofeware system

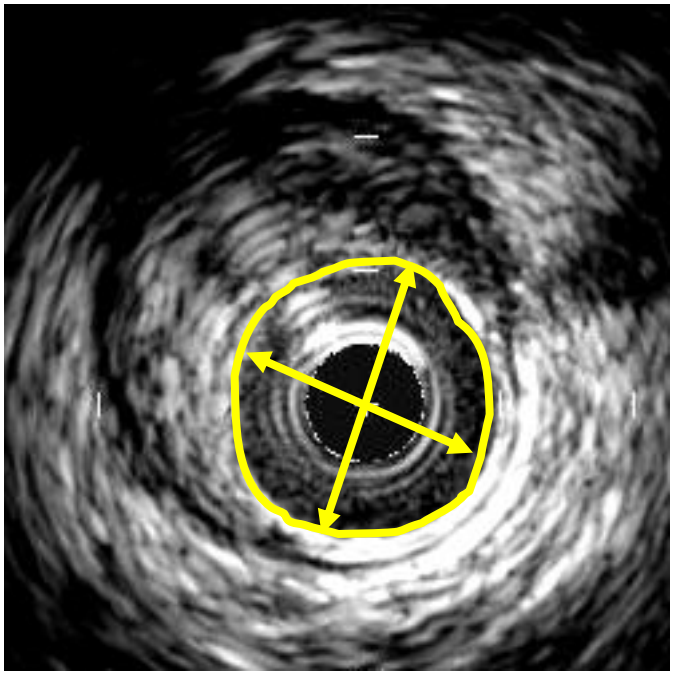
1. Lumen Detection

Lumen CSA: The area bounded by the luminal border

Minimum lumen diameter: The shortest diameter through the center point of the lumen.

Maximum lumen diameter: The longest diameter through the center point of the lumen.

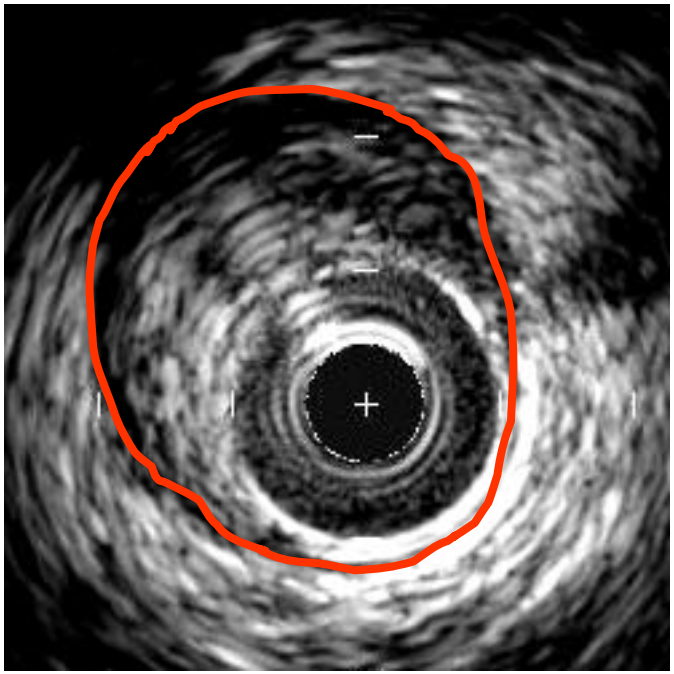
Lumen Eccentricity: (maximum lumen diameter - minimum lumen diameter)/ maximum lumen diameter



2. EEM Detection

EEM CSA; = "vessel area" or "total vessel area."

A discrete interface at the border between the media and the adventitia is almost invariably present within IVUS images and corresponds closely to the location of the EEM.



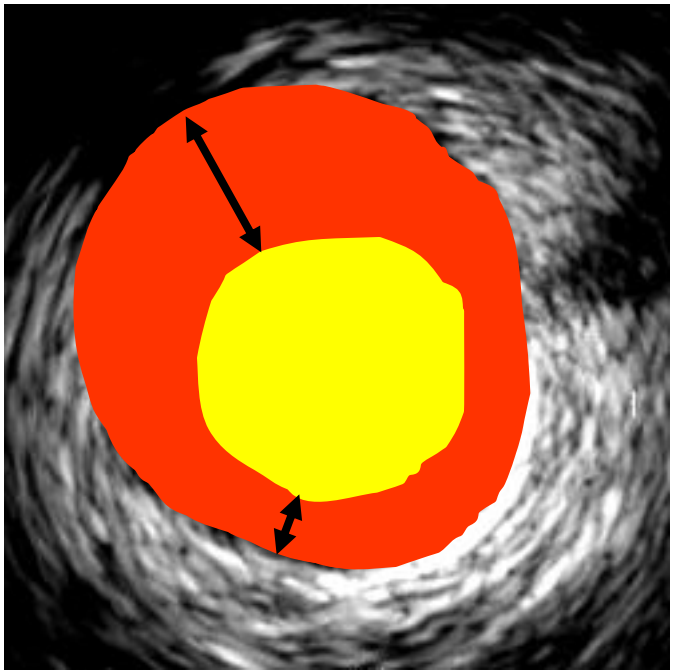
3. Plaque Analysis

Plaque plus media (or atheroma) CSA: The EEM CSA minus the lumen CSA.

Maximum atheroma thickness: The largest distance from the intimal leading edge to the EEM along any line passing through the center of the lumen.

Minimum atheroma thickness: The shortest distance from intimal leading edge to the EEM

Atheroma eccentricity: (Maximum atheroma thickness - minimum atheroma thickness/ maximum atheroma thickness



4. Stenosis Analysis

Plaque (or atheroma) burden :

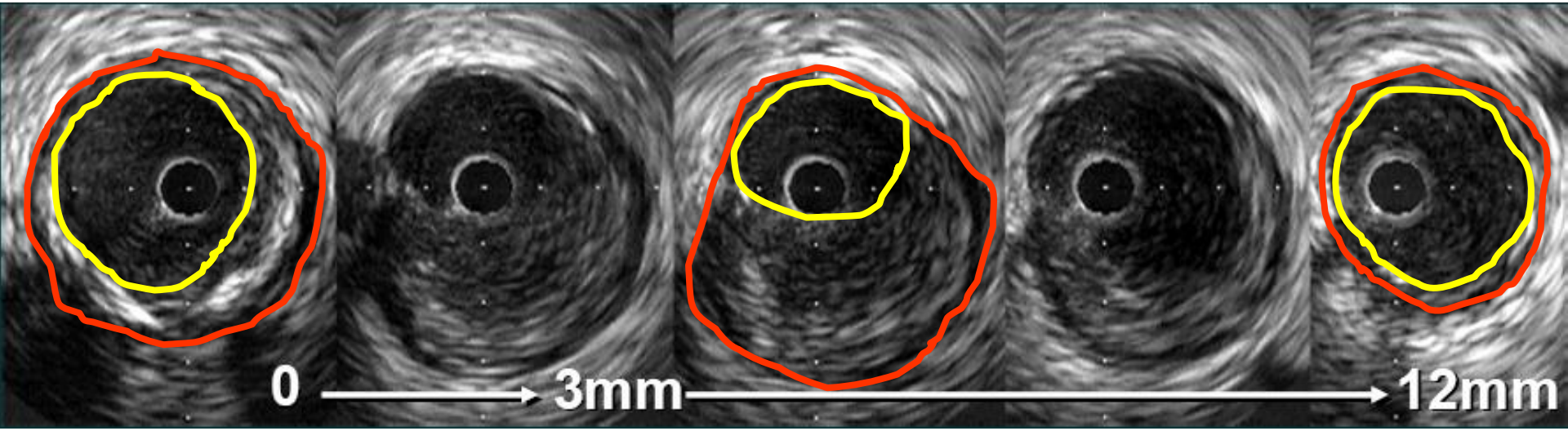
Atheroma CSA (EEM CSA-lumen CSA) / EEM CSA

Lumen area stenosis :

(Reference lumen CSA - minimum lumen CSA) / reference lumen CSA

Measurements

Proximal Reference | **Lesion Site** | **Distal reference**



EEM CSA=20.4mm²
Lumen CSA=9.7mm²
P+M CSA=10.7mm²
Plaque burden=52%

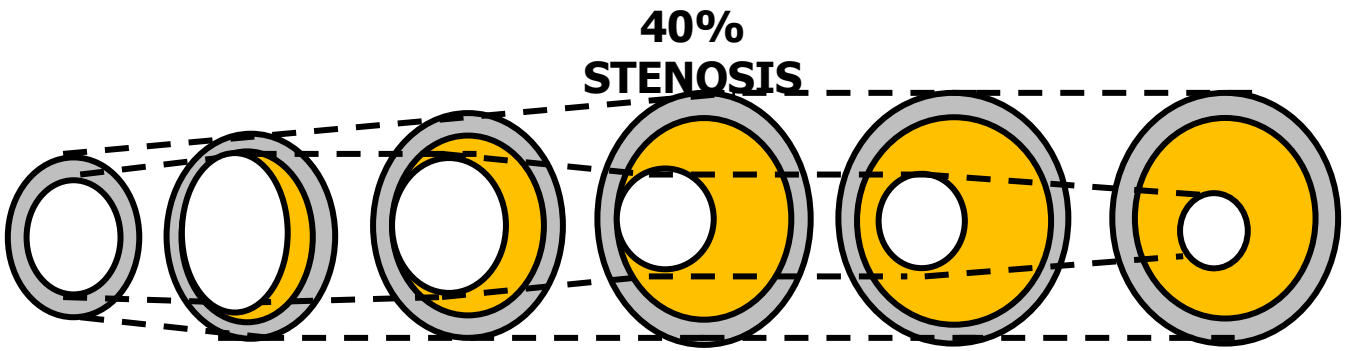
EEM CSA=21.6mm²
Lumen CSA=4.5 mm²
Max LD=2.8mm
MLD=2.3mm
P+M CSA=17.1mm²
Eccentricity=3.0/0.1
Plaque burden =79%

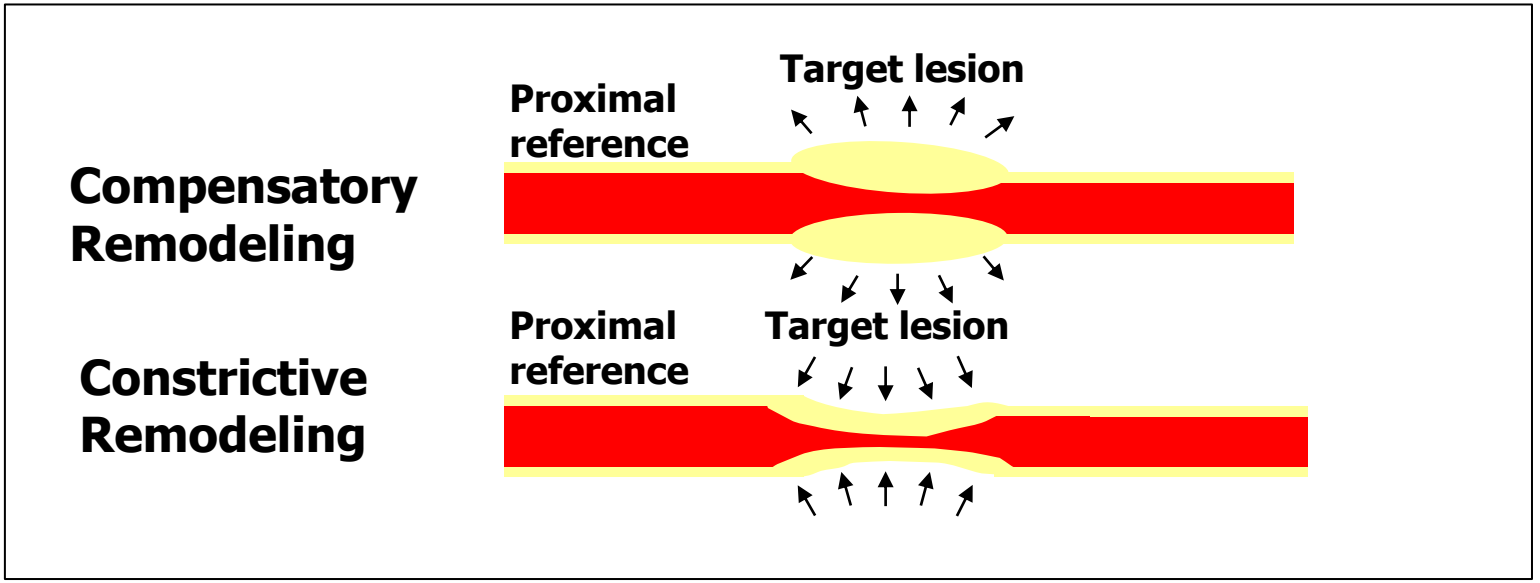
EEM CSA=13.3mm²
Lumen CSA=8.9mm²
P+M CSA=4.4mm²
Plaque burden=33%

Average reference EEM CSA =16.9mm²
Remodeling index = 1.3
Average reference lumen CSA =9.3mm²
Area stenosis(%) = 52%

Coronary Remodeling

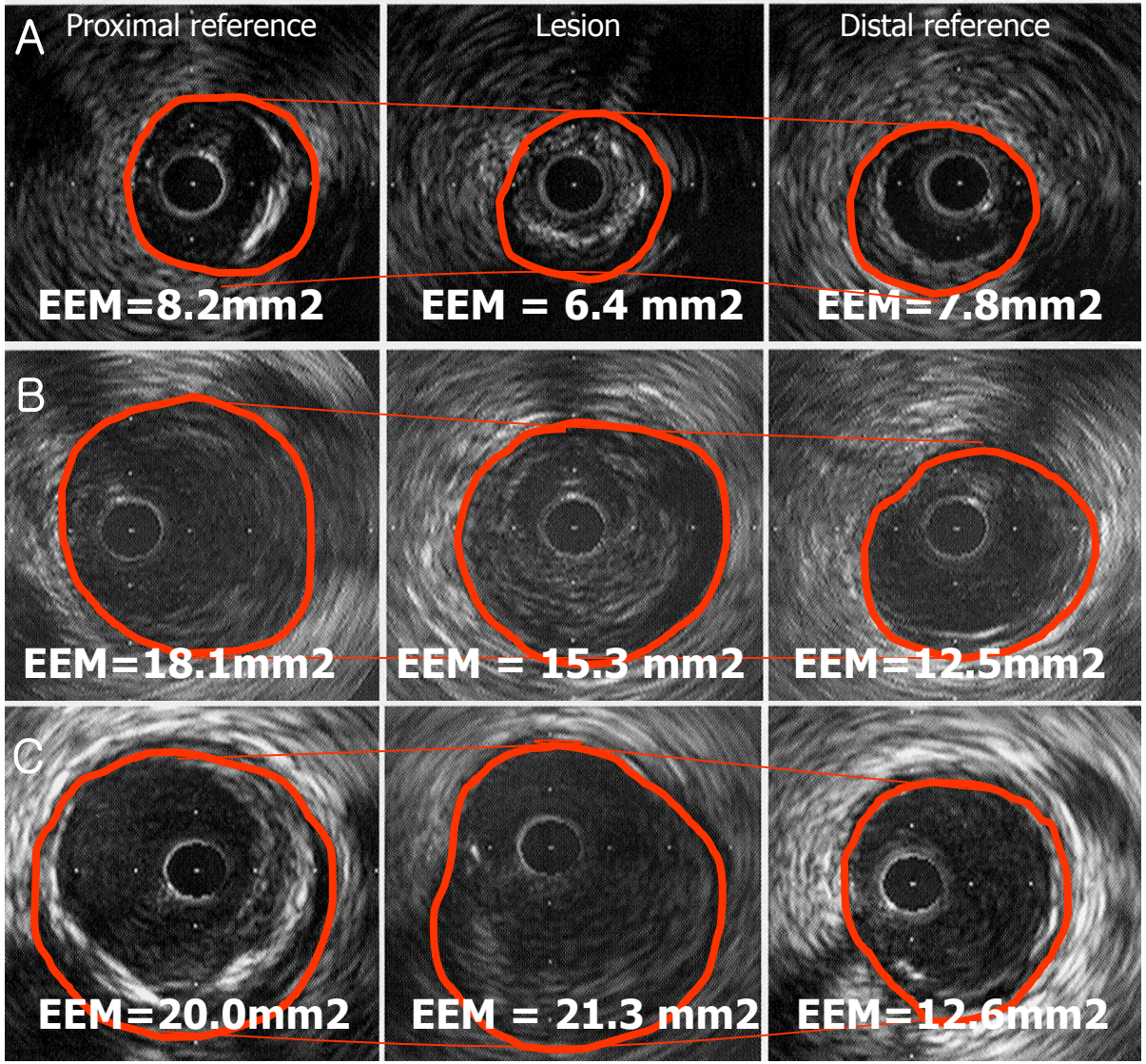
Glagov Phenomenon





Basic Imaging of IVUS

Plaque Morphology: Positive vs. Negative Remodeling



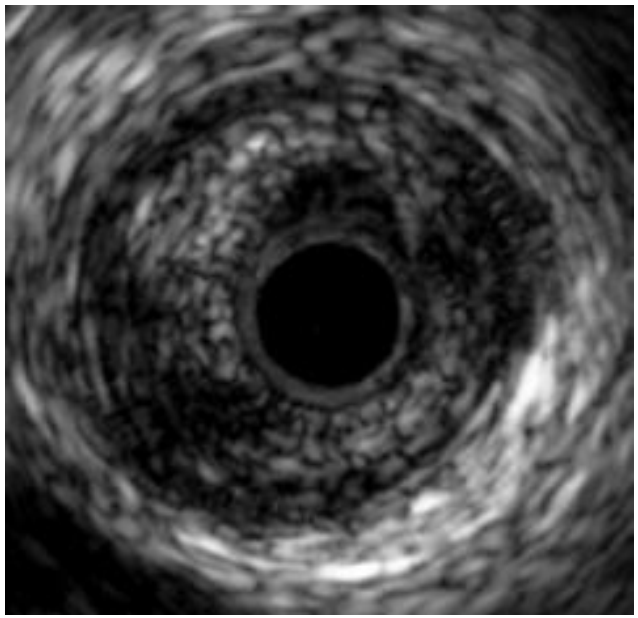
RI=0.80
Negative Remodeling

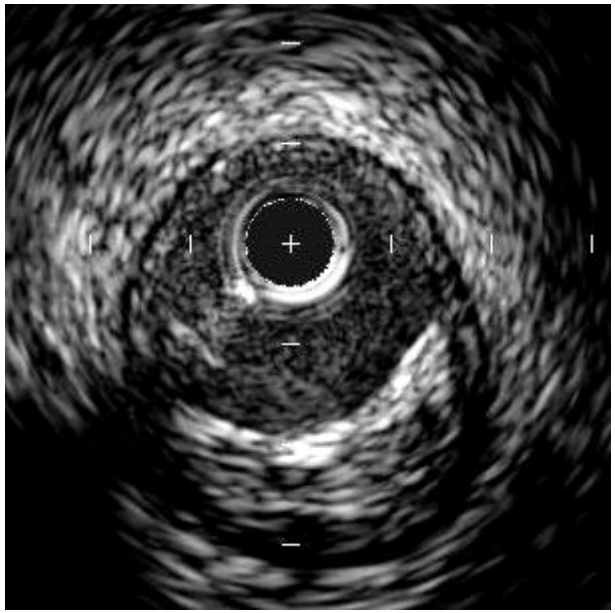
RI=1.00
Intermediate Remodeling

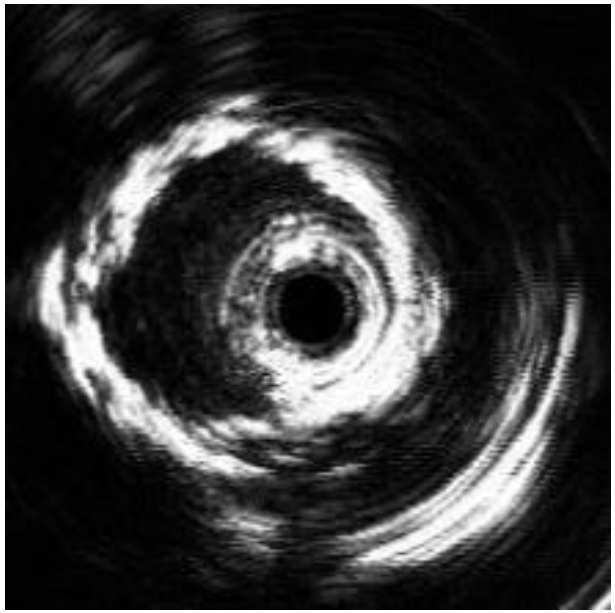
RI=1.31
Positive Remodeling

Plaque Composition

Fibrofatty vs. Fibrous vs. Calcified Plaque







Fibrofatty

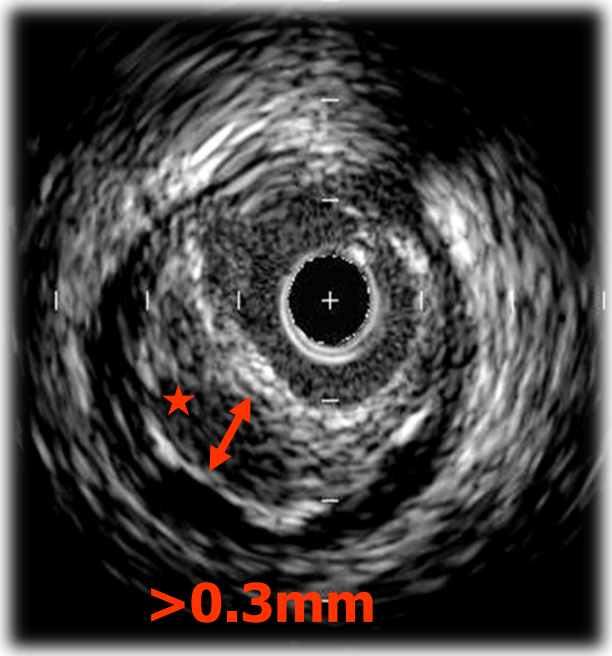
=Soft

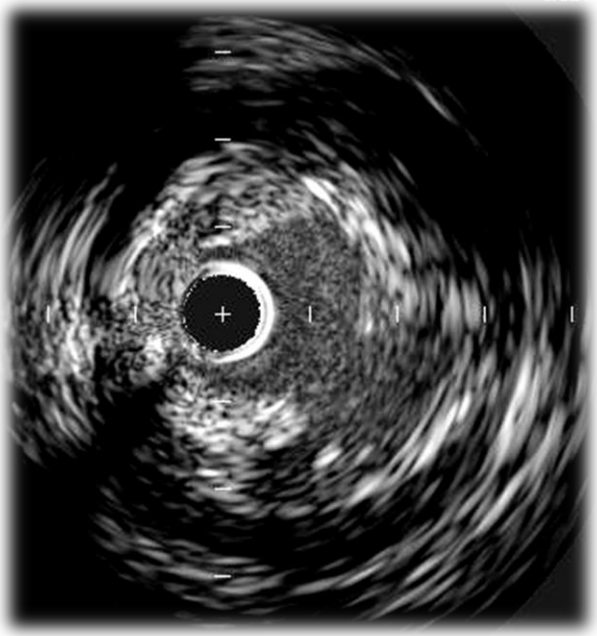
Fibrous

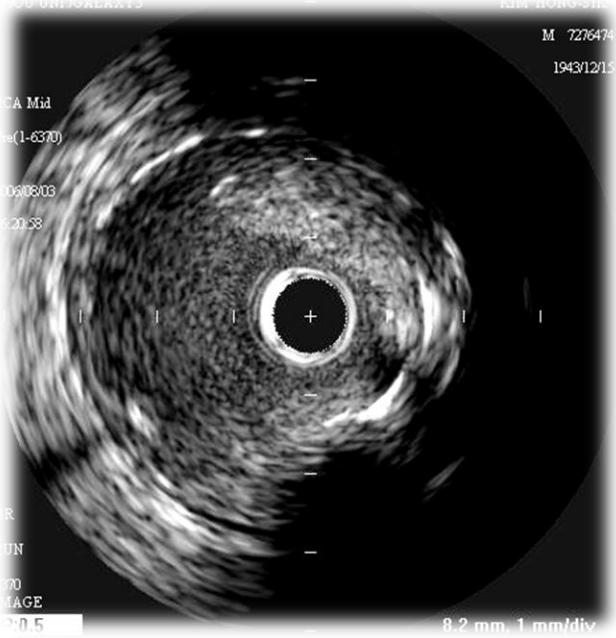
Calcified

Hard

Plaque Morphology

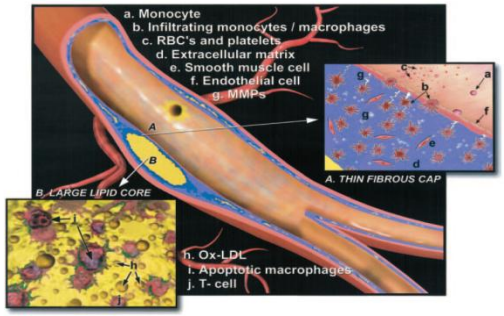






Criteria for Defining Vulnerable Plaque

Based on previously presented autopsy study



The vulnerable plaque characterized by thin fibrous cap, extensive macrophage infiltration, and large lipid core.

Circulation. 2003;108:1664-1672

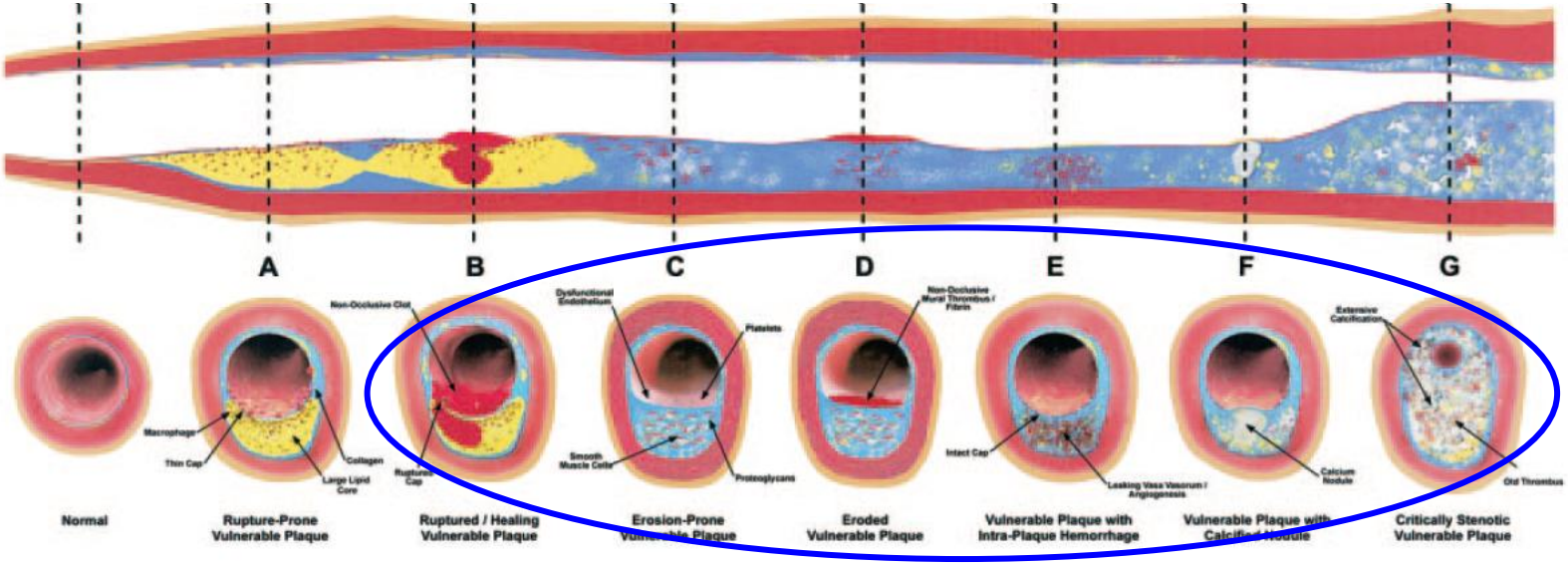
Major criteria

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

Minor criteria

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

Different Types of Vulnerable Plaques



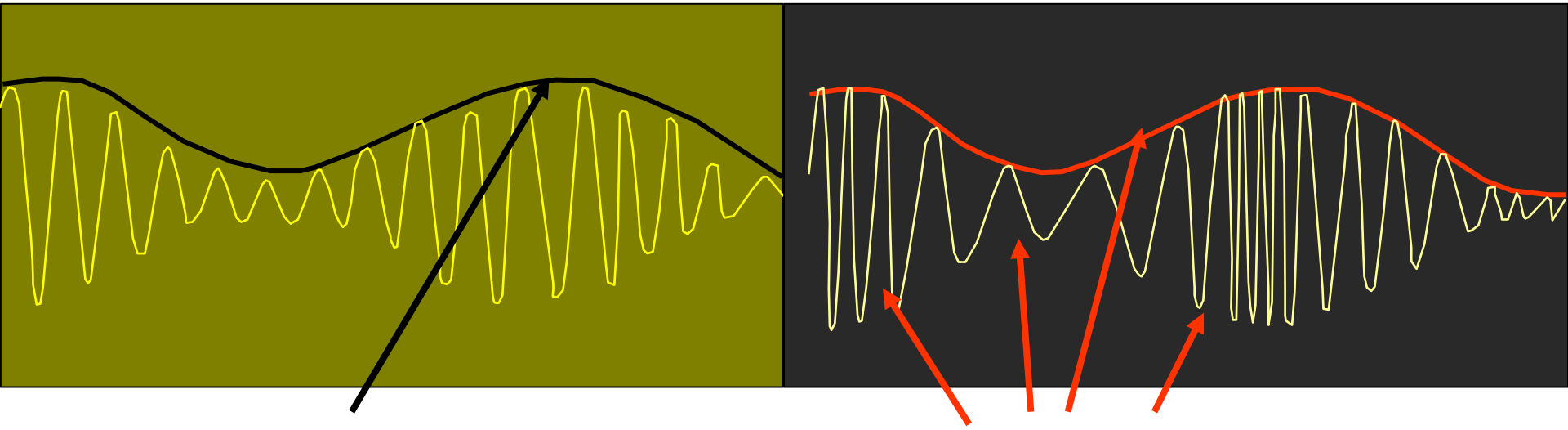
Every body is not same, every plaque is not same!

What is Radiofrequency IVUS?

Methods of Radiofrequency Analysis

Gray-scale IVUS image

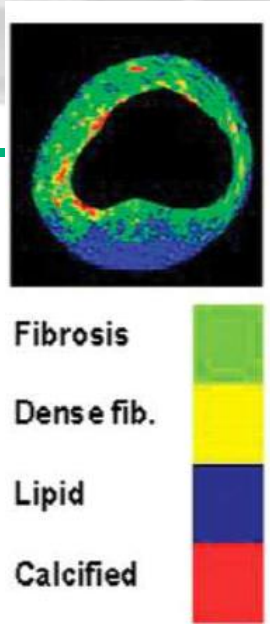
Radiofrequency-IVUS

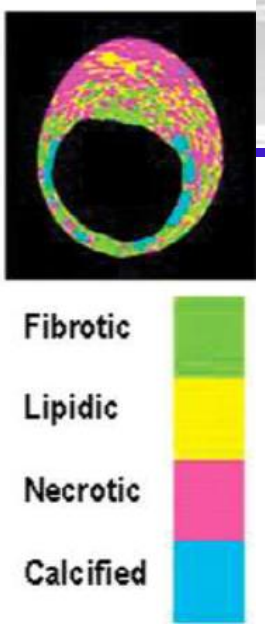


- Envelope amplitude(echo intensity) is used in formation of the gray-scale IVUS image

- Amplitude and frequency of echoes used in IB-IVUS or VH

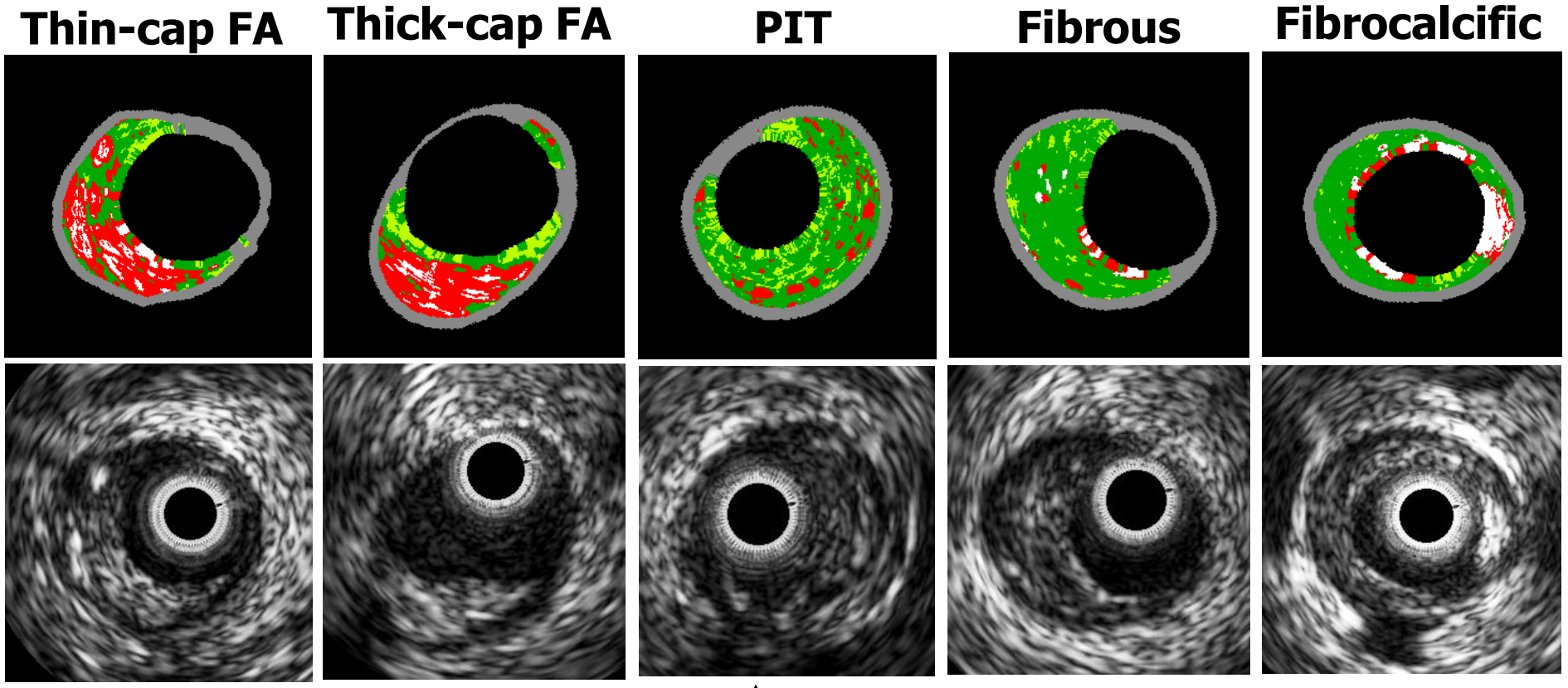
Adapted from Garcia-Garcia HM et al. Eur Heart J 2010:eurhearti.ehq280



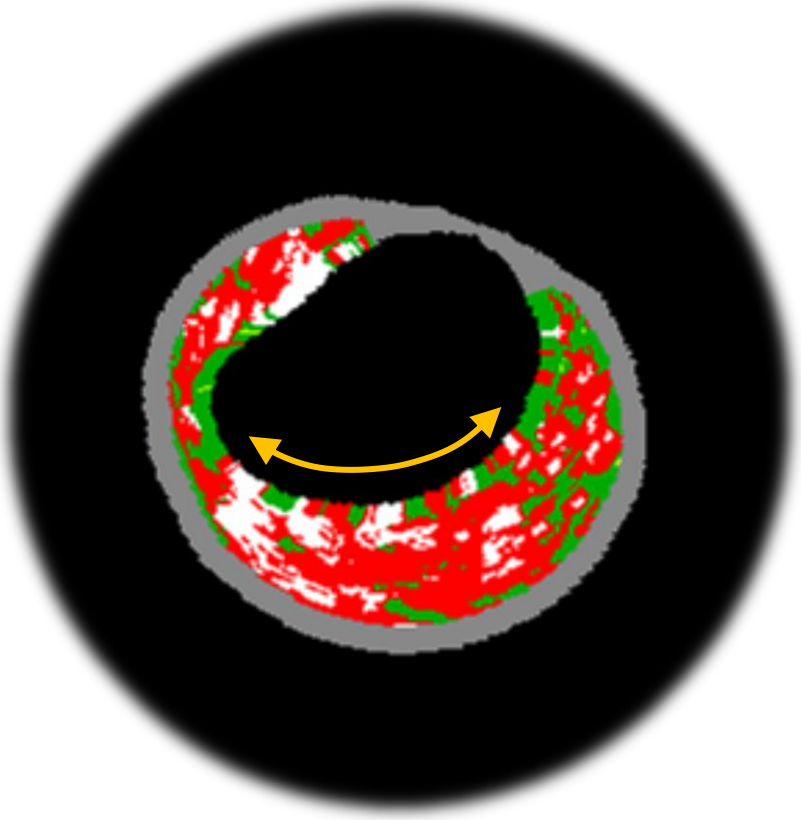


	VH	IB-IVUS	iMap
Catheter	20MHz	40MHz	40MHz
Wire artifact	No	No	NC
Peristent halo	Yes	Yes	No
Media	Yes	No	No
Acoustic shadow	NC+???	NC	NC
Attenuation	Fibrous???	NC	NC
Thrombus	Fibrous/FF	Fibrous	Fibrous
Confidence interval	No	No	Yes

VH-IVUS Classification



VH Thin cap fibroatheroma (TCFA)



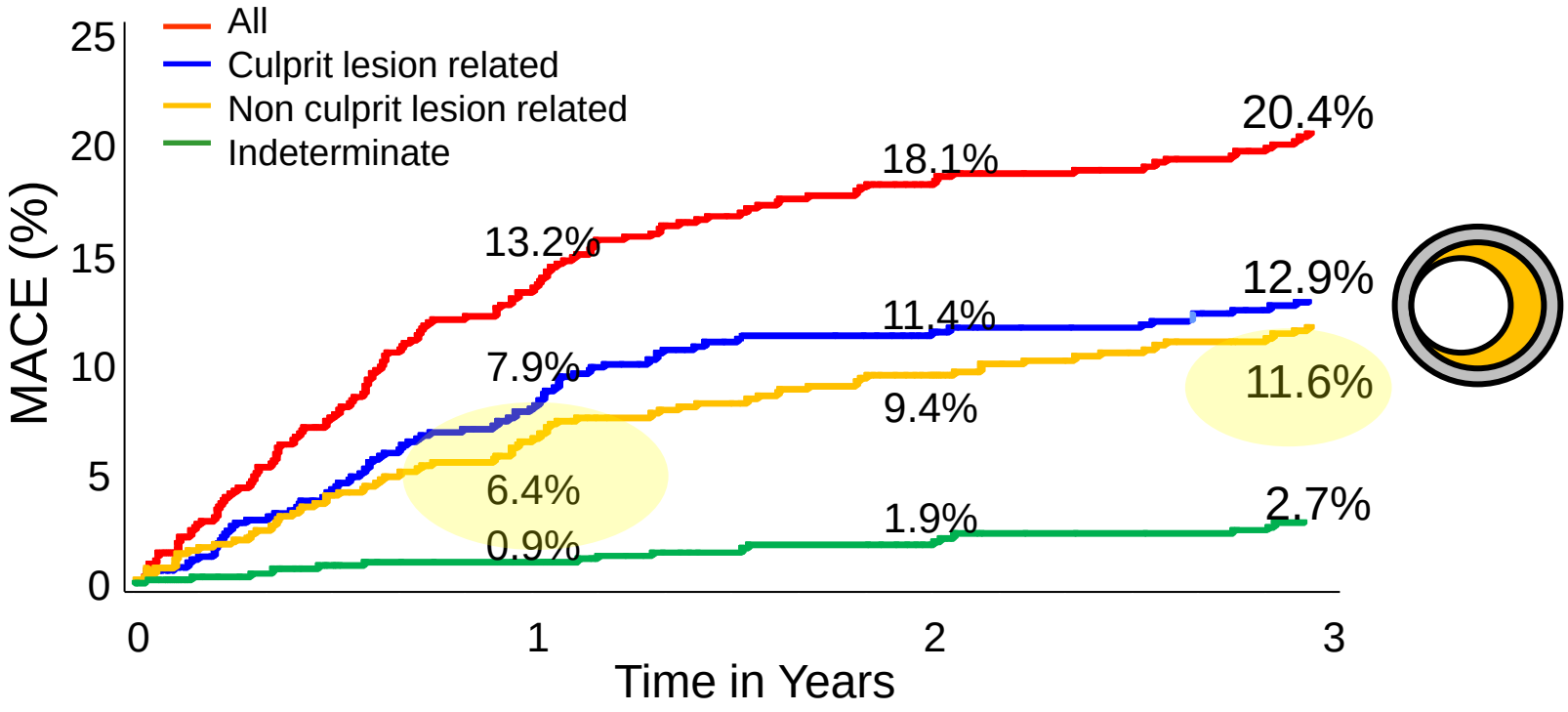
1. Confluent NC>10%
2. 30° NC abutting the lumen
3. 3 consecutive frames
   (=1.5mm in length)

Thin cap < 65 μm (less than the 200 μm resolution of IVUS)

Prospective Natural-Histology Study of Coronary Atherosclerosis

PROSPECT: MACE

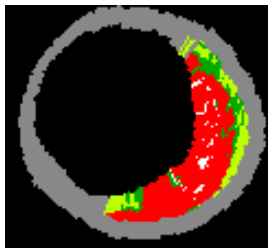
697 patients with ACS underwent PCI and 3V imaging study



Stone GW et al. N Engl J Med. 2011;364(3):226-35.

Predictors of Events in Non-culprit Lesion

PROSPECT: Non-culprit Lesion Related Events



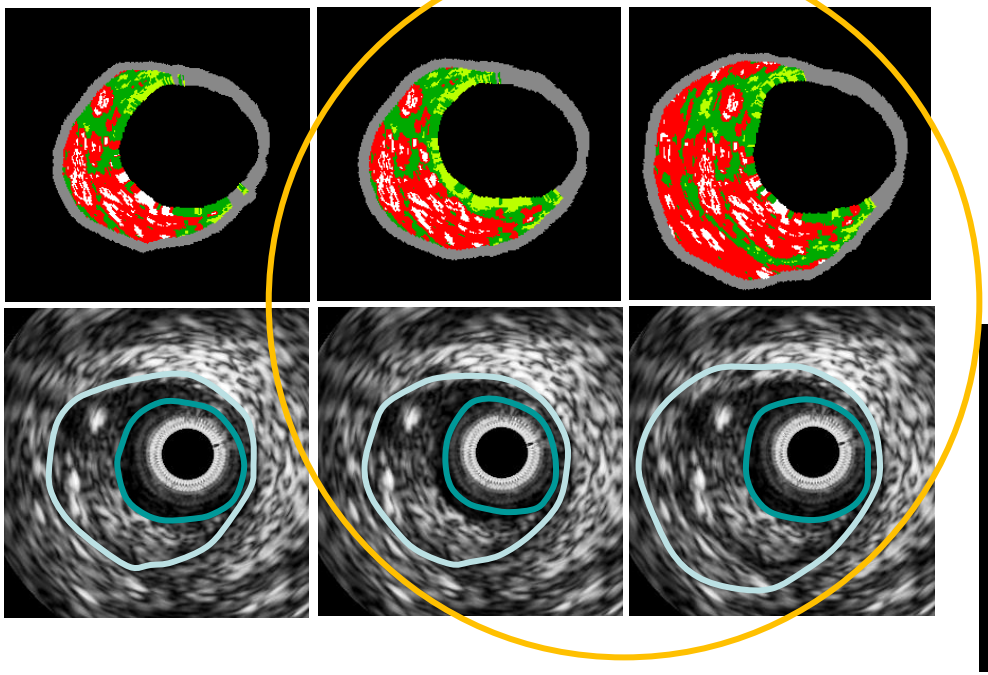
PB_{MLA} ≥70%	4.99 [2.54, 9.79]	<0.0001
VH-TCFA	3.00 [1.68, 5.37]	0.0002
MLA ≤4.0mm^2	2.77 [1.32, 5.81]	0.007

Lesion HR	3.84 (2.22, 6.65)	6.41 (3.35, 12.24)	10.77 (5.53, 21.00)	10.81 (4.30, 27.22)
P value	<0.0001	<0.0001	<0.0001	<0.0001
Prevalence*	51.2%	17.4%	11.0%	4.6%

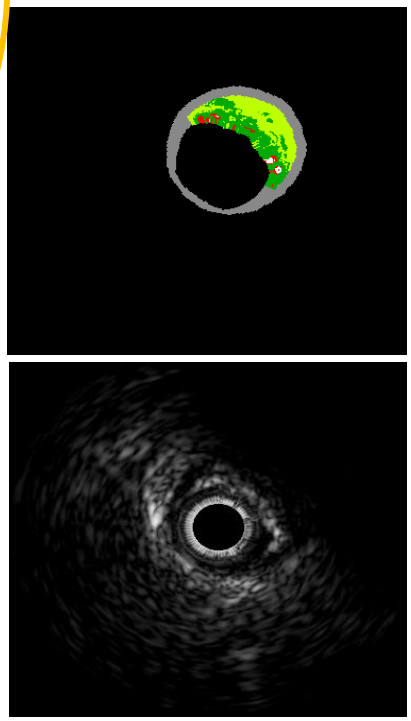
Stone GW et al. N Engl J Med. 2011;364(3):226-35.

VH Artifact/Tips to read

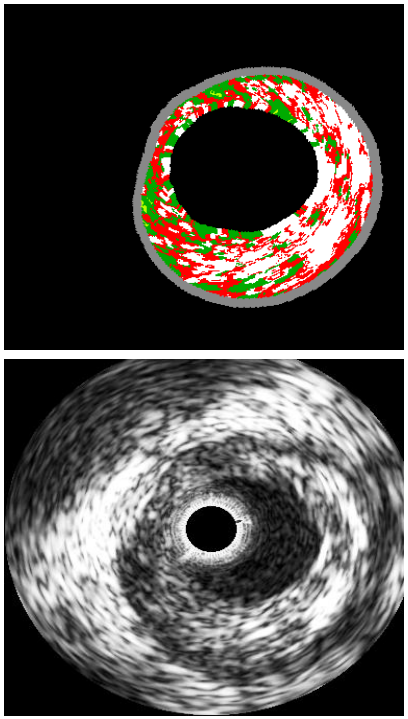
Wrong Lumen/Vessel Border



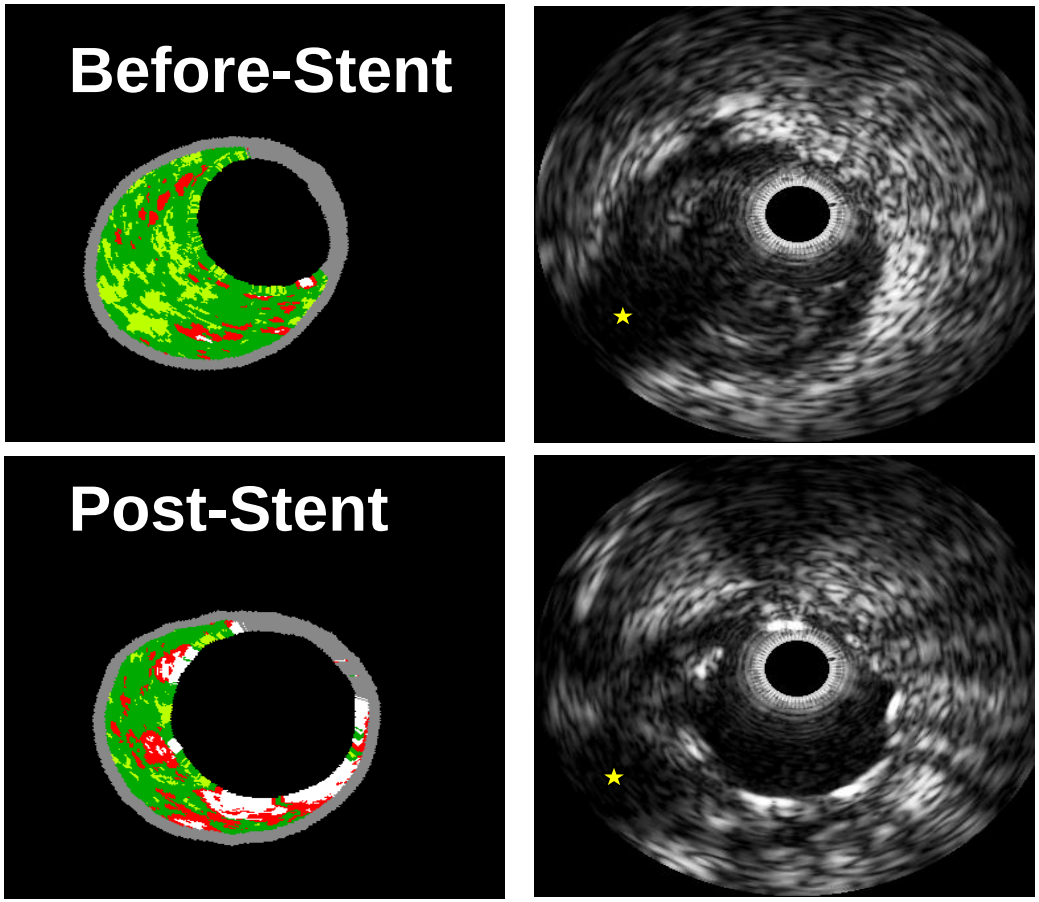
Weak Power



Strong Power



VH Artifact/Tips to read



What can we do with IVUS in Cath Lab?

IVUS Guided Intervention

Pre and during-PCI

Ambiguous lesion
Disease severity
Vulnerability
Anatomical relationship with other vessel
Making strategy of intervention
Determine device size and length and

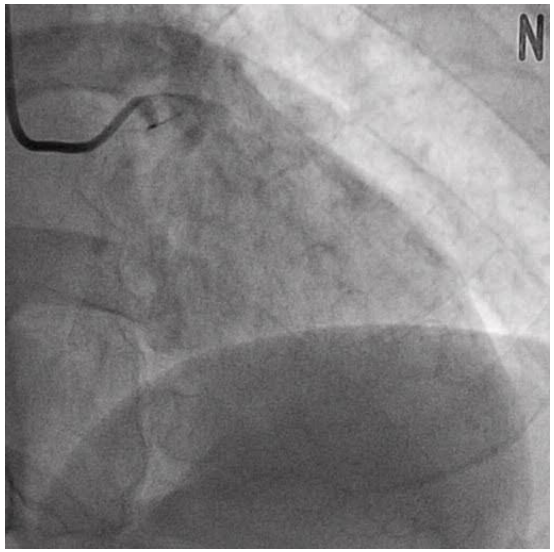
Post-PCI

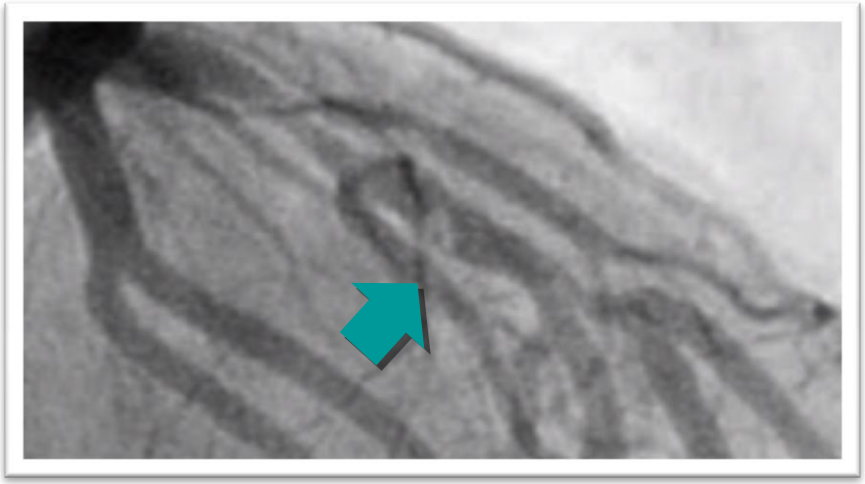
Decision of ending of procedure
Procedure-related complication

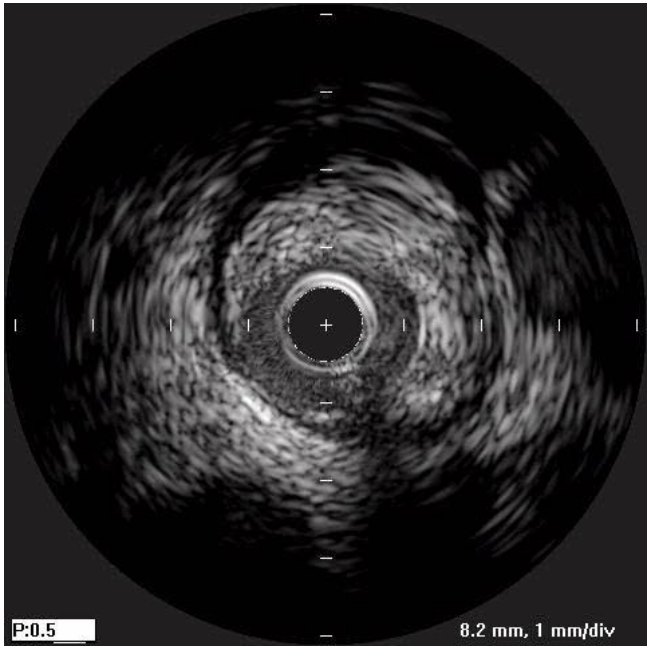
Follow-up PCI

Understanding of restenosis
Assessment of long-term complications

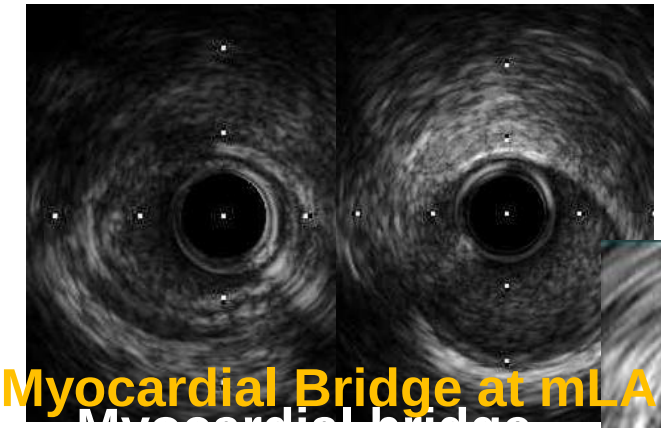
관동맥 조영술에서 보이는 병변은 무엇인가? 어떤 질환과 감별해야 하는가?





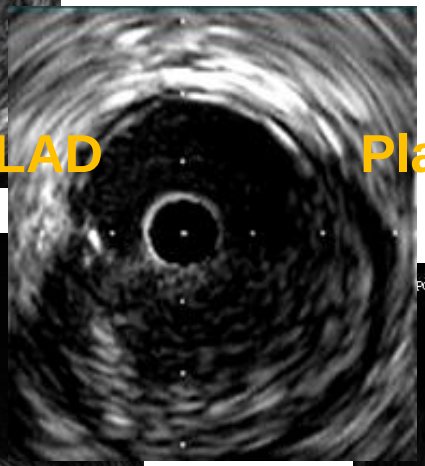


Revascularization 이 필요한 병변은 무엇인가?



Myocardial Bridge at mLAD

Plaque rupture at pLAD



Negative remodeling at osLCX

Compressing after stenting at diagonal ostium

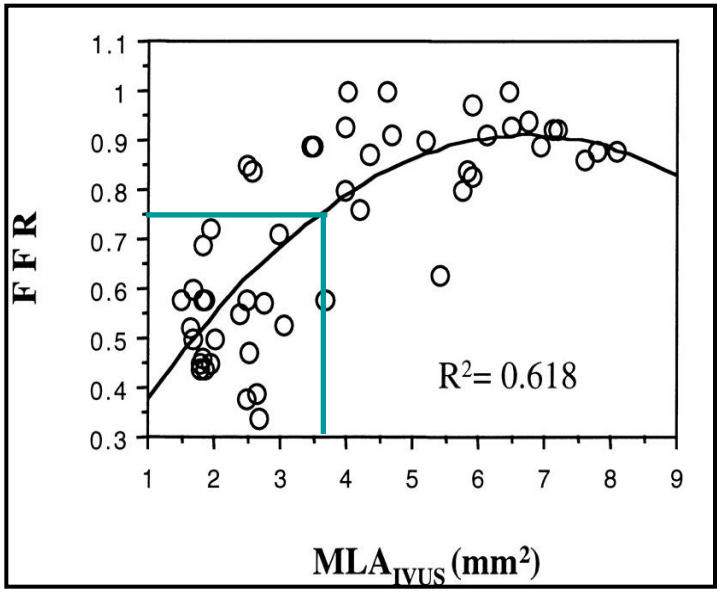
Validation of IVUS assessment of ischemia-producing stenoses

	IVUS MLA ≥4.0mm²	IVUS MLA <4.0mm²
CFR < 2.0	2	27
CFR ≥ 2.0	39	4

Diagnostic accuracy = 92%.
Abizaid et al. Am J Cardiol 1998;82:42-8

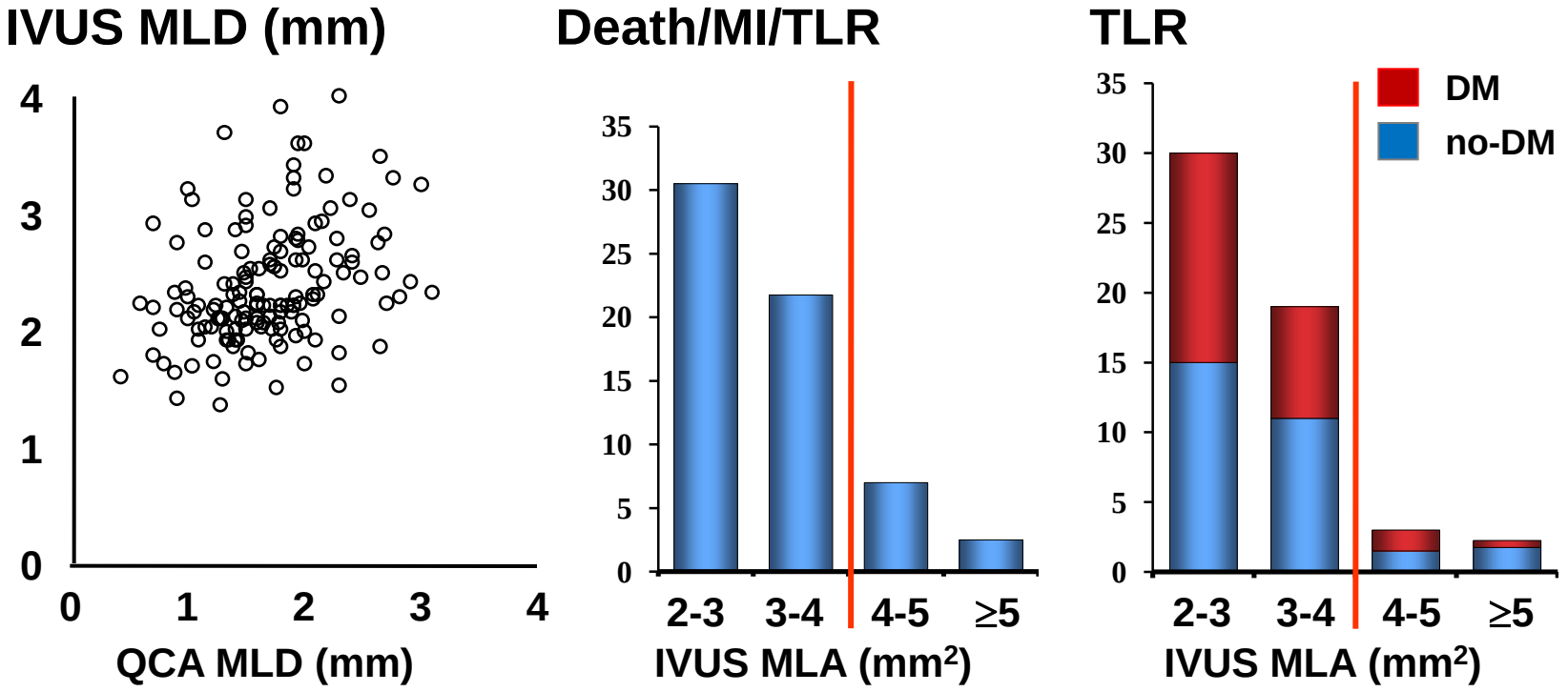
	IVUS MLA ≥4.0mm²	IVUS MLA <4.0mm²
+ SPECT	4	42
- SPECT	20	1

Diagnostic accuracy = 93%.
Nishioka et al. J Am Coll Cardiol 1999;33:1870-8



Takagi, et al. Circulation 1999;100:250-5

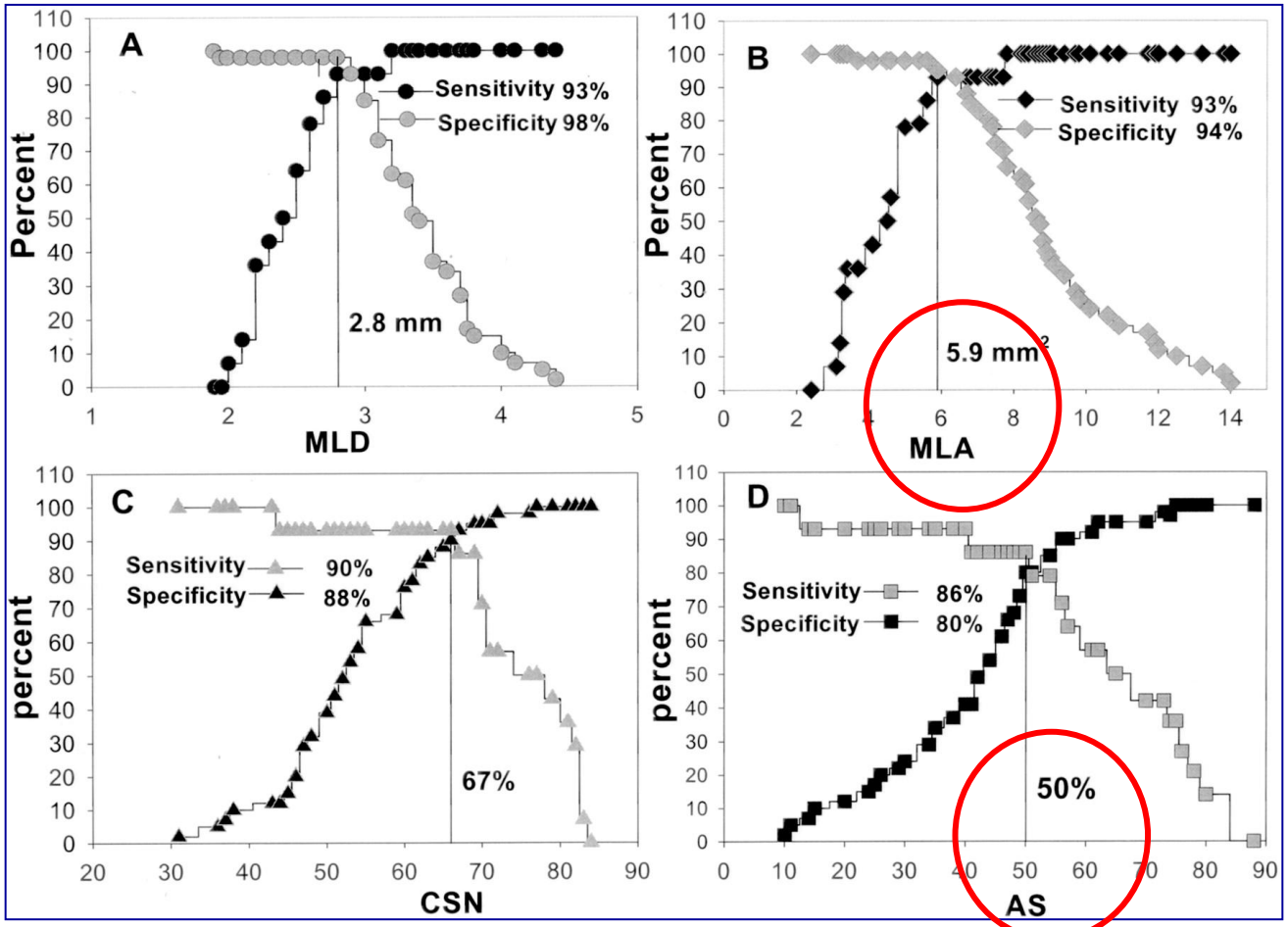
Clinical follow-up in 357 lesions in 300 pts with deferred intervention after IVUS imaging



- **Death/MI/TLR @ (mean) 13 mos = 8% overall (2% death/MI and 6% TLR)**
- **Death/MI/TLR @ (mean) 13 mos = 4.4% in lesions with MLA >4.0mm²**
- **Only independent predictor of death/MI/TLR was IVUS MLA (p=0.0041)**
- **Independent predictors of TLR were DM (p=0.0493) and IVUS MLA (p=0.0042)**

Abizaid et al. Circulation 1999;100:256-61

IVUS determinants of LM FFR <0.75



Jasti et al. Circulation 2004;110:2831-6

Indication for PCI in IVUS

Left main

Lumen CSA <6 mm^2

Major epicardial vessel

Lumen CSA <4 mm^2

*Plaque burden >50% and Area stenosis >50~70%

?

IVUS Predictor for FFR <0.8

Kang et al, Circ Cardiovasc Interv. 2011;4:65-71

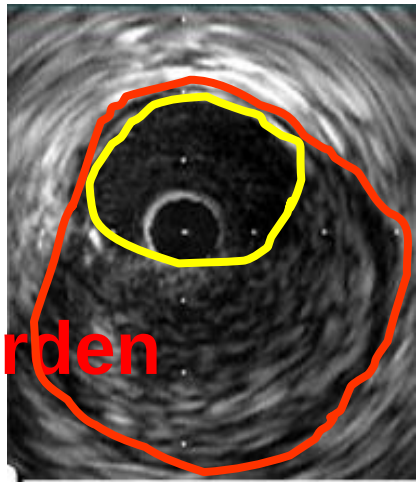
Ku et al, J Am Coll Cardiol Intv 2011;4:803-11

Yang et al, 2011ACC presented

Ben-Dor et al, EuroIntervention 2011;7(2):225-33

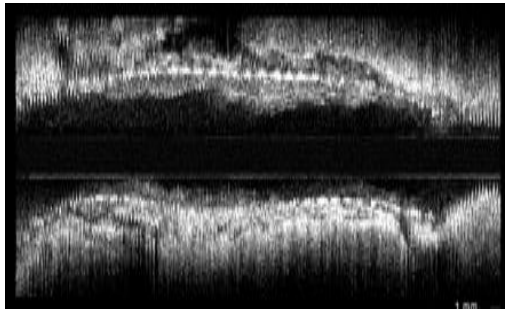
Minimum Lumen CSA

Plaque burden



Prox/LAD location

Lesion length



IVUS Predictor for FFR <0.8

Kang et al, Circ Cardiovasc Interv. 2011;4:65-71

Ku et al, J Am

Ya

Ben-Dor et

BCV= 2.4 mm² (90% sensitivity, 60% specificity, AUC=0.800, 95% CI, 0.742~0.848; p<0.001

	n	IVUS Predictors	B/OR	95% CI	p
Kang et al	236/201	**MLA**			.032
		PB			.005
		Length (LA<			.005
		LAD location	-0.035	-0.055~-0.016	0.001
Ku et al	267	**MLA**	0.35	0.19~0.66	0.001
		Proximal		1.20~7.32	0.02
		LAD		1.24~9.30	0.02
Ben-Dor et al.	92/84	**MLA**			

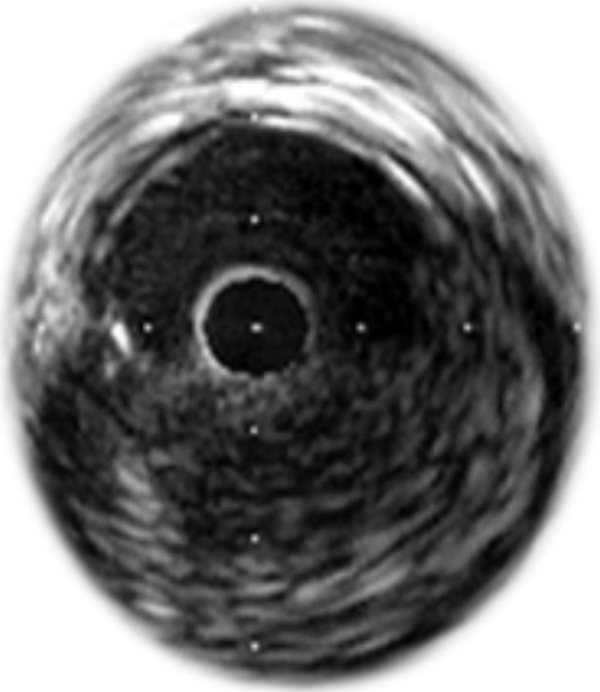
BCV= 3.0 mm² for pLAD (AUC=0.81, 95% CI, 0.68~0.91), 2.75 for mLAD AUC=0.76, 95% CI, 0.66~0.84)

<3.2mm² (sensitivity 69%, specificity 68%)

IVUS vs FFR for Evaluating Disease Severity

IVUS
Anatomical
Stenosis

FFR
Functional
Stenosis



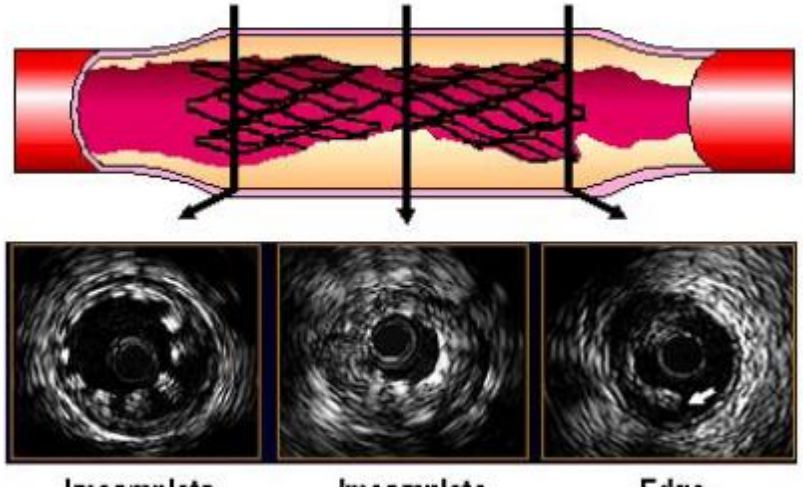
IVUS-Guided Optimal Stenting

Three fundamentals of stent placement (AVID and MUSIC)

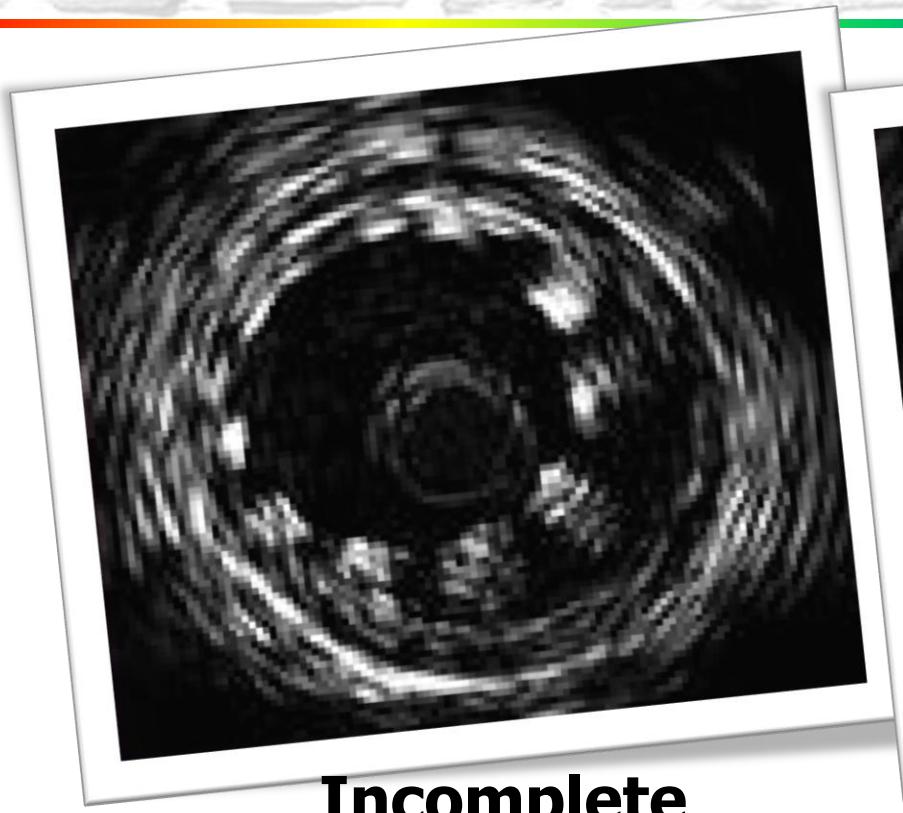
- Adequate expansion
- Full apposition of stent
- Absence of complication: dissection, hematoma etc….

* IVUS guided adequate expansion

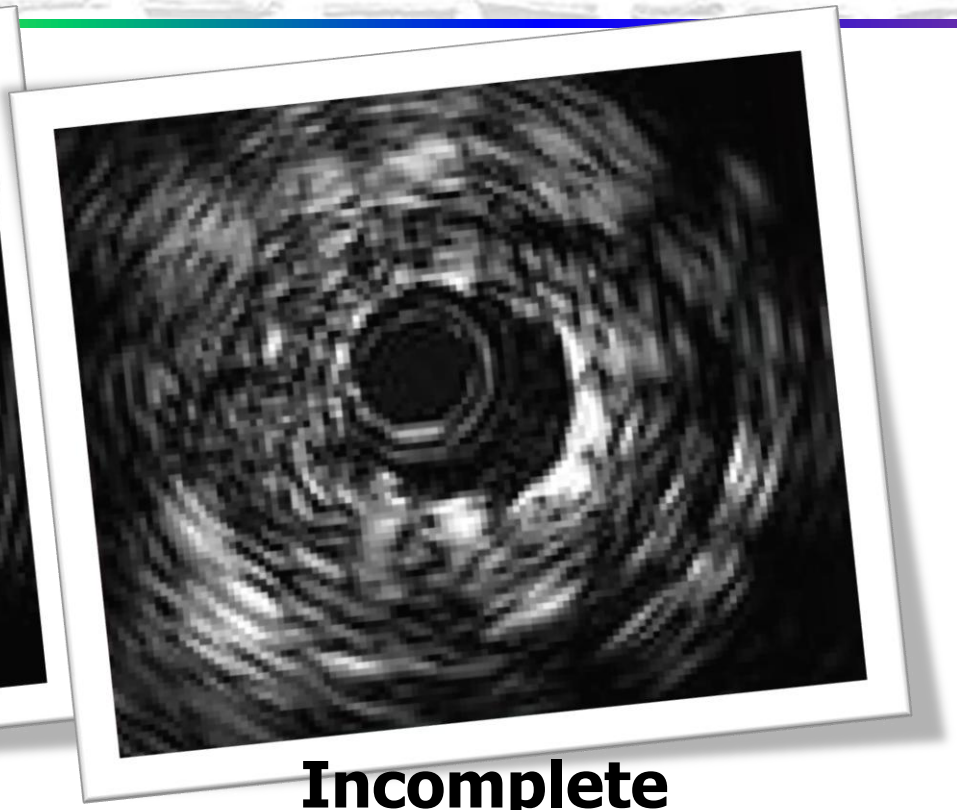
- Minimal stent area >6 mm^2 in BMS, >5~5.5 mm^2 in DES
- ≥ 80% of average reference vessel LA



Stent Apposition and Expansion



Incomplete Apposition



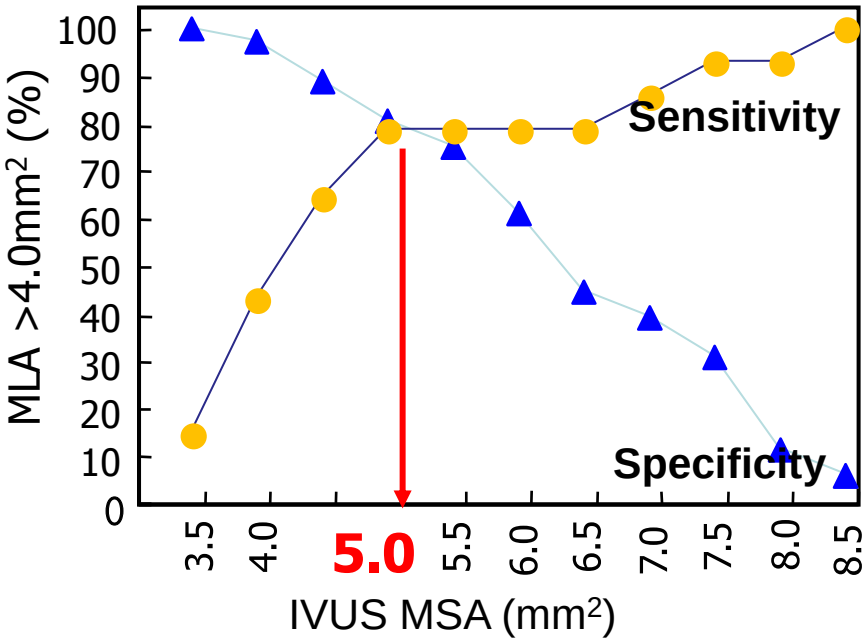
Incomplete Expansion

IVUS-Guided Optimal Stenting

BMS: Lumen CSA <6.0 mm^2
DES: Lumen CSA <5~5.5 mm^2

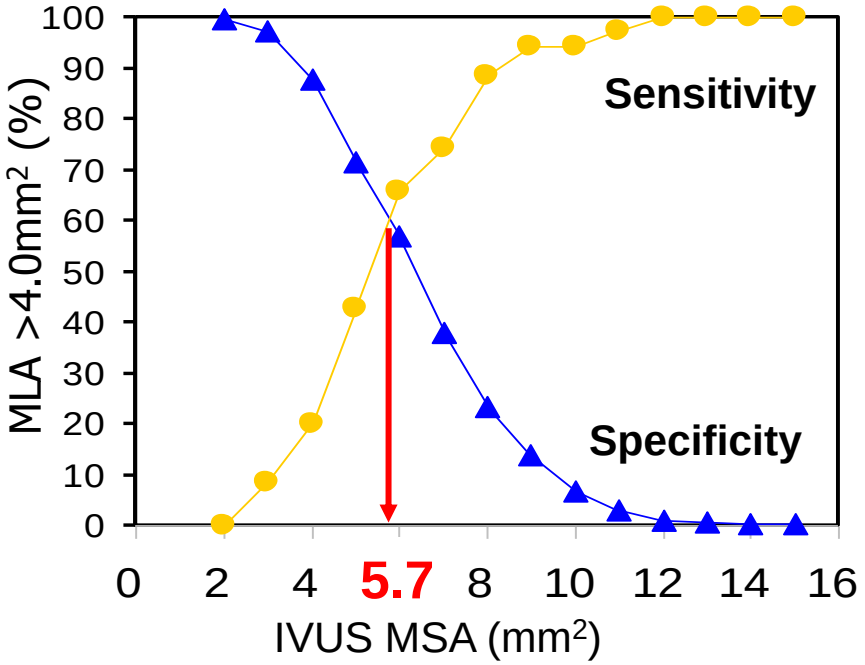
Final MSA for Prediction of Restenosis

Cypher



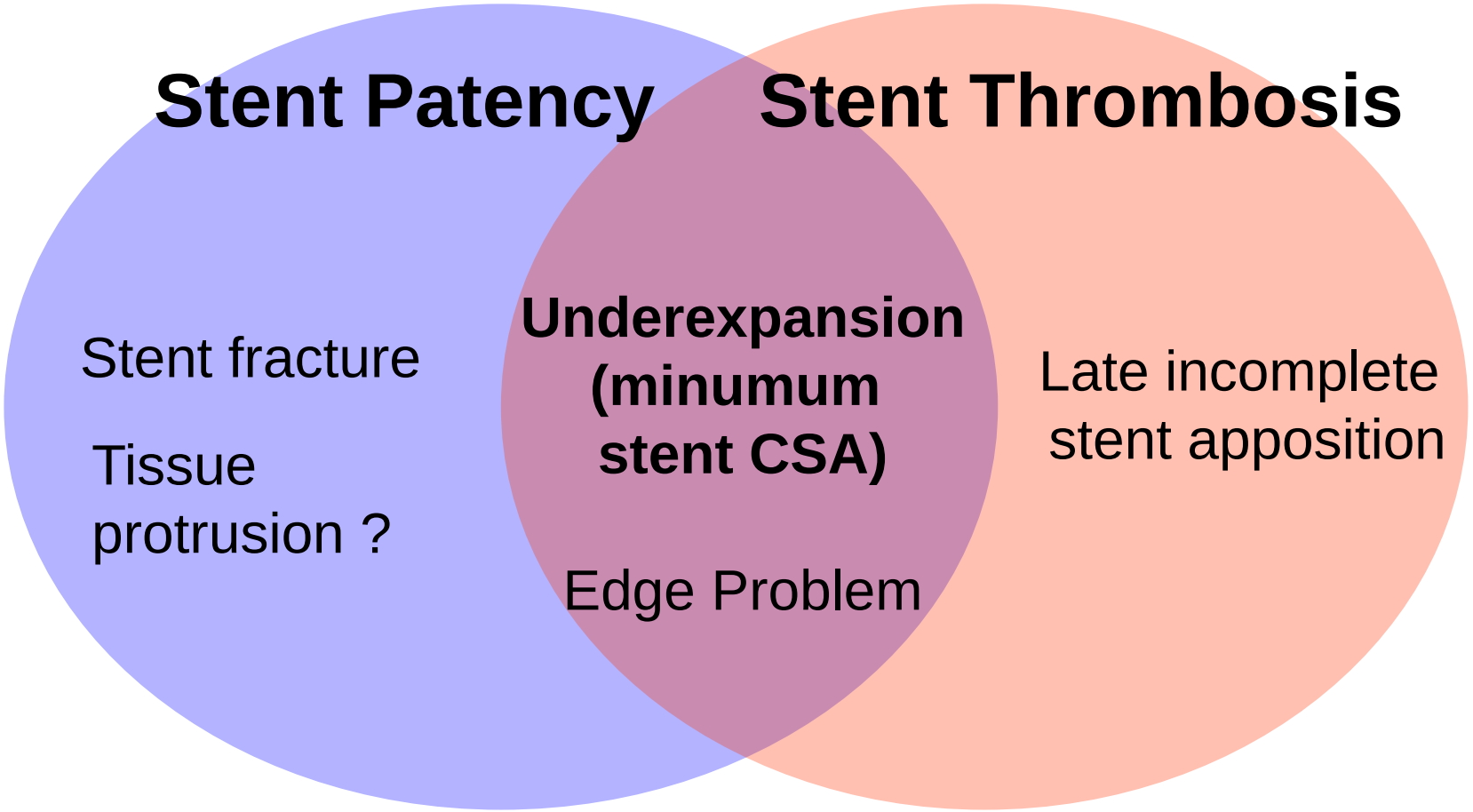
Sonoda et al. J Am Coll Cardiol 2004;43:1959-63

Taxus



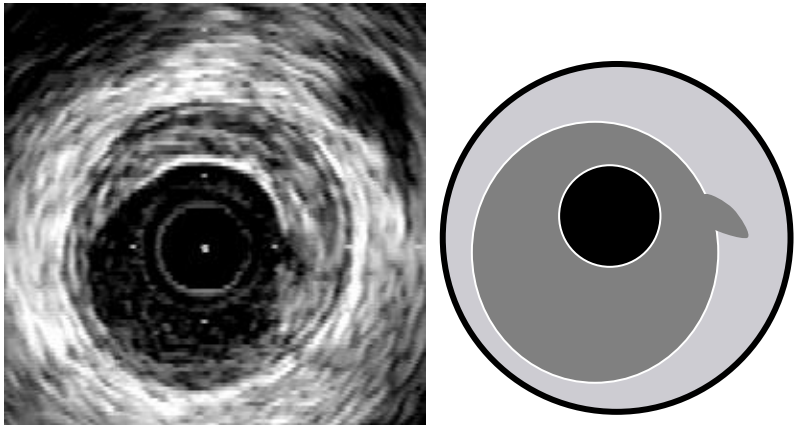
Doi et al. JACC Cardiovasc Interv. 2009;2:1269-75

IVUS Predictors of Restenosis and Stent Thrombosis

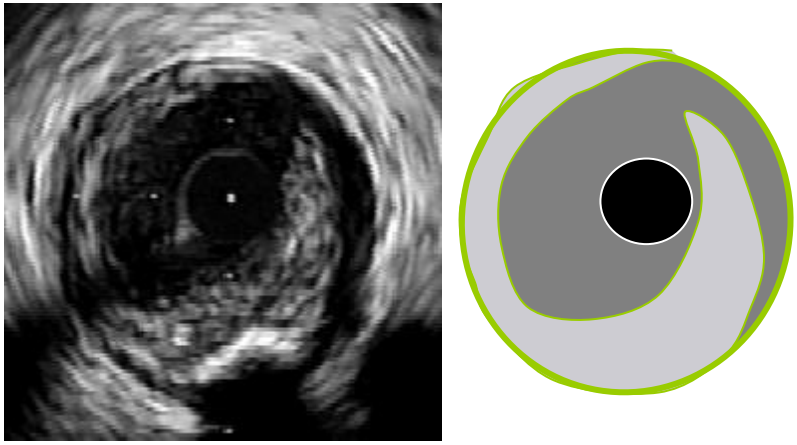


Post-PCI Complication

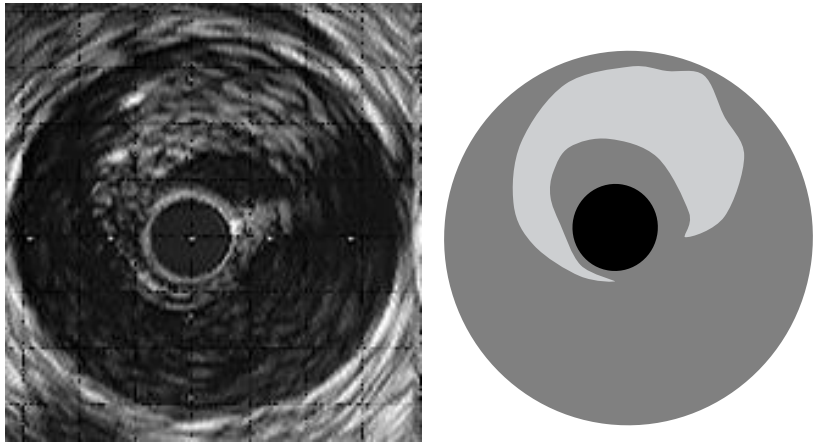
Intimal Dissection



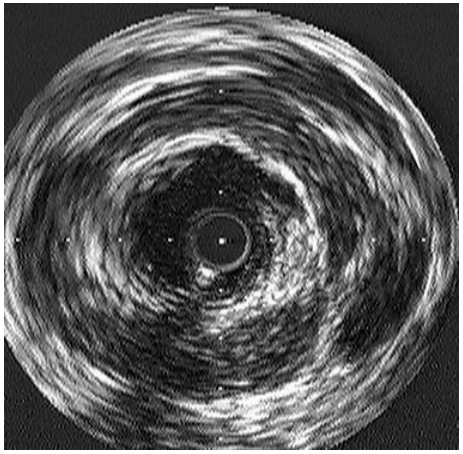
Medial Dissection



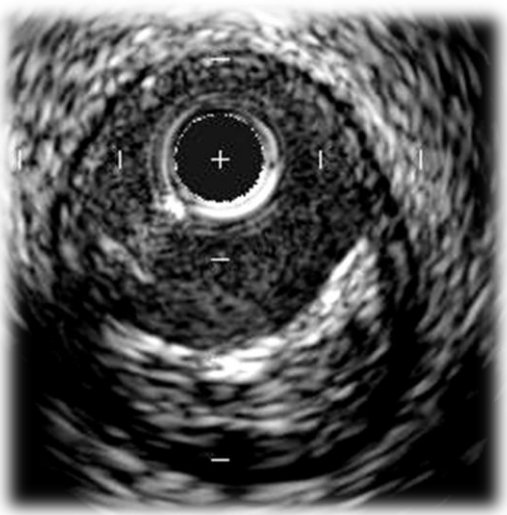
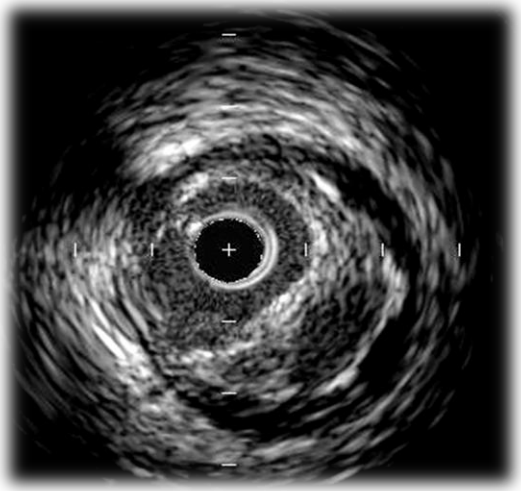
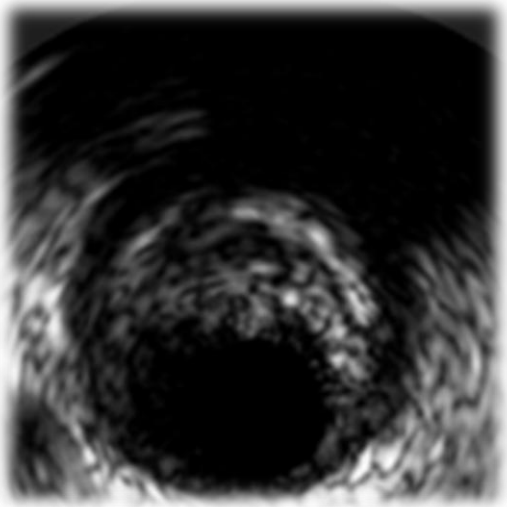
Intramural Hematoma

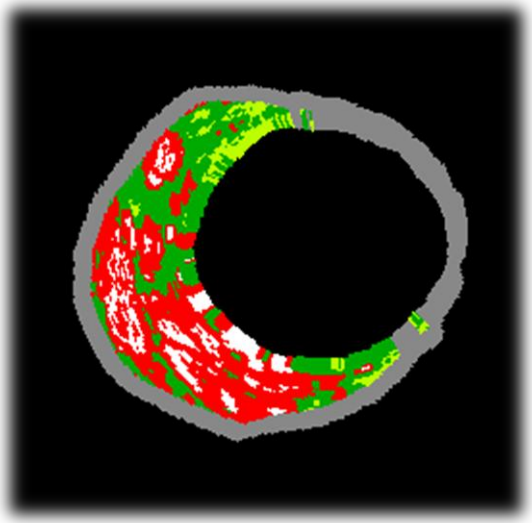


Perivascular Damage

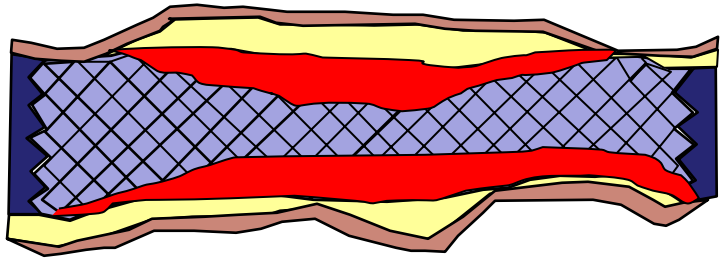


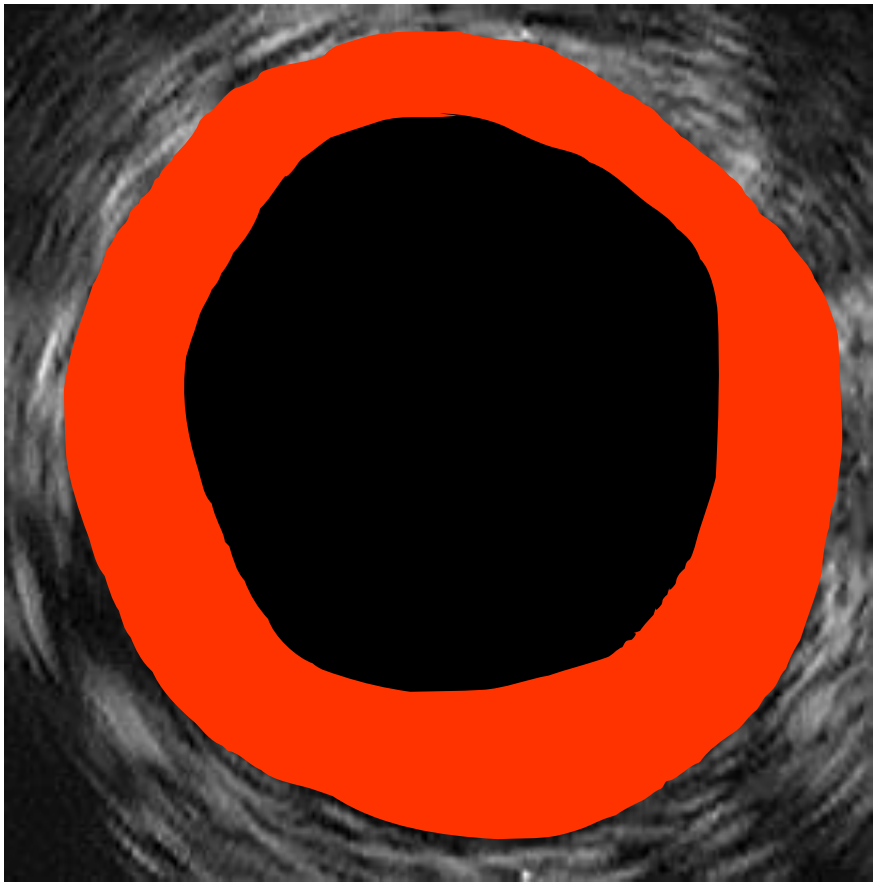
스텐트 삽입술 직후 no-reflow 또는 cardiac enzyme 상승과 관련이 있다고 알려진 동맥경화반은?

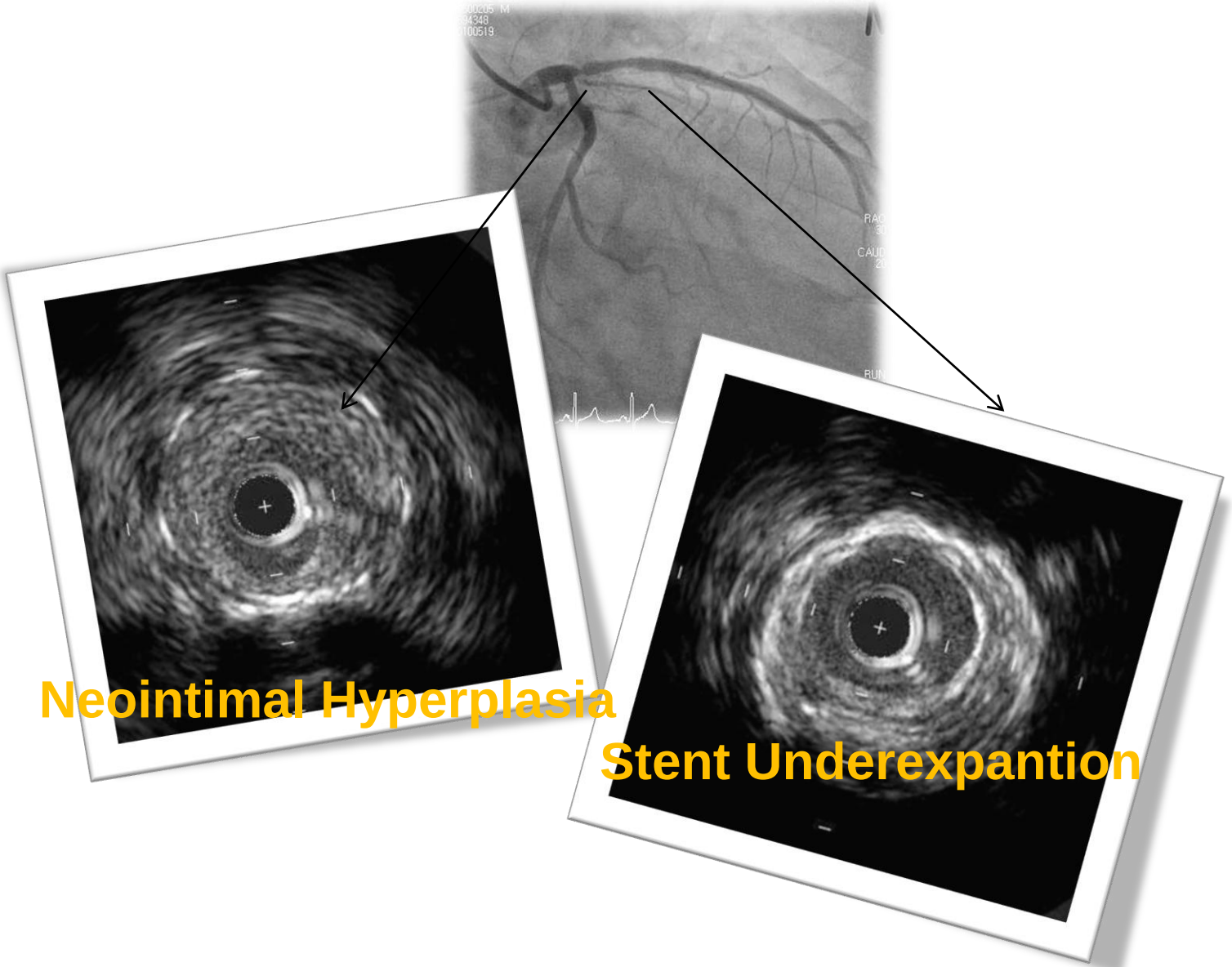



In-Stent Restenosis

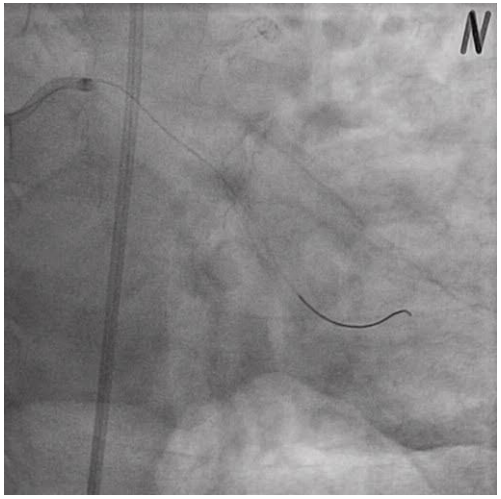




스텐트 삽입 후 재협착 병변에서 IVUS로 관찰되는 스텐트 재협착의 기전은?

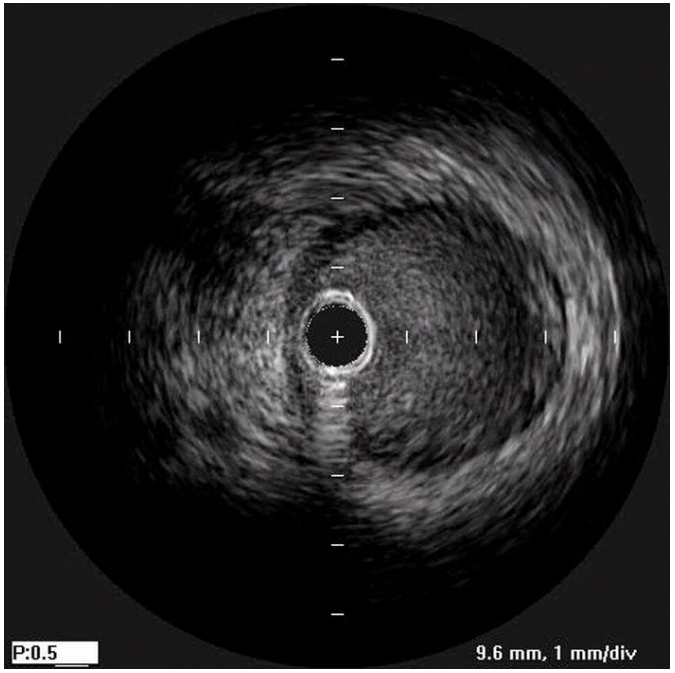


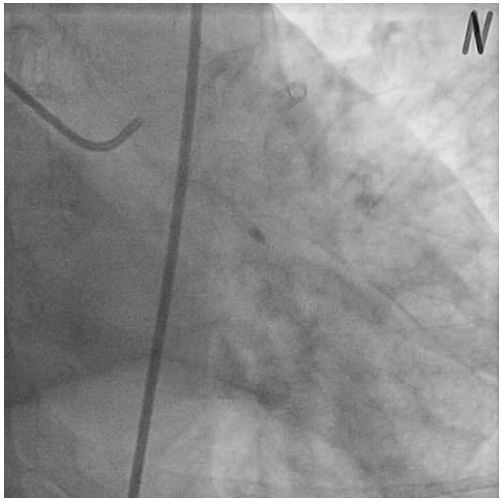
스텐트 삽입 후 발생한 stent thrombosis의 기전은?



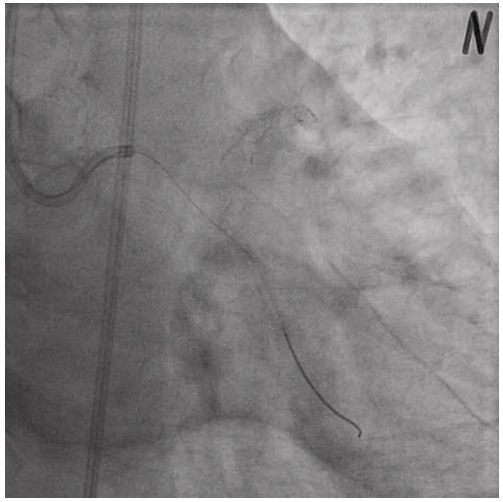
18mo ago

M/56 with AMI (lat)
PCI with Endeavor stent 2.75 x 12mm at OM 18 months ago





Baseline



After thrombosuction

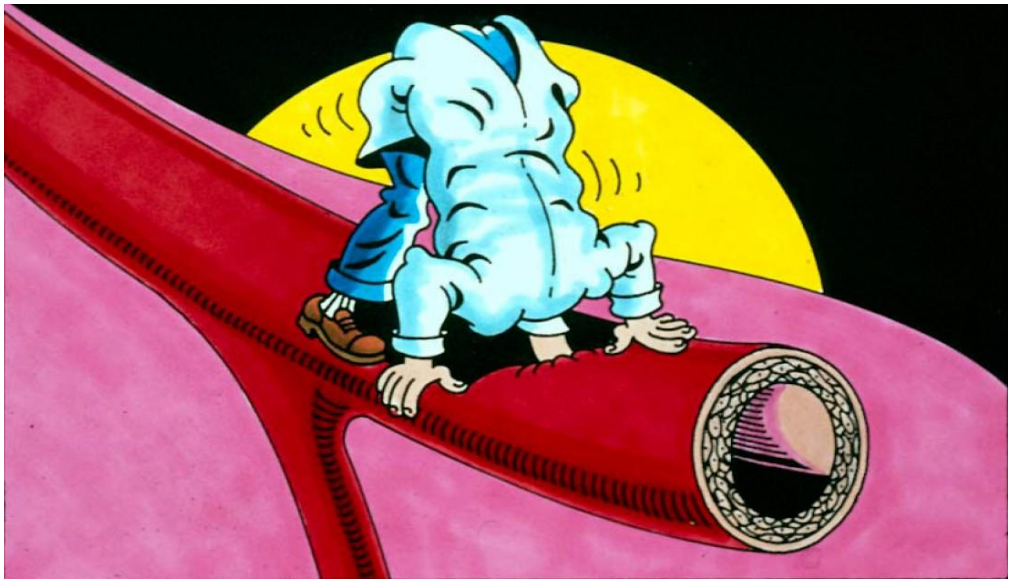
Is IVUS replaced with other Imaging Modality in Cath Lab?

Future Direction in IVUS

- High resolution IVUS
- Tissue characteristics
- 3D reconstruction
- Forward viewing intracoronary imaging
- Multimodality device for imaging and physiology study

IVUS is…….

A view from within the vessel!



Courtesy of Dr Fitzgerald, Stanford