Basic of IVUS & OCT

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이 봉 렬

Coronary aretry imaging

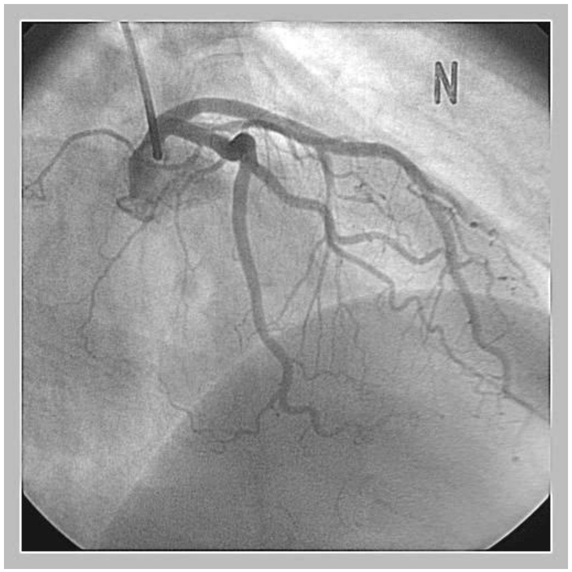
- Coronary angiography
- IVUS
  - Gray-scale
  - VH-IVUS
- OCT
- CTCA
- MRCA

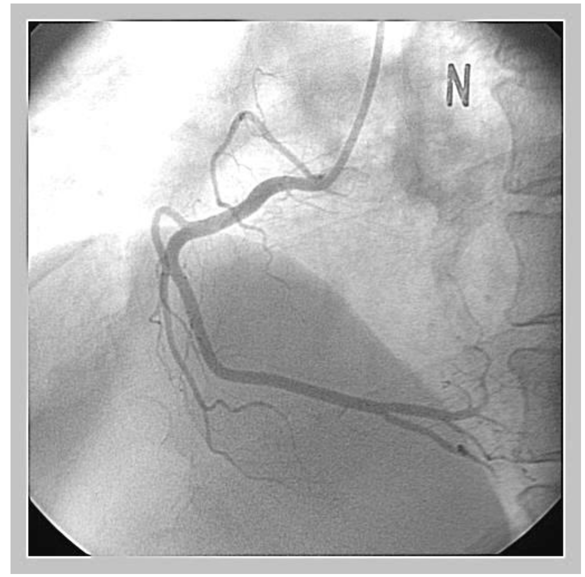
Selective coronary angiography

- First performed by Sones in 1959
- **"Gold standard"** for identifying the presence or absence of coronary arterial narrowings
- Define therapeutic options and determine the prognosis of patients with symptoms or signs of ischemic CAD.

Major Limitation of Coronary Angiography

Coronary Angiogram: *Is it enough to evaluate coronary disease?*



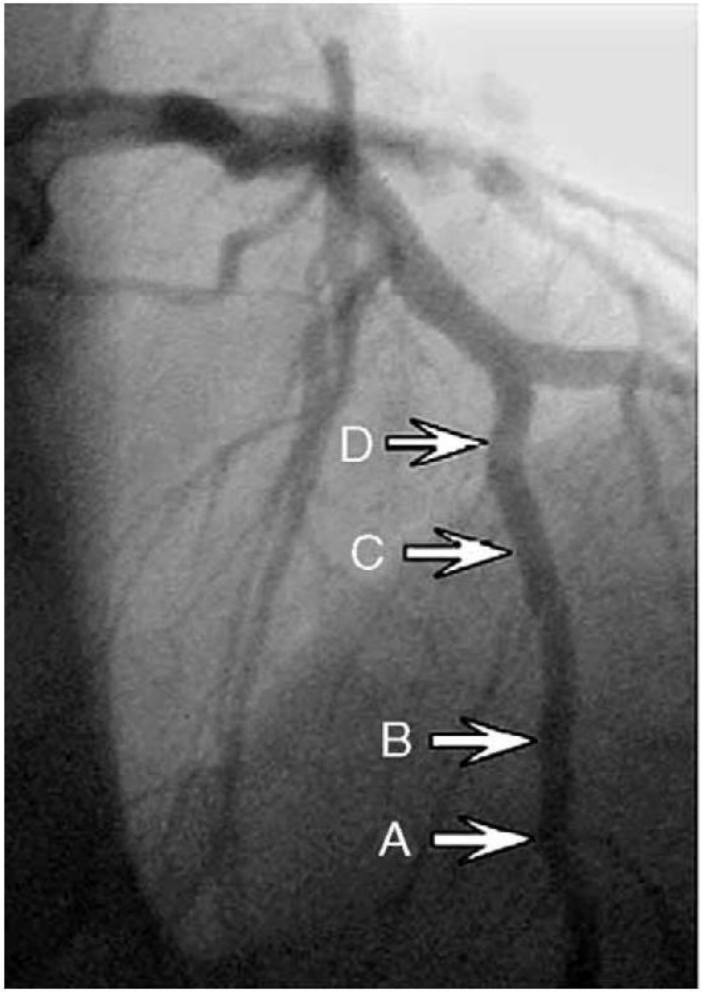


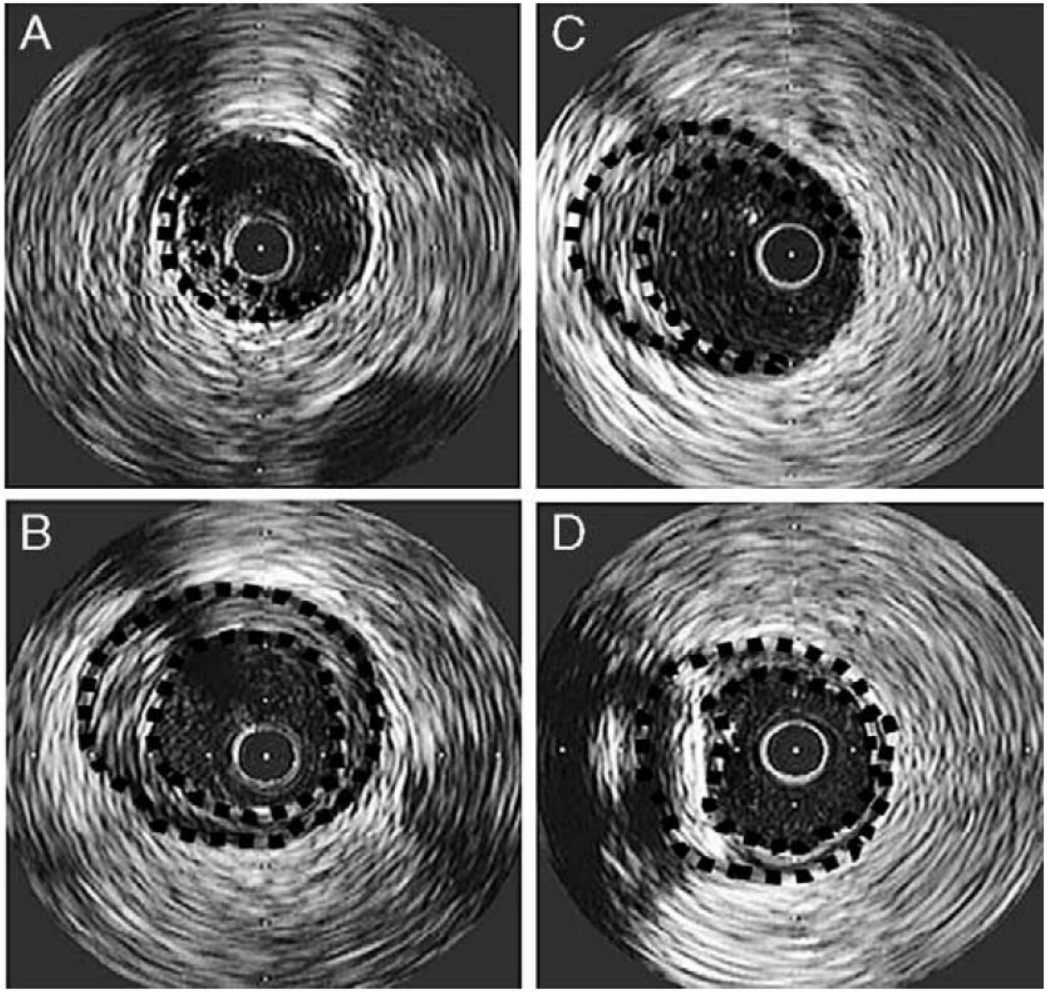
➔ *"Coronary angiography is only a luminogram."*

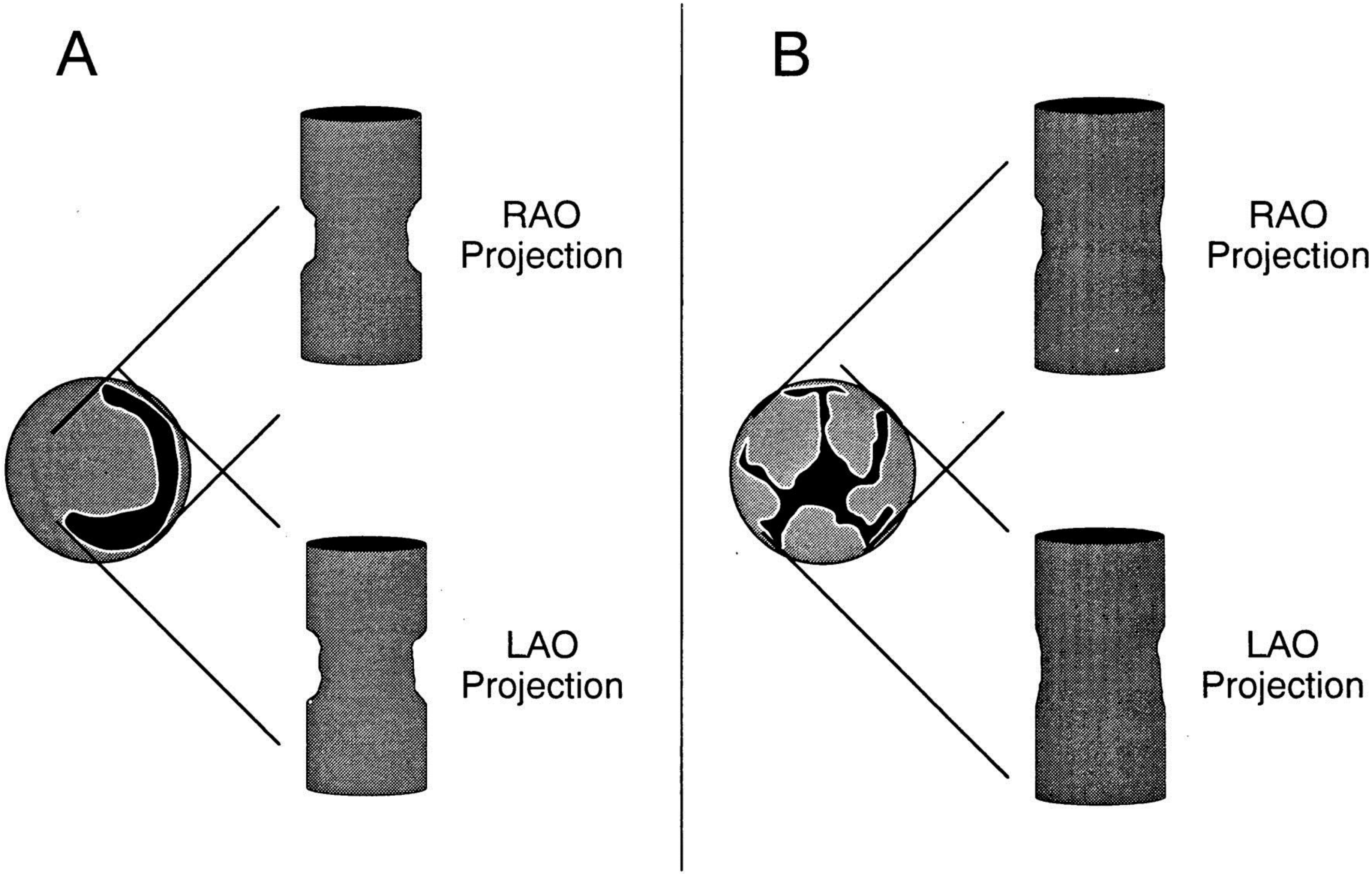
Limitations

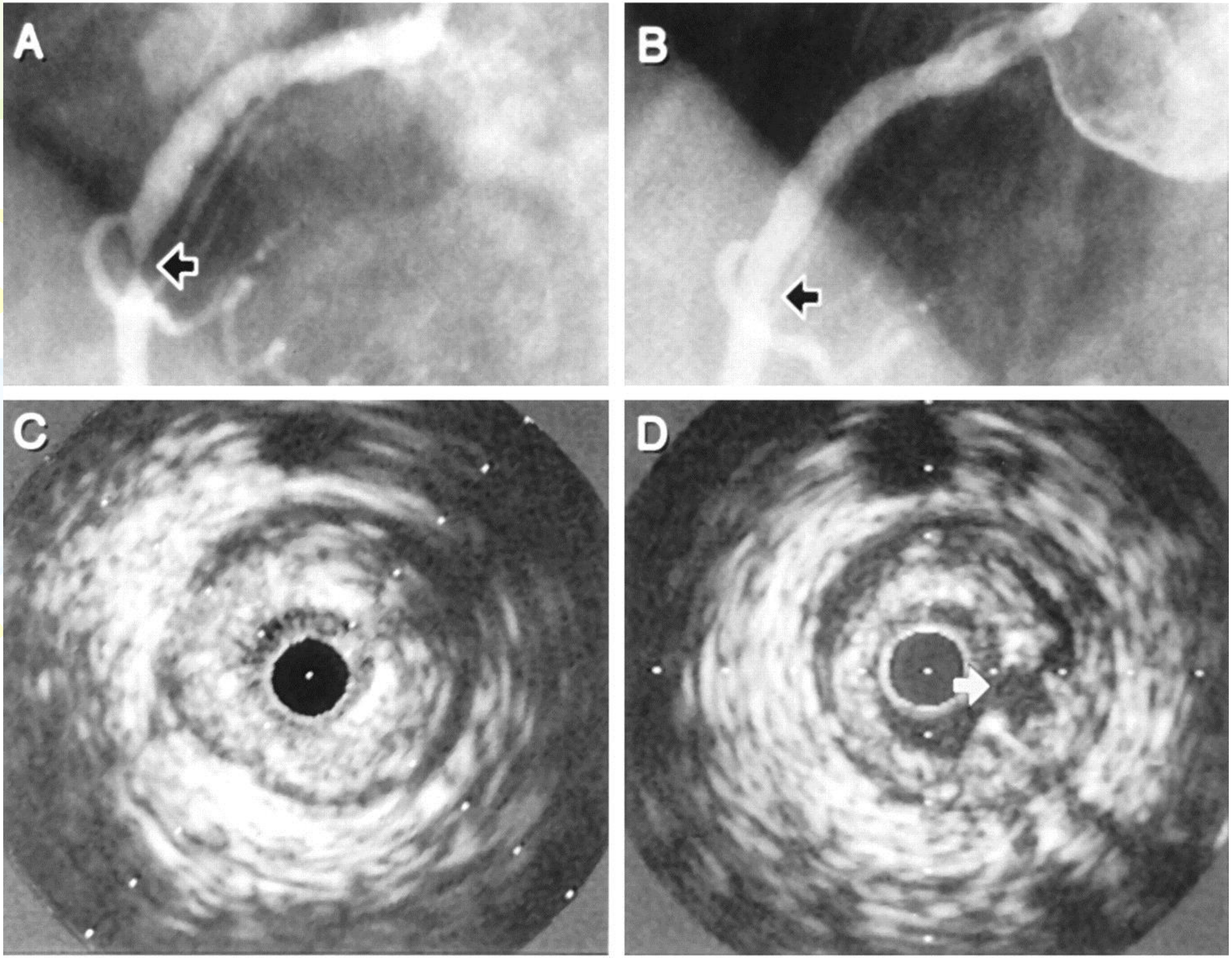
1. Simple planar information
2. Compromising the lumen in late stage of atherosclerosis (Glagov's theory)
3. No information about plaque characteristics

No information about the composition of the atherosclerotic plaque

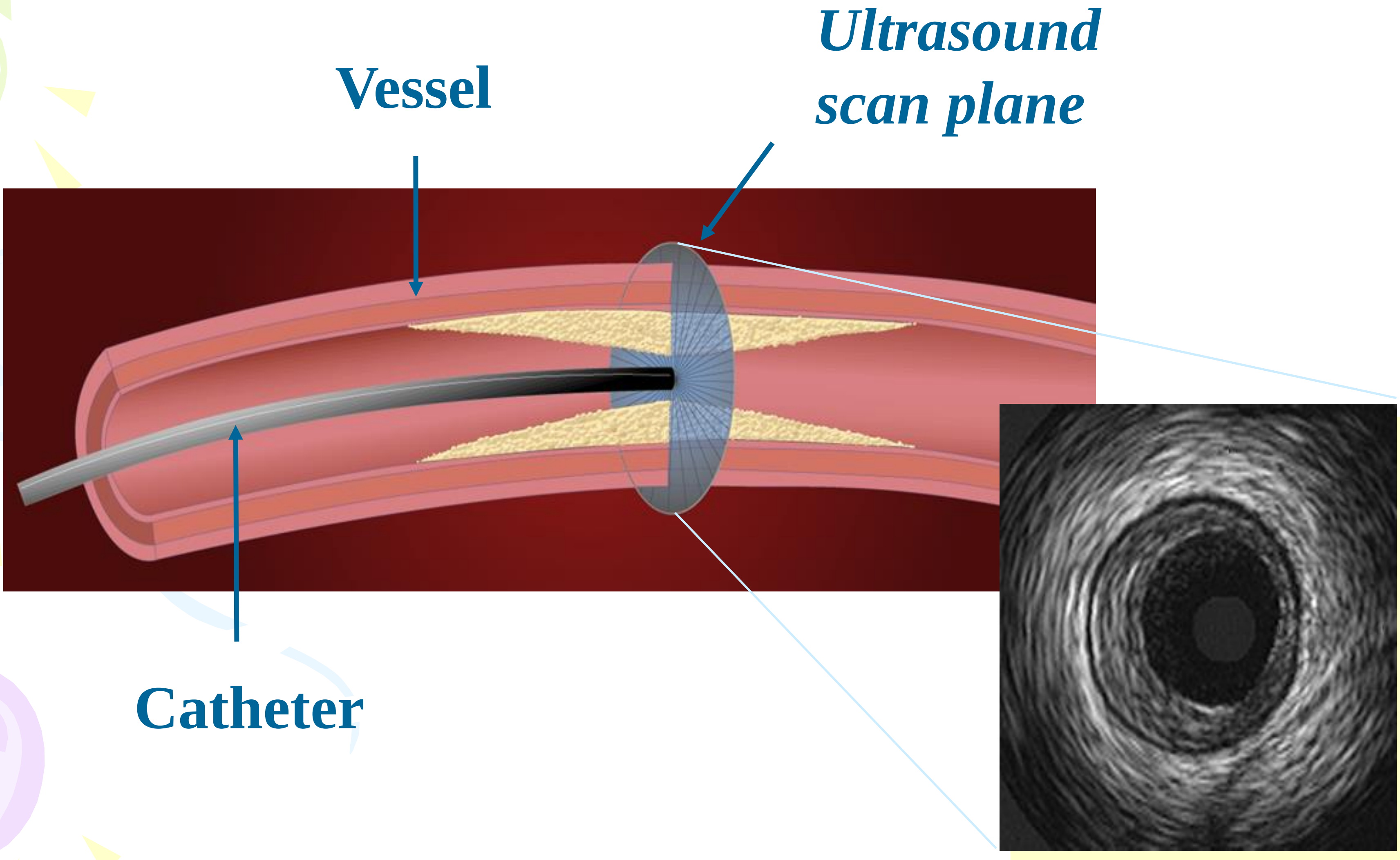





A
RAO
Projection
LAO
Projection
B
RAO
Projection
LAO
Projection


A
B
C
D

IVUS – A New Dimension in Imaging



Angiography vs. IVUS

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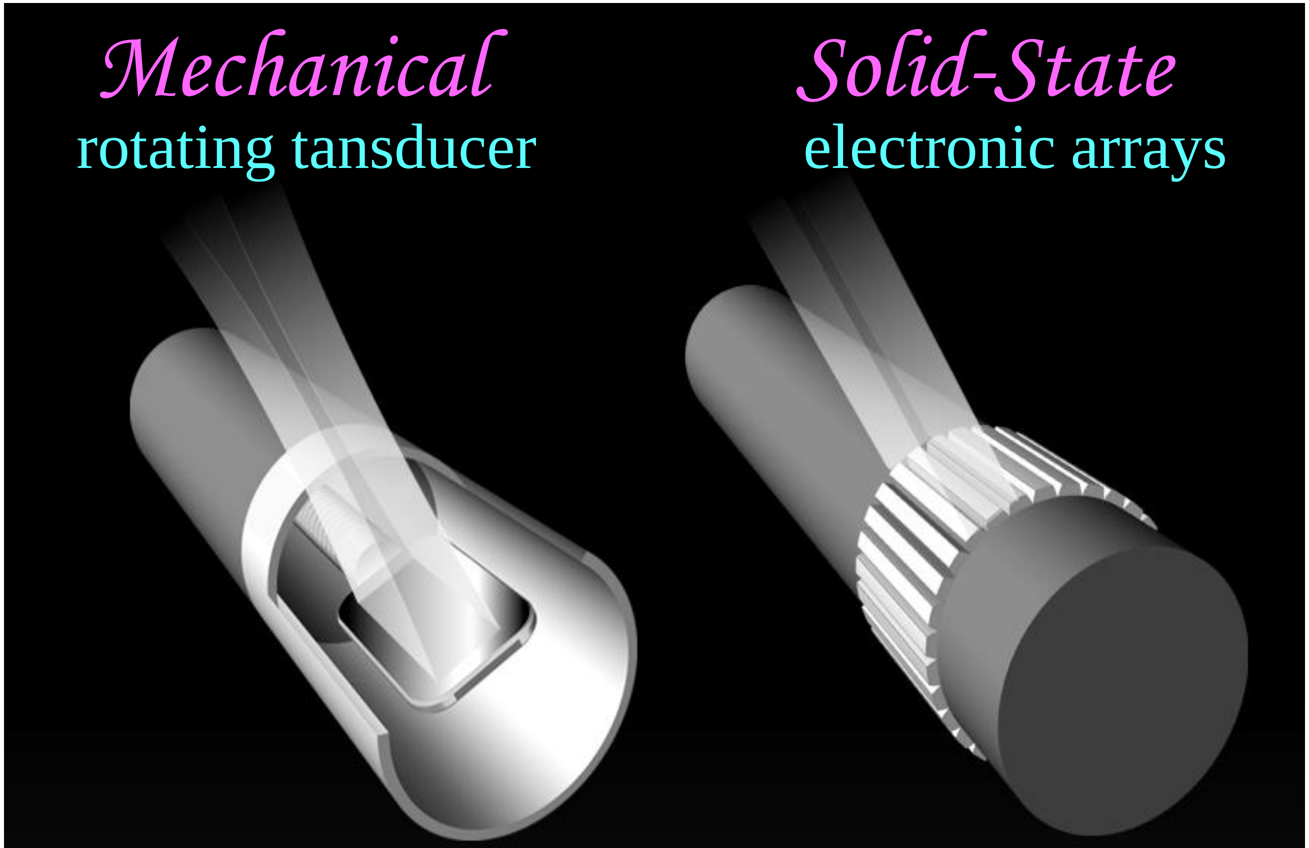
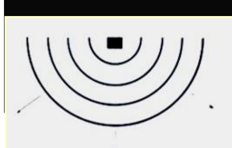
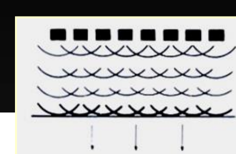
Characteristic	Angiography	IVUS
Vessel lumen detail	+	++
Vessel wall detail	-	++++
Plaque composition	-	+++
Vessel dimensions	++	++++
Identify disease in “normal”vessel	+	++++
Detect diffuse disease	+	++++
Evaluate “hazziness”	±	+++
Arterial remodeling	±	++++
Borderline lesions – morphology	+	++++
Suboptimal results	+	+++
Clot vs. dissection	±	+++
Predict complications	±	possible

Catheter Systems: Transducer Design





single piezoelectric transducer element



multiple piezoelectric transducer element

Catheter Systems: Commercial

Mechanical

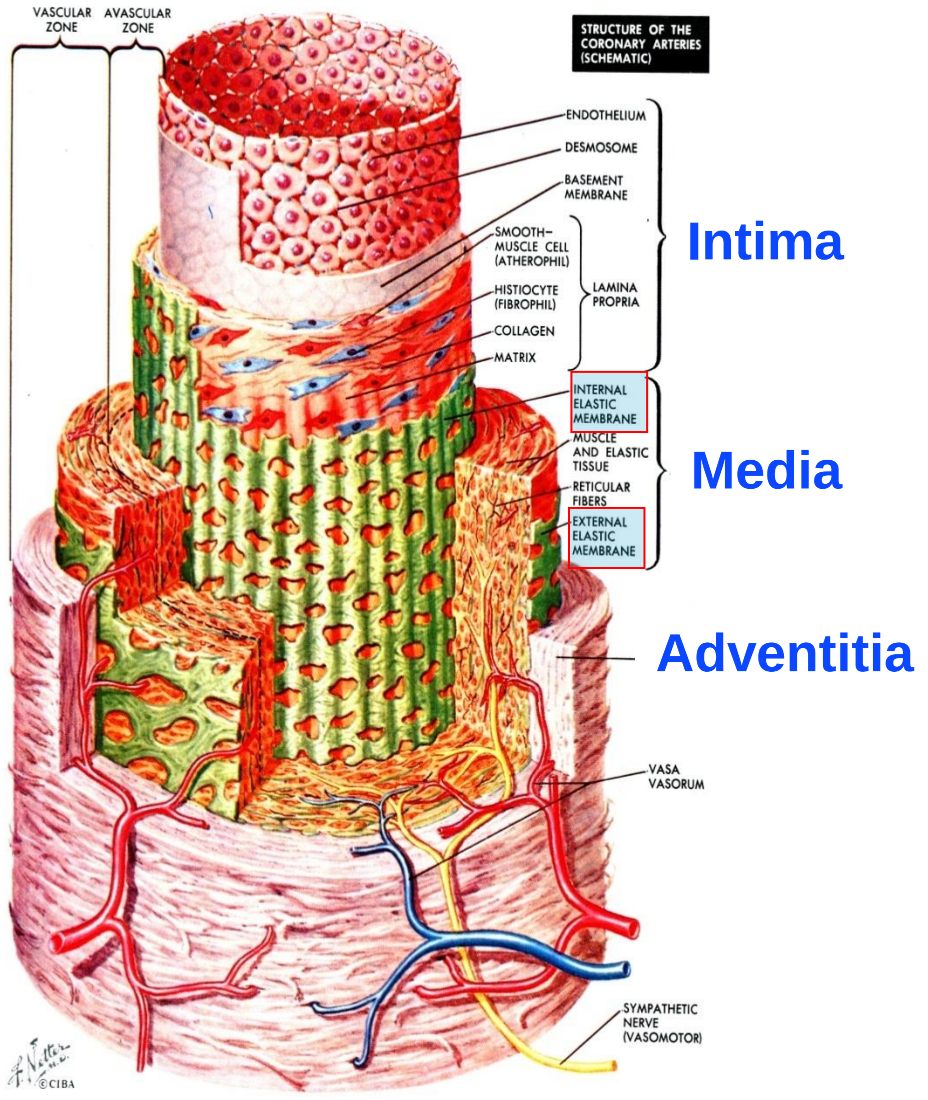
◈ Boston Scientific

- a 40-MHz coronary catheter that is 2.5 F at the tip and 3.2 F at the largest dimension
- compatible with a 6 F guiding catheter

Solid-State

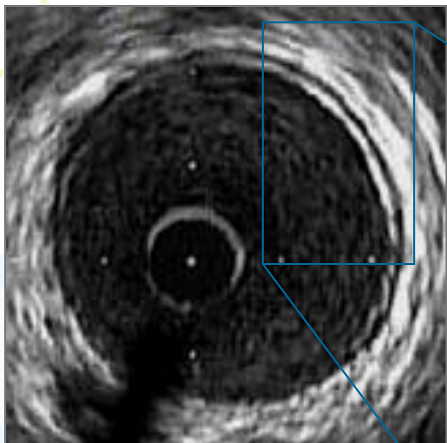
◈ Volcano Therapeutics

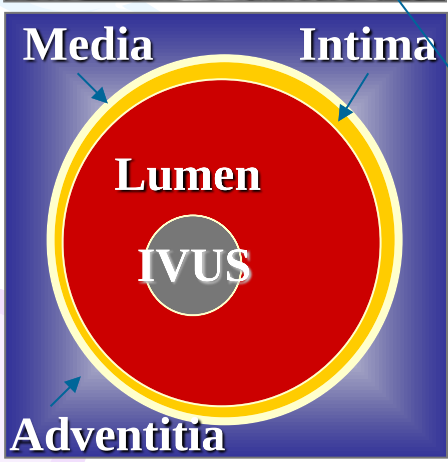
- a 20-MHz coronary catheter that is 2.9 F in size
- compatible with a 5 F guiding catheter

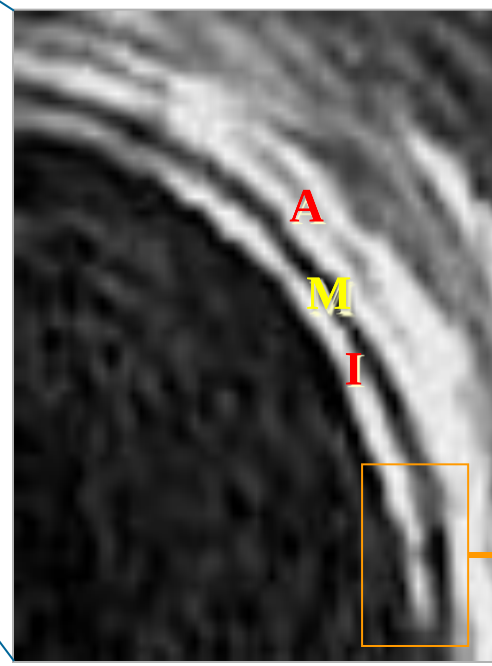

VASCULAR ZONE
AVASCULAR ZONE
STRUCTURE OF THE CORONARY ARTERIES (SCHEMATIC)
ENDOTHELIUM
DESMOSOME
BASEMENT MEMBRANE
SMOOTH-MUSCLE CELL (ATHEROPHIL)
HISTIOCYTE (FIBROPHIL)
COLLAGEN
MATRIX
LAMINA PROPRIA
INTERNAL ELASTIC MEMBRANE
MUSCLE AND ELASTIC TISSUE
RETICULAR FIBERS
EXTERNAL ELASTIC MEMBRANE
VASA VASORUM
SYMPATHETIC NERVE (VASOMOTOR)
©CIBA
Intima
Media
Adventitia

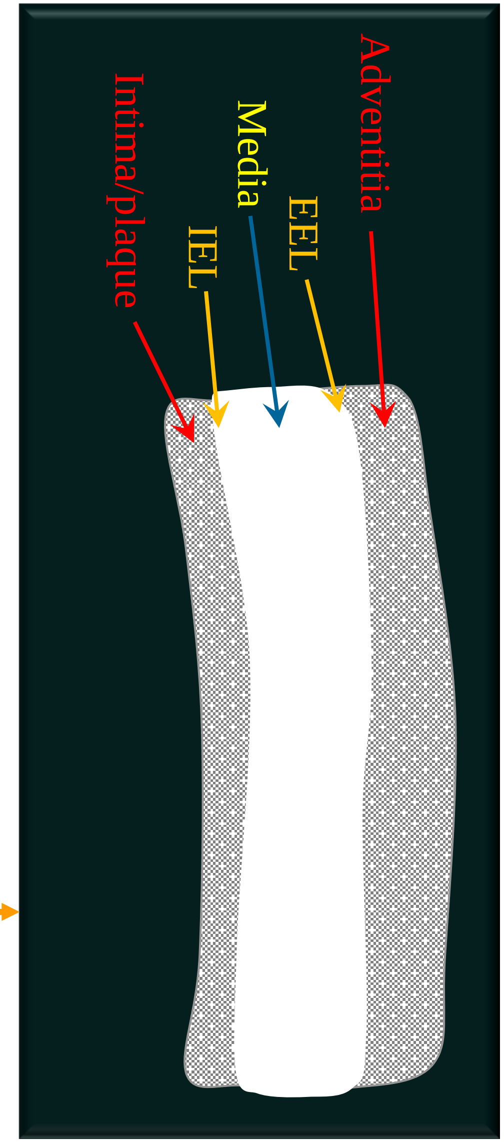
Normal Artery: 3-layered appearance

- Cross Sectional Imaging



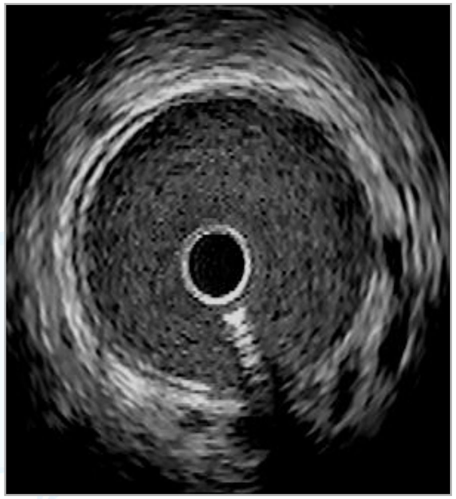


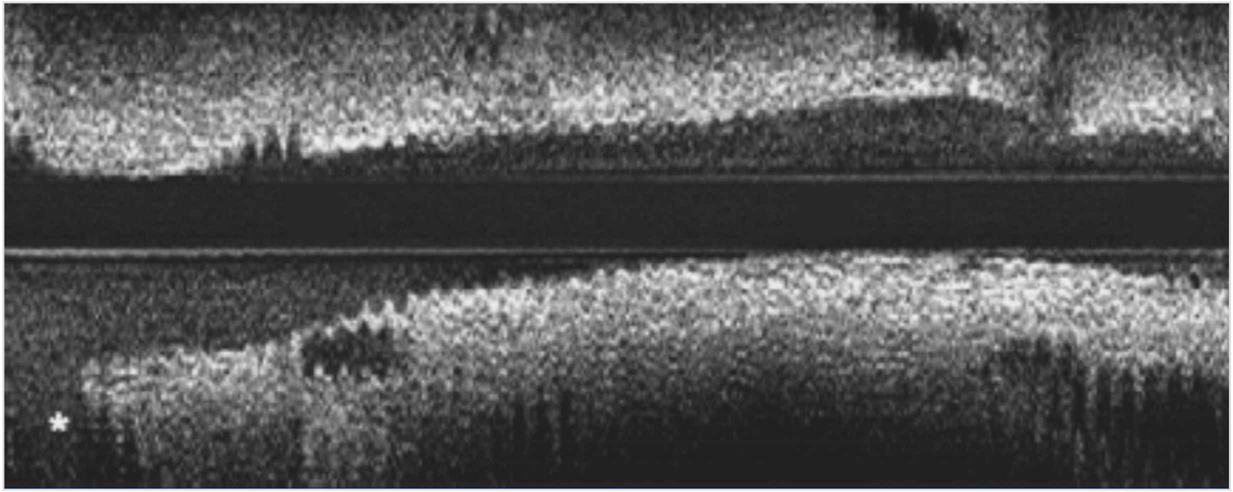


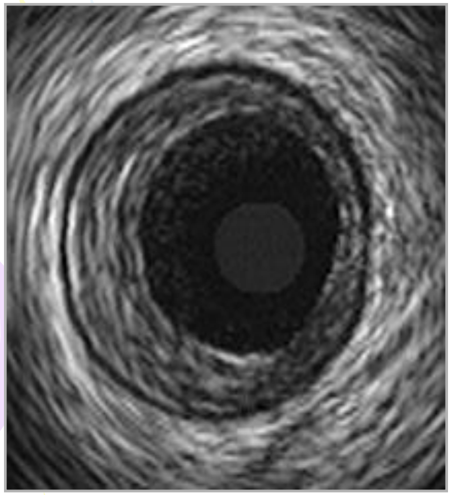


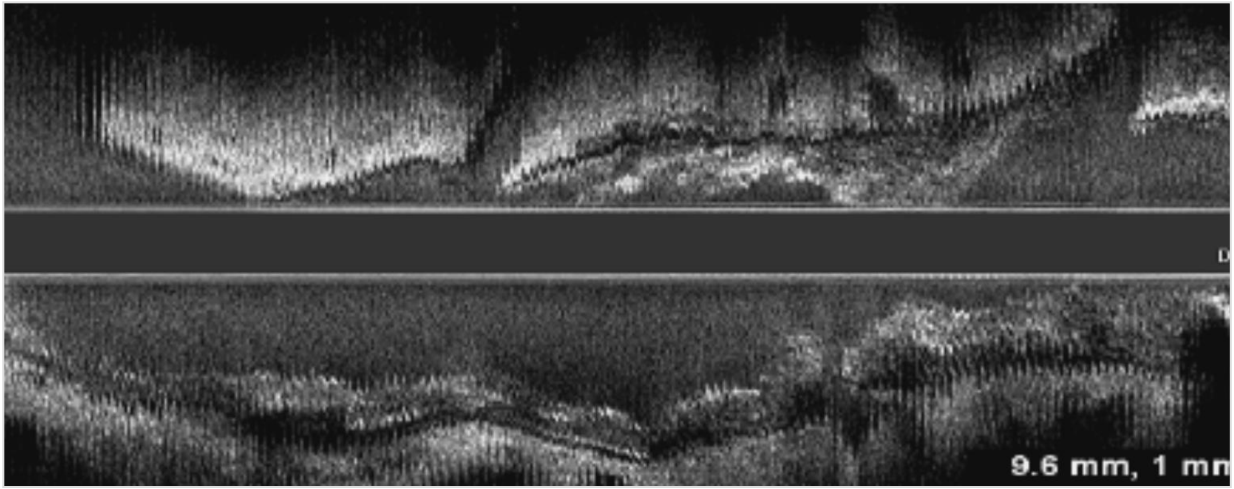
Normal vs. Diseased Coronary Artery

Cross-sectional image | **Longitudinal image**









IVUS Assessment

- Qualitative assessment
  - Plaque composition: soft, fibrous, calcific
  - Lesion morphology: dissection, plaque rupture
- Quantitative measurement
  - Diameter
  - Area
  - Volume
  - Length

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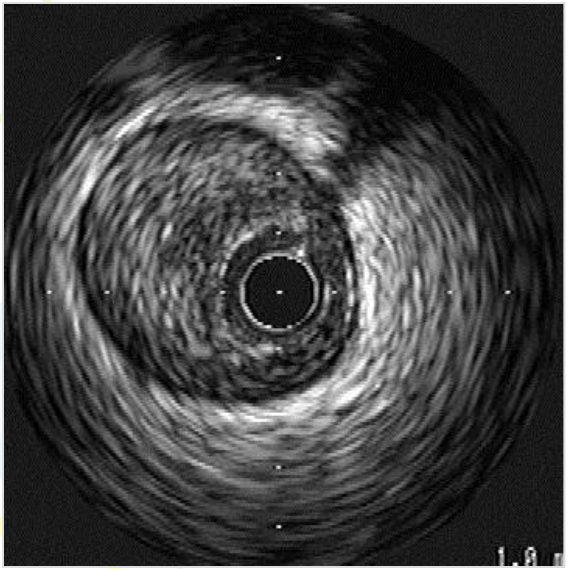
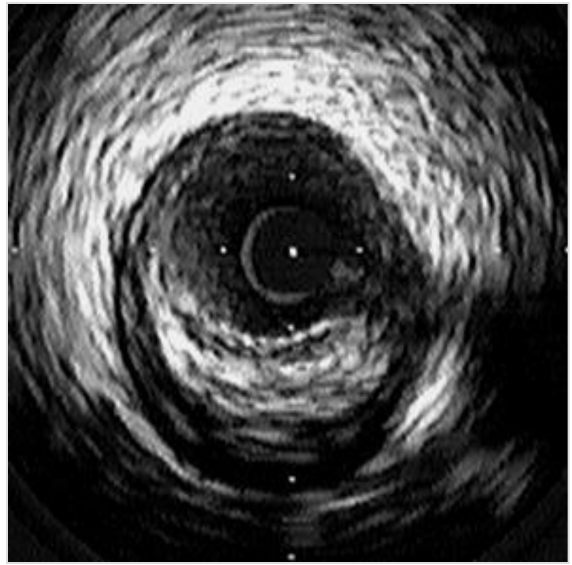
Plaque Composition

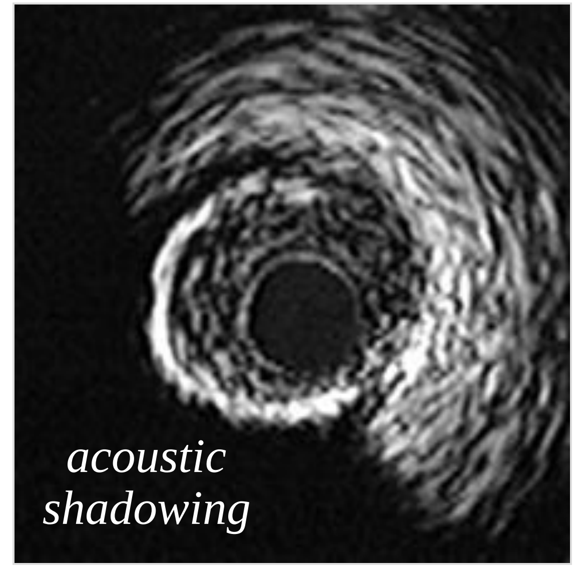
Soft



Fibrous

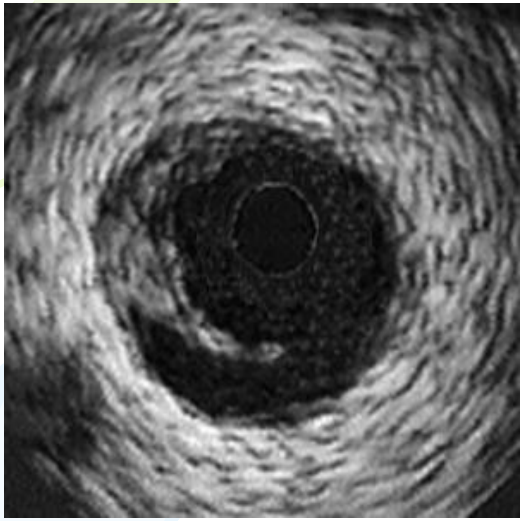


Calcified



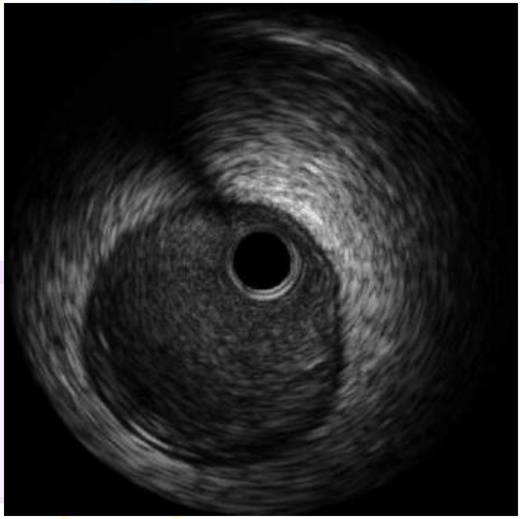
- Soft plaque has a low echogenic apperance (more echolucent than advenitia)
- Fibrous plaque shows an intermediate echogenecity between soft and calcified plaques, with some degree of signal attenuation
- Calcified plaque is characterized by brighted echo that overlies a dark shadow extended radially outward, known as an “acoustic shadowing”

Additional Plaque Features (I)



Dissection

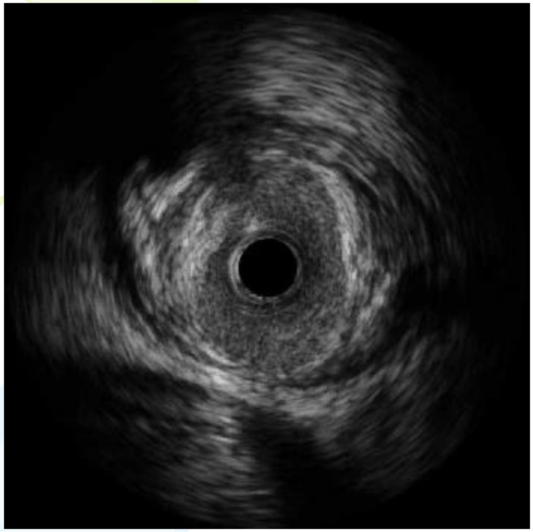
- a freely mobile tissue arm extending into the lumen with clear blood speckle bw this tissue structure and the vessel wall
- IVUS can detect whether intimal flap extends into intima, media, and adventitia



Thrombi

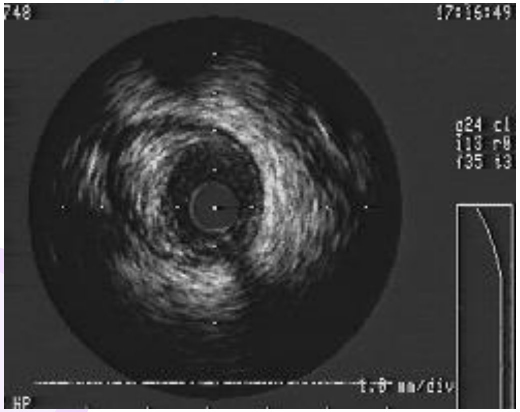
- a sparkling pattern on real-time ultrasound imaging
- a lobulated mss projecting into the lumen
- echodensity is heterogenous and presence of microchannel

Additional Plaque Features (II)



Ruptured plaque

- a plaque ulceration with a tear detected in a overlying fibrous cap
- multiple ruptures can be found in the same vessel as well as other vessel in patients with ACS



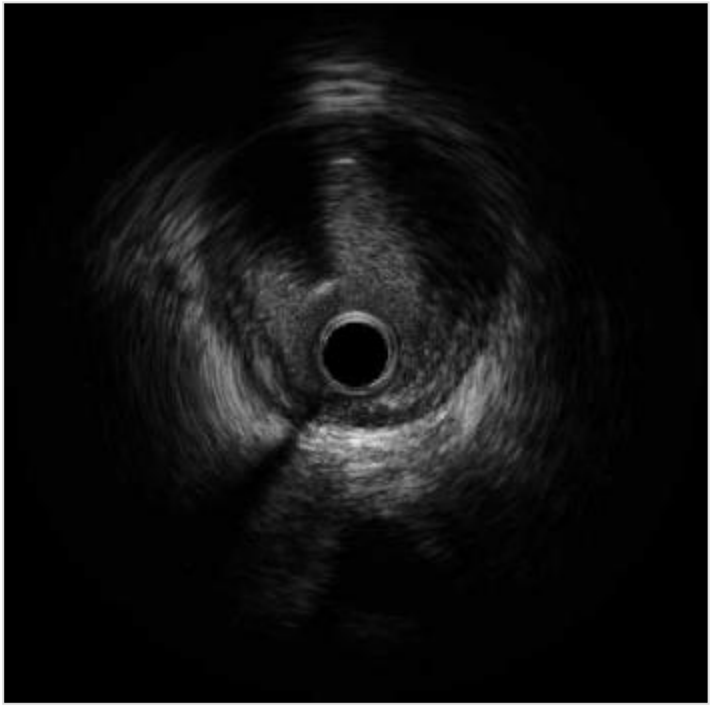
Intramural Hematoma

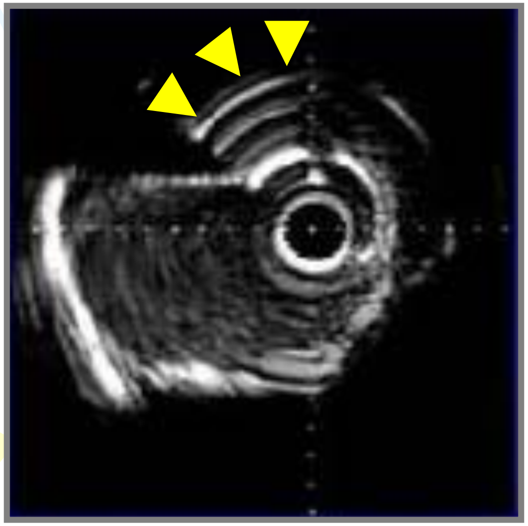
- an accumulation of blood within the medial space, displacing the IEM inward to EEM, with or without entry and exit point

NURD

(Non Uniform Rotational Distortion)

- When rotating transducer inside , the IVUS catheter is exposed to frictional forces (bending of catheter, hemostatic valve too tight), portion of the images are stretched or compacted.
- particularly, in tortous or calcified lesions





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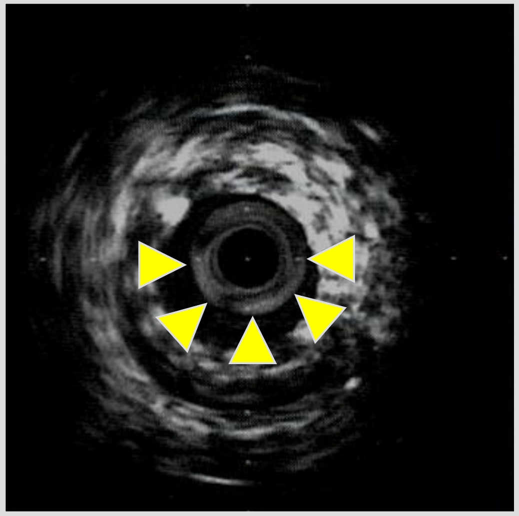
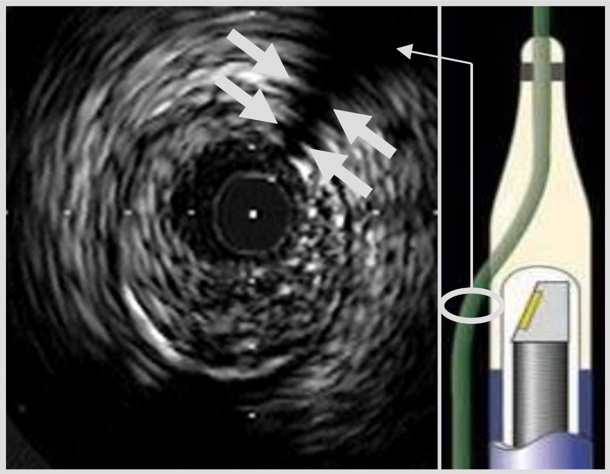
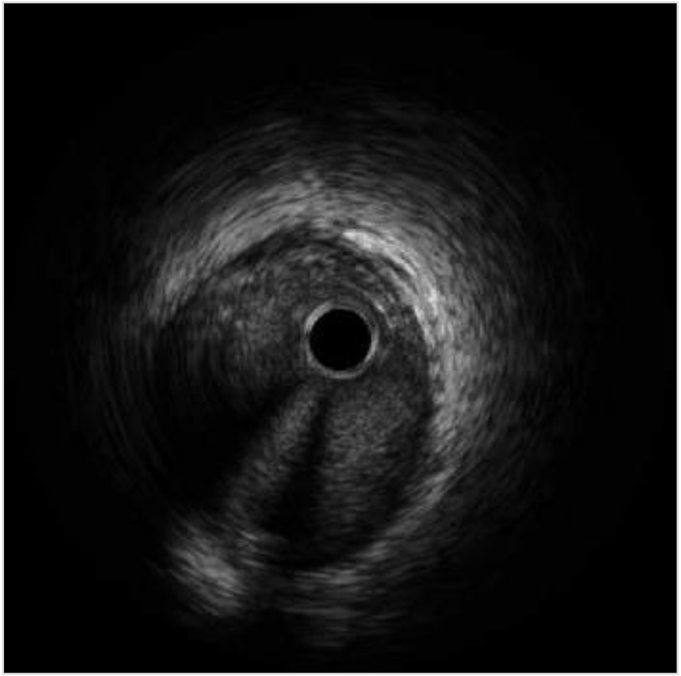
Ring-down

- Caused by transducer oscillation filling the area adjacent to the catheter with noise
- Bright halo of variable thickness surrounding the catheter



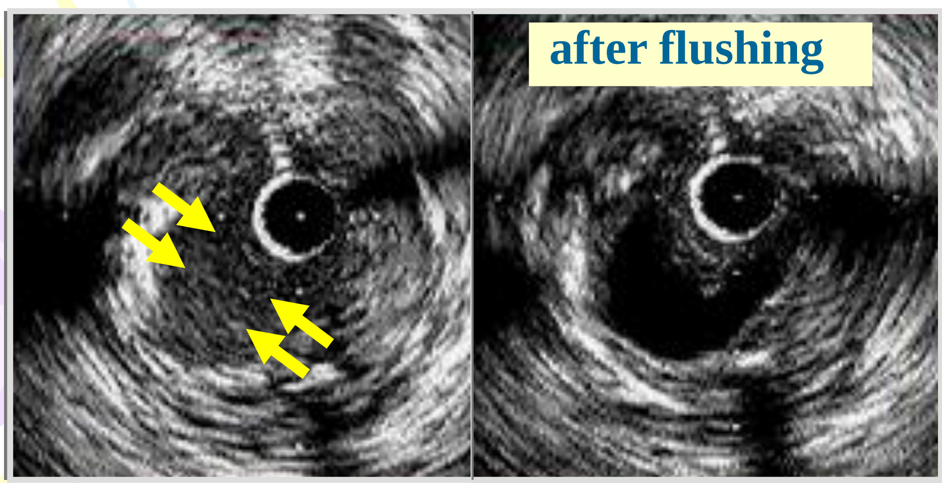
- Guide wire artifact

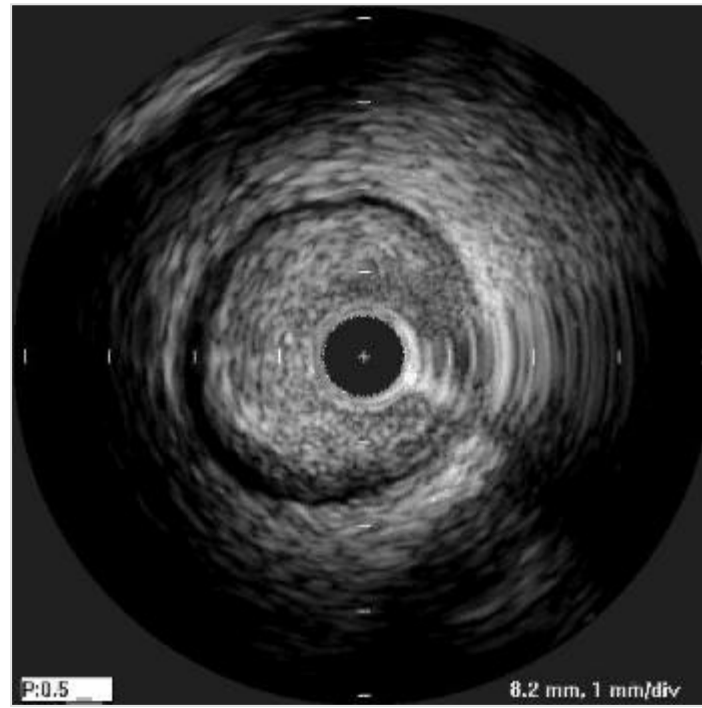




Blood Speckle

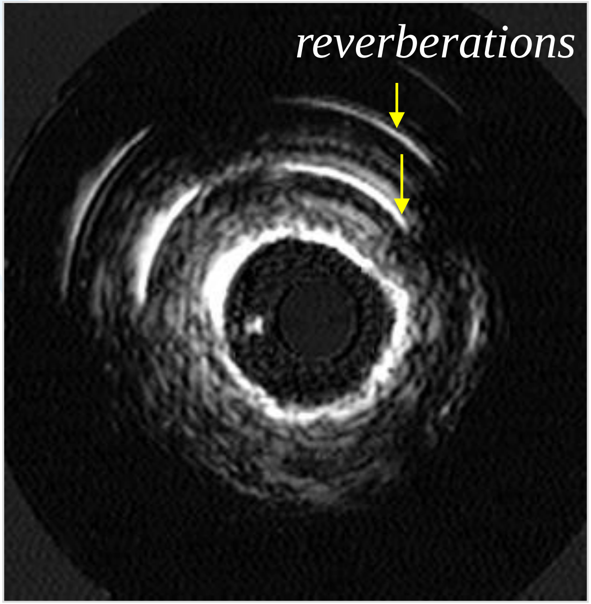
- Blood is echoreflective.
- The intensity of reflection increases as blood flow velocity decreases.
- Flushing contrast or saline through guiding catheter may clear the lumen and help to identify tissue border





Reverberations

- multiple, equally spaced echoes or reflections that may occur when two strong reflectors lie in the line of an ultrasound beam
- echoes that are formed as the ultrasound bounces back and forth between the reflectors may create artifacts



⇨ between transducer and leading edge of Ca^{++} causing concentric arc at reproducible distance

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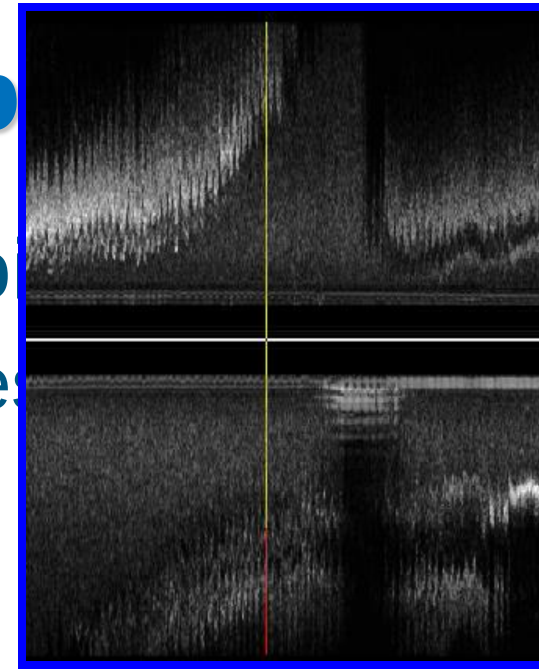
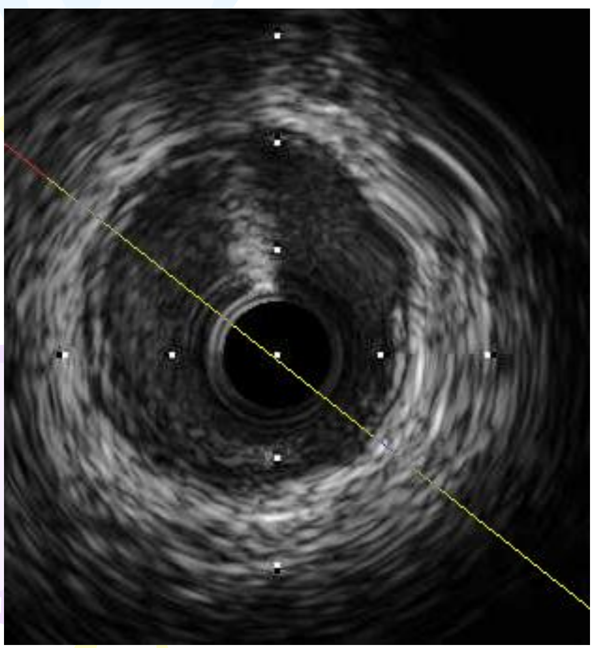
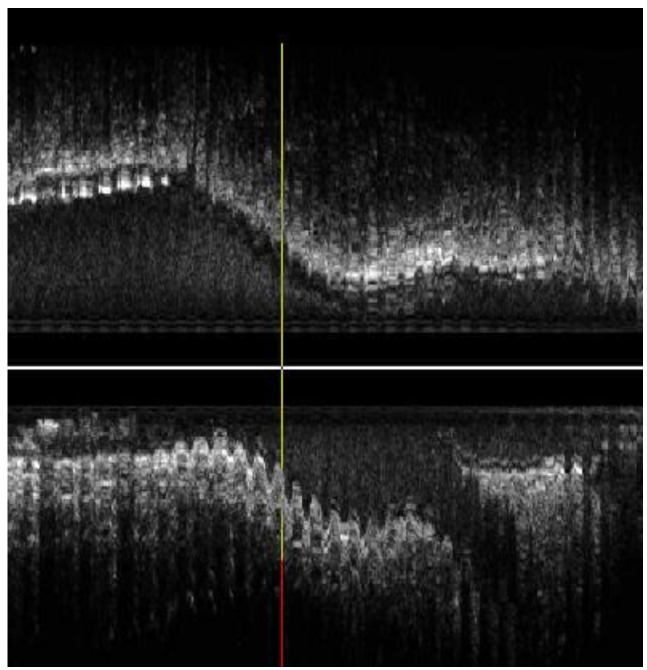
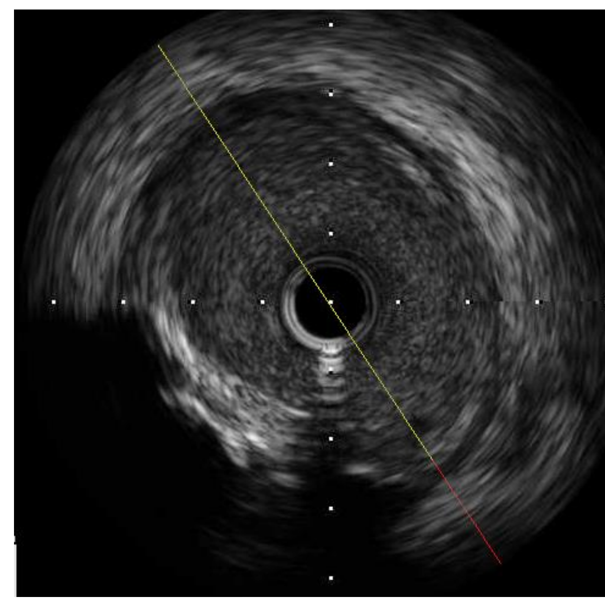
Measurement: Image Op



- Measurements should be avoi
  - artifacts such as NURD are pres
  - the IVUS catheter is positioned
    parallel to the vessel long axis)

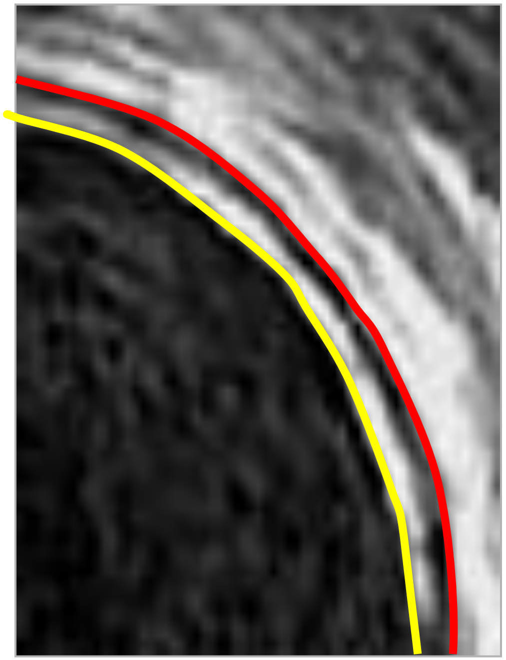




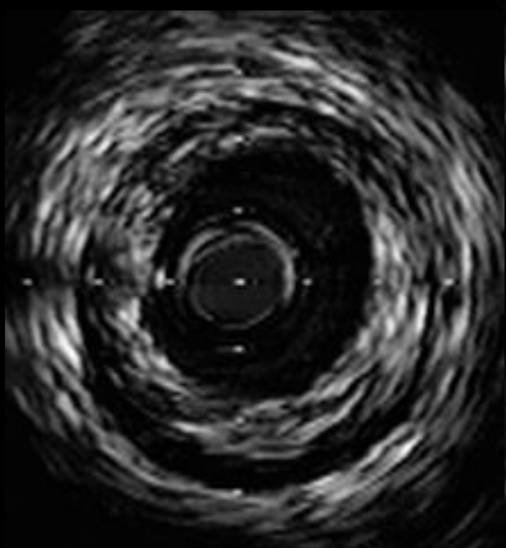


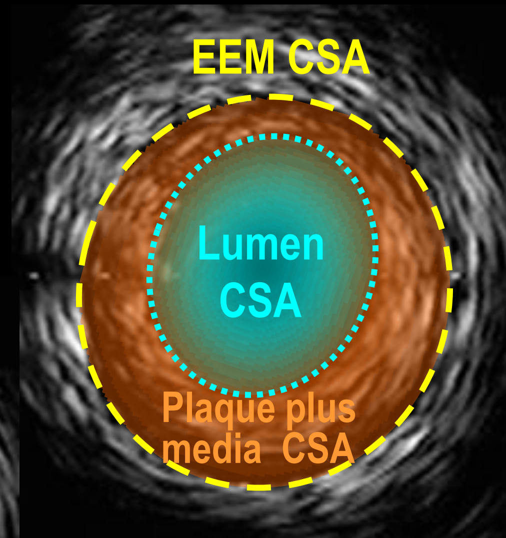
Border Identification

- Lumen - Intima interface
- Media - Adventitia interface

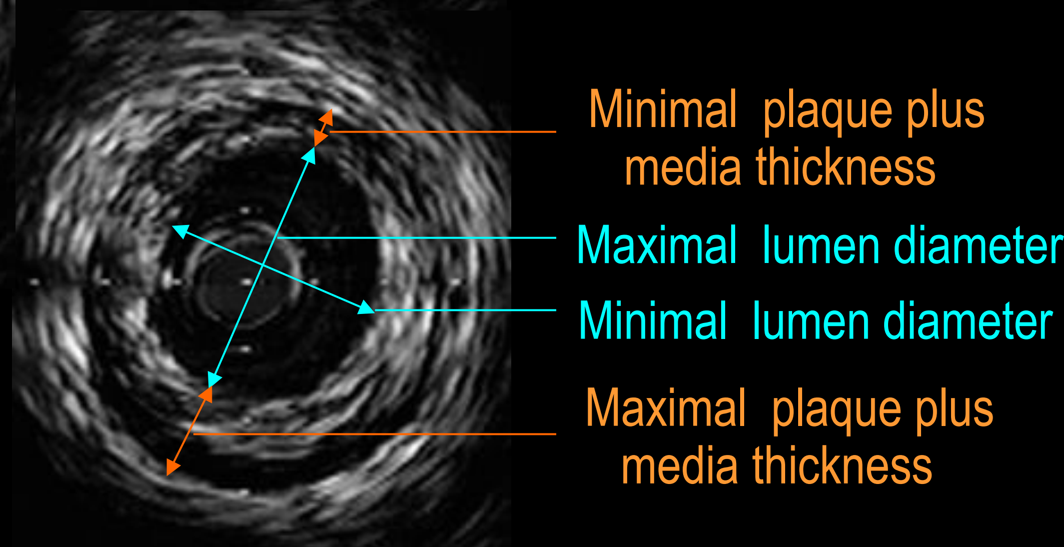


Quantitative IVUS Parameters (I)





- CSA : Cross Sectional Area
- EEM (External Elastic Membrane) CSA
  : Vessel Area (VA)
- Lumen CSA: Lumen Area (LA)
- Plaque plus Media CSA
  = (EEM – Lumen) CSA : Plaque Area (PA)



Mintz and Nissen et al. JACC 2001;37:1478-92

Quantitative IVUS Parameters (II)

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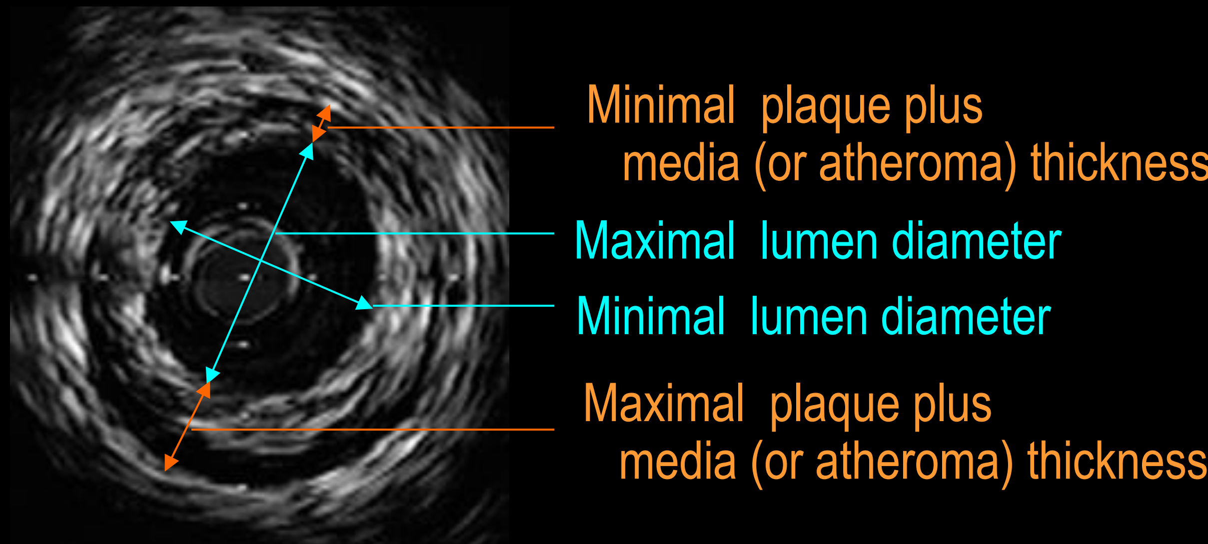


- **Lumen eccentricity**

$$= \frac{\text{(maximal – minimal) lumen diameter}}{\text{maximal lumen diameter}}$$

- **Plaque plus media (or atheroma) eccentricity**

$$= \frac{\text{(maximal – minimal) atheroma thickenss}}{\text{maximal atheroma thickness}}$$

- **Lumen area stenosis**

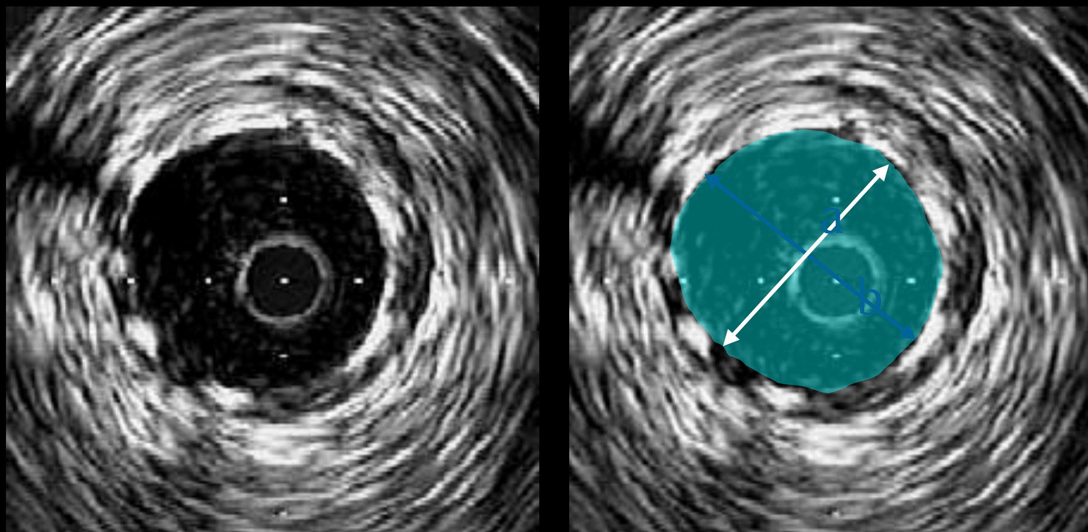
$$= \frac{\text{(reference – minimum) lumen CSA}}{\text{reference lumen CSA}}$$

- **Plaque (or atheroma) burden**

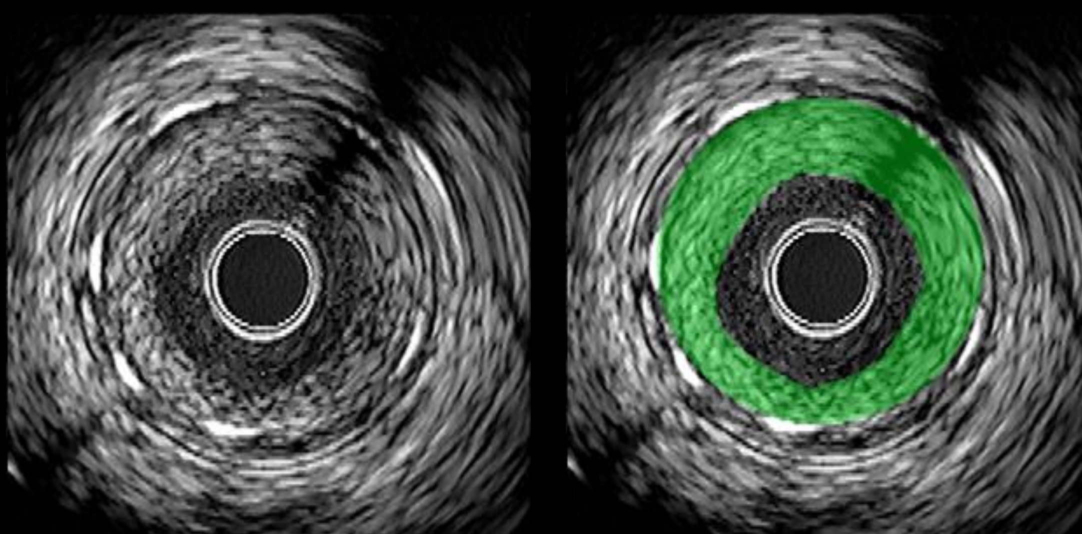
$$= \frac{\text{plaque plus media CSA}}{\text{EEM CSA}}$$

Mintz and Nissen et al. JACC 2001;37:1478-92

Quantitative IVUS Parameters



- **Post-stenting**
  - Stent CSA
  - Minimal stent diameter (a)
  - Maximal stent diameter (b)
  - Stent symmetry: (b-a) / b



- **Follow-up**
  - Intimal hyperplasia CSA
    = Stent CSA – Lumen CSA

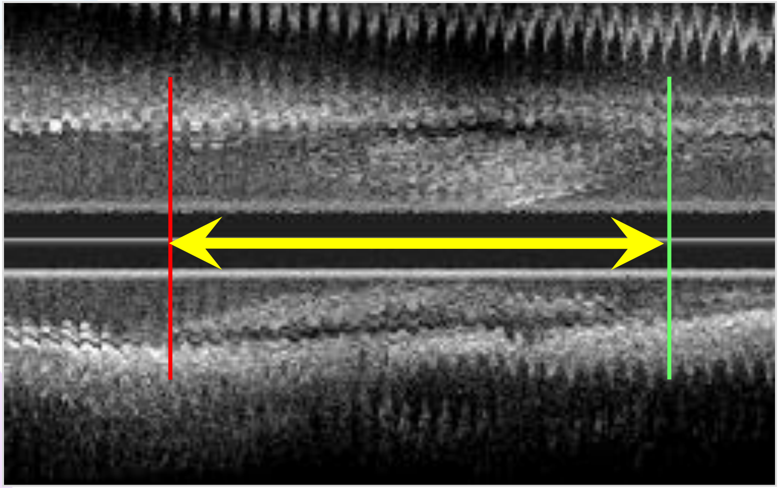
Basic Imaging of IVUS

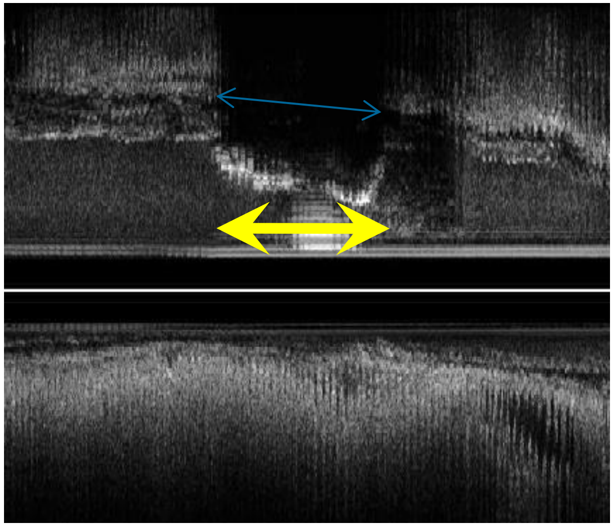
Definition of "Lesion" and "Reference" segment

- ***Lesion:*** A lesion represents accumulation of atherosclerotic plaque compared with a predefined reference
- ***Stenosis:*** A stenosis is a lesion that compromises the lumen by at least 50% by cross-sectional area (CSA) (compared with a predefined reference segment lumen)
- ***Proximal reference:*** The site with the largest lumen proximal to a stenosis but within the same segment (usually within 10 mm of the stenosis with no major intervening branches)
- ***Distal reference:*** The site with the largest lumen distal to a stenosis but within the same segment
- ***Average reference lumen size:*** The average value of lumen size at the proximal and distal reference sites

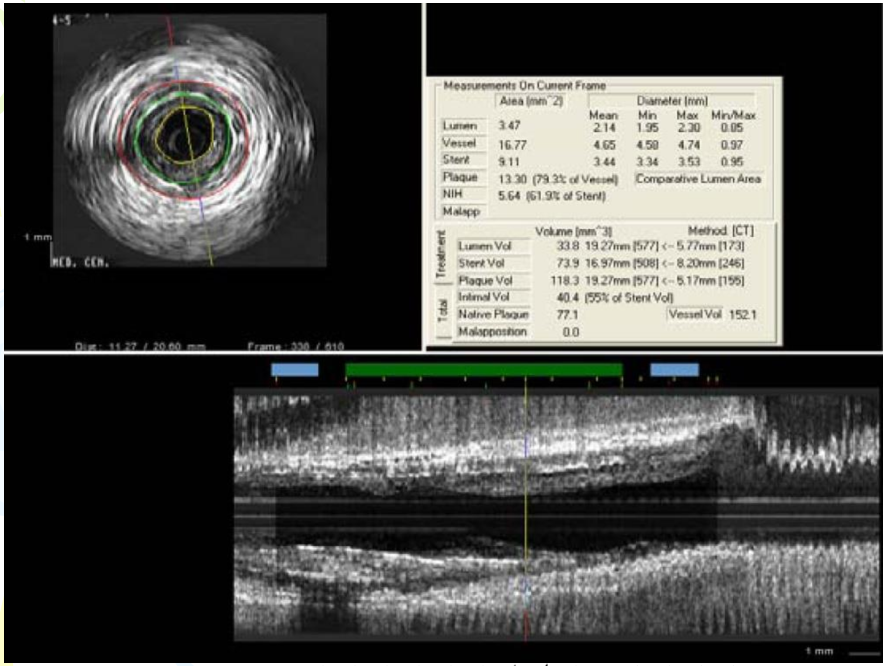
Length Measurements

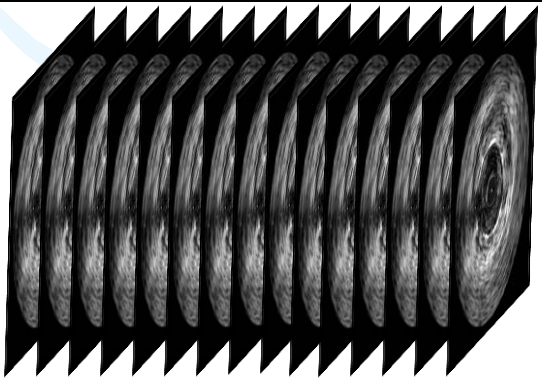
- Motorized transducer pullback
- Number of seconds X pullback speed
- (Number of frames / frame rate) X pullback speed





Automatic Volumetric Assessment

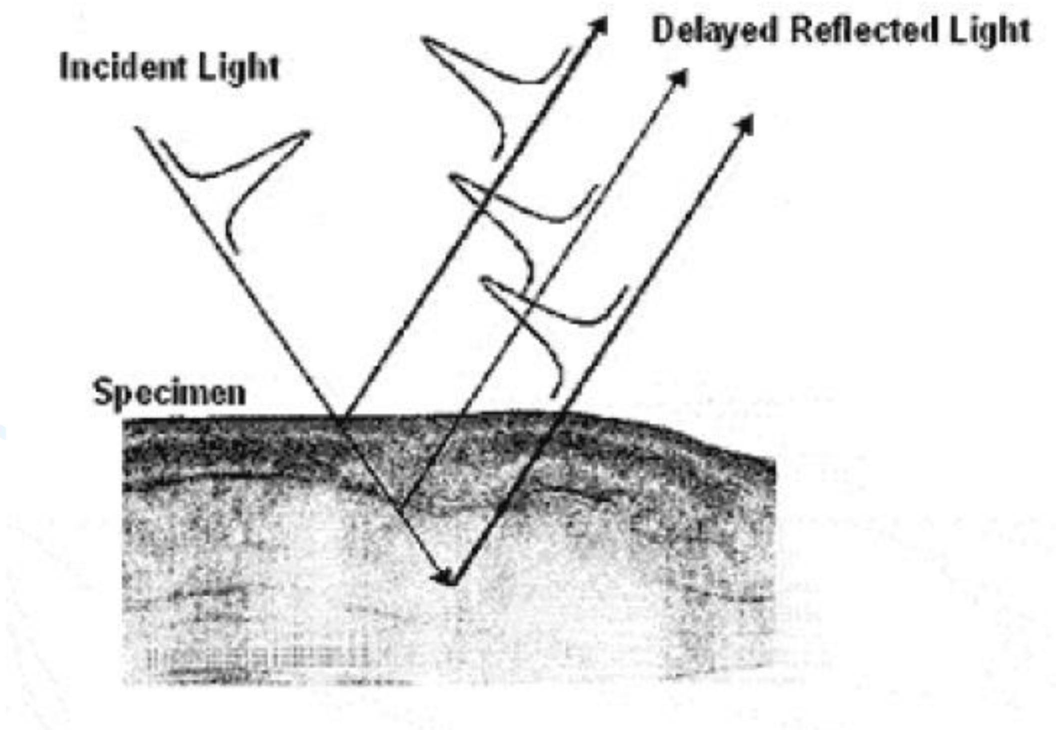




- ✓ Lumen volume
- ✓ EEM volume
- ✓ P&M volume
- ✓ % atheroma volume
- ✓ Stent volume
- ✓ IH volume
- ✓ %IH volume
- ✓ Malapposition volume

Optical Coherence Tomography

- Optical analogue of intravascular ultrasound
- high-resolution tomographic intra-arterial imaging



Imaging Wire 0.019"
"Occlusive Methoc

Regar et al. Eur Heart J 200
Regar E, van Leeuwen AMC
tomography in cardiovascula

Imaging Wire 0.019"
“Non-Occlusive Method“

Selective Guide Catheter Engagement

2nd Generation OCT

Fourier Domain OCT

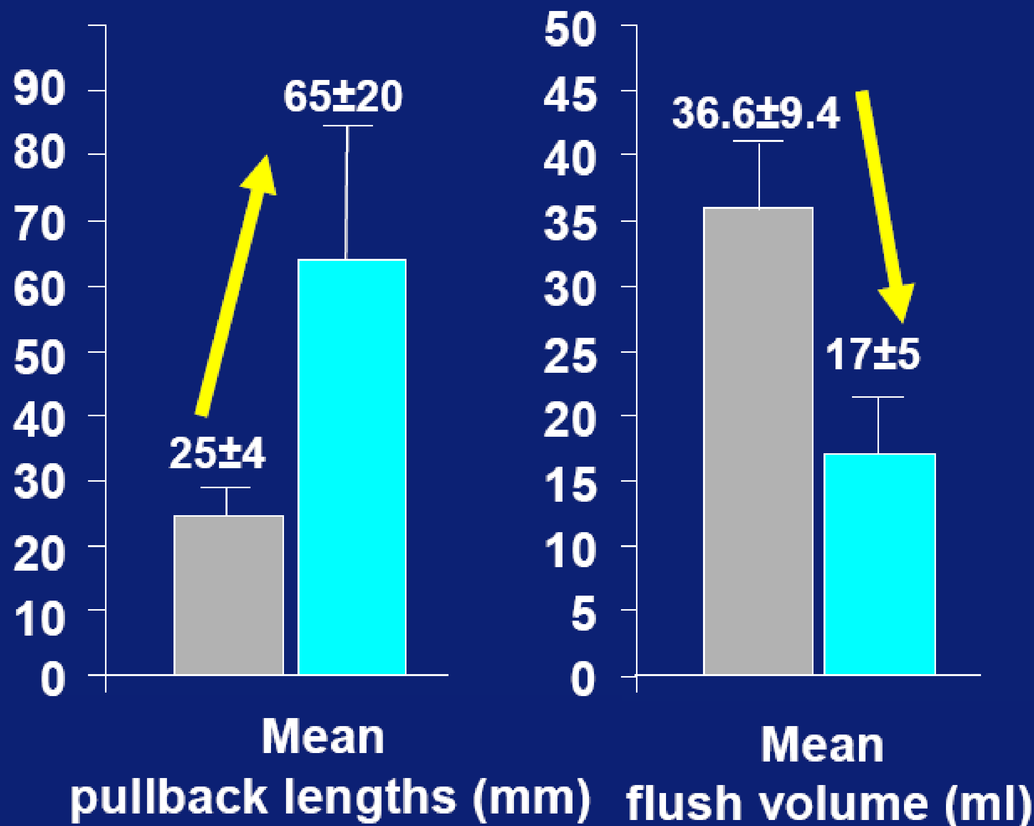
(OFDI/Frequency/Spectral Domain/Swept Source)

Monorail Imaging Catheter

Non-Occlusive

	IVUS	OCT	OFDI
Resolution *(axial)*	100 - 150 μm	10 μm	10 μm
Resolution *(lateral)*	150 - 300 μm	25 - 40 μm	25 - 40 μm
Size of imaging core	0.8 mm	0.4 mm	0.4 mm
Dynamic range	40 - 60 dB	90 - 100 dB	90 - 100 dB
Frame rate	30 frames/s	15 frames/s	400 frames/s
Scan area	10 - 15 mm	6-7 mm	6-7 mm
Max. penetration	4 - 8 mm	1 – 1.5 mm	1 – 1.5 mm
Blood clearing	Not required	Required	Required
Balloon Occlusion		Required	Not required
Flushing		Required	Required
Pullback	0.5mm/s (no limit)	1mm/s (35mm)	30mm/s (90mm)

Safety: 2nd Generation OCT

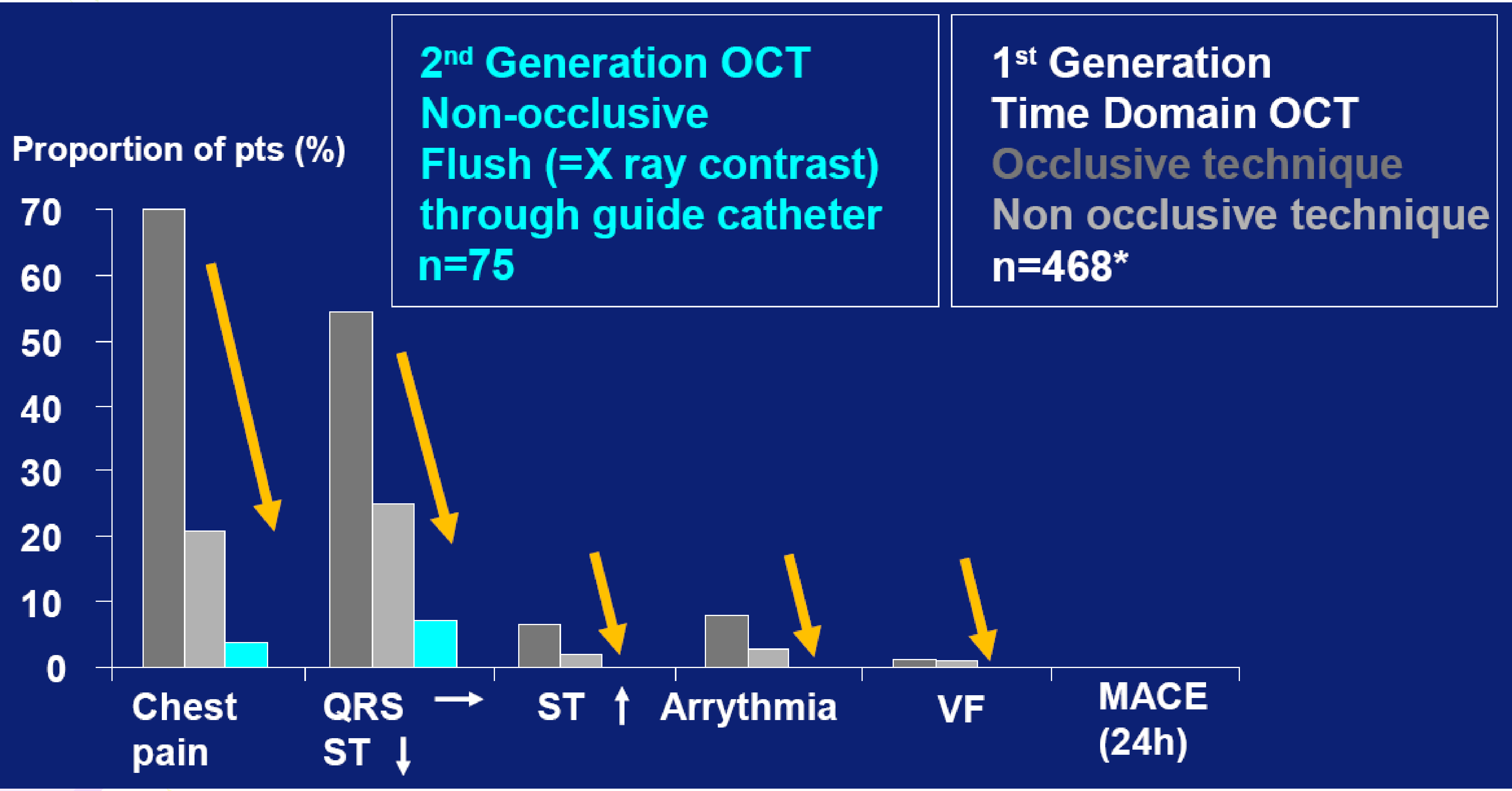


2^{nd} Generation OCT, n=75
Non-occlusive
Flush (=X ray contrast)
through guide catheter

Historical control:
1^{st} Generation
Time Domain OCT
Non occlusive technique
n=212*

P. Barlis et al, EuroIntervention 2009;5:90-95

Safety: 2nd Generation OCT



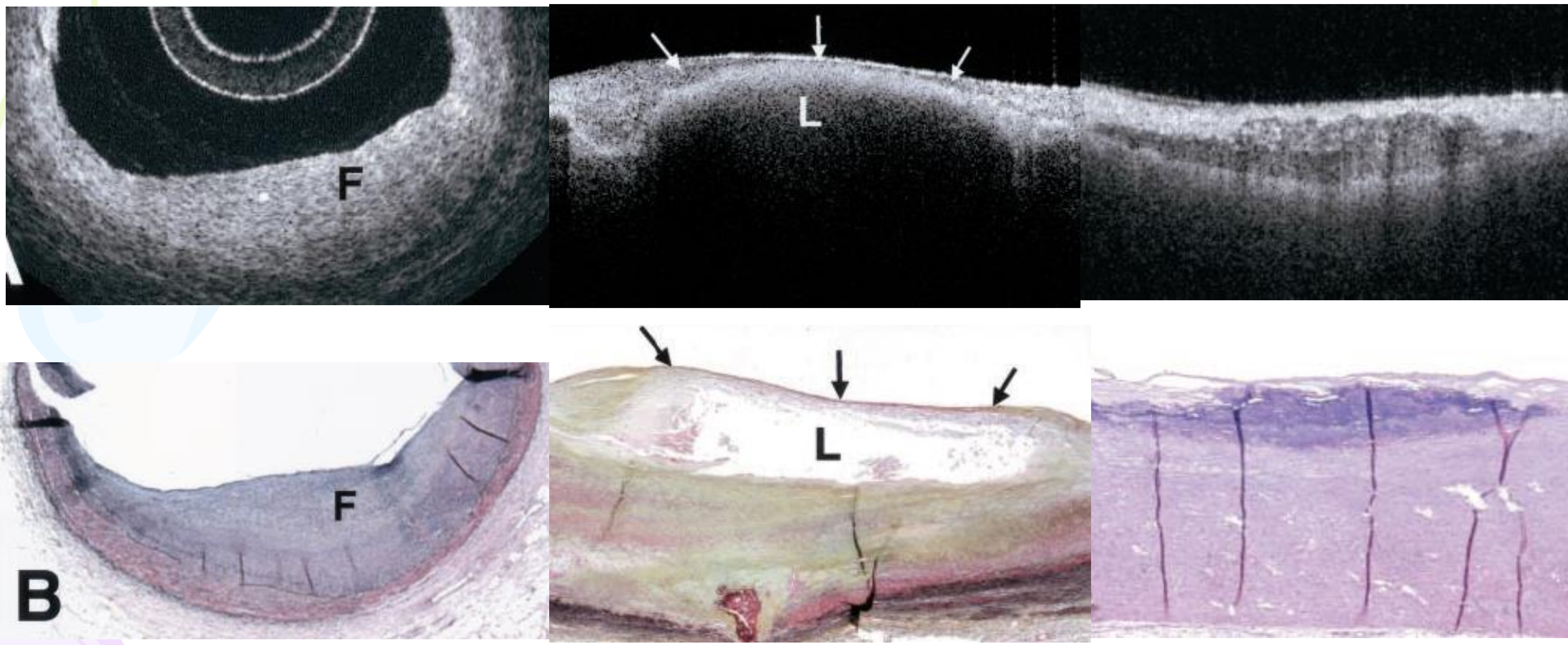
P. Barlis et al, EuroIntervention 2009;5:90-95

OCT: Clinical application

- Plaque characterization
- Stent assessment

Plaque characteristics

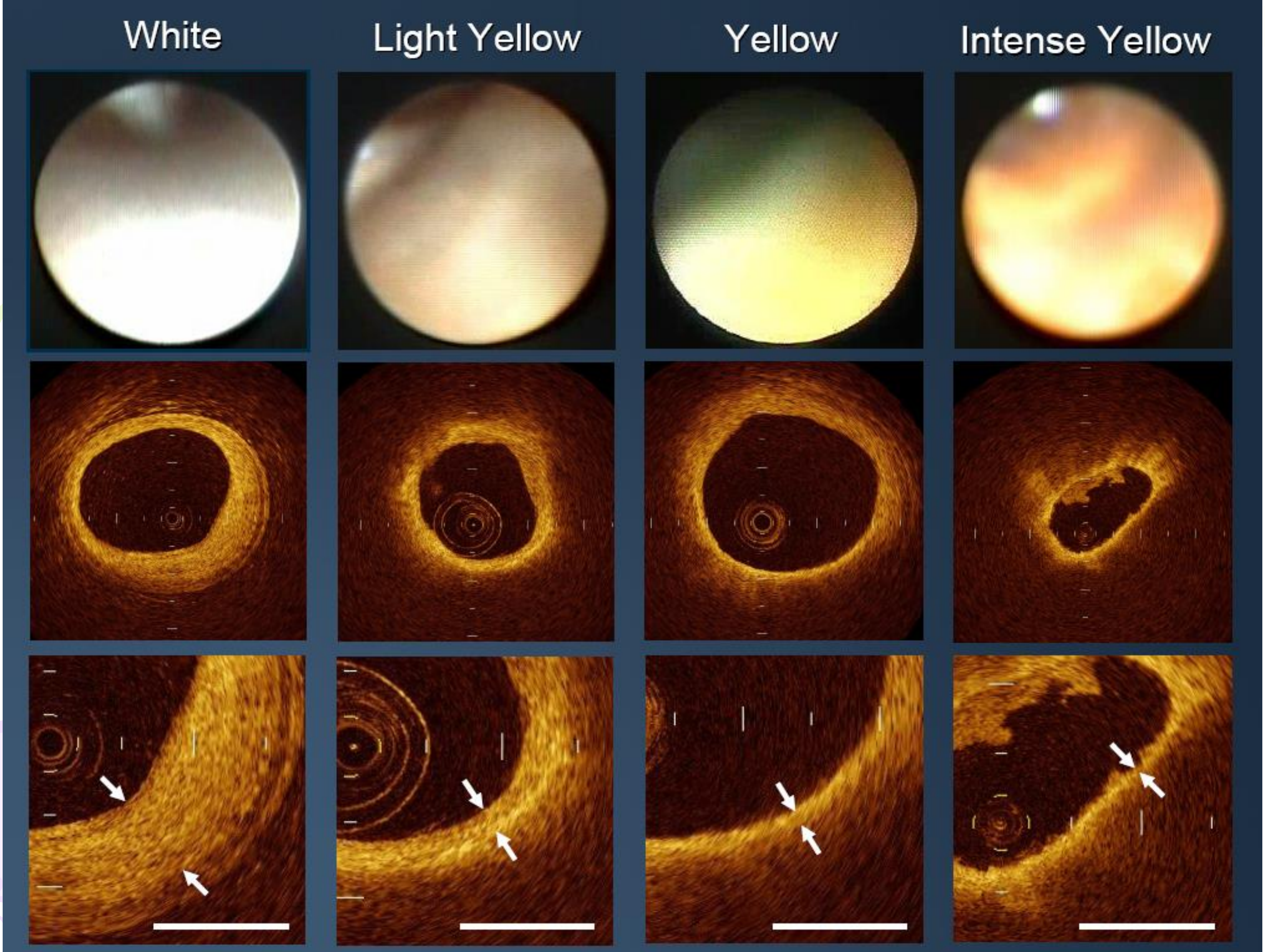
Fibrous	Lipid-rich	Calcific

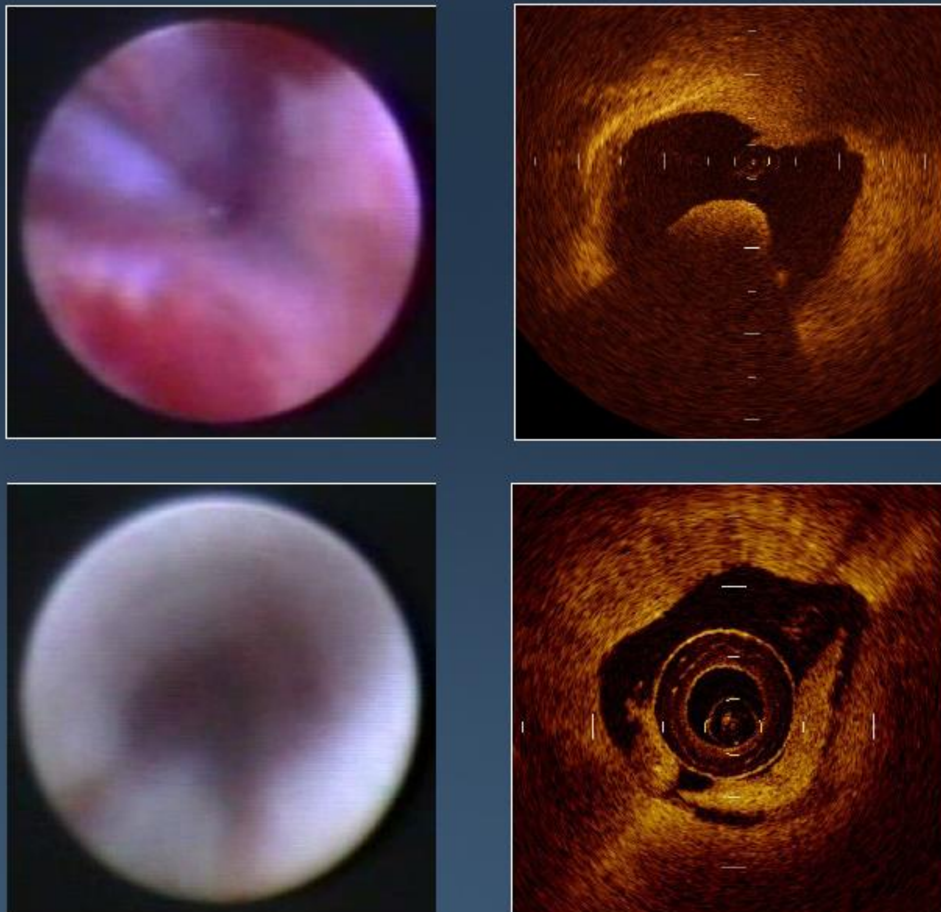


Fibrous
- Homogeneous
- Signal-rich regions

Lipid-rich
- Homogenous
- Signal-poor regions
- diffuse borders

Calcific
- Heterogeneous
- signal-poor regions
- Sharp borders


White
Light Yellow
Yellow
Intense Yellow



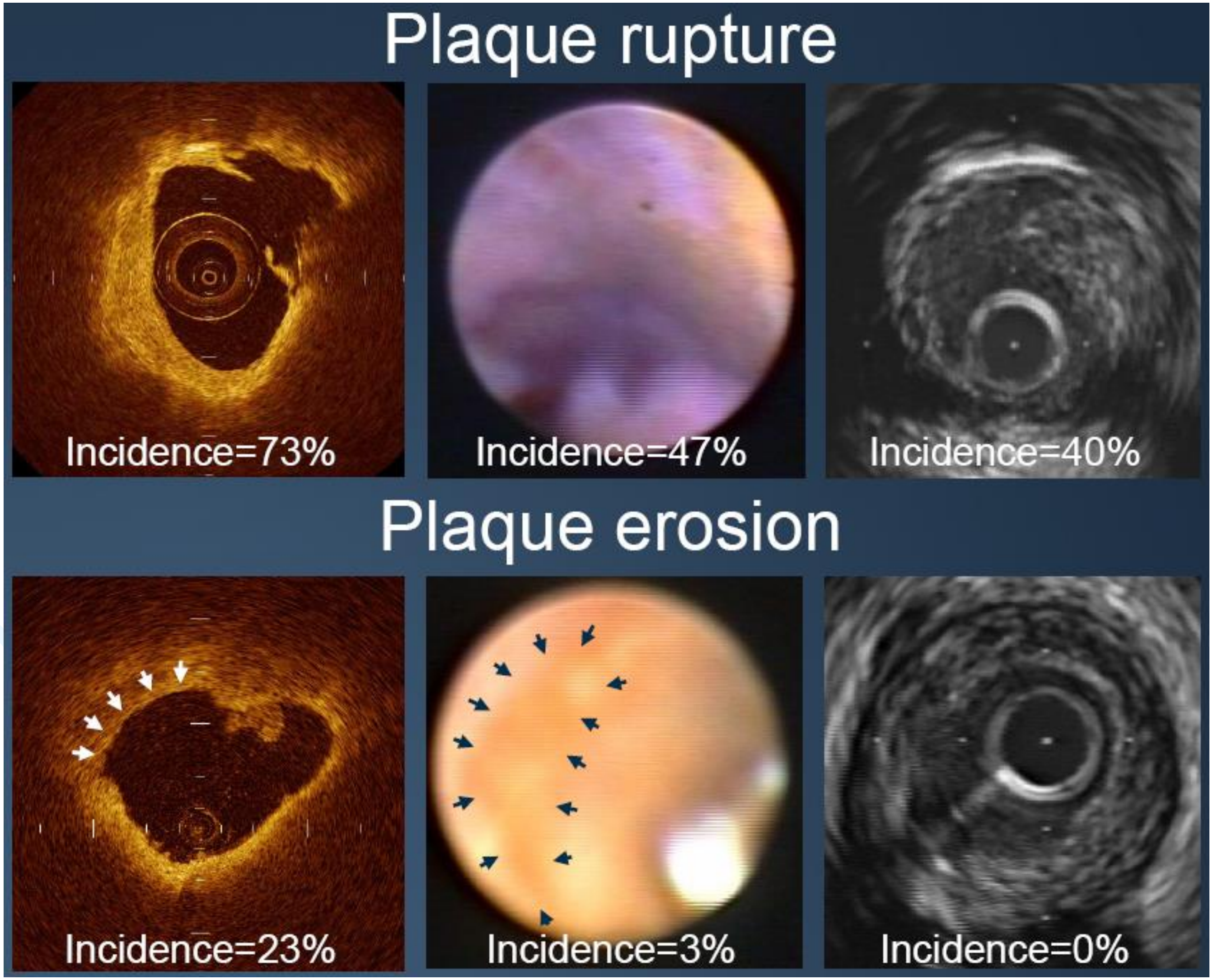
Red Thrombus

Sensitivity = 95%
Specificity = 88%
Positive predictive value = 86%
Negative predictive value =95%

White Thrombus

- ***Red thrombus*** *was identified as high-backscattering protrusions* inside the lumen of the artery, with signal-free shadowing in the OCT image.
- ***White thrombus*** *was identified as low-backscattering* projections in the OCT image.

In vivo comparison of OCT and angioscopy in assessing culprit lesions in 30 AMI patients



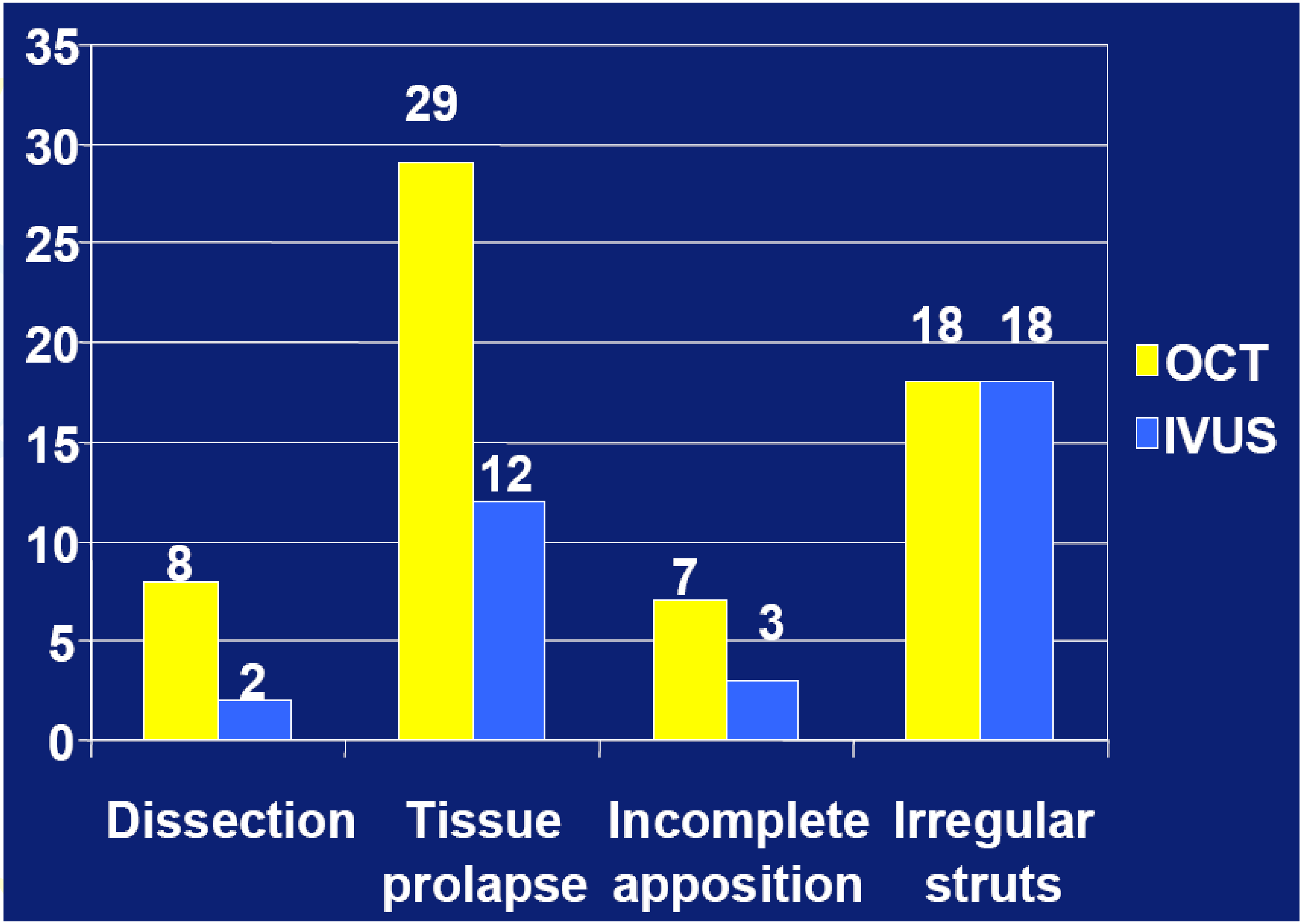
J Am Coll Cardiol 2007;50:933-9)

OCT: Clinical application

- Plaque characterization
- Stent assessment

OCT Findings Post Stenting

Comparison OCT vs IVUS

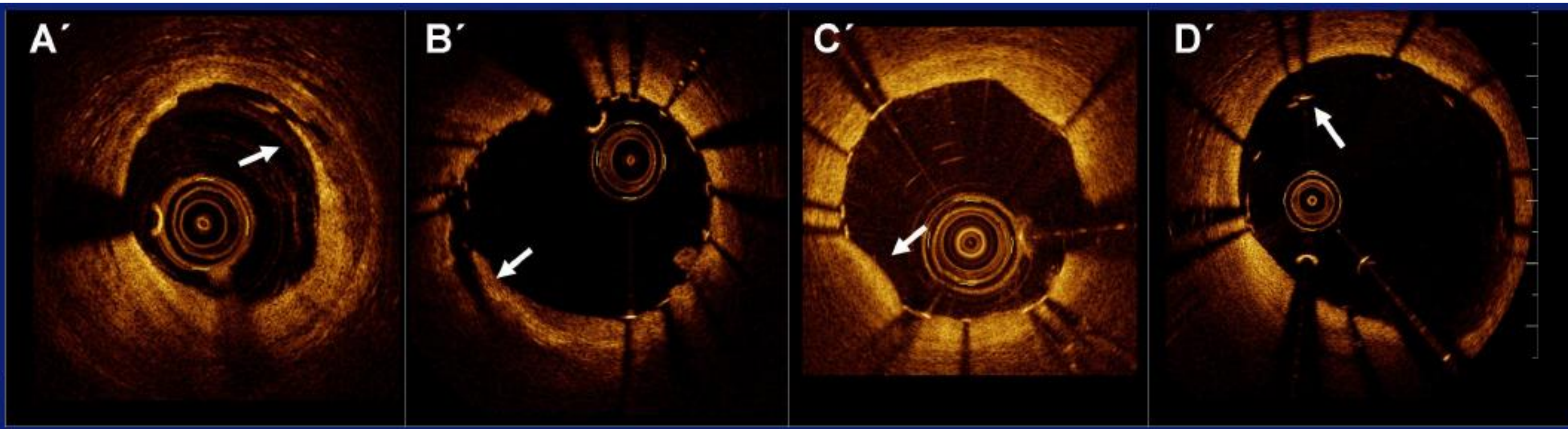


Bouma et al, Heart 2003;89:317-321

OCT Findings Post Stenting

Incidence of periprocedural vessel trauma

Lightlab Imaging



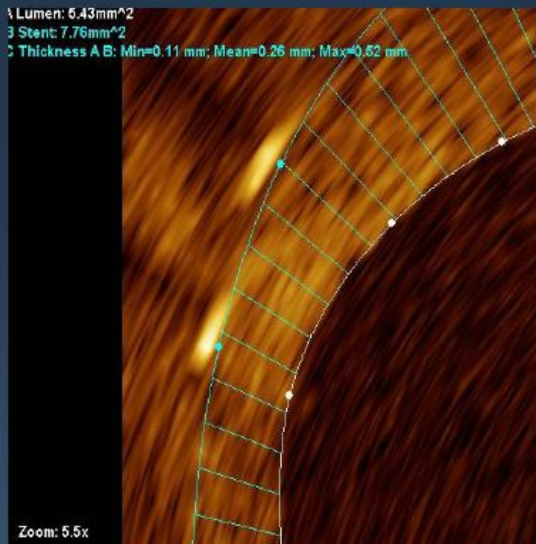
	Edge dissection	Intra-stent dissection	Tissue prolapse	Strut malapposition
	26.0%	87.5%	97.5%	65.5%
Cohen's Kappa	0.77	1.0	0.78	0.83

n=80 vessels

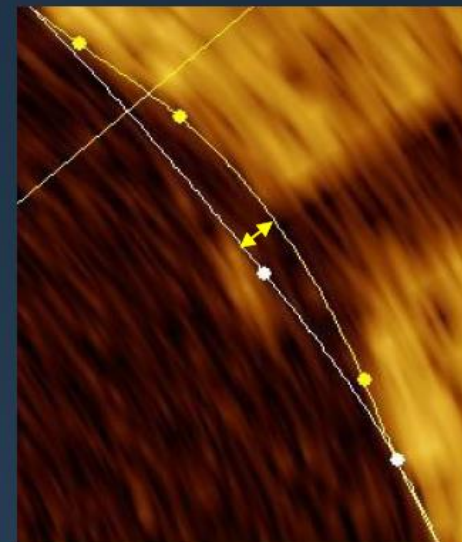
Gonzalo N et al., Heart 2009

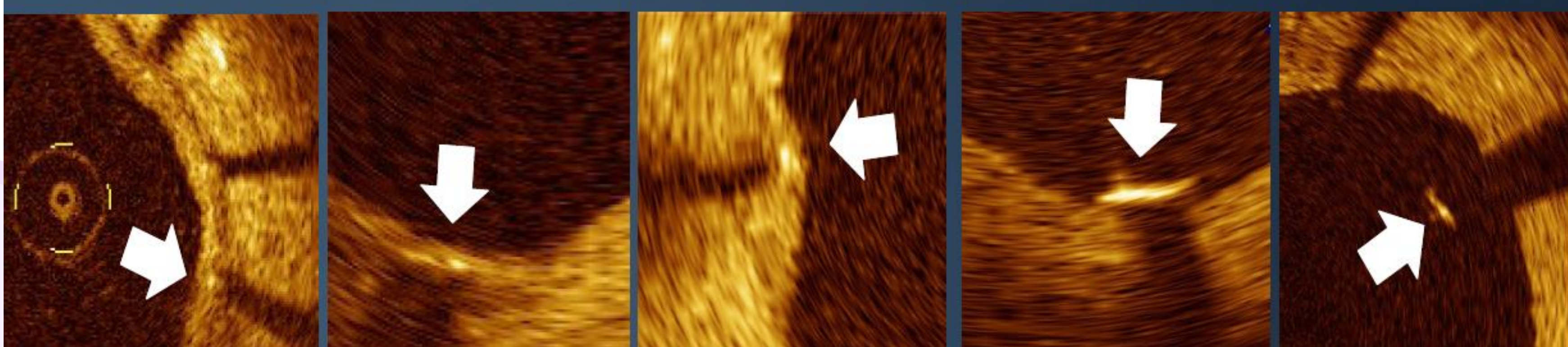
OCT Stent Assessment: Tissue Coverage at Long-term FUP

Lumen Area, Stent Area, Strut-Lumen Distance



Strut-Vessel Wall Distance





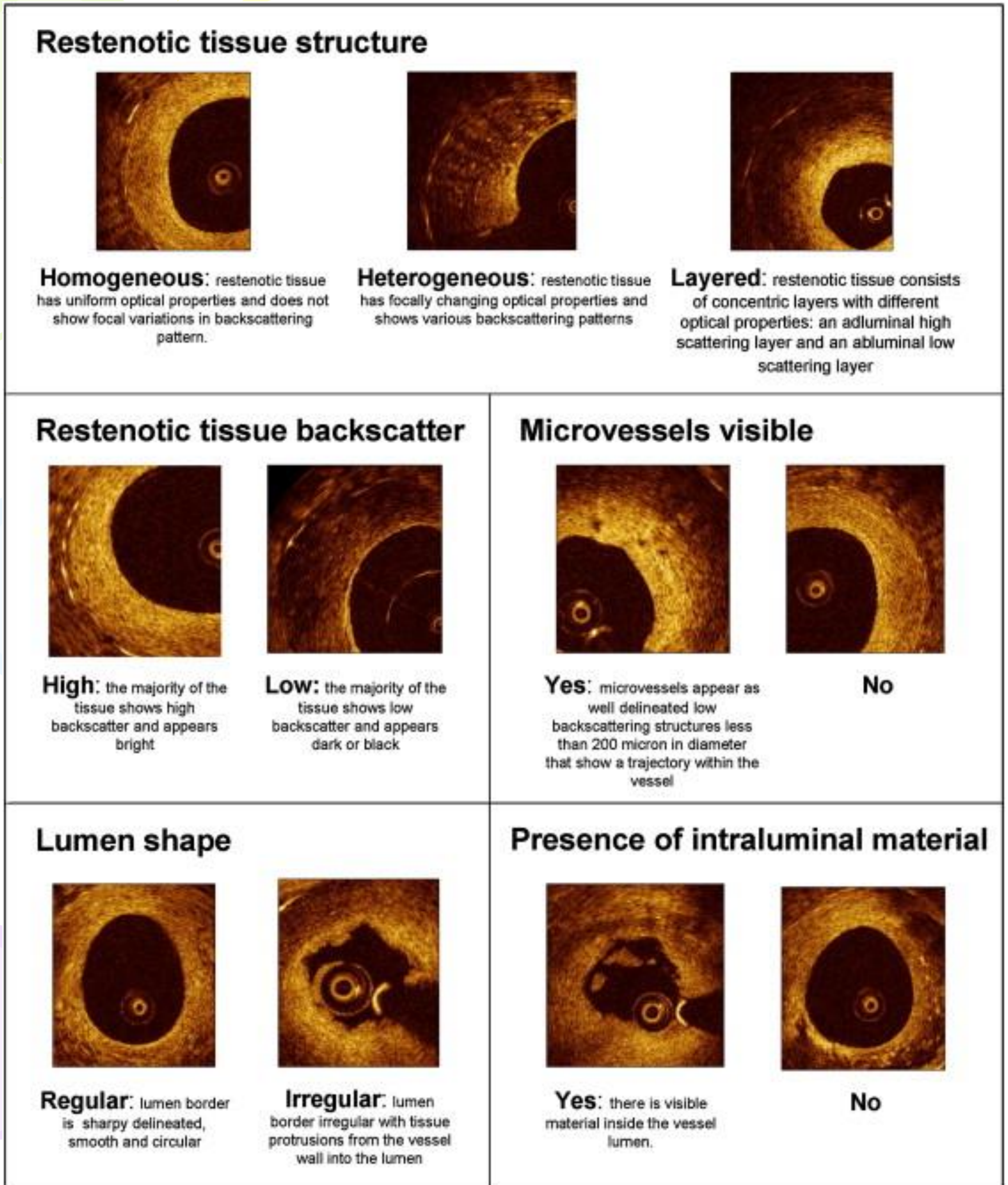
Embedded

Protruding Covered

Protruding Uncovered

Malapposed

OCT assessment of stent restenosis



OCT

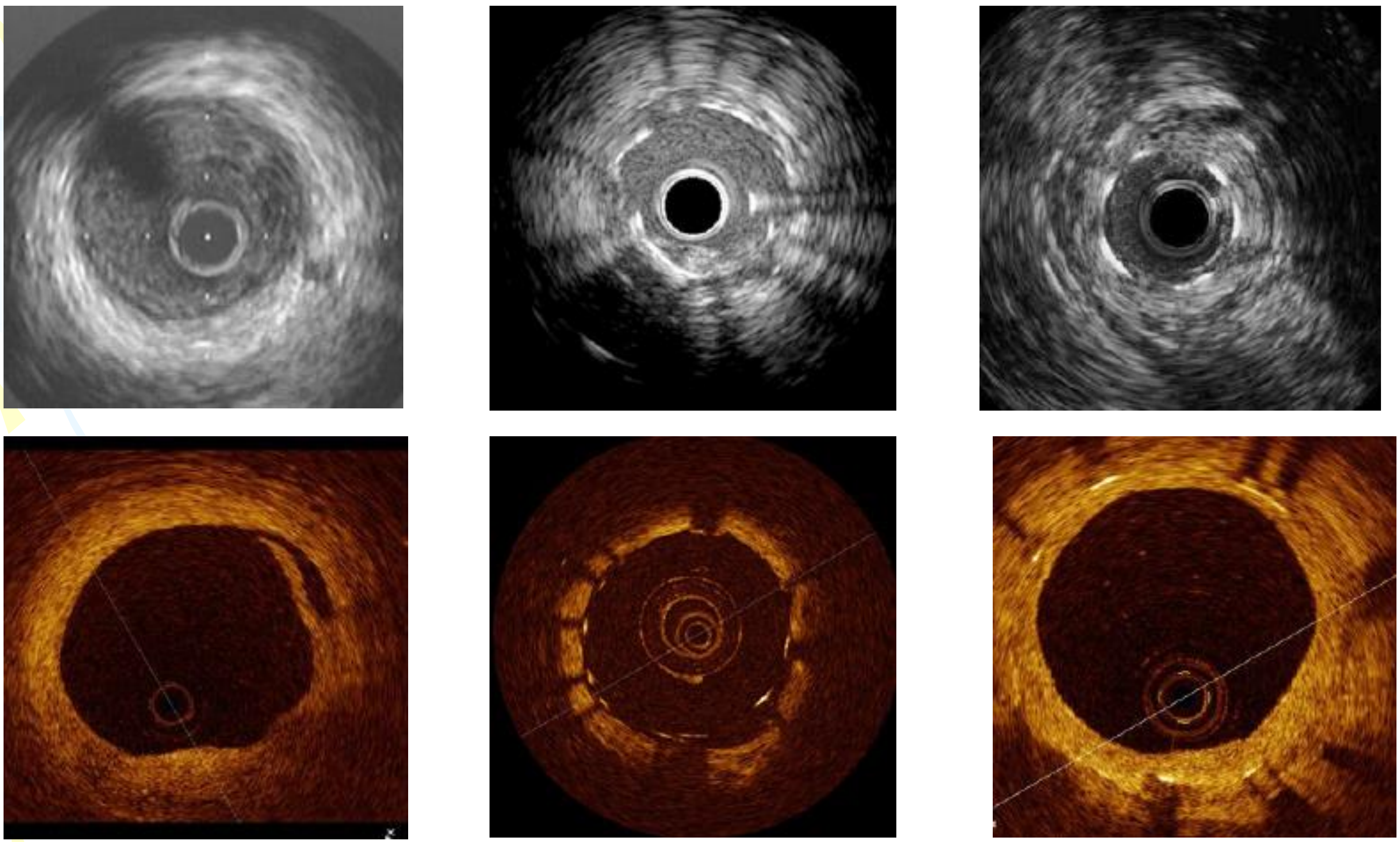
- Advantages
  - High resolution and seductive images
  - Evaluate detailed plaque morphology : lipid pool, cap thickness
  - Thrombus, vulnerable plaque
- Limitations
  - Shallow penetration depth (<2mm): true vessel sizing, assessment of plaque burden, large vessel or plaque, lesions with heterogenous composition
  - Discrimination between lipid and calcified lesions
  - Attenuation by blood ➔ Need to create blood free zone

OCT vs. IVUS:
Strengths and Weaknesses

	OCT	IVUS
Lumen Area	Mostly +++ (not ostia)	++
Dissection	+++	+
Stent assessment	+++	+
Plaque characteristics/plaque burden	+	+++
In-stent restenosis	+++	+
Thrombus	++	+
Lesion cap thickness, neointimal coverage	+++	+
Identifying "normal vessel" in diffuse disease	-	++
Ease of use	+	+++

The superior resolution of OCT compared to IVUS only improves on the identification of small, clinically unimportant edge dissections, stent malapposition, etc.

Dissections | Stent Malapposition | In-stent Restenosis




경청해주셔서
감사합니다.

IVUS Guided Intervention

Preinterventional lesion assessment
Significance
Lesion characteristics
Anatomical relationship with other vessel

↓

Choice of devices
Determine device size and length
Making strategy of intervention

↓

Postinterventional assessment
Accuracy of intervention
Procedure-related complication

Pre Intervention Assessment

- Lesion Significance Determination -

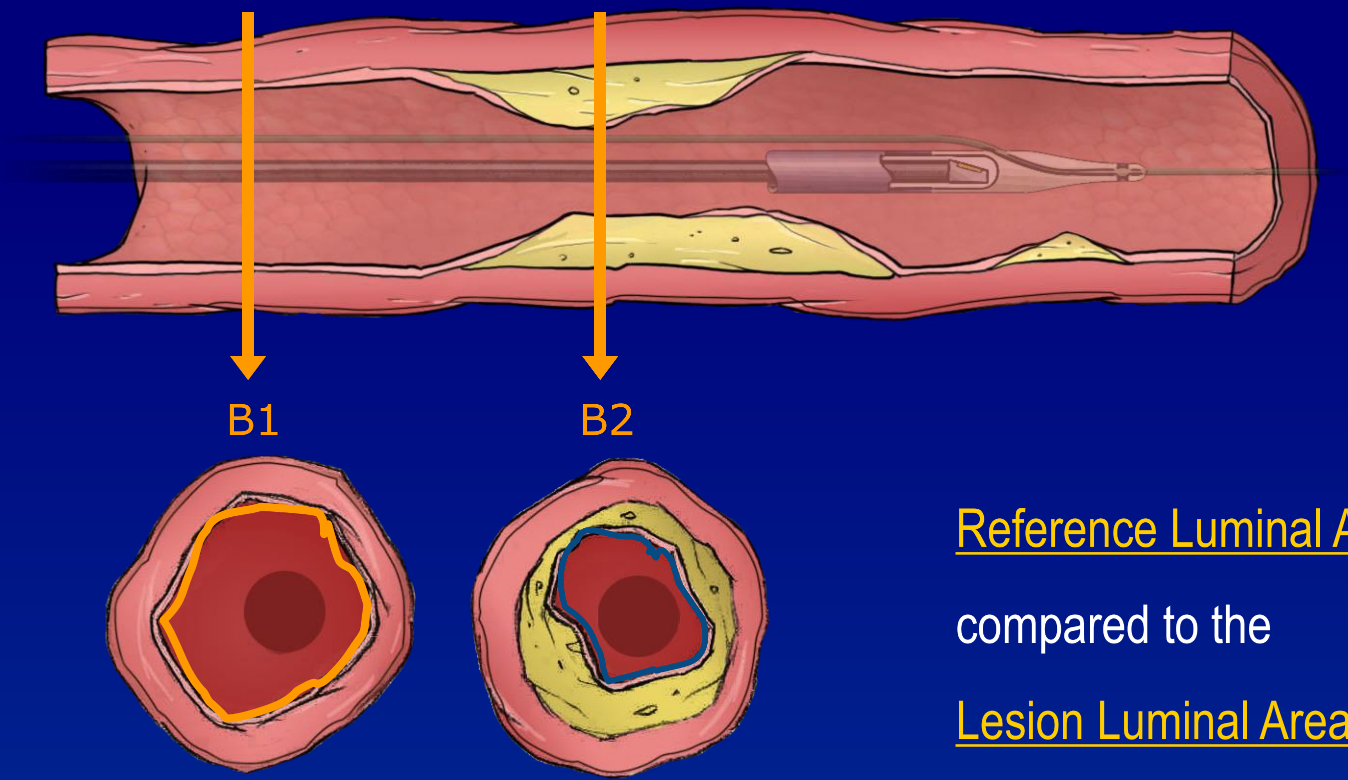
Large plaque burden can occur in the *absence* of any obstruction

Assess whether it is “flow limiting”

- Percent Lumen Area Stenosis
- Minimal Lumen Area (MLA)

Lesion Significance

Percent Lumen Area Stenosis



Reference Luminal Area

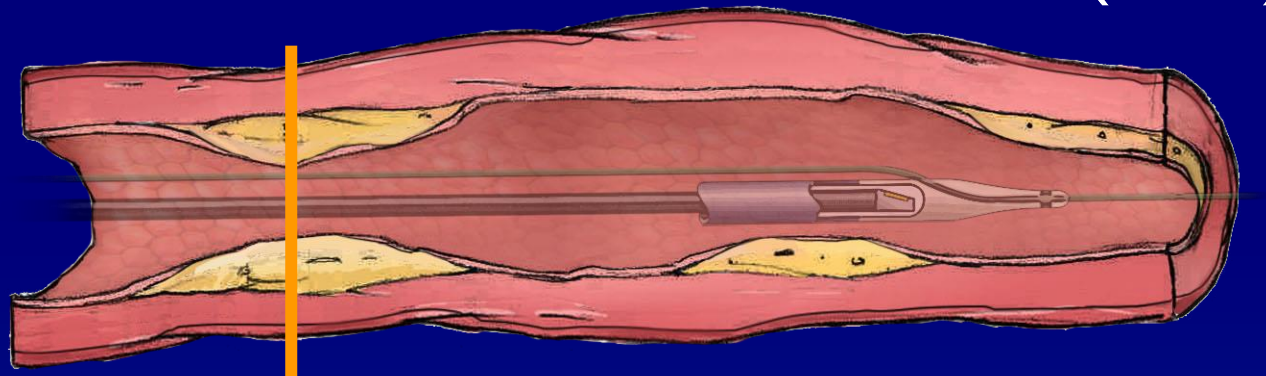
compared to the

Lesion Luminal Area[1]

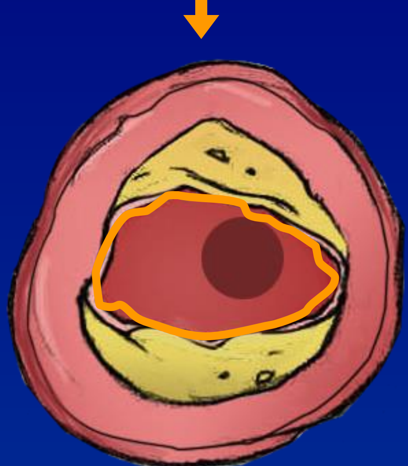
Mintz G et al. American College of Cardiology Clinical Expert Consensus Document on Standards for Acquisition, measurement and Reporting of Intravascular Ultrasound; J. Amer. College of Card. 2001:1478-1492. Images Property of Boston Scientific, Corp.

Lesion Significance

Minimum Lumen Area (MLA)



ONE measurement



Measure lumen area at the tightest point

In Proximal Epicardial Vessels:

<4.0 mm^2 - generally considered significant[1]

In Left Main Vessel Type:

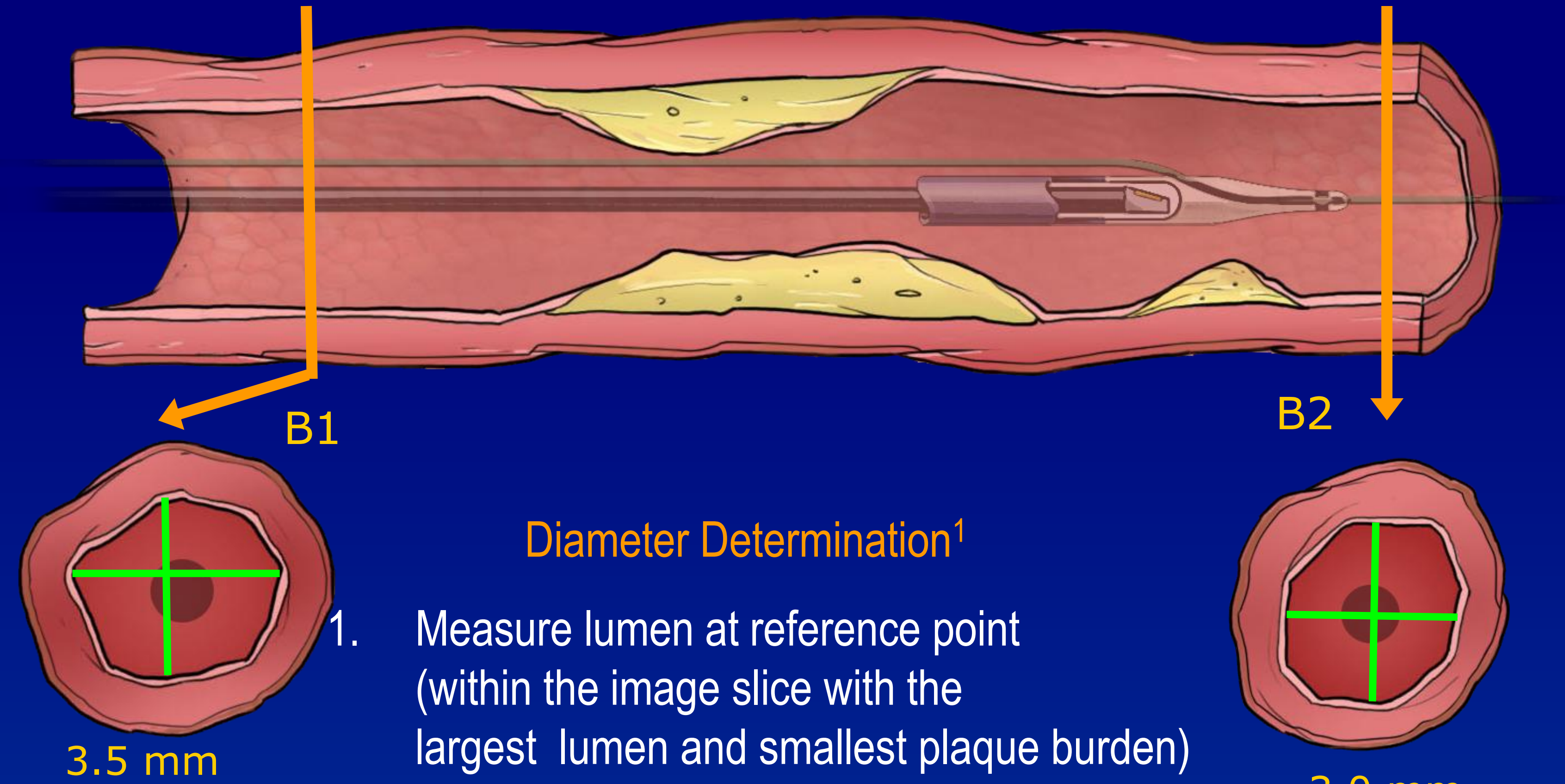
<6.0 mm^2 - generally considered significant in an average-sized patient with focal disease[2]

1. Abizaid A, et al. Long term follow-up after percutaneous transluminal coronary angioplasty was not performed based on intravascular ultrasound findings: importance of lumen dimensions. Circulation. 1999 Jul 20; 100(3):256-261

2 Jasti V, et al. Correlations between fractional flow reserve and intravascular ultrasound in patients with ambiguous left main coronary artery stenosis. Circulation. 2004; 110:2831-2836. Images Property of Boston Scientific, Corp.

Interventional Sizing

IVUS Diameter Determination



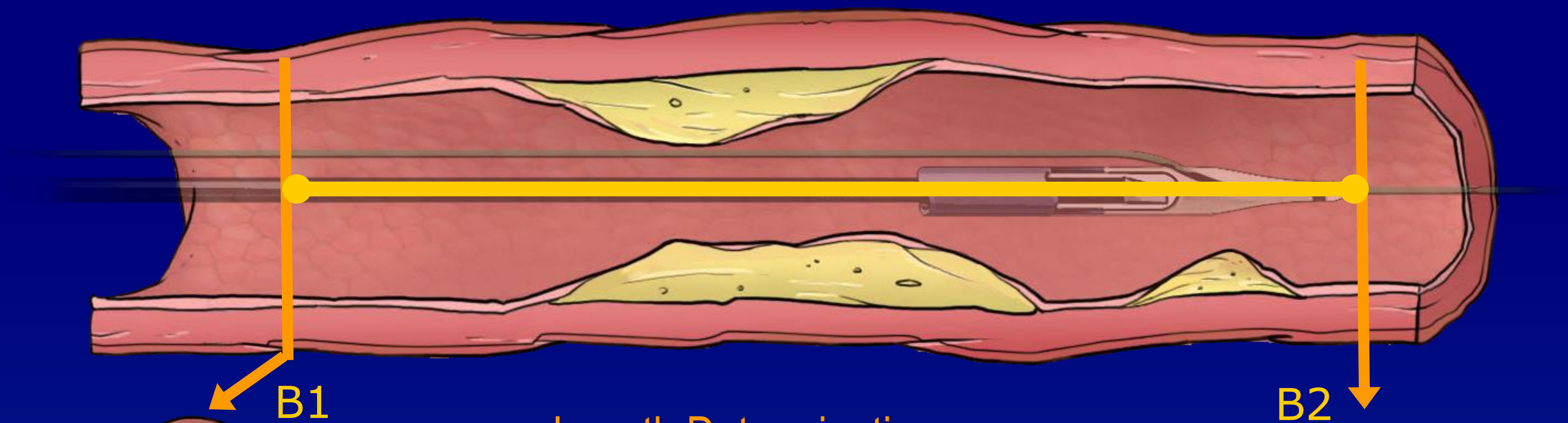
Diameter Determination[1]

1. Measure lumen at reference point (within the image slice with the largest lumen and smallest plaque burden)
2. Size Interventional device accordingly

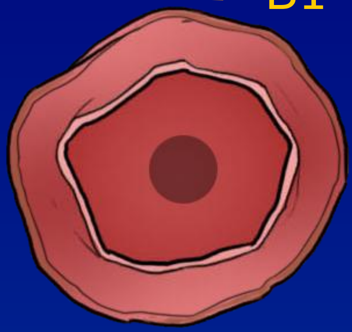
1. Mintz G et al. American College of Cardiology Clinical Expert Consensus Document on Standards for Acquisition, Measurement and Reporting of Intravascular Ultrasound; J. Amer. College of Card. 2001:1478-1492 Images Property of Boston Scientific, Corp.

Interventional Sizing

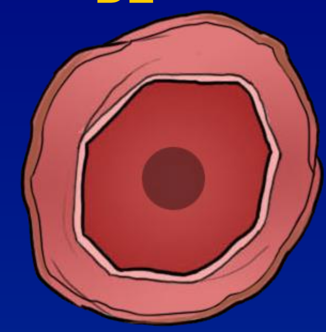
IVUS Length Determination



Length Determination

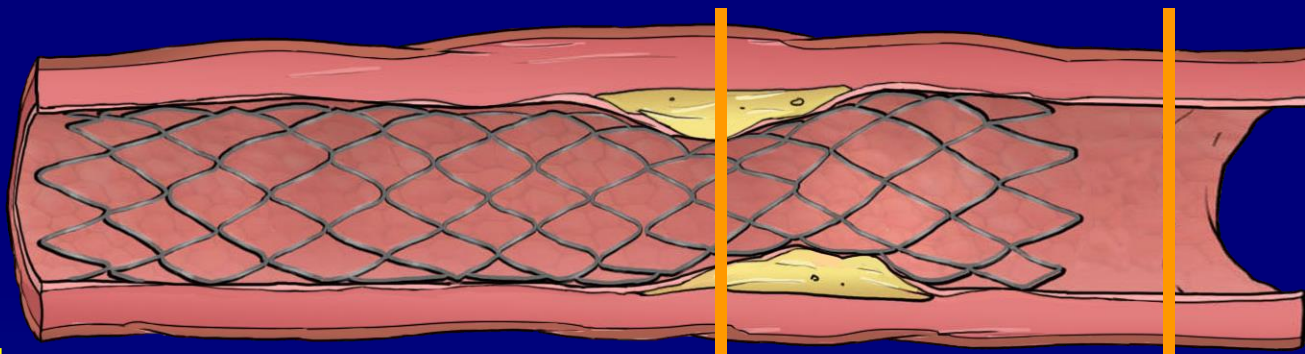


1. Automatic pullback required
2. Bookmark proximal reference point and distal reference point
3. Measure length between two bookmarks



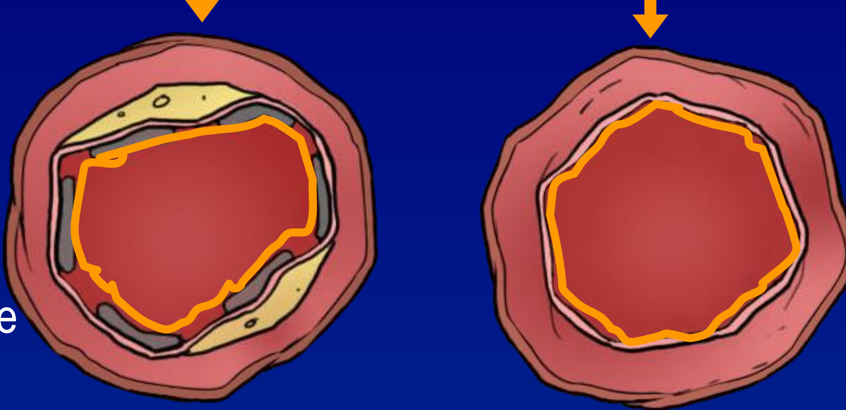
Post Stent Measurement

Stent Expansion Measurement



Stent Expansion

1. Ensure apposition to vessel wall
2. Measure stent lumen area at the tightest point
3. Compare measurement to distal reference lumen area
4. A stent MLD that is 90% of the distal reference lumen area is generally considered fully expanded[1]



Apposition

Lesion coverage

Complications - Dissection

Percent

Minimal Stent Diameter

Minimal Stent Area

De Jaegere, P., et al. Intravascular ultrasound-guided optimized stent deployment. Euro heart Jour (1998), 19, 1214-1223. Images Property of Boston Scientific, Corp