Basics of IVUS: The Concept of PLAN, LAND, and EXPAND

S. Jay Mathews, MD, MS, FACC, FSCAI

Director, Cardiac Catheterization Lab, Structural Heart Program, & PERT

Manatee Memorial Hospital, Bradenton, FL

DISCLOSURES

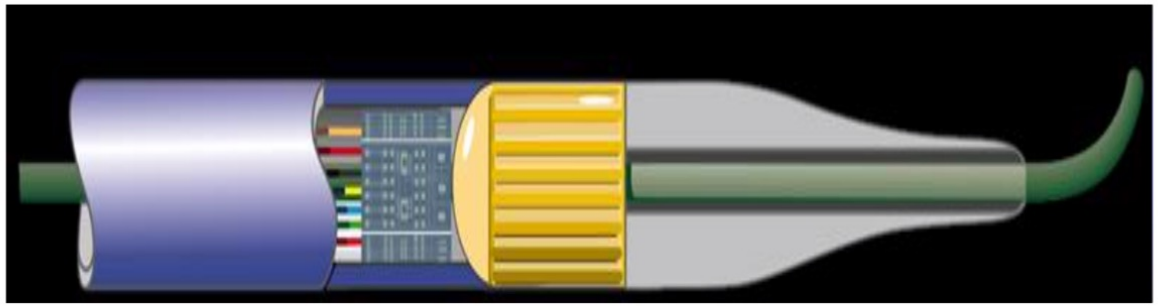
S. Jay Mathews, MD, MS, FACC

Speaker, Advisory Board, Consultant, Research Support **Philips**

Introduction to IVUS

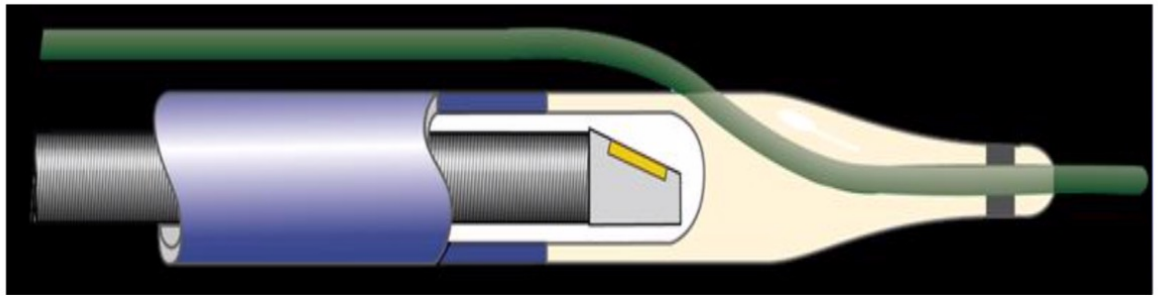
Phased array (digital) IVUS:

- 64 transducers with sequential imaging
- Lower frequency (20MHz)
- Long monorail with wire central to imaging plane



Rotational (mechanical) IVUS:

- Single, rotating transducer
- high frequency (>40MHz)
- Automated pullback, short monorail



Introduction to IVUS

Phased array	Rotational
Plug and play with minimal catheter prep and no flushing during procedure	Prep and flush catheter before and during use
No moving parts	High speed rotation of transducer driven by mechanical sled
Long monorail and coaxial design for enhanced pushability and trackability	RX design only
Greater depth of penetration and larger field-of-view for peripheral applications	Lower depth of penetration and smaller field-of-view
Lower axial resolution	Higher axial resolution

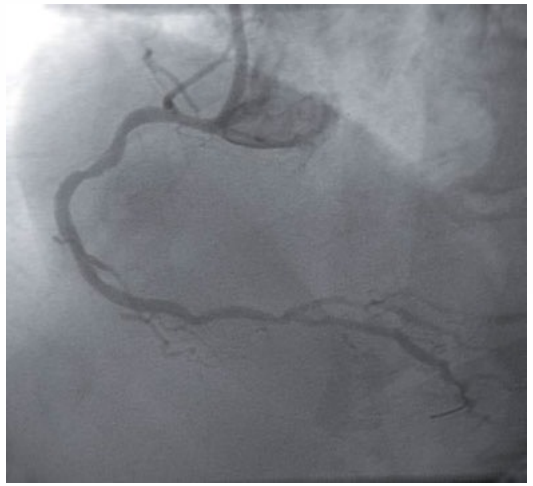
Introduction to IVUS

Imaging Catheter	Phased Array IVUS	Rotational IVUS			OCT
	Eagle Eye Platinum Philips	Refinity Philips	OptiCross HD Boston Scientific	Kodama ACIST	Dragonfly OPTIS Abbott
Frequency	20 MHz	45 MHz	60 MHz	40 or 60 MHz	Infrared
Approximate resolution	~120 micron	~50 micron	~22 micron	~30 micron (60 MHz)	~15 micron
Penetration	10 mm	7 mm	5-6 mm	5 mm (60 MHz mode)	1-2 mm in tissue
Lumen characteristics	Dark, clear lumen Low blood speckle ChromaFlo capable	Moderate blood speckle	Significant blood speckle	Significant blood speckle	Black, clear lumen (requires contrast flush)
Setup	Plug-and-play	Requires catheter flush and draped pullback device	Requires catheter flush and draped pullback device	Requires catheter flush and draped pullback device	Requires draped pullback device, vessel flushing
Pullback Length (mm)	Unlimited	150	100	120	75
Guide compatibility	5F (ID≥0.056")	5F (ID≥0.056")	5F (ID≥0.058")	6F (ID≥0.064")	6F (ID≥0.070")

Angio vs. IVUS

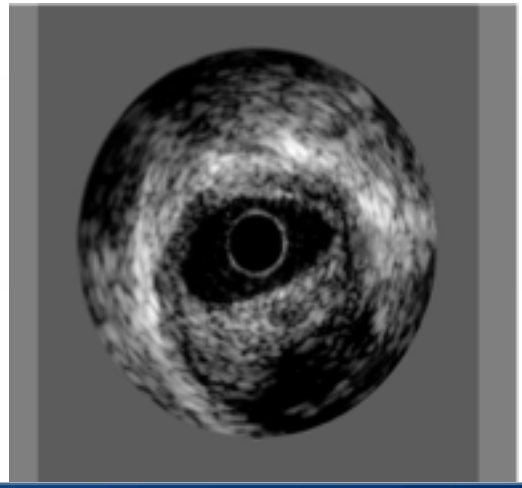
Angio

- Only able to visualize lumen
- Wall structures not imaged
- Underestimates extent of disease
- Reveals large dissections

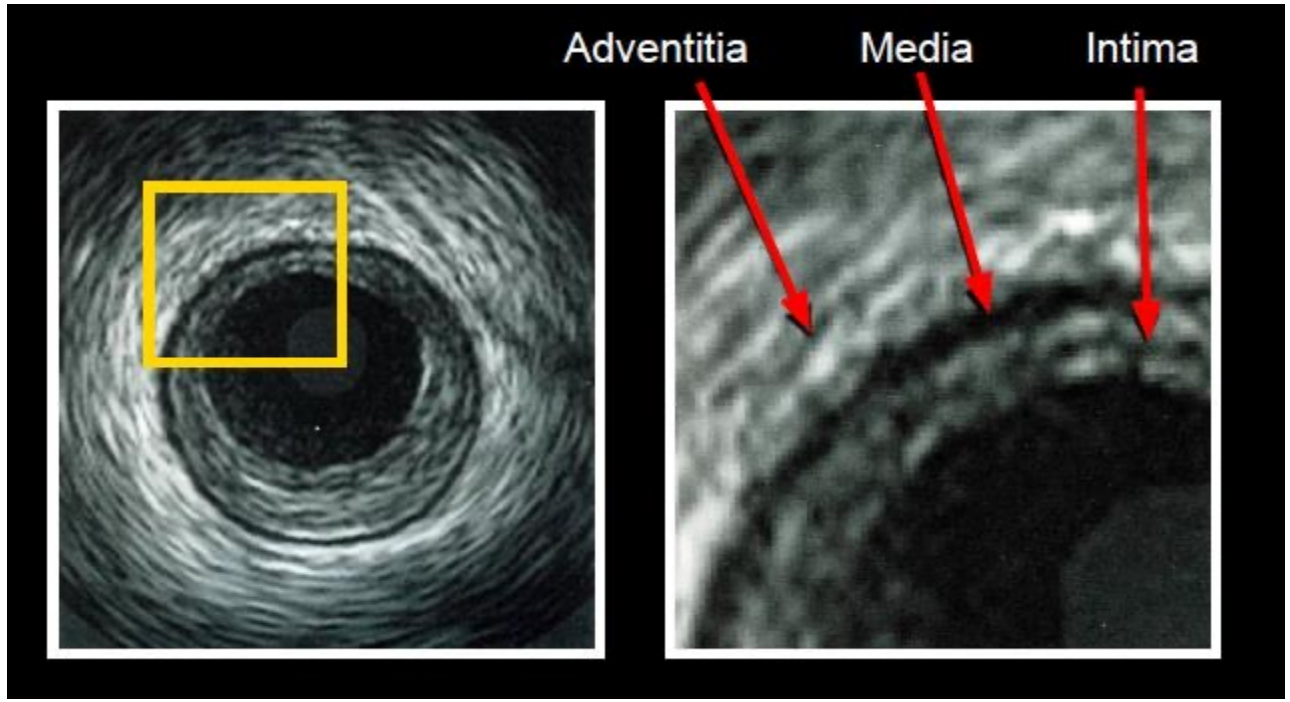


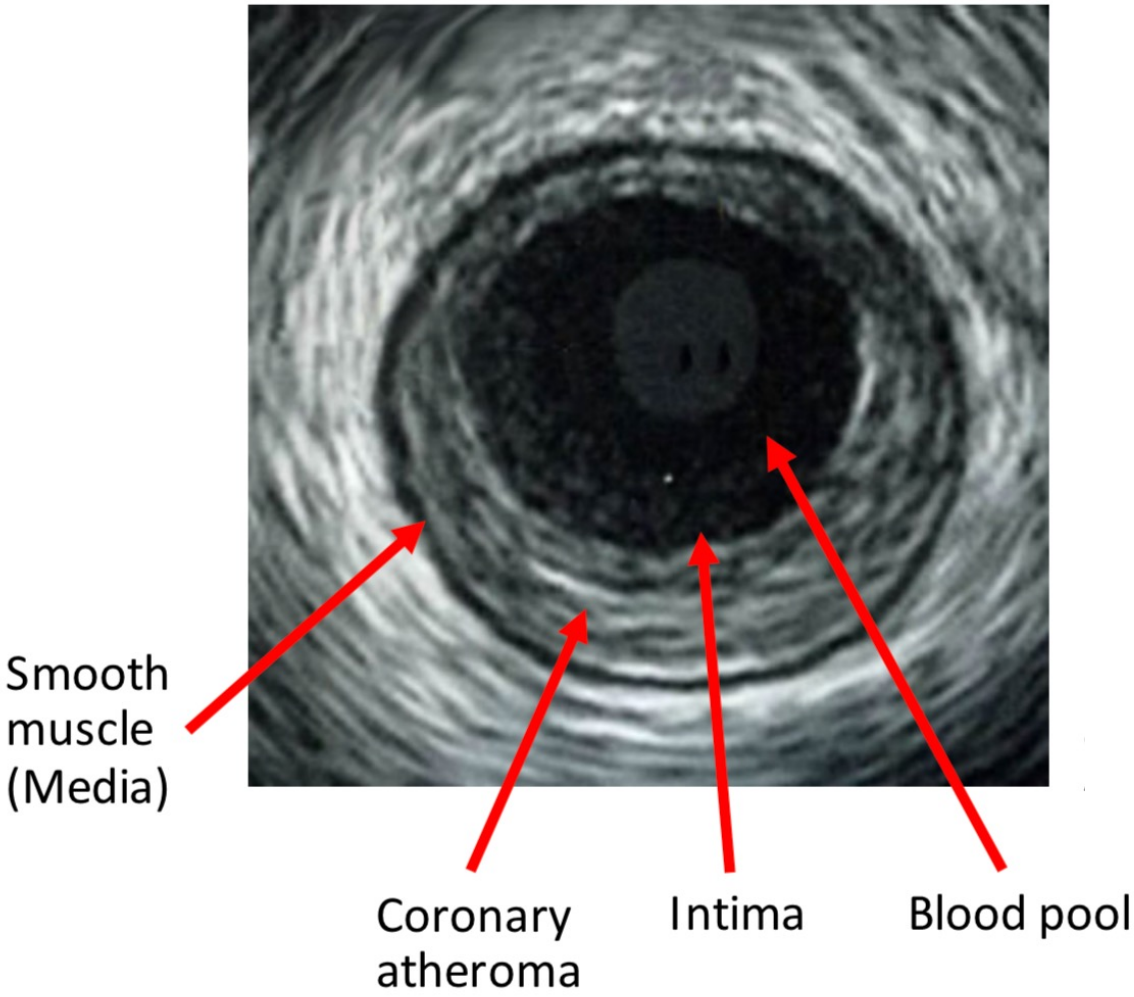
IVUS

- Tomographic
- Direct visualization of lumen shape & plaque location
- Characterizes extent of plaque
- Characterizes morphology of plaque
- Detects smaller dissections



Anatomy

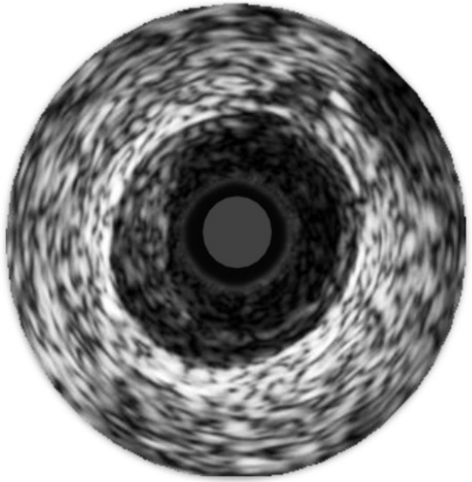




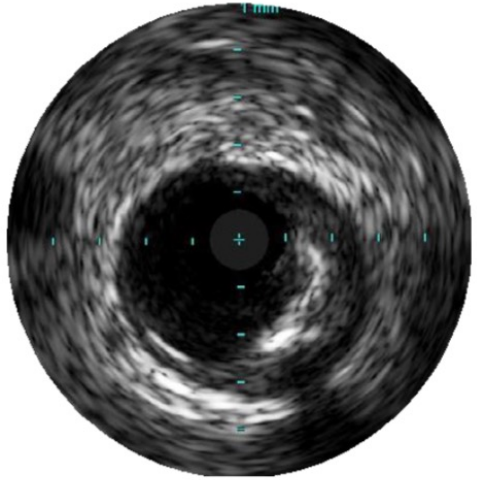
Courtesy Andrew Sharp

Pathology

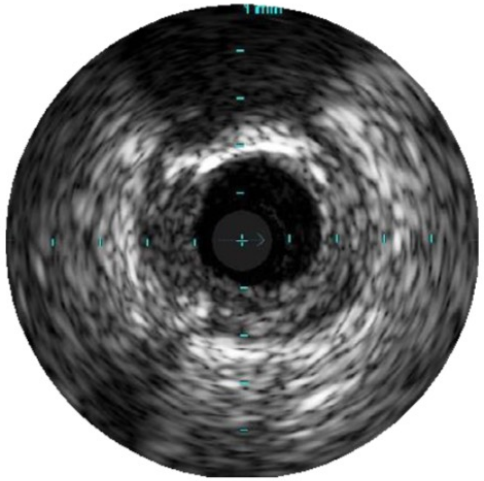
1. Soft (fatty)
Echolucent light gray flecks



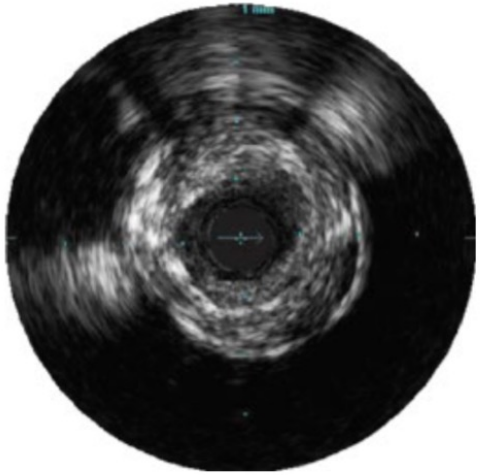
2. Fibrous
Echogenic, light gray with white surfaces



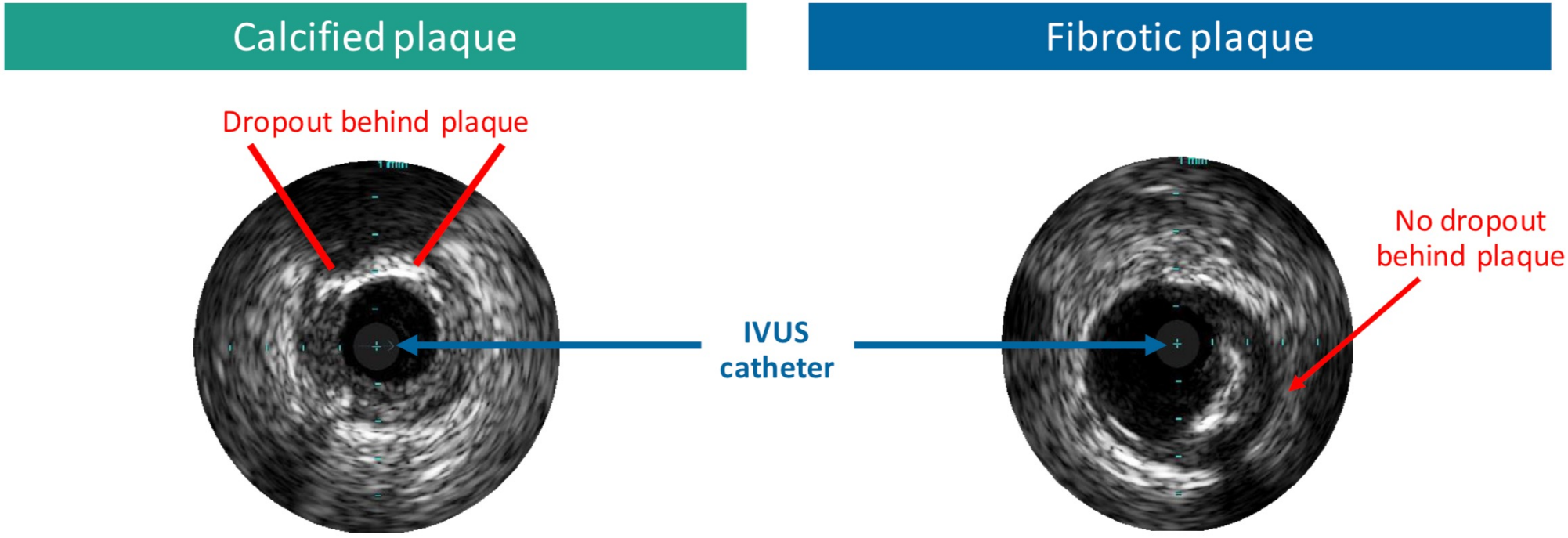
3. Calcified
Highly echogenic, white areas with shade



4. Mixed plaque
Mixed plaque is a combination of tissues of varying echogenicity



Pathology



- Bright white
- Reflects ultrasound
- Signal dropout behind

- Gray to white
- Partially reflects ultrasound
- No signal dropout behind

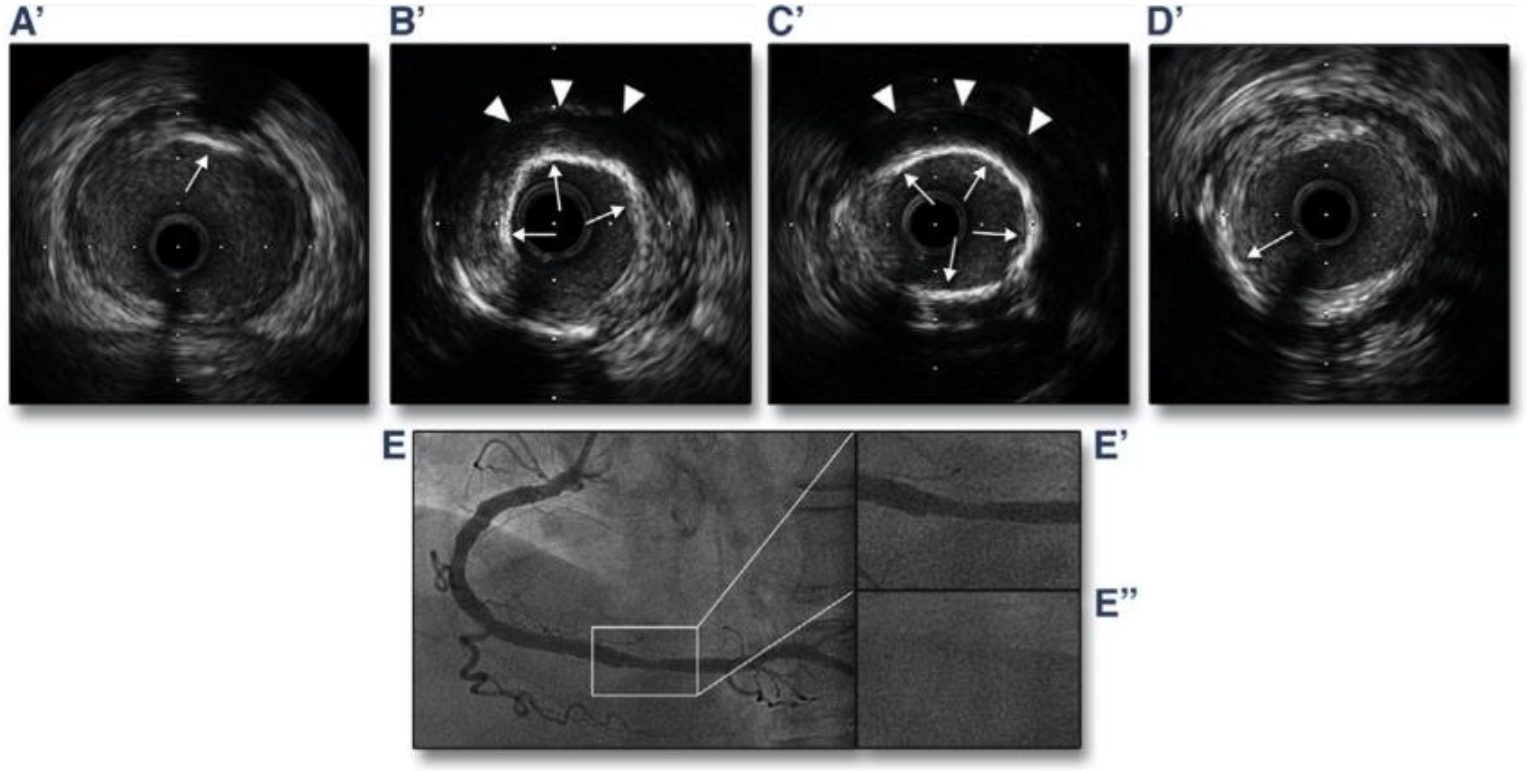
Pathology

Among 440 lesions calcium was detected by:

- Angio in 40.2%
- IVUS in **82.7%**
- OCT in 76.8%

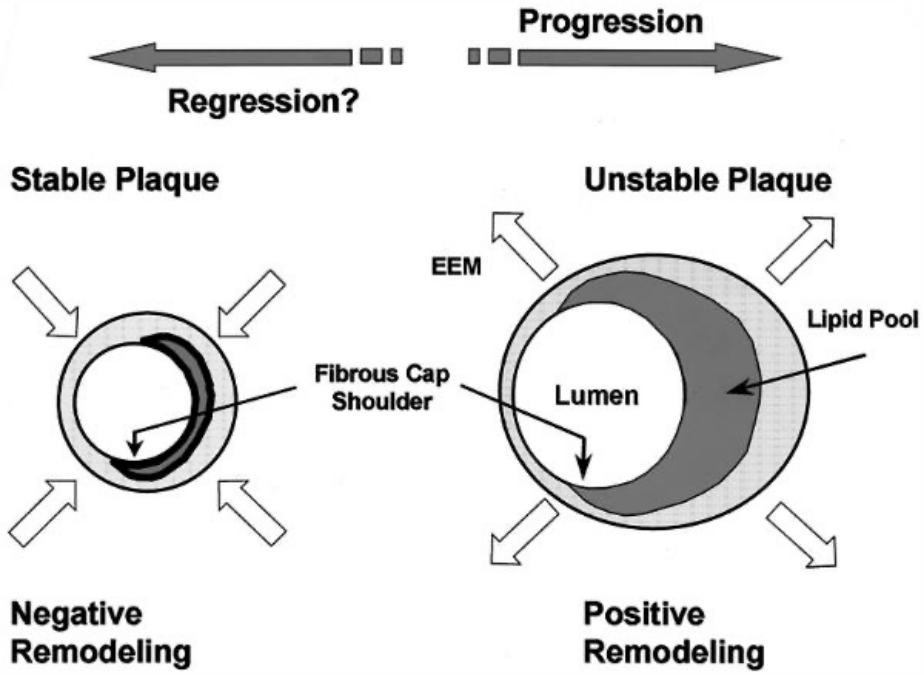
In **21.6% of lesions with IVUS calcium angle >180°, angio did not detect any calcium**

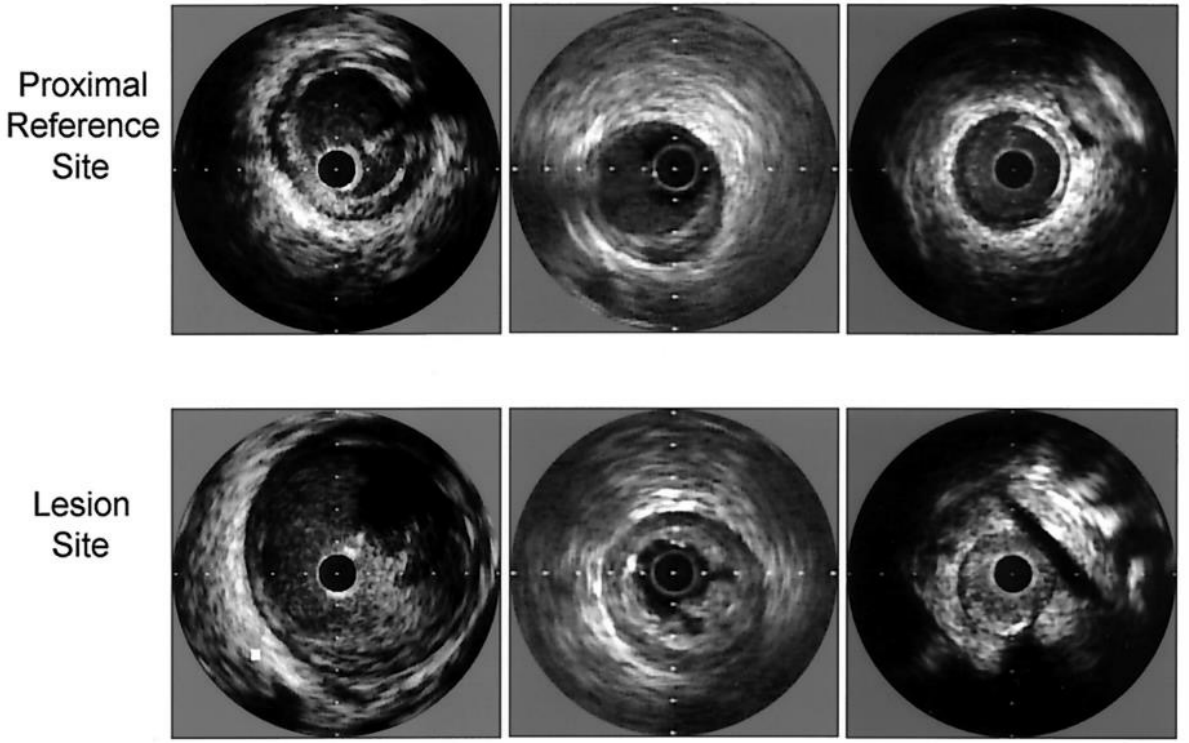
In **13.2% of lesions with IVUS-detected calcium, calcium was either not visible or underestimated by OCT** (mostly due to superficial OCT plaque attenuation)



ng X, et al. JACC Cardiovasc Imaging. 2017 Aug;10(8):869-879

Remodeling





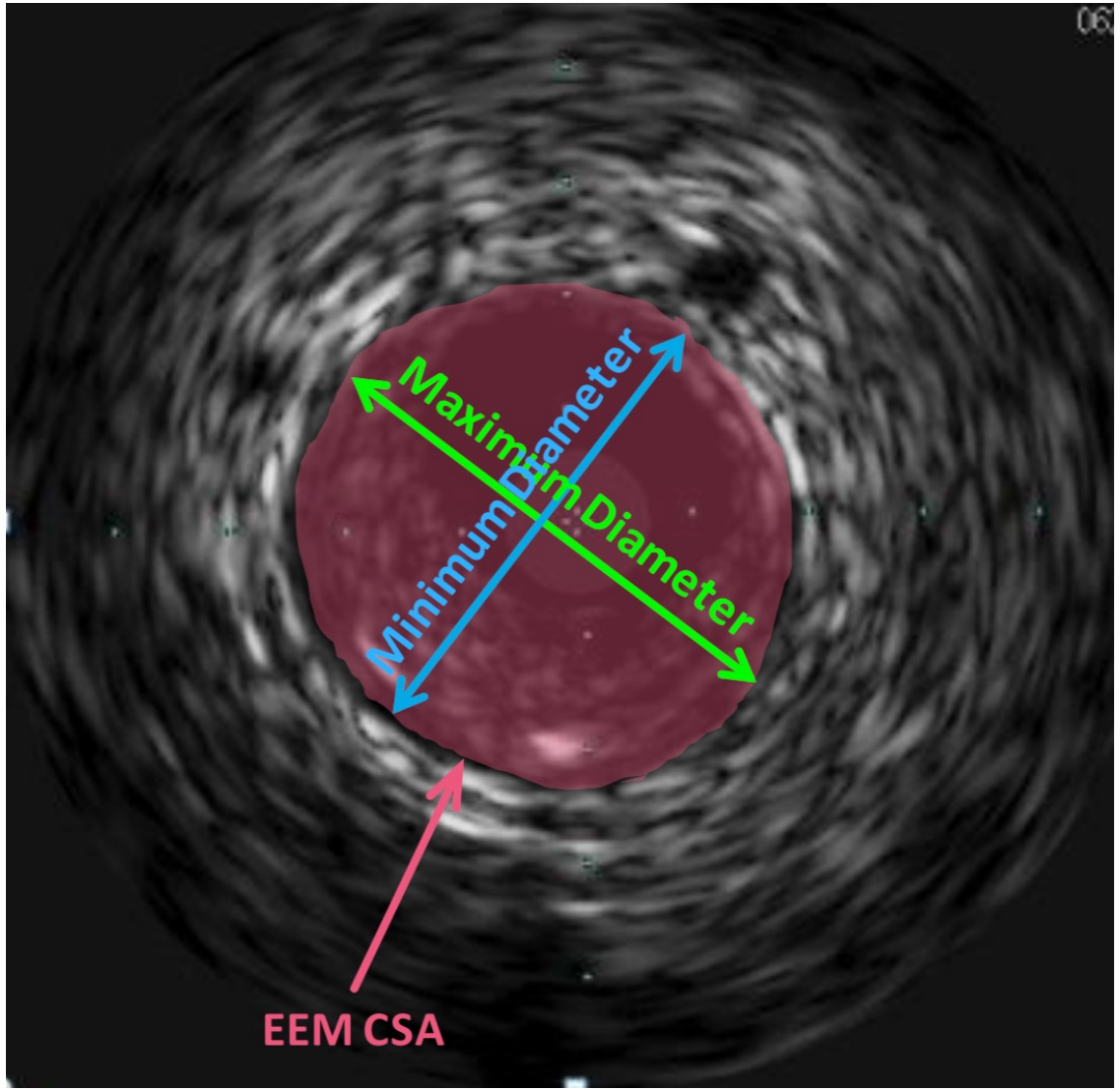
Aneurysm Pos Remodeling Neg Remodeling

Quantification

Vessel measurements

Vessel Diameter (mm):
•Measure minimal and maximal dimensions
•Adventitia to adventitia (EEM to EEM)

•**Vessel Cross-Sectional Area (mm^2):**
• Measure along the adventitia (EEM)

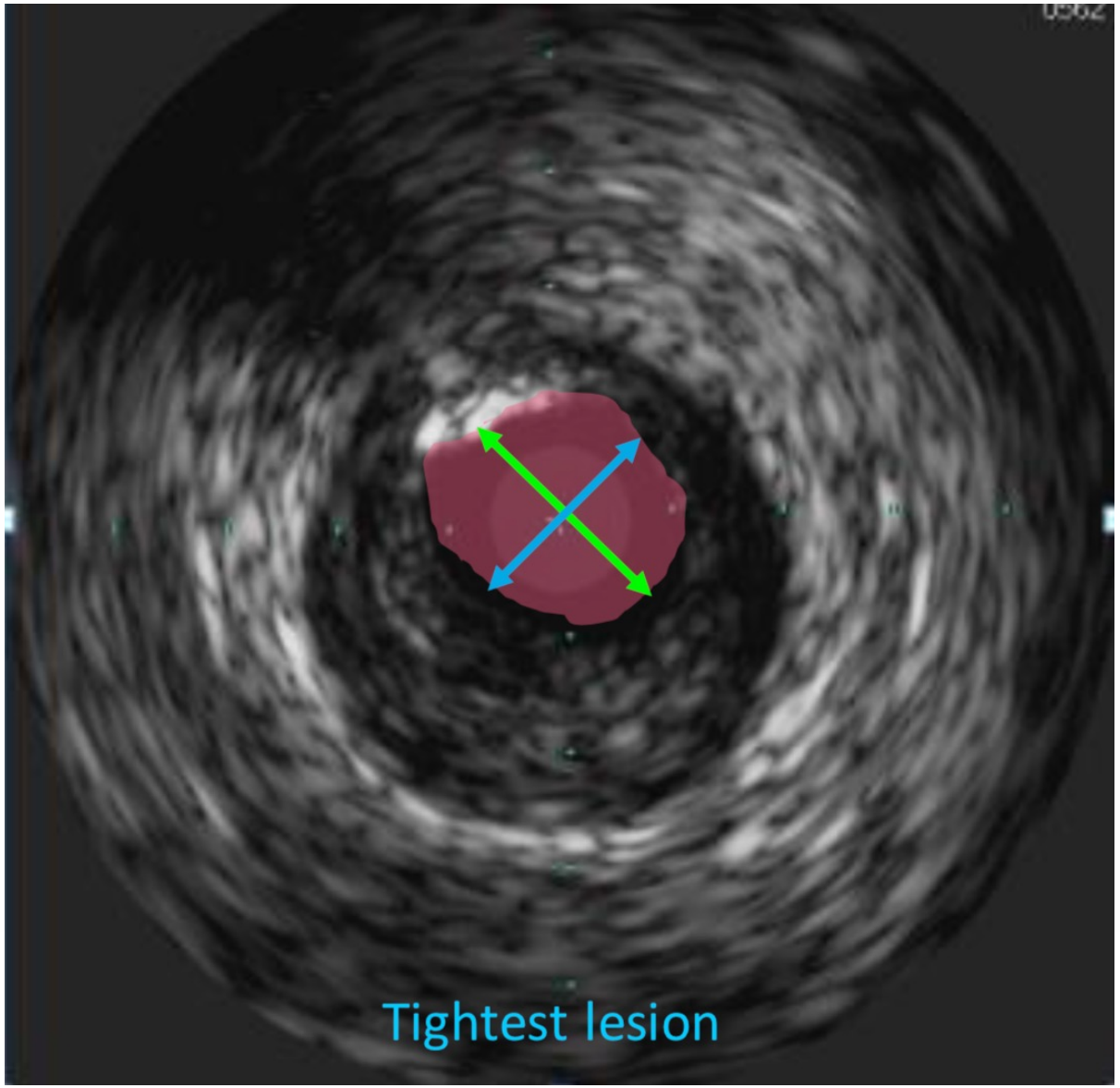


Mintz, G. and Nissen S. et al. *JACC.* 2001; 37,5: 1478-92

Quantification

Lumen measurements

- Lumen Diameter
  - Measure intima to intima
  - Maximum Diameter x Minimum Diameter
- Minimal Lumen Diameter (MLD)
  - Smallest Lumen Diameter within lesion segment
- Lumen Area
  - Cross-sectional area inside of lumen
- Minimal Lumen Area (MLA)
  - Smallest Lumen CSA within lesion segment



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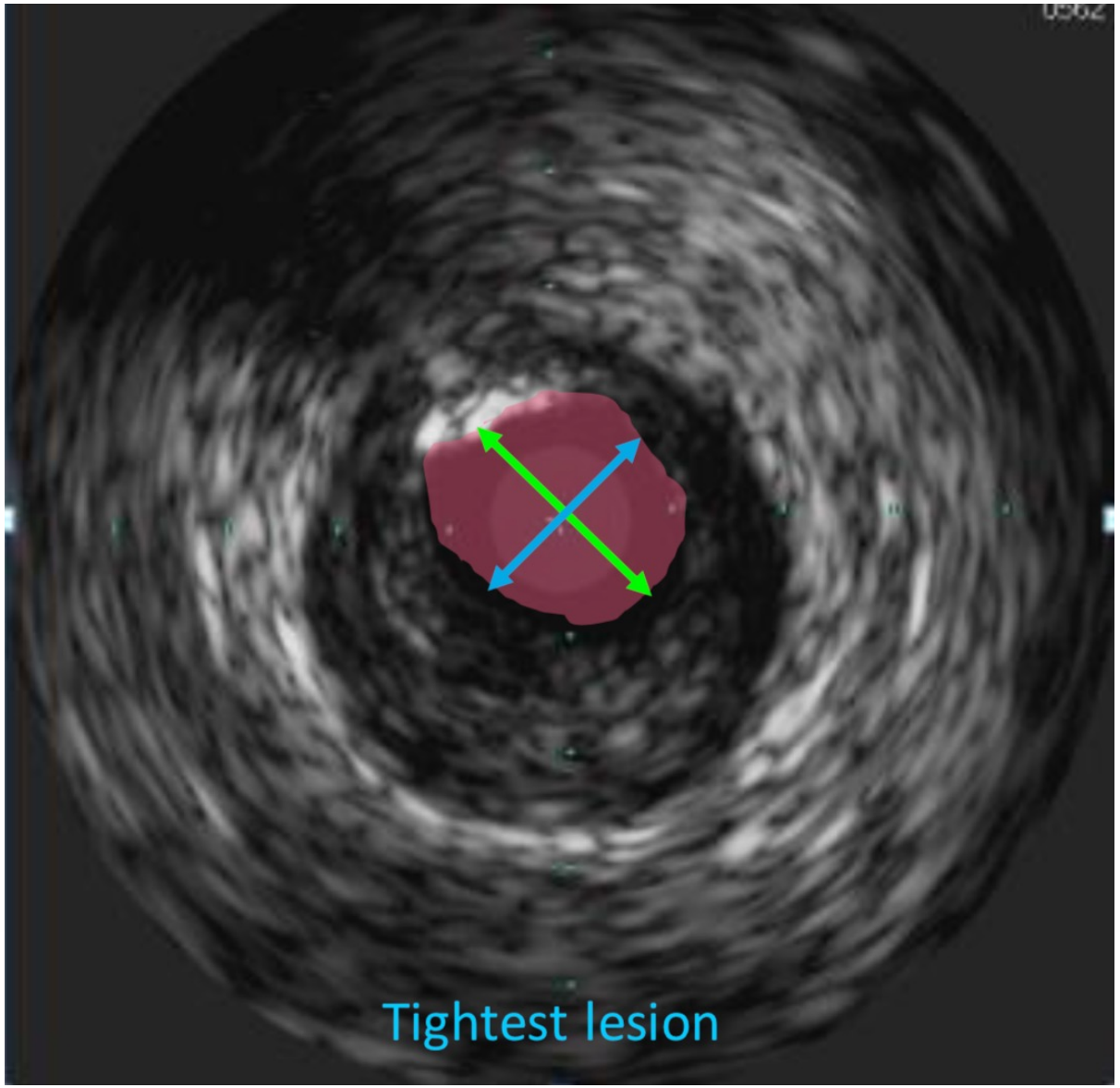
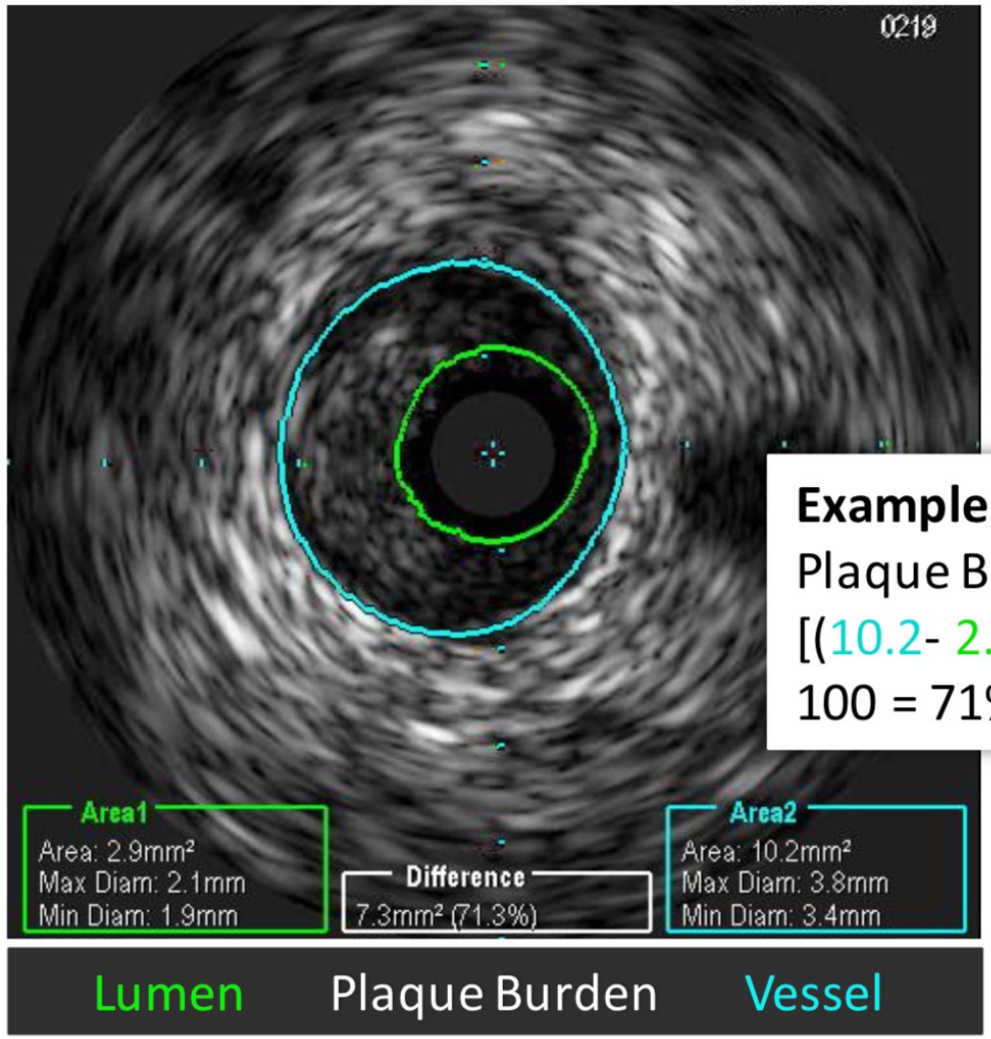


Mintz, G. and Nissen S. et al. *JACC.* 2001; 37,5: 1478-92

Quantification

$$\text{Plaque Burden} = \frac{\text{Vessel Area} - \text{Lumen Area}}{\text{Vessel Area}} \times 100$$

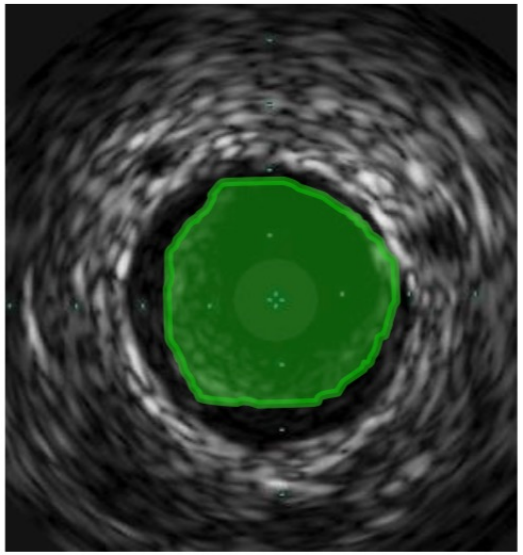


Example:

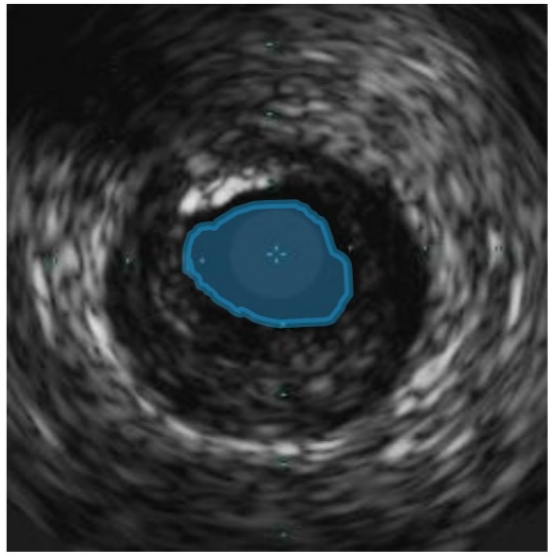
Plaque Burden= [(10.2- 2.9)/10.2] x 100 = 71%

Quantification

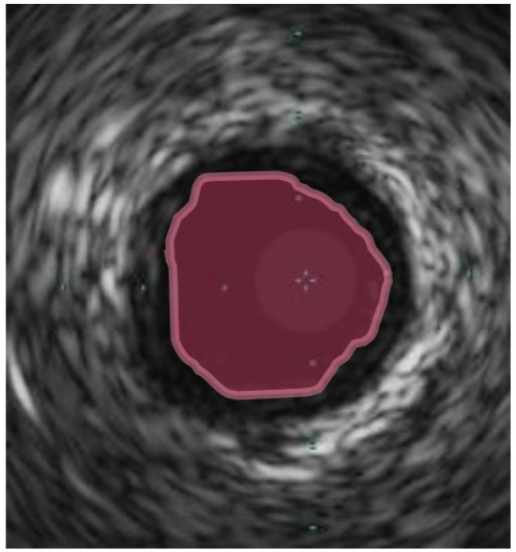
*Percent stenosis is not the same thing as plaque burden



Proximal reference CSA



Lesion MLA



Distal reference CSA

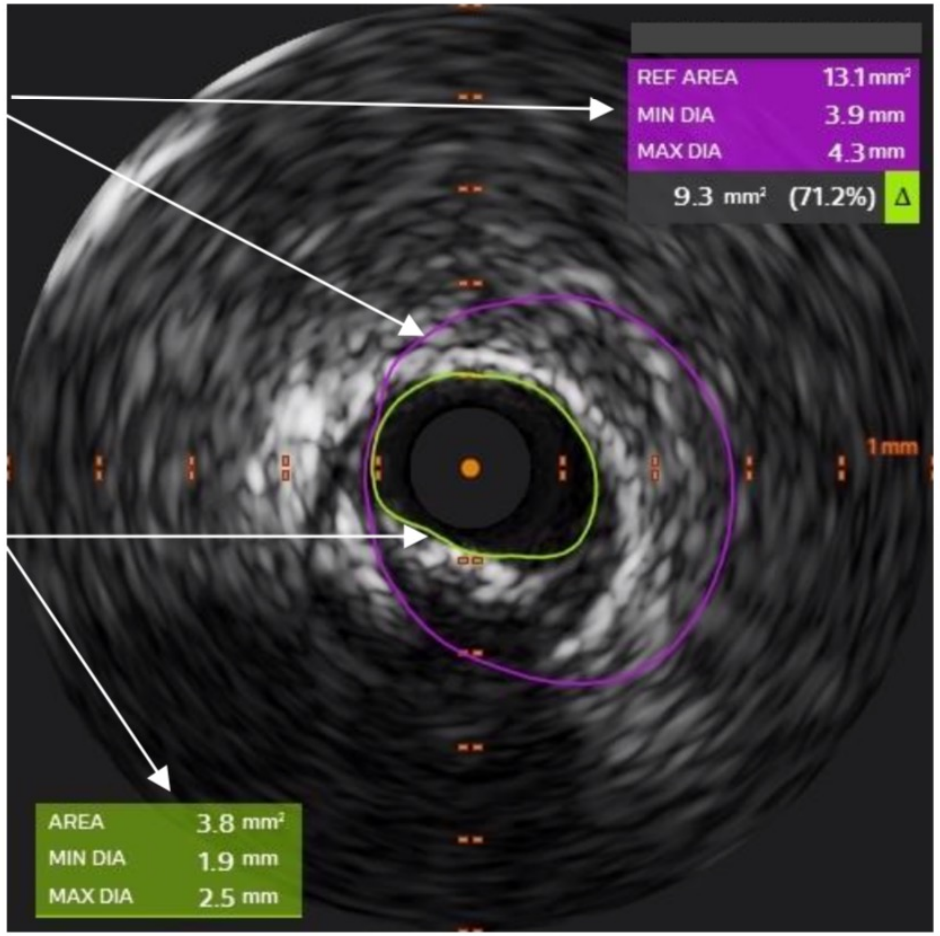
To calculate percent stenosis:

- First measure Reference Lumen Area (RLA) which can be:
  - Proximal Lumen CSA
  - Distal Lumen CSA
  - Average of Proximal and Distal CSAs

Quantification

Reference Lumenal Area (RLA)*

Lesion MLA



Example:
% area stenosis =
71.2% in display

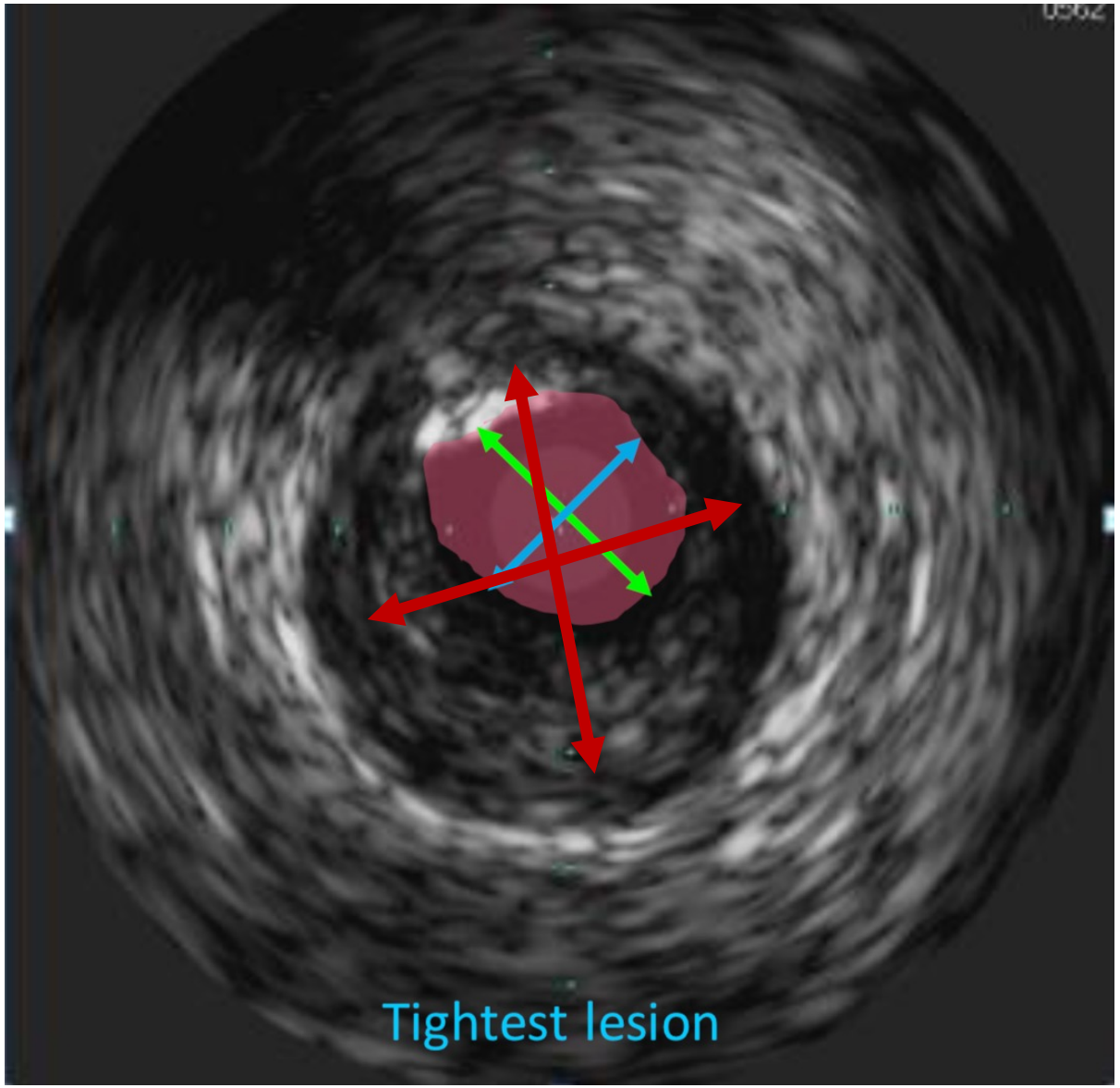
$$\% \text{ area stenosis} = \frac{\text{RLA} - \text{MLA}}{\text{RLA}} \times 100$$

*RLA can use either proximal, distal or mean reference lumen areas.

Quantification

Stent Sizing

- Multiple strategies of varying aggressiveness
- Mid Plaque to Mid Plaque
- Avoids barotrauma with pushing plaque outwards excessively
- Adequate vessel prep may also be important with severe plaque burden to avoid undersizing stents
- Reassess post-stent deployment



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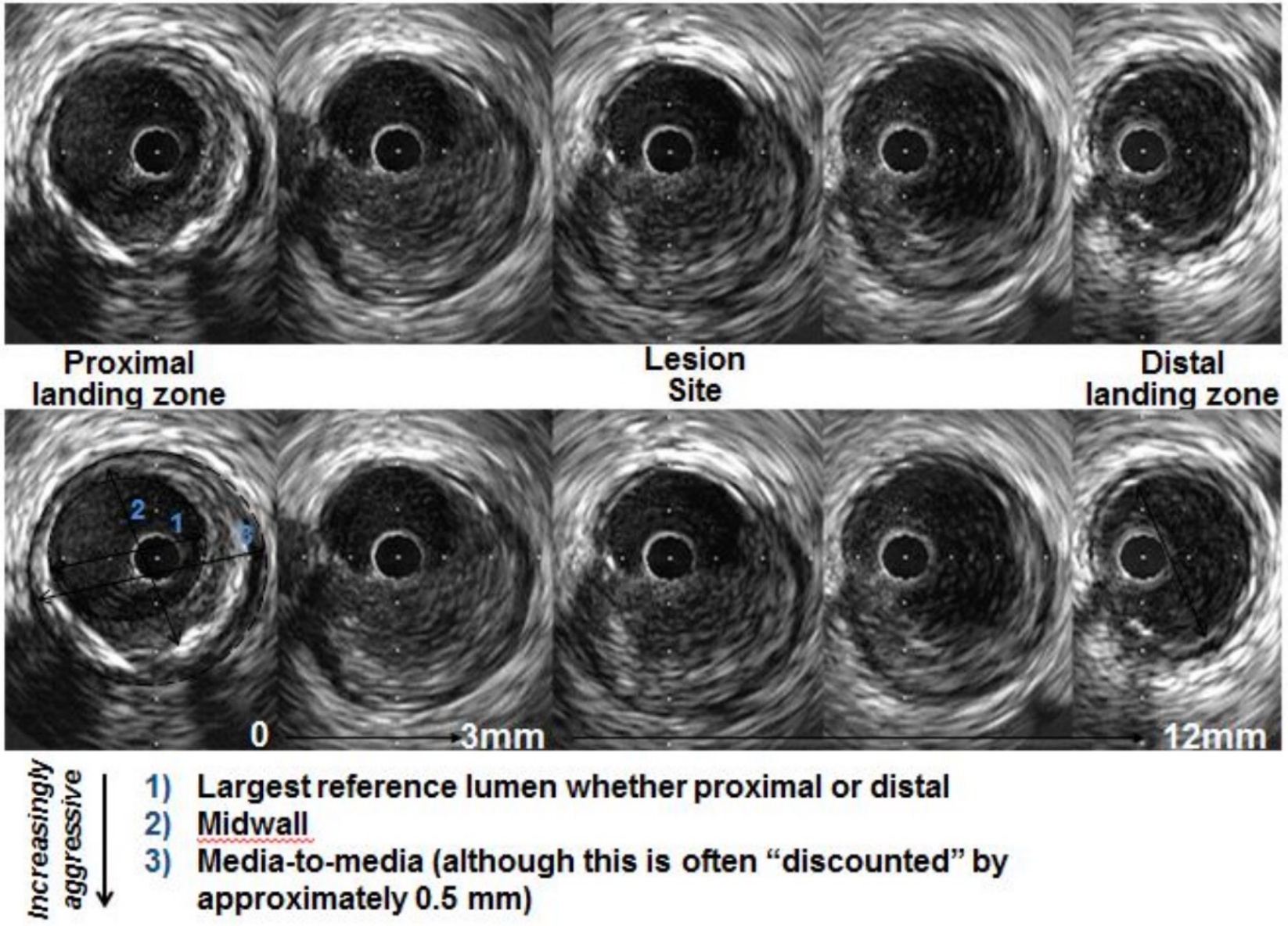
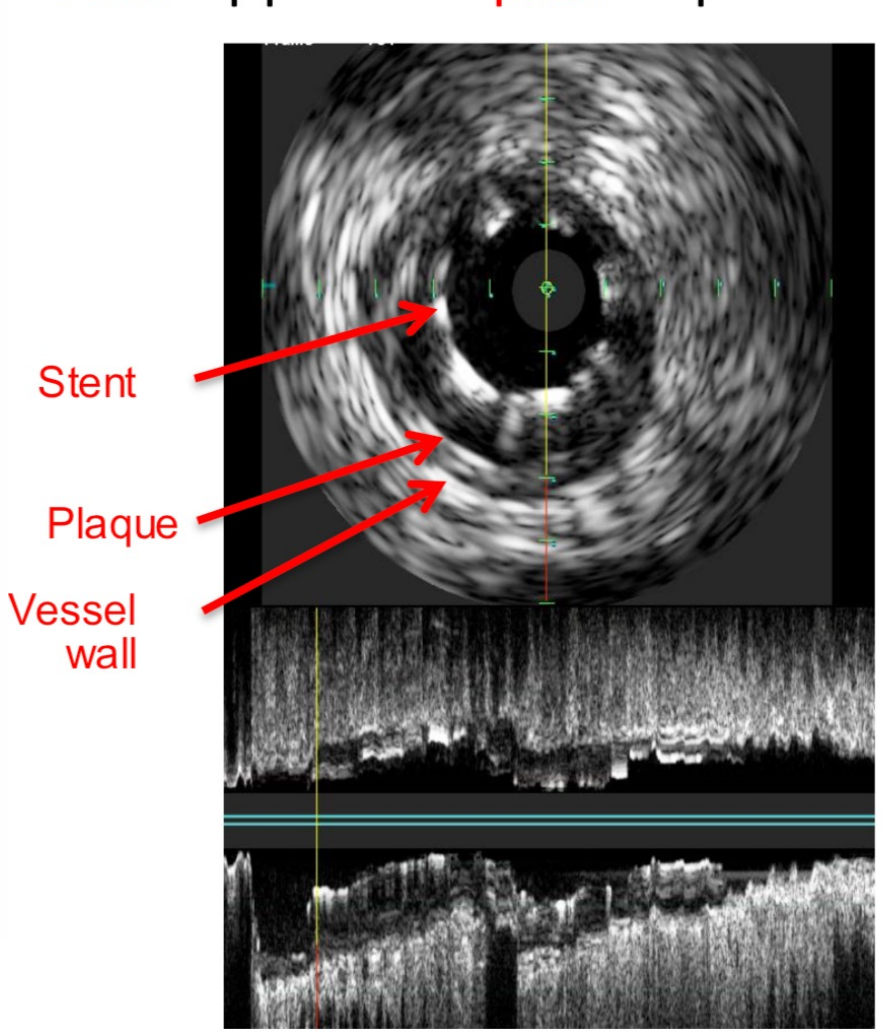
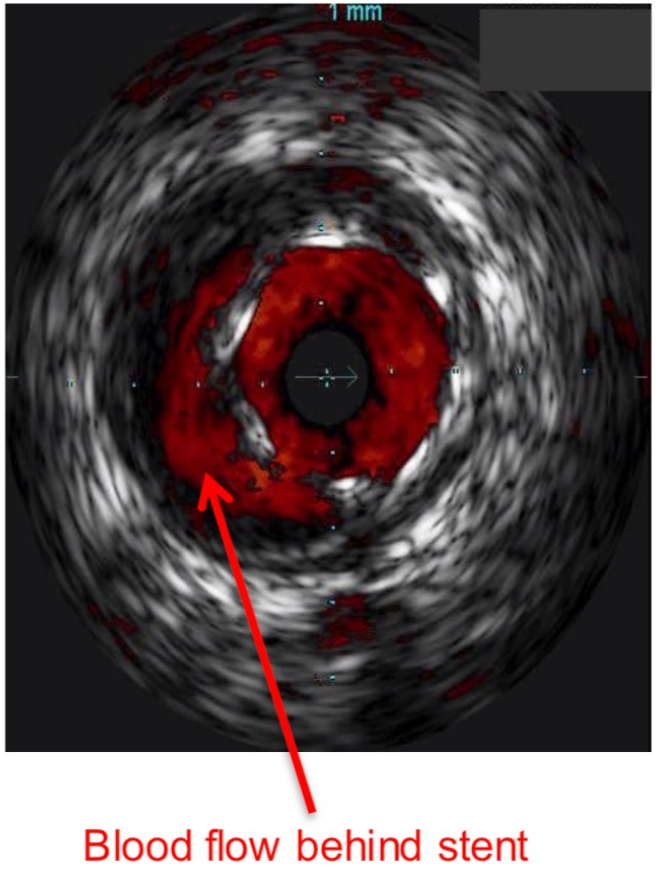


PCI Optimization

Malapposition:

- Patients with spasm
- Positive remodeling (resolving thrombus/inflammation in late acquired malapposition)
- Significant stent/vessel mismatch (aneurysms)
- Common post PCI but most resolve- minor cases usually not associated with ISR and ST with modern DES





Types of Malapposition

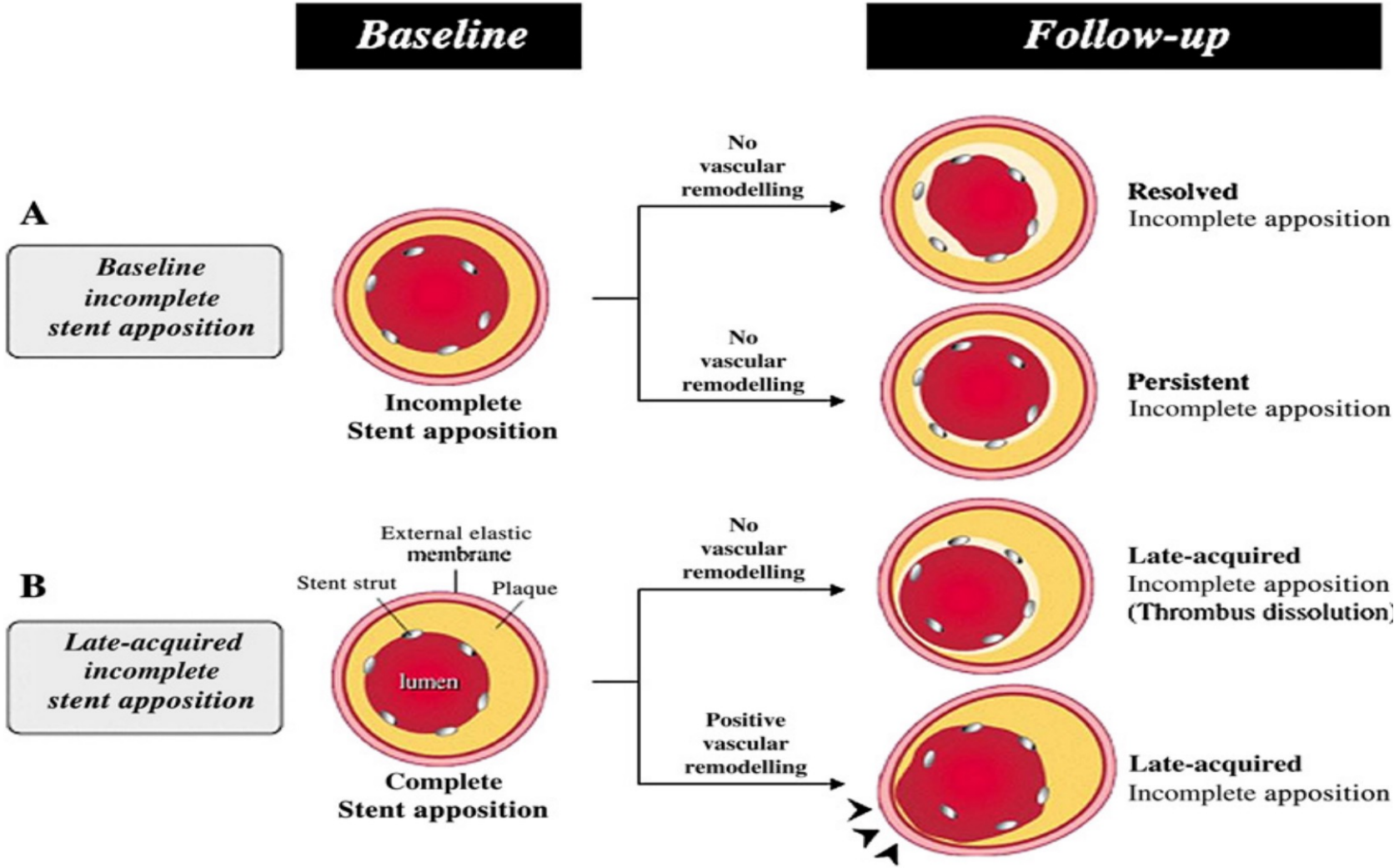


Figure 1 Various types of stent malapposition. Reproduced with permission from Hur *et al.*[2]

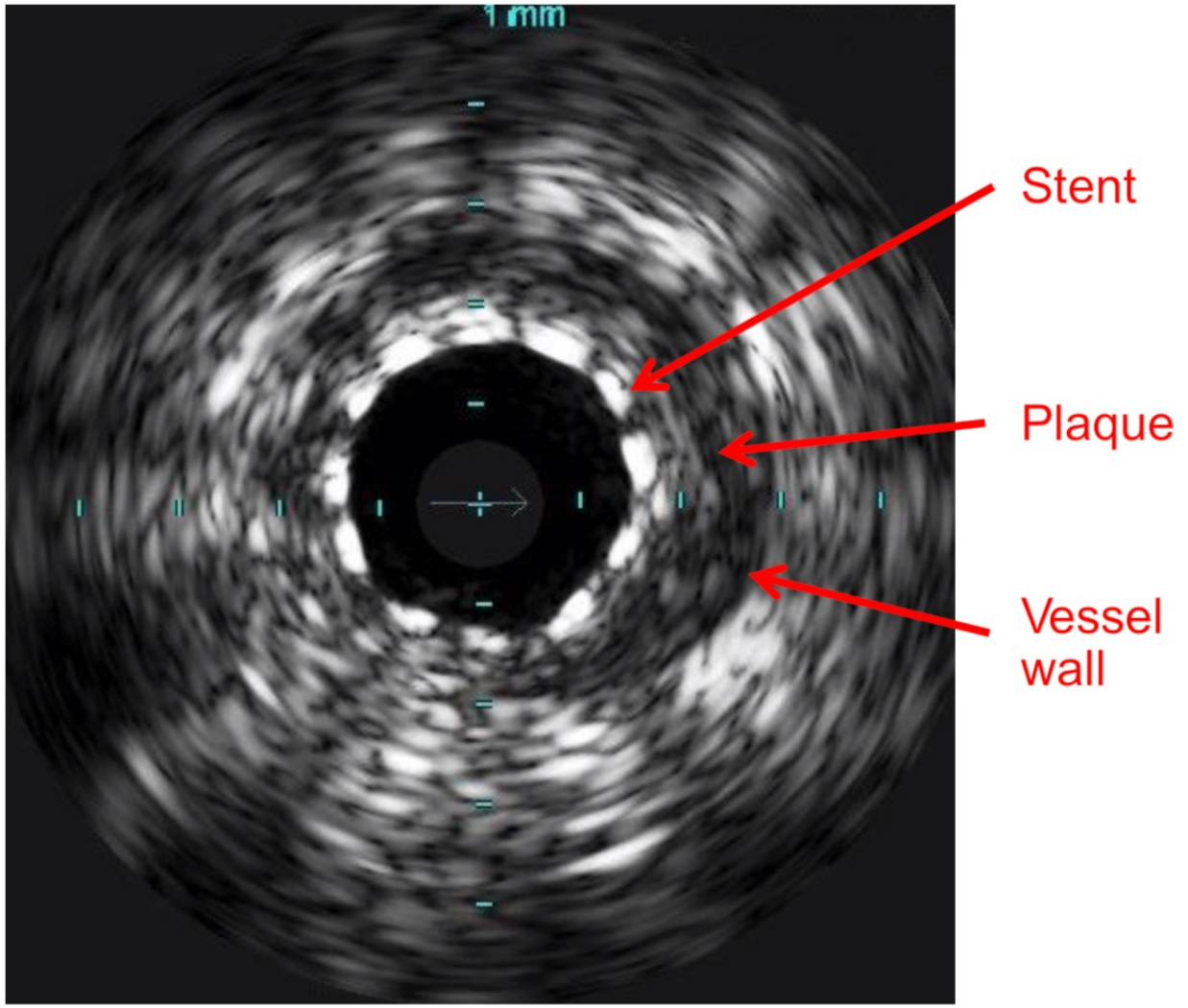
ARCH ELITE FELLOWS PROGRAM

PCI Optimization

Incomplete Expansion

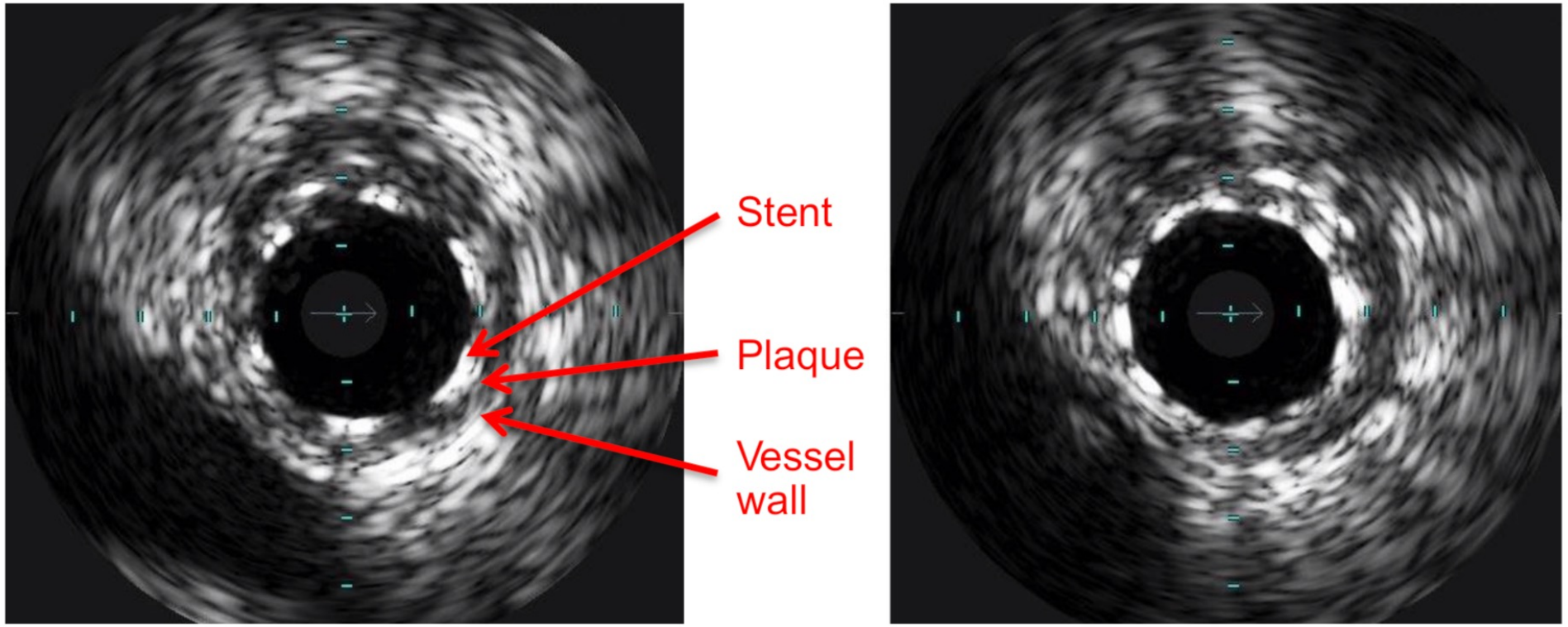
- Direct stenting
- Inadequate vessel prep
- Severe plaque
- Predictor of PCI failure/ISR and ST

Good apposition, poor expansion



PCI Optimization

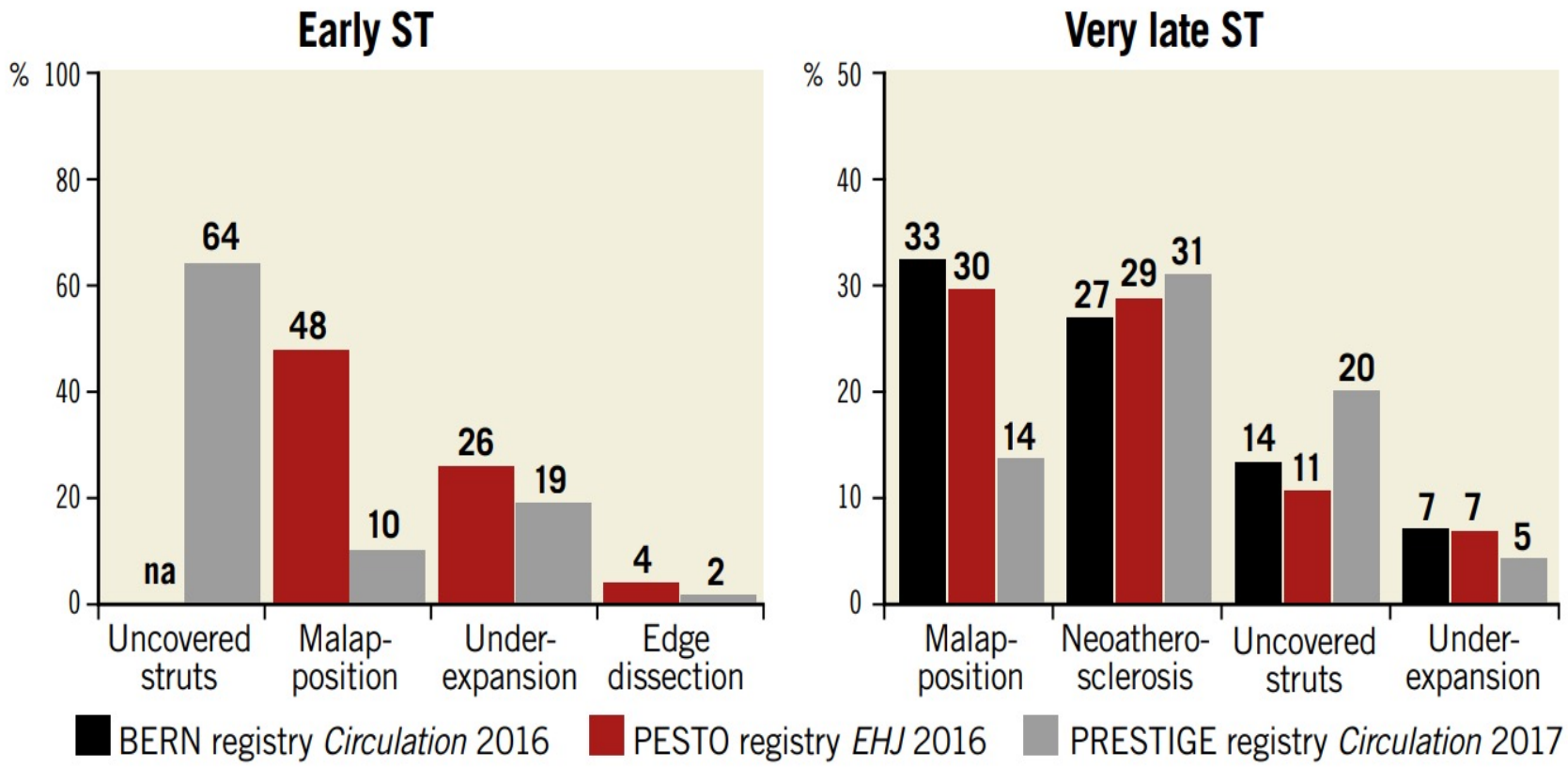
Good apposition,
good expansion



PCI Optimization

MSA

- Best predictor of failure
- Larger MSA associated with improved outcomes (Less ST and TLR)



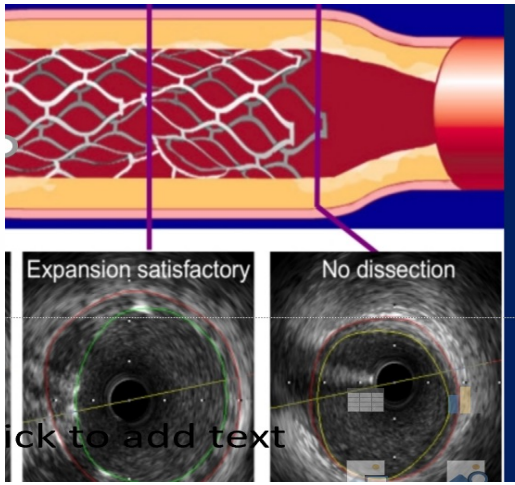
Stent Expansion Criteria (Non-LM)

Study	Target
IVUS-XPL	MSA ≥distal reference lumen area
CTO-IVUS	MSA ≥distal reference lumen area > than 5mm² at CTO
HOME DES	MSA > than 5mm² or MSA ≥80% distal reference lumen area for small vessel
AVID	MSA ≥90% of distal reference lumen area
TULIP	MLD ≥80% of mean reference lumen diameters MSA ≥distal reference lumen area
OPTICUS	MSA ≥90% of mean reference lumen area or ≥100% of the reference with lowest lumen area
SIPS	MSA ≥90% of mean reference lumen area or ≥100% of the reference with lowest lumen area
RESIST	MSA ≥80% of mean reference lumen area
ILUMIEN 3	MSA ≥90% in proximal and distal reference segments relative to closest reference
OPINION	MSA ≥90% of average reference lumen area
DOCTORS	MSA ≥80% of average reference lumen area
OCTACS	MSA ≥90% of average reference lumen area

Consensus Document

MSA ≥80% of mean reference lumen area

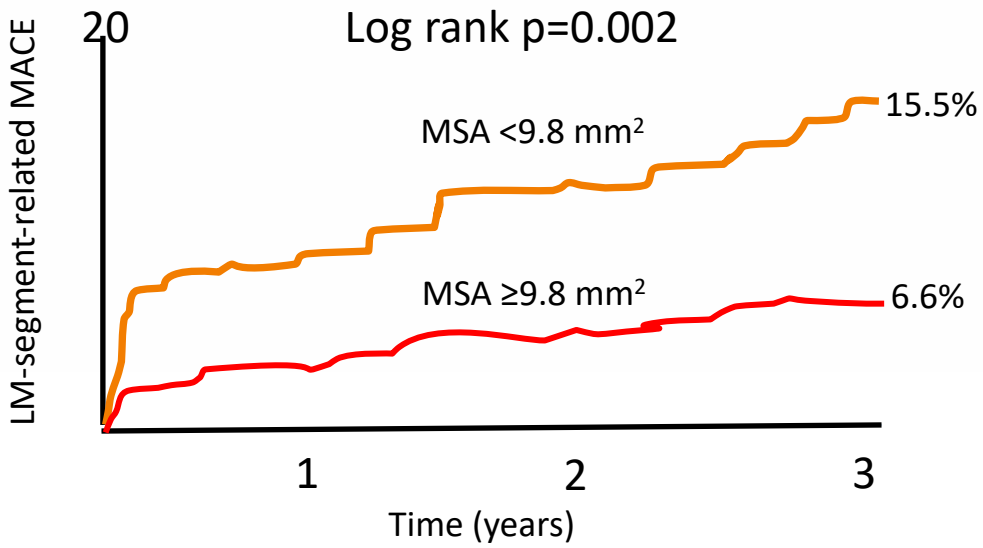
MSA > 5mm² by IVUS and 4.5mm² by OCT.

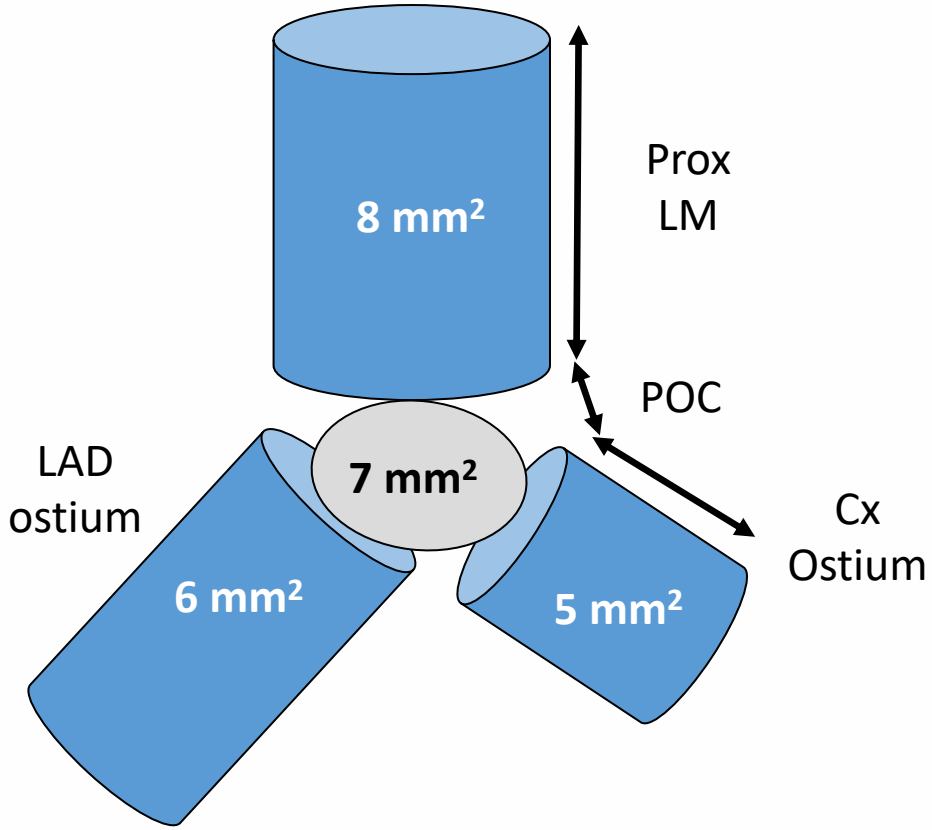


1. *Minimal lumen CSA in stented segmen >5.0 mm², or 90% of distal reference lumen CSA;*
2. *Plaque burden at the 5-mm proximal or distal to the stent edge <50%;*
3. *no edge dissection involving media with length >3mm.*

Stent Expansion Criteria (LM)

EXCEL trial
1905 with unprotected LMCAD
randomized to CABG vs. PCI
IVUS Substudy (n=504)





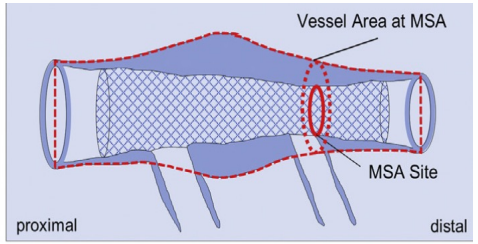
Add 0.5 mm² for non Asian or larger BSA patients

Kang et al. Circ CV Intv 2011

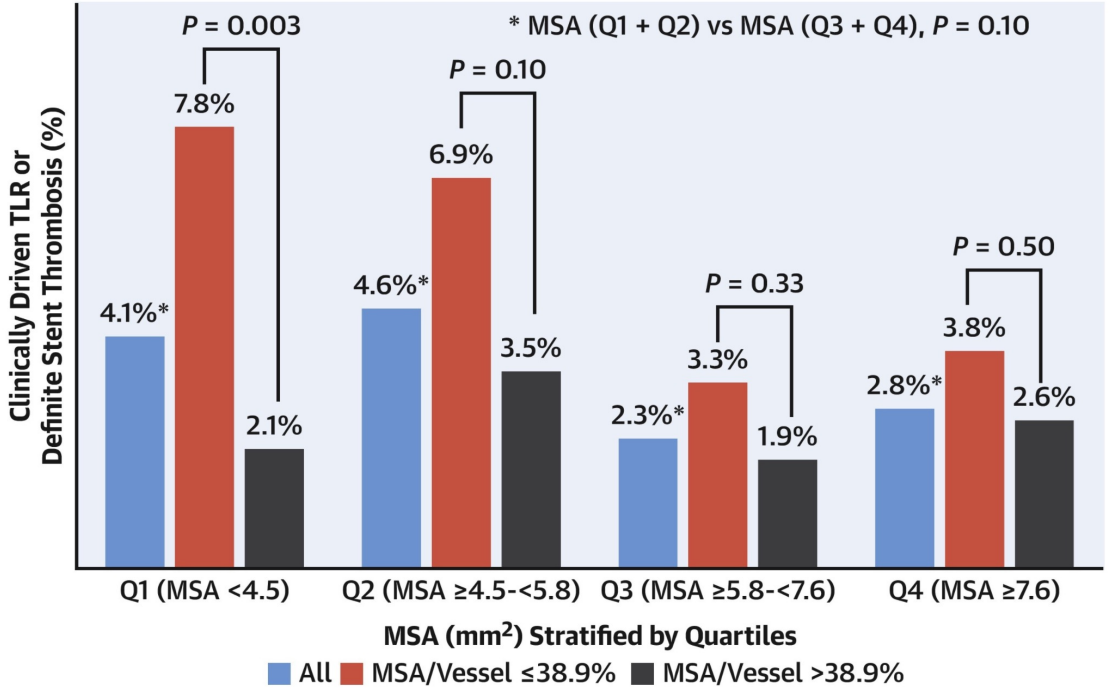
Stent Expansion

MSA/Vessel Area Stent Exp

$$\frac{\text{MSA}}{\text{Vessel Area at MSA}} \times 100$$

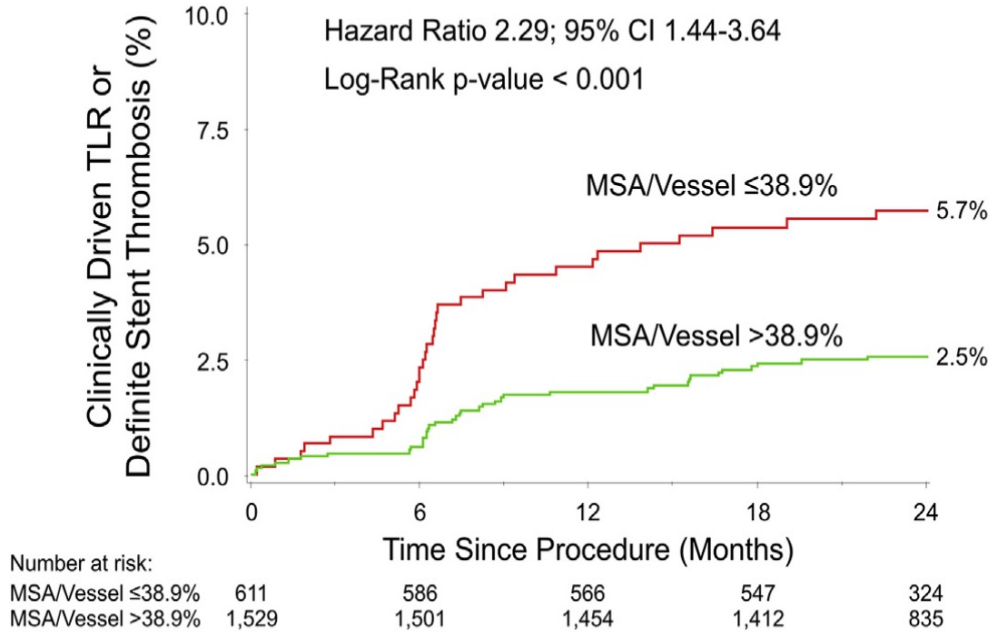


CENTRAL ILLUSTRATION: 2-Year Rate of Clinically Driven Target Lesion Revascularization or Definite Stent Thrombosis Stratified by Minimum Stent Area Quartiles and Minimum Stent Area/Vessel (≤38.9% Versus >38.9%)



Fujimura, T. et al. J Am Coll Cardiol Intv. 2021;14(15):1639-50.

FIGURE 2 2-Year Kaplan-Meier Curves for Clinically Driven Target Lesion Revascularization or Definite Stent Thrombosis



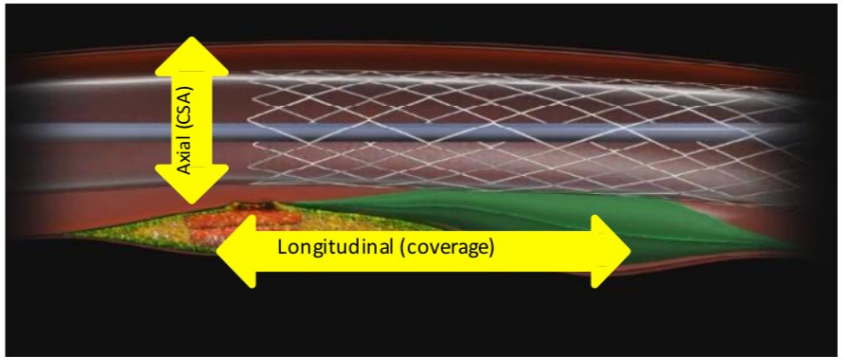
ARCH ELITE FELLOWS PROGRAM

Geographic Miss

Axial GM: Under or over inflation of a stent where ratio between size of stent and reference vessel diameter was ≤ 0.9 or >1.3.

Longitudinal GM: A deployed stent which does not cover an injured or significantly diseased segment at one or both of the edges.

Geographic Miss

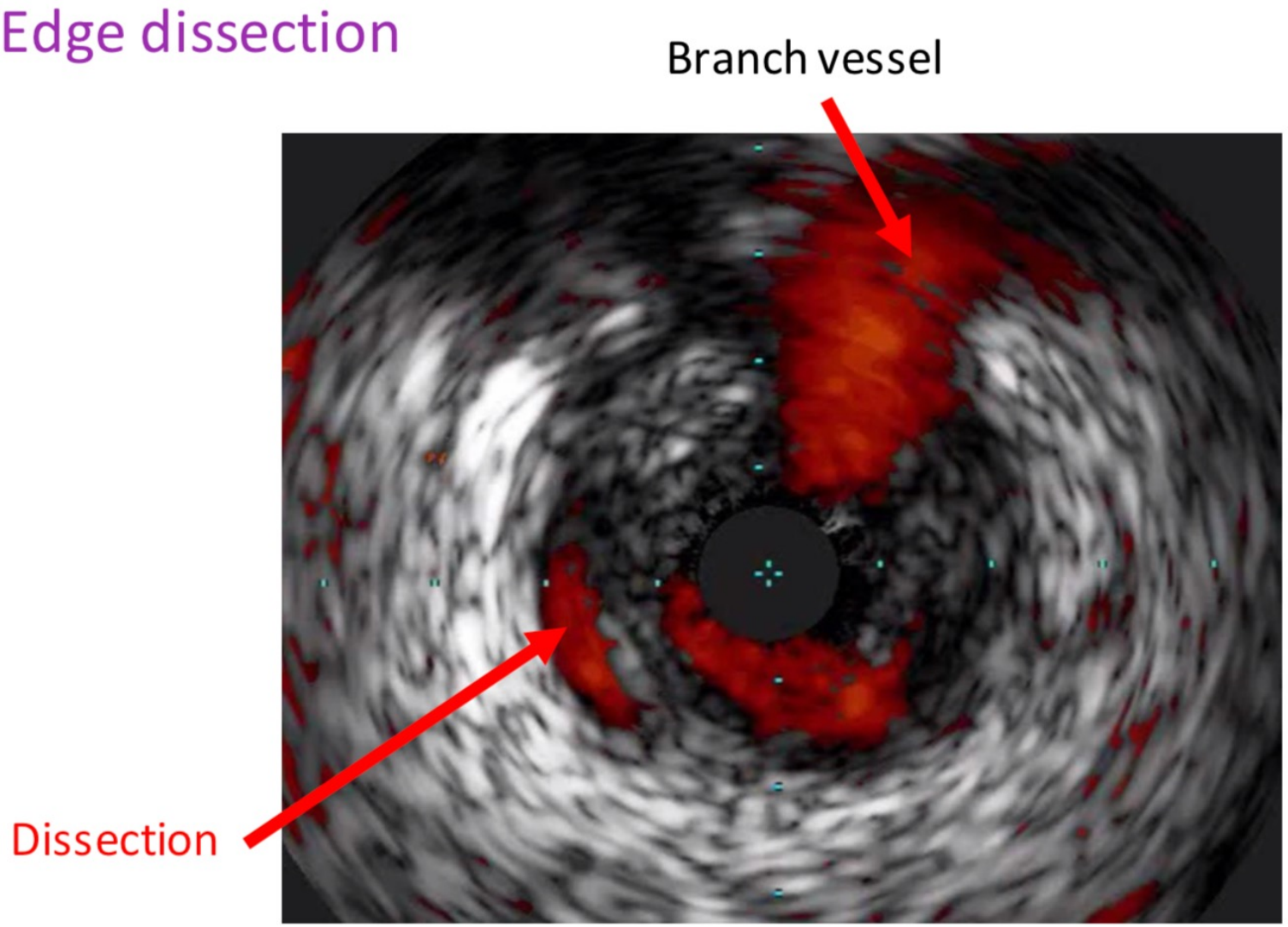


STLLR study : 66.5% of stents had "geographic miss," associated with 3 times the MI and 2 times the TVR.[1]

Stent optimization (STOP) study: IVUS guided deployment and high pressure post-dilation eventually achieved more frequent stent optimization (81%) compared to angiography guidance alone (21%).[2]

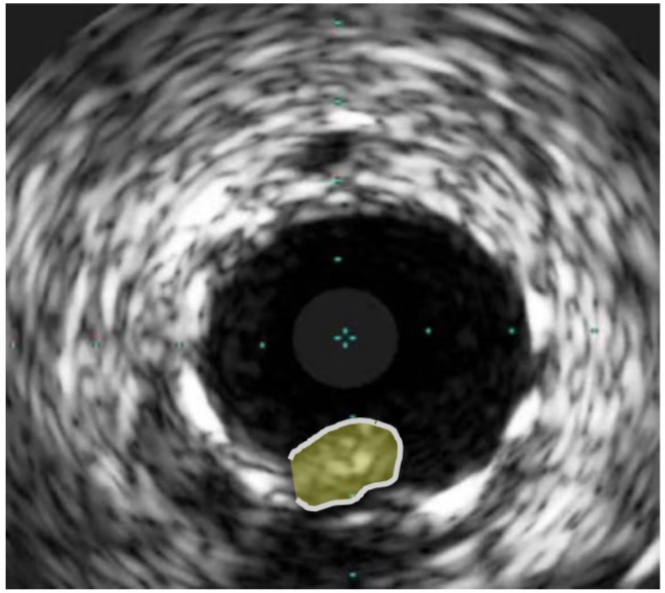
Cos ta et al. *Am J Cardiol.* 2008 Jun 15; 101(12):1704-11.
2. Rana O et al. *J Invasive Cardiol.* 2014;26(12):640-646.

Pathology



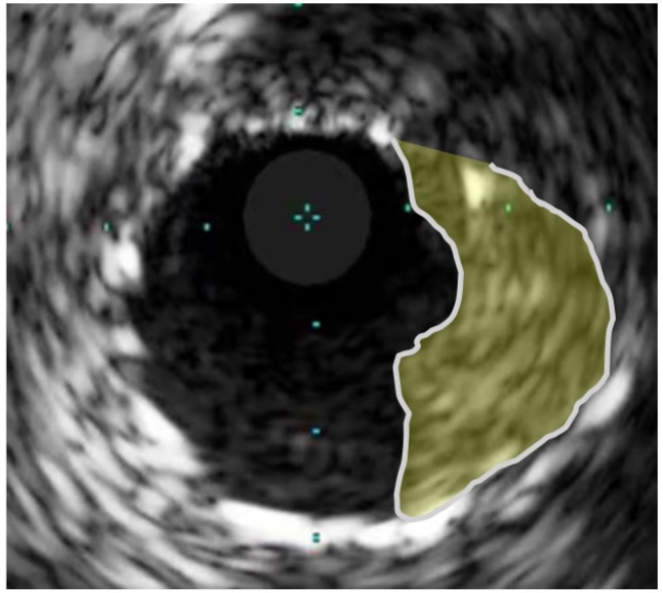
Pathology

Tissue Prolapse



- Frequently cannot be corrected
- Distinguish from thrombus
- Some papers associate with worse outcome

Thrombus



- Irregular edges
- Oscillation at periphery
- Low density
- Context important

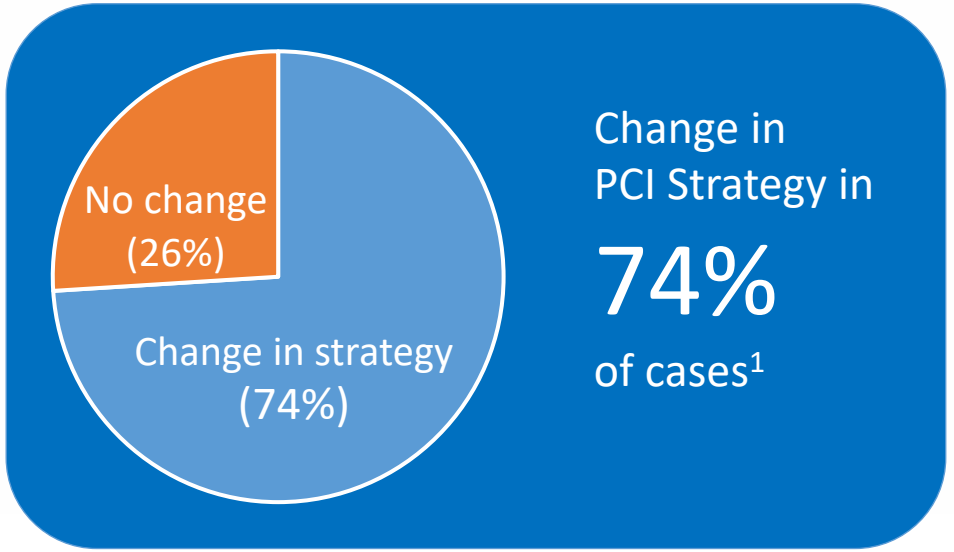
ADAPT-DES

(Assessment of Dual Antiplatelet Therapy with Drug-Eluting Stents)

Results from the Prospective, Multicenter ADAPT-DES[1] study

- **Largest study ever conducted with IVUS guidance**
- **Multi-center global registry with 8583 consecutive patients**
- **3349 patients had PCI with IVUS guidance**
- **64% Xience / Promus stents**

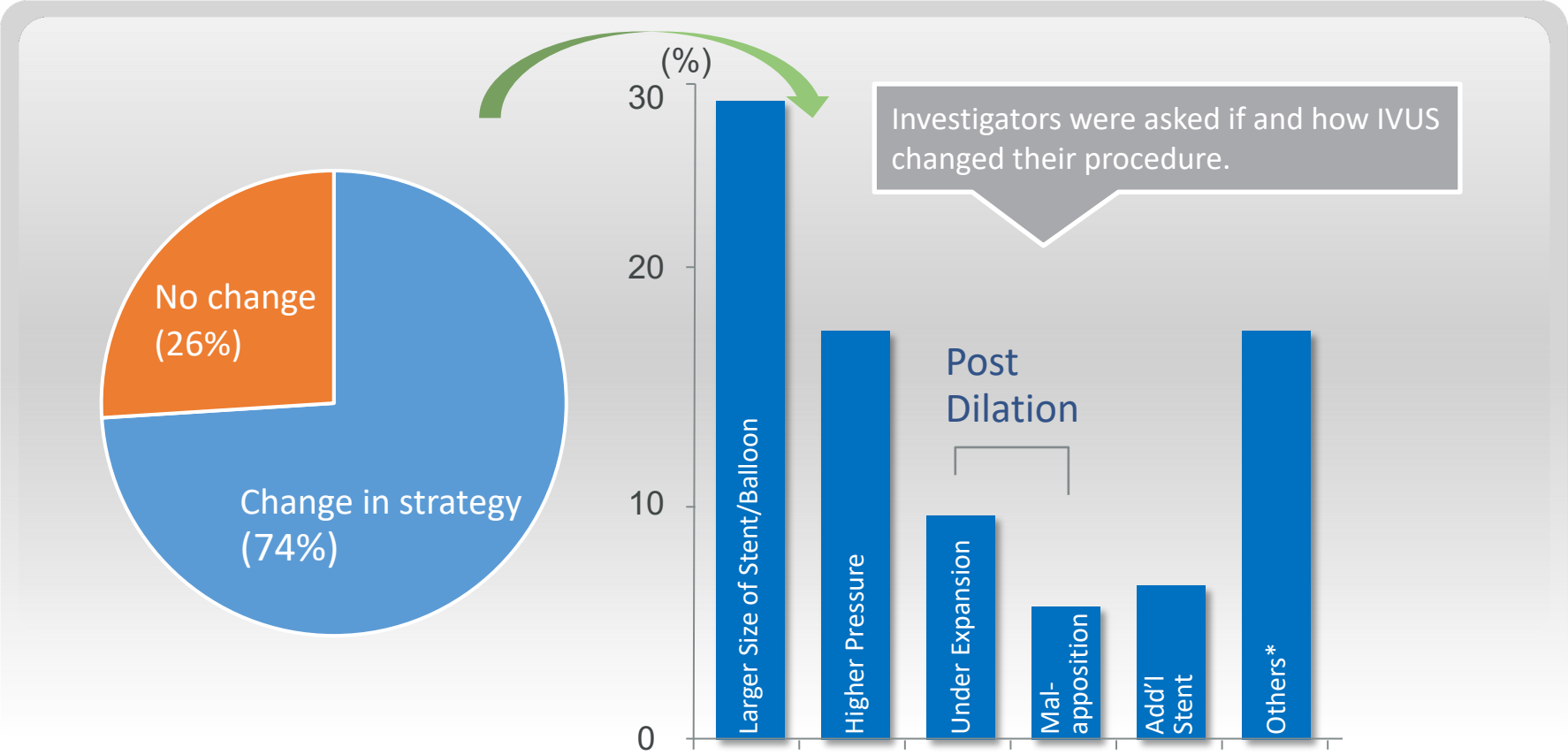
- **Study data reported IVUS guidance was associated with:**



1. Witzenbichler B et al. Relationship Between Intravascular Ultrasound Guidance and Clinical Outcomes After Drug-Eluting Stents: The ADAPT-DES Study. Circulation 2014 Jan: 129,4;463-470.

ADAPT-DES

How investigators reported IVUS changed their procedure



*"Others" category may include a combination of "Higher Pressure", "Under Expansion", "Malapposition", and "Additional Stent".

Witzenbichler B. ADAPT-DES: Two-Year Insights from the Largest IVUS Substudy. TCT 2013. Lecture conducted from San Francisco, CA. Graphics adapted from slide presentation.

ADAPT-DES

Study data reported IVUS guidance was associated with:

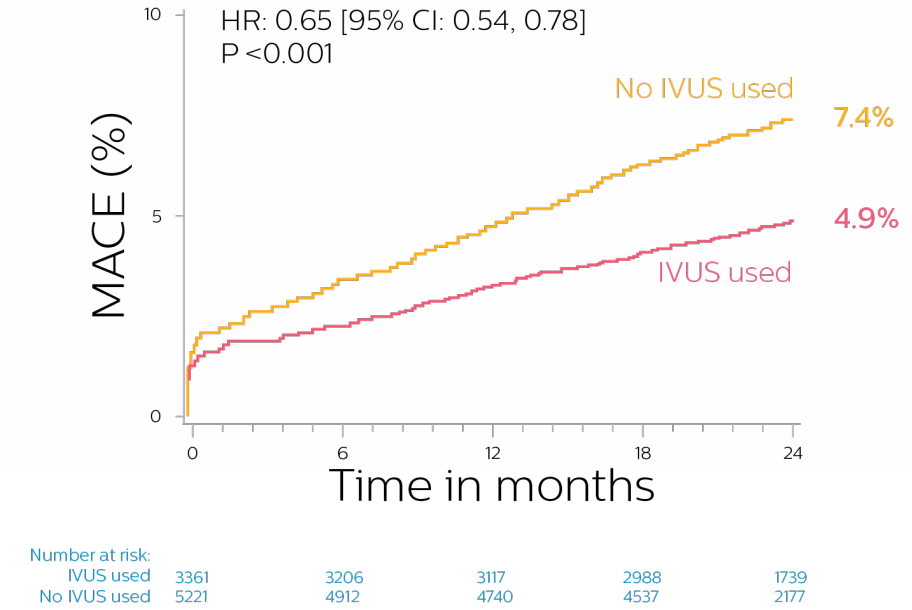
34%

Reduction in MACE at 2 yrs[1]

(4.9% vs. 7.4%, p<0.001)

Relationship between IVUS use and MACE

(Definite/probable ST, cardiac death, MI) within 2 years



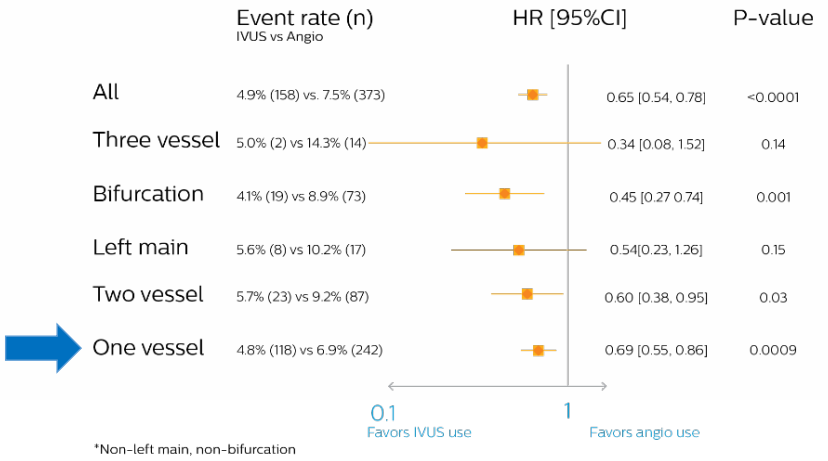
1. Witzenbichler B. ADAPT-DES: Two-Year Insights from the Largest IVUS Substudy. TCT 2013. Lecture conducted from San Francisco, CA

ADAPT-DES

Study data reported IVUS use benefited even the simplest cases (1 vessel, non-LM/bifurcation, stable CAD)[1]

Association of IVUS use and MACE

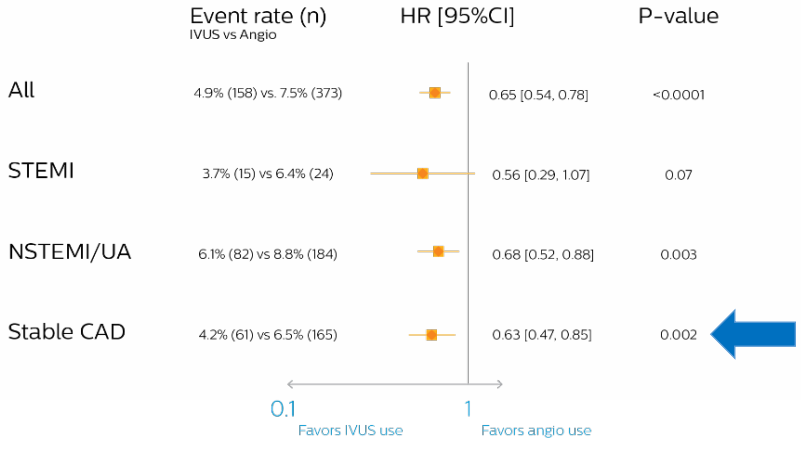
(Definite/probable ST, cardiac death, MI) in relation to lesion complexity



*Non-left main, non-bifurcation

Association of IVUS use and MACE

(Definite/probable ST, cardiac death, MI) in relation to index presentation



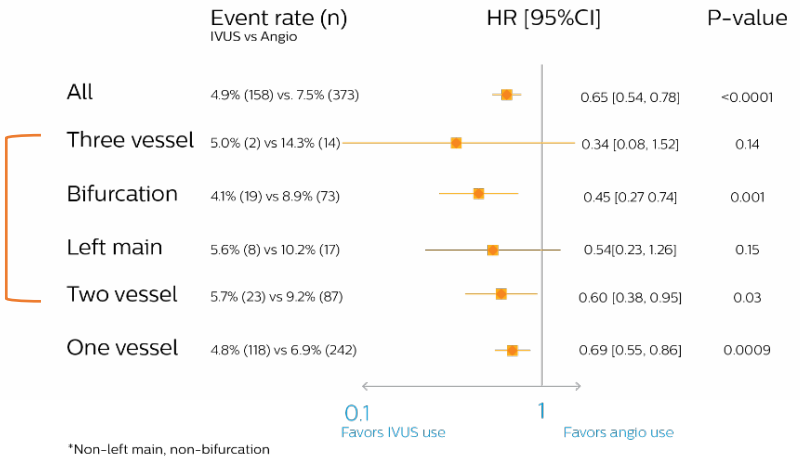
1. Witzenbichler B et al. Relationship Between Intravascular Ultrasound Guidance and Clinical Outcomes After Drug-Eluting Stents: The ADAPT-DES Study. Circulation 2014 Jan: 129,4;463-470.

ADAPT-DES

IVUS guidance may reduce the rates of ST and MI within 1 year of DES implantation, with the greatest benefits present in patients with ACS and complex target lesions.” [1]

Association of IVUS use and MACE

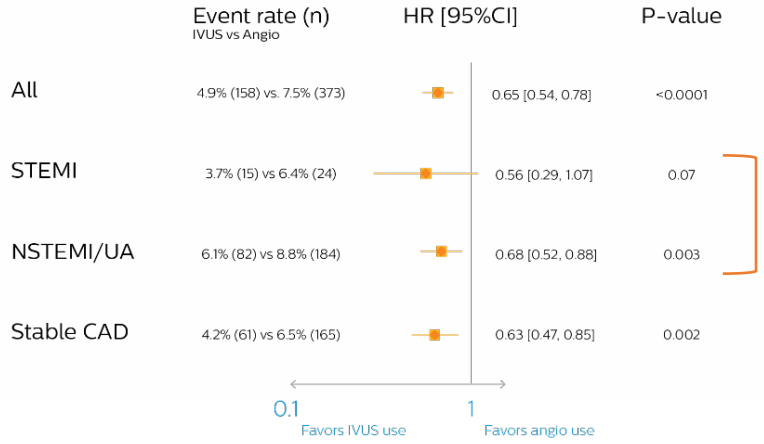
(Definite/probable ST, cardiac death, MI) in relation to lesion complexity



*Non-left main, non-bifurcation

Association of IVUS use and MACE

(Definite/probable ST, cardiac death, MI) in relation to index presentation



1. Witzenbichler B et al. Relationship Between Intravascular Ultrasound Guidance and Clinical Outcomes After Drug-Eluting Stents: The ADAPT-DES Study. Circulation 2014 Jan: 129,4;463-470.

IVUS Improves Outcomes

Ahn, et al. Metanalysis- 39 studies, 36000 pts

IVUS guidance is associated with reduced MACE, MI, ST and death.[1,2,3,4,5,6]

Author	Ahn JM	Elgendy IY	Klersey C	Zhang YJ	Jang JS	Total*
IVUS patients	12,499	1,593	9,965	8,102	11,793	15,469
DES patients	26,503	3,192	18,707	19,619	24,849	36,831

1. Ahn JM, Kang SJ, Yoon SH, et al. "Meta-Analysis of Outcomes After Intravascular Ultrasound - Guided Versus Angiography-Guided Drug-Eluting Stent Implantation in 26,503 Patients Enrolled in Three Randomized Trials and 14 Observational Studies" Am J Cardiol. 2014;113:1338-1347.
2. Elgendy IY et al. Outomes with Intravascular Ultrasound-Guided Stent Implantation: A Meta-Analysis of Randomized Trials in the Era of Drug-Eluting Stents. Circ Cardiovasc Interv. 2016;9:e003700
3. Jang JS, et al. Intravascular Ultrasound-Guided Implantation of Drug-Eluting Stents to Improve Outcome, A Meta-Analysis. J Am Coll Cardiol Intv. 2014;7(3):233-243
4. Zhang YJ, et al. Comparison of intravascular ultrasound versus angiography-guided drug-eluting stent implantation: a meta-analysis of one randomized trial and ten observational studies involving 19,619 patients. EuroIntervention. 2013;9:891-892
5. Klersey C, et al. Use of IVUS guided coronary stenting with drug eluting stent: A systematic review and meta-analysis of randomized controlled clinical trials and high quality observational studies. Int J Cardiol. 2013 Dec 5;170(1):54-63.
6. Mintz GS. Intravascular ultrasound and outcomes after drug-eluting stent implantation. Coronary Artery Dis. 2017 Jun; 28(4):346-352
* All the numbers of patients participated in the studies are deduplication.

SCAI Expert Consensus Statement on IVUS in PCI Guidance:

Definitely beneficial:

- IVUS is an accurate method to determine complete stent expansion and apposition and lack of edge dissection or other complications after implantation, and the size of the vessel undergoing stent implantation.

Probably beneficial:

- IVUS can be used to appraise the significance of LMCA stenosis and, employing a cutoff MLA >6 mm2, to assess whether revascularization is warranted. It is recommended when downstream severe stenosis are present.

Possibly beneficial:

- IVUS imaging may be used to characterize plaque morphology (i.e., calcification), which may alter the PCI technique chosen
- IVUS has been shown in meta-analyses to decrease major adverse events in PCI
- In long lesion/long stents, IVUS guided PCI is associated with significantly reduced MACE

No proven value/should be discouraged

- IVUS measurements for determination of non-LMCA lesion severity should not be performed to determine stenosis significance.

Lotfi A, et al. Focused update of expert consensus statement: Use of invasive assessments of coronary physiology and structure: A position statement of the society of cardiac angiography and interventions. Catheter Cardiovasc Interv. 2018;92:336-347.

Guidelines

ESC/EACTS 2018 guidelines[1] (actual wording)	Class	Level of evidence
IVUS should be considered to assess the severity of unprotected left main lesions	IIa	B
IVUS should be considered to optimize treatment of unprotected left main lesions	IIa	B
IVUS or OCT should be considered in selected patients to optimize stent implantation	IIa	B
IVUS and/or OCT should be considered to detect stent- related mechanical problems leading to restenosis	IIa	C
IVUS or OCT to assess mechanisms of stent failure	IIa	C

ACC/AHA/SCAI 2011 guidelines[2] use IVUS:	Class	Level of evidence
For the assessment of angiographically indeterminate left main CAD	IIa	B
4 to 6 weeks and 1 year after cardiac transplantation to exclude donor CAD, detect rapidly progressive cardiac allograft vasculopathy, and provide prognostic information	IIa	B
To determine the mechanism of stent restenosis	IIa	C
For the assessment of non-left main coronary arteries with angiographically intermediate coronary stenoses (50% to 70% diameter stenosis)	IIb	B
For guidance of coronary stent implantation, particularly in cases of left main coronary artery stenting	IIb	B

. Neumann et al. 2018 ESC/EACTS Guidelineson myocardial revascularization. *Euro Intervention.* 2019;14:1435-1534.
. Levine G et al, 2011 ACCF/AHA/SCAI Guideline for Percutaneous Coronary Intervention.

PLAN

Example Questions:

Severe ISR:

- What is the mode of failure? Underexpansion?
- Is the plaque fibrotic, calcific, thrombotic? Do I need laser?

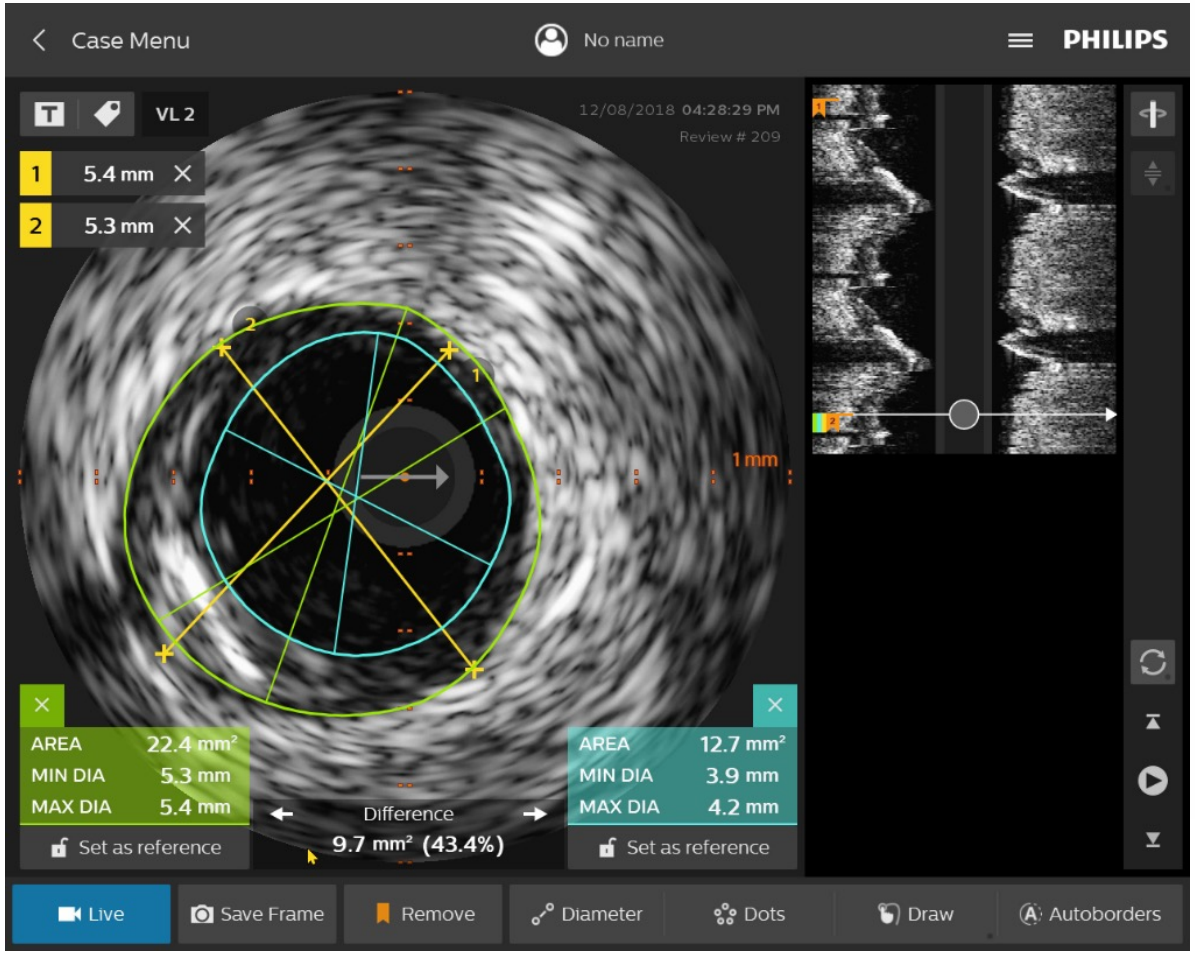
Native Plaque:

- Morphology?
- Is there 3-4 quadrant calcium? Will my stents expand without vessel prep?
- Where is the plaque burden? Where can I land my stents where plaque is <50%?

What is the true vessel size?

Left Main: Is the left main significant (MLA < 5-6 mm^2)?

Bifurcations: Can I get away with provisional? SB involved?



ARCH ELITE FELLOWS PROGRAM

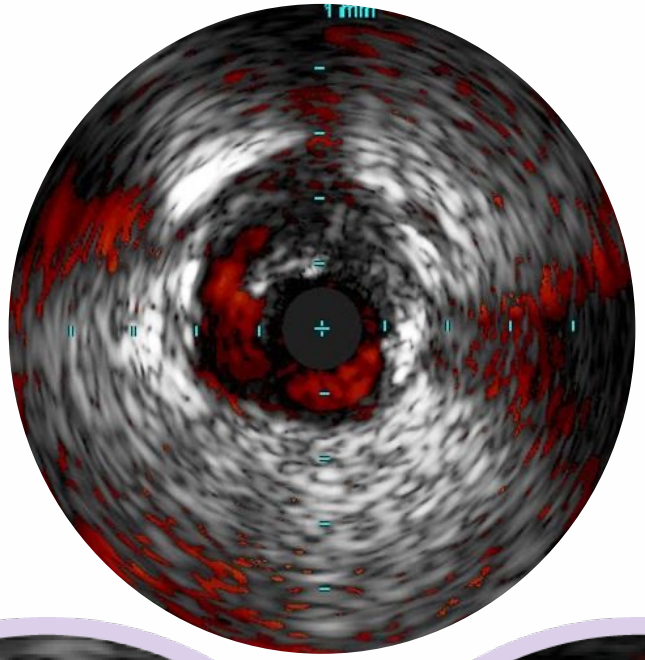
LAND

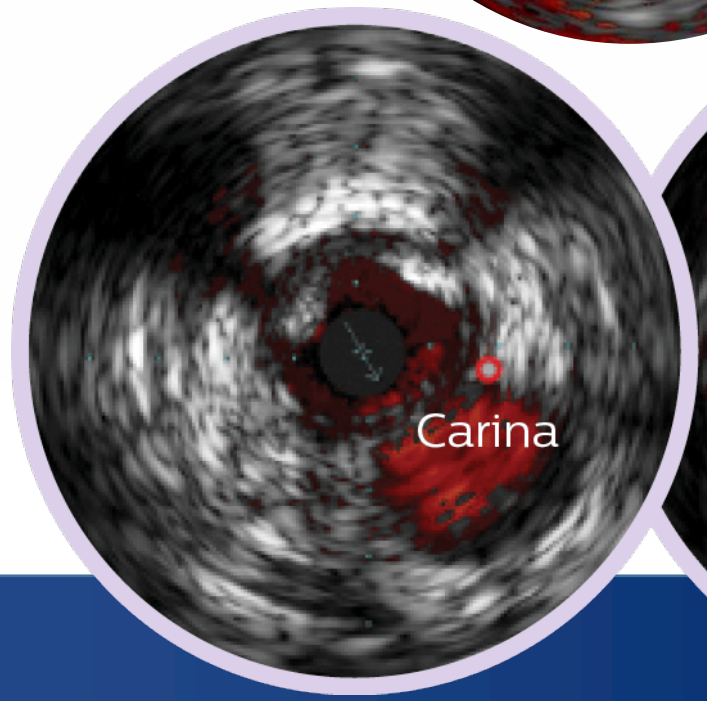
Example Questions:

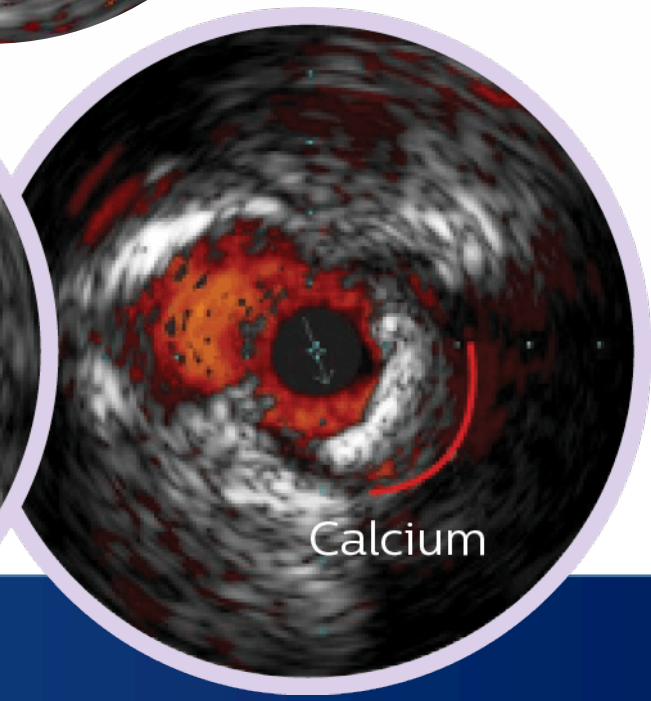
Where is the ostium?

Where can I land where there is less than 50% plaque?

Did I cause a dissection outside of my treatment zone (atherectomy/cutting balloons)?





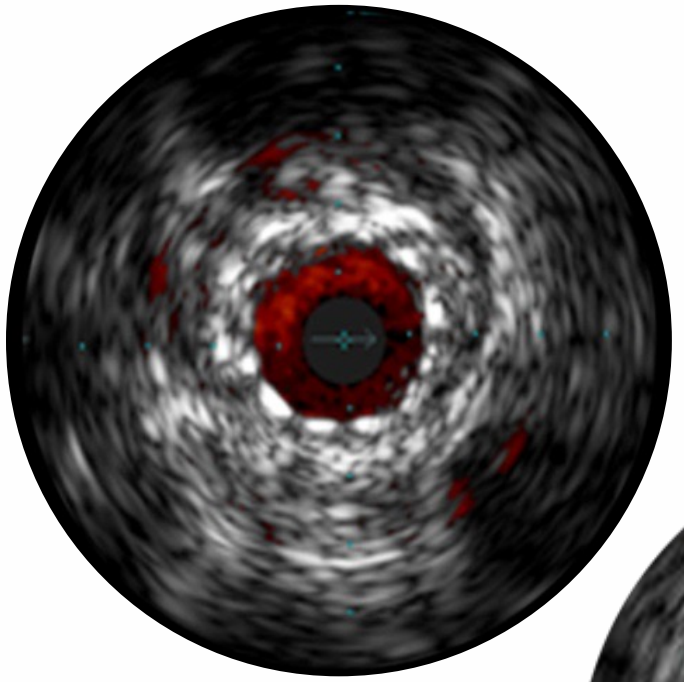


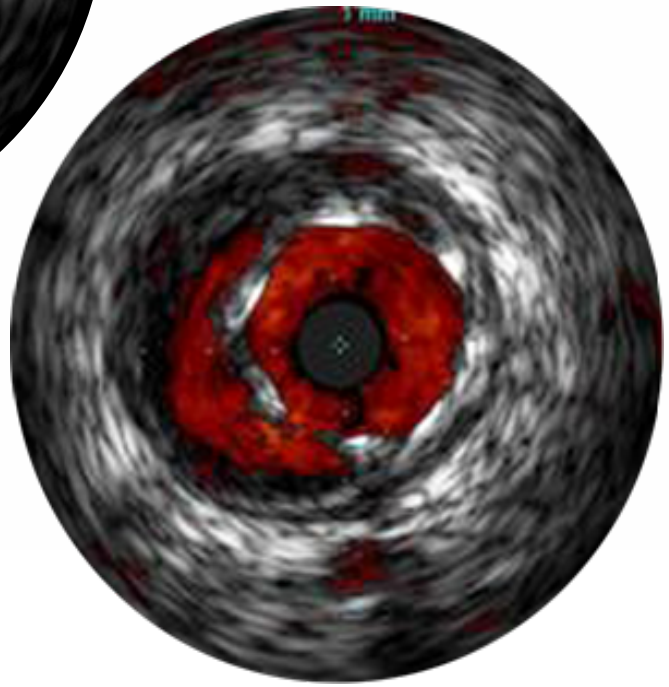
EXPAND

Example Questions:

Do I have an edge dissection?
Is there plaque prolapse?
Is my stent adequately apposed/expanded?
Is there plaque shift compromising my SB?

Am I done?

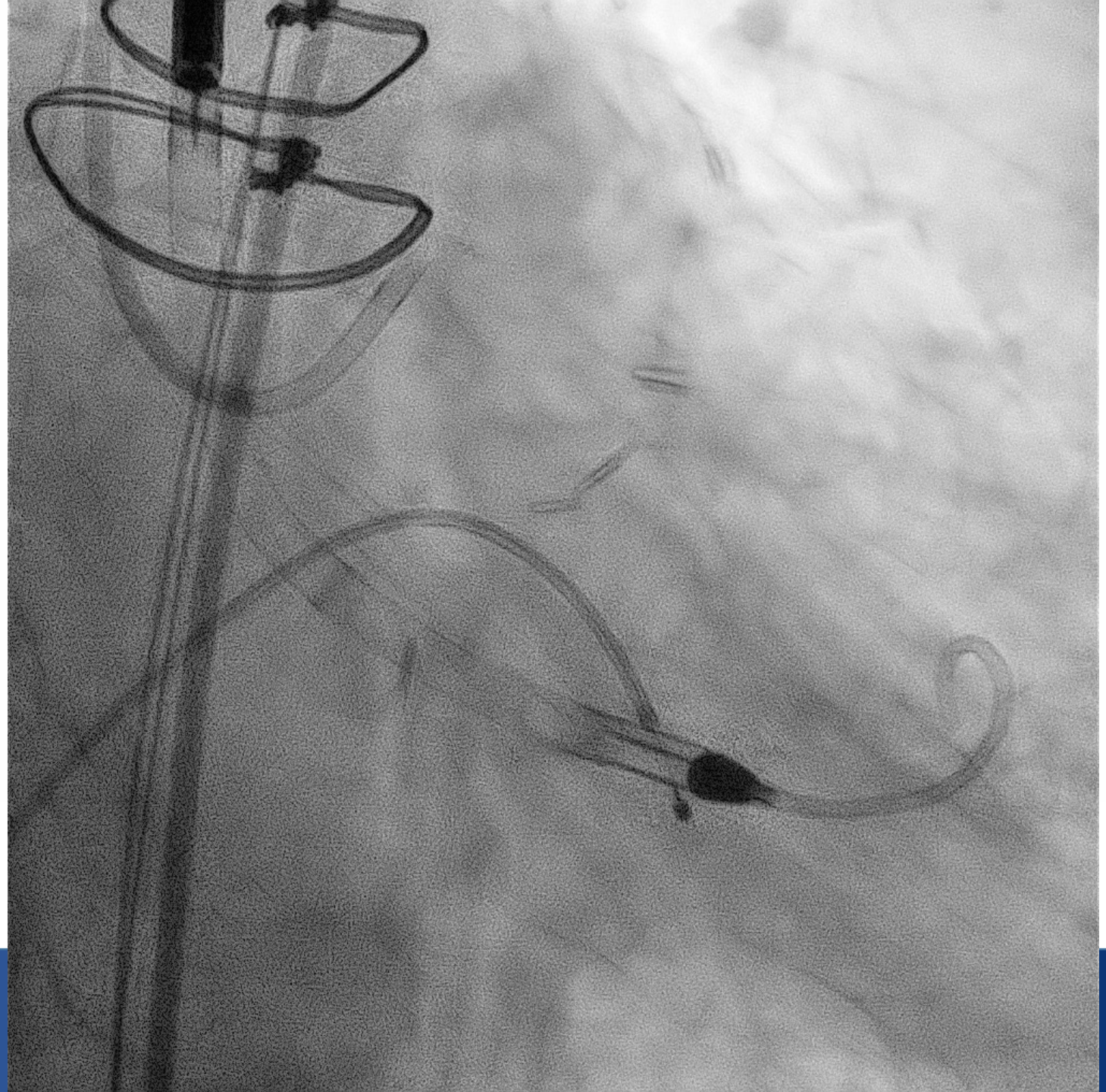




CASE #1

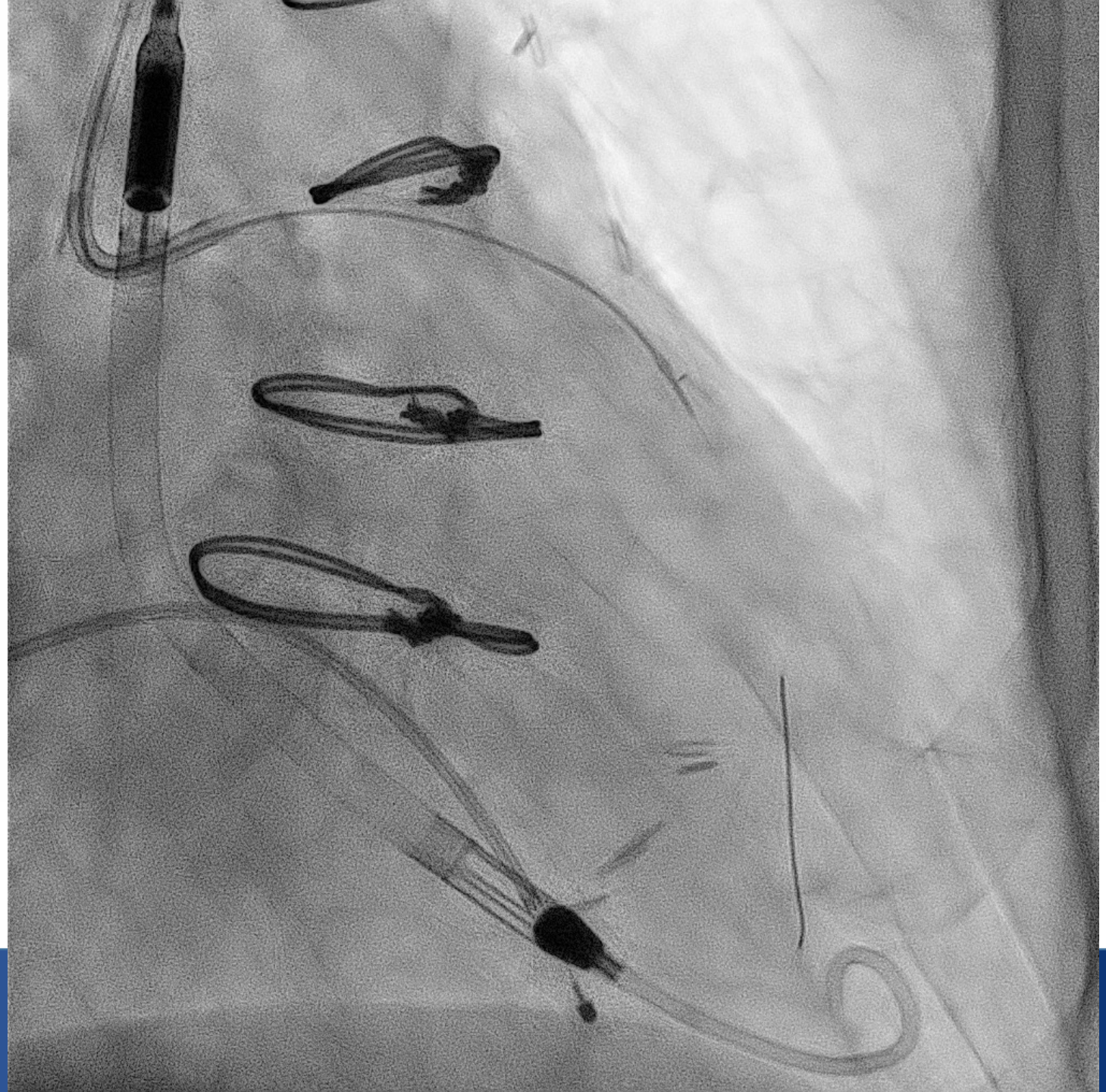
- 73 year old man with NSTEMI/3VCAD
  - HTN
  - Dyslipidemia
  - DM
  - Smoker
  - COPD
  - LV Dysfunction EF 30-35%
  - CABG Turndown

CASE #1



ARCH
ELITE FELLOWS PROGRAM

CASE #1



ARCH
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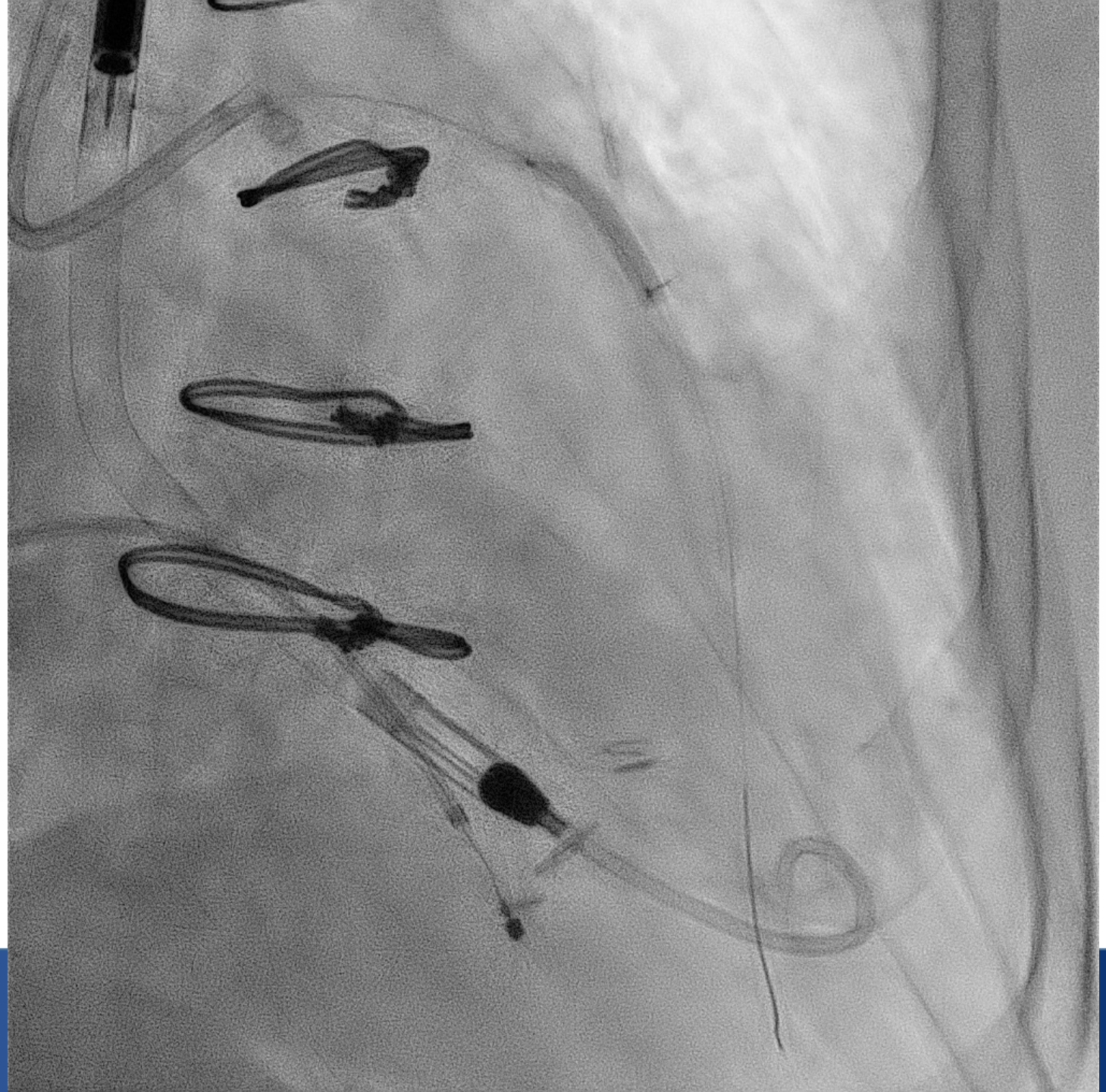

ARCH
ELITE FELLOWS PROGRAM

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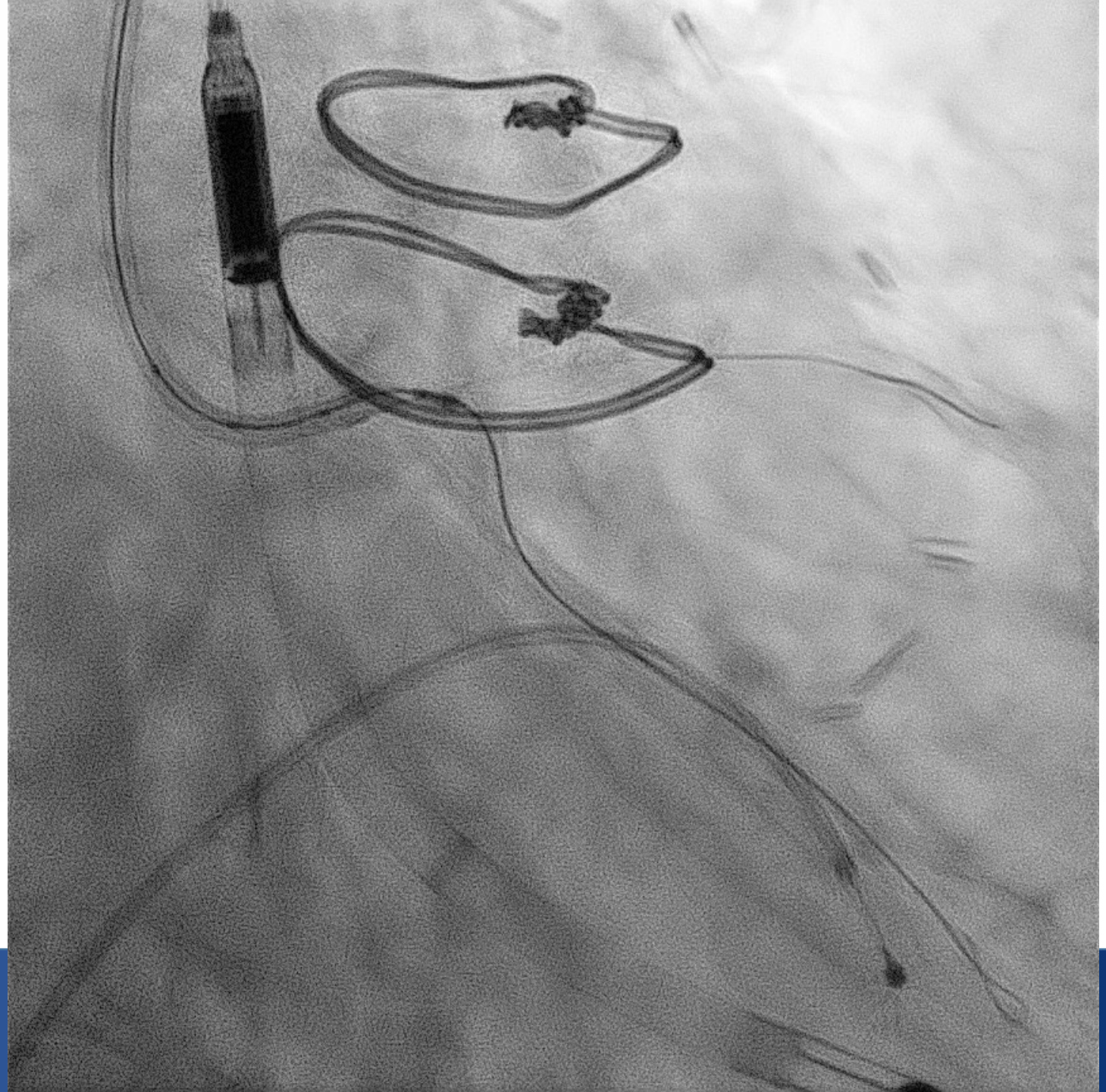

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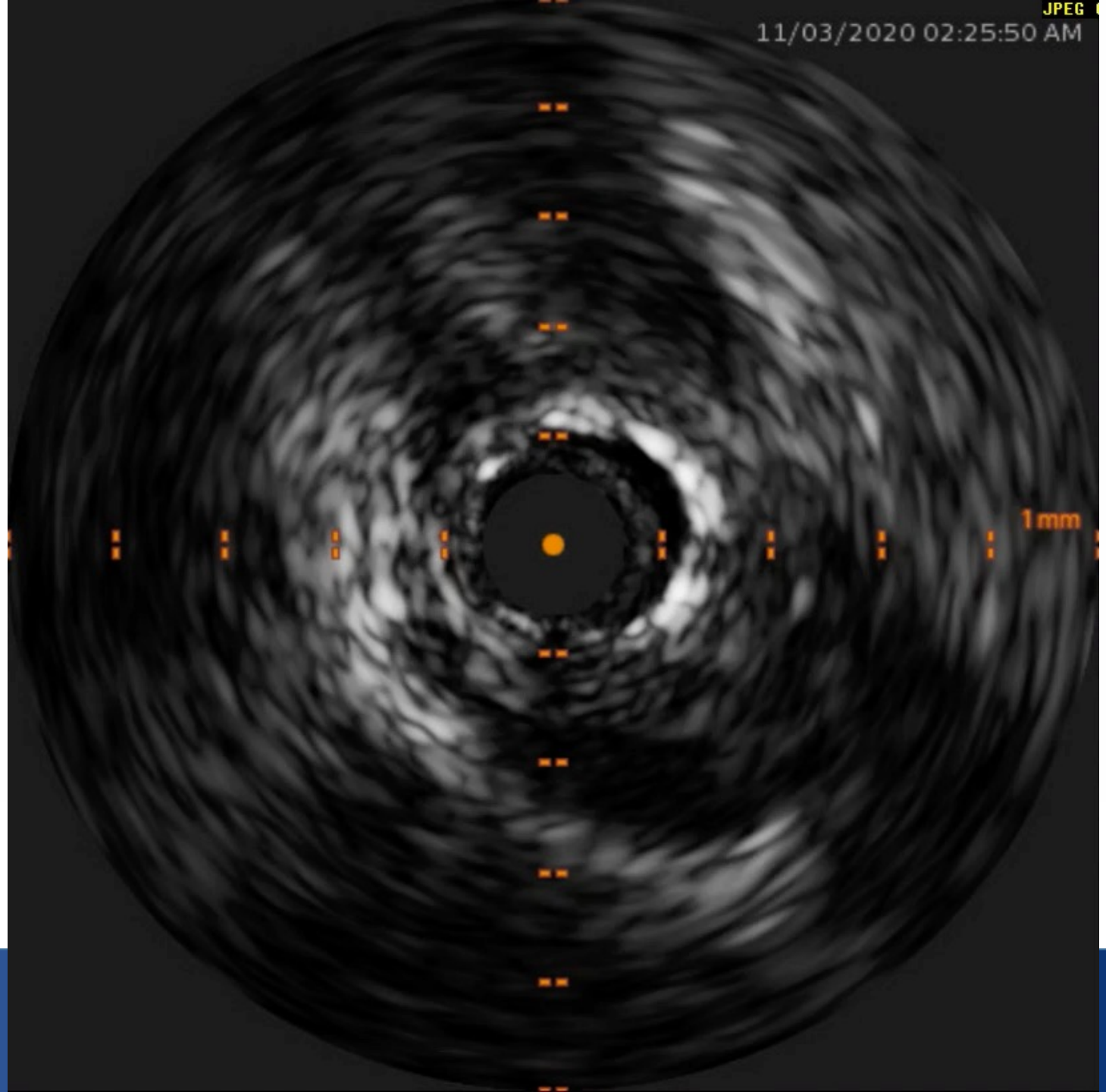

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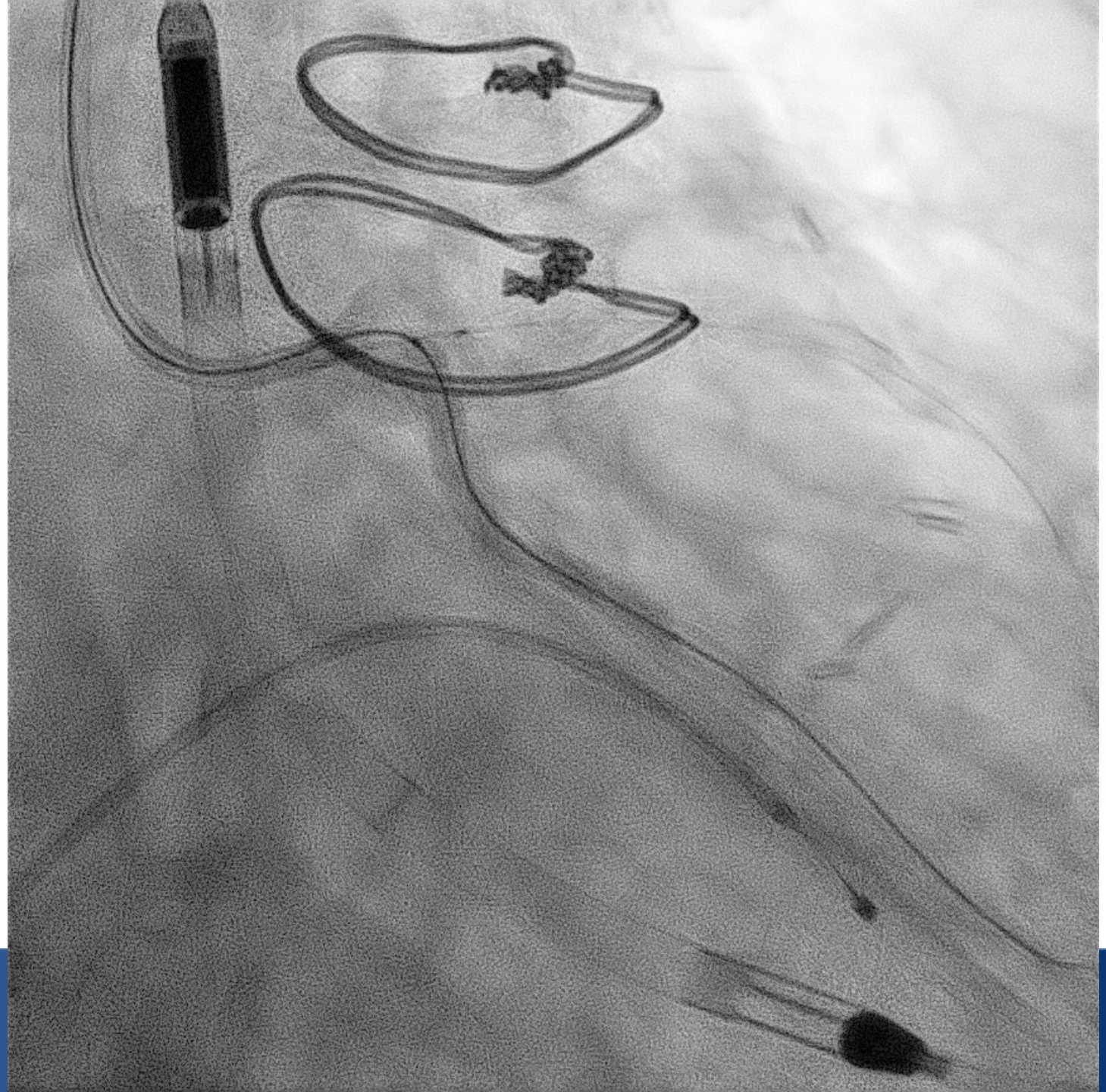

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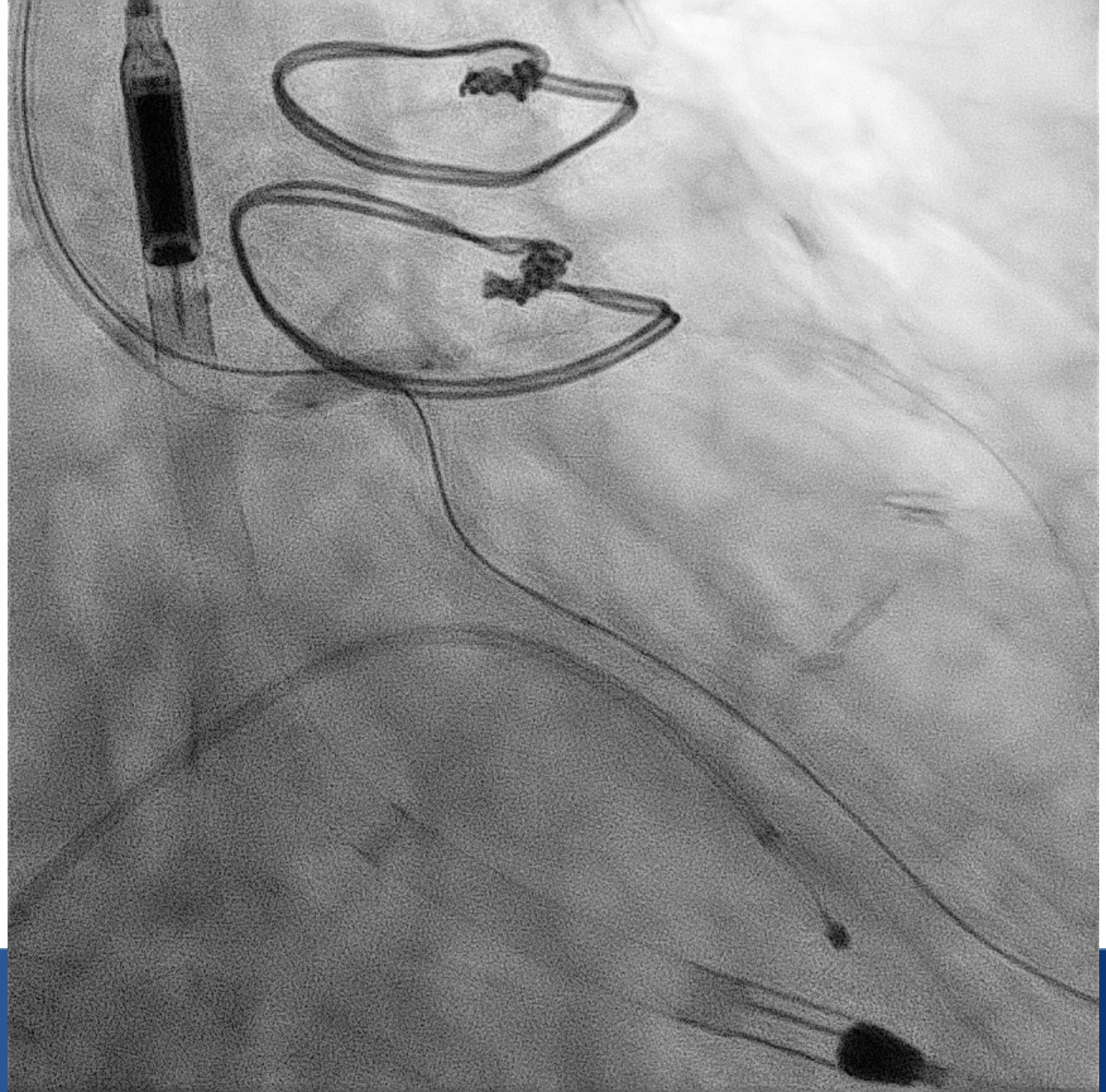

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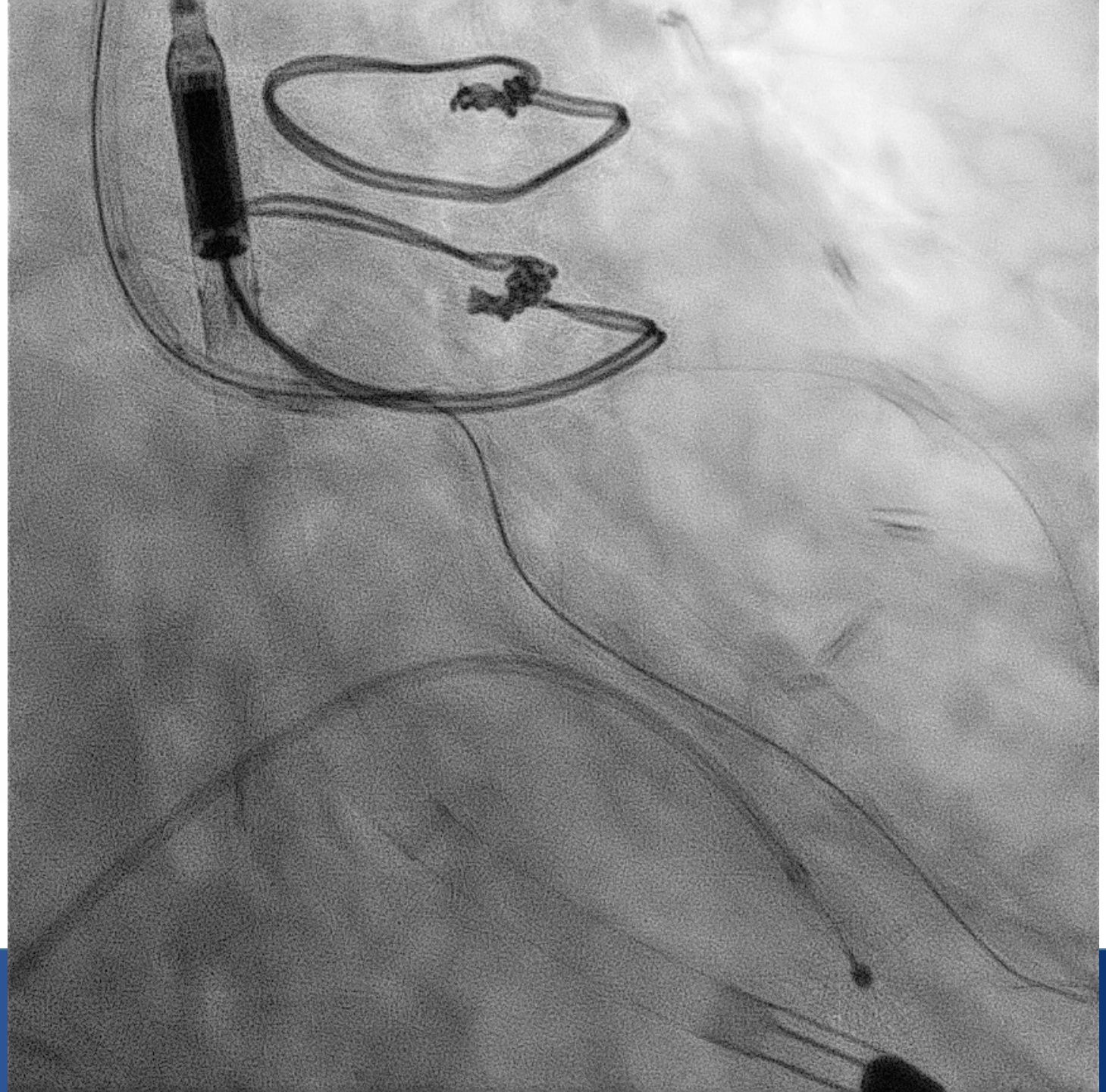

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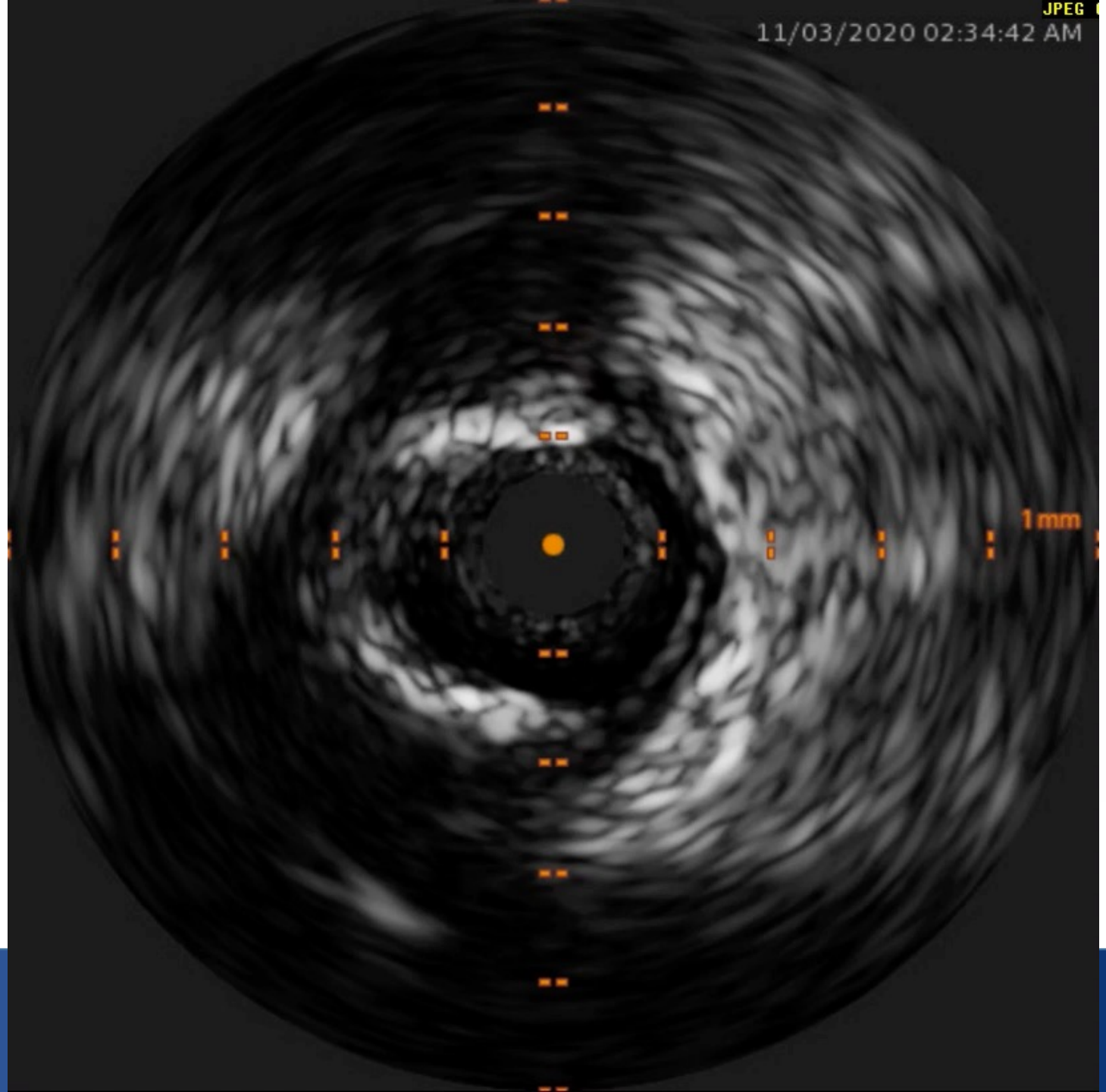

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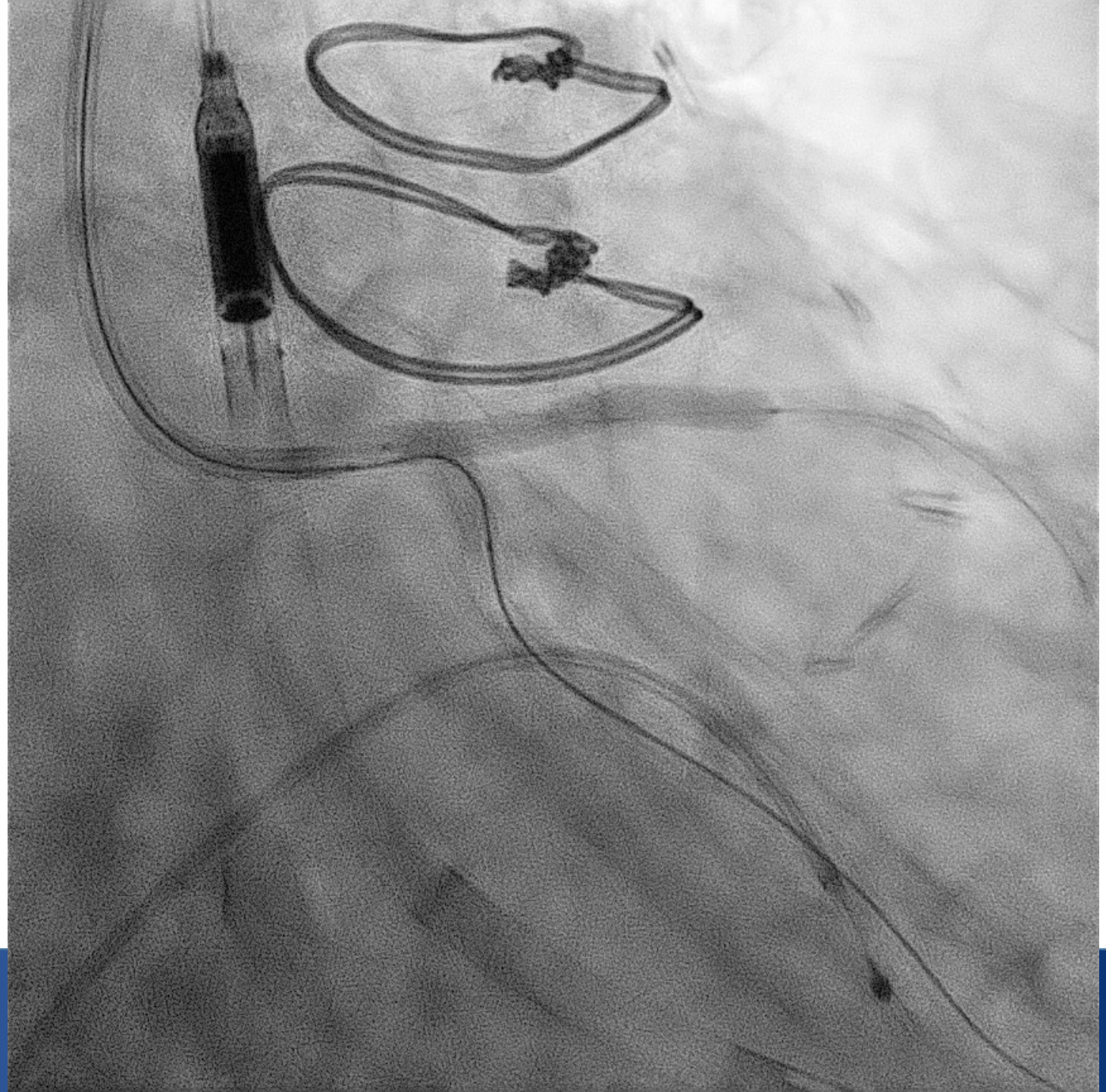

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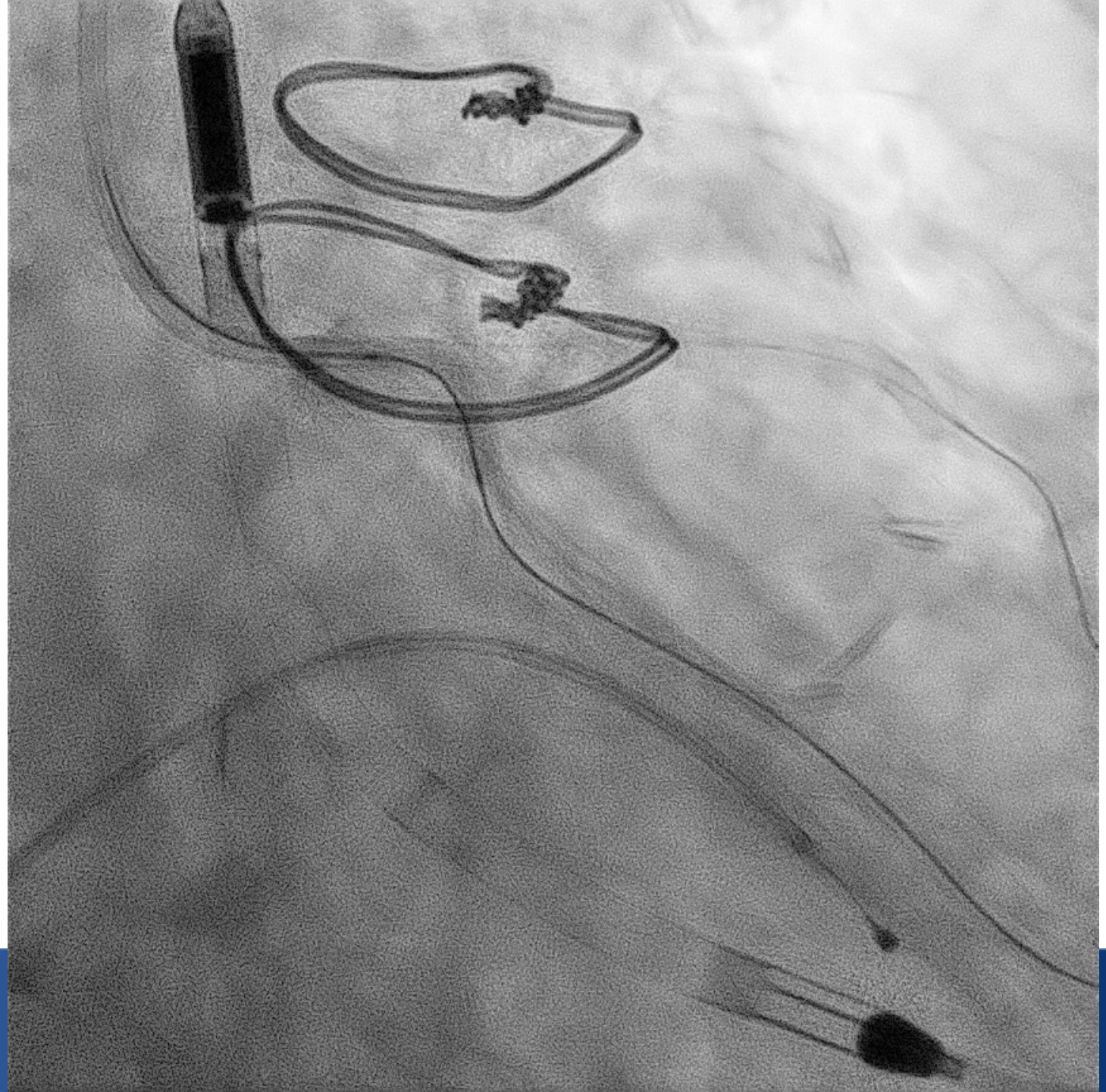

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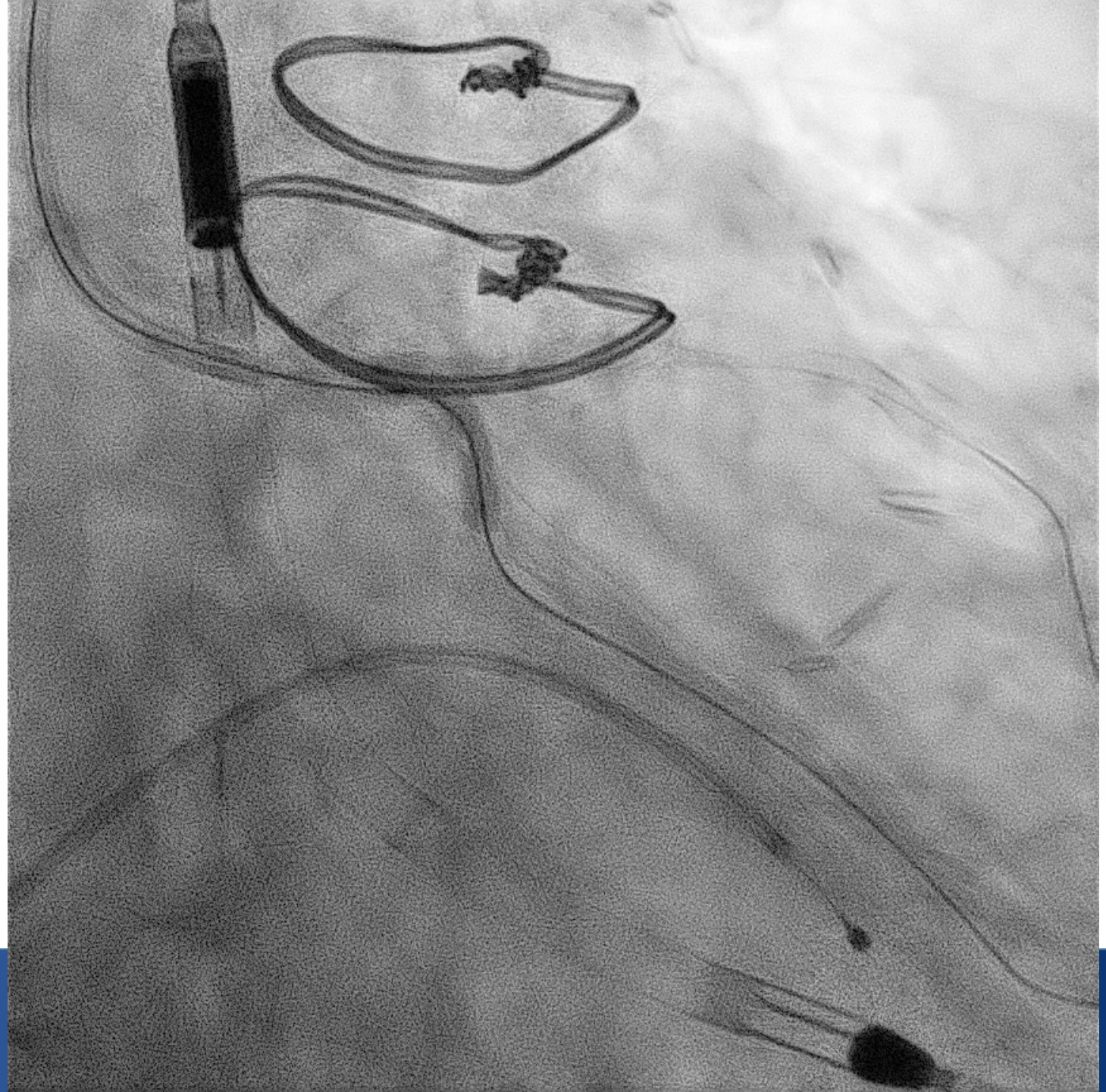

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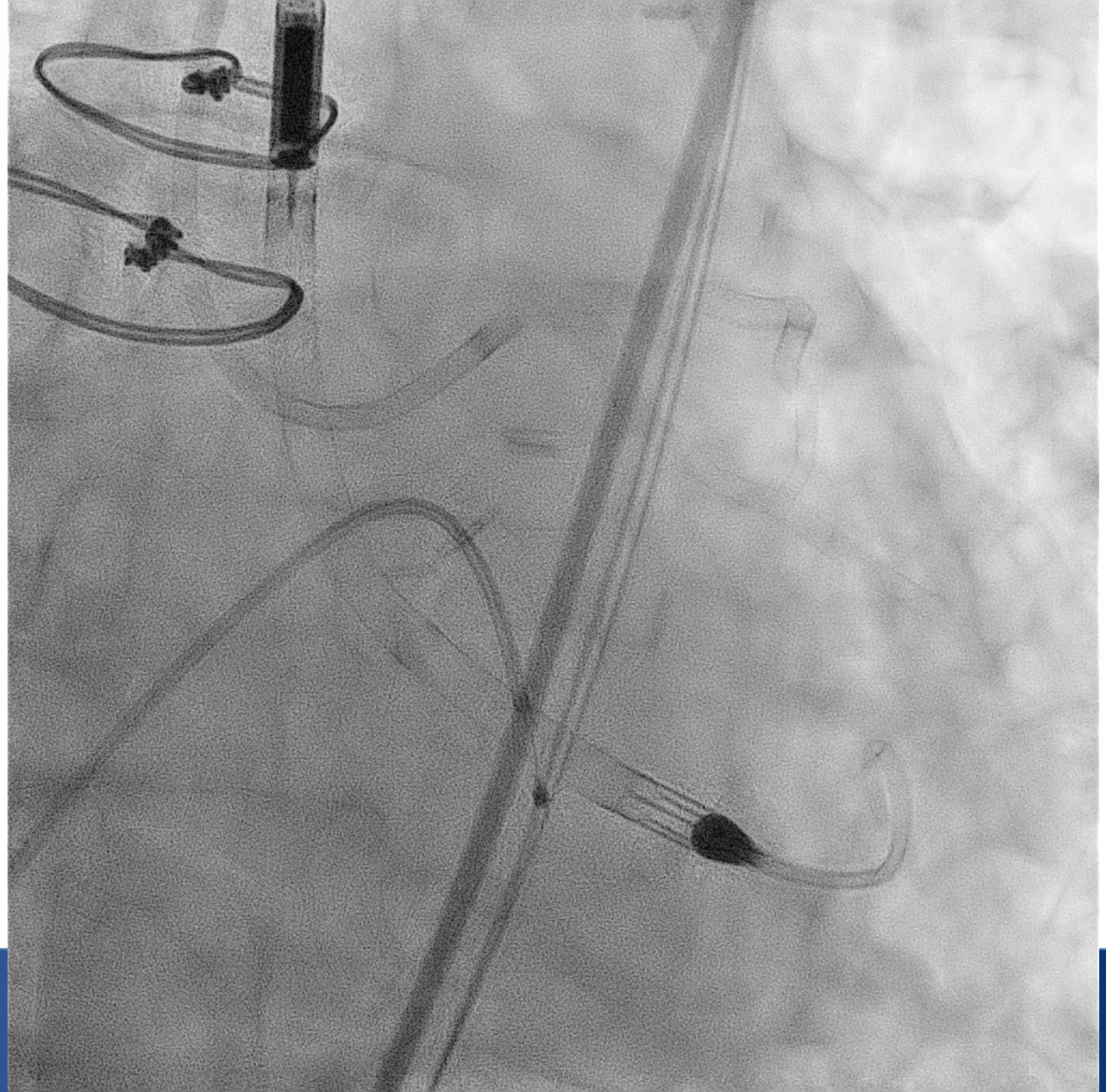
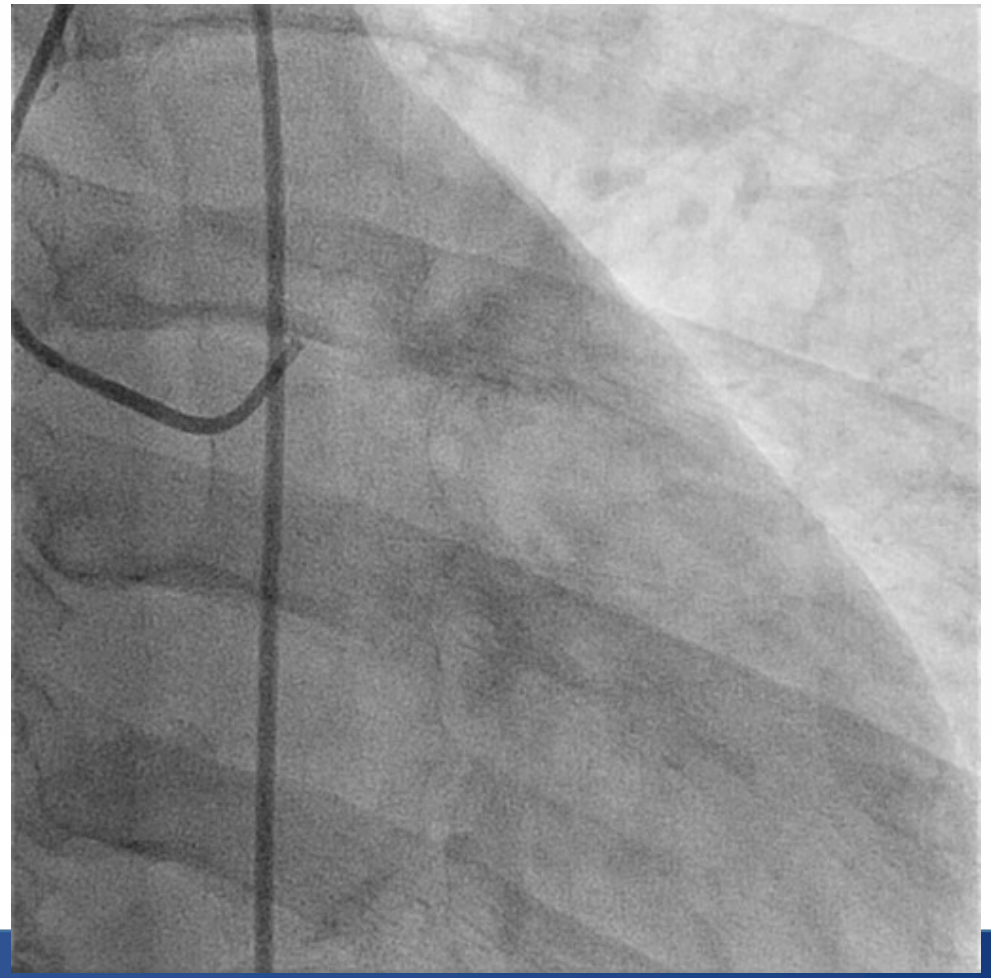


ARCH
ELITE FELLOWS PROGRAM

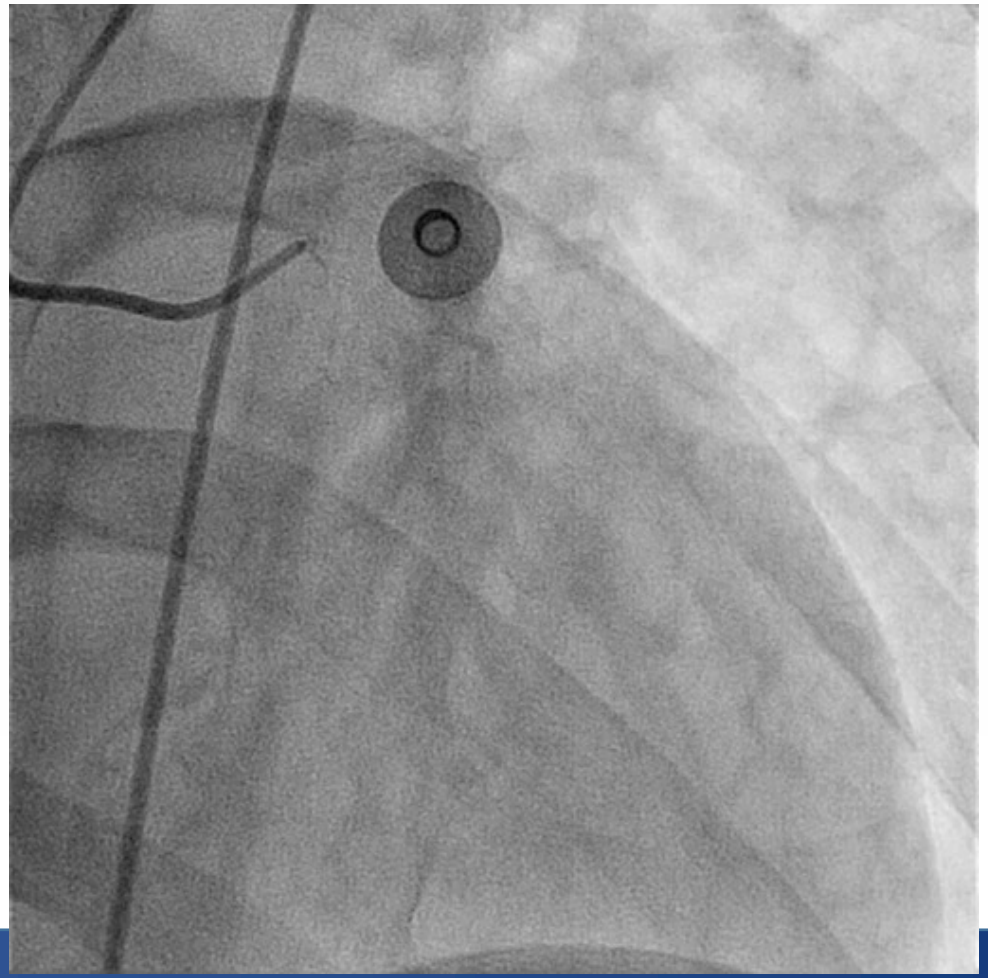
CASE #2

- 72 year old man
  - Presenting with NSTEMI
  - Ongoing chest pain
  - HTN and Dyslipidemia

CASE #2



CASE #2



CASE #2

CASE #2

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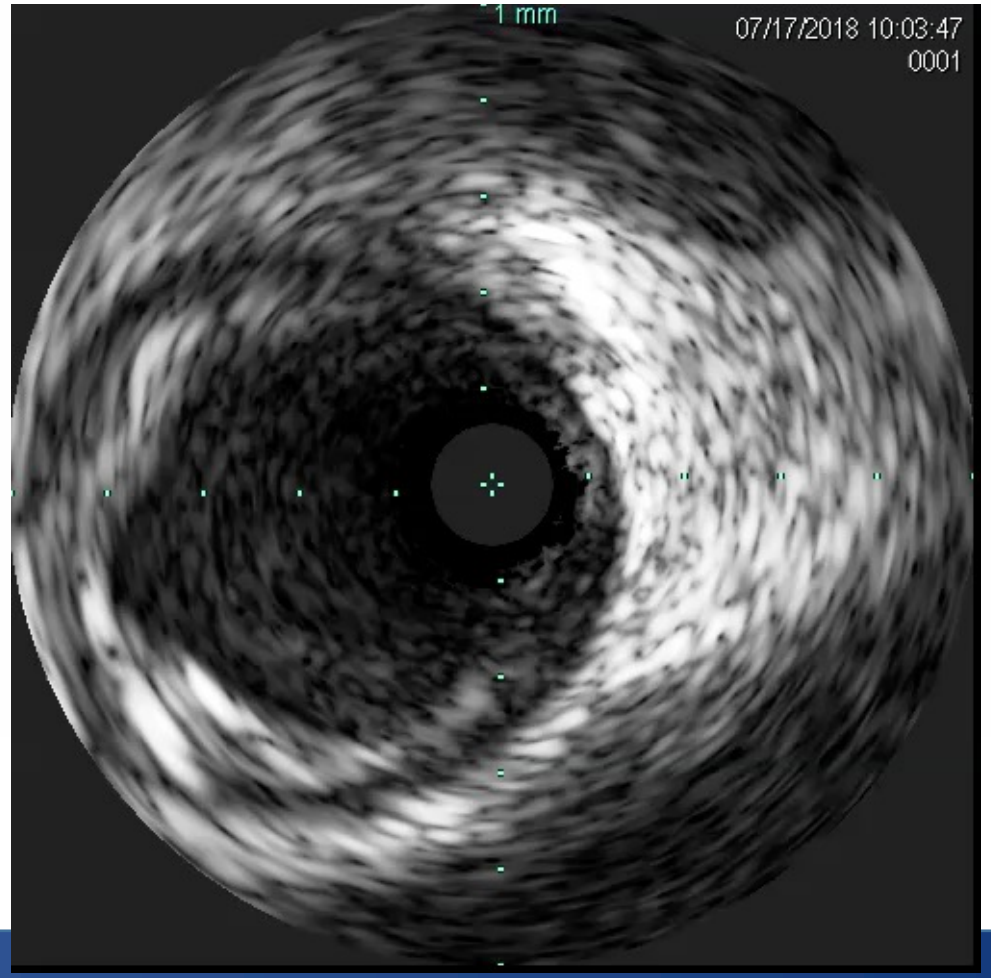
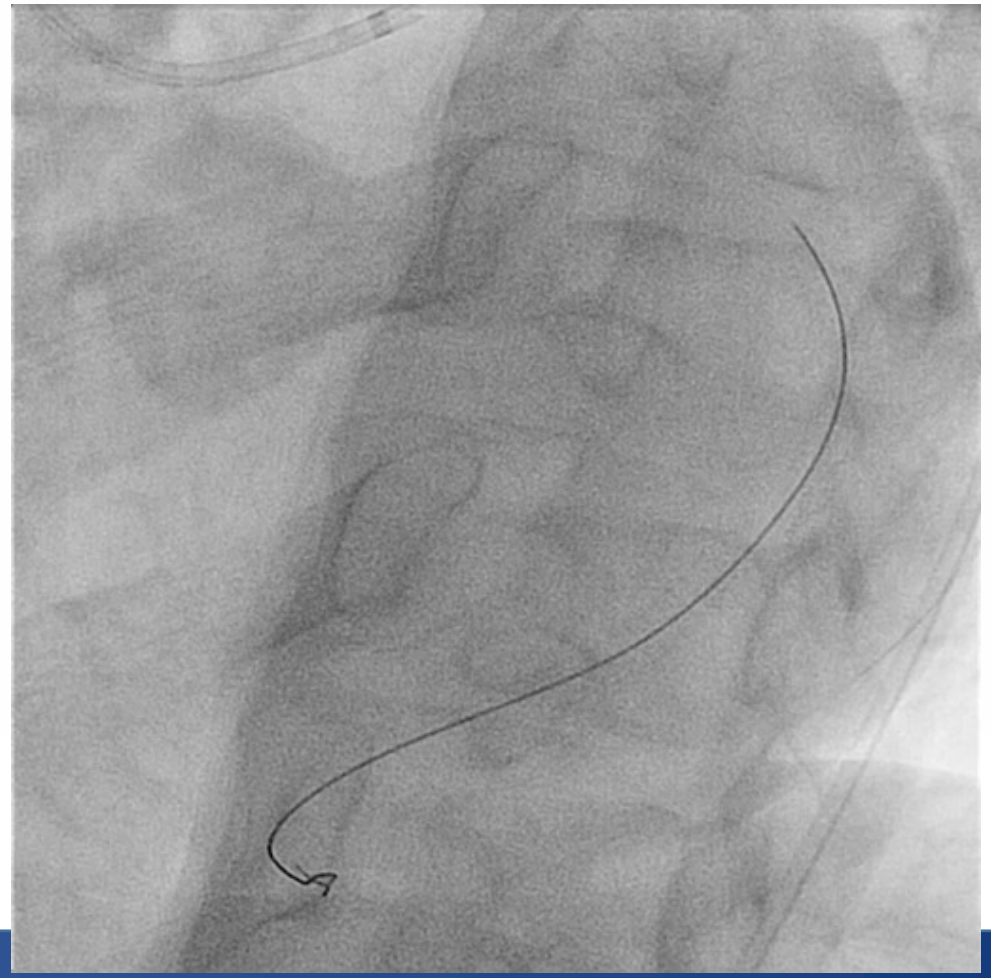


CASE #2

CASE #2



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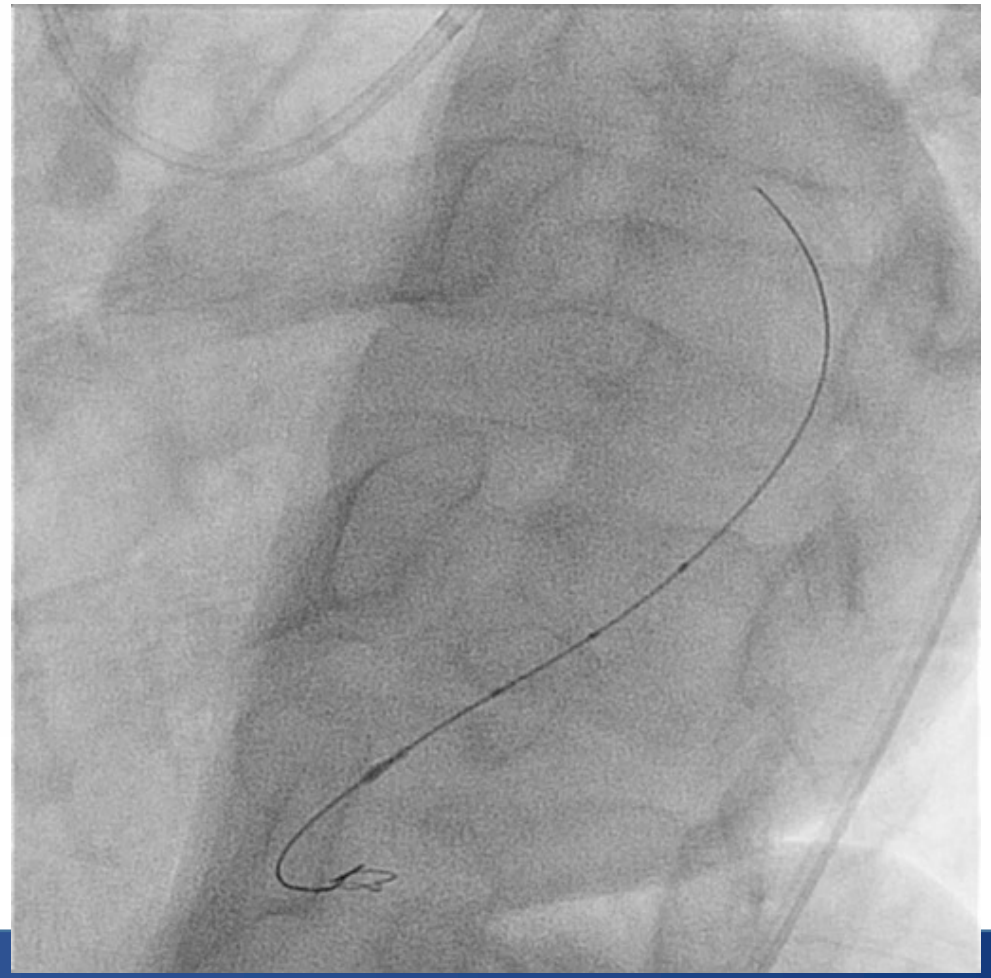

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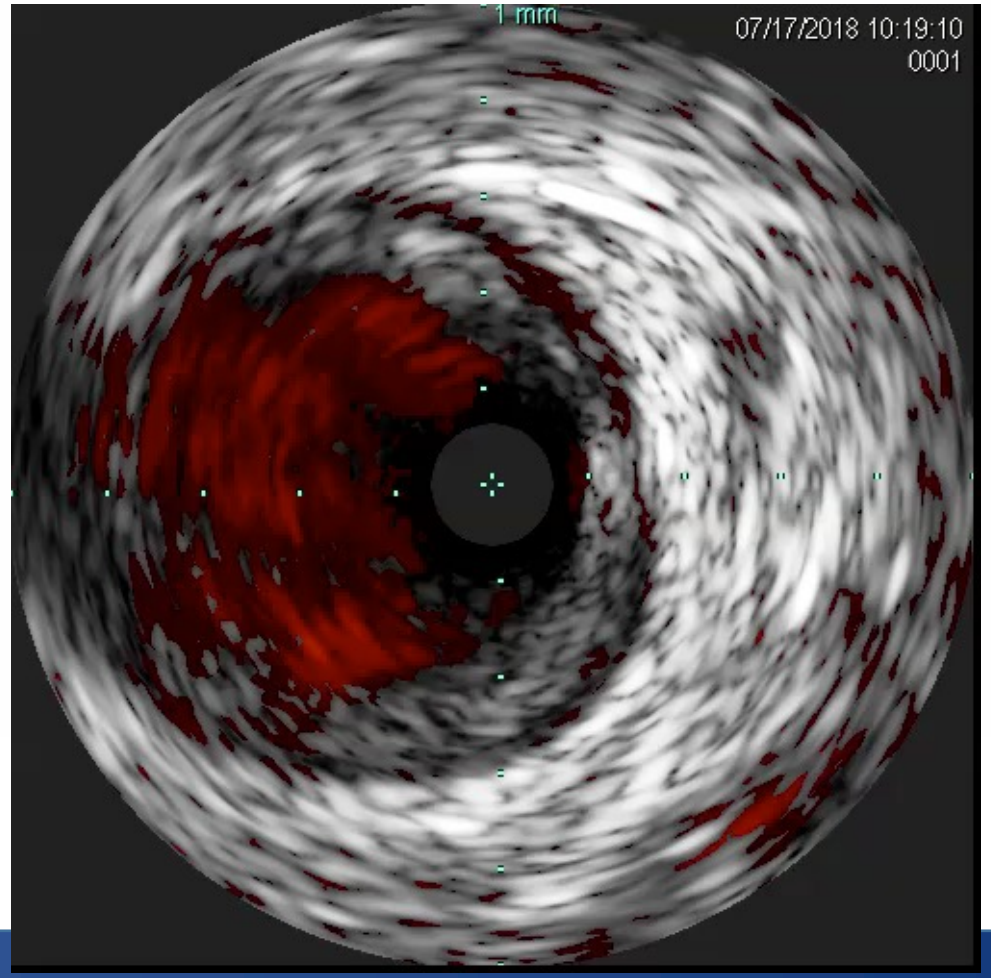

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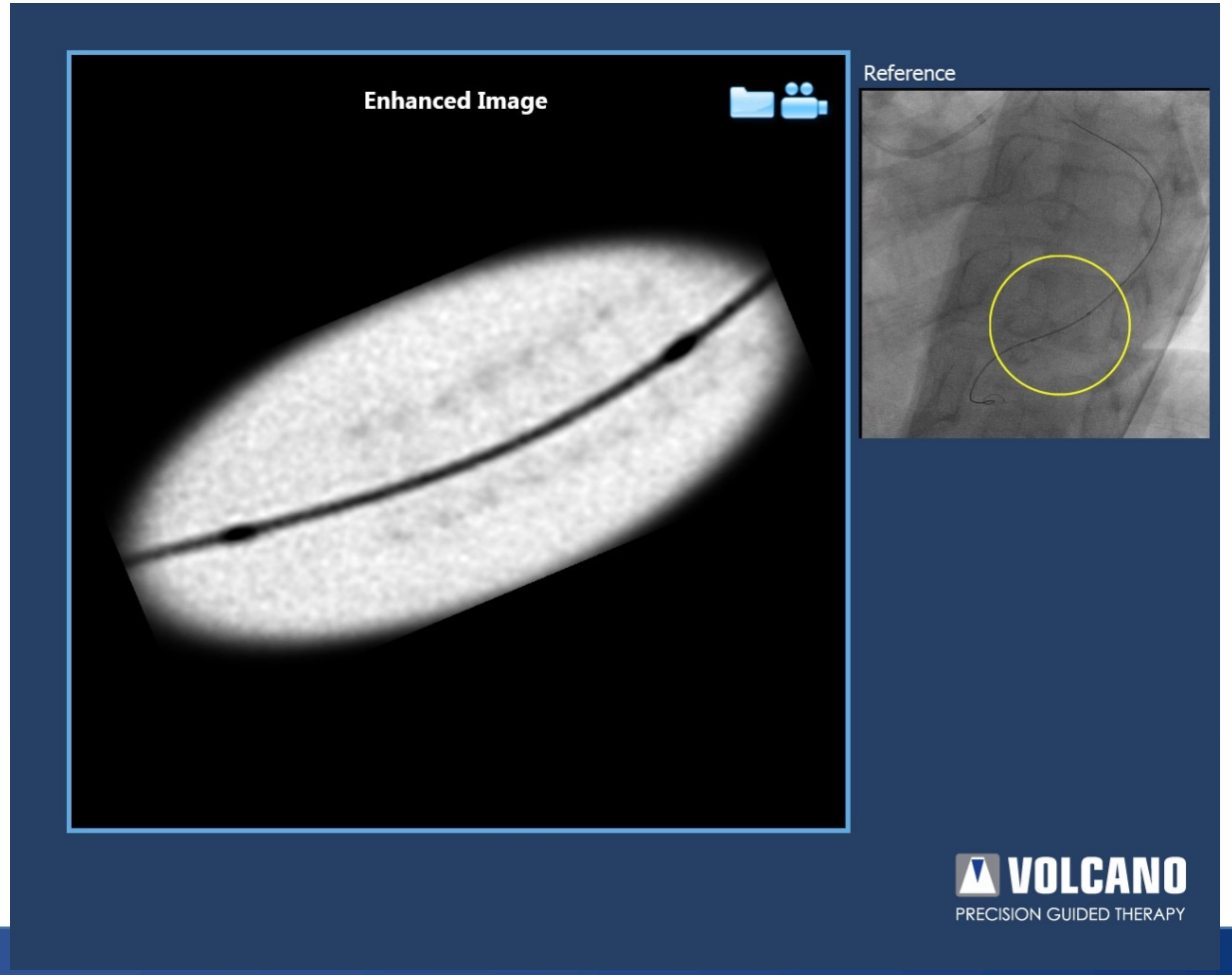
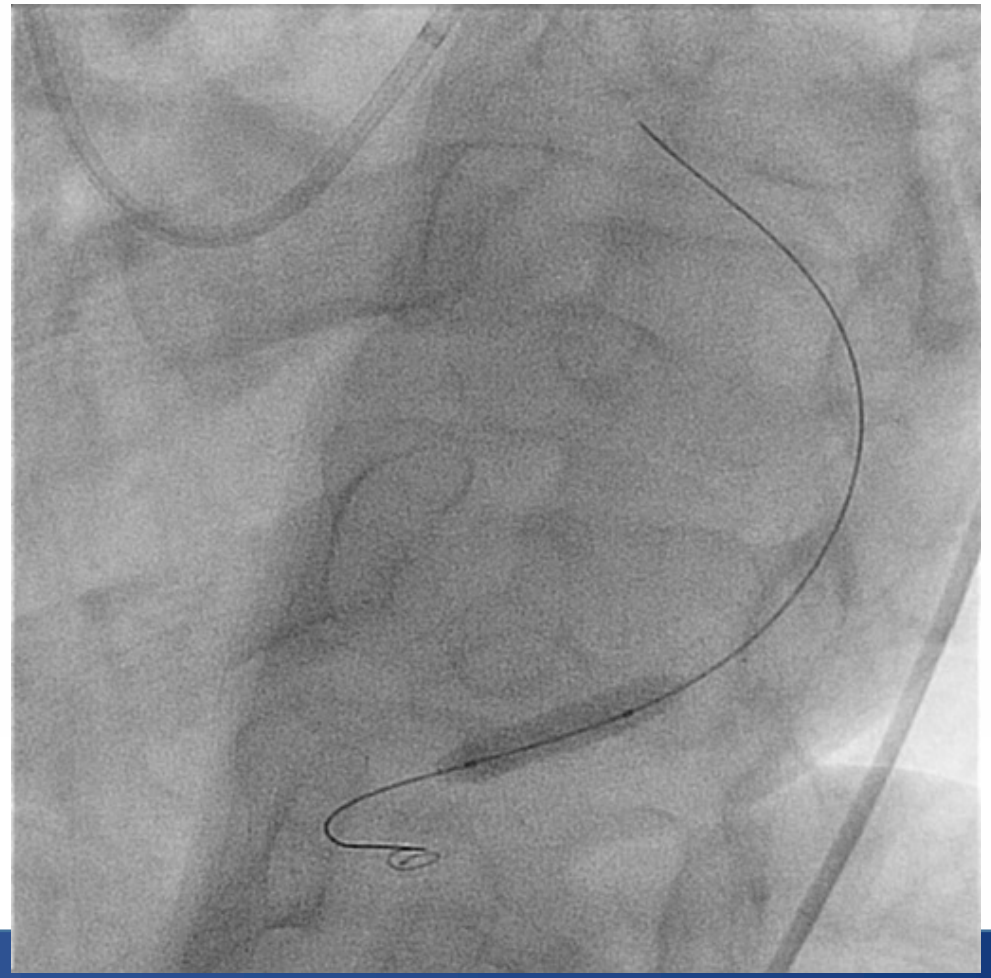

Enhanced Image
Reference
VOLCANO
PRECISION GUIDED THERAPY

CASE #2



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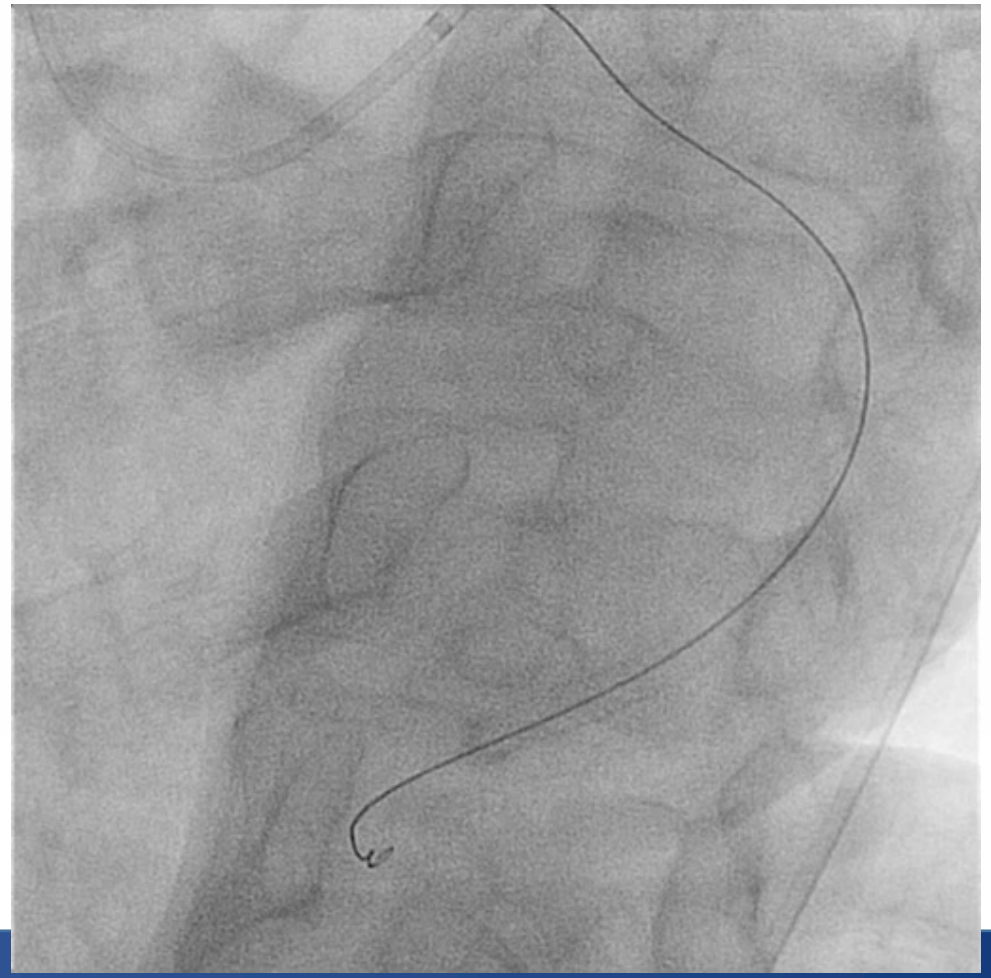

SUMMARY

- IVUS is associated with improved procedural outcomes, reduced MACE, and improved mortality
- PLAN the Case: It takes the guesswork out of PCI outcomes
- LAND the Stent: Land your stent/Perform PCI within the target zone consistently
- EXPAND: Post-dilate your stent to maximize outcomes and avoid complications

Basics of IVUS Use in Pre, Peri, and Post-Intervention

S. Jay Mathews, MD, MS, FACC

Director, Cardiac Catheterization Lab, Structural Heart Program, & PERT

Manatee Memorial Hospital, Bradenton, FL