

Intravascular Imaging-Guided PCI: A Universal Approach for Optimization of Stent Implantation

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Cardiovascular Research Foundation

REVIEW ARTICLE
Circulation: Cardiovascular Interventions
CONTEMPORARY REVIEWS IN INTERVENTIONAL CARDIOLOGY
Intravascular Imaging-Guided Percutaneous Coronary Intervention
A Universal Approach for Optimization of Stent Implantation
Evel D'Elia, MD; David A. M. MD; Philip A. M. MD; Gary S. Mintz, MD; Richard D. White, MD; Alan J. Cantor, MD, PhD

ABSTRACT Despite considerable debate regarding the use of intravascular imaging with percutaneous coronary intervention (PCI), a practical and standardized approach to incorporating intravascular imaging with percutaneous coronary intervention may overcome the barriers to adoption. The review focuses on basic stent implantation with intravascular ultrasound and optical coherence tomography and proposes an algorithmic approach to stent sizing and optimization. Incorporation of this strategic method for percutaneous coronary intervention may aid in the greater adoption of intravascular imaging for percutaneous coronary intervention.

KEY WORDS: coronary artery disease • percutaneous coronary intervention • stents • intravascular imaging

TECHNICAL ASPECTS OF IVI
The use of stent implantation largely unchanged since the introduction of drug-eluting stents. Despite significant advancements in stent design, delivery, and deployment, randomized controlled trials and registries consistently support incremental and long-term benefit with the use of intravascular imaging (IVI) for percutaneous coronary intervention (PCI) guidance.¹⁻³ Stent expansion, especially the final in-stent diameter (ISD), has been the most reliable predictor of future stent-related events, including stent thrombosis and restenosis,⁴ and determination of the optimal stent size and assessment of adequate stent expansion is a basic step with IVI. Multicenter IVI remains underutilized for PCI.⁵ There are a number of barriers both perceived and real that have been cited to explain this low adoption, including separate departments for image interpretation and lack of a universal approach to IVI-guided PCI.⁶ We herein review practical steps for integration and present a universal approach for IVI-guided PCI as a new standard of care.

TECHNICAL ASPECTS OF IVI
Intravascular ultrasound (IVUS) and optical coherence tomography (OCT) can often be used interchangeably in most clinical contexts, but there are notable differences. IVUS offers the advantage of being able to penetrate bioabsorbable coatings for image acquisition and has greater penetration while OCT utilizes infrared light for image acquisition and has higher image resolution but requires fluid media for stent clearance to obtain an image with OCT. Notably, contrast that is not needed with IVUS. Angiographic contrast is available in an option with both imaging modalities. Acoustic backscatter speeds very by approximately 10 times. OCT pullback speeds are significantly faster than IVUS but require a slightly shorter pullback length. IVUS requires more manual measurements for comprehensive assessment including visualization and measurement of the proximal lesion and stent area, whereas the OCT software automates much of the process potentially reducing interoperator variability, though vessel lumen measurements may still be obtained manually.

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Education in Heart
Use of intracoronary imaging to guide optimal percutaneous coronary intervention procedures and outcomes
Gary S. Mintz, David A. M., Philip A. M., Gary S. Mintz, Richard D. White, Alan J. Cantor

INTRODUCTION
Although it is the tool used by most interventional cardiologists to assess the extent of coronary artery disease and guide treatment, coronary angiography has many limitations because it is a luminescent depicting shadowgraph, shows projections of the coronary blood lumen that are often foreshortened and often the imaging of the blood vessel lumen is incomplete. Intravascular ultrasound (IVUS) and recently optical coherence tomography (OCT) and near-infrared spectroscopy (NIRS) and near-infrared tomography (NIRT) are available noninvasive techniques that provide cross-sectional images of the coronary arteries. These techniques aid in physician decision-making, selection of treatment strategies, stent expansion and assessing operators that aids during percutaneous coronary intervention (PCI). Multicenter randomized trials, registries, and non-randomized observational studies support procedural and long-term benefits of IVI-guided PCI especially drug-eluting stent (DES) implantation.

KEY WORDS: coronary artery disease • percutaneous coronary intervention • stents • intravascular imaging

KEY POINTS
• To understand the differences among intravascular imaging devices.
• To understand how and when to use (and when not to use) available intravascular imaging devices.
• To understand what is meant by stent optimization and how to improve patient outcomes.

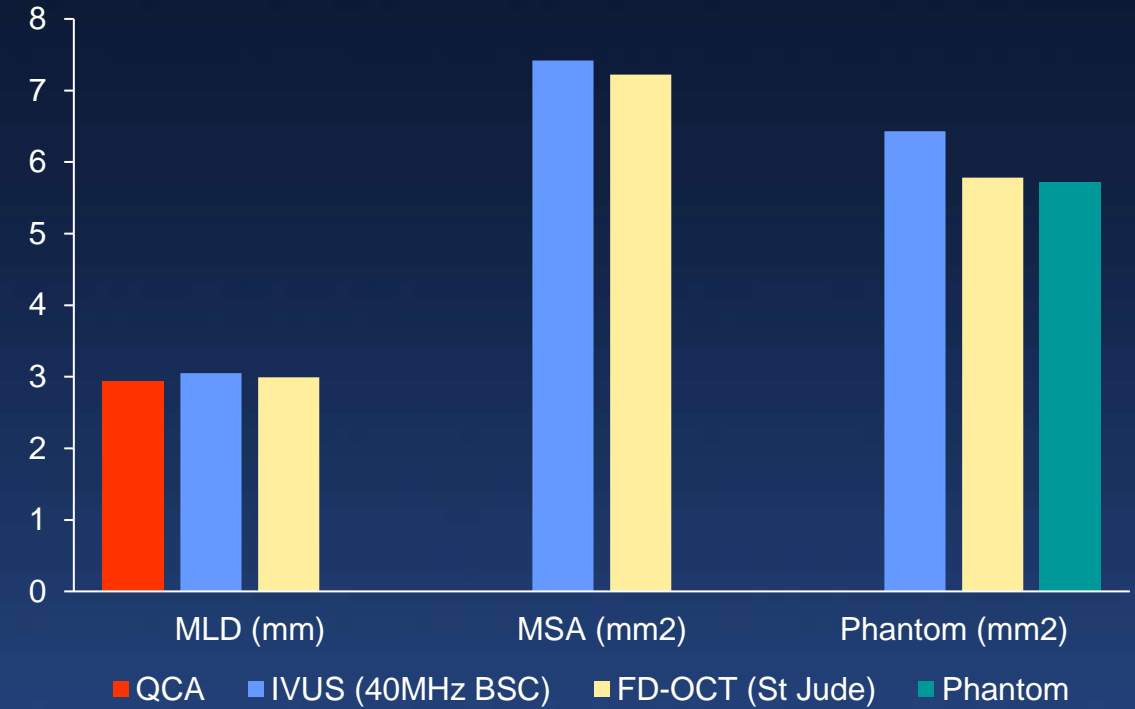
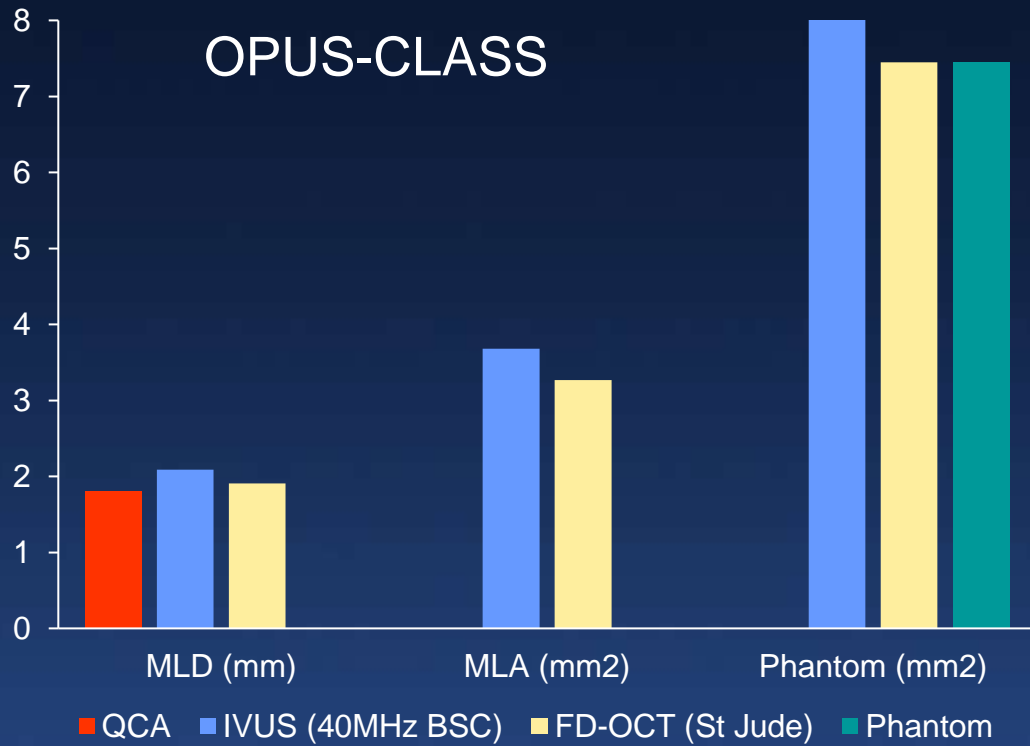
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Intravascular ultrasound (IVUS) and optical coherence tomography (OCT) can often be used interchangeably in most clinical contexts, but there are notable differences. IVUS offers the advantage of being able to penetrate bioabsorbable coatings for image acquisition and has greater penetration while OCT utilizes infrared light for image acquisition and has higher image resolution but requires fluid media for stent clearance to obtain an image with OCT. Notably, contrast that is not needed with IVUS. Angiographic contrast is available in an option with both imaging modalities. Acoustic backscatter speeds very by approximately 10 times. OCT pullback speeds are significantly faster than IVUS but require a slightly shorter pullback length. IVUS requires more manual measurements for comprehensive assessment including visualization and measurement of the proximal lesion and stent area, whereas the OCT software automates much of the process potentially reducing interoperator variability, though vessel lumen measurements may still be obtained manually.

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OCT vs IVUS vs QCA in Coronary Lesions and Phantoms



- IVUS-MLD - OCT-MLD = 0.18 mm
- QCA-MLD - OCT-MLD = -0.10 mm
- IVUS-MLA - OCT-MLA was significantly greater in non-stented vs stented segments (0.56 mm² vs. 0.25 mm²; p<0.007).

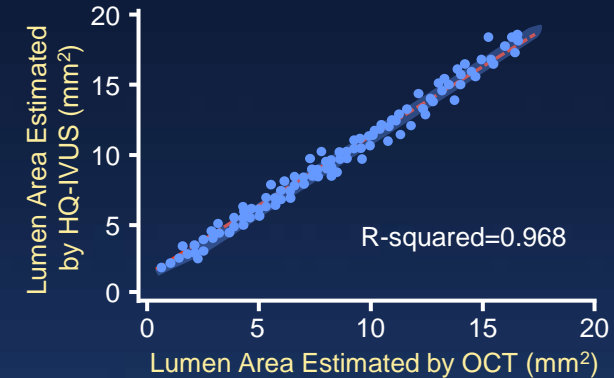
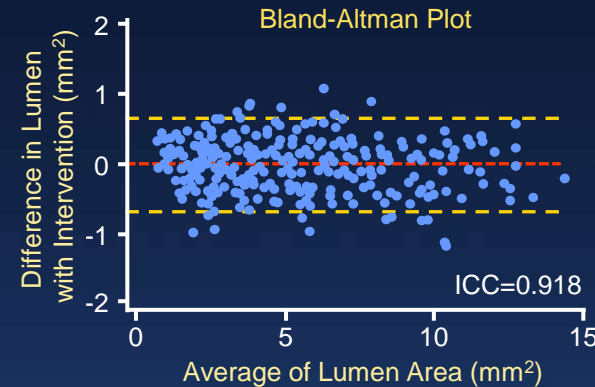
- IVUS-MLA - OCT-MLA was significantly greater in non-stented vs stented segments (11.3% vs. 2.7%).

In vivo comparison of OCT vs HD-IVUS

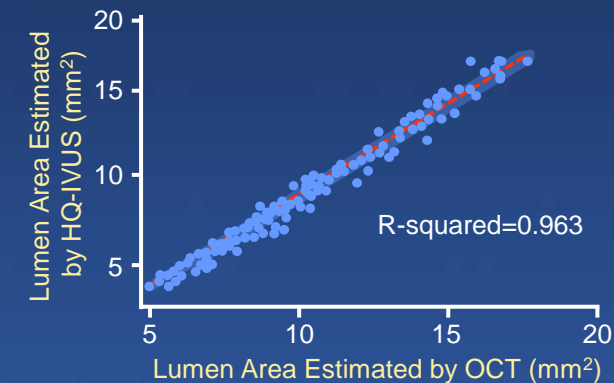
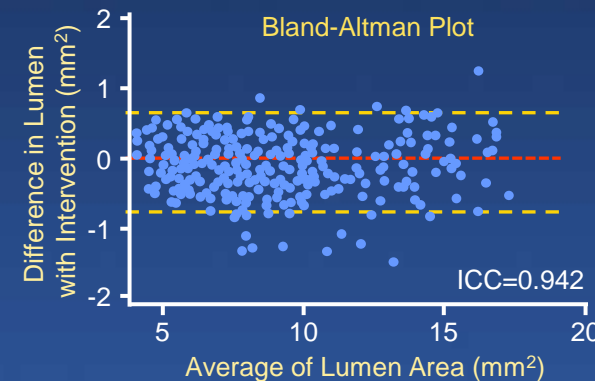
- Pre-intervention. . .
 - no significant differences regarding proximal and distal reference lumen areas as well as in the assessment of MLA or lesion length.
 - Some lipid-predominant lesions on OCT were classified as fibrotic with HD-IVUS
 - OCT more frequently revealed the presence of plaque rupture or intraluminal thrombus
 - HD-IVUS enabled better visualization of the external elastic membrane

- Post-intervention. . .
 - HD-IVUS was comparable to OCT in the estimation of MSA
 - OCT more frequently detected the presence of tissue protrusion as well as both the number and percentage of malapposed struts
 - OCT more frequently identified the presence of stent-edge dissections

Pre-intervention



Post-intervention



Predictors of DES Early ST, Restenosis, MACE, or DoCE

	IVUS		OCT
	Early ST	Restenosis/MACE	Restenosis/MACE/DoCE
<p>Small MSA or underexpansion in stable lesions</p> <p>Small MLA in ACS/MI lesions</p>	<ul style="list-style-type: none"> •Fujii et al. J Am Coll Cardiol 2005;45:995-8 •Okabe et al. Am J Cardiol. 2007;100:615-20 •Liu et al. JACC Cardiovasc Interv. 2009;2:428-34 •Choi et al. Circ Cardiovasc Interv 2011;4:239-47 	<ul style="list-style-type: none"> •Sonoda et al. J Am Coll Cardiol 2004;43:1959-63 •Hong et al. Eur Heart J 2006;27:1305-10 •Doi et al JACC Cardiovasc Interv. 2009;2:1269-75 •Fujii et al. Circulation 2004;109:1085-1088 •Kang et al. Circ Cardiovasc Interv 2011;4:9-14 •Choi et al. Am J Cardiol 2012;109:455-60 •Song et al. Catheter Cardiovasc Interv 2014;83:873-8 •Kang et al. PLoS One 2015;10(10):e0140421 •Hong et al. JAMA 2015;314(:2155-63. •Lee et al. Rev Esp Cardiol 2017;70:88-95 •Katagiri et al. Catheter Cardiovasc Interv. 2019 Jan 31. doi: 10.1002/ccd.28105. •Kim et al. EuroIntervention. 2019 Dec 10. pii: EIJ-D-19-00762. •Park et al. JACC Cardiovasc Interv 2020;13:1403-13 •Ladwiniec et al. EuroIntervention 2020;16:201-9 •Sugane et al. Atherosclerosis, in press 	<ul style="list-style-type: none"> •Prati et al. JACC Cardiovasc Imaging 2015;8:1297-305 •Prati et al. Circ Cardiovasc Interv. 2016;9. pii: e003726. •Soeda et al. Circulation 2015;132:1020-9 •Matsuo et al. Cathet Cardiovasc Interv 2015;87:E9-14 •Prati et al. EuroIntervention 2018;14:e443-e451 •Katsura et al. Catheter Cardiovasc Interv 2020: 10.1002/ccd.28871
Edge problems (geographic miss, secondary lesions, large plaque burden, dissections, etc)	<ul style="list-style-type: none"> •Fujii et al. J Am Coll Cardiol 2005;45:995-8 •Okabe et al., Am J Cardiol. 2007;100:615-20 •Liu et al. JACC Cardiovasc Interv. 2009;2:428-34 •Choi et al. Circ Cardiovasc Interv 2011;4:239-47 	<ul style="list-style-type: none"> •Sakurai et al. Am J Cardiol 2005;96:1251-3 •Liu et al. Am J Cardiol 2009;103:501-6 •Costa et al, Am J Cardiol, 2008;101:1704-11 •Kang et al. Am J Cardiol 2013;111:1408-14 •Kobayashi et al. Circ Cardiovasc Interv. 2016;9:e003553 •Calvert et al. Catheter Cardiovasc Interv 2016;88:340-7 •Park et al. JACC Cardiovasc Interv 2020;13:1403-13 	<ul style="list-style-type: none"> •Prati et al. JACC Cardiovasc Imaging 2015;8:1297-305 •Prati et al. Circ Cardiovasc Interv. 2016;9. pii: e003726. •Ino et al. Circ Cardiovasc Interv. 2016;9:e004231 •Prati et al. EuroIntervention 2018;14:e443-e451 •van Zandvoort et al. Circ Cardiovasc Interv. 2020;13:e008685
<p>Protrusion in ACS/MI</p> <p>Irregular Protrusion</p>	<ul style="list-style-type: none"> •Choi et al. Circ Cardiovasc Interv 2011;4:239-47 •Hong et al. Int J Cardiol 2013;168:1674-5 		<ul style="list-style-type: none"> •Prati et al. Circ Cardiovasc Interv. 2016;9. pii: e003726. •Soeda et al. Circulation 2015;132:1020-9
Stent length (>40mm)		<ul style="list-style-type: none"> •Hong et al. Eur Heart J 2006;27:1305-10 	
Asymmetry/Eccentricity		<ul style="list-style-type: none"> •Suwannasom et al. JACC Cardiovasc Interv 2016;9:1231-42 (not significant at long term follow-up: JACC Cardiovasc Interv 2018;11:1013-5) 	
Acute malapposition			<ul style="list-style-type: none"> •Souteyrand et al. Eur Heart J. 2016;37:1208-16

Acute malapposition is detected in 14% by IVUS and 50% by OCT after routine stenting

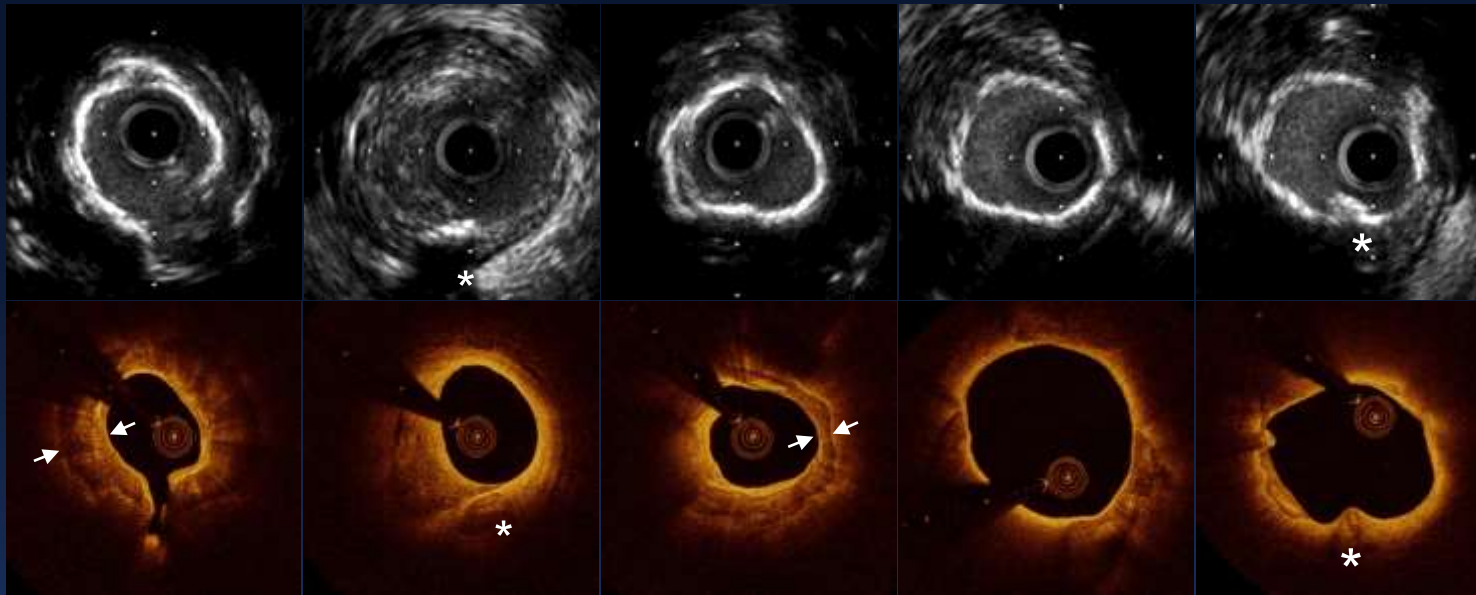
	Study	#	IVUS	OCT
Hong et al. Circulation. 2006;113:414-9	AMC	683	7%	
Steinberg et al. JACC Cardiovasc Interv 2010;3:486-94	Combined TAXUS	1200	8%	
Guo et al. Circulation 2010;122:1077-84	HORIZONS-AMI	263	36%	
Kang et al. Circ Cardiovasc Interv 2011;4:562-9.		403	7%	
Van der Hoven et al. JACC Cardiovasc Interv 2008;1:192-201	MISSION-AMI	184	35%	
Bezerra et al. JACC Cardiovasc Interv 2013;6:228-36		26	42%	96%
Kubo et al. JACC Cardiovasc Imaging 2013;6:1095-1104	OPUS-CLASS	100	14%	39%
Im et al. Circ Cardiovasc Interv 2014;7:88-96		356		62%
Kawamori et al. EHJ Cardiovasc Imaging 2013;14:865-75		40		65%
Shimamura et al. EHJ Cardiovasc Imaging 2015;16:23-8		77		100%
Soeda et al. Circulation 2015;132:1020-9		1001		39%
Prati et al. JACC Cardiovasc Imaging 2015;8:1297-305	CLI-OPCI-II	1002		49%
Bernelli et al. Circ J 2016;80:895-905	OCTAVIA	114		72%
Kim et al. J Interv Cardiol 2016;29:216-24		122		48%
		168	37%	
Wang et al. J Am Heart Assoc. 2016;5. pii: e004438. doi: 10.1161	ADAPT-DES	2430	13%	
Prati et al. Circ Cardiovasc Interv. 2016;9. pii: e003726	CLI-OPCI ACS	588		48%
Ali et al. Lancet. 2016;388:2618-28	ILUMIEN III	304		36%
		146	18%	
Agarwal et al. Catheter Cardiovasc Interv 2017;90:225-232		110		75%
Lee et al. Circ Cardiovasc Interv. 2018;11:e007192	DETECT-OCT	390		45%
Ladwiniec et al. Eurointervention 2020;16:201-9	NOBLE	224	5%	
Overall			14%	50%

Events related to acute stent malapposition (6426 pts)

	Study		F-U	Acute malapposition	No acute malapposition
Steinberg et al. JACC Cardiovasc Interv 2010;3:486-94	Combined TAXUS	IVUS	9 mos	8.2% MACE	10.7% MACE
Van der Hoeven et al. JACC Cardiovasc Interv 2008;1:192-201	MISSION-AMI	IVUS	9 mos	0% ST	0% ST
Guo et al. Circulation 2010;122:10-77-84	HORIZONS-AMI	IVUS	13 mos	0% ST	0% ST
Soeda et al. Circulation 2015;132:1020-9		OCT	1 yr	4.4% DoCE	4.8% DoCE
Prati et al. JACC Cardiovasc Imaging 2015;8:1297-305	CLI-OPCI-II	OCT	1 yr	13% MACE	10% MACE
Wang et al. J Am Heart Assoc. 2016;5. pii: e004438. doi: 10.1161	ADAPT-DES	IVUS	2 yrs	5.2% MACE (0.65% ST)	4.5% MACE (0.43% ST)
Prati et al. Circ Cardiovasc Interv. 2016;9. pii: e003726.	CLI-OPCI-ACS	OCT	9 mos	12.8% MACE	12.4% MACE
Ladwiniec et al. Eurointervention 2020;16:201-9	NOBLE	IVUS	5 yrs	33% MACCE (8% mortality, 0% ST)	21% MACCE (6% mortality, 1% ST)

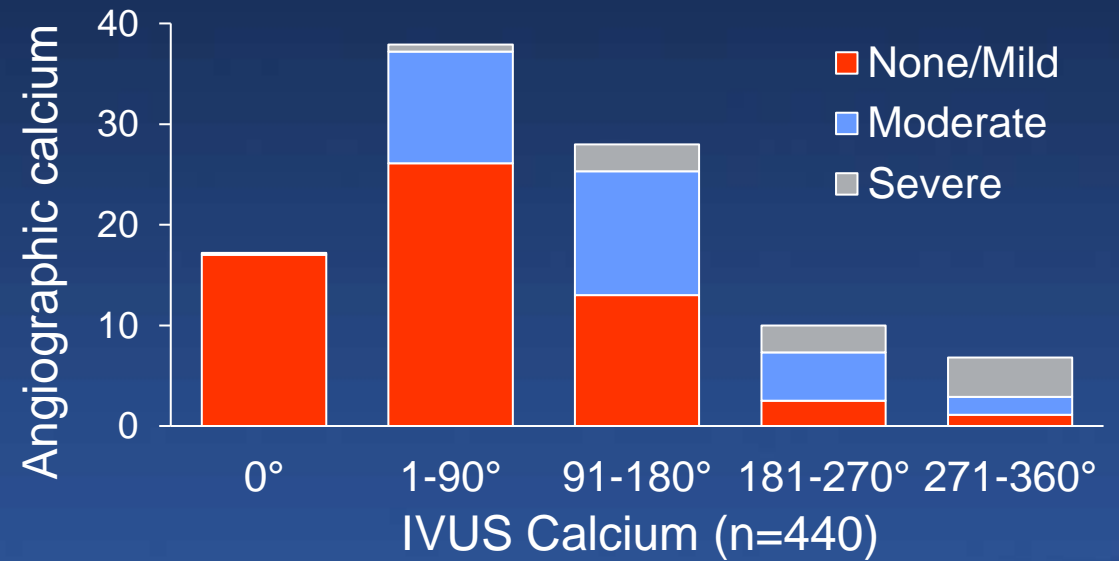
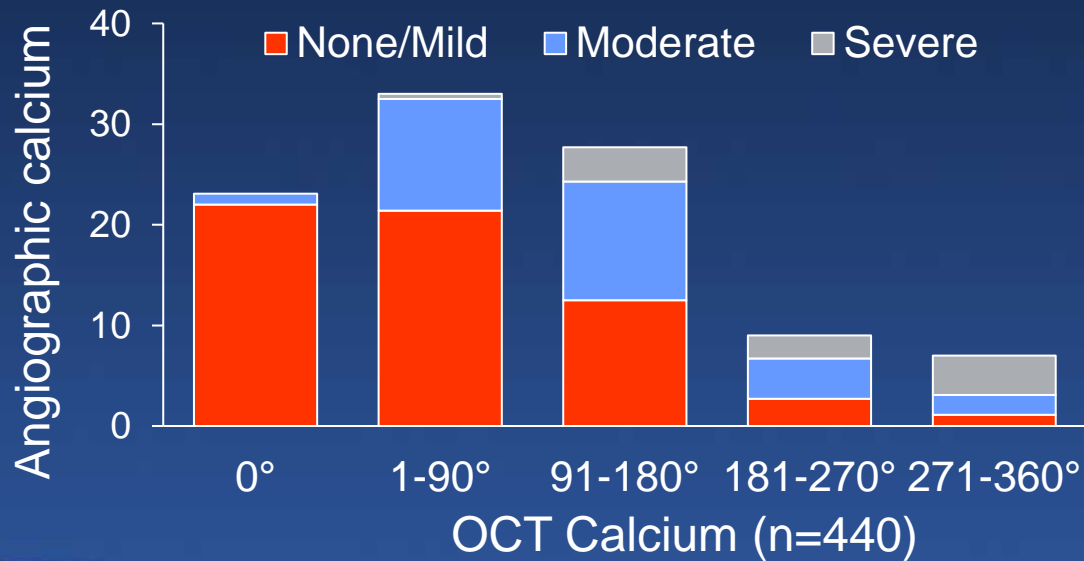
IVUS

OCT



Arc Length

Arc Length
Thickness
Area
Volume



OCT calcium scoring system predicting stent expansion

Test cohort of 128 pts

	Regression Coefficient	95% CI	P-value	Calcium Score		
Maximum calcium angle (per 180°)	-7.43	-12.6 to -2.21	<0.01	Maximum calcium angle	≤180°	0
					>180°	2
Maximum calcium thickness (per 0.5 mm)	-3.40	-6.35 to -0.45	0.02	Maximum calcium thickness	≤0.5mm	0
					>0.5mm	1
Calcium length (per 5 mm)	-3.32	-4.09 to -0.55	0.01	Calcium length	≤5mm	0
					>5mm	1

Validation cohort of 133 pts

Score	0 (n=27)	1 (n=45)	2 (n=34)	3 (n=3)	4 (n=24)	P-value
MSA, mm ²	7.2 (5.4, 9.2)	6.3 (5.2, 8.4)	5.9 (4.8, 8.0)	6.7 (5.8, 7.1)	5.7 (4.4, 7.4)	0.21
Stent expansion at target lesion calcium, %	99 (93, 108)	98 (86, 109)	86 (77, 100)	98 (83, 104)	78 (70, 86)	<0.01
Stent expansion at MSA, %	91 (84, 95)	85 (78, 93)	80 (73, 93)	80 (73, 85)	69 (60, 77)	<0.01

IVUS calcium score predicting stent expansion (as a continuous variable) in lesions with calcium >270°

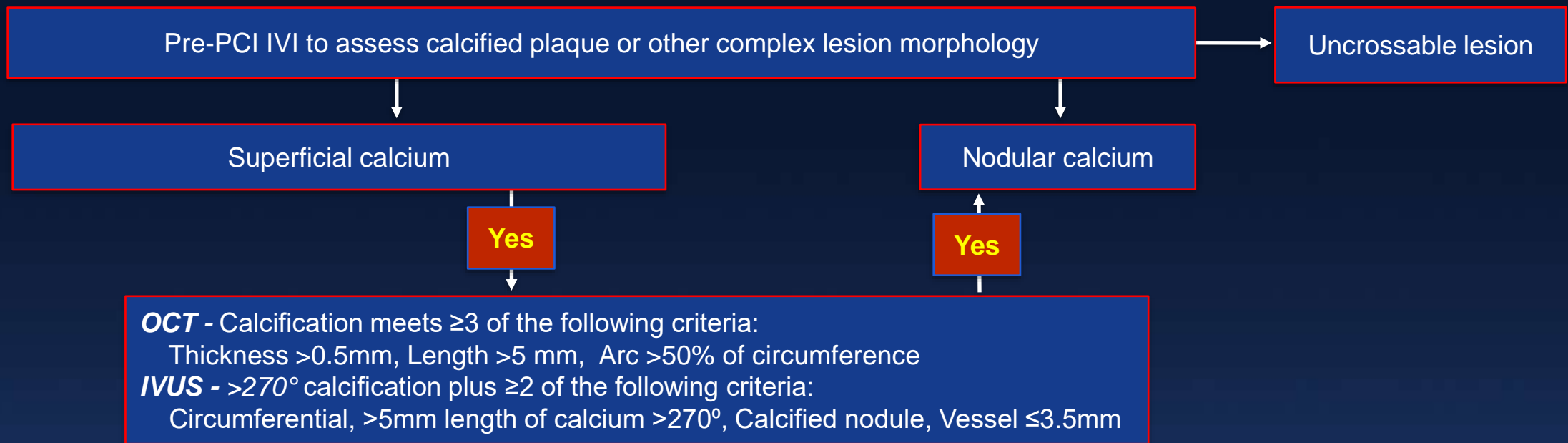
Test cohort of 97 pts

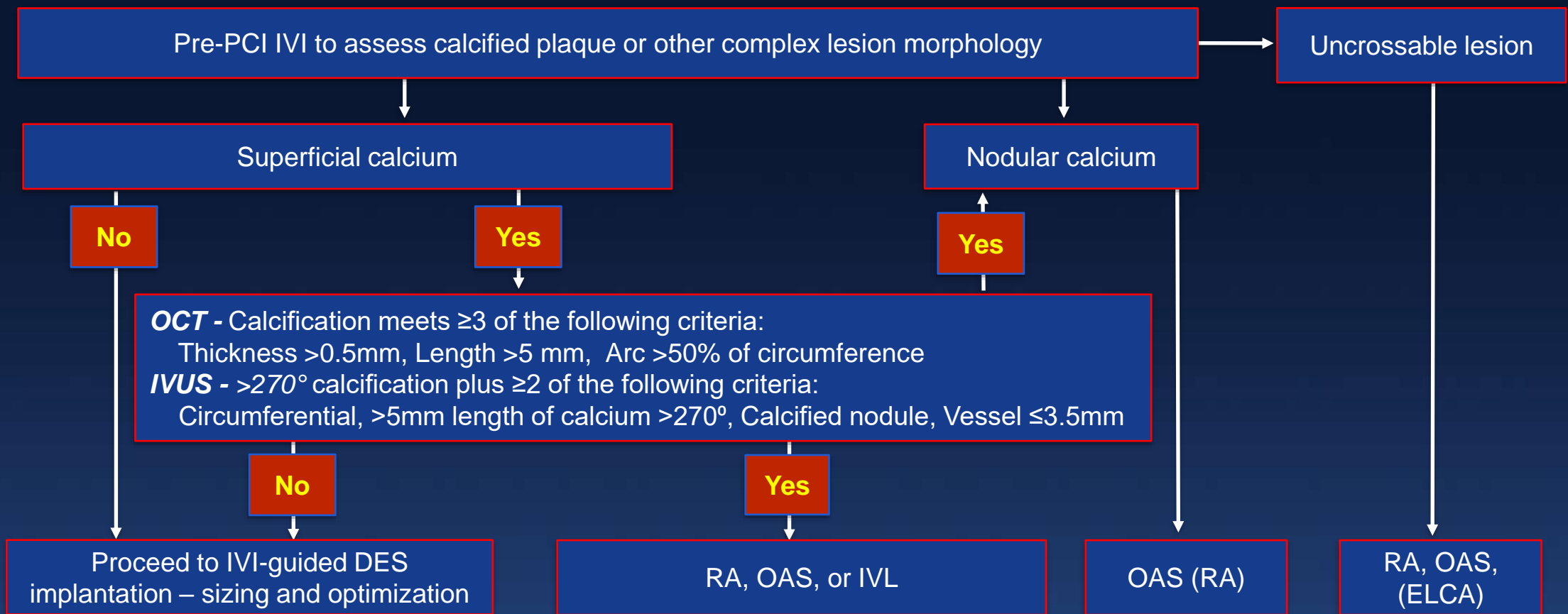
	Regression Coeff	95% CI	P-value	Cut-off	Calcium Score	
Length of calcium >270° (per 5mm)	-5.5	-9.7, -1.2	0.01	5.0	≤5mm	0
					>5mm	1
Calcium Nodule	-10.2	-16.3 to -4.2	0.0009		absent	0
					present	1
Vessel diameter (per 1mm)	8.6	2.7 to 14.4	0.004	3.5	>3.5mm	0
					≤3.5mm	1
Circumferential calcium	-14.3	-25.0 to -3.5	0.009		absent	0
					present	1

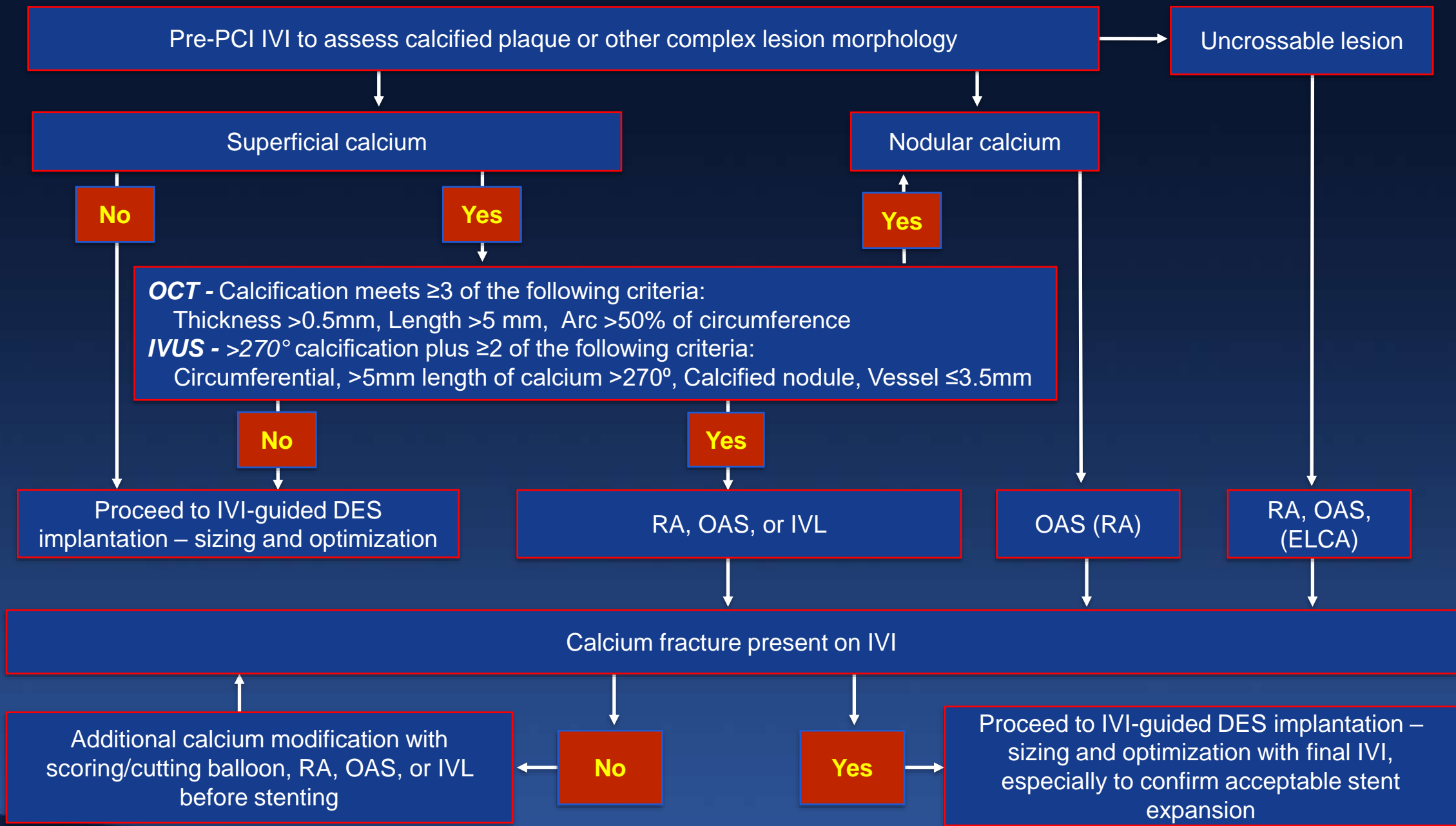
Stent underexpansion (<70%) in the validation cohort of 97 pts

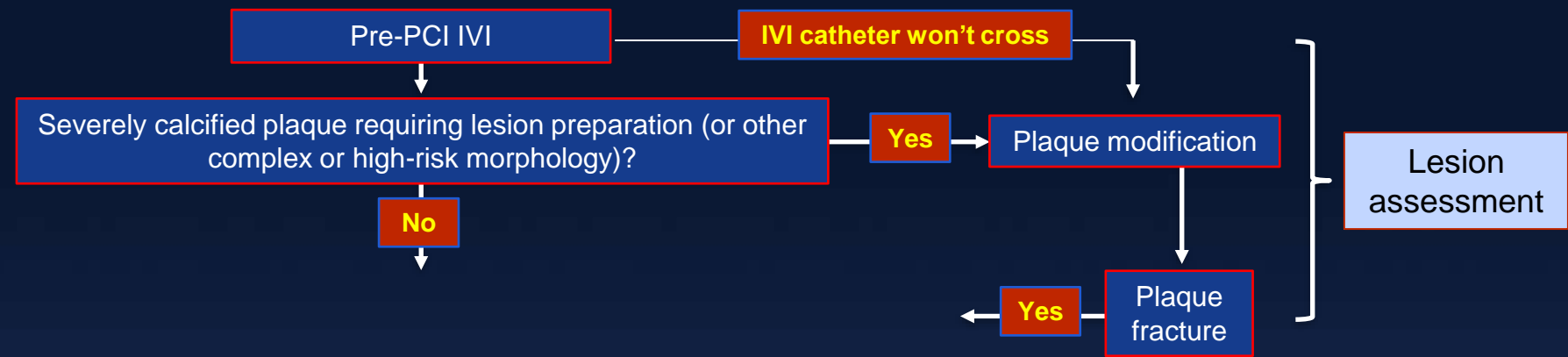
	Cut-off	C-statistics	Sensitivity	Specificity	PPV	NPV
Score	≥2	0.85 [0.77, 0.93]	89%	63%	48%	94%

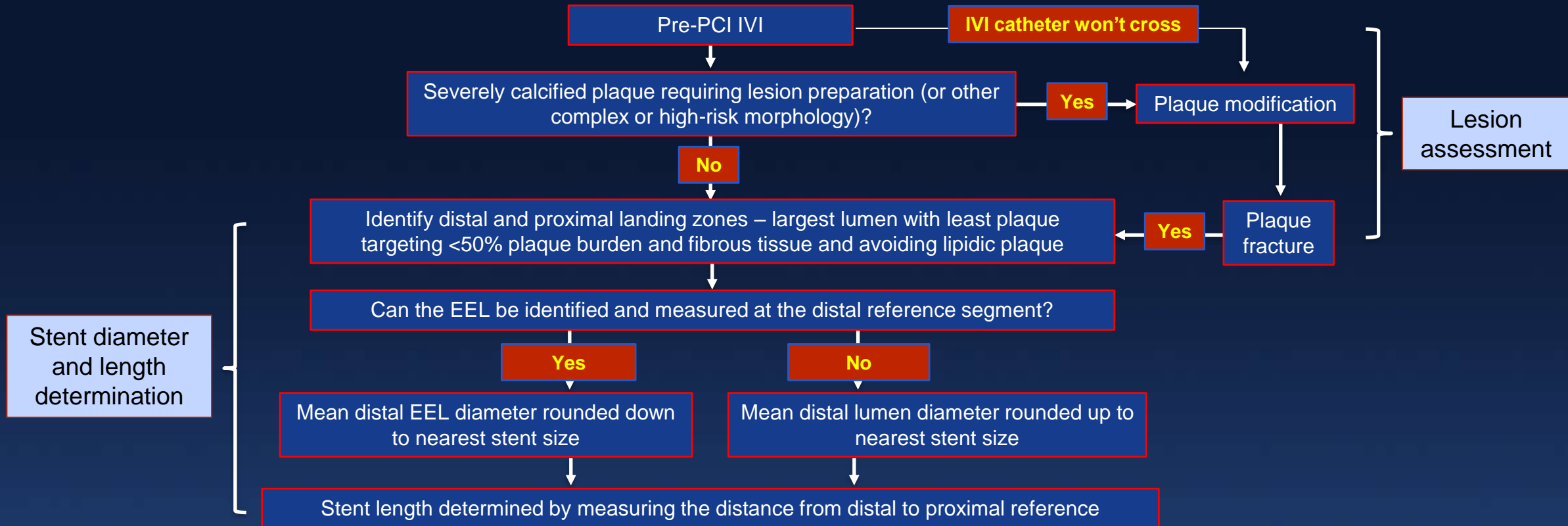
In 67 lesions without angiographically visible calcium, but with a maximum IVUS angle of superficial calcium >270°, there were none with a calcium score of 4 and only 1 with stent underexpansion.

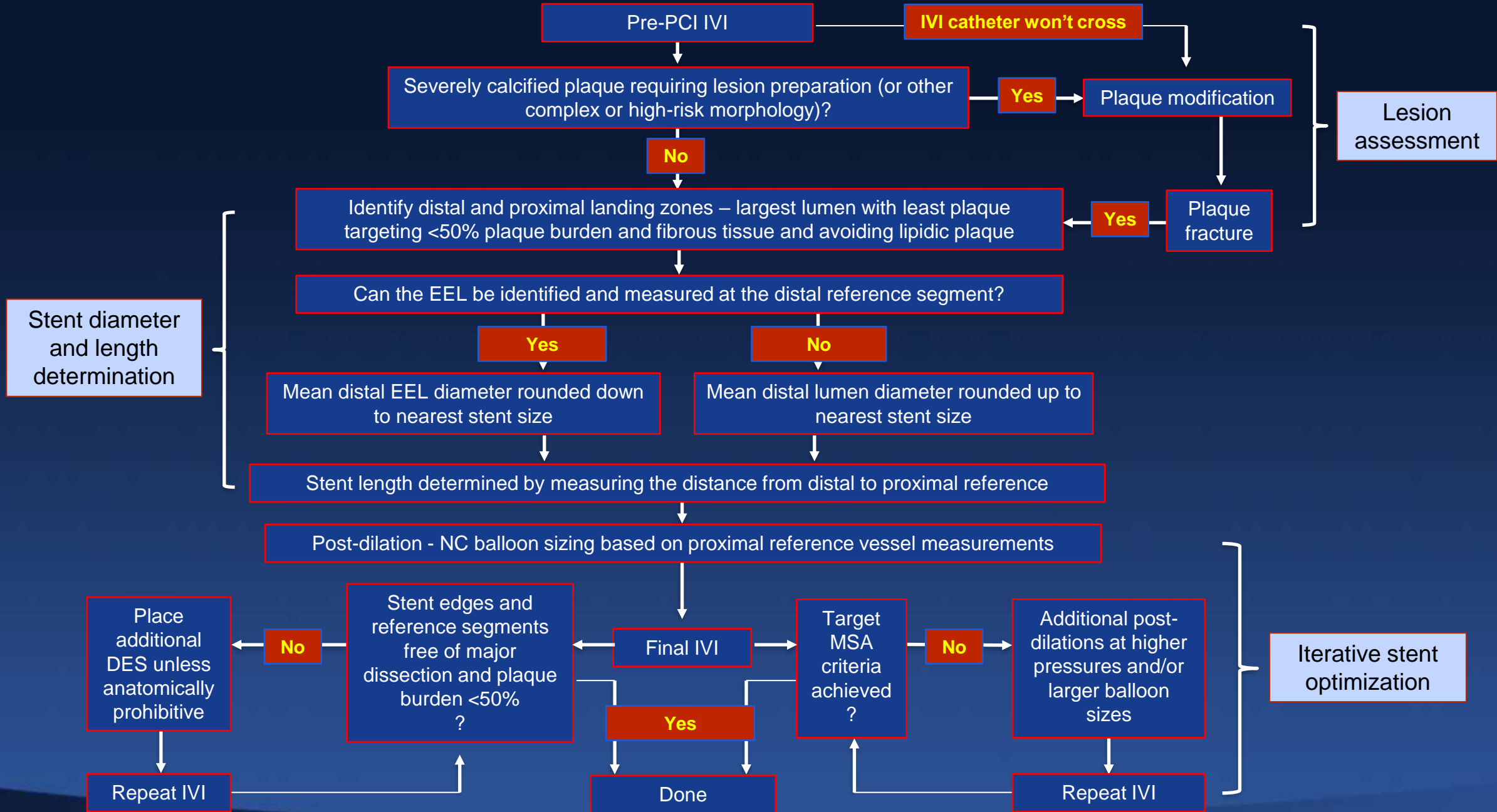






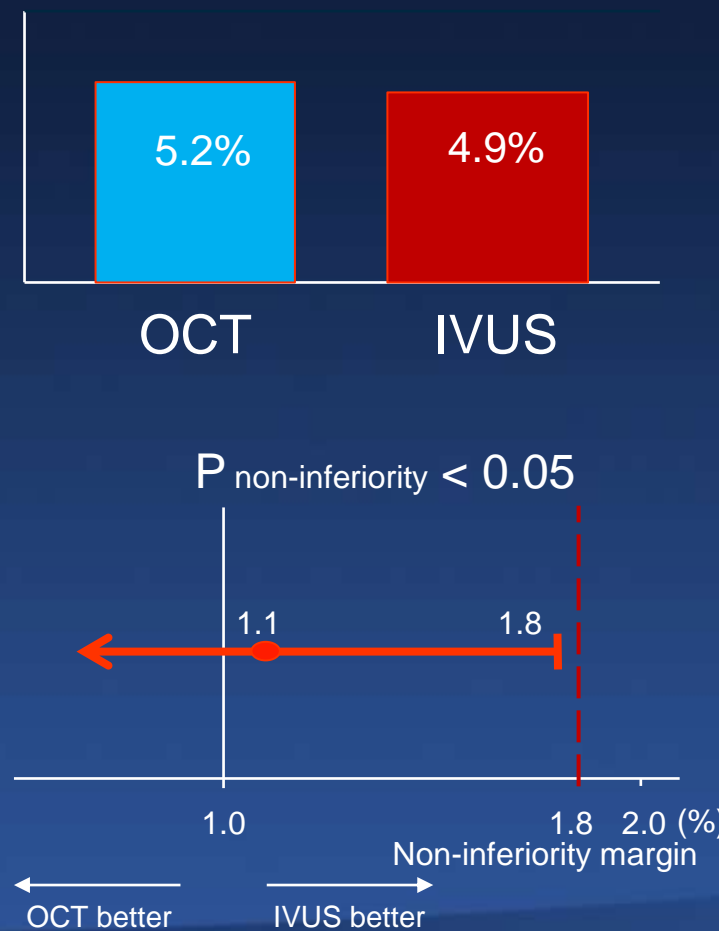
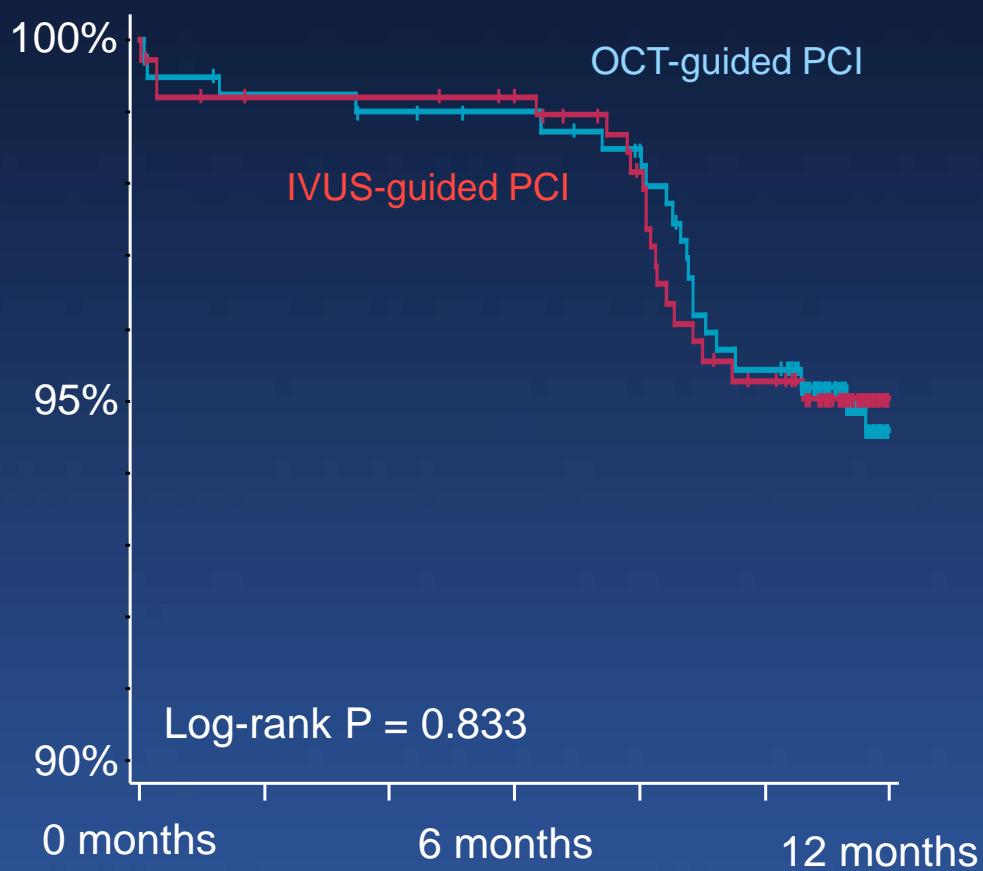






OPINION: Randomized trial of IVUS vs OCT-guided DES implantation in ~800 patients

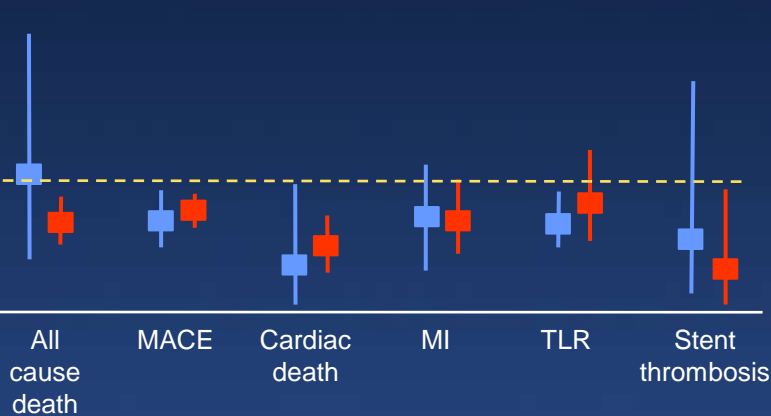
Primary endpoint: Target vessel failure (cardiac death, target vessel related MI, clinically driven TVR)-free survival



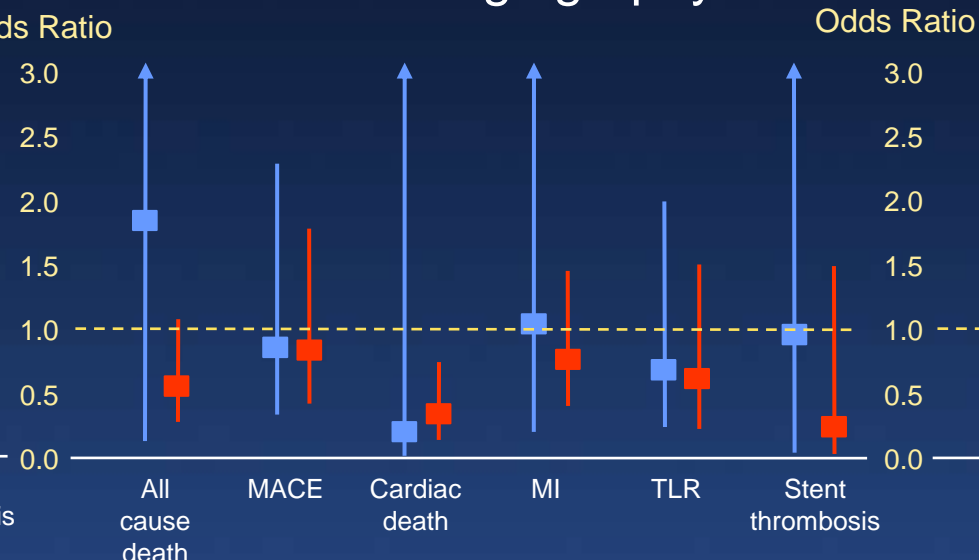
Bayesian network meta-analysis of 31 studies and 17,882 pts comparing clinical outcomes of PCI with BMS and/or DES implantation guided by angiography, IVUS, or OCT

IVUS vs Angiography

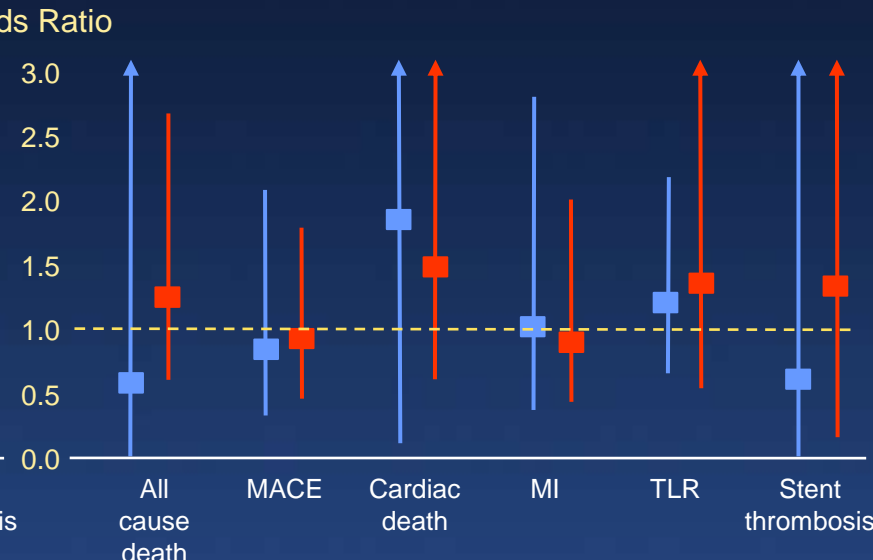
■ Randomized trials (n=17)
■ Observational, matched studies (n=14)



OCT vs Angiography



IVUS vs OCT

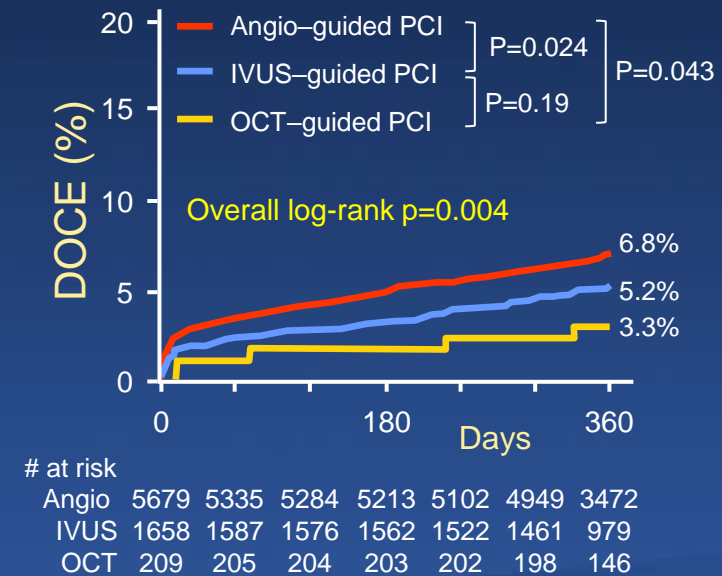
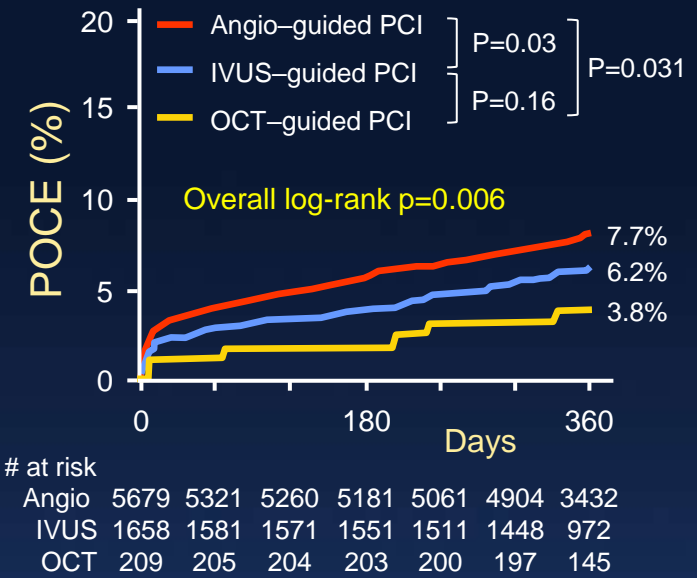
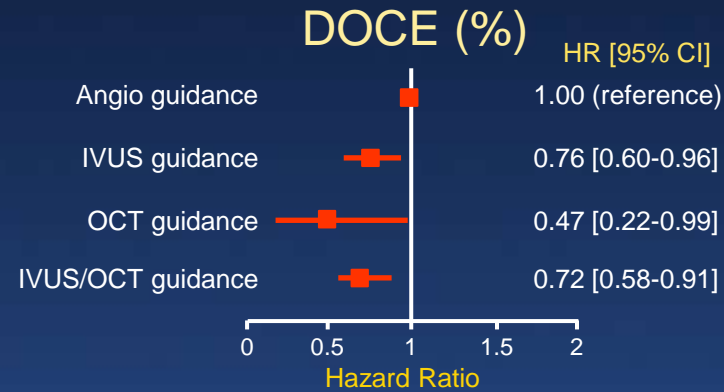
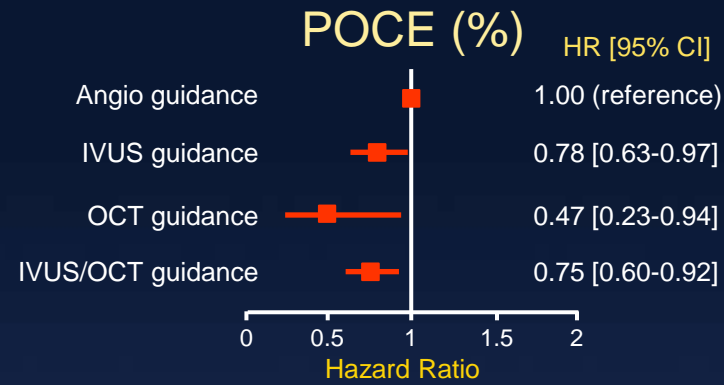


- Angiography (29 studies; 8434 pts), IVUS (17 studies; 7825 pts), OCT (7 studies; 1623 pts)
- Angiography vs IVUS (24 studies; 14295 pts), Angiography vs OCT (4 studies; 2092 pts), IVUS vs OCT (2 studies; 1045 pts), Angiography vs IVUS vs OCT (1 study; 450 pts)

IVUS and OCT-guided primary PCI in the KAMIR Registry

- KAMIR (Korean AMI Registry) is an online, open-label registry at 20 sites that was established in 2011 with the help of the Korean NIH
- From 11/2011 to 12/2015, 11,731 STEMI pts underwent 1° PCI: 9072 with angio-guidance and 2333 with IVUS and 277 with OCT to optimize stent expansion, apposition, and lesion coverage.

In the propensity-score matched cohort, difference in POCE was mainly driven by reduced all-cause mortality with IVUS (4.9% vs. 7.0%; log-rank p=0.002) and OCT (1.9% vs. 7.0%; log-rank p=0.004). The difference in DOCE was mainly driven by reduced cardiac mortality in IVUS (3.6% vs. 5.2%; log-rank p=0.009) and OCT-guided PCI (1.4 vs. 5.2%; log-rank p=0.014).



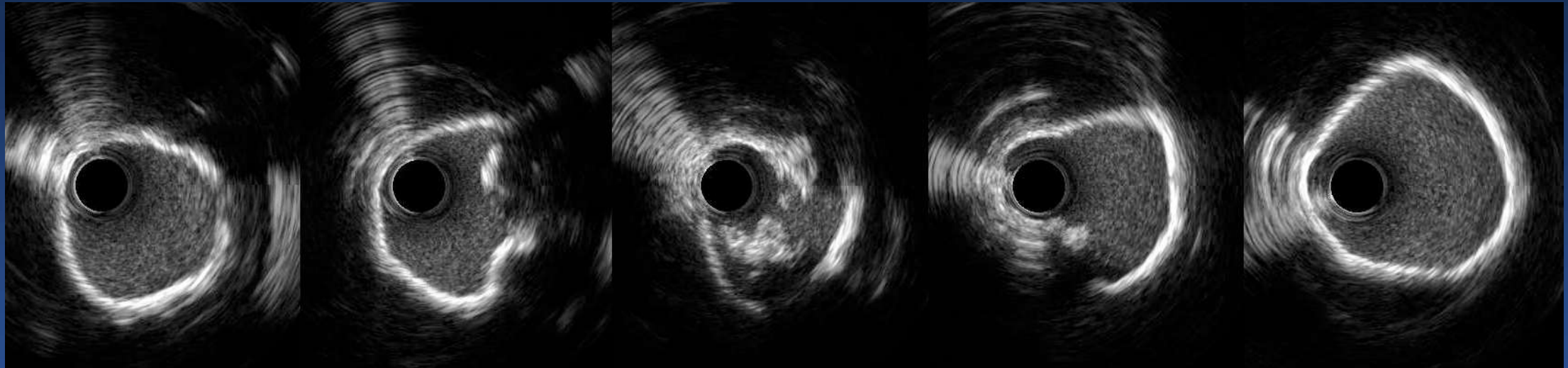
45 year-old male with CCS class 2 chest pain.

- Coronary risk factors
 - Type 1 diabetes mellitus
 - Hypertension
 - Current smoker
- Past medical history
 - Chronic renal failure on hemodialysis

c/o Myong Hwa Yamamoto and Masahiko Ochiai
Showa University Northern Yokohama Hospital
Yokohama, Japan

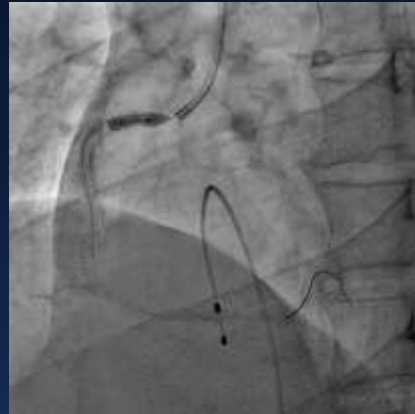
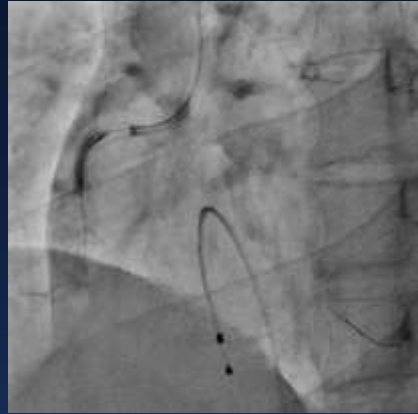
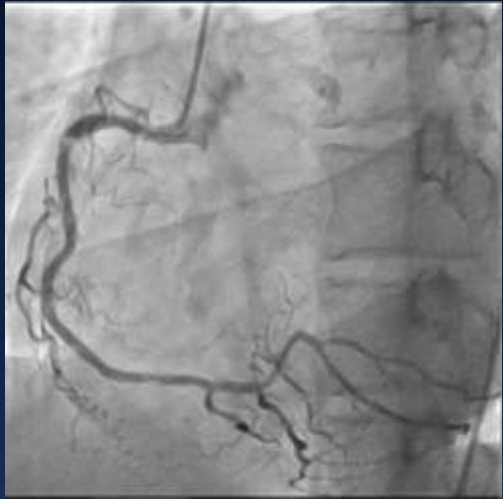


	Calcium Score	
Length of calcium >270°	≤5mm	0
	>5mm	1
Calcium Nodule	absent	0
	present	1
Vessel diameter	>3.5mm	0
	≤3.5mm	1
Circumferential calcium	absent	0
	present	1



0 ——— 5mm

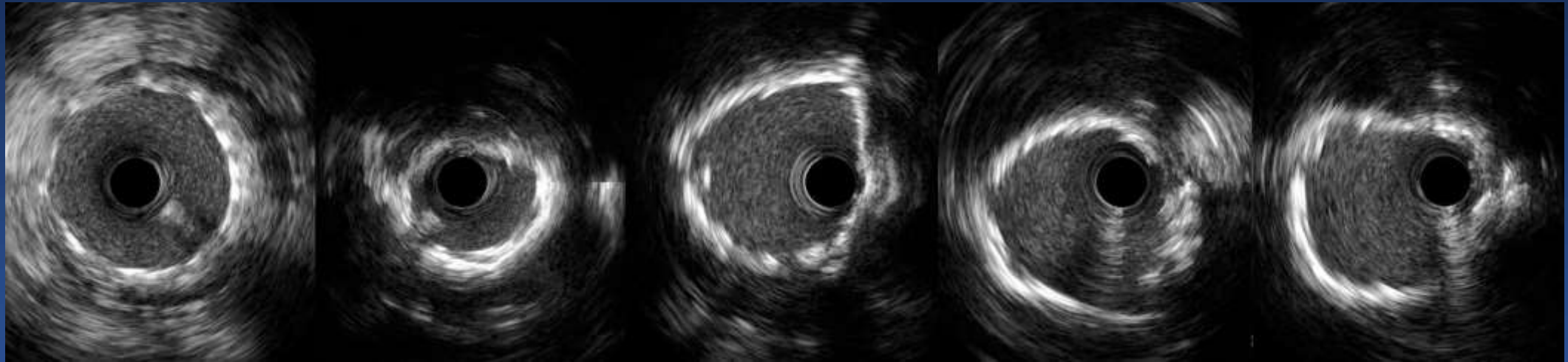
————— 20mm



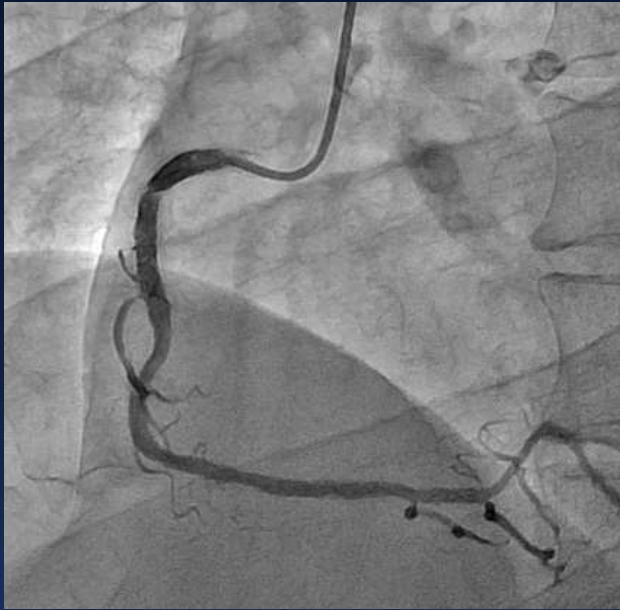
Balloon pre-dilation

**Promus Premier
3.0*38mm@18atm**

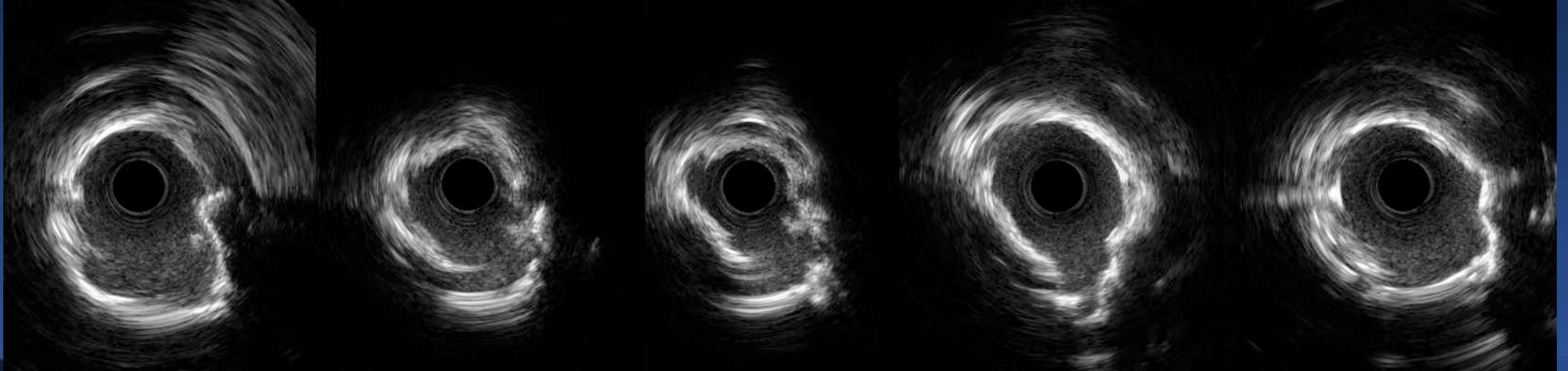
**Balloon post-dilation
Quantum 4.0mm@24atm**



Stent expansion=45%



Two months later

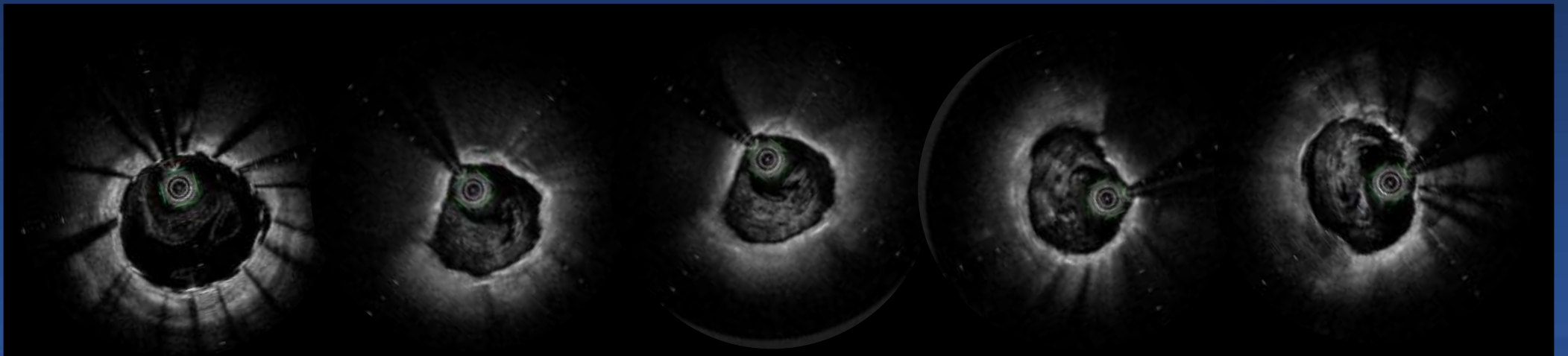




**Standard NC balloon
3.5mm@20atm**

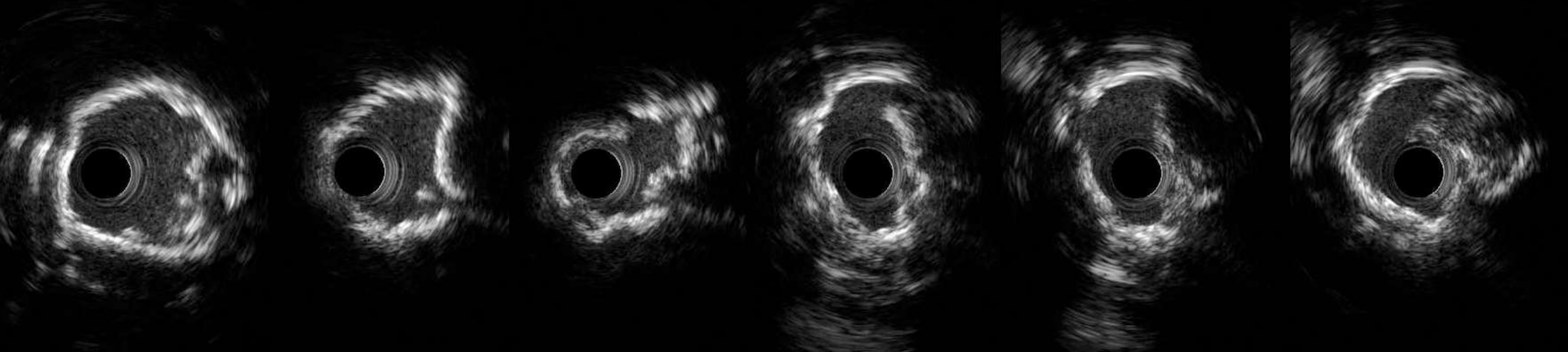


**Drug-coated balloon
3.5mm@20atm**





Another two months later



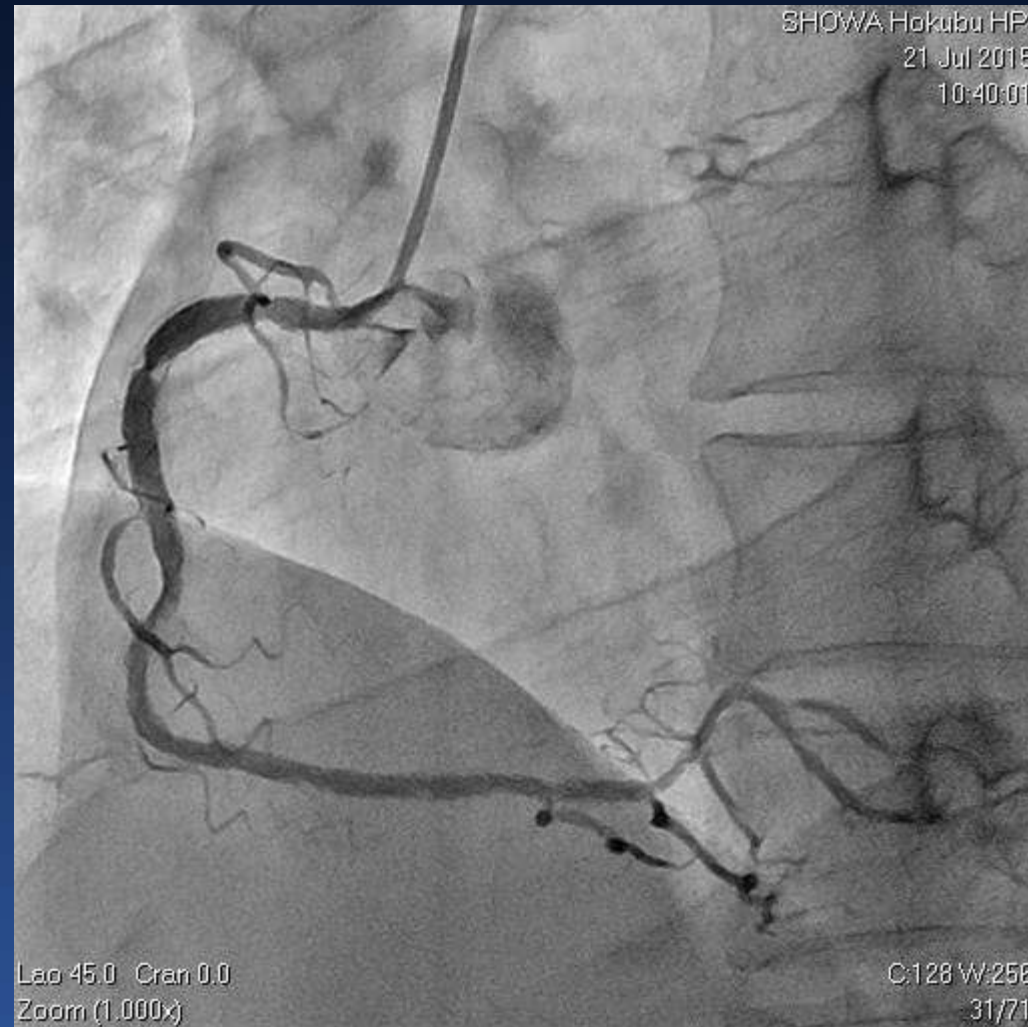


Pre-dilation
3.75mm@20atm

Nobori
3.5*14mm@16atm



Another one month later



IVUS**OCT**

Stent sizing & optimization	+++	+++
Ruptured plaque and thrombus	+	+++
Left main lesions	+++	+
Aorto-ostial lesions	+++	-
Calcium	++	+++
Chronic total occlusions	+++	-
In-stent restenosis	++	+++
Impaired renal function	+++	-

- 80-90% of your PCI-guidance needs can be addressed with either IVUS or OCT. Pick one and get good at it!
- In the other 10-20% of cases and depending on your practice, it is important to know which patient, which lesion, and which clinical scenario will be better suited to IVUS vs OCT assessment and/or guidance.

