Intravascular Imaging Guidance to Optimize PCI

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Disclosure Statement of Financial Interest

Within the past 12 months, I or my spouse/partner have had a financial interest/arrangement or affiliation with the organization(s) listed below.

Affiliation/Financial Relationship	Company
Institutional Support	Abbott, Philips, Boston Scientific, Abiomed, ACIST Medical, Shockwave
Consulting Fees/Honoraria	Abbott, Philips, Boston Scientific, Abiomed, ACIST Medical, Shockwave, Neovasc, Zoll, Novo Nordisk
Equity	Xenter, Covanos
Other	Co-Director, Optimizing PCI (OPCI)

Barriers to Physiology and Intravascular Imaging Utilization

1. “angio is good enough…”
2. “there’s not enough proof intravascular imaging impacts outcomes”
3. “I have always done it this way….” (i.e. lack of training)
4. “I am busy and it takes too long”
5. “procedure cost”

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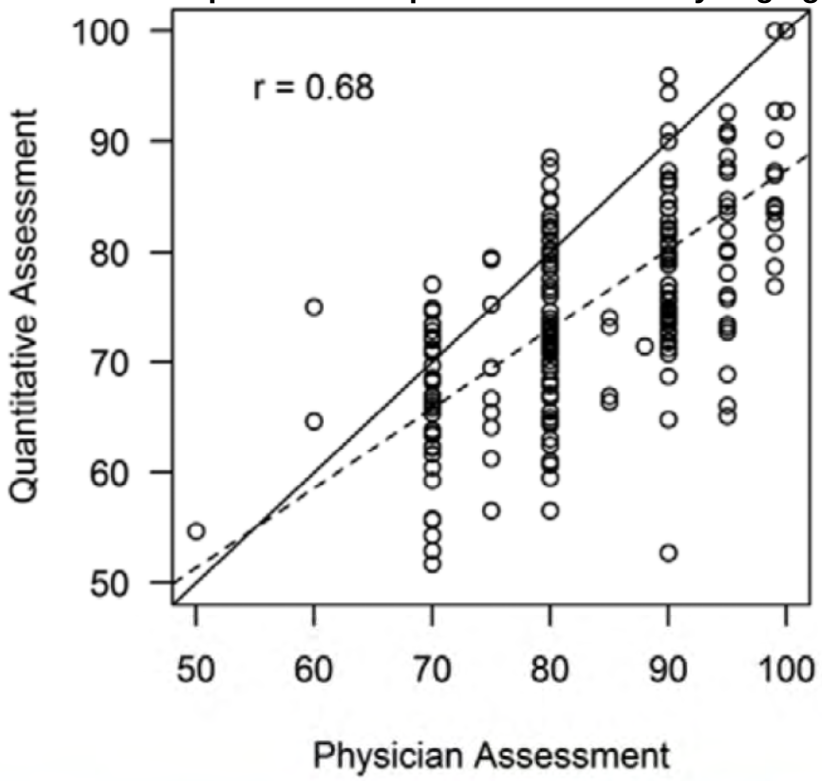
Angiography – A Blunt Tool: Significant Interobserver Variation

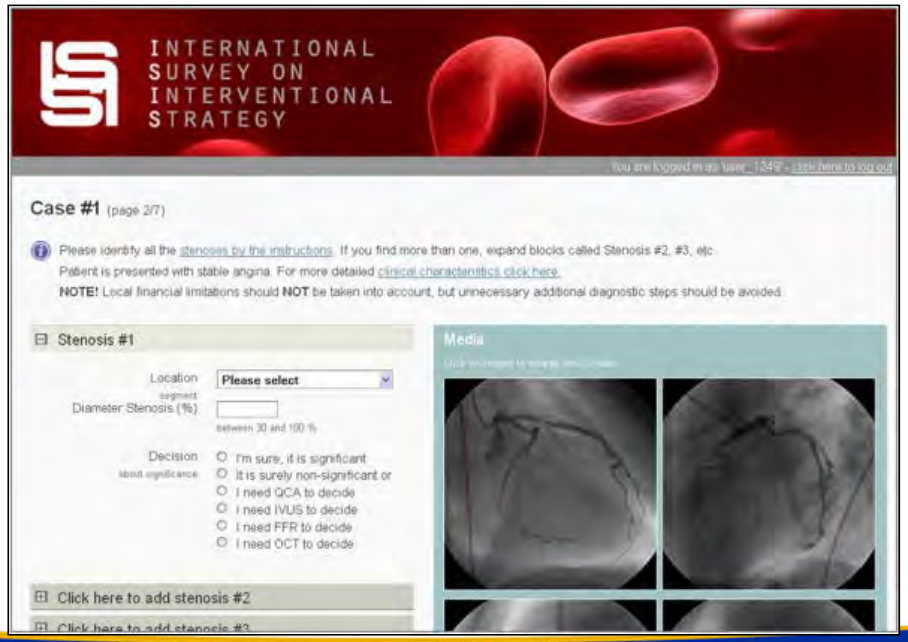
Comparison of percent diameter stenosis:
Clinical interpretation vs. quantitative coronary angiography



Nallamothu, B. Circulation. 2013;127:1793

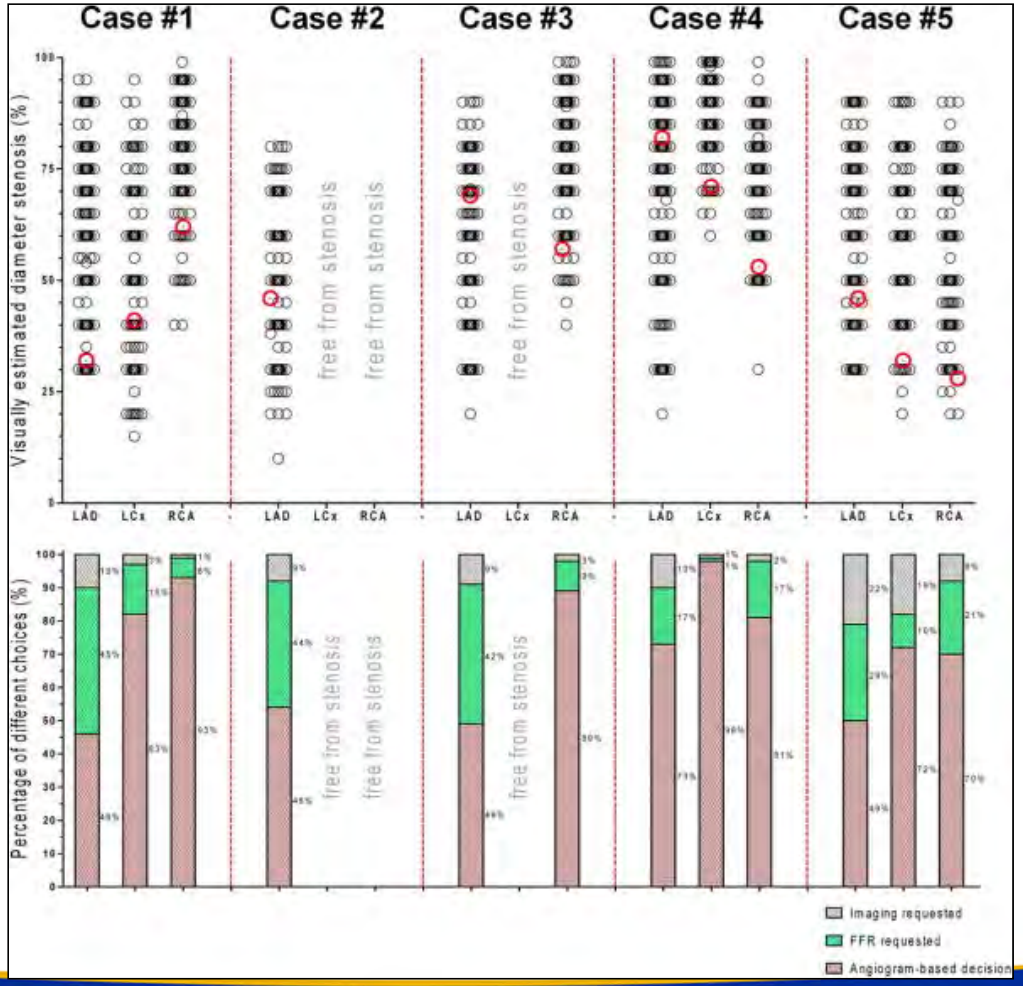
International Survey on Interventional Strategy (ISIS)

- 5 complete web-based angiograms analyzed by 495 experienced IC presenting only focal intermediate stenoses
- FFR and QCA values were known but remained undisclosed
- Determination of stenosis significance was asked for each lesion
- In cases of uncertainty, participants were allowed to chose adjunctive testing, including FFR, IVUS or OCT



Toth G, et al., Circ Cardiovasc Interv. 2014;7(6):751-9.

International Survey on Interventional Strategy (ISIS)



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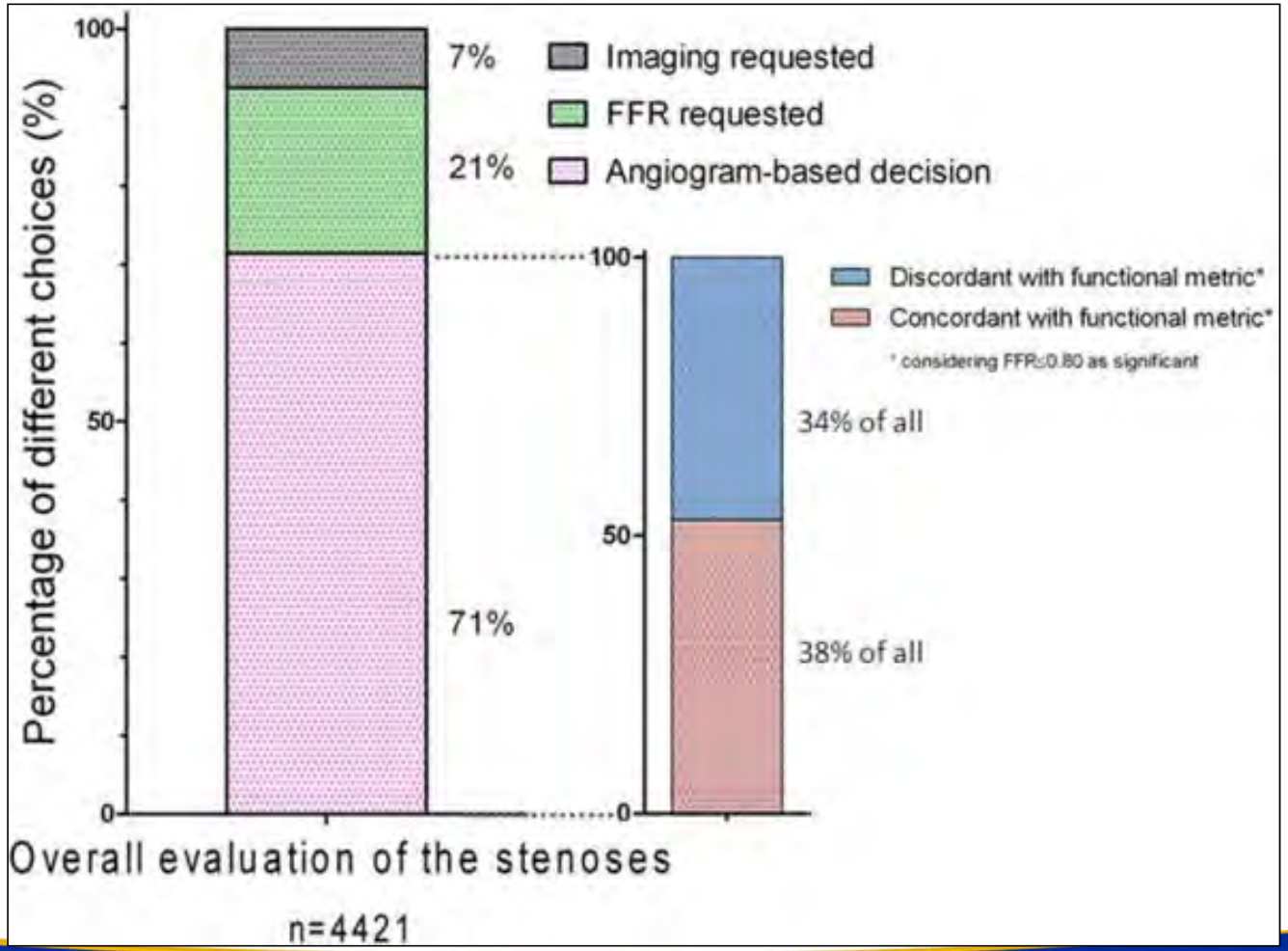
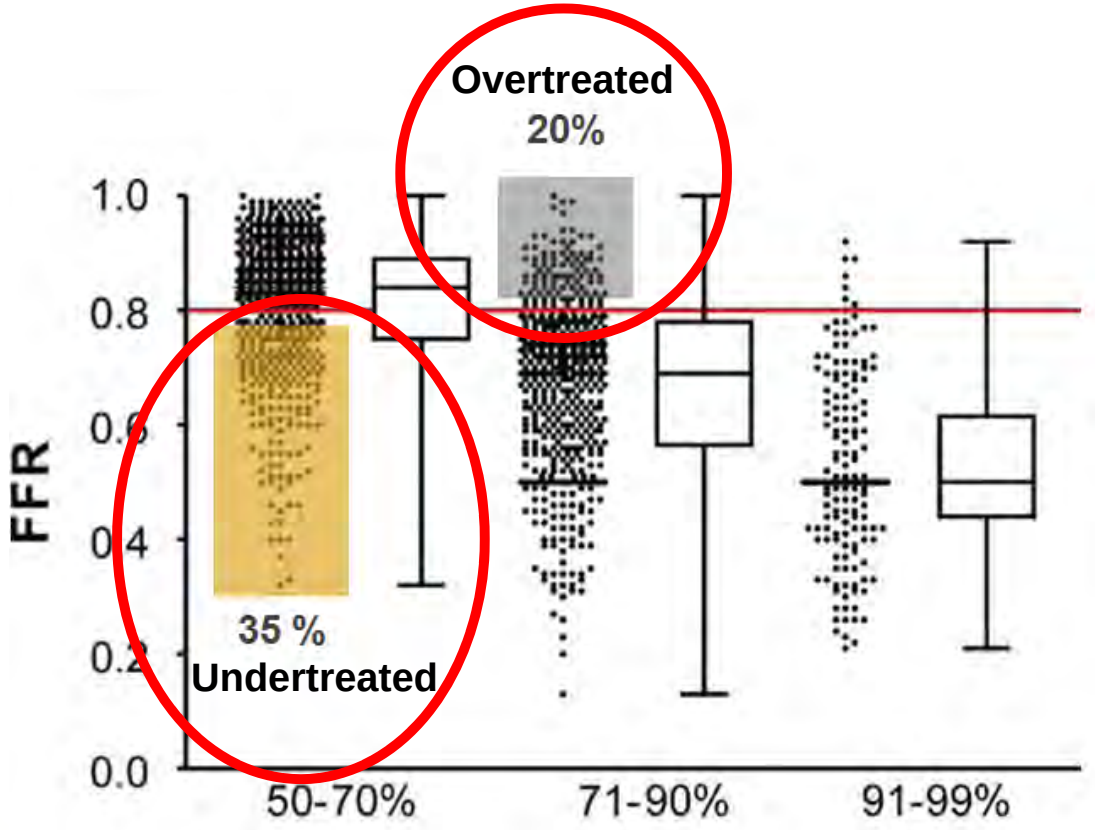
International Survey on Interventional Strategy (ISIS)



Toth G, et al., Circ Cardiovasc Interv. 2014;7(6):751-9.

STENOSIS CLASSIFICATION BY ANGIOGRAPHY VS FFR



Tonino J Am Coll Cardiol. 2010;55(25):2816-21

There are only 2 fundamental questions in Interventional Cardiology

1) Should I treat?
2) How should I treat - or do the best job treating?

Everything else is commentary

**“Why do I need to image?
I have great results.”**

TWENTE 5-Years: Clinical Events

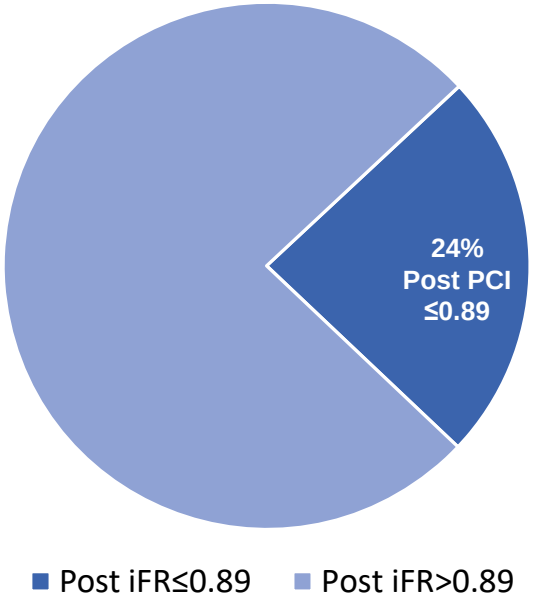
	RESOLUTE ZES	XIENCE V EES	Hazard Ratio (95% CI)	Log-Rank *P*
Death, any	62 (9.0)	80 (11.6)	0.77 (0.55 – 1.07)	0.12
Cardiac death	25 (3.7)	35 (5.2)	0.71 (0.42 – 1.18)	0.18
Myocardial infarction, any	49 (7.2)	52 (7.7)	0.94 (0.63 – 1.38)	0.73
Target vessel myocardial infarction	46 (6.8)	45 (6.6)	1.02 (0.67 – 1.53)	0.94
Revascularization, any	95 (14.1)	105 (15.9)	0.90 (0.68 – 1.18)	0.43
Target vessel revascularization (TVR)	60 (8.9)	69 (10.5)	0.86 (0.61 – 1.22)	0.41
Target lesion revascularization (TLR)	47 (7.0)	50 (7.7)	0.94 (0.63 – 1.40)	0.77
Target vessel failure (TVF)	110 (16.1)	123 (18.1)	0.89 (0.69 – 1.15)	0.36
Target lesion failure (TLF)	102 (15.0)	110 (16.2)	0.93 (0.71 – 1.21)	0.58
Major adverse cardiac events (MACE)	138 (19.9)	157 (22.7)	0.88 (0.70 – 1.10)	0.26
Patient-oriented composite endpoint (POCE)	176 (25.4)	196 (28.4)	0.89 (0.73 – 1.10)	0.27
Definite-or-probable stent thrombosis	13 (1.9)	14 (2.1)	0.92 (0.43 – 1.96)	0.83
Definite stent thrombosis	7 (1.0)	4 (0.6)	1.74 (0.51 – 5.94)	0.37

Data are frequencies (%) and Hazard Ratio (95% Confidence Interval).
Target vessel and target lesion revascularizations were clinically indicated.

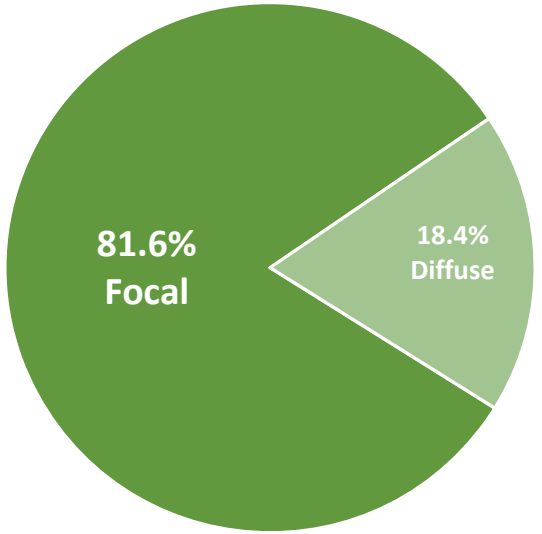
DEFINE PCI

Post-PCI Physiology Assessment

467 Patients with Angiographically Successful PCI and qualified iFR pullbacks



24% Residual Ischemia (112 patients with Post PCI iFR≤0.89)



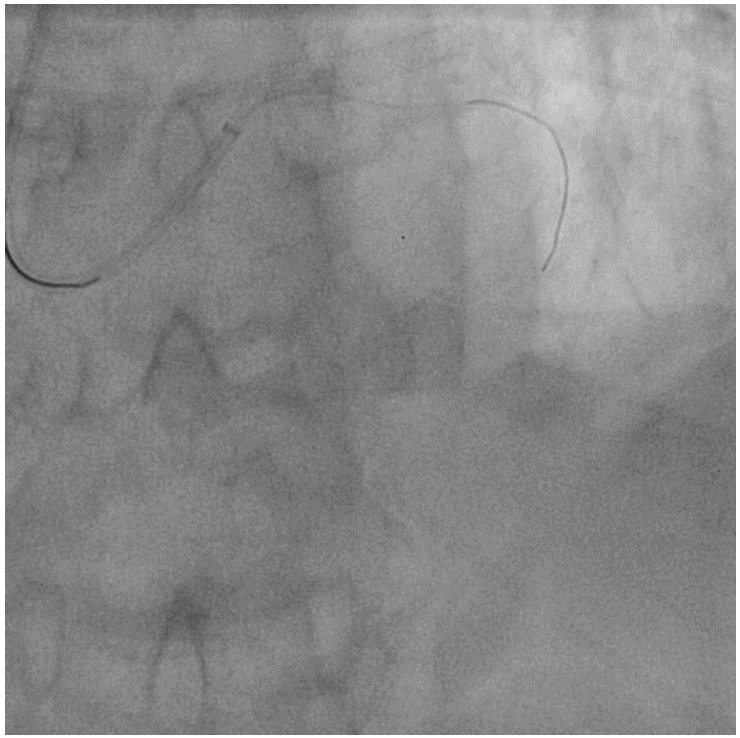
Focal defined as step-up of ≥0.03 units in ≤15 mm segment
Diffuse defined as >15 mm segment

Jeremias, A et al. JACC Cardiovasc Interv. 2019;12:1991-2001

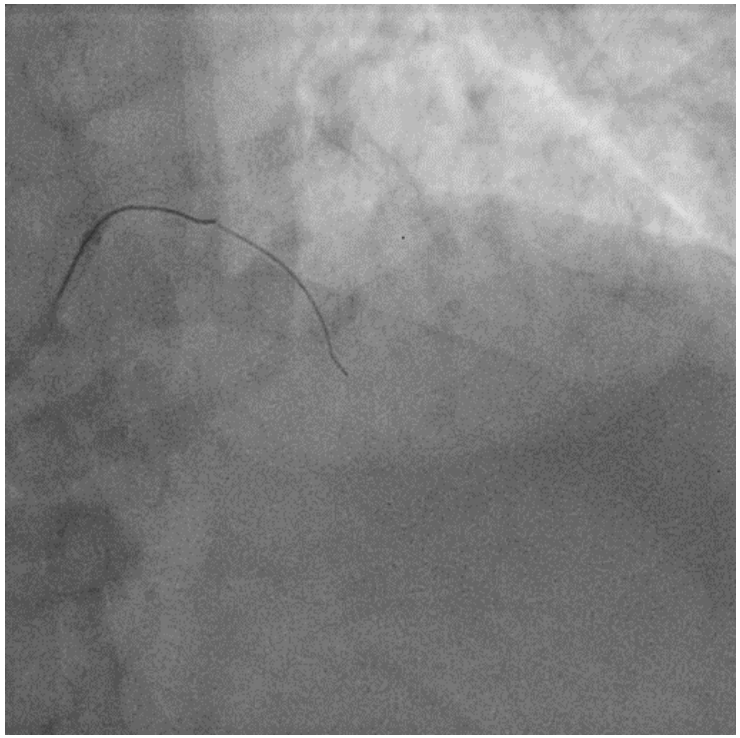
DEFINE PCI

Case example

Pre Angiogram



Final Angiogram

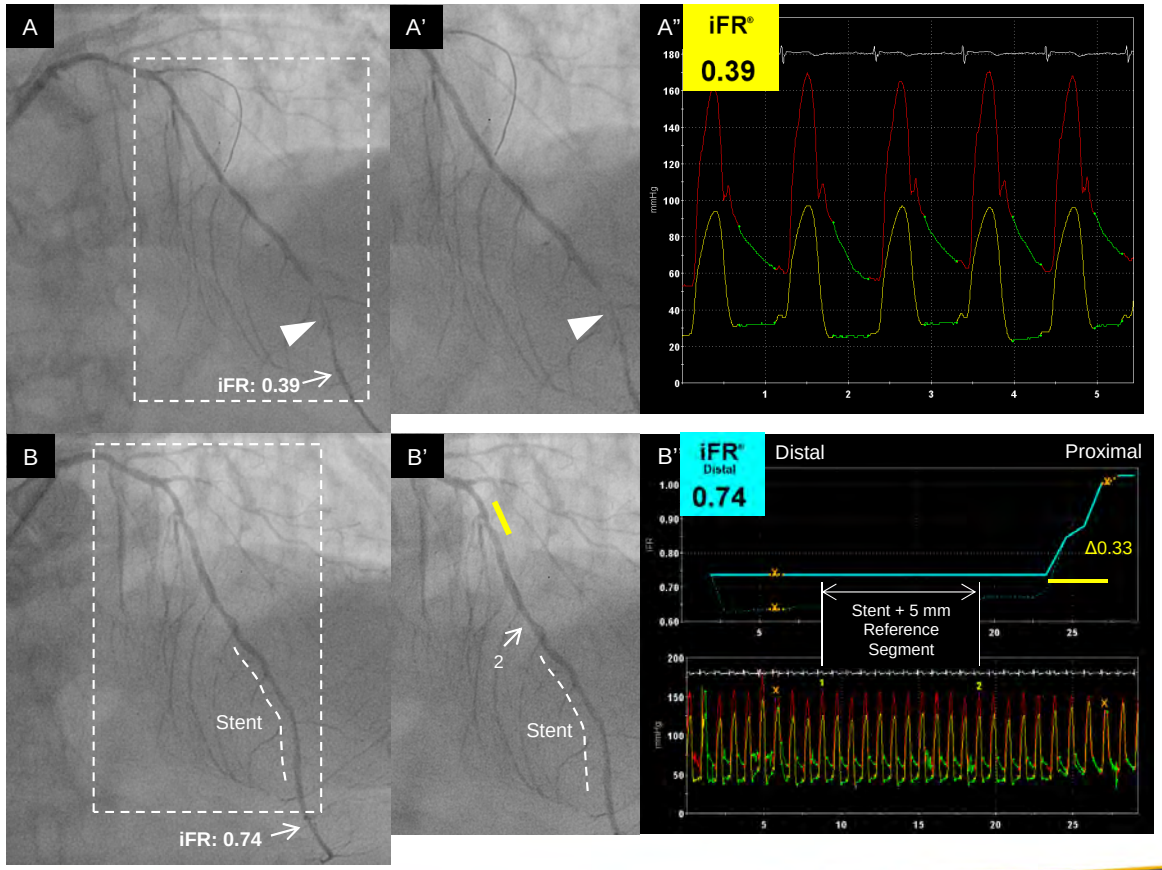


DEFINE PCI

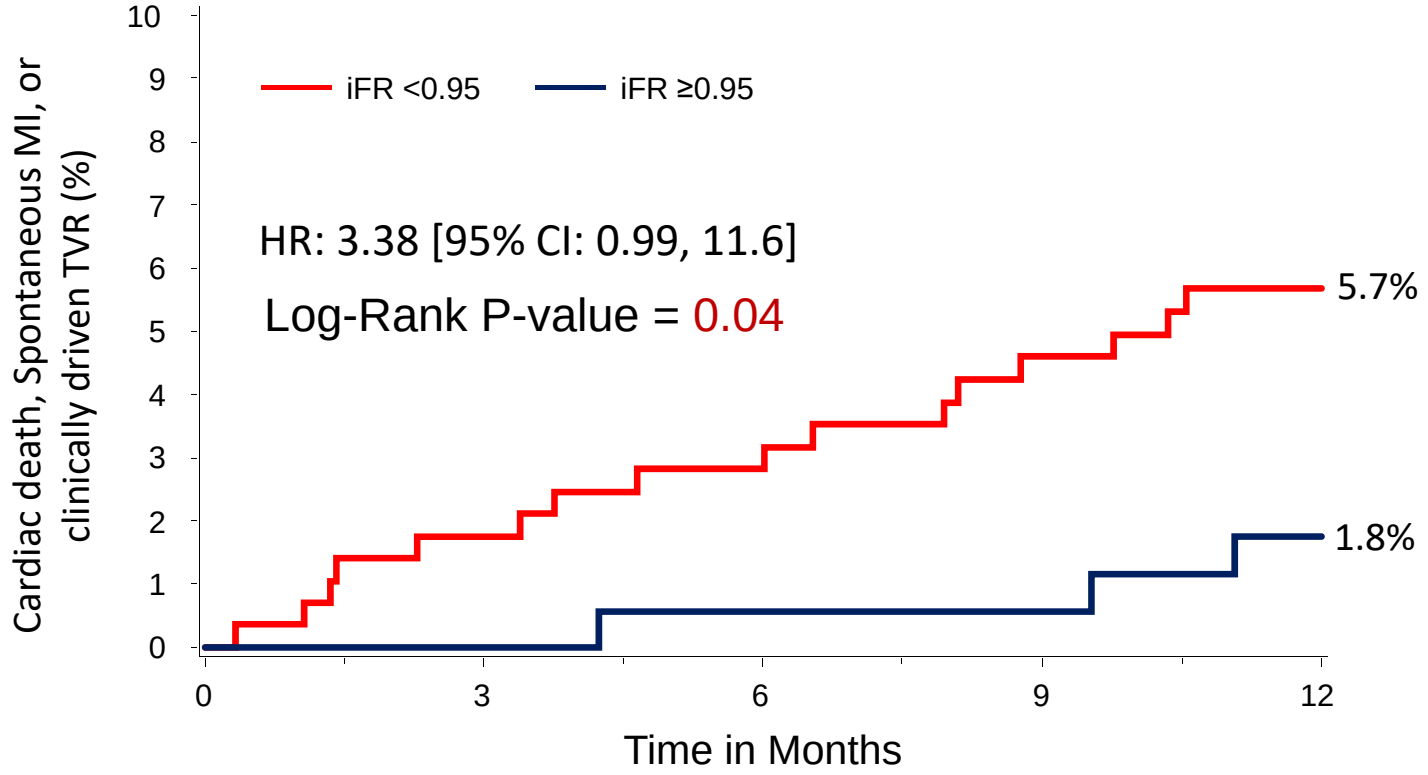
Case example

Pre-PCI

Post-PCI



Cardiac Death, Spontaneous MI, or Clinically Driven TVR



Number at risk:

iFR <0.95	285	279	275	264	252
iFR ≥0.95	182	179	175	166	162

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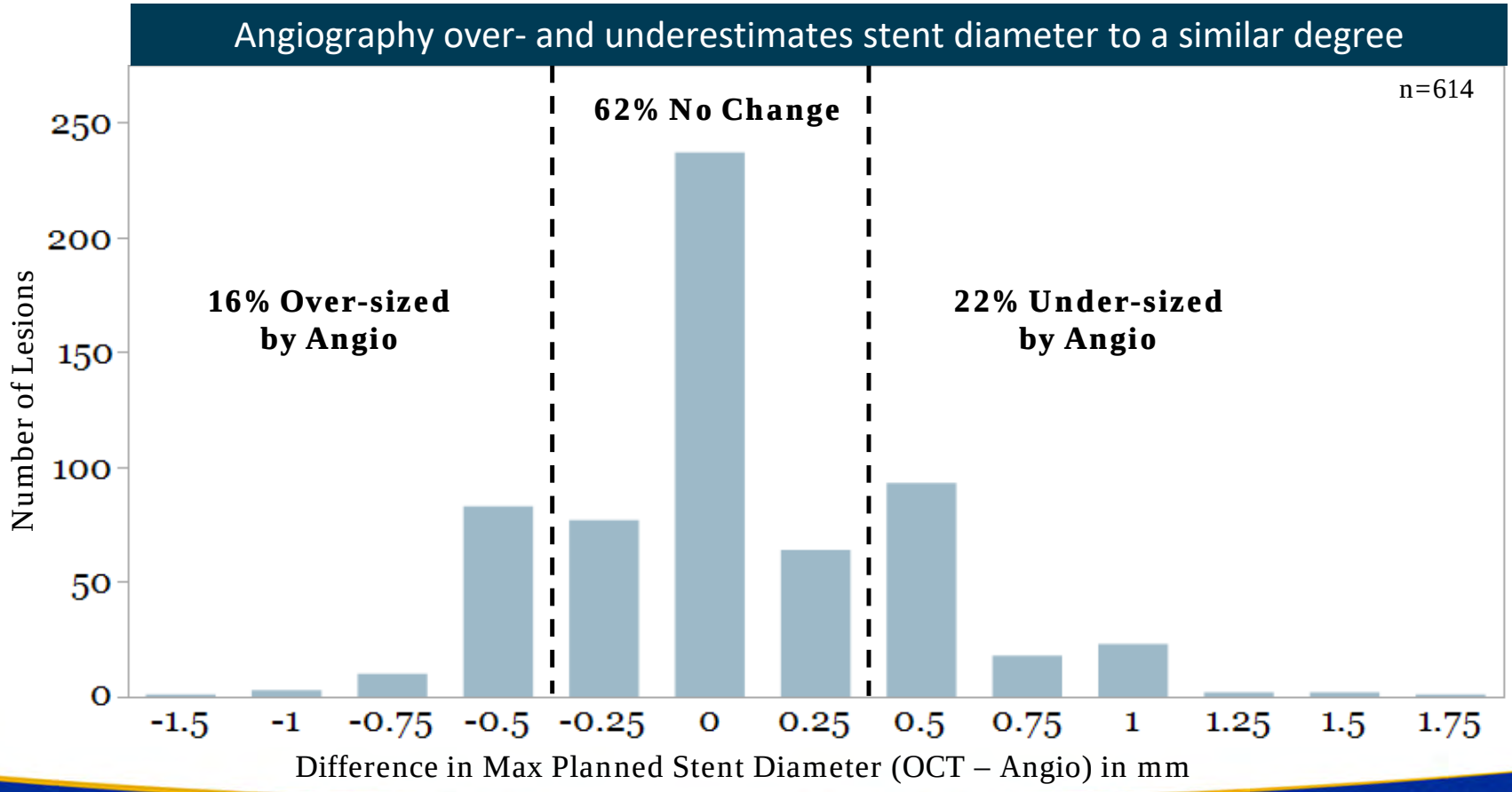
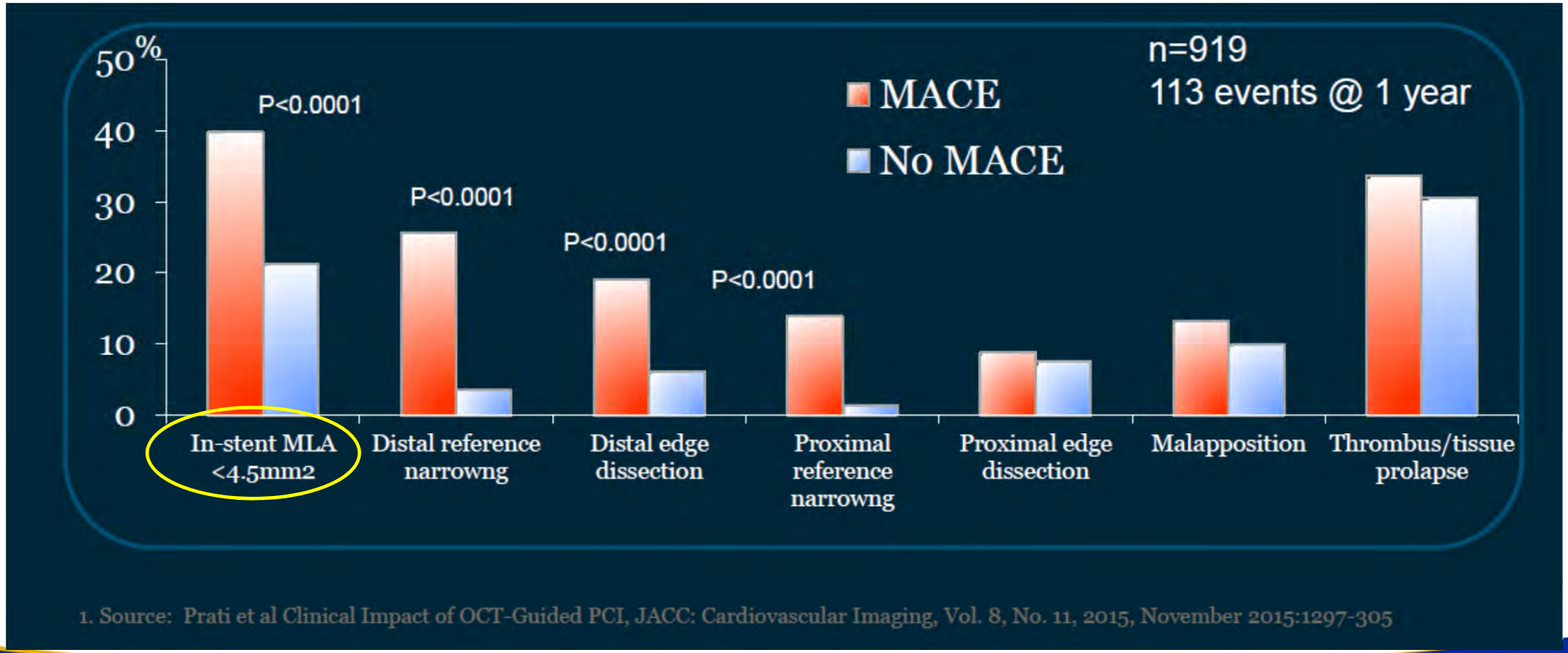
Angiographic guidance leads to inaccurate stent diameter in 38% of stented lesions



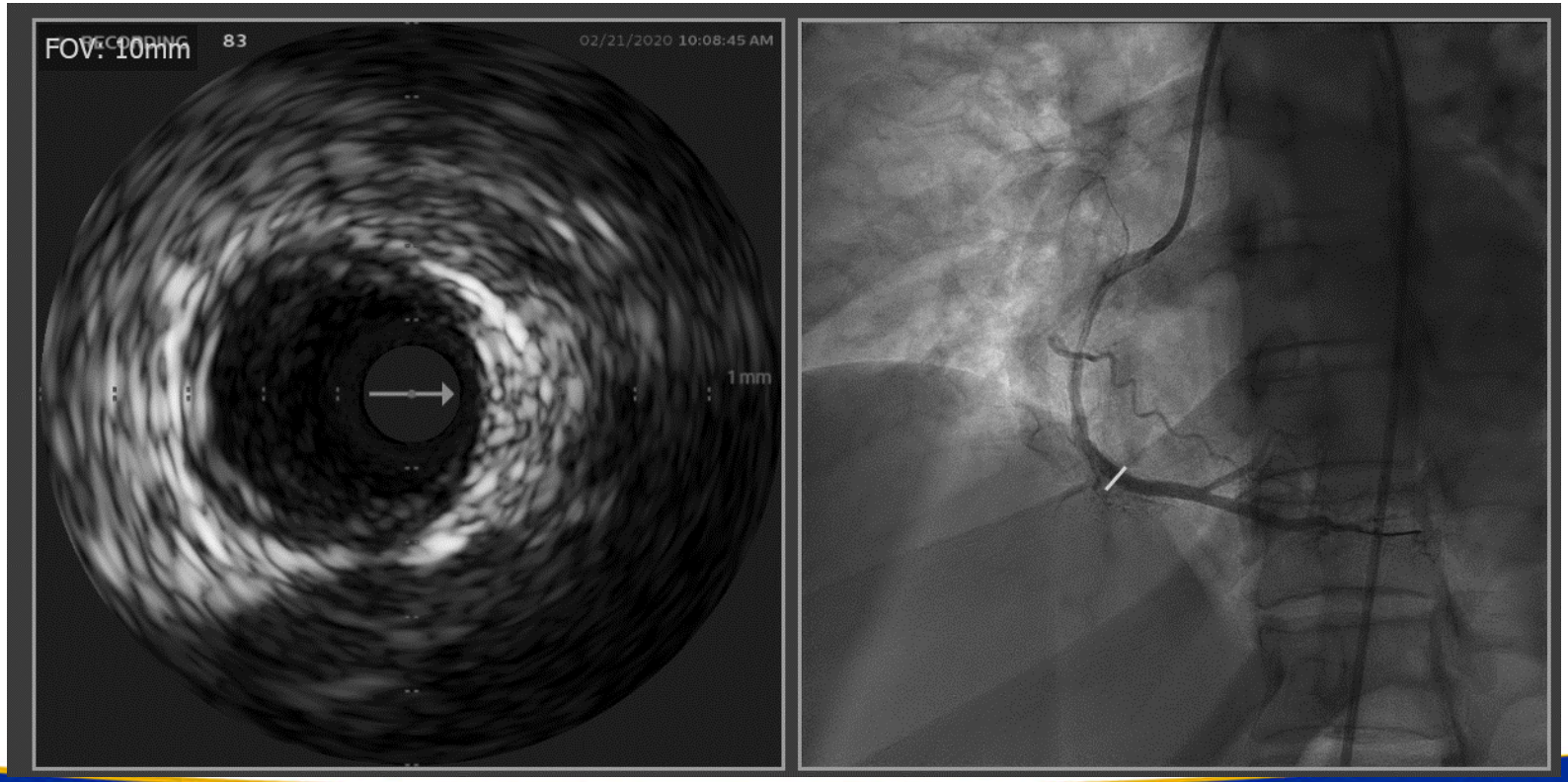
Stent Size and Under Expansion Main Predictor of Stent Failure



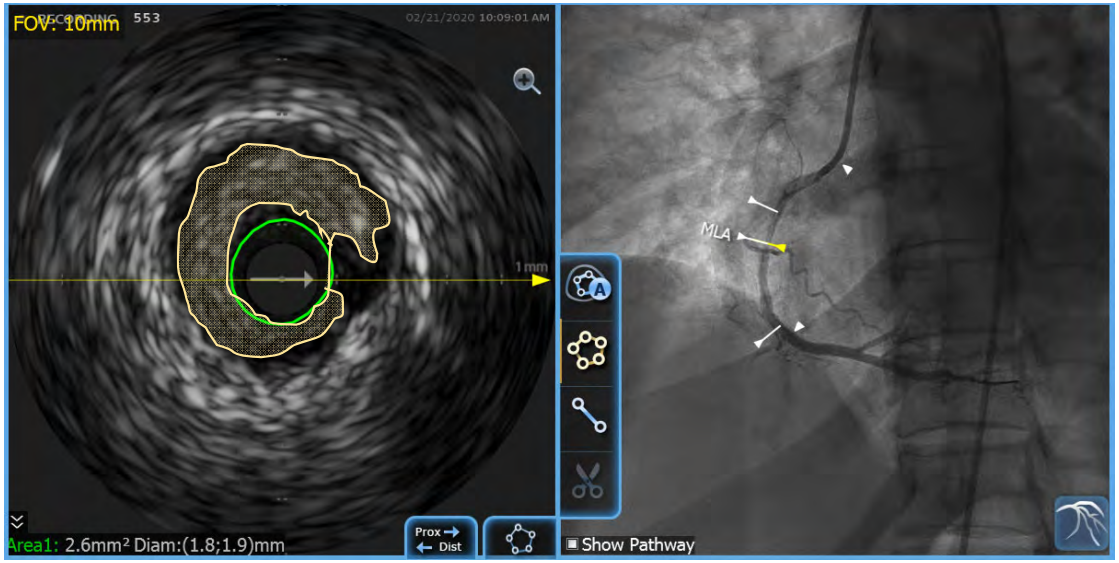
1. Source: Prati et al Clinical Impact of OCT-Guided PCI, JACC: Cardiovascular Imaging, Vol. 8, No. 11, 2015, November 2015:1297-305

Standard PCI Practice

How would you treat this lesion?



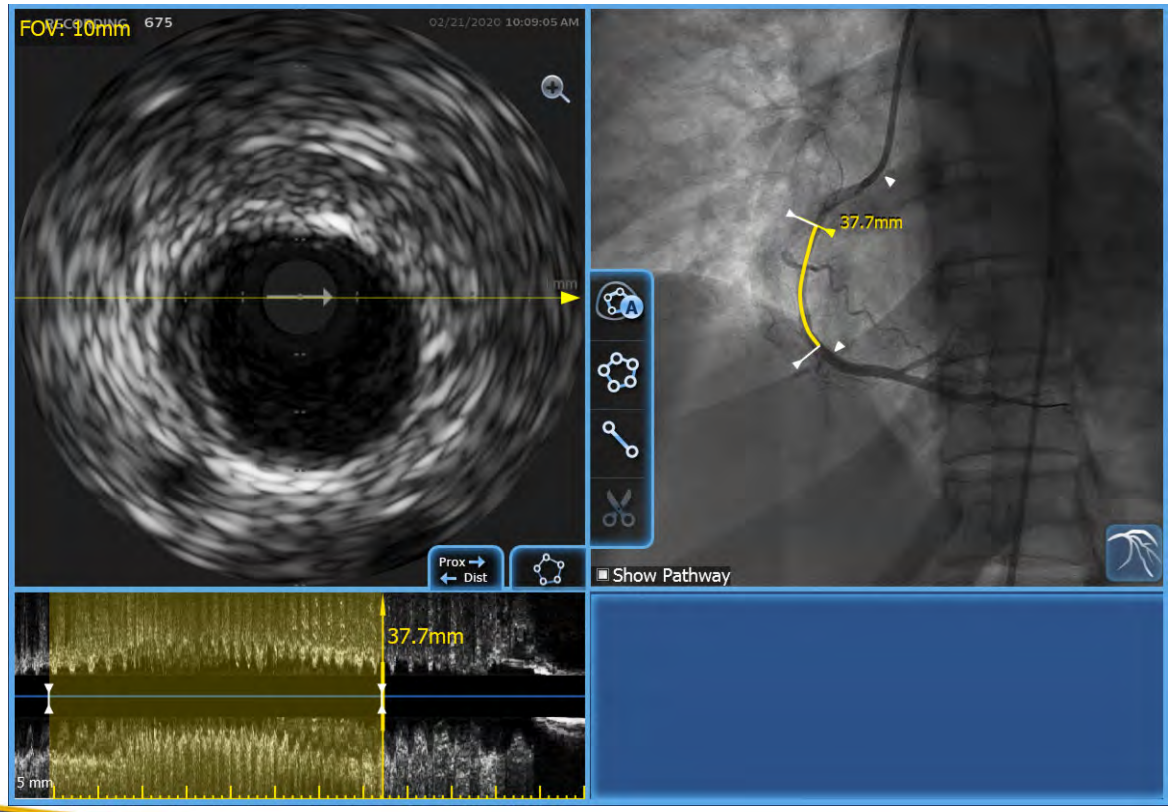
MLD MAX Step-by-Step Assessment



Morphology:

- Fibrous and lipidic lesion

MLD MAX Step-by-Step Assessment



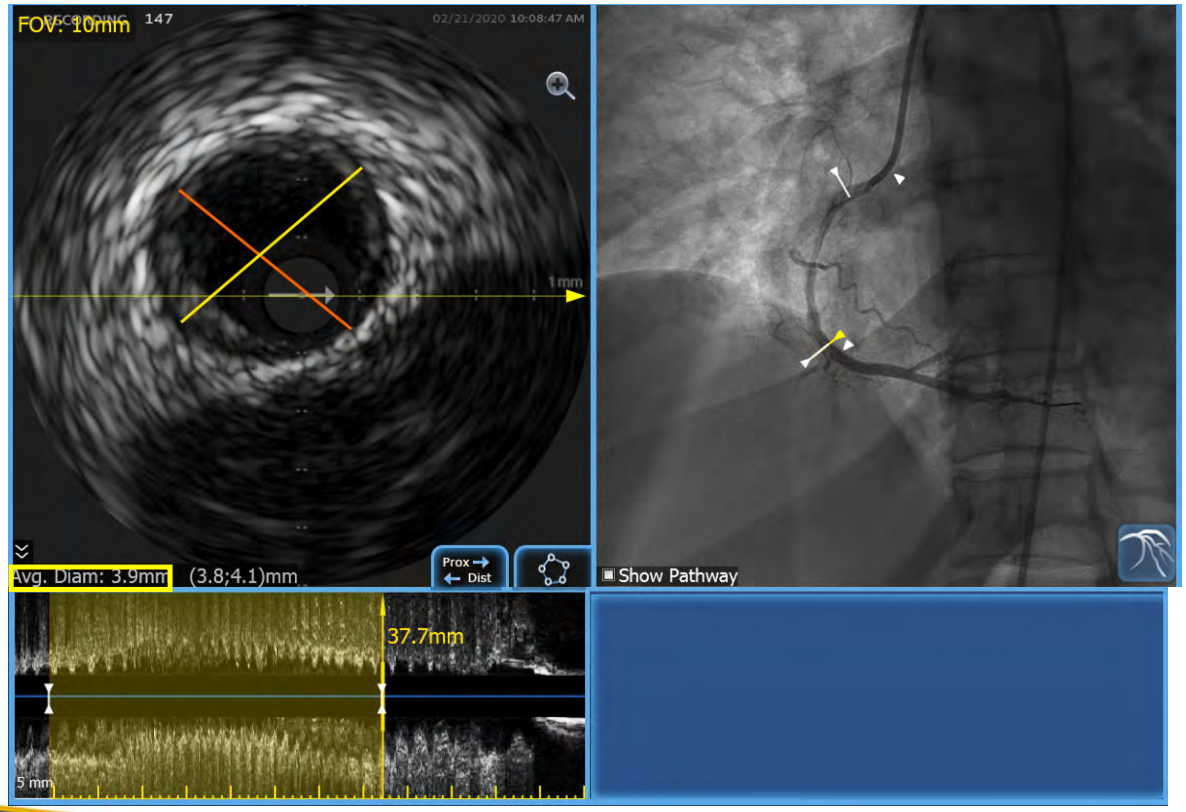
Morphology:

- Fibrous and lipidic lesion

Length:

- Angiographic – 15 mm
- IVUS Sync Vision – 38 mm

MLD MAX Step-by-Step Assessment



Morphology:

- Fibrous and lipidic lesion

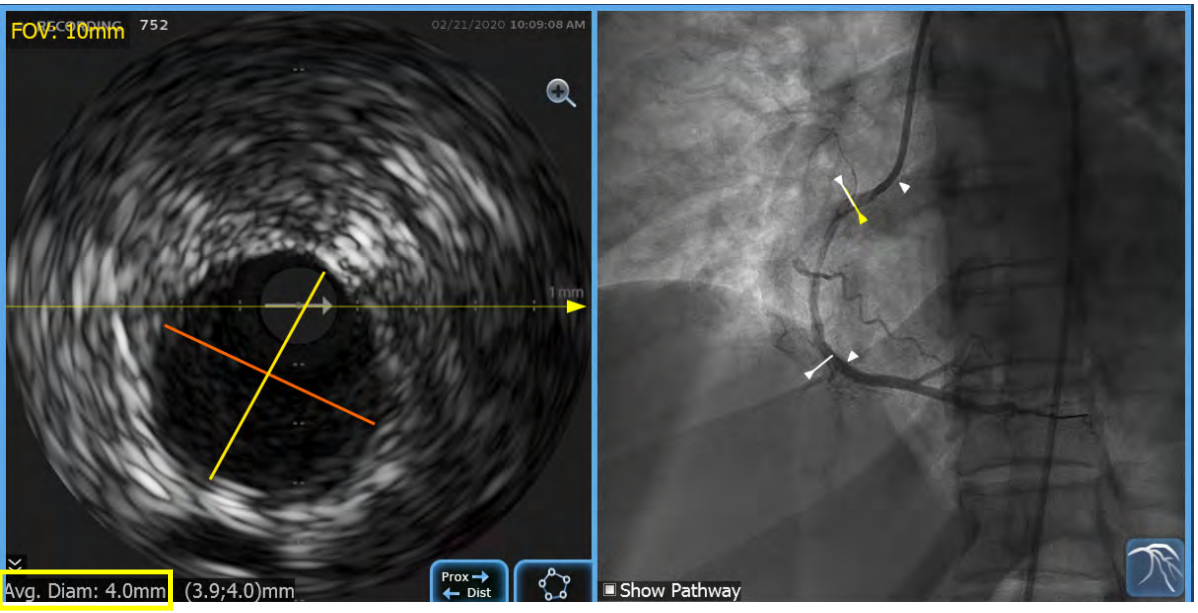
Length:

- Angiographic – 15 mm
- IVUS Sync Vision – 38 mm

Diameter:

- Distal – 3.9 mm → 3.5 x 38 mm EES

MLD MAX Step-by-Step Assessment



Morphology:

- **Fibrous and lipidic lesion**

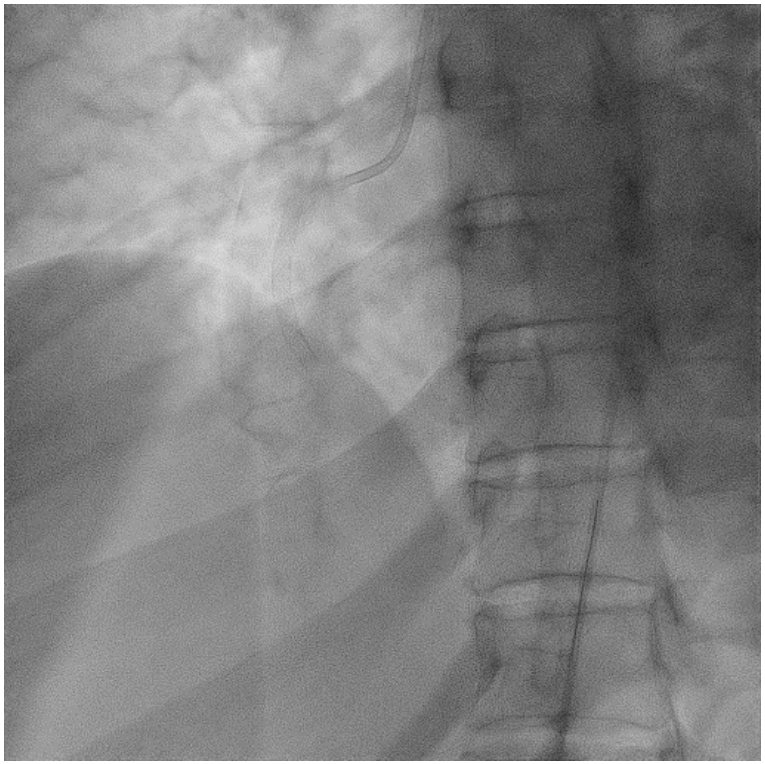
Length:

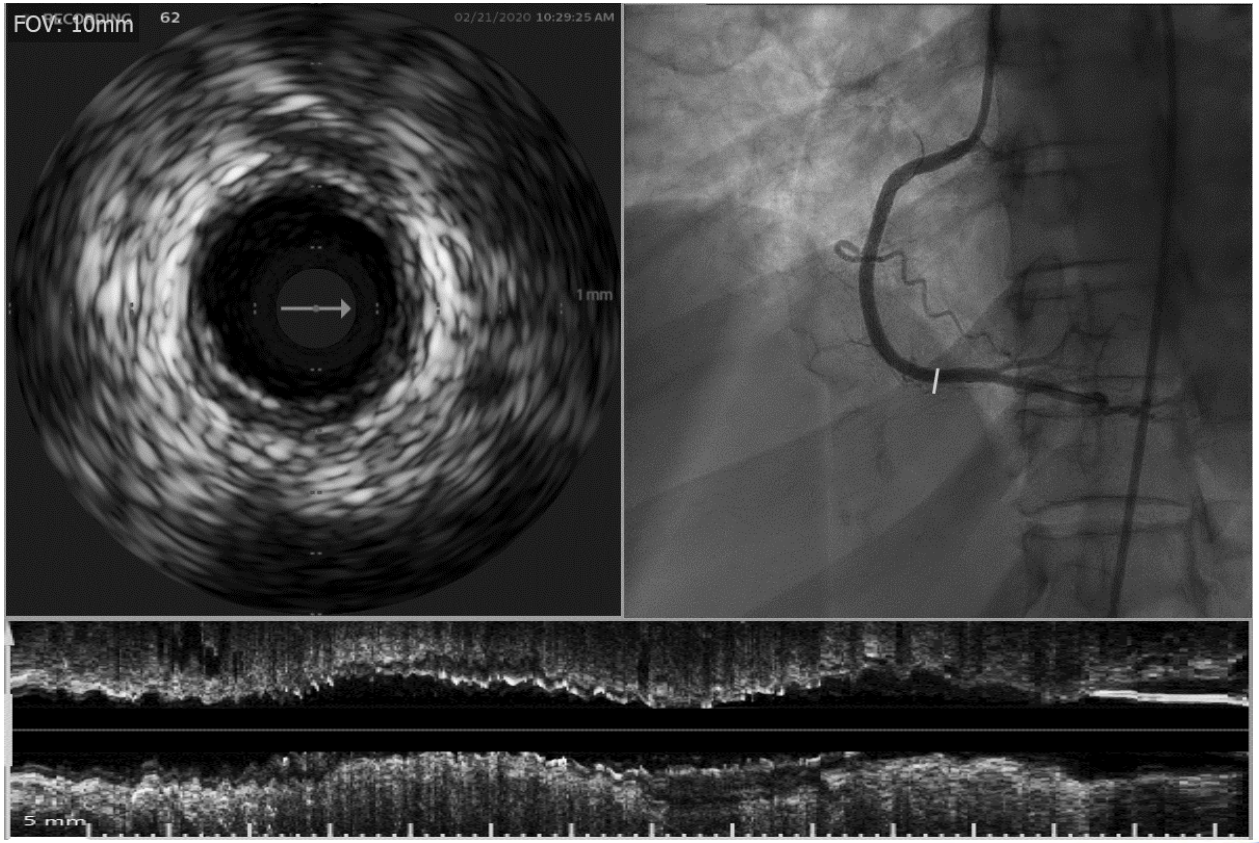
- **Angiographic – 15 mm**
- **IVUS Sync Vision – 38 mm**

Diameter:

- **Distal – 3.9 mm → 3.5 x 38 mm EES**
- **Prox – 4.0 → post dil 3.75 mm NC**

Final

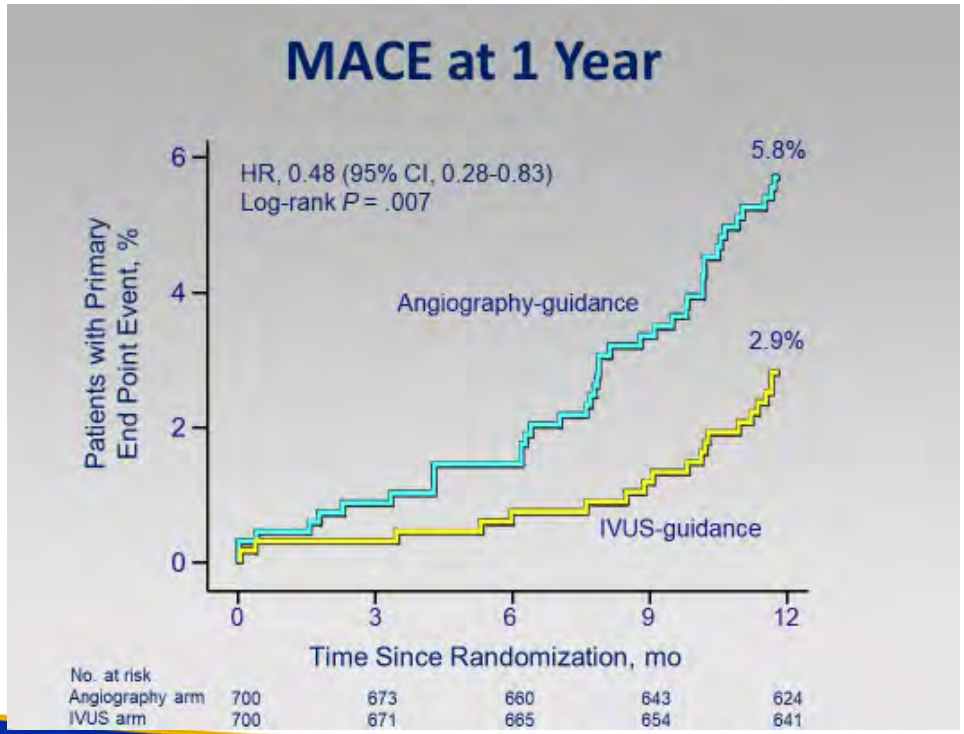




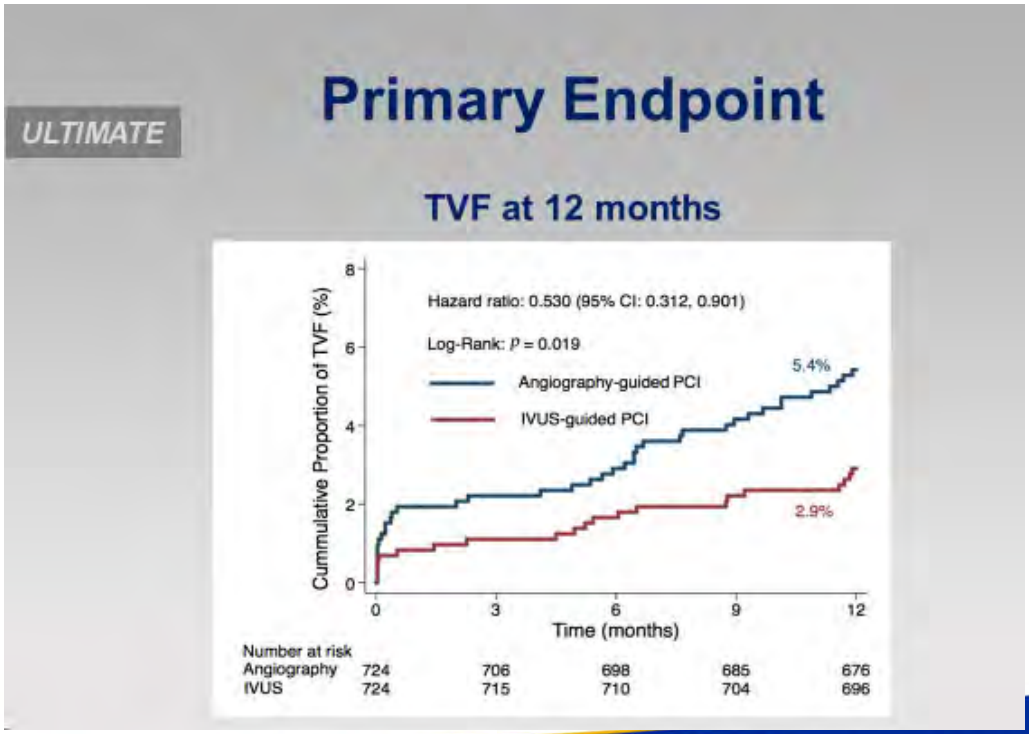
What makes it a Precision PCI?

IMAGING

IVUS XPL



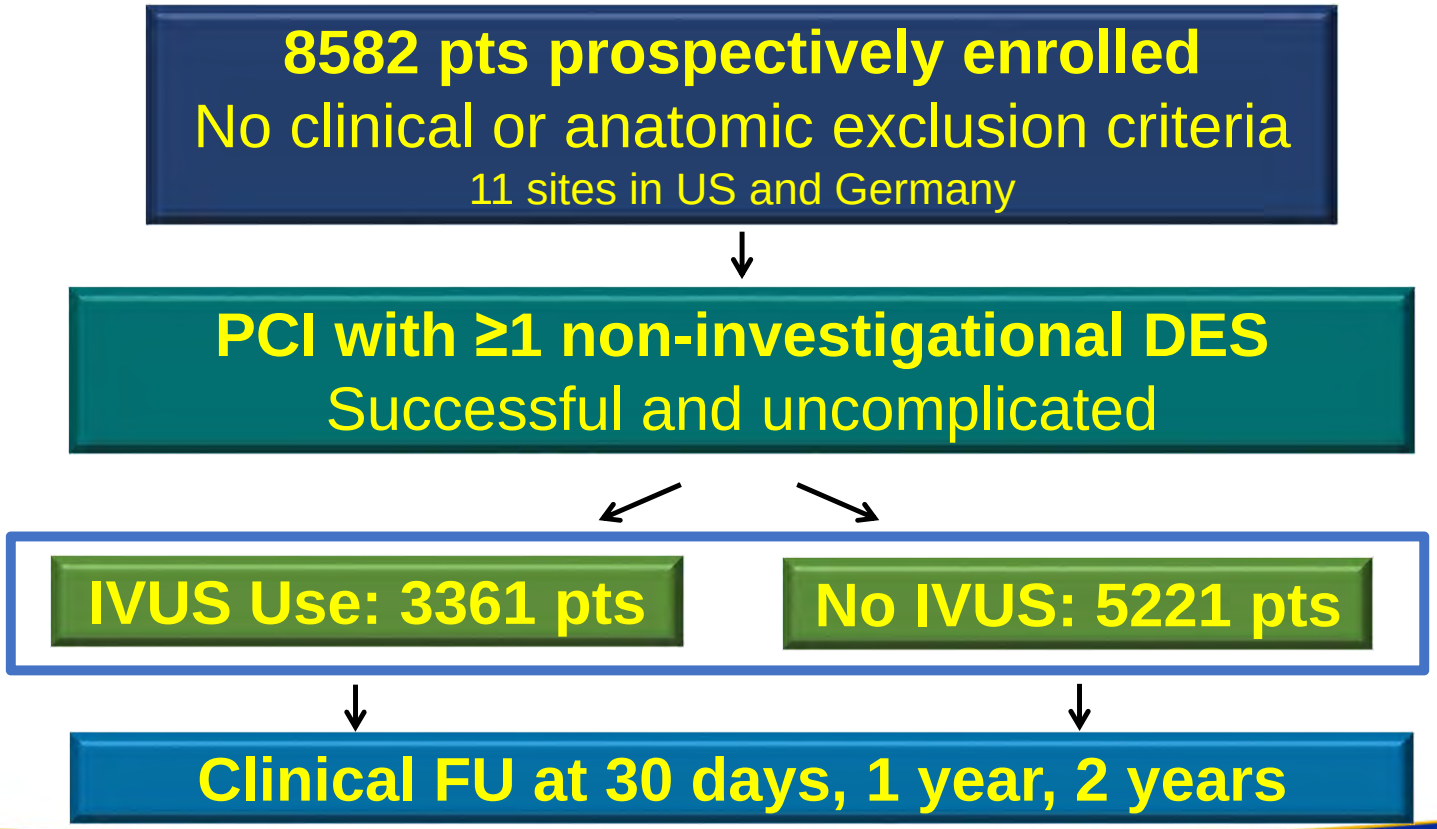
ULTIMATE



“Where is the data?”

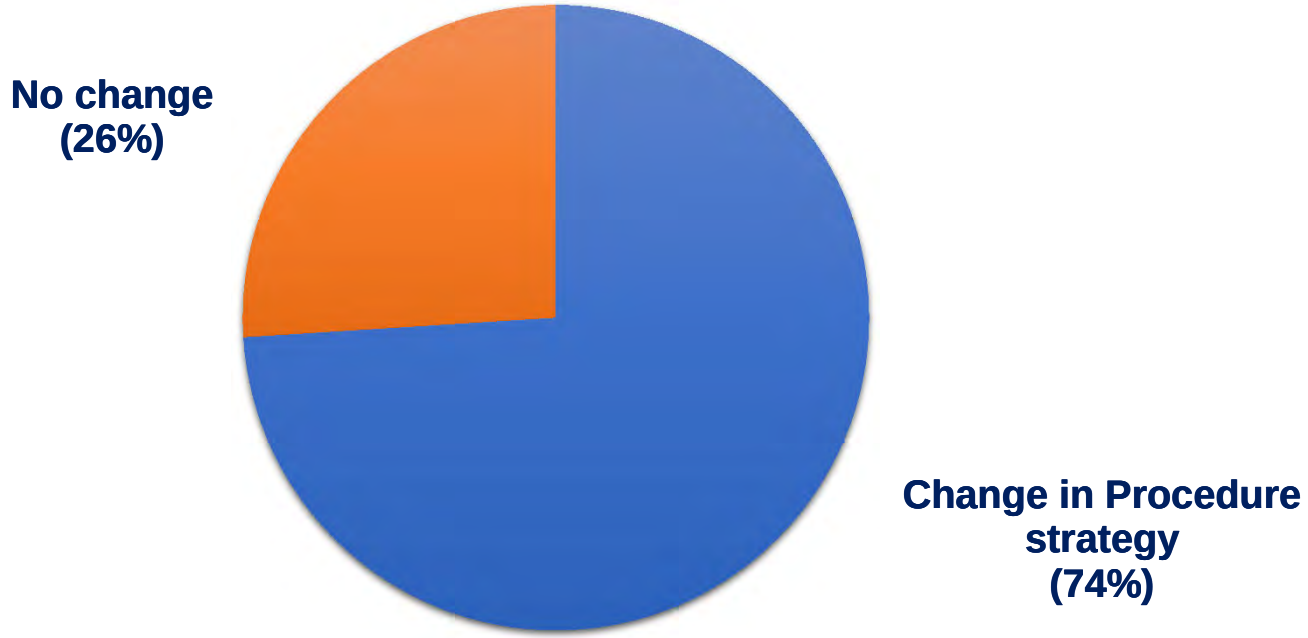
ADAPT-DES - Current Cohort -

Assessment of Dual AntiPlatelet Therapy with Drug-Eluting Stents



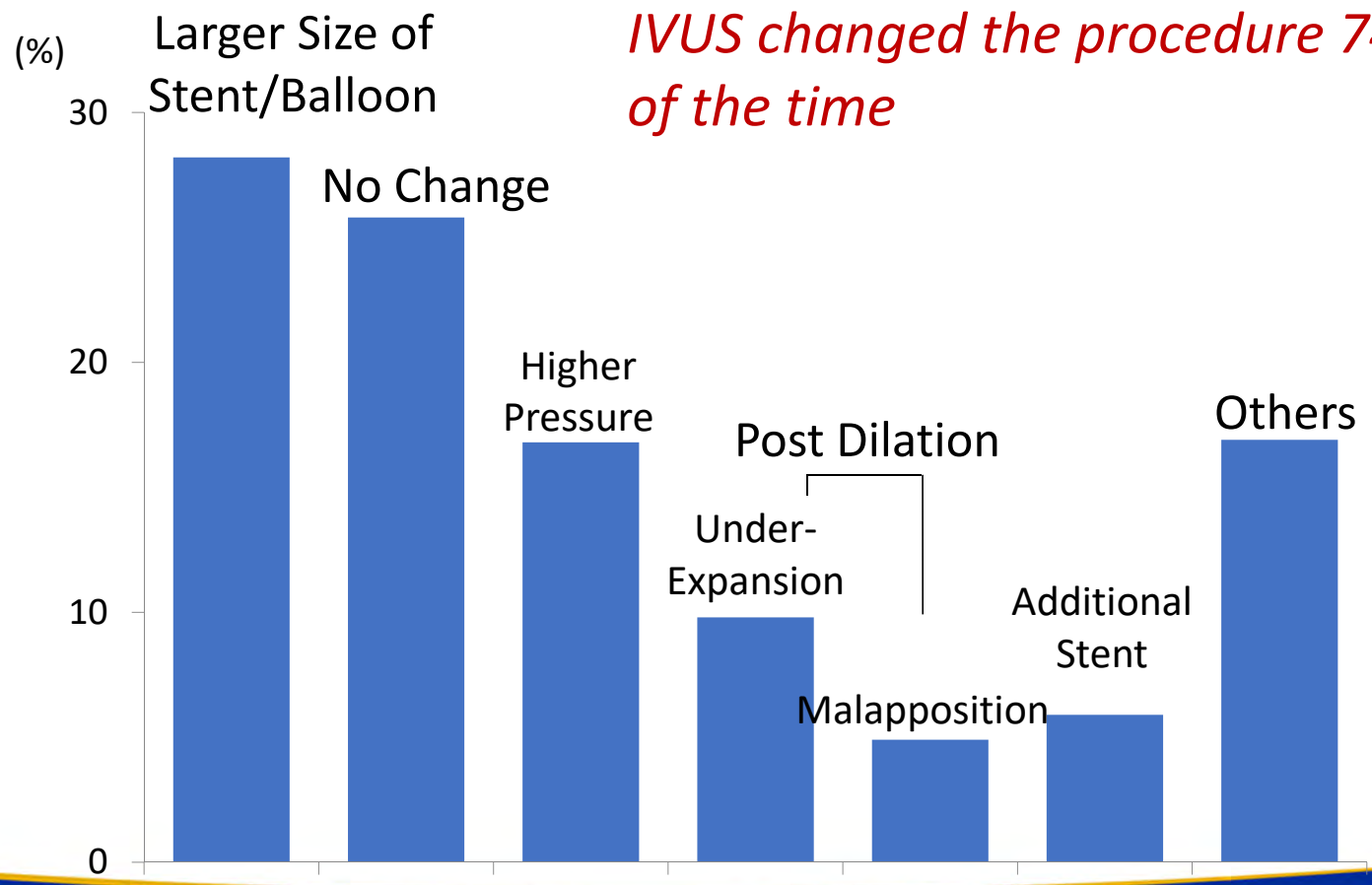
Witzenbichler B et al. Circulation 2014;129,4;463-470.

IVUS Impact on Procedures: ADAPT-DES



Witzenbichler B et al. Circulation 2014;129,4;463-470.

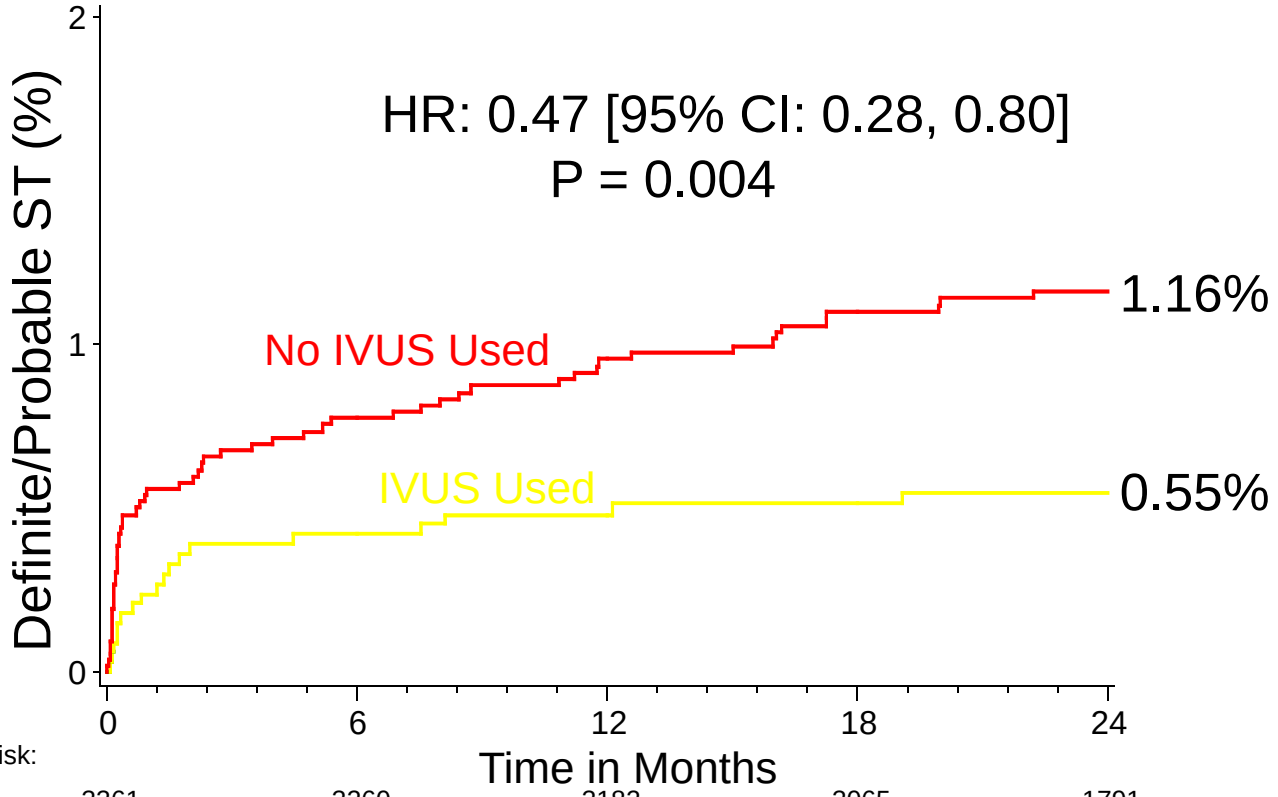
How did IVUS change the procedure?



IVUS changed the procedure 74% of the time

Witzenbichler B et al. Circulation 2014;129,4;463-470.

Relationship Between IVUS Use and Definite/Probable Stent Thrombosis Within 2 Years

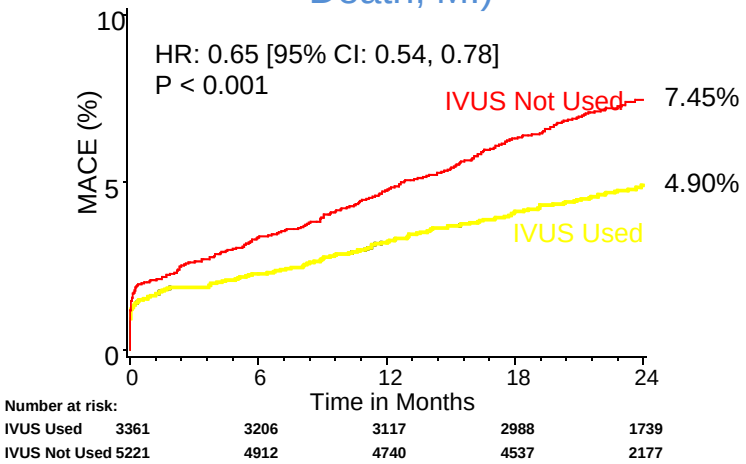


Number at risk:

IVUS Used	3361	3260	3182	3065	1791
IVUS Not Used	5221	5019	4886	4713	2279

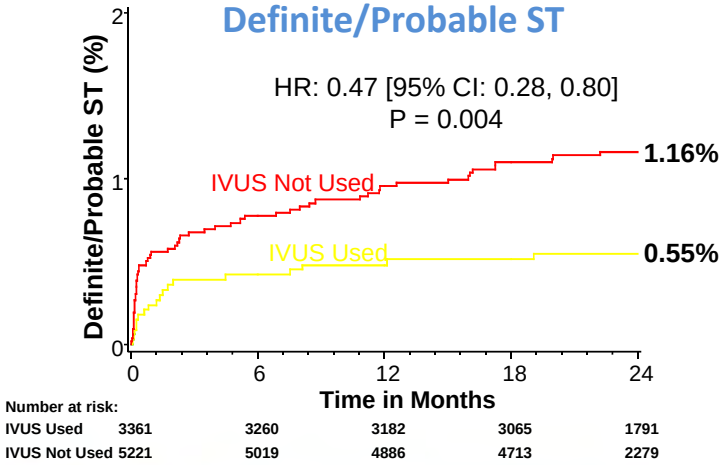
Witzenbichler B et al. Circulation 2014;129,4;463-470.

MACE (Definite/Probable ST, Cardiac Death, MI)

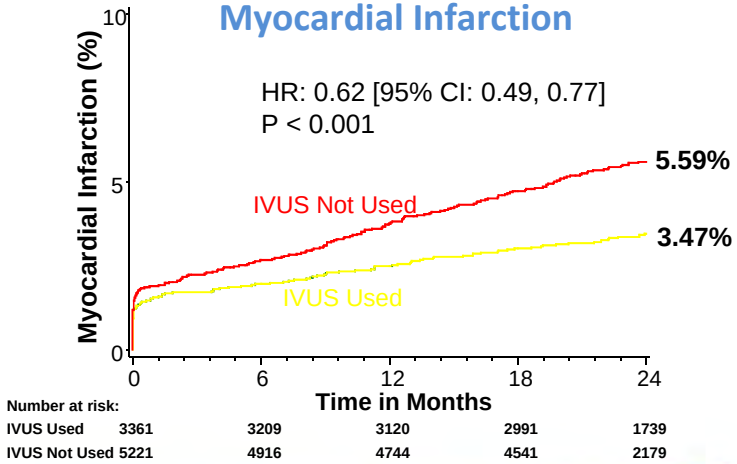


Two year follow-up data from ADAPT-DES (3361 pts treated with IVUS-guidance vs 5221 pts treated with angiographic guidance)

Definite/Probable ST



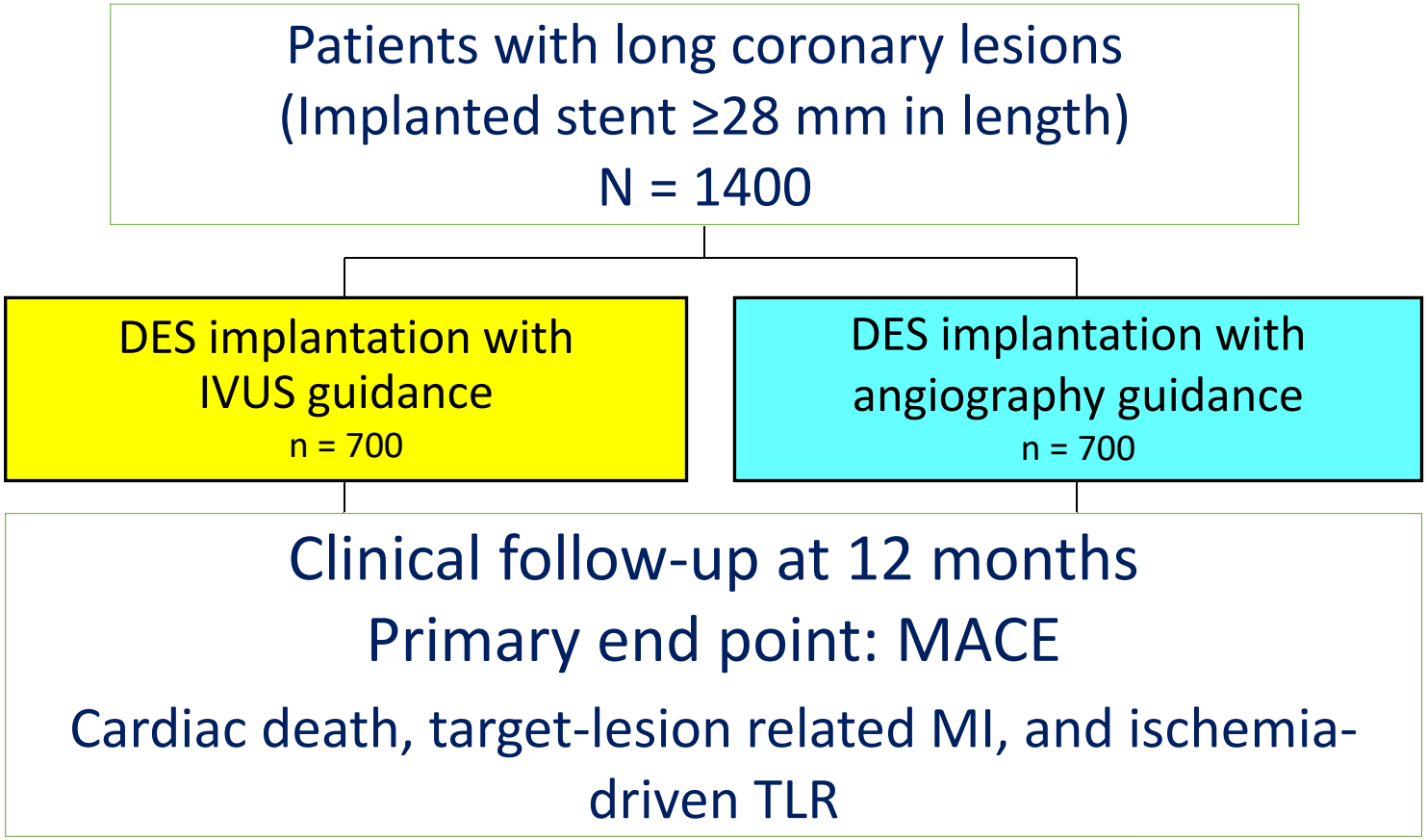
Myocardial Infarction



Maehara et al. J Am Coll Cardiol 2013;62:B21-B22

“That’s a registry.
Where is the RCT data?”

IVUS-XPL Randomized Clinical Trial



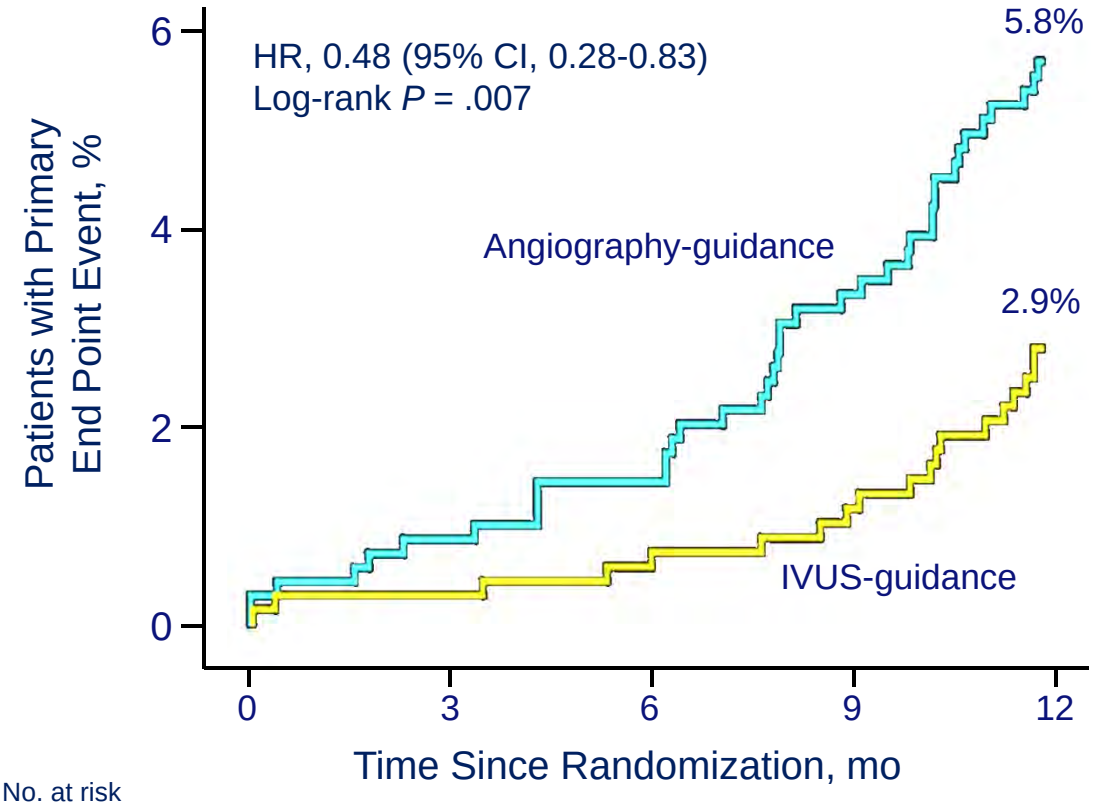
Hong et al. JAMA 2015;314:2155-63

Angiographic and Procedural Characteristics

Characteristics	IVUS-guidance	Angiography-guidance	*P* value
Adjunct post-dilatation	534 (76)	402 (57)	<.001
Final balloon size, mm	3.14 ± 0.43	3.04 ± 0.42	<.001
Overlapping stent	145 (21)	138 (20)	.64
No. of stents per lesions	1.3 (0.5)	1.3 (0.5)	.48
Stent edge dissections	15 (2)	13 (2)	.70
Coronary perforation	0	0	1.00
Maximal inflation pressure, atm	16.5 ± 4.1	15.9 ± 4.1	.052
Post-intervention QCA data			
Reference vessel diameter, mm	3.03 ± 0.44	2.97 ± 0.43	.01
Minimum lumen diameter, mm	2.64 ± 0.42	2.56 ± 0.39	<.001
Diameter stenosis, %	12.79 ± 8.66	13.74 ± 8.05	.04

Hong et al. JAMA 2015;314:2155-63

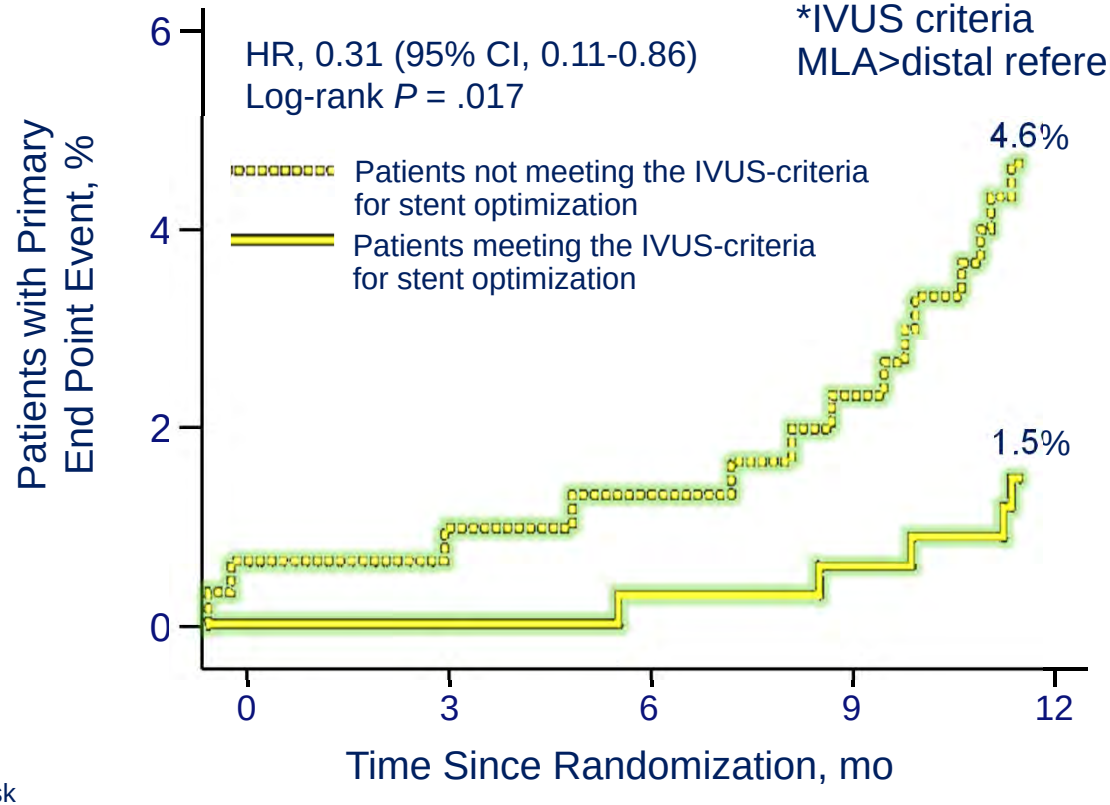
MACE at 1 Year



No. at risk					
Angiography arm	700	673	660	643	624
IVUS arm	700	671	665	654	641

Hong et al. JAMA 2015;314:2155-63

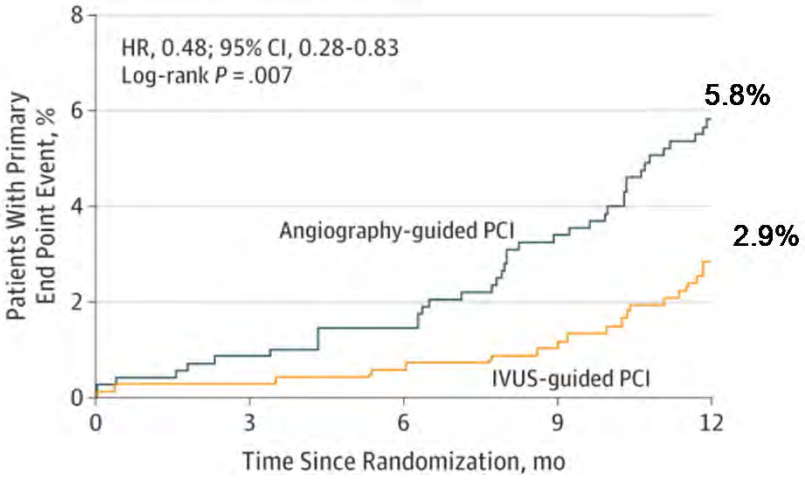
MACE at 1 Year in the IVUS Group



No. at risk					
Not meeting the criteria	315	299	297	394	285
Meeting the criteria	363	362	345	338	334

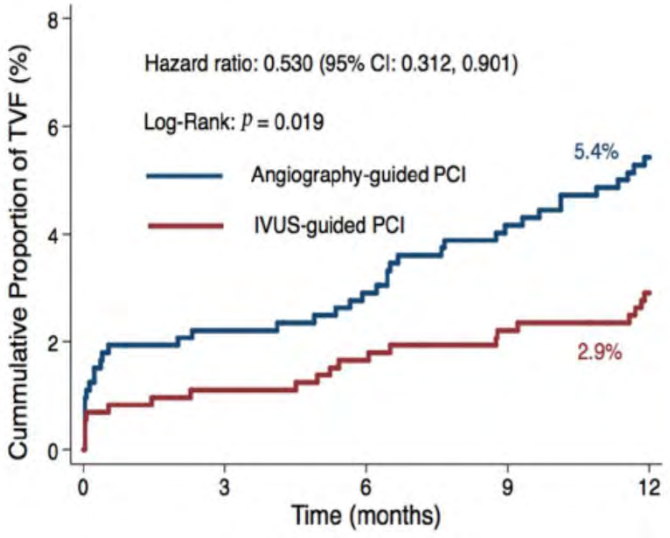
Intravascular Imaging Improves PCI Outcomes

IVUS XPL



Hong, S. JAMA. 2015;314(20)

Ultimate

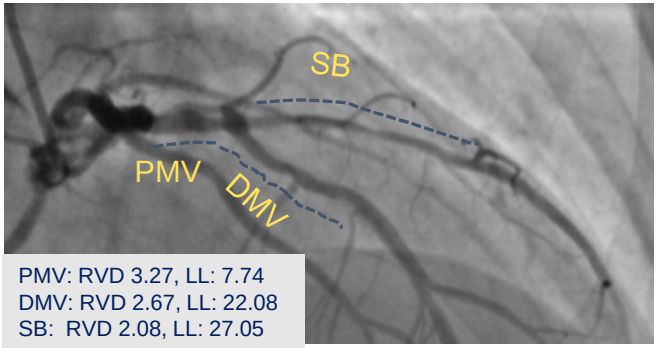


Zhang, J. J Am Coll Cardiol. 2018 Dec 18;72(24)

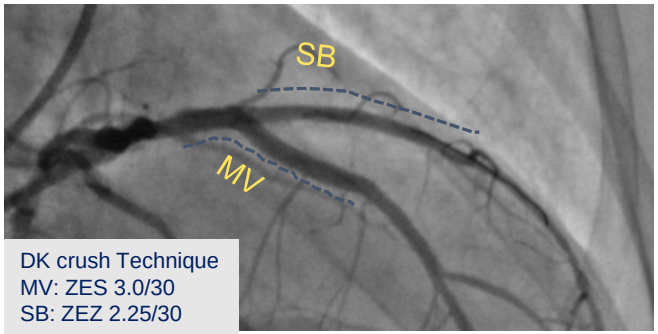
Intravascular imaging cuts stent failure in half!

ULTIMATE

Angiography-guided PCI



PMV: RVD 3.27, LL: 7.74
DMV: RVD 2.67, LL: 22.08
SB: RVD 2.08, LL: 27.05



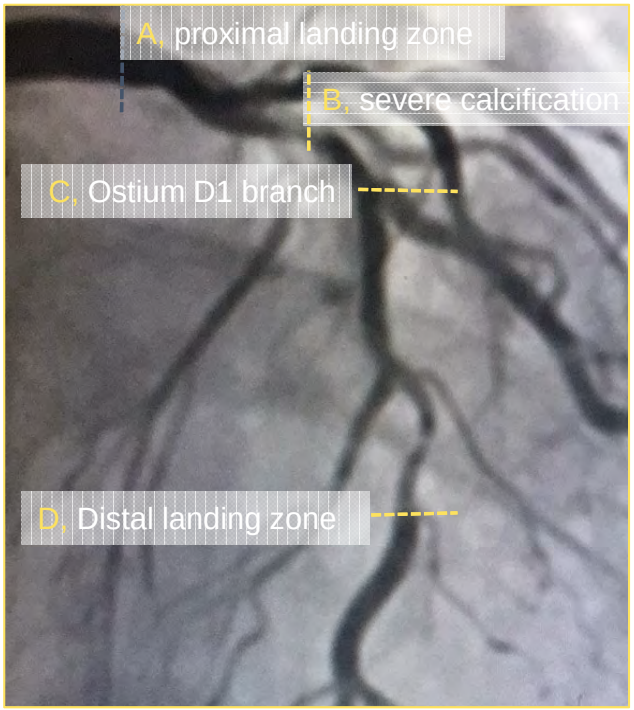
DK crush Technique
MV: ZES 3.0/30
SB: ZEZ 2.25/30

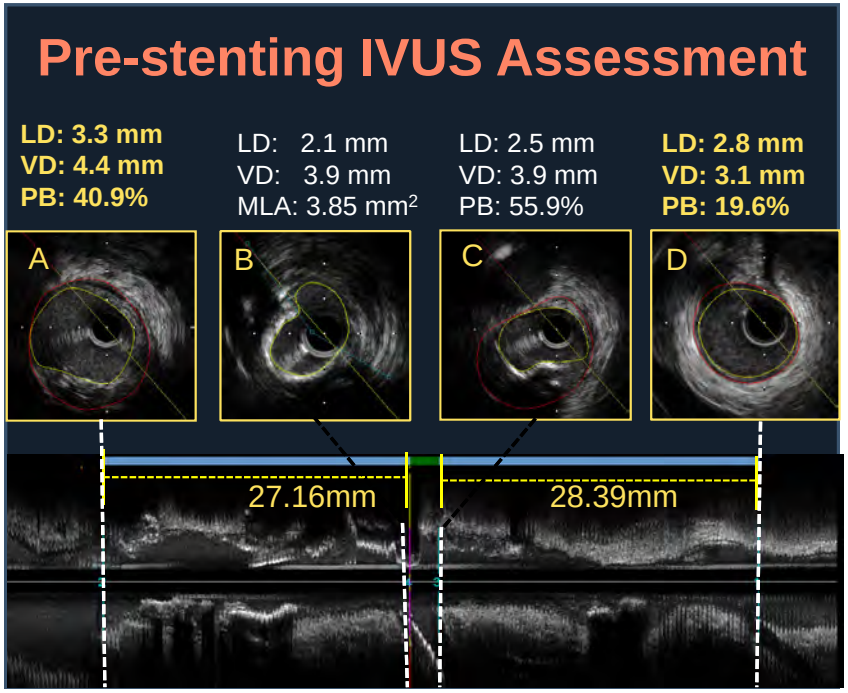
- Stent size by visual estimation
- Routine post-dilation
- Angiographic success
  - ✓ TIMI 3 flow
  - ✓ Residual stenosis <20%
  - ✓ Dissection <Type B

Zhang J, et al. J Am Coll Cardiol 2018.

ULTIMATE

IVUS-guided PCI

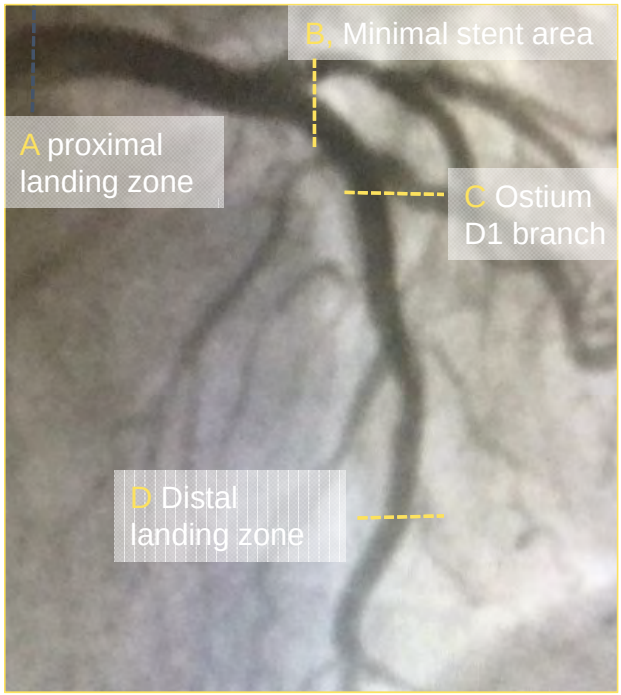


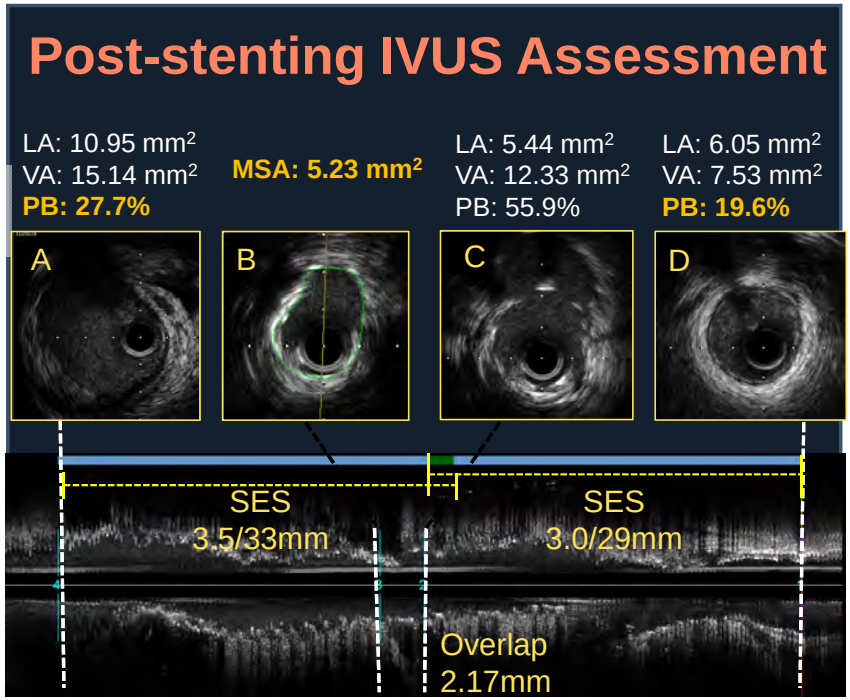


Zhang J, et al. J Am Coll Cardiol 2018.

ULTIMATE

IVUS-guided PCI





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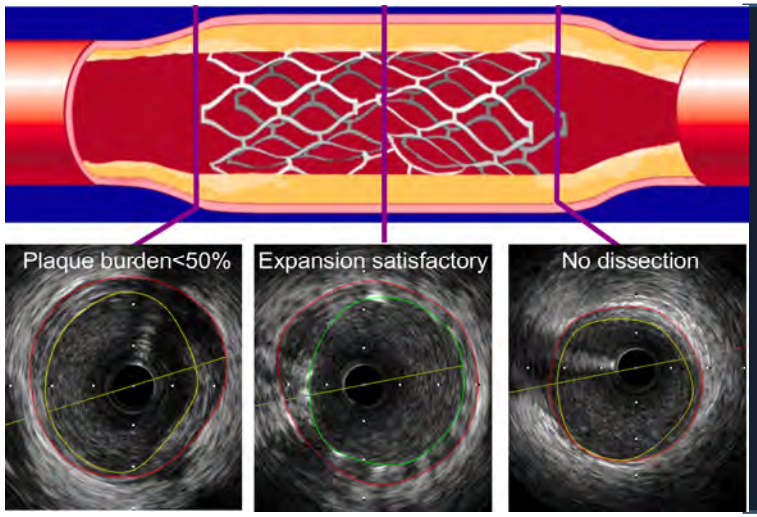
IVUS-defined Criteria for The Optimal Stent Deployment



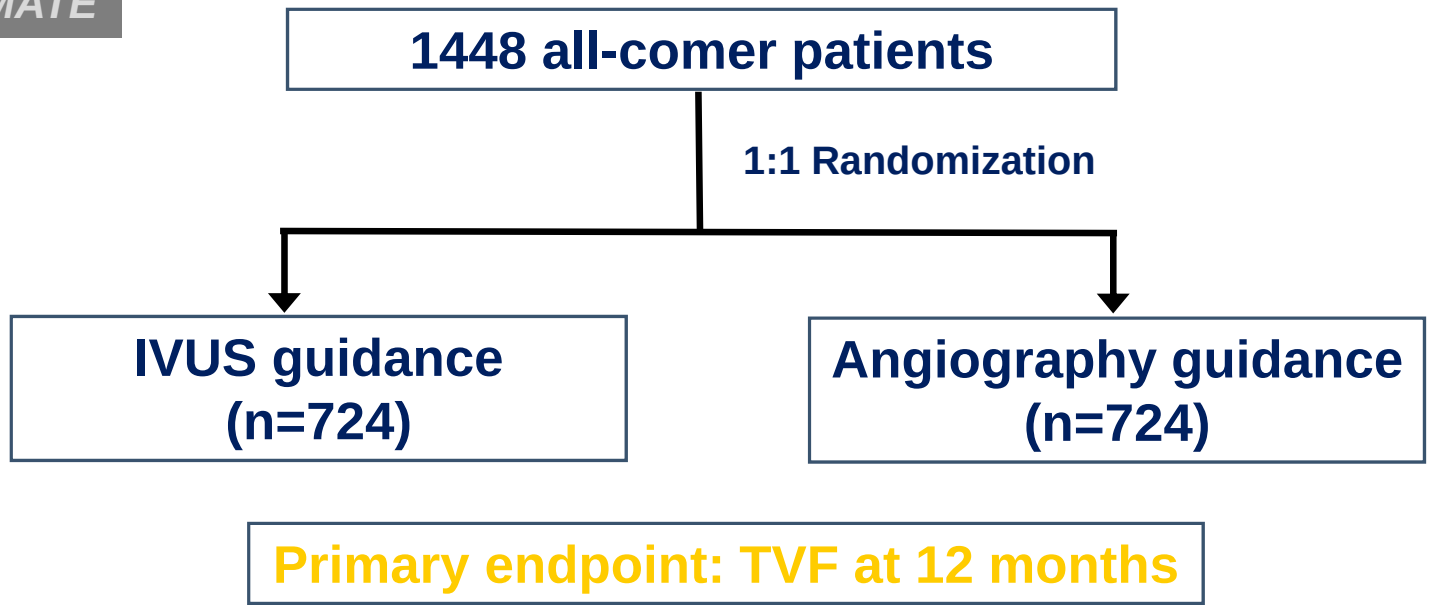
1. Minimal lumen CSA in stented segment >5.0 mm^2, or 90% of distal reference lumen CSA;
2. Plaque burden at the 5-mm proximal or distal to the stent edge <50%;
3. no edge dissection involving media with length >3mm.

Zhang J, et al. J Am Coll Cardiol 2018.

“That’s just a couple of studies…”

ULTIMATE

ULTIMATE



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Endpoints

Endpoints	Timing of follow-up	Powered for
Primary composite endpoint TVF	12 months	Superiority
Secondary endpoints CD, TVMI, TVR, TLR separately	12 months	-
Safety endpoints Definite/probable ST	12 months	-

Zhang J, et al. J Am Coll Cardiol 2018.

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Sample Size Calculation

IVUS guidance		*Angiography guidance*
	1-year TVF	
2.8-3.1%	***Prior studies***	***6.0-6.5%***

Conservative assumption

2.9% ***6.1%***

80% power with a 2-sided alpha of 0.05
N=658 pts/group, 10% lost = total 1448 pts

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Procedural Data

	IVUS guidance (n=724)	Angiography guidance (n=724)	*P*
Per patient, n (%)			
Stent number	2.40±1.55	2.47±1.56	0.39
Mean stent length, mm	66.42±46.17	66.49±44.36	0.98
Mean stent diameter, mm	3.15±0.42	2.99±0.38	<0.001
Max balloon diameter, mm	3.84±0.52	3.62±0.51	<0.001
Max Post-dilation pressure, atm	19.8±3.7	19.2±3.6	0.003

Zhang J, et al. J Am Coll Cardiol 2018.

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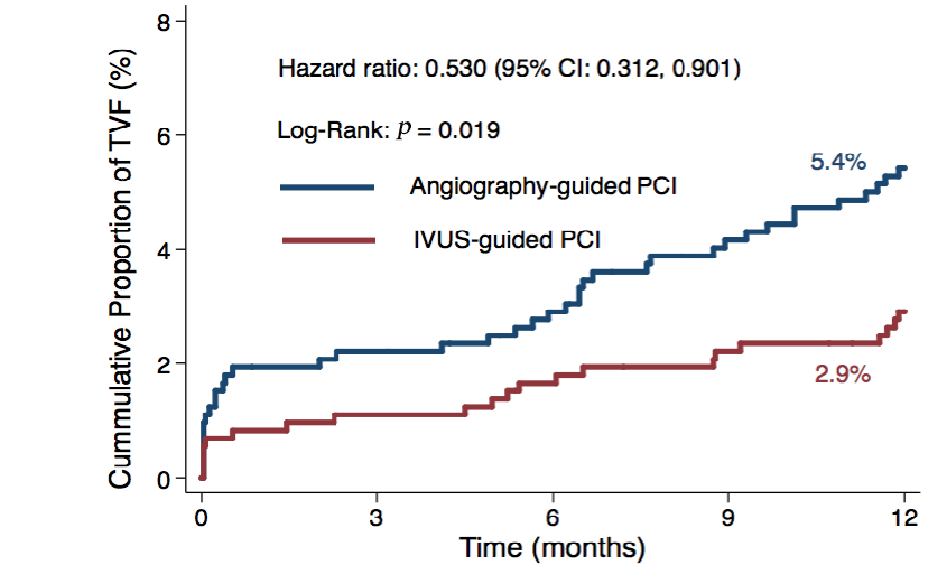
Primary Endpoint

TVF at 12 months



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Clinical Outcomes

	IVUS guidance (n = 724)	Angiography guidance (n = 724)	*P*
Primary endpoint at 30-day			
TVF	0.8%	1.9%	0.08
Primary endpoint at 12-month			
TVF	**2.9%**	**5.4%**	**0.019**
Cardiac death	0.7%	1.4%	0.19
TVMI	1.0%	1.5%	0.34
Clinically-driven TVR	1.5%	2.9%	0.07
Safety endpoint at 12-month			
Definite/probable ST	0.1%	0.7%	0.10

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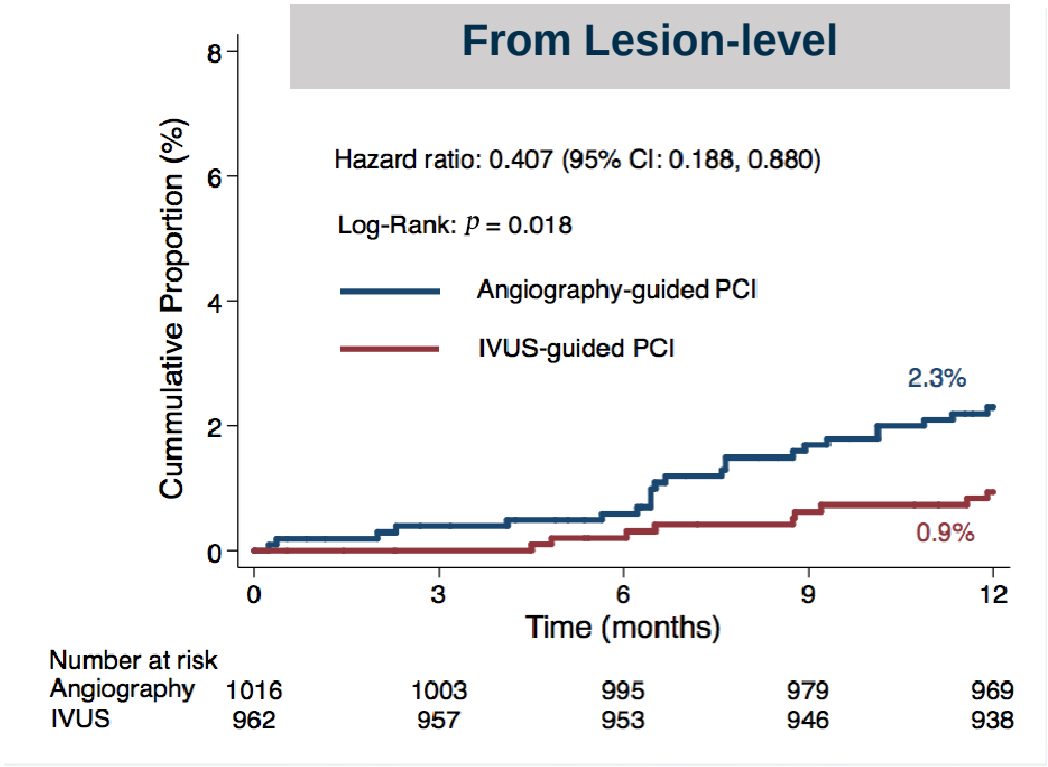
Secondary Endpoint

CD-TLR or Definite ST at 12 months



Optimal vs. Suboptimal IVUS-guided PCI

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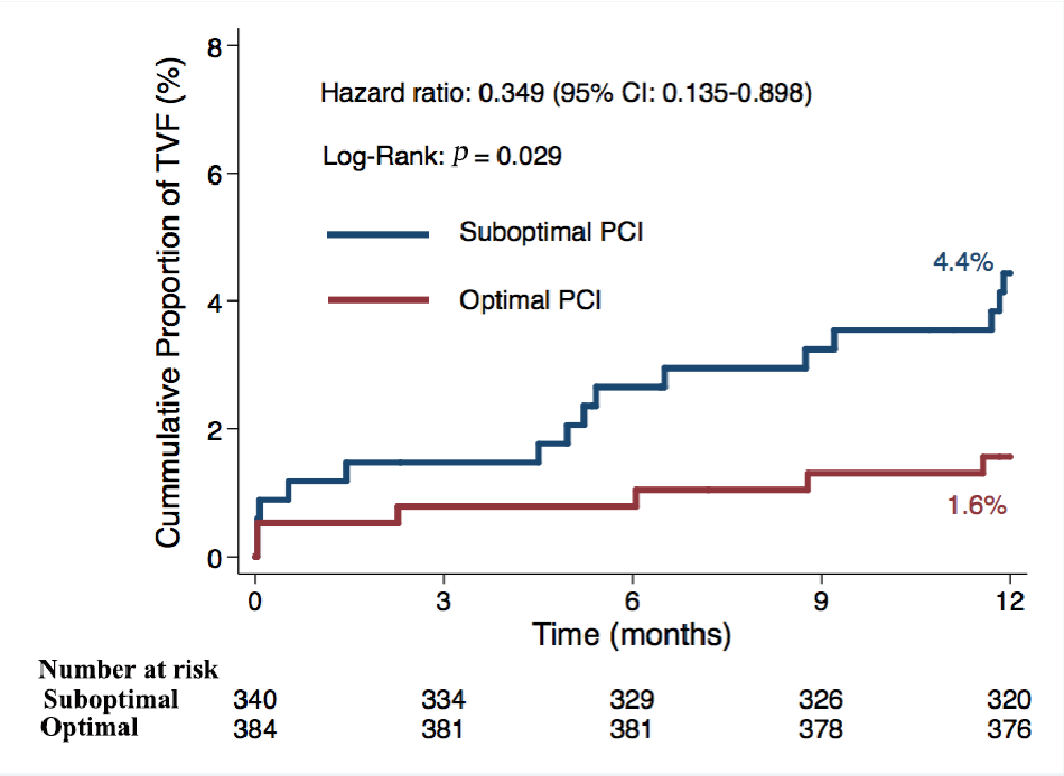
TVF at 12 months

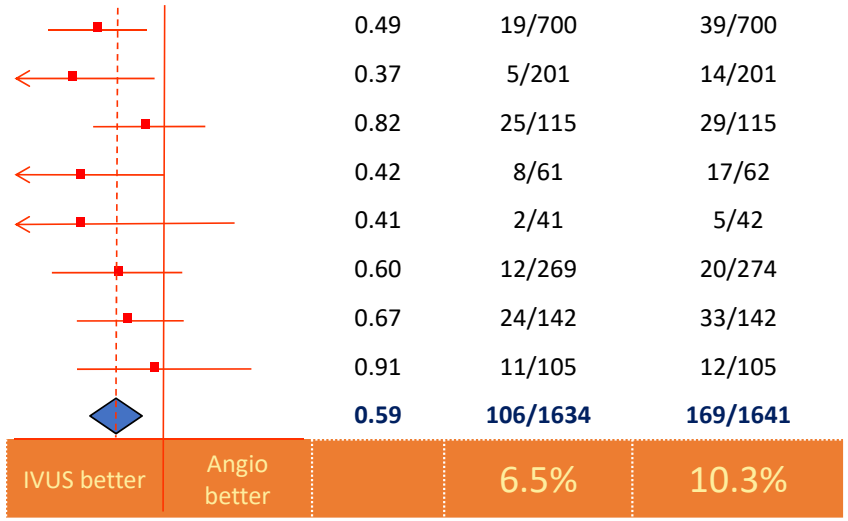


Zhang J, et al. J Am Coll Cardiol 2018.

“Okay, maybe there are a couple of randomized trials….”

Meta-analysis of 8 Randomized Trials of IVUS vs Angio-Guided DES Implantation

Study	Year	#	OR	IVUS MACE	Angio MACE
IVUS-XPL	2015	1400	0.49	19/700	39/700
CTO-IVUS	2015	402	0.37	5/201	14/201
AIR-CTO	2015	230	0.82	25/115	29/115
Tan-LM	2015	123	0.42	8/61	17/62
MOZART	2014	83	0.41	2/41	5/42
RESET	2013	543	0.60	12/269	20/274
AVIO	2013	284	0.67	24/142	33/142
Home-DES	2010	210	0.91	11/105	12/105
OVERALL		**3275**	**0.59**	**106/1634**	**169/1641**



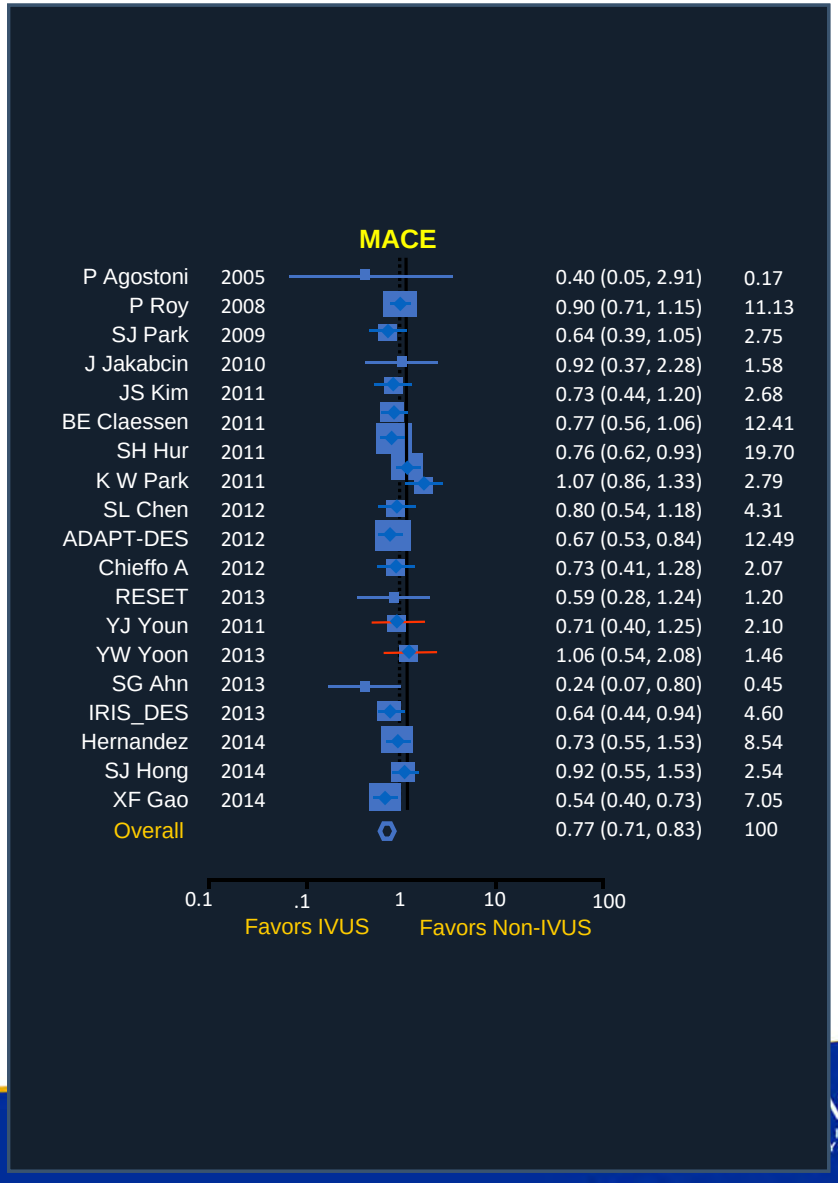
Event	IVUS events	Angio events	OR	95% CI	P-value
MACE	6.5%	10.3%	**0.59**	0.46-0.76	<0.0001
CV mortality	0.5%	1.2%	**0.46**	0.21-1.00	0.05
MI	0.9%	1.6%	**0.58**	0.30-1.11	0.10
TLR	4.1%	6.6%	**0.60**	0.43-0.84	0.003
TVR	5.5%	8.7%	**0.61**	0.41-0.91	0.02
ST	0.6%	1.3%	**0.49**	0.24-0.99	0.04

Elgendy et al. Circ Cardiovasc Interv. 2016;9(4):e003700.

Meta-Analysis of 20 DES Studies (n=29,068)

Compared with angiographic guidance, IVUS-guided DES implantation was associated with reduced rates of:

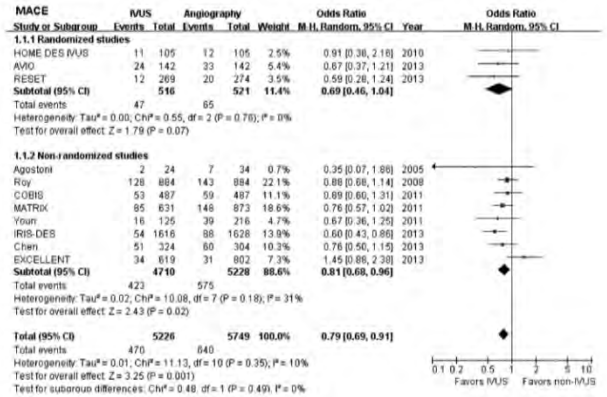
- Death
  HR 0.62 (0.54-0.71), p<0.001
- MACE
  HR 0.77 (0.71-0.83), p<0.001
- Stent thrombosis
  HR 0.59 (0.47-0.73), p<0.001



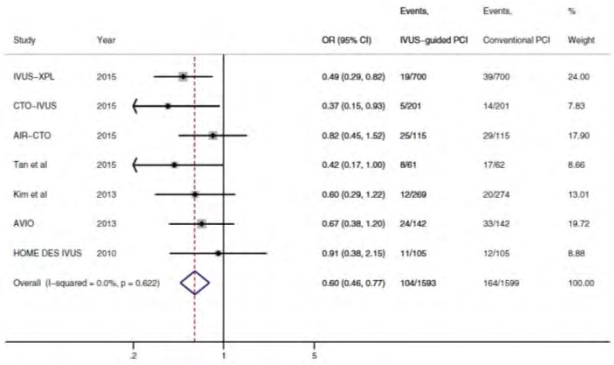
Zhang Y et al.
Int J Cardiovasc Sci 2015;15:153

“That’s just one meta-analysis.”

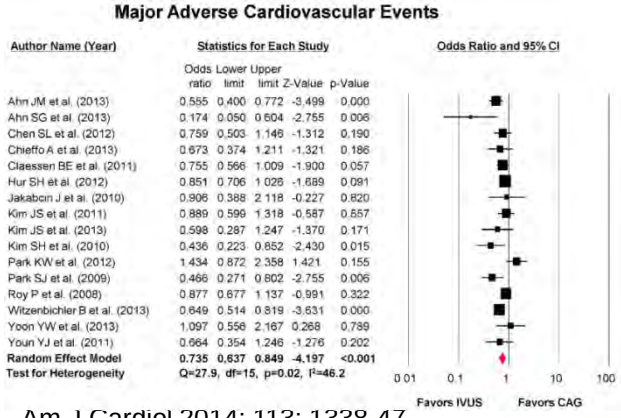
More Meta-Analyses



JACC Cardiovasc Interv 2014; 7: 233-43.



Circ Cardiovasc Interv. 2016 Apr;9(4):e003700



Am J Cardiol 2014; 113: 1338-47.

“Those are simple lesions.”

Meta-analysis in Complex Lesions

8 trials, 3276 randomized pts (3 studies 1st gen DES, 3studies 2nd gen DES, 2 studies not stated)

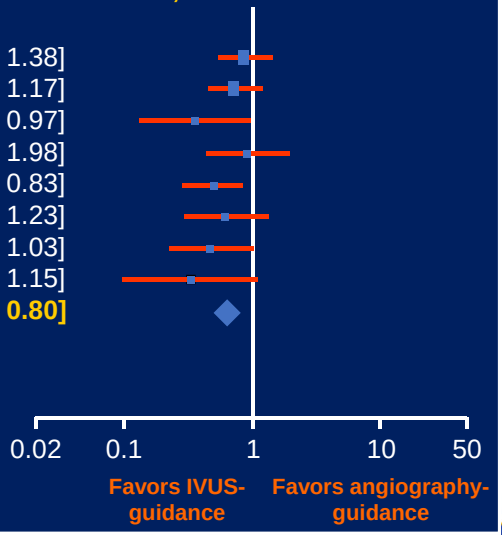
Mean FU 1.4 ± 0.5 years

MACE

Study or Subgroup	IVUS guided PCI Events	Total	Angiography guided PCI Events	Total	Weight	Risk Ratio M-H, Random 95% CI
MACE						
AIR-CTO, 2015	25	115	29	115	23.2%	0.86 [0.54, 1.38]
AVIO, 2013	24	142	33	142	22.9%	0.73 [0.45, 1.17]
CTO-IVUS, 2015	5	201	14	201	5.1%	0.36 [0.13, 0.97]
HOME DES IVUS, 2010	11	105	12	105	8.5%	0.92 [0.42, 1.98]
IVUS-XPL, 2015	19	700	39	700	17.6%	0.49 [0.28, 0.83]
RESET, 2013	12	269	20	274	10.5%	0.61 [0.30, 1.23]
Tan et al, 2015	8	61	17	62	8.8%	0.48 [0.22, 1.03]
Zhang et al, 2016	3	42	9	42	3.3%	0.33 [0.10, 1.15]
Subtotal (95%)		**1635**		**1641**	**100.0%**	**0.64 [0.51, 0.80]**
Total events	107		173			

Heterogeneity: $Tau^2=0.00$; $Chi^2=6.67$, df=7 (P=0.46); $I^2=0\%$

Test for overall effect: Z=3.88, P=0.0001



Bavishi C and Stone GW. AHJ 2017;185:26-34

Randomized Trials

1) Jakabcin J, Spacek R, Bystron M, et al. Long-term health outcome and mortality evaluation after invasive coronary treatment using drug eluting stents with or without the IVUS guidance. Randomized control trial. HOME DES IVUS. Catheter Cardiovasc Interv 2010;75:578-583.
2) Chieffo A, Latib A, Caussin C, et al. A prospective, randomized trial of intravascular-ultrasound guided compared to angiography guided stent implantation in complex coronary lesions: the AVIO trial. Am Heart J 2013;165:65-72.
3) Kim JS, Kang TS, Mintz GS, et al. Randomized comparison of clinical outcomes between intravascular ultrasound and angiography-guided drug-eluting stent implantation for long coronary artery stenoses. JACC Cardiovasc Interv 2013;6:369-376.
4) Hong SJ, Kim BK, Shin DH, et al; IVUS-XPL Investigators. Effect of intravascular ultrasound-guided vs angiography-guided everolimus-eluting stent implantation: the IVUS-XPL randomized clinical trial. JAMA 2015;314:2155-63.
5) Tian NL, Gami SK, Ye F, et al. Angiographic and clinical comparisons of intravascular ultrasound- versus angiography-guided drug-eluting stent implantation for patients with chronic total occlusion lesions: two-year results from a randomised AIR-CTO study. EuroIntervention 2015;10:1409-17.
6) Kim BK, Shin DH, Hong MK, et al; CTO-IVUS Study Investigators. Clinical impact of intravascular ultrasound-guided chronic total occlusion intervention with zotarolimus-eluting versus biolimus-eluting stent implantation: randomized study. Circ Cardiovasc Interv 2015;8, e002592.
7) Tan Q, Wang Q, Liu D, et al. Intravascular ultrasound–guided unprotected left main coronary artery stenting in the elderly. Saudi Med J 2015;36:549-53.
8) Zhang JQ, Shi R, Pang W, et al. Application of intravascular ultrasound in stent implantation for small coronary arteries. J Clin Invasive Cardiol 2016;3:1-8.
9) Mariani J Jr, Guedes C, Soares P, et al. Intravascular ultrasound guidance to minimize the use of iodine contrast in percutaneous coronary intervention: the MOZART (Minimizing cOntrast utiliZation With IVUS Guidance in coRonary angioplasTy) randomized controlled trial. JACC Cardiovasc Interv. 2014;7:1287-93
10) Habara M, Nasu K, Terashima M, et al. Impact of frequency-domain optical coherence tomography guidance for optimal coronary stent implantation in comparison with intravascular ultrasound guidence. Circ Cardiovasc Interv. 2012;5:193-201
11) Ali ZA, Maehara A, Généreux P, et al. Optical coherence tomography compared with intravascular ultrasound and with angiography to guide coronary stent implantation (ILUMIEN III: OPTIMIZE PCI): a randomised controlled trial. Lancet. 2016;388:2618-28
12) Meneveau N, Souteyrand G, Motreff P, et al. Optical Coherence Tomography to Optimize Results of Percutaneous Coronary Intervention in Patients with Non-ST-Elevation Acute Coronary Syndrome: Results of the Multicenter, Randomized DOCTORS Study (Does Optical Coherence Tomography Optimize Results of Stenting). Circulation. 2016;134:906-17
13) Kubo T, Shinke T, Okamura T, et al. Optical frequency domain imaging vs. intravascular ultrasound in percutaneous coronary intervention (OPINION trial): one-year angiographic and clinical results. Eur Heart J. 2017;38:3139-47.

Meta-analyses

1) Zhang Y, Farooq V, Garcia-Garcia HM, et al. Comparison of intravascular ultrasound versus angiography-guided drug-eluting stent implantation: a meta-analysis of one randomised trial and ten observational studies involving 19,619 patients. EuroIntervention. 2012;8:855-65.
2) Klersy C, Ferlini M, Raisaro A, 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;170:54-63.
3) Jang JS, Song YJ, Kang W, et al. Intravascular ultrasound-guided implantation of drug-eluting stents to improve outcome: a meta-analysis. JACC Cardiovasc Interv. 2014;7:233-43.
4) 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;113:1338-47
5) Zhang YJ, Pang S, Chen XY, et al. Comparison of intravascular ultrasound guided versus angiography guided drug eluting stent implantation: a systematic review and meta-analysis. BMC Cardiovasc Disord. 2015;15:153.
6) Alsidawi S, Effat M, Rahman S, Abdallah M, Leesar M. The role of vascular imaging in guiding routine percutaneous coronary interventions: A meta-analysis of bare Metal stent and drug-eluting stent trials. Cardiovasc Ther. 2015;33:360-6.
7) Nerlekar N, Cheshire CJ, Verma KP, et al. Intravascular ultrasound guidance improves clinical outcomes during implantation of both first and second-generation drug-eluting stents: a meta-analysis. EuroIntervention 2017;12:1632-42.
8) Steinvil A, Zhang YJ, Lee SY, et al. Intravascular ultrasound-guided drug-eluting stent implantation: An updated meta-analysis of randomized control trials and observational studies. Int J Cardiol. 2016;216:133-9.
9) Elgendy IY, Mahmoud AN, Elgendy AY, et al. Outcomes 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.
10) Shin DH, Hong SJ, Mintz GS, et al. Effects of intravascular ultrasound-guided versus angiography-guided new-generation drug-eluting stent implantation: Meta-Analysis With Individual Patient-Level Data From 2,345 Randomized Patients. JACC Cardiovasc Interv. 2016;9:2232-9.
11) Bavishi C, Sardar P, Chatterjee S, et al. Intravascular ultrasound–guided vs angiography-guided drug-eluting stent implantation in complex coronary lesions: Meta-analysis of randomized trials. Am Heart J. 2017 Mar;185:26-34.
12) Fan ZG, Gao XF, Li XB, Shao MX, Gao YL, Chen SL, Tian NL. The outcomes of intravascular ultrasound-guided drug-eluting stent implantation among patients with complex coronary lesions: a comprehensive meta-analysis of 15 clinical trials and 8,084 patients. Anatol J Cardiol. 2017;17:258-68
13) Ye Y, Yang M, Zhang S, Zeng Y. Percutaneous coronary intervention in left main coronary artery disease with or without intravascular ultrasound: A meta-analysis. PLoS One. 2017 Jun 22;12(6):e0179756.
14) Buccheri S, Franchina G, Romano S, Puglisi S, Venuti G, D'Arrigo P, Francaviglia B, Scalia M, Condorelli A, Barbanti M, Caprazonzo P, Tamburino C, Capodanno D. Clinical outcmoes following intravascular imaging-guided versus coronary angiography guided percutaneous coronary intervention with stent implantation. A systematic review and Bayesian network meta-analysis of 31 studies and 17,882 patients. JACC Cardiovasc Interv 2017;10:2488-98.
15) Kuku KO, Ekanem E, Azizi V, et al. Optical coherence tomography-guided percutaneous coronary intervention compared with other imaging guidance: a meta-analysis. Int J Cardiovasc Imaging. 2018;34:503-13

Registries

1) Agostoni P, Valgimigli M, Van Mieghem CA, et al. Comparison of early outcome of percutaneous coronary intervention for unprotected left main coronary artery disease in the drug-eluting stent era with versus without intravascular ultrasonic guidance. Am J Cardiol 2005;95:644-647.
2) Roy P, Steinberg DH, Sushinsky SJ, et al. The potential clinical utility of intravascular ultrasound guidance in patients undergoing percutaneous coronary intervention with drug-eluting stents. Eur Heart J 2008;29:1851-7.
3) Fujimoto H, Tao S, Dohi T, et al. Primary and mid-term outcome of sirolimus-eluting stent implantation with angiographic guidance alone. J Cardiol. 2008;51:18-24 .
4) Park SJ, Kim YH, Park DW, et al; Investigators M-C. Impact of intravascular ultrasound guidance on long-term mortality in stenting for unprotected left main coronary artery stenosis. Circ Cardiovasc Interv 2009;2:167-177.
5) Kim SH, Kim YH, Kang SJ et al. Long-term outcomes of intravascular ultrasound-guided stenting in coronary bifurcation lesions. Am J Cardiol 2010;106:612-618.
6) Maluenda G, Lemesle G, Ben-Dor I, et al. Impact of intravascular ultrasound guidance in patients with acute myocardial infarction undergoing percutaneous coronary intervention. Catheter Cardiovasc Interv 2010;75:86-92.
7) Claessen BE, Mehran R, Mintz GS, et al. Impact of intravascular ultrasound imaging on early and late clinical outcomes following percutaneous coronary intervention with drug-eluting stents. JACC Cardiovasc Interv 2011;4:974-981.
8) Kim JS, Hong MK, Ko YG, et al. Impact of intravascular ultrasound guidance on long-term clinical outcomes in patients treated with drug-eluting stent for bifurcation lesions: data from a Korean multicenter bifurcation registry. Am Heart J 2011;161:180-187.
9) Youn YJ, Yoon J, Lee JW, et al. Intravascular ultrasound-guided primary percutaneous coronary intervention with drug-eluting stent implantation in patients with ST-segment elevation myocardial infarction. Clin Cardiol 2011;34:706-713.
10) Chen SL, Ye F, Zhang JJ, et al. Intravascular ultrasound-guided systematic two-stent techniques for coronary bifurcation lesions and reduced late stent thrombosis. Catheter Cardiovasc Interv 2013;81:456-463.
11) Hur SH, Kang SJ, Kim YH, et al. Impact of intravascular ultrasound-guided percutaneous coronary intervention on long-term clinical outcomes in a real world population. Catheter Cardiovasc Interv 2013;81:407-416.
12) Park KW, Kang SH, Yang HM, et al. Impact of intravascular ultrasound guidance in routine percutaneous coronary intervention for conventional lesions: data from the EXCELLENT trial. Int J Cardiol 2013;167:721-726.
13) Witzenbichler B, Maehara A, Weisz G, et al. Relationship between intravascular ultrasound guidance and clinical outcomes after drug-eluting stents: The ADAPT-DES Study. Circulation. 2014;129:463-70
14) Ahn SG, Yoon J, Sung JK, et al. Intravascular ultrasound-guided percutaneous coronary intervention improves the clinical outcome in patients undergoing multiple overlapping drug-eluting stents implantation. Korean Circ J 2013;43:231-8.
15) Ahn JM, Han S, Park YK, et al; RESET Investigators. Differential prognostic effect of intravascular ultrasound use according to implanted stent length. Am J Cardiol 2013;111:829-835.
16) Yoon YW, Shin S, Kim BK, et al; Investigators R. Usefulness of intravascular ultrasound to predict outcomes in short-length lesions treated with drug-eluting stents. Am J Cardiol 2013;112:642-646.
17) de la Torre Hernandez JM, Baz Alonso JA, Gómez Hospital JA, et al; IVUS-TRONCO-ICP Spanish study. Clinical impact of intravascular ultrasound guidance in drug-eluting stent implantation for unprotected left main coronary disease: pooled analysis at the patient-level of 4 registries. JACC Cardiovasc Interv. 2014;7:244–54.
18) Hong SJ, Kim BK, Shin DH, et al; K-CTO Registry. Usefulness of intravascular ultrasound guidance in percutaneous coronary intervention with second-generation drug-eluting stents for chronic total occlusions (from the Multicenter Korean-Chronic Total Occlusion Registry). Am J Cardiol. 2014;114:534–40.
19) Gao XF, Kan J, Zhang YJ, et al. Comparison of one-year clinical outcomes between intravascular ultrasound-guided versus angiography-guided implantation of drug-eluting stents for left main lesions: a single-center analysis of a 1,016-patient cohort. Patient Prefer Adherence. 2014;8:1299–309.
20) Fröhlich GM, Redwood S, Rakhit R, et al. Long-term survival in patients undergoing percutaneous interventions with or without intracoronary pressure wire guidance or intracoronary ultrasonographic imaging: a large cohort study. JAMA Intern Med. 2014;174:1360-6.
21) Yazici HU, Agamaliyev M, Aydar Y, Goktekin O. The impact of intravascular ultrasound guidance during drug eluting stent implantation on angiographic outcomes. Eur Rev Med Pharmacol Sci. 2015;19:3012-7.
22) Singh V, Badheka AO, Arora S, et al. Comparison of inhospital mortality, length of hospitalization, costs, and vascular complications of percutaneous coronary interventions guided by ultrasound versus angiography. Am J Cardiol 2015;115:1357-66.
23) Magalhaes MA, Minha S, Torguson R, et al. The effect of complete percutaneous revascularisation with and without intravascular ultrasound guidance in the drug-eluting stent era. EuroIntervention 2015;11:625-33.
24) Nakatsuma K, Shiomi H, Morimoto T, et al; CREDO-Kyoto AMI investigators. Intravascular Ultrasound Guidance vs. Angiographic Guidance in Primary Percutaneous Coronary Intervention for ST Segment Elevation Myocardial Infarction - Long-Term Clinical Outcomes From the CREDO-Kyoto AMI Registry. Circ J 2016;80:477-84.
25) Patel Y, Depta JP, Patel JS, et al. Impact of intravascular ultrasound on the long-term clinical outcomes in the treatment of coronary ostial lesions. Catheter Cardiovasc Interv 2016;87:232-40.
26) Ahmed K, Jeong MH, Chakraborty R, et al. Role of intravascular ultrasound in patients with acute myocardial infarction undergoing percutaneous coronary intervention. Am J Cardiol. 2011;108:8-14.
27) Roy P, Torguson R, Okabe T, et al. Angiographic and procedural correlates of stent thrombosis after intracoronary implantation of drug-eluting stents. J Interv Cardiol 2007;20:307–13.
28) Gerber RT, Latib A, Ielasi A, et al. Defining a new standard for IVUS optimized drug eluting stent implantation: the PRAVIO study. Catheter Cardiovasc Interv 2009;74:348–56.
29) Biondi-Zoccai G, Sheiban I, Romagnoli E, et al. Is intravascular ultrasound beneficial for percutaneous coronary intervention of bifurcation lesions? Evidence from a 4314-patient registry. Clin Res Cardiol 2011;100:1021–8.
30) Wakabayashi K, Lindsay J, Laynez-Carnicero A, et al. Utility of intravascular ultrasound guidance in patients undergoing percutaneous coronary intervention for type C lesions. J Interv Cardiol 2012;25:452–9.
31) Patel Y, Depta JP, Novak E, et al. Long-term outcomes with use of intravascular ultrasound for the treatment of coronary bifurcation lesions. Am J Cardiol 2012;109:960–5.
32) De la Torre Hernandez JM, Alfonso F, Sanchez Recalde A, et al; ESTROFA-LM Study Group. Comparison of paclitaxel-eluting stents (Taxus) and everolimus-eluting stents (Xience) in left main coronary artery disease with 3 years follow-up (from the ESTROFA-LM registry). Am J Cardiol 2013;111:676-83.
33) Patel Y, Depta JP, Patel JS, Masrani SK, Novak E, Zajarias A, Kurz HI, Lasala JM, Bach RG, Singh J. Impact of intravascular ultrasound on the long-term clinical outcomes in the treatment of coronary ostial lesions. Catheter Cardiovasc Interv 2016;87:232-40.
34) Andell P, Karlsson S, Mohammad MA, Gotberg M, James S, Jensen J, Frobert O, Angeras O, Nilsson J, Omerovic E, Lagerqvist B, Persson J, Koul S, Erlinge D. Intravascular ultrasound guidance is associated with better outcome in patients undergoing unprotected left main coronary artery stenting compared with angigarphy guidance alone. Circ Cardiovasc Interv 2017;10:e004813.
35) Tian J, Guan C, Wang W, Zhang K, Chen J, Wu Y, Yan H, Zhao Y, Qiao S, Yang Y, Mintz GS, Xu B, Tang Y. Intravascular Ultrasound Guidance Improves the Long-term Prognosis in Patients with Unprotected Left Main Coronary Artery Disease Undergoing Percutaneous Coronary Intervention. Sci Rep. 2017 May 24;7(1):2377.
36) Prati F, Di Vito L, Biondi-Zoccai G, et al. Angiography alone versus angiography plus optical coherence tomography to guide decision-making during percutaneous coronary intervention: the Centro per la Lotta contro l'Infarto-Optimisation of Percutaneous Coronary Intervention (CLI-OPCI) study. EuroIntervention. 2012;8:823-9.
37) Wijns W, Shite J, Jones MR, et al. Optical coherence tomography imaging during percutaneous coronary intervention impacts physician decision-making: ILUMIEN I study. Eur Heart J. 2015;36:3346-55
38) Maehara A, Ben-Yehuda O, Ali Z, et al. Comparison of Stent Expansion Guided by Optical Coherence Tomography Versus Intravascular Ultrasound: The ILUMIEN II Study (Observational Study of Optical Coherence Tomography [OCT] in Patients Undergoing Fractional Flow Reserve [FFR] and Percutaneous Coronary Intervention). JACC Cardiovasc Interv. 2015;8:1704-14.
39) Iannaccone M, D'Ascenzo F, Frangieh AH, et al. Impact of an optical coherence tomography guided approach in acute coronary syndromes: A propensity matched analyssi from the international FORMIDABLE-CARDIOGROUP IV and USZ Registry. Catheter Cardiovasc Interv 2017;90:E46-E52

Randomized Trials

1) Jakabcin J, Spacek R, Bystron M, et al. Long-term health outcome and mortality evaluation after invasive coronary treatment using drug eluting stents with or without the IVUS guidance. Randomized control trial. HOME DES IVUS. Catheter Cardiovasc Interv 2010;75:578-583.
2) Chieffo A, Latib A, Caussin C, et al. A prospective, randomized trial of intravascular-ultrasound guided compared to angiography guided stent implantation in complex coronary lesions: the AVIO trial. Am Heart J 2013;165:65-72.
3) Kim JS, Kang TS, Mintz GS, et al. Randomized comparison of clinical outcomes between intravascular ultrasound and angiography-guided drug-eluting stent implantation for long coronary artery stenoses. JACC Cardiovasc Interv 2013;6:369-376.
4) Hong SJ, Kim BK, Shin DH, et al; IVUS-XPL Investigators. Effect of intravascular ultrasound-guided vs angiography-guided everolimus-eluting stent implantation: the IVUS-XPL randomized clinical trial. JAMA 2015;314:2155-63.
5) Tian NL, Gami SK, Ye F, et al. Angiographic and clinical comparisons of intravascular ultrasound- versus angiography-guided drug-eluting stent implantation for patients with chronic total occlusion lesions: two-year results from a randomised AIR-CTO study. EuroIntervention 2015;10:1409-17.
6) Kim BK, Shin DH, Hong MK, et al; CTO-IVUS Study Investigators. Clinical impact of intravascular ultrasound-guided chronic total occlusion intervention with zotarolimus-eluting versus biolimus-eluting stent implantation: randomized study. Circ Cardiovasc Interv 2015;8, e002592.
7) Tan Q, Wang Q, Liu D, et al. Intravascular ultrasound–guided unprotected left main coronary artery stenting in the elderly. Saudi Med J 2015;36:549-53.
8) Zhang JQ, Shi R, Pang W, et al. Application of intravascular ultrasound in stent implantation for small coronary arteries. J Clin Invasive Cardiol 2016;3:1-8.
9) Mariani J Jr, Guedes C, Soares P, et al. Intravascular ultrasound guidance to minimize the use of iodine contrast in percutaneous coronary intervention: the MOZART (Minimizing cOntrast utiliZation With IVUS Guidance in coRonary angioplasTy) randomized controlled trial. JACC Cardiovasc Interv. 2014;7:1287-93
10) Zhang J, Gao X, Kan J, et al. Intravascular Ultrasound-Guided Versus Angiography-Guided Implantation of Drug-Eluting Stent in All-Comers: The ULTIMATE trial. J Am Coll Cardiol 2018;72:3126-37
11) Habara M, Nasu K, Terashima M, et al. Impact of frequency-domain optical coherence tomography guidance for optimal coronary stent implantation in comparison with intravascular ultrasound guidence. Circ Cardiovasc Interv. 2012;5:193-201
12) Ali ZA, Maehara A, Généreux P, et al. Optical coherence tomography compared with intravascular ultrasound and with angiography to guide coronary stent implantation (ILUMIEN III: OPTIMIZE PCI): a randomised controlled trial. Lancet. 2016;388:2618-28
13) Meneveau N, Souteyrand G, Motreff P, et al. Optical Coherence Tomography to Optimize Results of Percutaneous Coronary Intervention in Patients with Non-ST-Elevation Acute Coronary Syndrome: Results of the Multicenter, Randomized DOCTORS Study (Does Optical Coherence Tomography Optimize Results of Stenting). Circulation. 2016;134:906-17
14) Kubo T, Shinke T, Okamura T, et al. Optical frequency domain imaging vs. intravascular ultrasound in percutaneous coronary intervention (OPINION trial): one-year angiographic and clinical results. Eur Heart J. 2017;38:3139-47.
15) Kala P, Cervinka P, Jakl M, et al. OCT guidance during stent implantation in primary PCI: A randomized multicenter study with nine months of optical coherence tomography follow-up. Int J Cardiol. 2018;250:98-103

Meta-analyses

1) Zhang Y, Farooq V, Garcia-Garcia HM, et al. Comparison of intravascular ultrasound versus angiography-guided drug-eluting stent implantation: a meta-analysis of one randomised trial and ten observational studies involving 19,619 patients. EuroIntervention. 2012;8:855-65.
2) Klersy C, Ferlini M, Raisaro A, 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;170:54-63.
3) Jang JS, Song YJ, Kang W, et al. Intravascular ultrasound-guided implantation of drug-eluting stents to improve outcome: a meta-analysis. JACC Cardiovasc Interv. 2014;7:233-43.
4) 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;113:1338-47
5) Zhang YJ, Pang S, Chen XY, et al. Comparison of intravascular ultrasound guided versus angiography guided drug eluting stent implantation: a systematic review and meta-analysis. BMC Cardiovasc Disord. 2015;15:153.
6) Alsidawi S, Effat M, Rahman S, Abdallah M, Leesar M. The role of vascular imaging in guiding routine percutaneous coronary interventions: A meta-analysis of bare Metal stent and drug-eluting stent trials. Cardiovasc Ther. 2015;33:360-6.
7) Nerlekar N, Cheshire CJ, Verma KP, et al. Intravascular ultrasound guidance improves clinical outcomes during implantation of both first and second-generation drug-eluting stents: a meta-analysis. EuroIntervention 2017;12:1632-42.
8) Steinvil A, Zhang YJ, Lee SY, et al. Intravascular ultrasound-guided drug-eluting stent implantation: An updated meta-analysis of randomized control trials and observational studies. Int J Cardiol. 2016;216:133-9.
9) Elgendy IY, Mahmoud AN, Elgendy AY, et al. Outcomes 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.
10) Shin DH, Hong SJ, Mintz GS, et al. Effects of intravascular ultrasound-guided versus angiography-guided new-generation drug-eluting stent implantation: Meta-Analysis With Individual Patient-Level Data From 2,345 Randomized Patients. JACC Cardiovasc Interv. 2016;9:2232-9.
11) Bavishi C, Sardar P, Chatterjee S, et al. Intravascular ultrasound–guided vs angiography-guided drug-eluting stent implantation in complex coronary lesions: Meta-analysis of randomized trials. Am Heart J. 2017 Mar;185:26-34.
12) Fan ZG, Gao XF, Li XB, et al. The outcomes of intravascular ultrasound-guided drug-eluting stent implantation among patients with complex coronary lesions: a comprehensive meta-analysis of 15 clinical trials and 8,084 patients. Anatol J Cardiol. 2017;17:258-68
13) Ye Y, Yang M, Zhang S, Zeng Y. Percutaneous coronary intervention in left main coronary artery disease with or without intravascular ultrasound: A meta-analysis. PLoS One. 2017 Jun 22;12(6):e0179756.
14) DiMario C, Koskinas KC, Raber L. Clinical benefit of IVUS guidance for coronary stenting. J Am Coll Cardiol 2018;72:3128-41
15) Buccheri S, Franchina G, Romano S, et al. Clinical outcmoes following intravascular imaging-guided versus coronary angiography guided percutaneous coronary intervention with stent implantation. A systematic review and Bayesian network meta-analysis of 31 studies and 17,882 patients. JACC Cardiovasc Interv 2017;10:2488-98.
16) Kuku KO, Ekanem E, Azizi V, et al. Optical coherence tomography-guided percutaneous coronary intervention compared with other imaging guidance: a **meta**-analysis. Int J Cardiovasc Imaging. 2018;34:503-13

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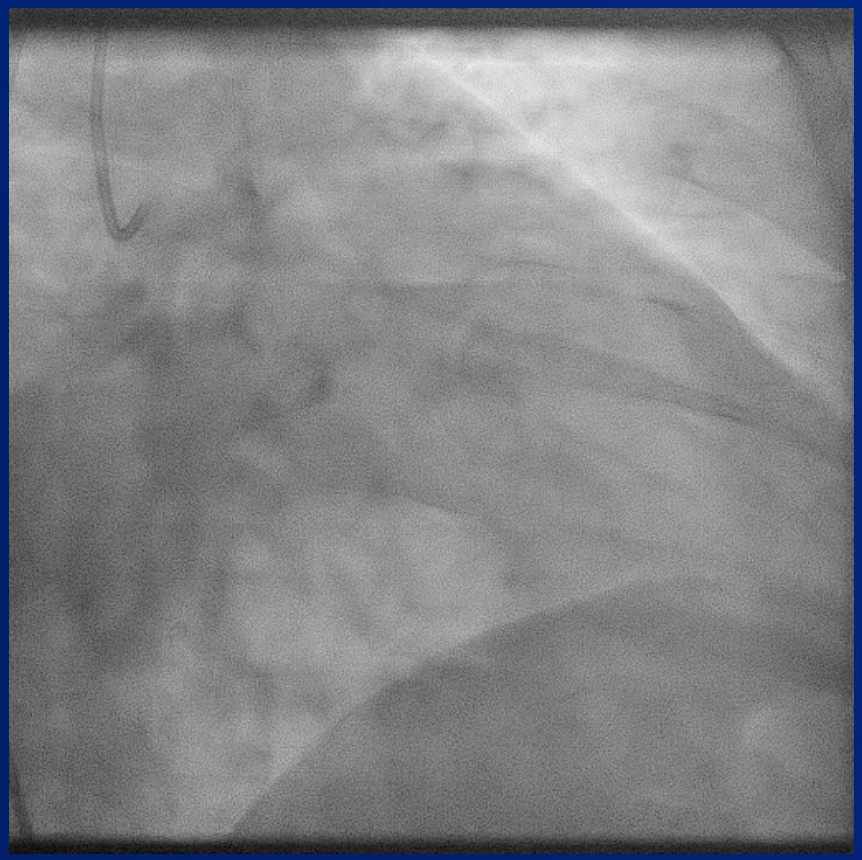
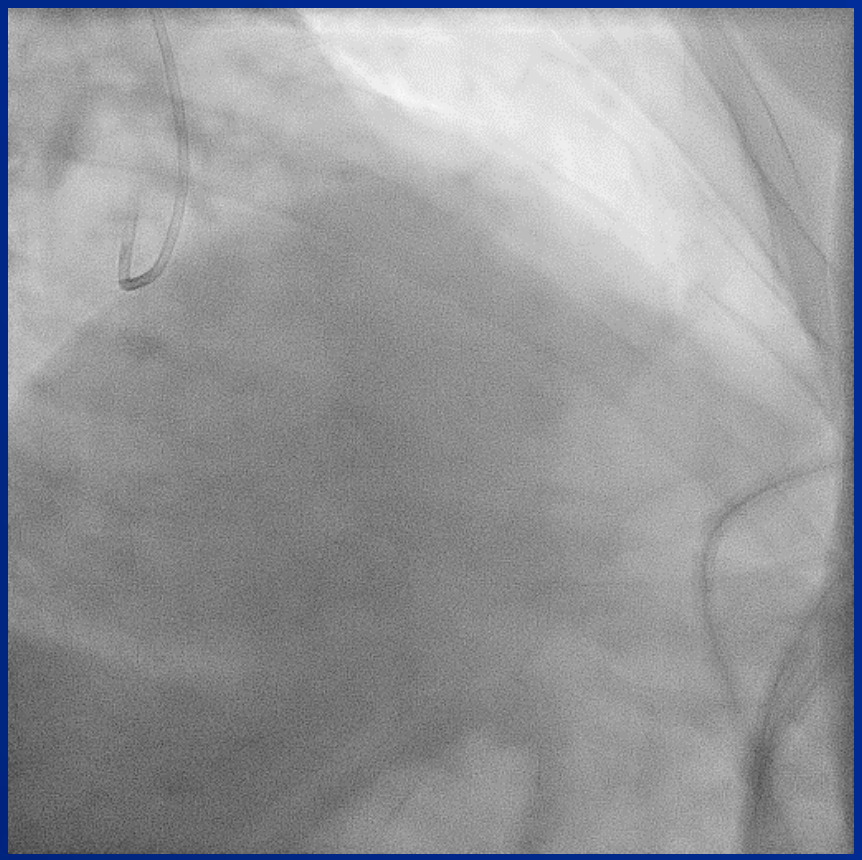
Registries

1) Agostoni P, Valgimigli M, Van Mieghem CA, et al. Comparison of early outcome of percutaneous coronary intervention for unprotected left main coronary artery disease in the drug-eluting stent era with versus without intravascular ultrasonic guidance. Am J Cardiol 2005;95:644-647.
2) Roy P, Steinberg DH, Sushinsky SJ, et al. The potential clinical utility of intravascular ultrasound guidance in patients undergoing percutaneous coronary intervention with drug-eluting stents. Eur Heart J 2008;29:1851-7.
3) Fujimoto H, Tao S, Dohi T, et al. Primary and mid-term outcome of sirolimus-eluting stent implantation with angiographic guidance alone. J Cardiol. 2008;51:18-24 .
4) Park SJ, Kim YH, Park DW, et al; Investigators M-C. Impact of intravascular ultrasound guidance on long-term mortality in stenting for unprotected left main coronary artery stenosis. Circ Cardiovasc Interv 2009;2:167-177.
5) Kim SH, Kim YH, Kang SJ et al. Long-term outcomes of intravascular ultrasound-guided stenting in coronary bifurcation lesions. Am J Cardiol 2010;106:612-618.
6) Maluenda G, Lemesle G, Ben-Dor I, et al. Impact of intravascular ultrasound guidance in patients with acute myocardial infarction undergoing percutaneous coronary intervention. Catheter Cardiovasc Interv 2010;75:86-92.
7) Claessen BE, Mehran R, Mintz GS, et al. Impact of intravascular ultrasound imaging on early and late clinical outcomes following percutaneous coronary intervention with drug-eluting stents. JACC Cardiovasc Interv 2011;4:974-981.
8) Kim JS, Hong MK, Ko YG, et al. Impact of intravascular ultrasound guidance on long-term clinical outcomes in patients treated with drug-eluting stent for bifurcation lesions: data from a Korean multicenter bifurcation registry. Am Heart J 2011;161:180-187.
9) Youn YJ, Yoon J, Lee JW, et al. Intravascular ultrasound-guided primary percutaneous coronary intervention with drug-eluting stent implantation in patients with ST-segment elevation myocardial infarction. Clin Cardiol 2011;34:706-713.
10) Chen SL, Ye F, Zhang JJ, et al. Intravascular ultrasound-guided systematic two-stent techniques for coronary bifurcation lesions and reduced late stent thrombosis. Catheter Cardiovasc Interv 2013;81:456-463.
11) Hur SH, Kang SJ, Kim YH, et al. Impact of intravascular ultrasound-guided percutaneous coronary intervention on long-term clinical outcomes in a real world population. Catheter Cardiovasc Interv 2013;81:407-416.
12) Park KW, Kang SH, Yang HM, et al. Impact of intravascular ultrasound guidance in routine percutaneous coronary intervention for conventional lesions: data from the EXCELLENT trial. Int J Cardiol 2013;167:721-726.
13) Witzenbichler B, Maehara A, Weisz G, et al. Relationship between intravascular ultrasound guidance and clinical outcomes after drug-eluting stents: The ADAPT-DES Study. Circulation. 2014;129:463-70
14) Ahn SG, Yoon J, Sung JK, et al. Intravascular ultrasound-guided percutaneous coronary intervention improves the clinical outcome in patients undergoing multiple overlapping drug-eluting stents implantation. Korean Circ J 2013;43:231-8.
15) Ahn JM, Han S, Park YK, et al; RESET Investigators. Differential prognostic effect of intravascular ultrasound use according to implanted stent length. Am J Cardiol 2013;111:829-835.
16) Yoon YW, Shin S, Kim BK, et al; Investigators R. Usefulness of intravascular ultrasound to predict outcomes in short-length lesions treated with drug-eluting stents. Am J Cardiol 2013;112:642-646.
17) de la Torre Hernandez JM, Baz Alonso JA, Gómez Hospital JA, et al; IVUS-TRONCO-ICP Spanish study. Clinical impact of intravascular ultrasound guidance in drug-eluting stent implantation for unprotected left main coronary disease: pooled analysis at the patient-level of 4 registries. JACC Cardiovasc Interv. 2014;7:244–54.
18) Hong SJ, Kim BK, Shin DH, et al; K-CTO Registry. Usefulness of intravascular ultrasound guidance in percutaneous coronary intervention with second-generation drug-eluting stents for chronic total occlusions (from the Multicenter Korean-Chronic Total Occlusion Registry). Am J Cardiol. 2014;114:534–40.
19) Gao XF, Kan J, Zhang YJ, et al. Comparison of one-year clinical outcomes between intravascular ultrasound-guided versus angiography-guided implantation of drug-eluting stents for left main lesions: a single-center analysis of a 1,016-patient cohort. Patient Prefer Adherence. 2014;8:1299–309.
20) Fröhlich GM, Redwood S, Rakhit R, et al. Long-term survival in patients undergoing percutaneous interventions with or without intracoronary pressure wire guidance or intracoronary ultrasonographic imaging: a large cohort study. JAMA Intern Med. 2014;174:1360-6.
21) Yazici HU, Agamaliyev M, Aydar Y, Goktekin O. The impact of intravascular ultrasound guidance during drug eluting stent implantation on angiographic outcomes. Eur Rev Med Pharmacol Sci. 2015;19:3012-7.
22) Singh V, Badheka AO, Arora S, et al. Comparison of inhospital mortality, length of hospitalization, costs, and vascular complications of percutaneous coronary interventions guided by ultrasound versus angiography. Am J Cardiol 2015;115:1357-66.
23) Magalhaes MA, Minha S, Torguson R, et al. The effect of complete percutaneous revascularisation with and without intravascular ultrasound guidance in the drug-eluting stent era. EuroIntervention 2015;11:625-33.
24) Nakatsuma K, Shiomi H, Morimoto T, et al; CREDO-Kyoto AMI investigators. Intravascular Ultrasound Guidance vs. Angiographic Guidance in Primary Percutaneous Coronary Intervention for ST Segment Elevation Myocardial Infarction - Long-Term Clinical Outcomes From the CREDO-Kyoto AMI Registry. Circ J 2016;80:477-84.
25) Patel Y, Depta JP, Patel JS, et al. Impact of intravascular ultrasound on the long-term clinical outcomes in the treatment of coronary ostial lesions. Catheter Cardiovasc Interv 2016;87:232-40.
26) Ahmed K, Jeong MH, Chakraborty R, et al. Role of intravascular ultrasound in patients with acute myocardial infarction undergoing percutaneous coronary intervention. Am J Cardiol. 2011;108:8-14.
27) Roy P, Torguson R, Okabe T, et al. Angiographic and procedural correlates of stent thrombosis after intracoronary implantation of drug-eluting stents. J Interv Cardiol 2007;20:307–13.
28) Gerber RT, Latib A, Ielasi A, et al. Defining a new standard for IVUS optimized drug eluting stent implantation: the PRAVIO study. Catheter Cardiovasc Interv 2009;74:348–56.
29) Biondi-Zoccai G, Sheiban I, Romagnoli E, et al. Is intravascular ultrasound beneficial for percutaneous coronary intervention of bifurcation lesions? Evidence from a 4314-patient registry. Clin Res Cardiol 2011;100:1021–8.
30) Wakabayashi K, Lindsay J, Laynez-Carnicero A, et al. Utility of intravascular ultrasound guidance in patients undergoing percutaneous coronary intervention for type C lesions. J Interv Cardiol 2012;25:452–9.
31) Patel Y, Depta JP, Novak E, et al. Long-term outcomes with use of intravascular ultrasound for the treatment of coronary bifurcation lesions. Am J Cardiol 2012;109:960–5.
32) De la Torre Hernandez JM, Alfonso F, Sanchez Recalde A, et al; ESTROFA-LM Study Group. Comparison of paclitaxel-eluting stents (Taxus) and everolimus-eluting stents (Xience) in left main coronary artery disease with 3 years follow-up (from the ESTROFA-LM registry). Am J Cardiol 2013;111:676-83.
33) Patel Y, Depta JP, Patel JS, Masrani SK, Novak E, Zajarias A, Kurz HI, Lasala JM, Bach RG, Singh J. Impact of intravascular ultrasound on the long-term clinical outcomes in the treatment of coronary ostial lesions. Catheter Cardiovasc Interv 2016;87:232-40.
34) Andell P, Karlsson S, Mohammad MA, et al. Intravascular ultrasound guidance is associated with better outcome in patients undergoing unprotected left main coronary artery stenting compared with angigarphy guidance alone. Circ Cardiovasc Interv 2017;10:e004813.
35) Tian J, Guan C, Wang W, et al. Intravascular Ultrasound Guidance Improves the Long-term Prognosis in Patients with Unprotected Left Main Coronary Artery Disease Undergoing Percutaneous Coronary Intervention. Sci Rep. 2017 May 24;7(1):2377.
36) Chen L, Xu T, Xue XJ, Zhang JJ, Ye F, Tian NL, Chen SL. Intravascular ultrasound-guided drug-eluting stent implantation is associated with improved clinical outcomes in patients with unstable angina and complex coronary artery true bifurcation lesions. Int J Cardiovasc Imaging. 2018 Jul 6. doi: 10.1007/s10554-018-1393-2
37) Maehara A, Mintz GS, Witzenbichler B, et al. Relationship between intravascular ultrasound guidance and clinical outcomes after drug-eluting stents. Circ Cardiovasc Interv. 2018 Nov;11(11):e006243. doi: 10.1161
38) Amat-Santos IJ, Martin-Yuste V, Fernández-Díaz JA, et al. Procedural, Functional and Prognostic Outcomes Following Recanalization of Coronary Chronic Total Occlusions. Results of the Iberian Registry. Rev Esp Cardiol (Engl Ed). 2018. pii: S1885-5857(18)30212-3. doi: 10.1016/j.rec.2018.05.020
39) Prati F, Di Vito L, Biondi-Zoccai G, et al. Angiography alone versus angiography plus optical coherence tomography to guide decision-making during percutaneous coronary intervention: the Centro per la Lotta contro l'Infarto-Optimisation of Percutaneous Coronary Intervention (CLI-OPCI) study. EuroIntervention. 2012;8:823-9.
40) Wijns W, Shite J, Jones MR, et al. Optical coherence tomography imaging during percutaneous coronary intervention impacts physician decision-making: ILUMIEN I study. Eur Heart J. 2015;36:3346-55
41) Maehara A, Ben-Yehuda O, Ali Z, et al. Comparison of Stent Expansion Guided by Optical Coherence Tomography Versus Intravascular Ultrasound: The ILUMIEN II Study (Observational Study of Optical Coherence Tomography [OCT] in Patients Undergoing Fractional Flow Reserve [FFR] and Percutaneous Coronary Intervention). JACC Cardiovasc Interv. 2015;8:1704-14.
42) Iannaccone M, D'Ascenzo F, Frangieh AH, et al. Impact of an optical coherence tomography guided approach in acute coronary syndromes: A propensity matched analyssi from the international FORMIDABLE-CARDIOGROUP IV and USZ Registry. Catheter Cardiovasc Interv 2017;90:E46-E52
43) Sheth TN, Kajander OA, Lavi S, et al. Optical Coherence Tomography-Guided Percutaneous Coronary Intervention in ST-Segment-Elevation Myocardial Infarction: A Prospective Propensity-Matched Cohort of the Thrombectomy Versus Percutaneous Coronary Intervention Alone Trial. Circ Cardiovasc Interv. 2016 Apr;9(4):e003414. doi: 10.1161
44) Jones DA, Rathod KS, Koganti S, et al. Angiography Alone Versus Angiography Plus Optical Coherence Tomography to Guide Percutaneous Coronary Intervention: Outcomes From the Pan-London PCI Cohort. JACC Cardiovasc Interv. 2018;11:1313-21

Baseline





Physiology Step-by-Step

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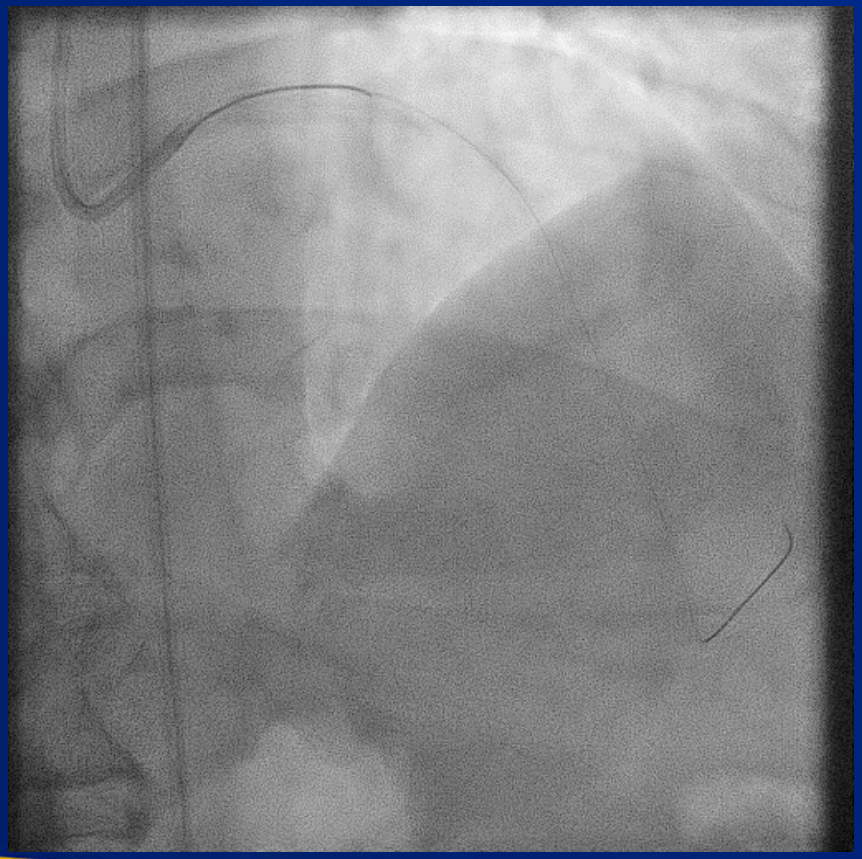
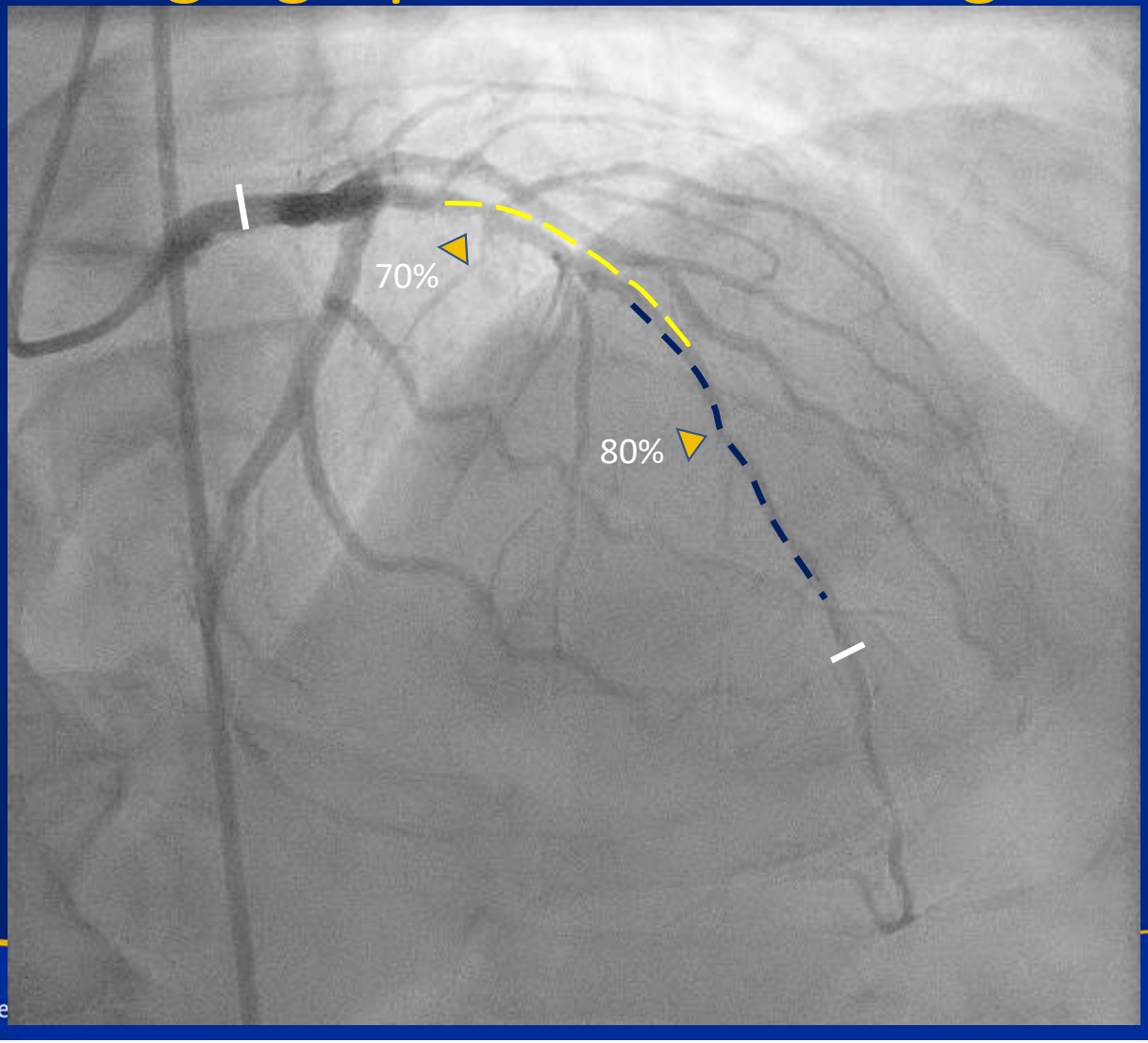
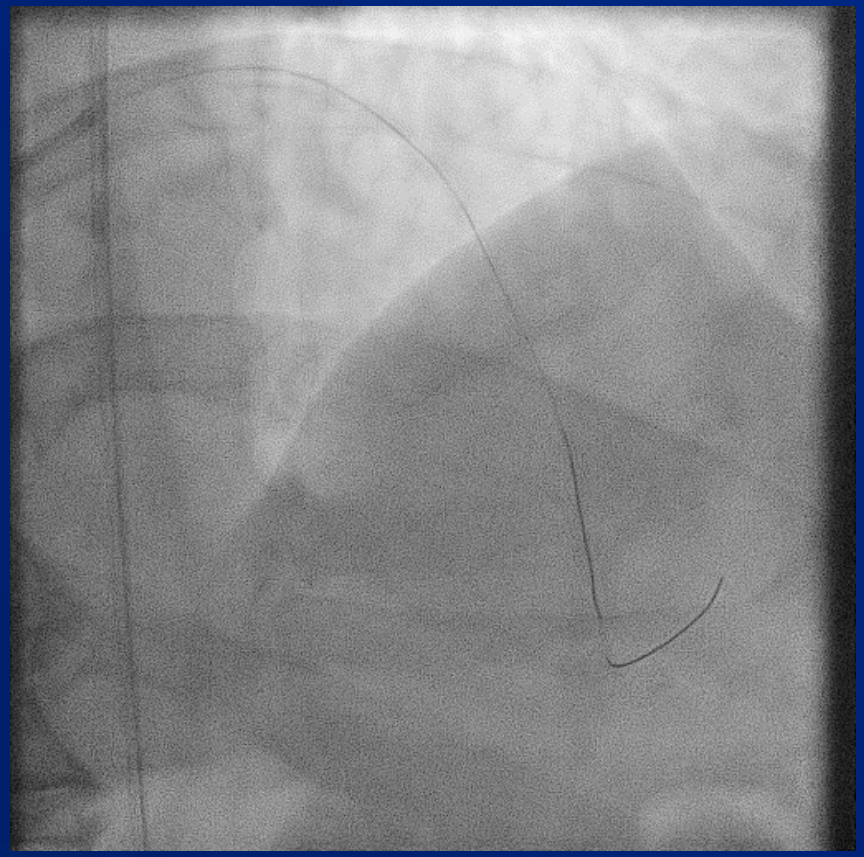


Angiographic PCI Planning



Spot iFR



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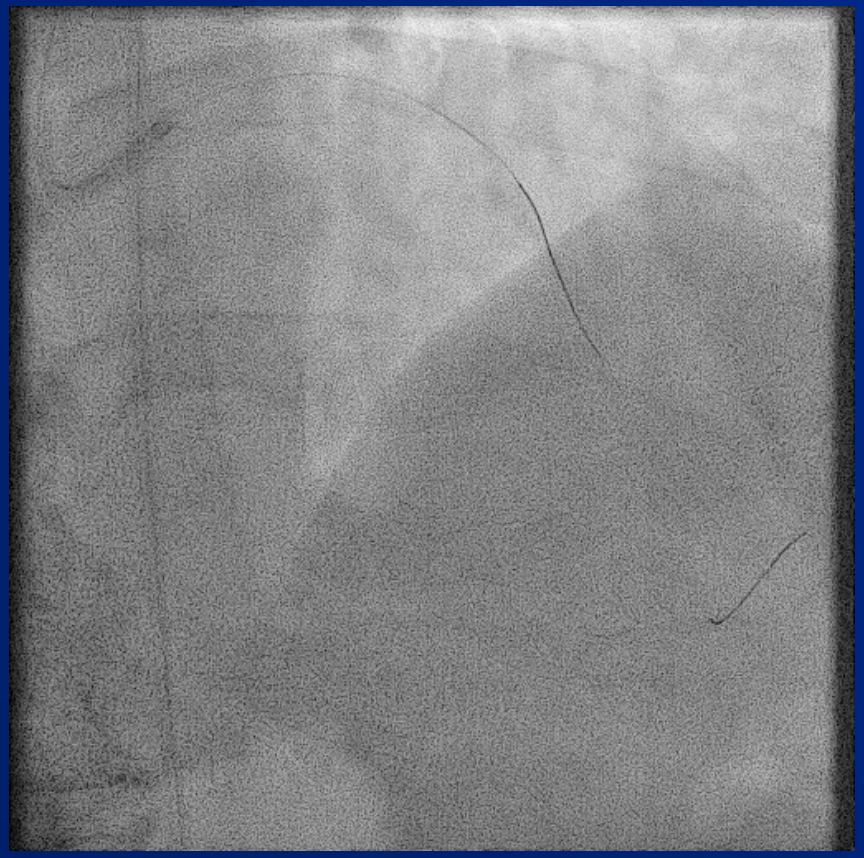
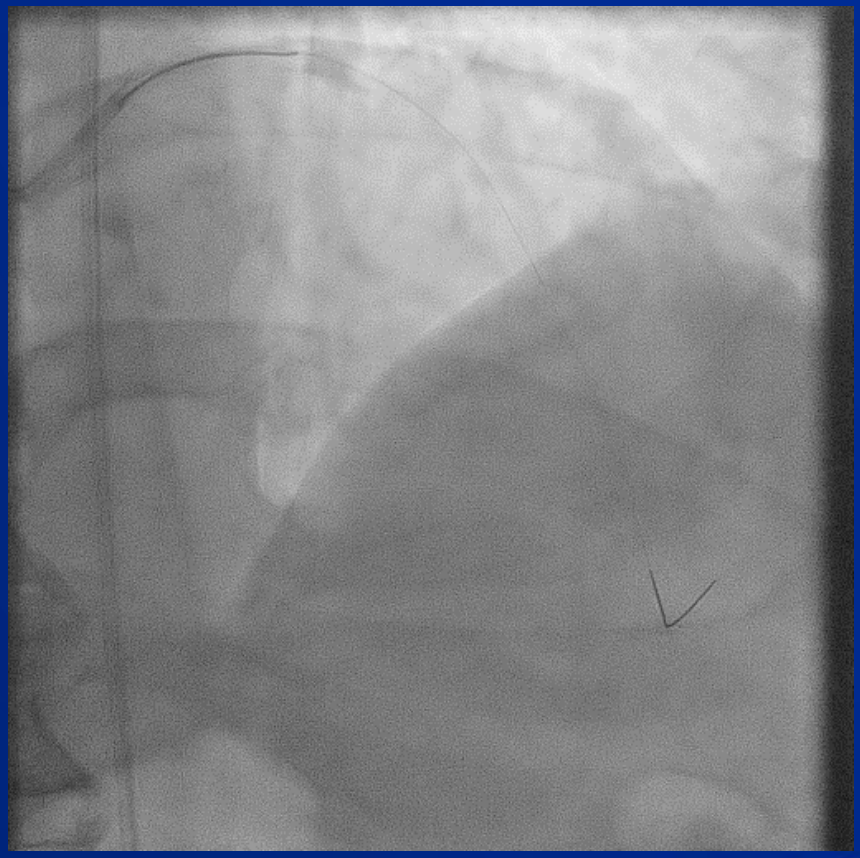
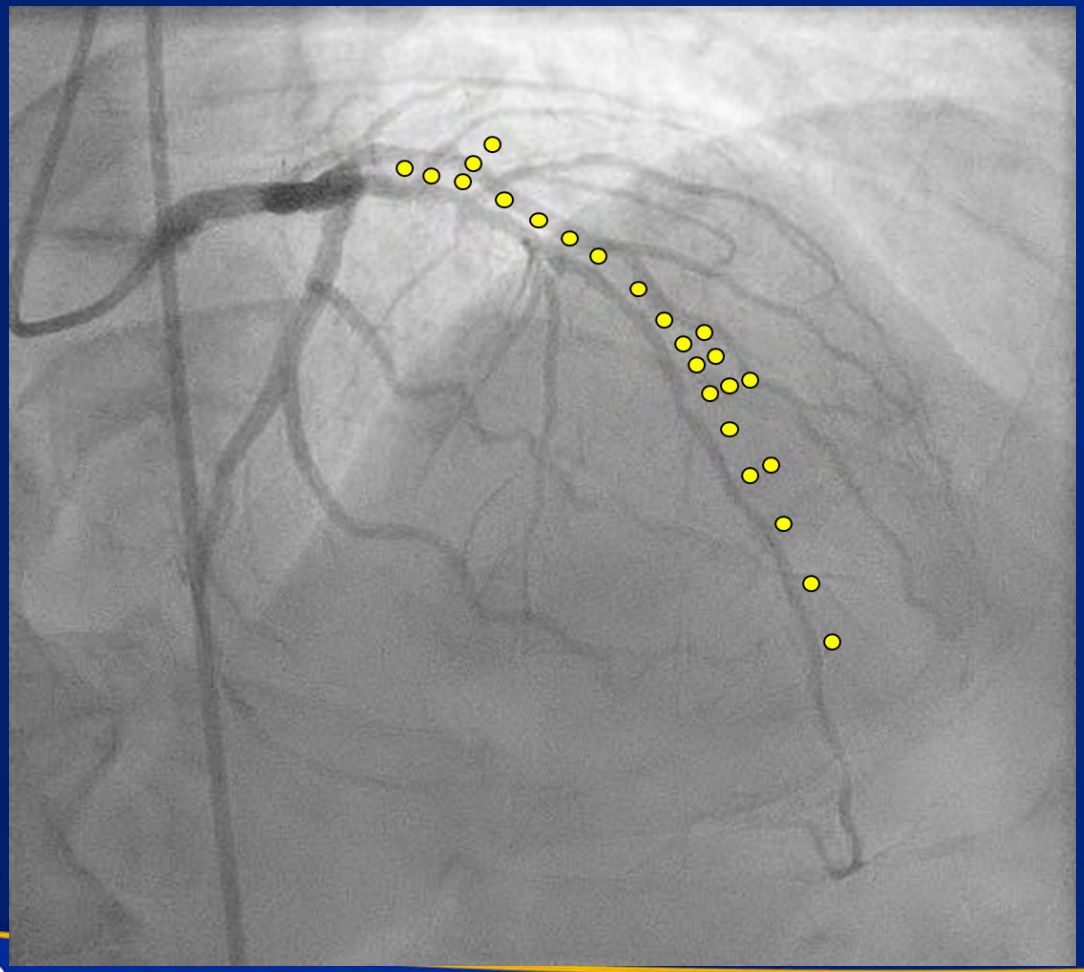
Pd/Pa

iFR Pullback





Best Assessment of Physiological Pattern

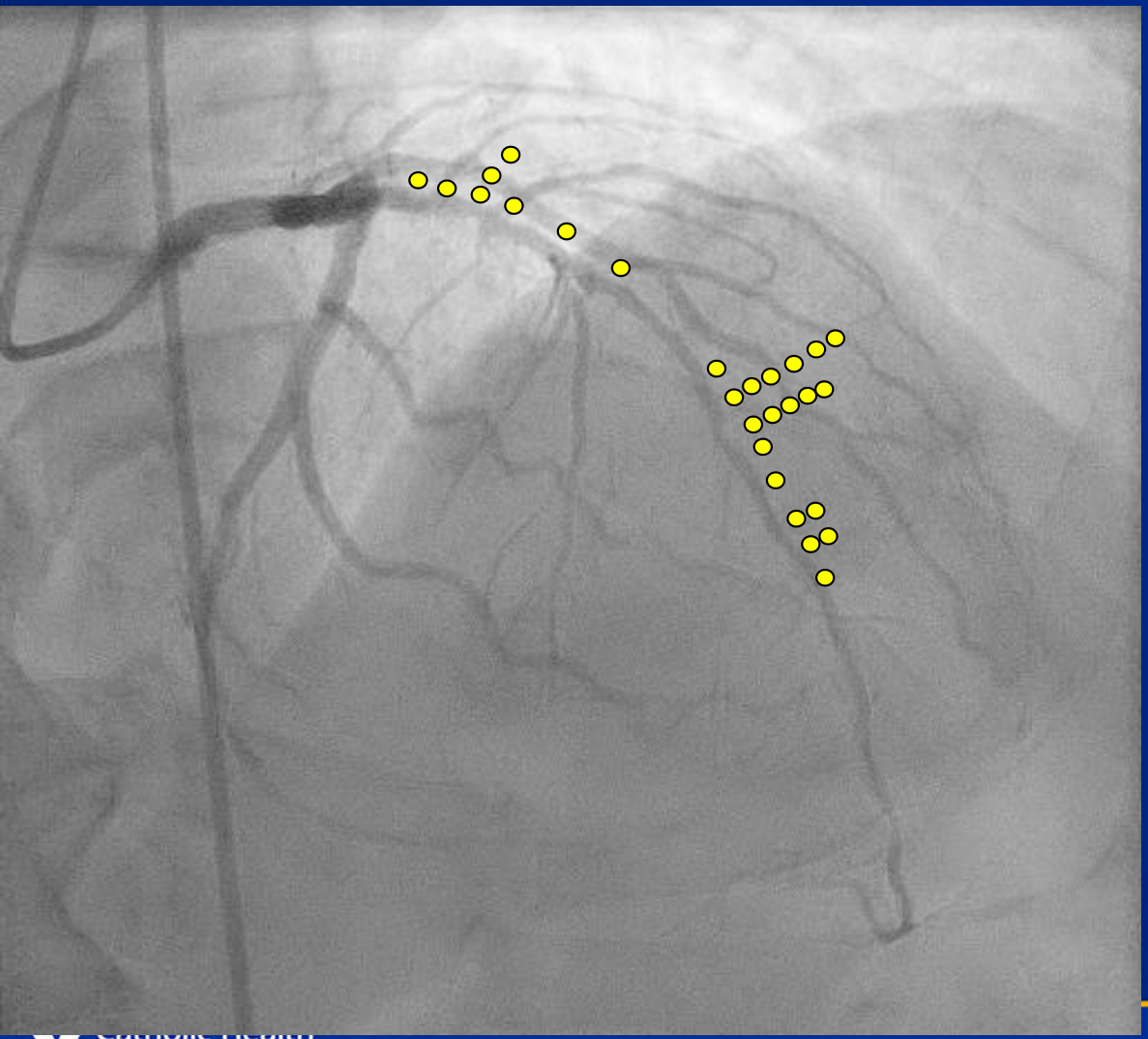


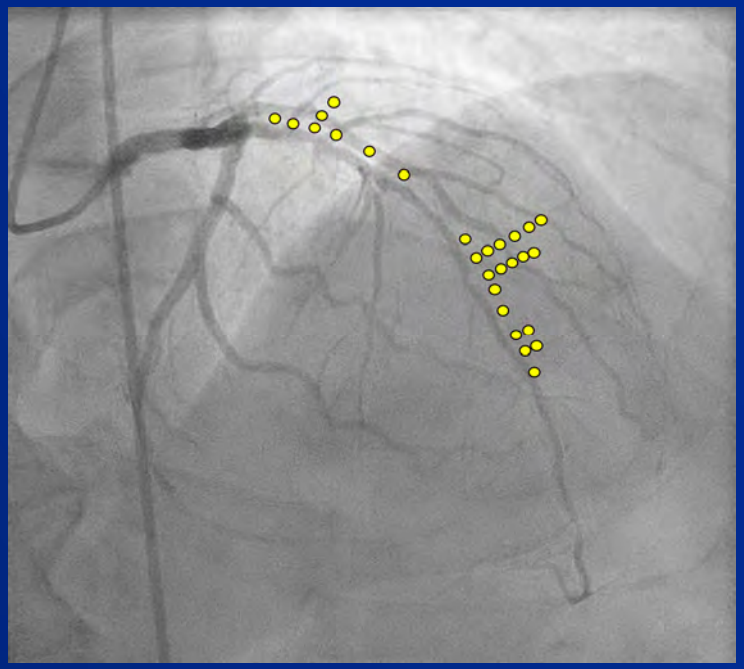
(1) DIFFUSE:

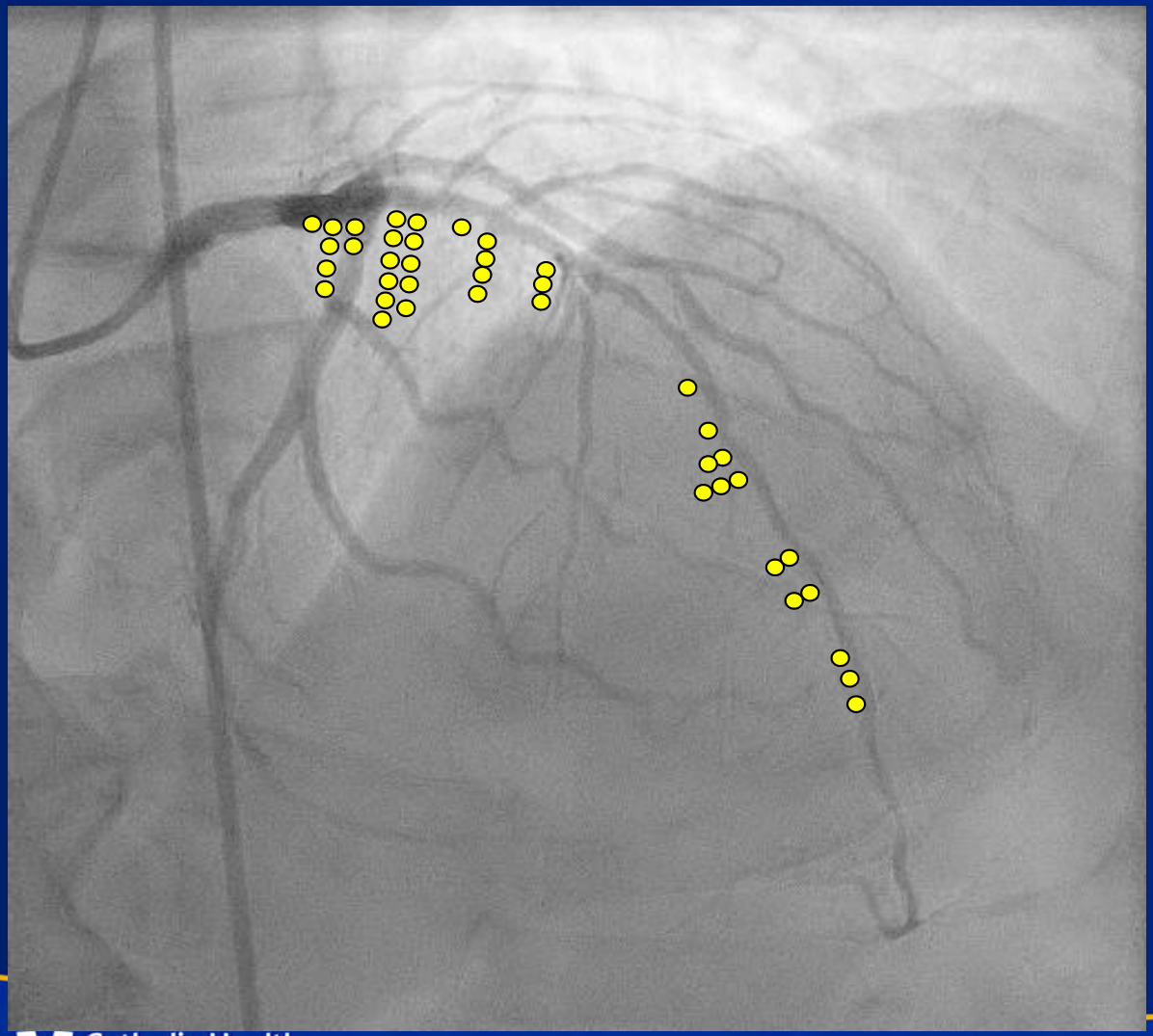
CAD distributed throughout vessel

GOAL: Acceptable iFR = 0.90

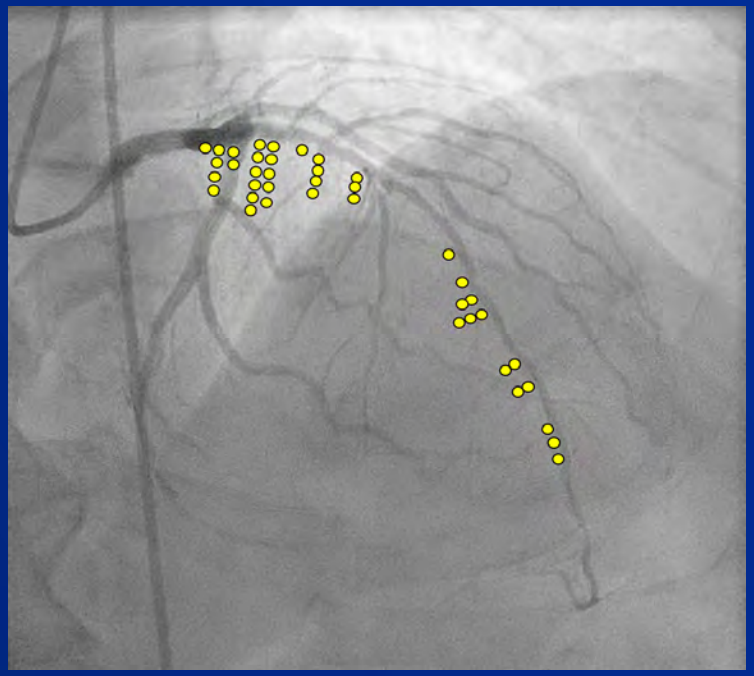
(2) FOCAL DISTAL



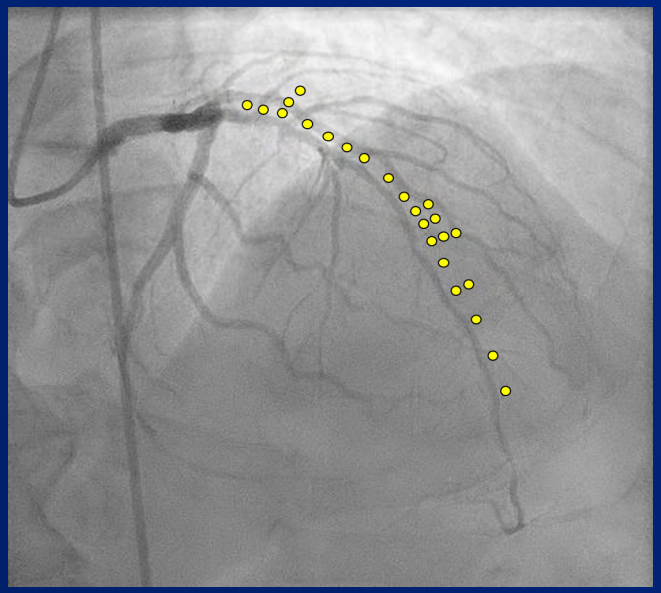




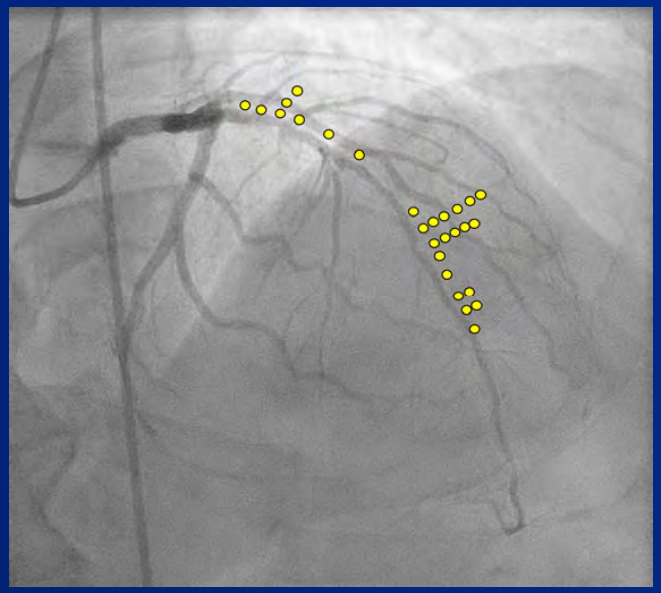
(3) FOCAL PROX and DIFFUSE DISTAL



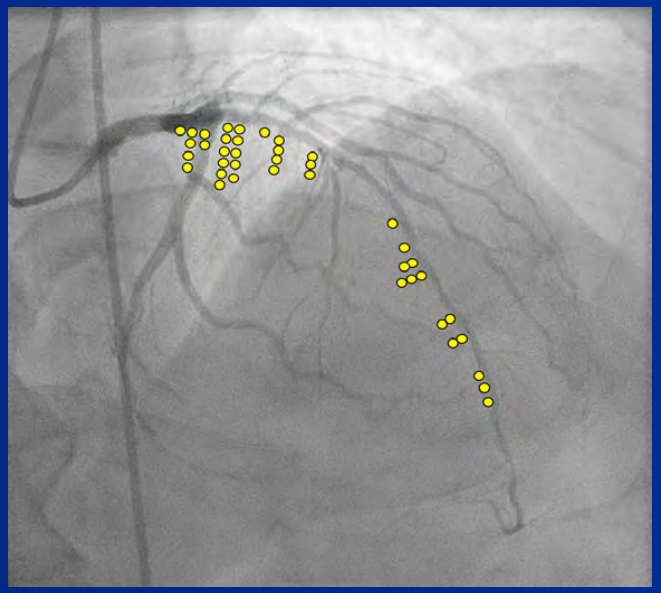
Which best describes the predicted iFR co-reg?



(i) Diffuse Disease

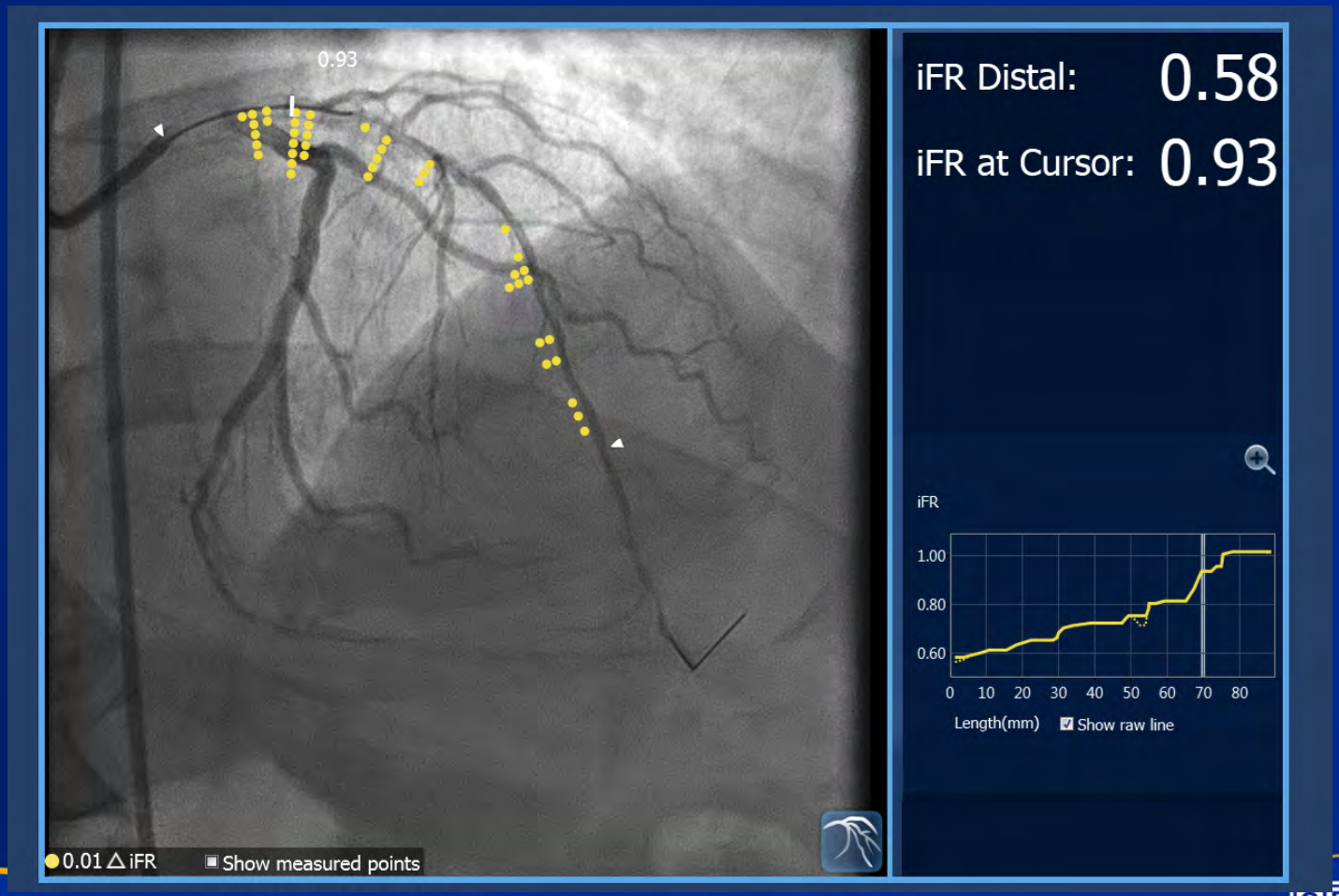


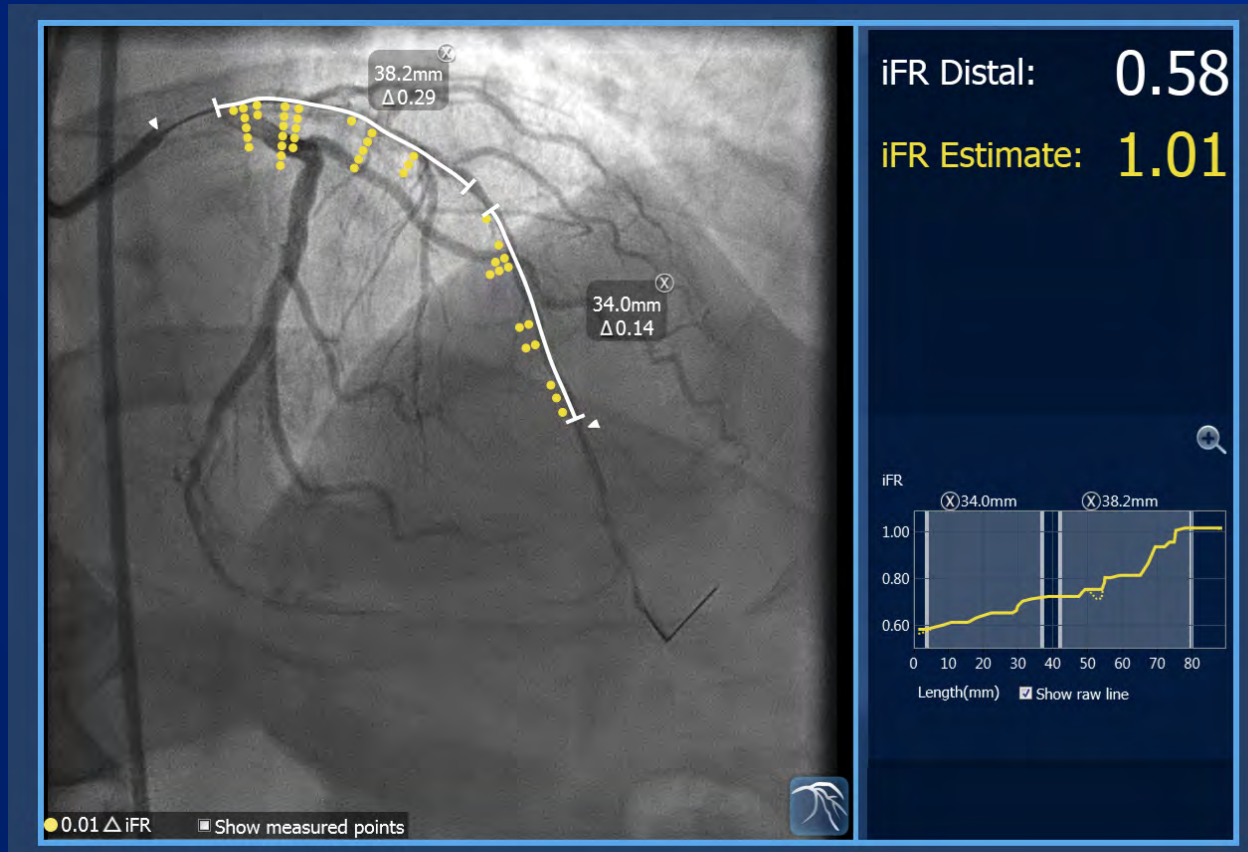
(ii) Focal Disease (distal)
Diffuse Disease (prox)



(i) Focal Disease (prox)
Diffuse Disease (distal)

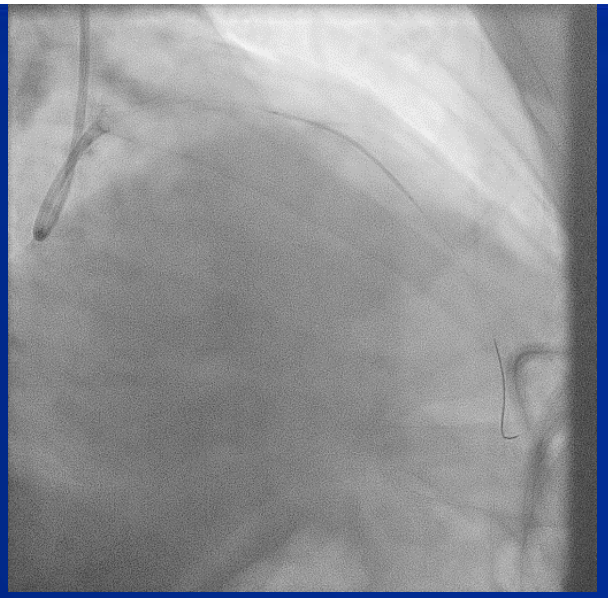
SyncVision Co-Registration

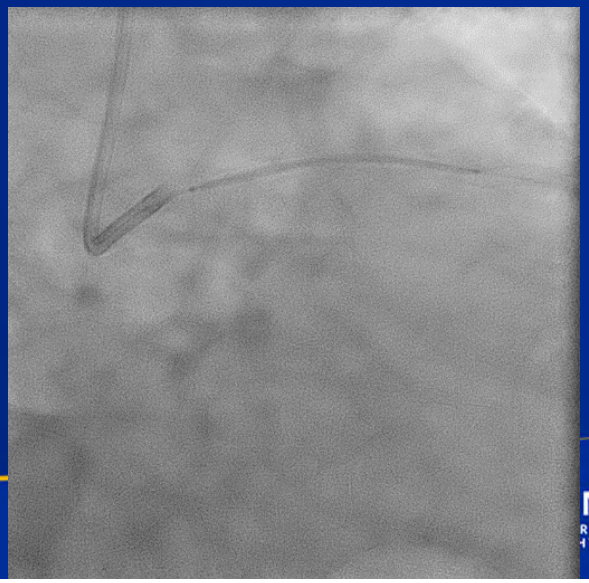




02/08/2022 05:05:13

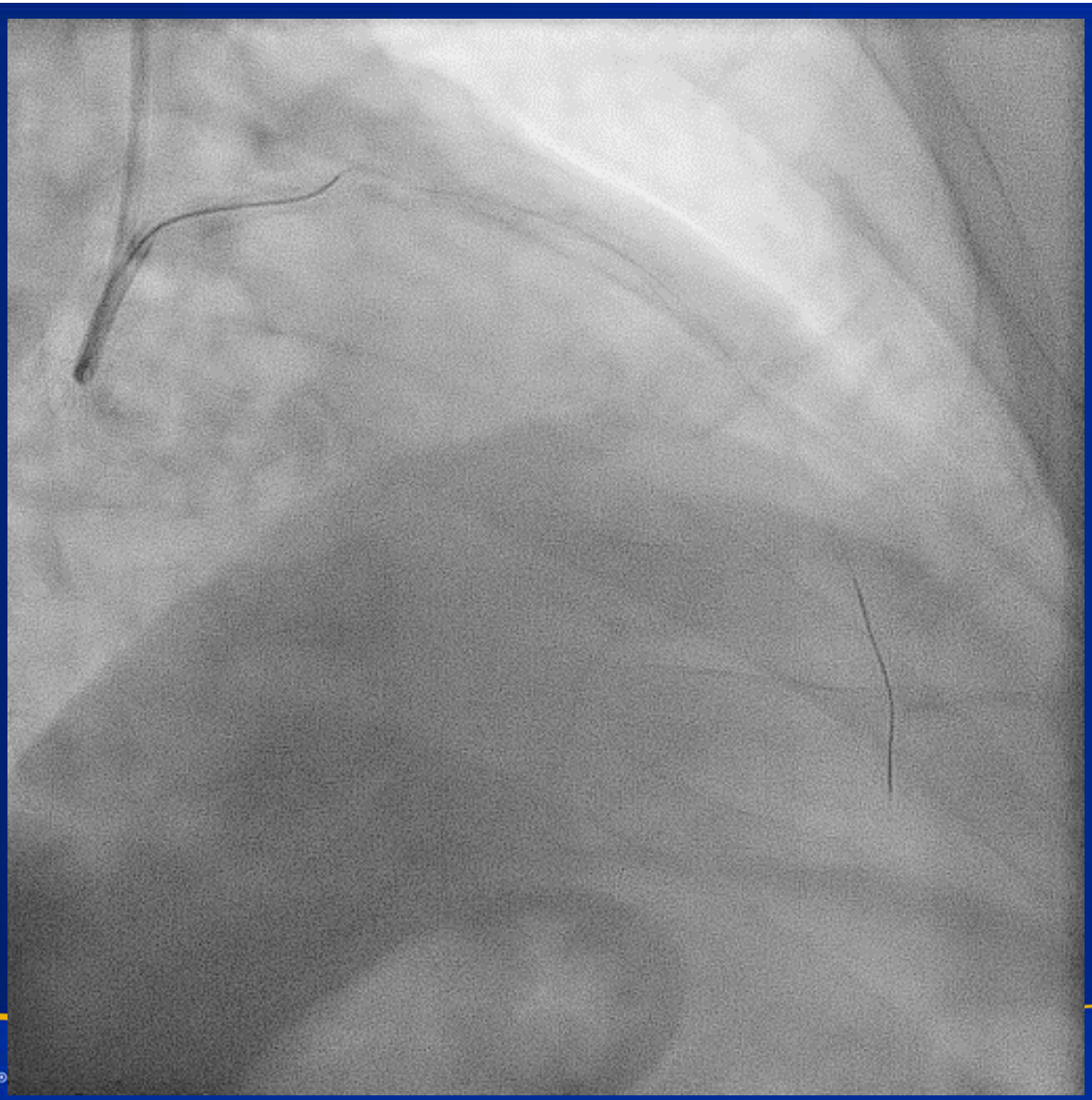
Philips SyncVision

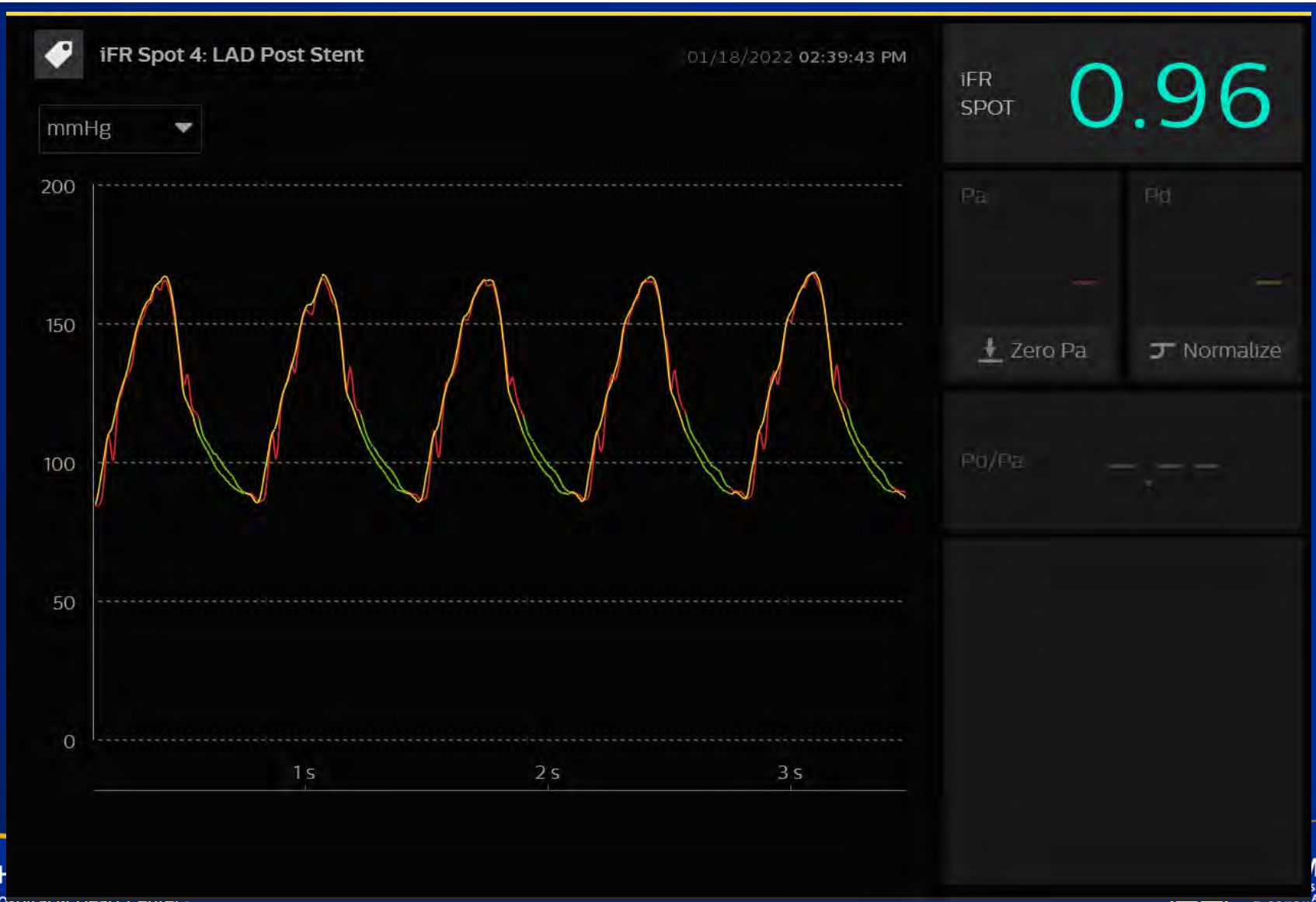




Catholic Health
St. Francis Hospital & Heart Center®

NG PCI
R IMAGING
HYSIOLOGY

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01/18/2022 02:39:43 PM
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1 s
2 s
3 s
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SPOT
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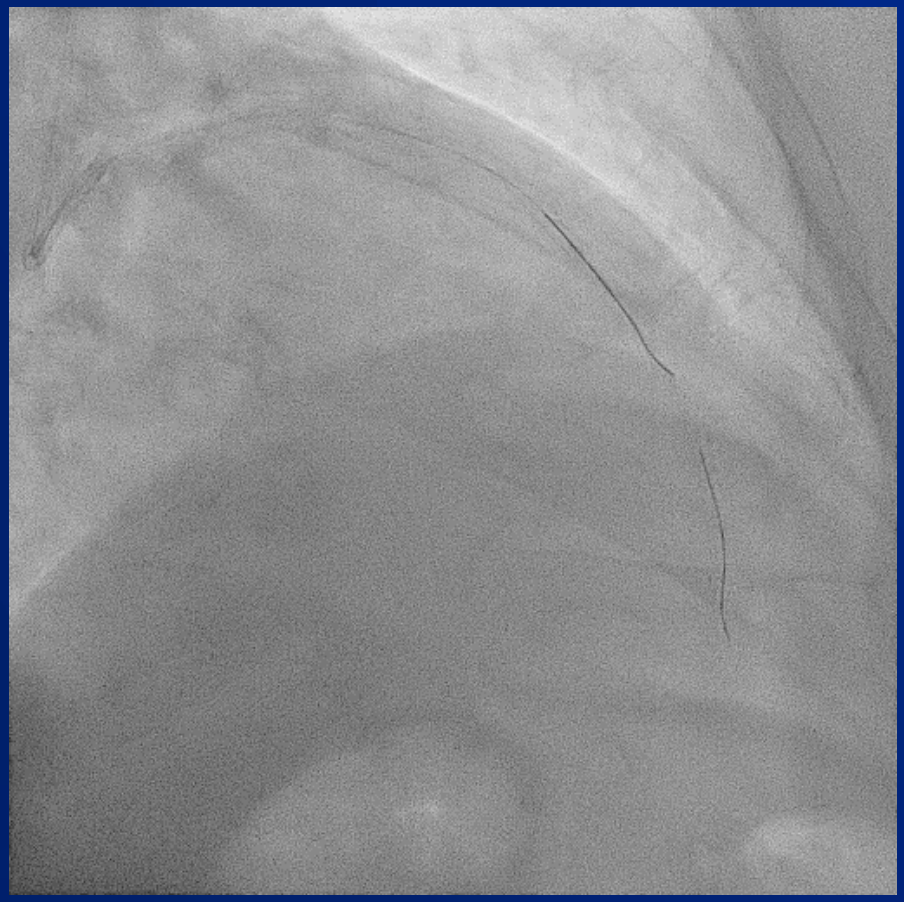
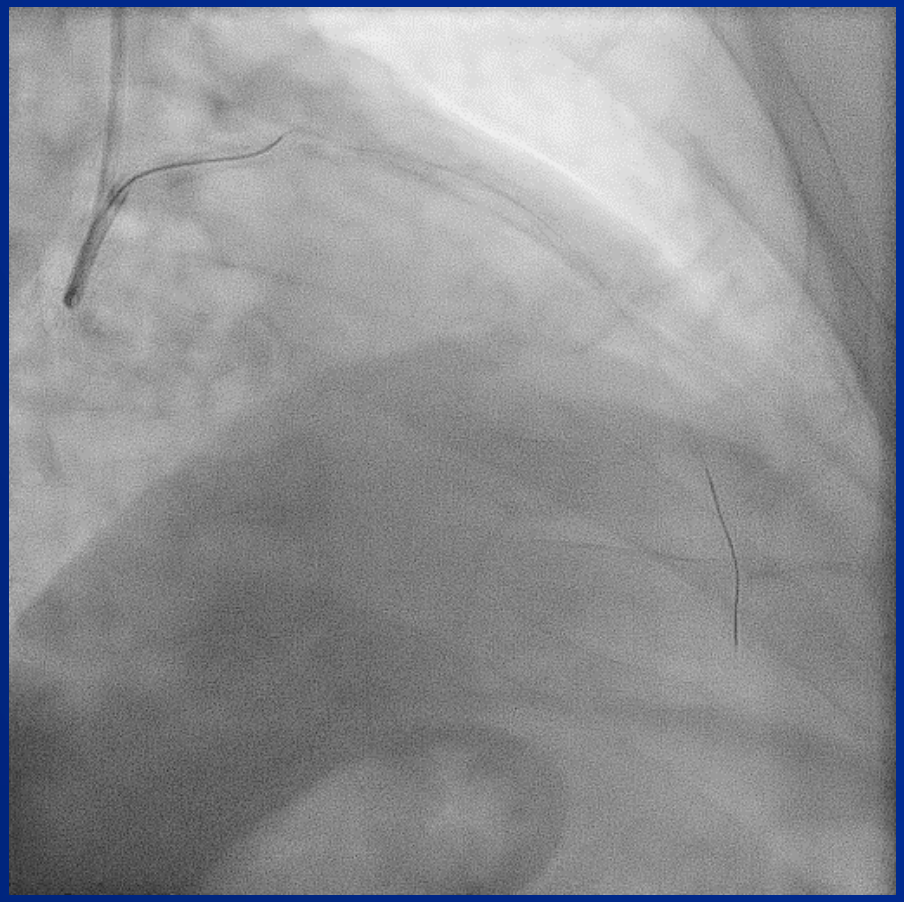
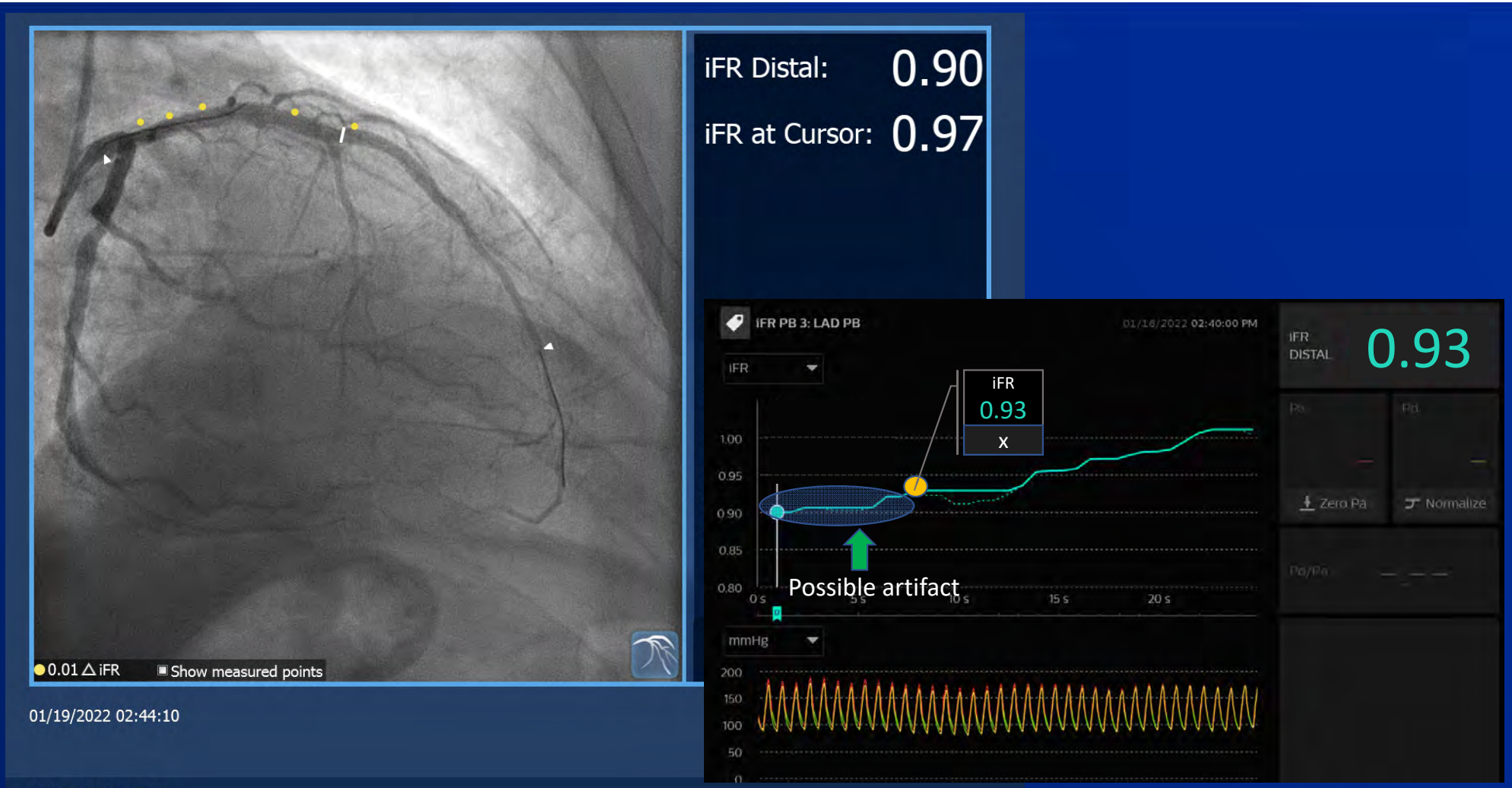
Pa
Pd
Zero Pa
Normalize
Pd/Pa



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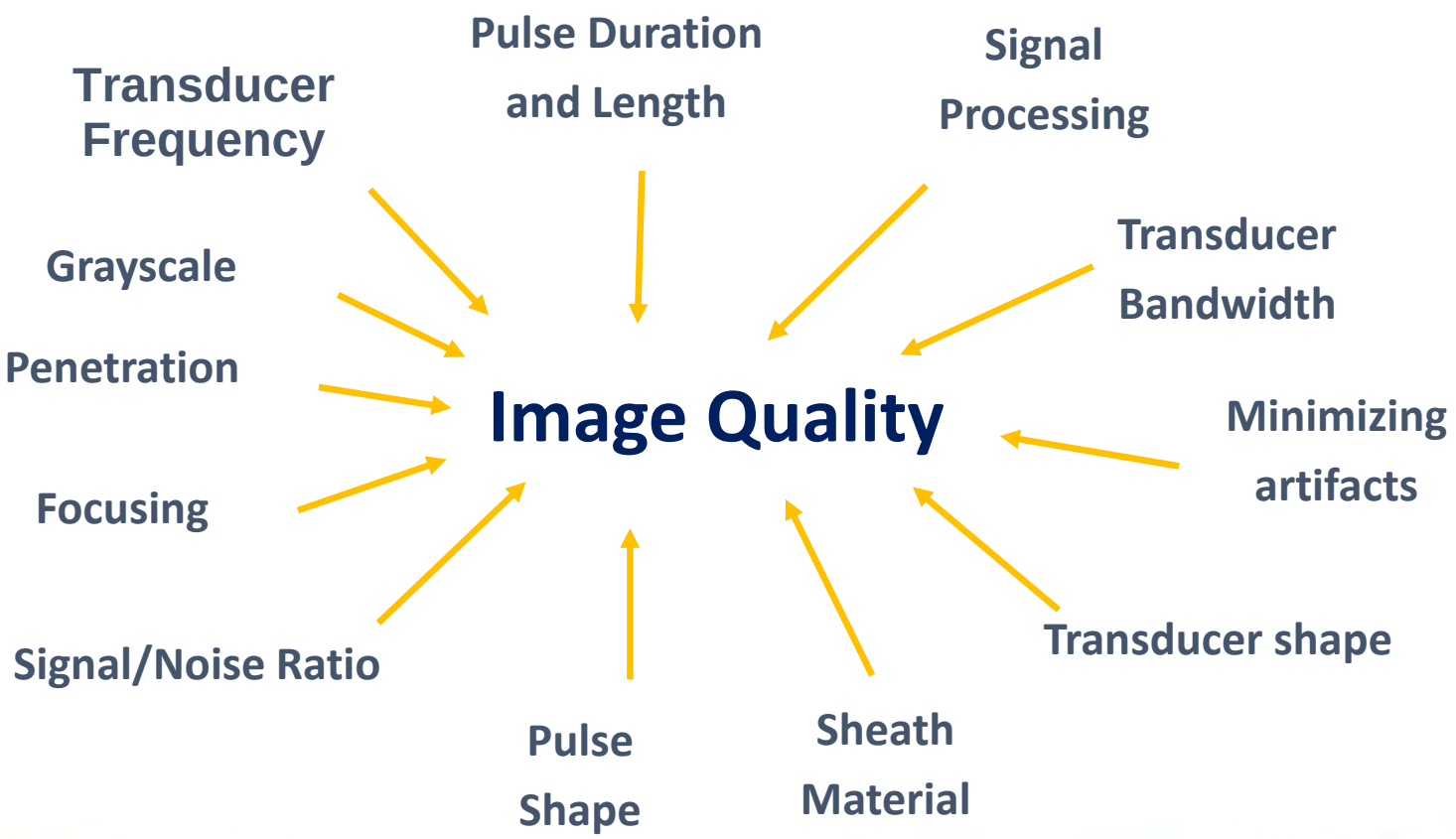
iFR at Cursor: 0.97
0.01 △ iFR
Show measured points
01/19/2022 02:44:10
Philips SyncVision
iFR PB 3: LAD PB
01/18/2022 02:40:00 PM
iFR
iFR
0.93
x
1.00
0.95
0.90
0.85
0.80
0 s
5 s
10 s
15 s
20 s
Possible artifact
mmHg
200
150
100
50
0
iFR DISTAL 0.93
Pa
Pd
Zero Pa
Normalize
Pd/Pa

“Its too complicated.”

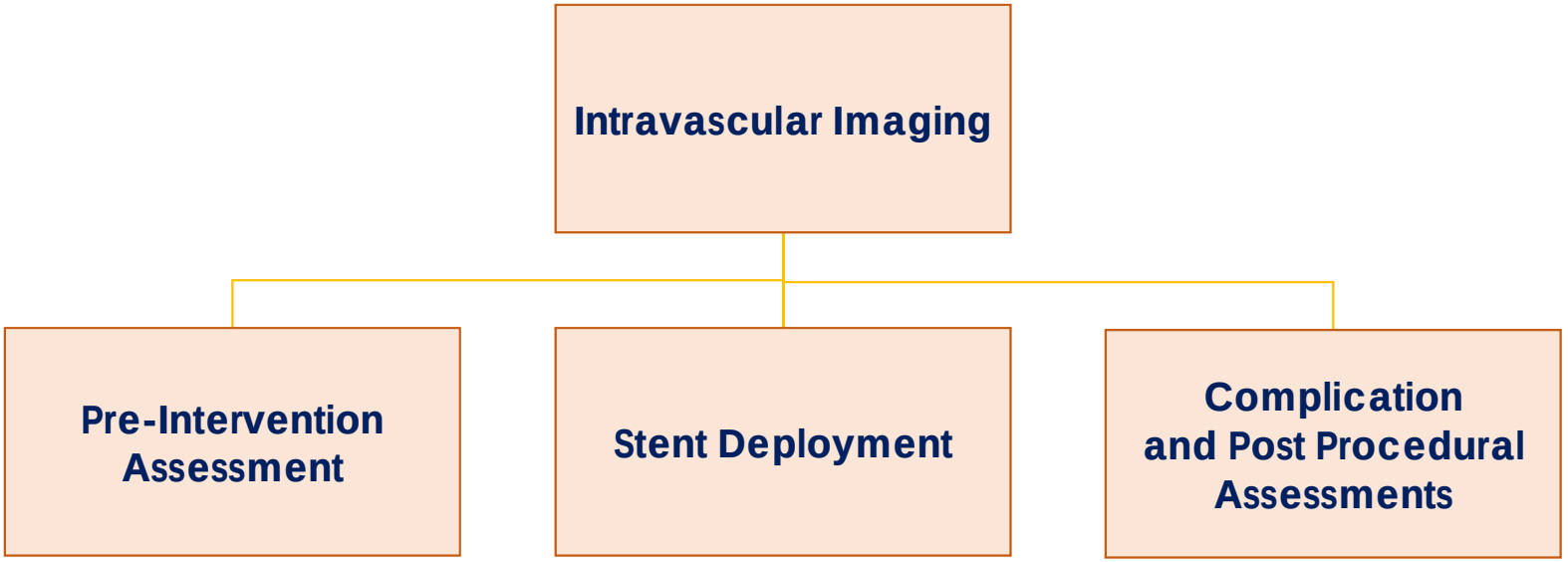
Barriers to Physiology and Intravascular Imaging Utilization

1. “angio is good enough…”
2. “there’s not enough proof intravascular imaging impacts outcomes”
3. “I have always done it this way….”
4. “I am busy and it takes too long”
5. “procedure cost”

Imaging for the Engineer



Imaging for the Interventionalist



1. Assess plaque composition
2. Identify reference segments
3. Choose stent size

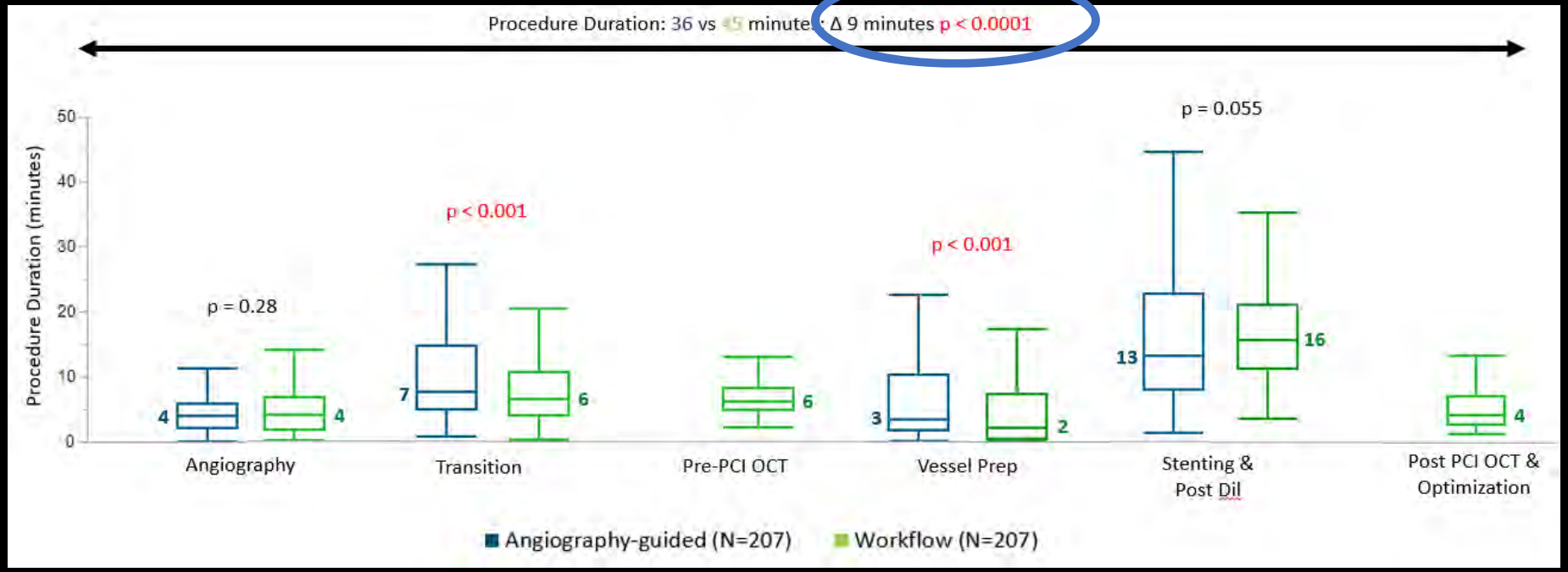
4. Deploy normal-to-normal
5. Determine expansion/MSA

6. Identify stent problems
   - Malapposition
   - Tissue Protrusion
7. Identify edge problems
   - Edge dissection
   - Reference Segment Disease

Barriers to Physiology and Intravascular Imaging Utilization

1. “angio is good enough…”
2. “there’s not enough proof intravascular imaging impacts outcomes”
3. “I have always done it this way….” (i.e. lack of training)
4. “I am busy and it takes too long”
5. “procedure cost”

MLD MAX: Improved Accuracy: Minimal Increase in Procedure Time



Barriers to Physiology and Intravascular Imaging Utilization

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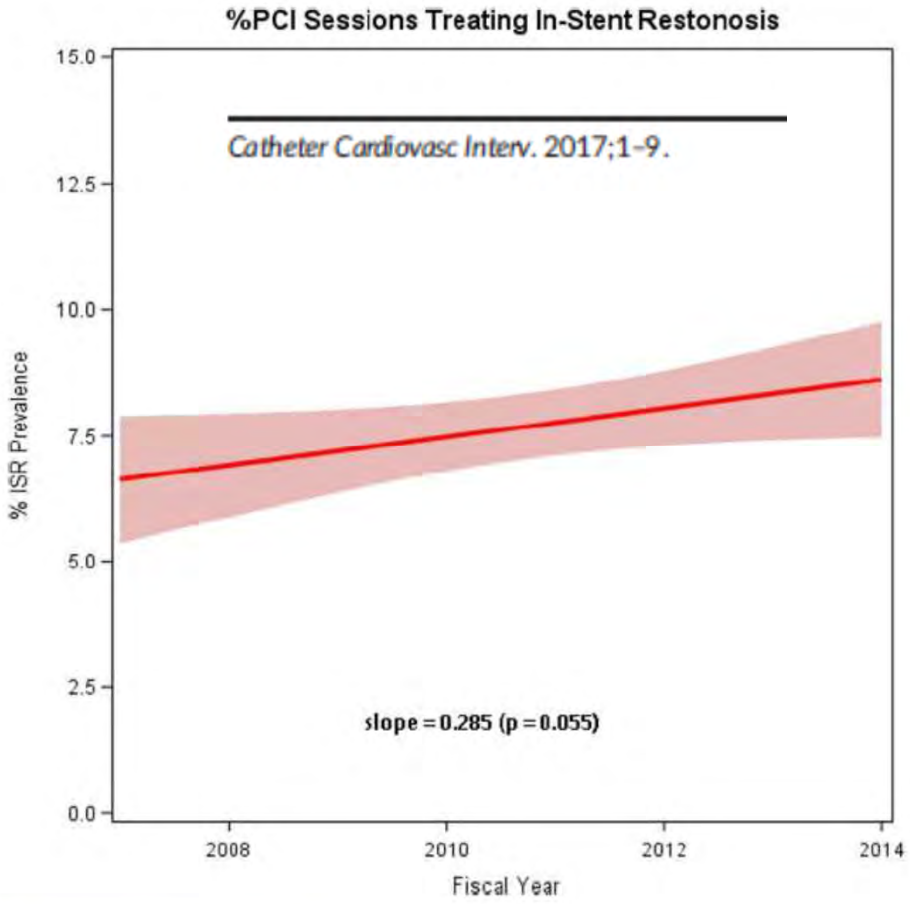
Cost of Not Using Intravascular Imaging!



12.6% of U.S. PCI are for ISR

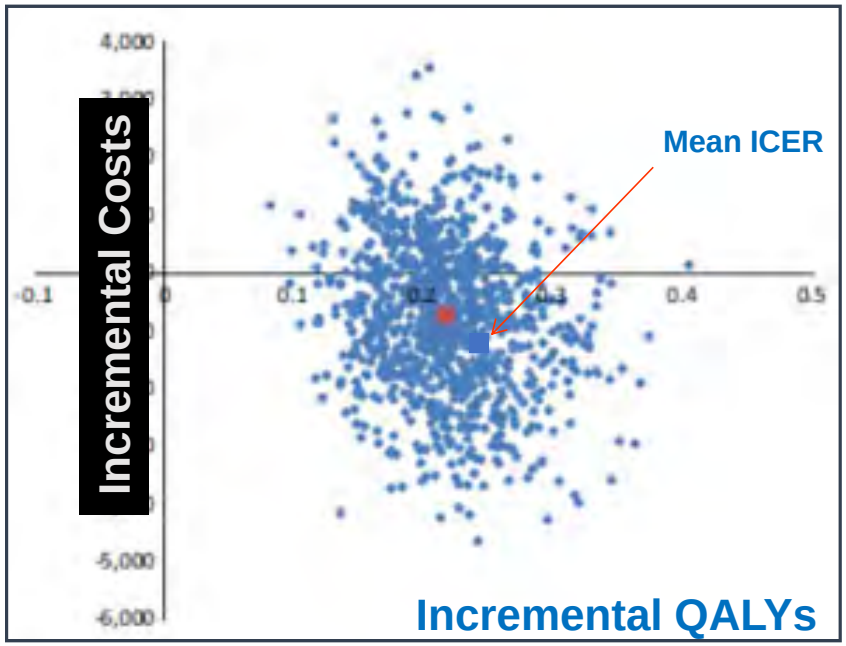
80-90,000 cases per year

Imaging cuts TLF in half!!

Health Care Savings $$$

IVUS – Cost Effectiveness

From the healthcare payer perspective, IVUS is a dominant treatment option, providing improved outcomes at lower costs, with greater economic benefit in higher risk subgroups (diabetes, renal insufficiency, ACS)



Assumptions: hypothetical population of 1000 pts with an average age of 60, all of whom underwent PCI with DES, guided either by IVUS and angiography, or angiography alone with 1.6% probability of MI and 2.7% probability of repeat revascularization in one year

Eur J Health Econ. 2016 Mar;17(2):185-93

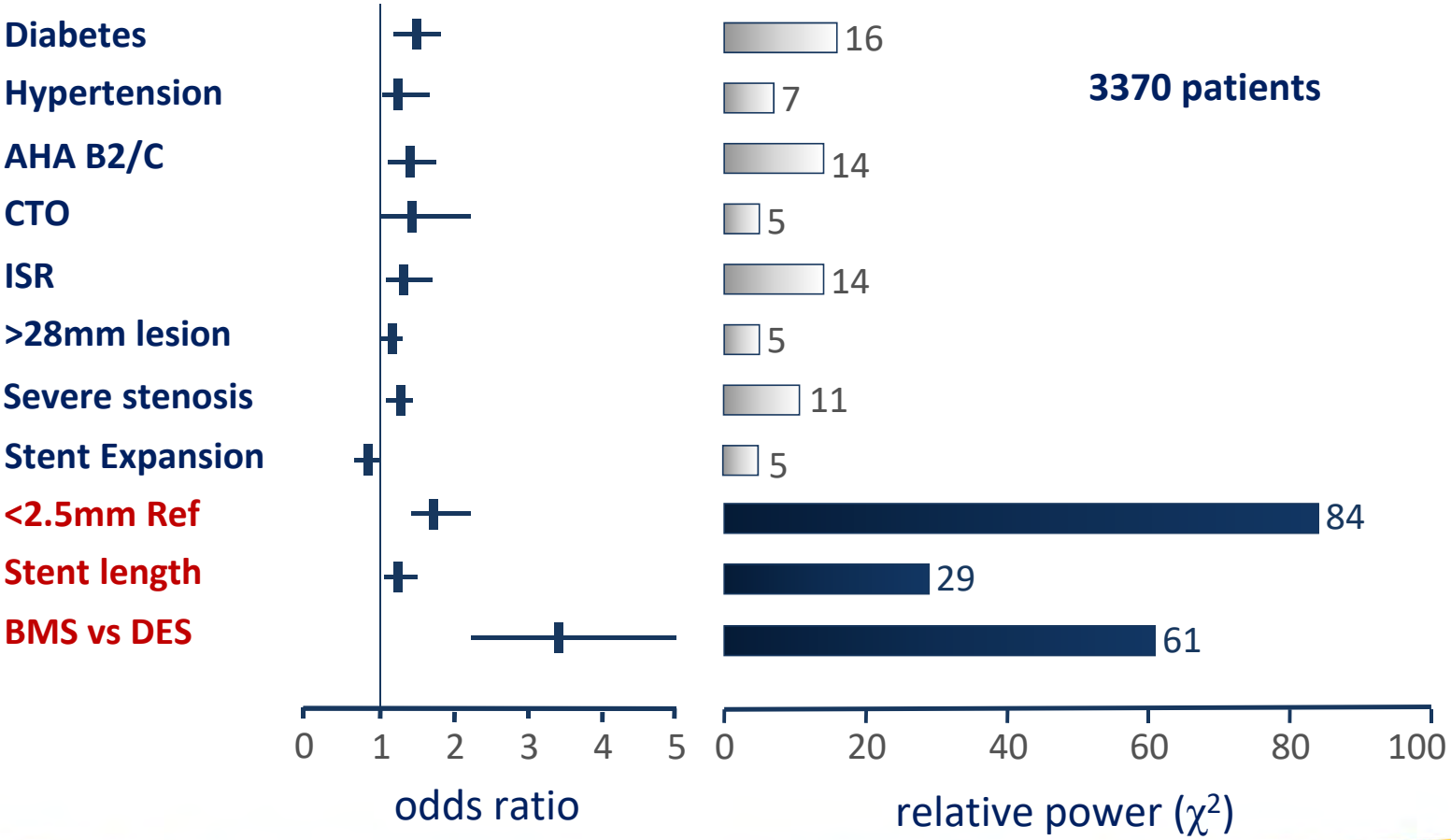
“I don’t know when, and when not, to use it.”

Patient Comorbidities

In whom is the risk of TVF the highest?

- Diabetes Mellitus
- End Stage Renal Disease
- Previous Stent Failure
- Co-morbidity necessitating the use of BMS

Independent Risk Factors for Restenosis

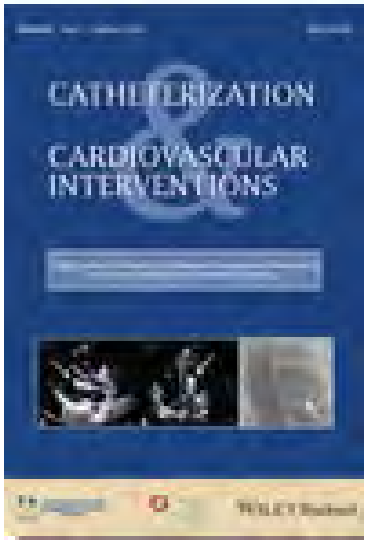


Kastrati et al., *Am J Cardiol* 2000

SCAI Expert Consensus on IVUS in PCI

Expert Consensus Statement on the Use of Fractional Flow Reserve, Intravascular Ultrasound, and Optical Coherence Tomography: A Consensus Statement of the Society of Cardiovascular Angiography and Interventions

Amir Lotfi,[1] MD, FSCAI, Allen Jeremias,[2] MD, FSCAI, William F. Fearon,[3] MD, FSCAI, Marc D. Feldman,[4] MD, FSCAI, Roxana Mehran,[5] MD, John C. Messenger,[6] MD, FSCAI, Cindy L. Grines,[7] MD, FSCAI, Larry S. Dean,[8] MD, FSCAI, Morton J. Kern,[9] MD, FSCAI, and Lloyd W. Klein,[10*] MD, FSCAI



Intravascular ultrasound (IVUS).

Definitely Beneficial. IVUS is an accurate method for determining optimal stent deployment (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 mm^2, assess whether revascularization is warranted.

Possibly Beneficial. IVUS can be useful for the assessment of plaque morphology.

No Proven Value/Should be Discouraged. IVUS measurements for determination of non-LMCA lesion severity should not be relied upon, in the absence of additional functional evidence, for recommending re-

✓ "Definitely Beneficial"

IVUS Use Supported by ACC/AHA/SCAI Guidelines

Use of 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
To determine the mechanism of stent thrombosis	IIb	C

Levine G et al,, Catheterization Cardiovasc Interv 2011

Additional Published Studies Assessing the Benefit of IVUS

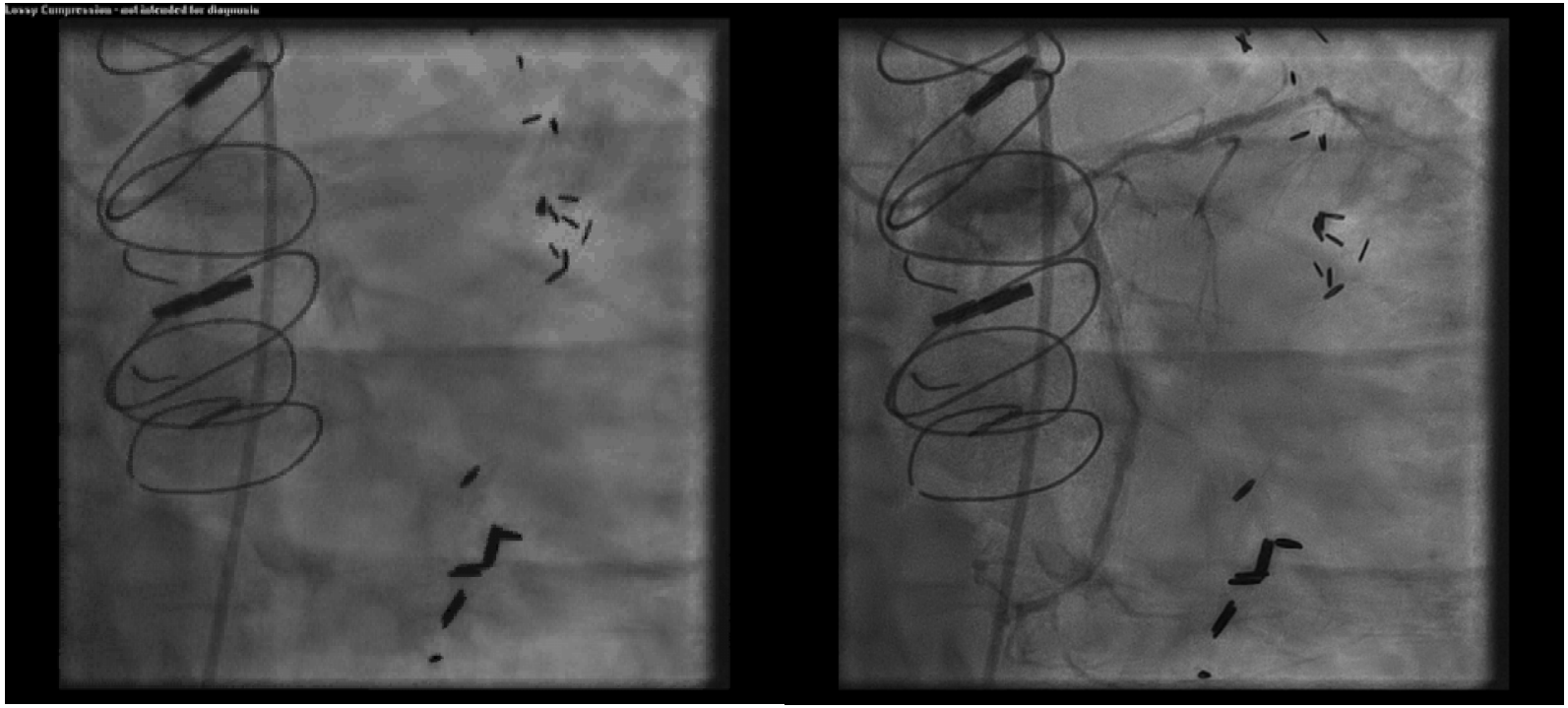
Studies showing benefit of IVUS				
Reference	Subset	Stats	# Pts	Endpoint
Patel et al. Cath Cardiovasc Interv, in press	Ostial	Propensity score matched	225	MACE (HR=0.54, p=0.04)
Tian et al. Eurointervention 2015;10:1409-17	CTO	Randomized	230	LLL (0.28mm vs 0.46mm, p=0.025); restenosis (3.9% vs 13.7%, p=0.021)
Singh et al. Am J Cardiol 2015,115:1357-66	All		377,096 angio vs 24,475 IVUS	In-hospital mortality (0.4% vs. 0.8%, P<0.001)
Kim et al. Circ Cardiovasc Interv 2015, in press	CTO	Randomized	402	MACE (death, MI, TVR) 2.6% vs 7.1%, p=0.035
Hong et al. JAMA 2015;314:2155-63	Long lesions	Randomized	1400	MACE (2.9% vs 5.8%, p=0.007)
Magalhaes et al. Eurointervention 2015;11:625-33	All		2132	IVUS decreased rates of TLR irrespective of completeness of revascularization
Studies showing NO benefit of IVUS				
Reference	Lesion subset	Stats	# Pts	Endpoint
Fröhlich et al. JAMA Intern Med. 2014;174:1360-1366	All	Propensity score matched	803 pairs	also no benefit for FFR-guidance

Patient History

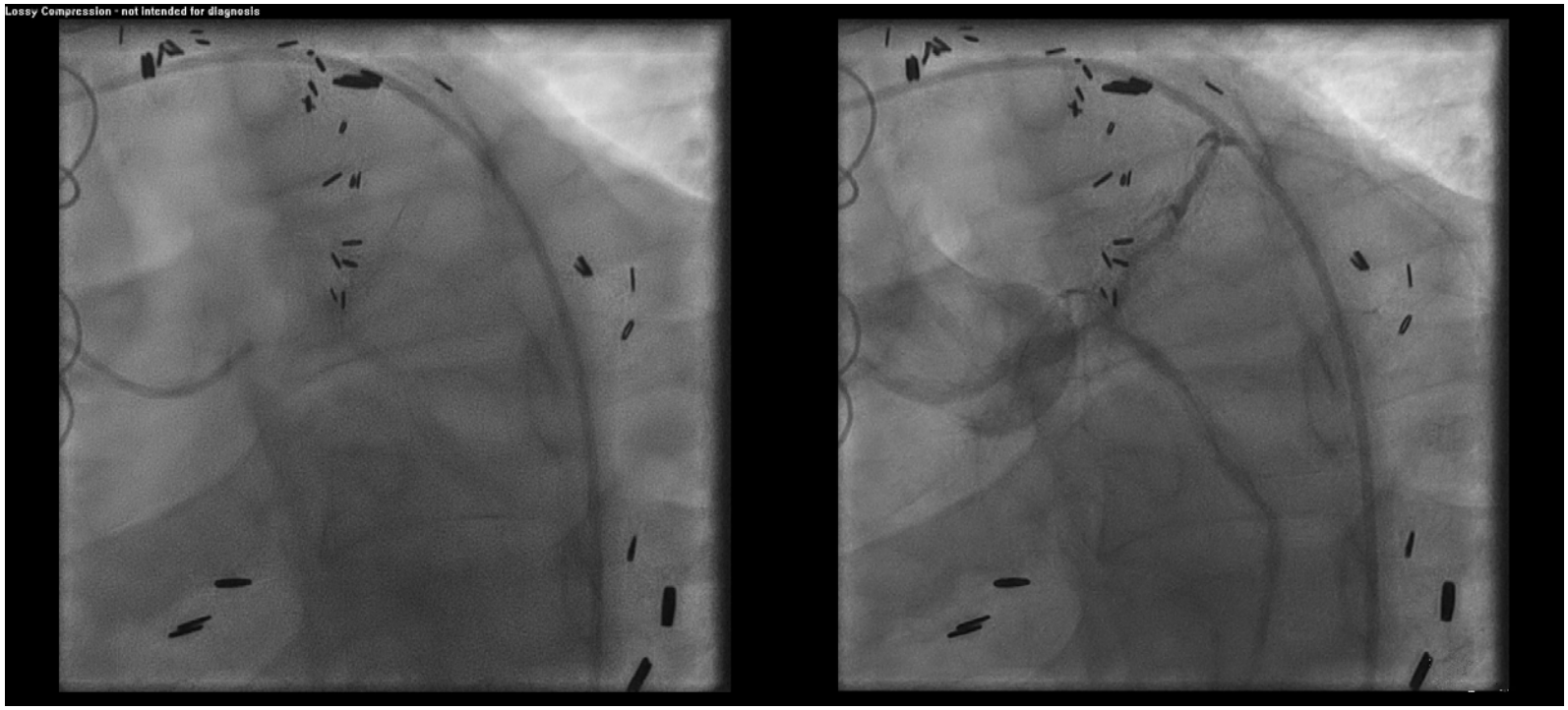
- 53 year old male p/w chest pain, found to have NSTEMI
- Past medical history:
  CAD with s/p CABG and multiple PCIs, DM, HTN

- Clinical course:
  - Pt. states that his symptoms started 1 days ago with progressive CP with relatively minor exertion and at rest
  - Chest pain free in hospital on therapy with heparin
  - Decision made for cardiac catheterization given NSTEMI

Severe In-stent Restenosis of LCX



Severe In-stent Restenosis of LCX



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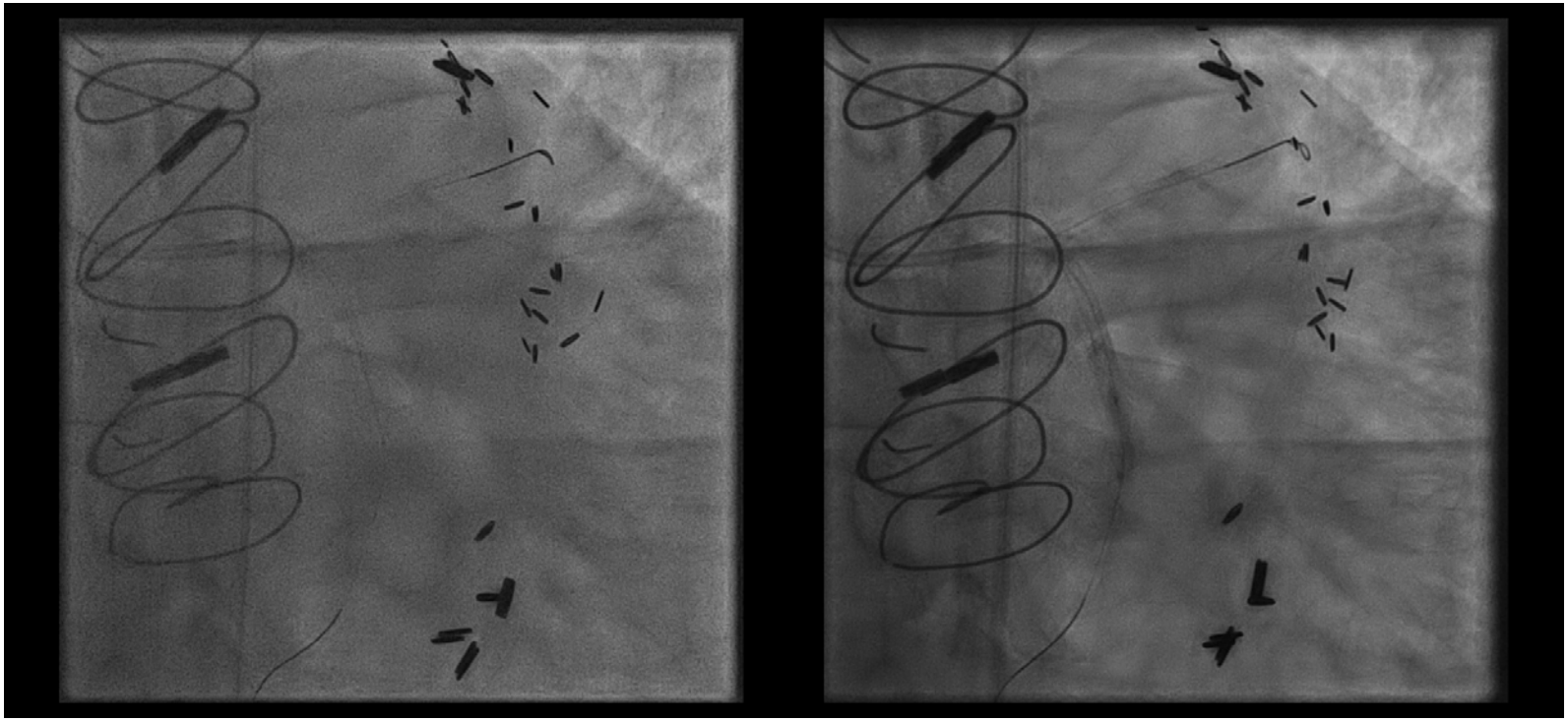

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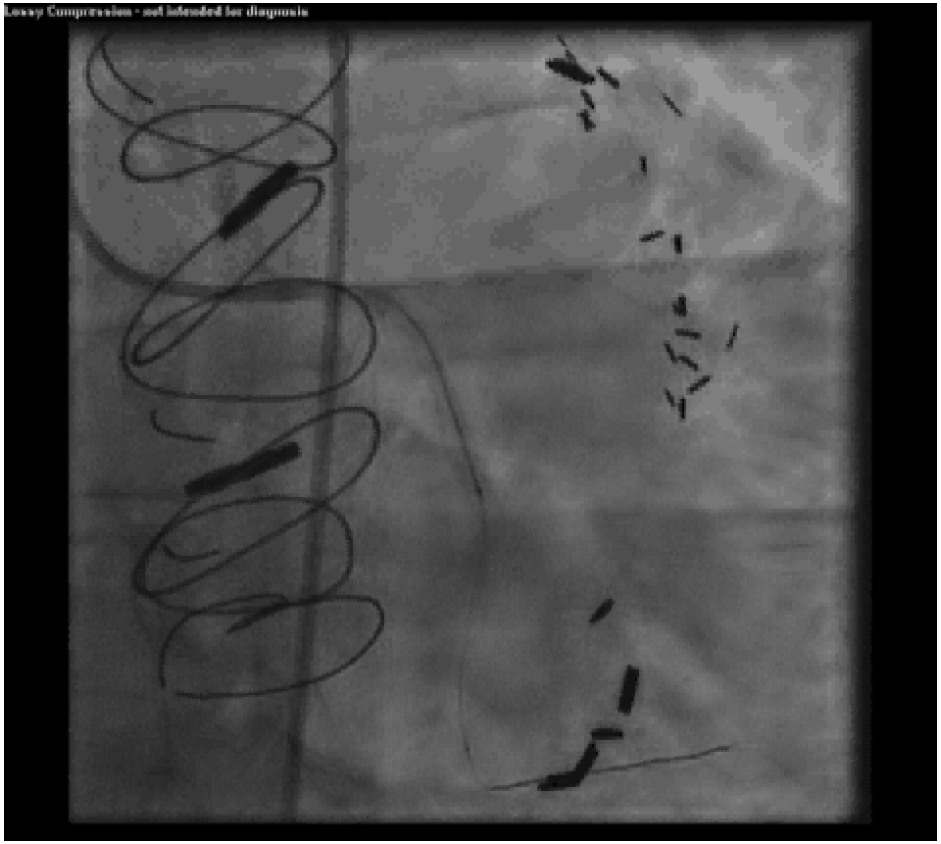
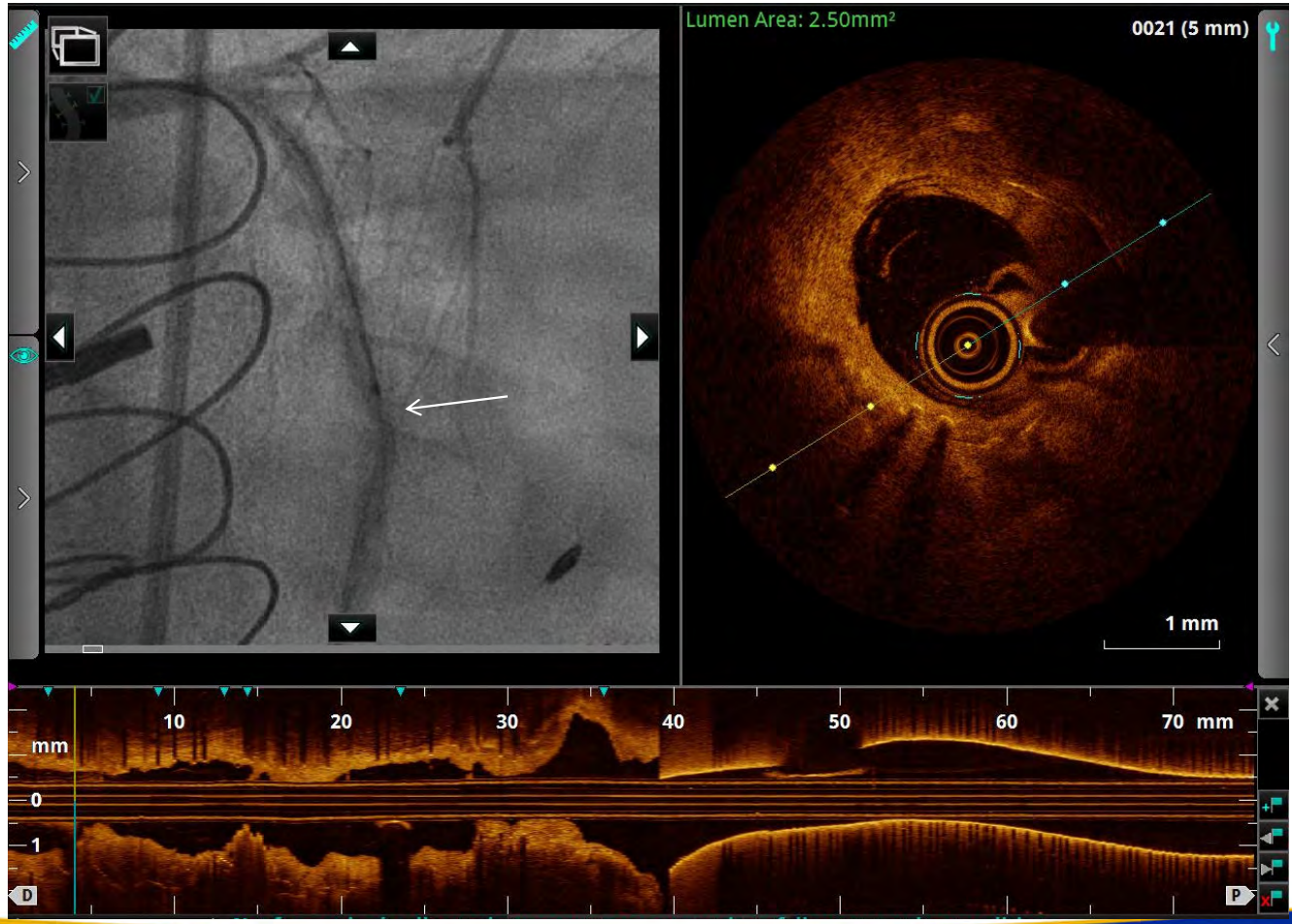
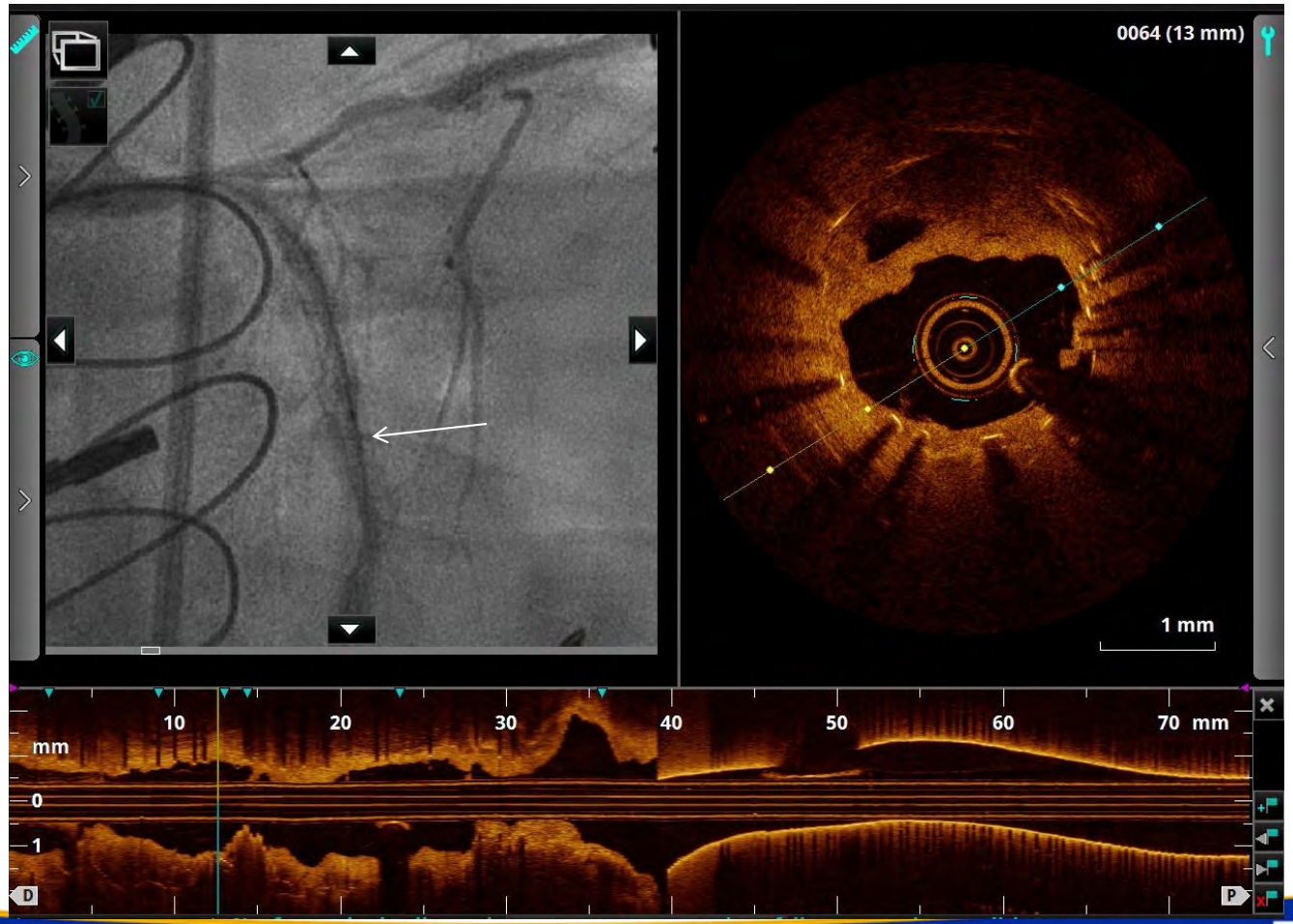


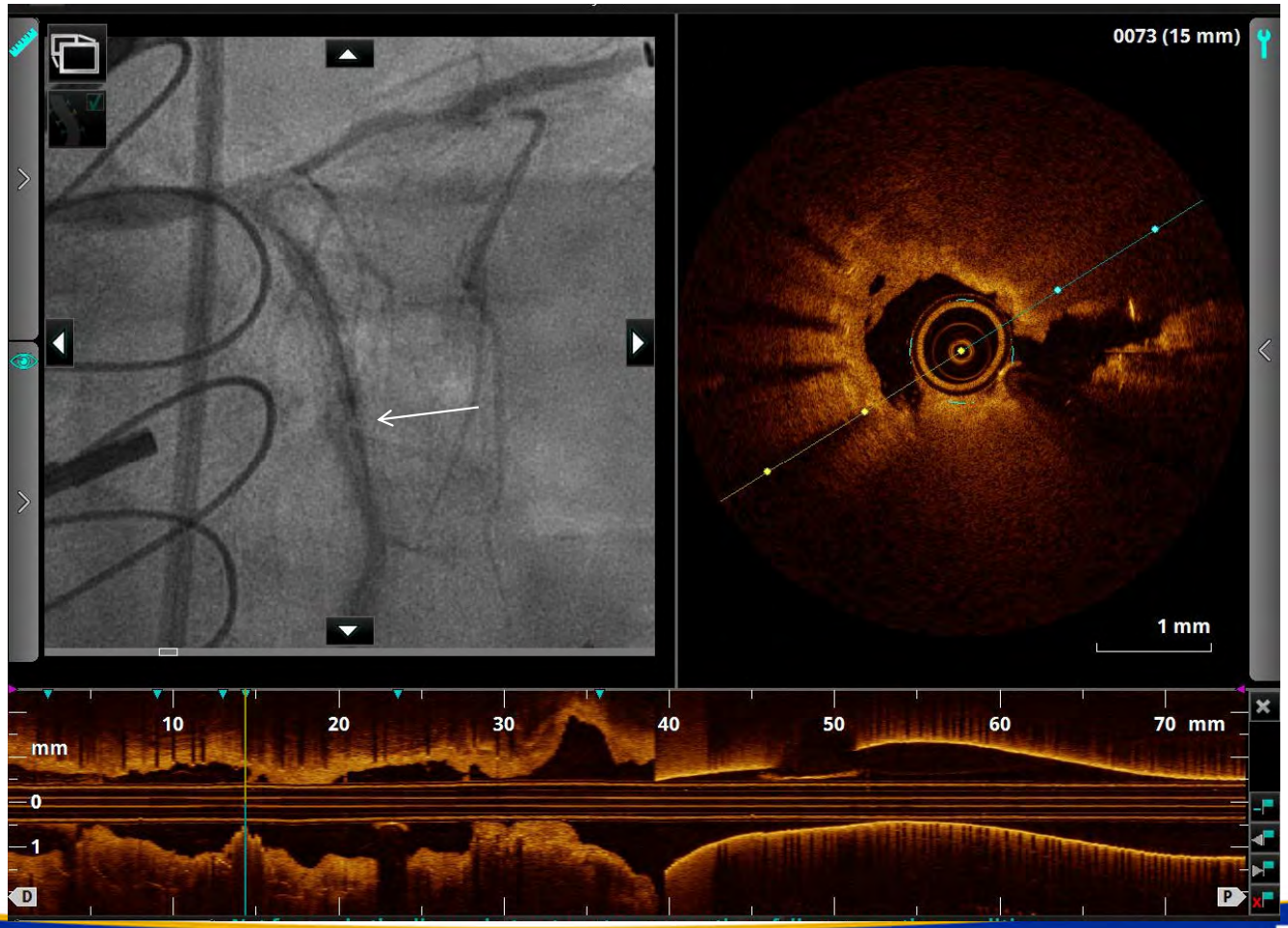
Distal Reference



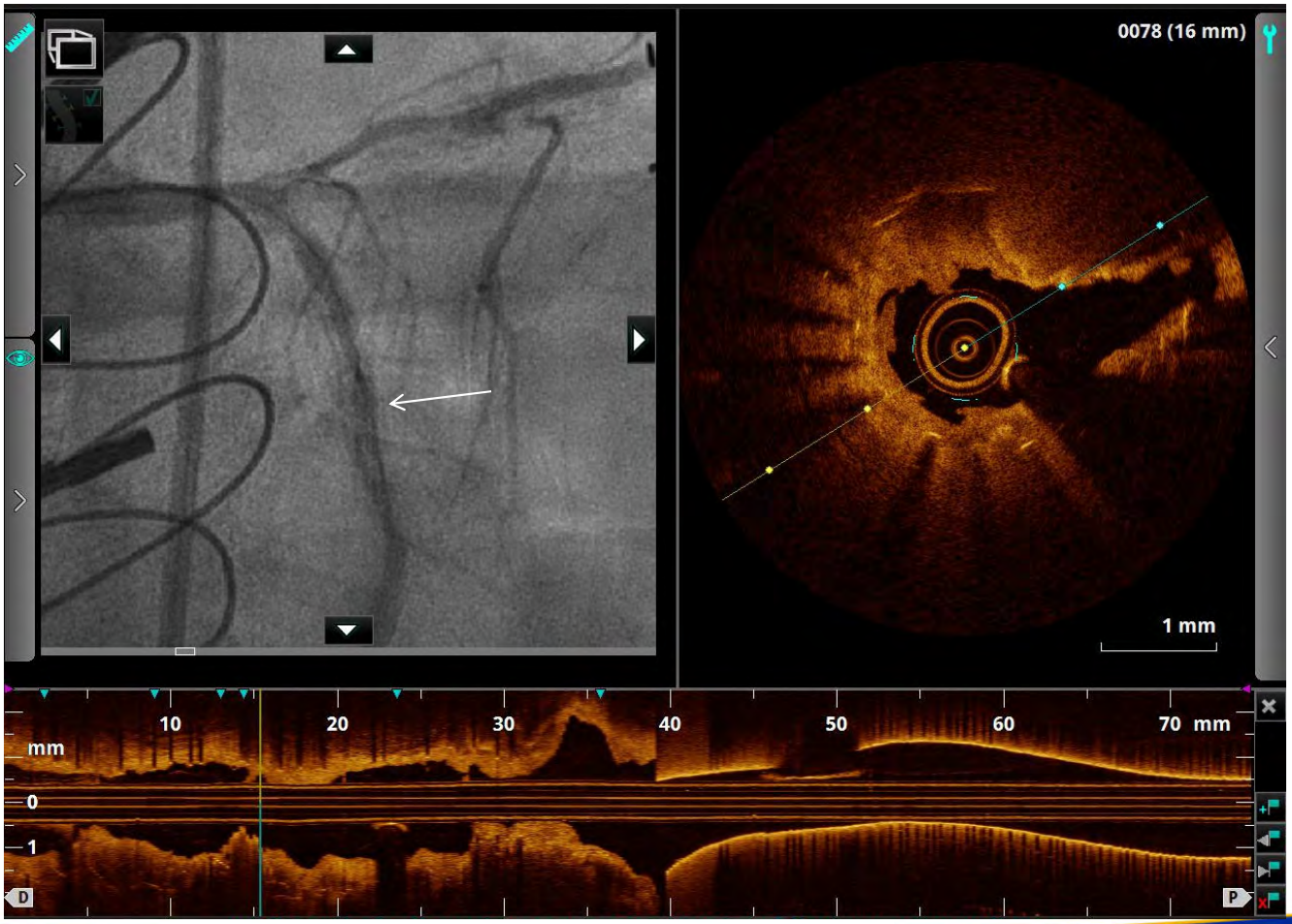
Neo-atheroma



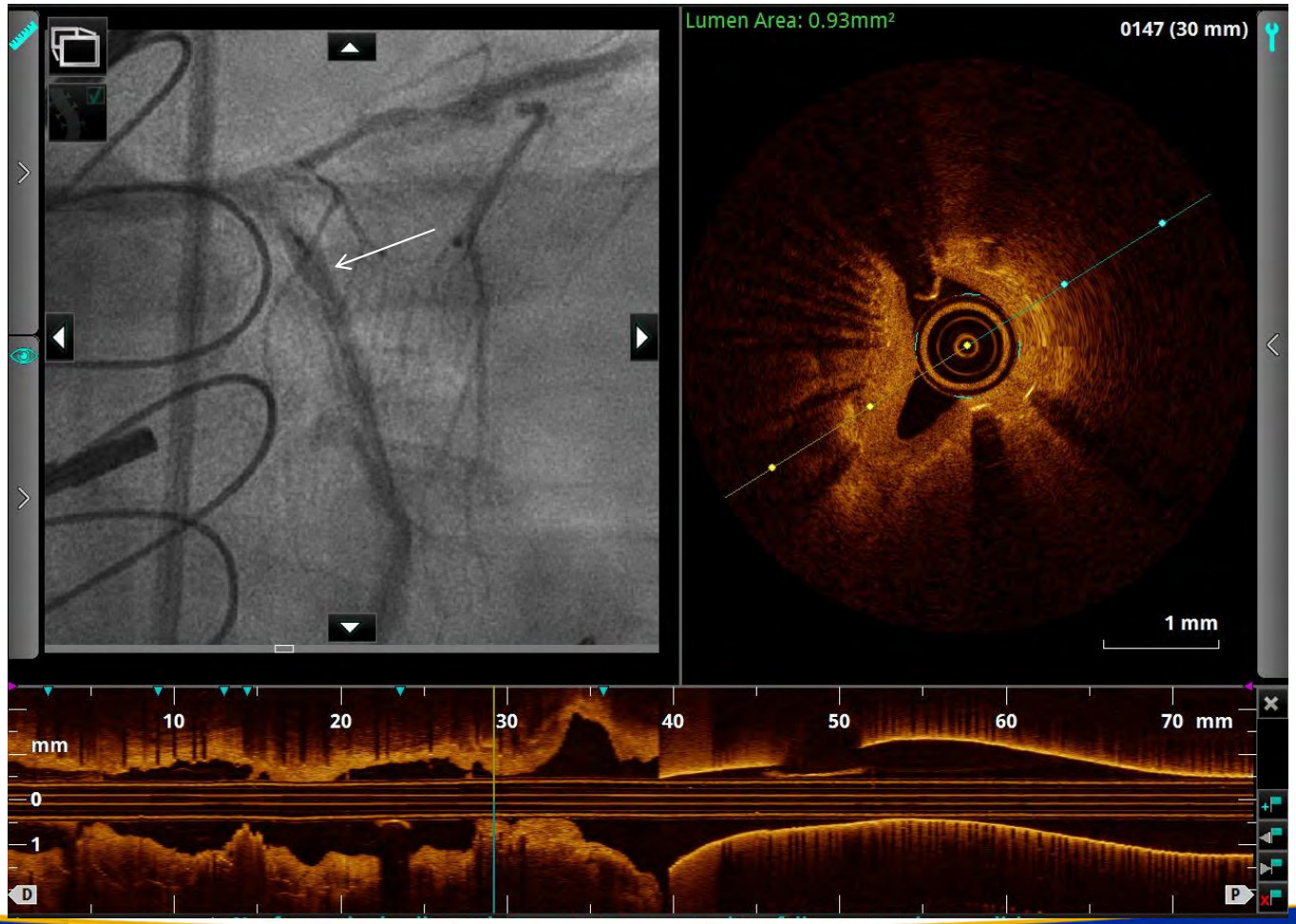
Calcified Nodule



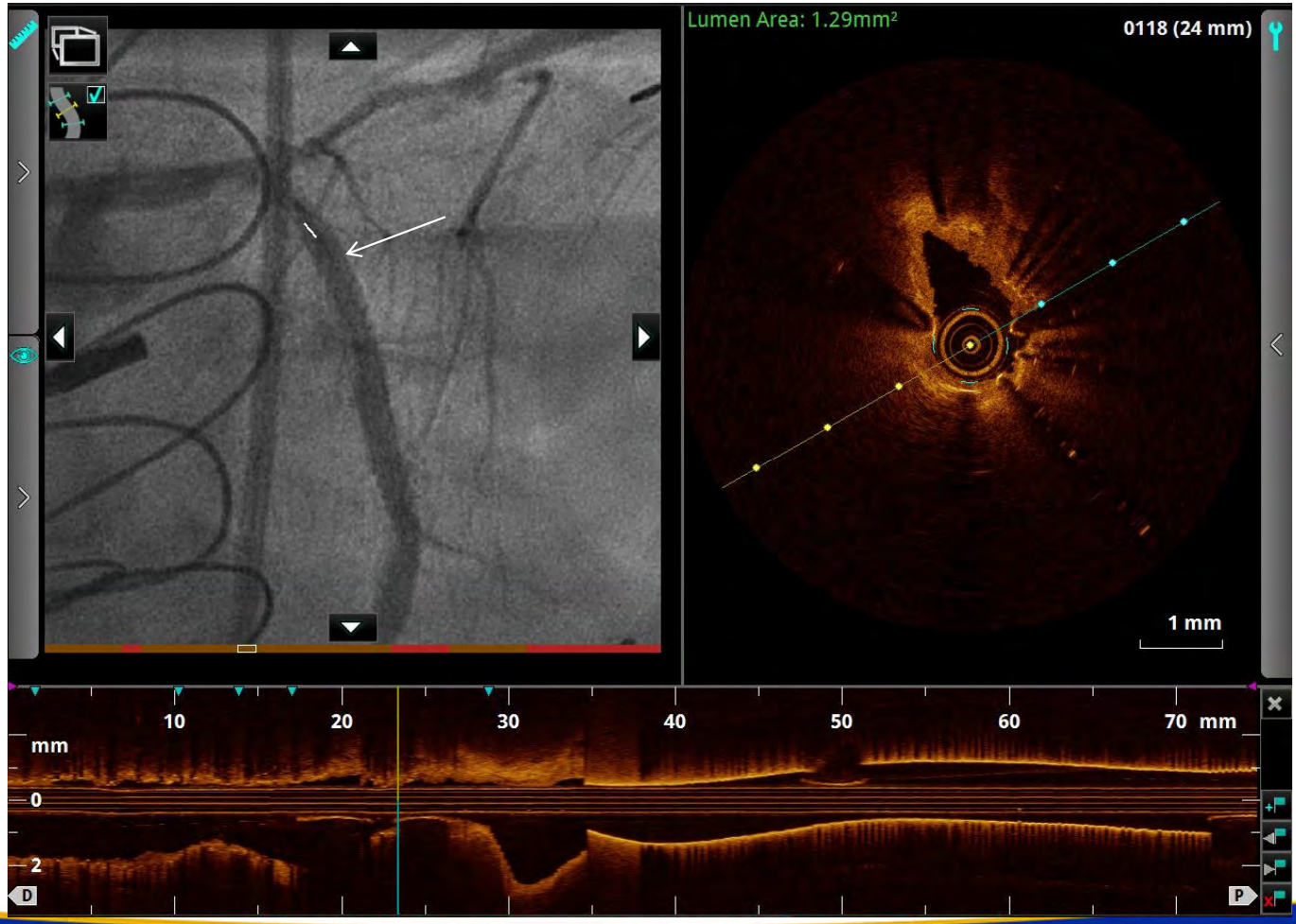
Calcified Nodule



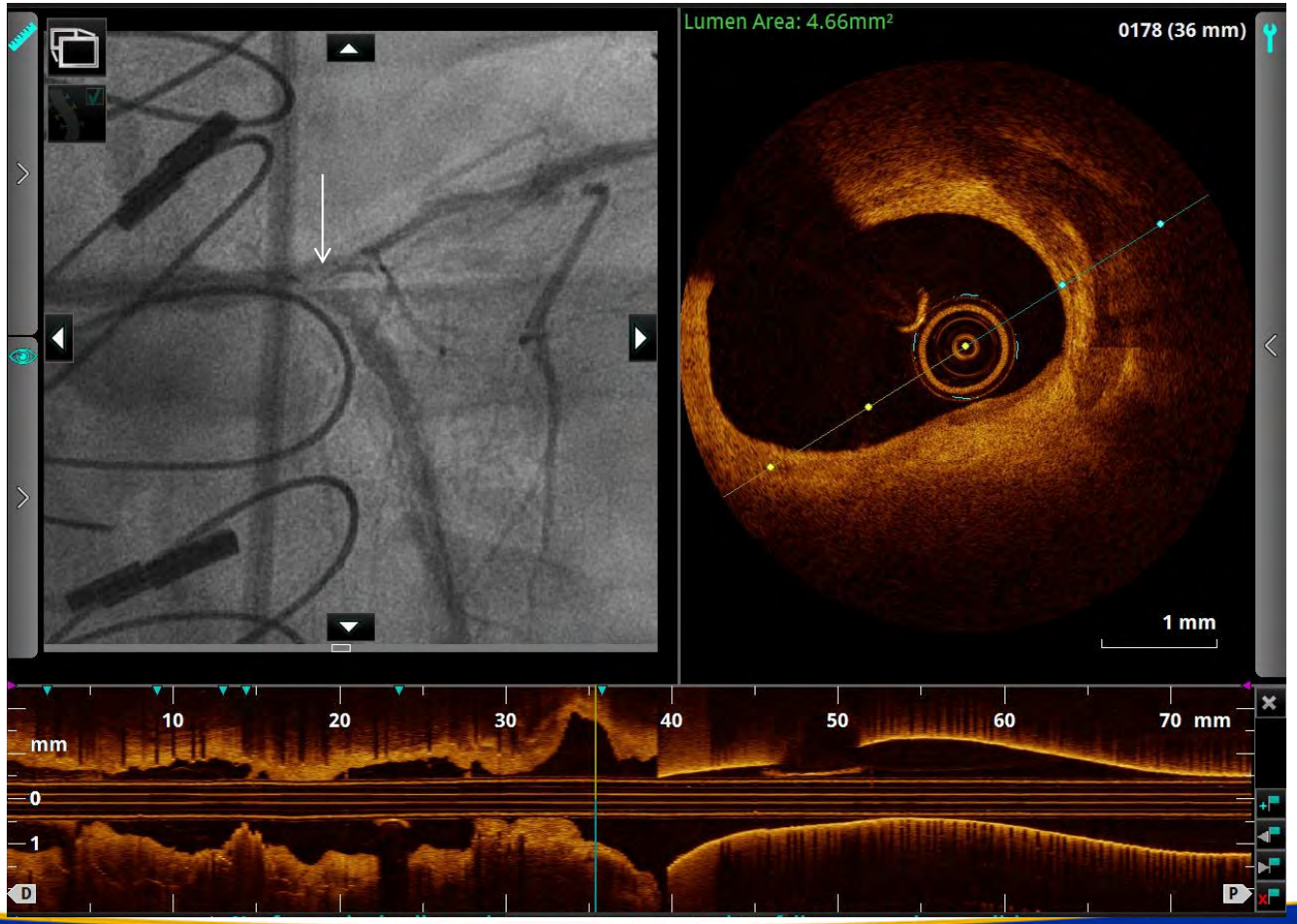
Severe Stent Under-Expansion (MLA 0.93)



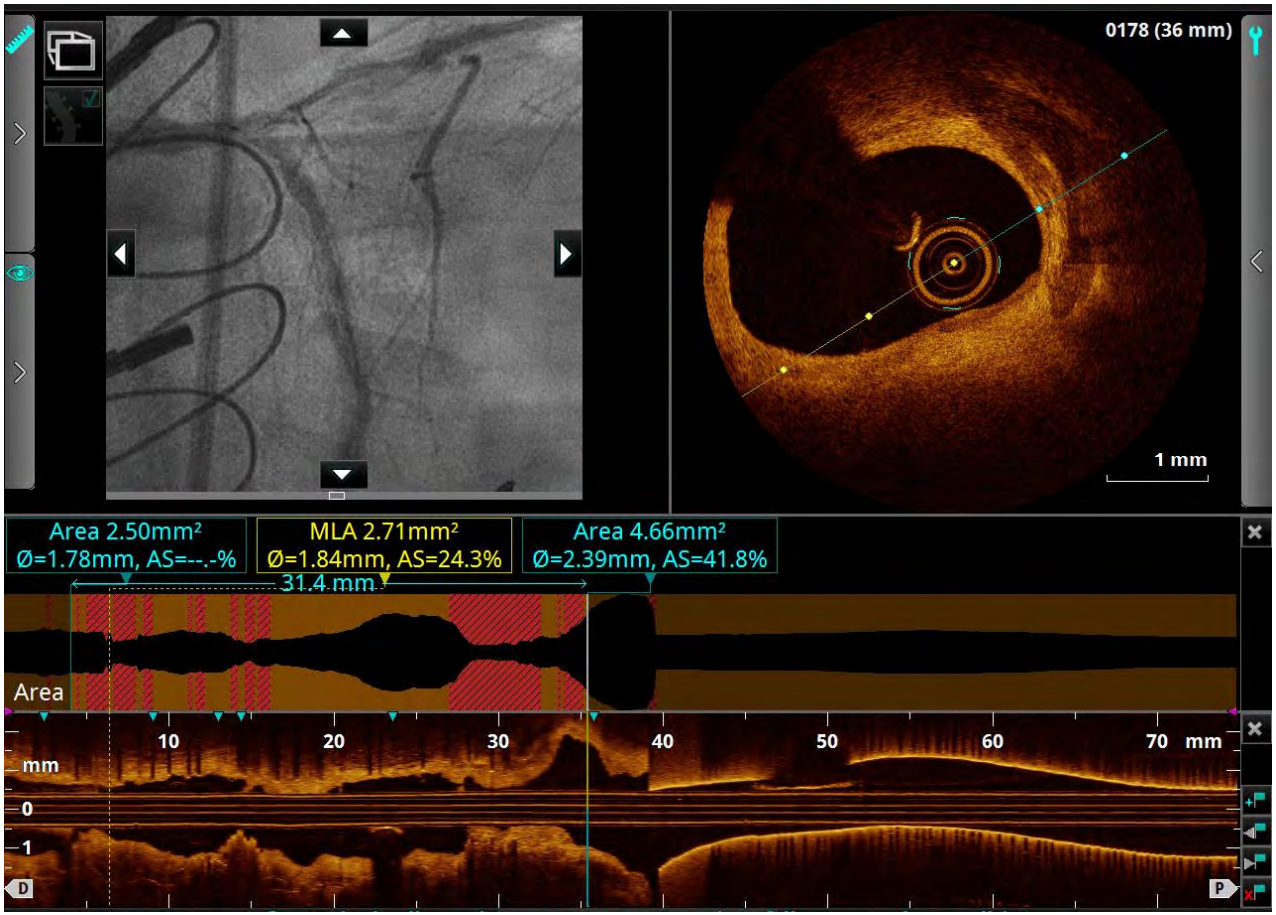
Severe Stent Under-Expansion (MLA 1.29)



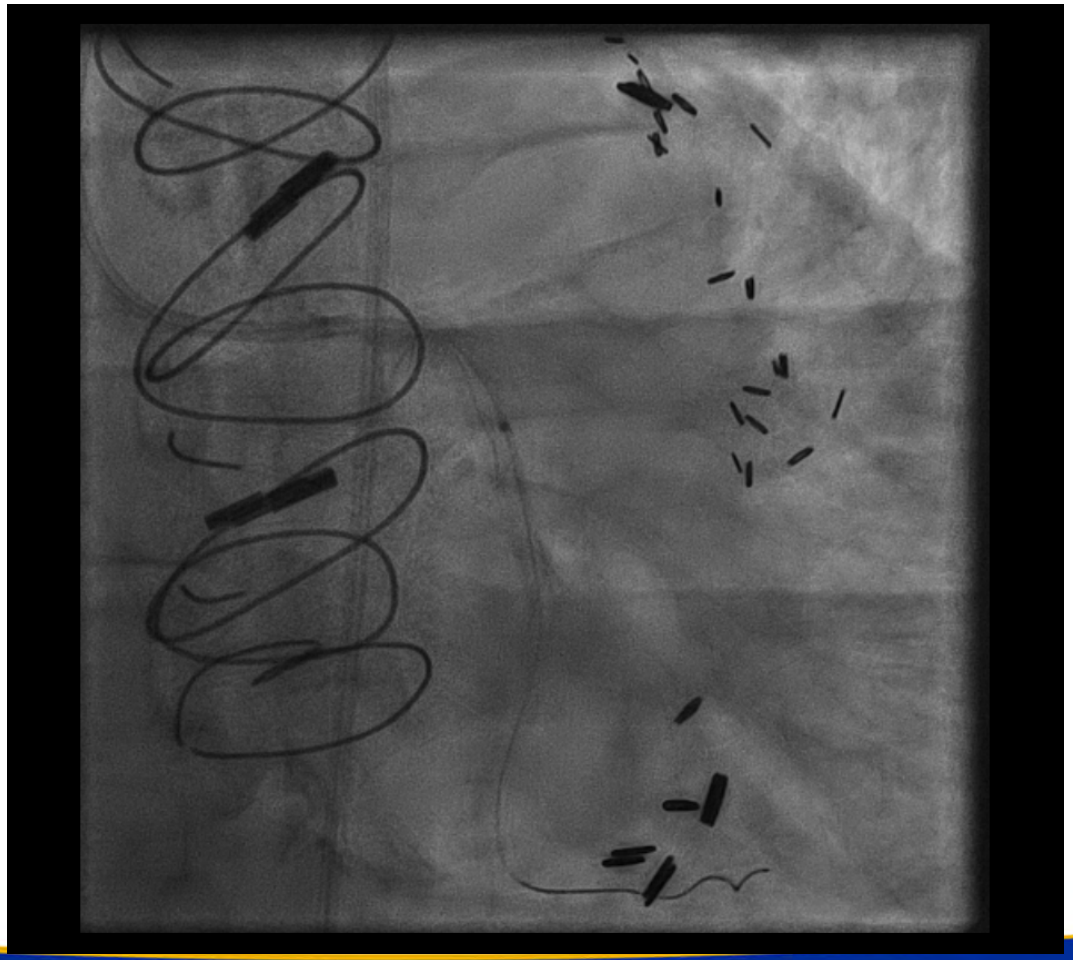
Proximal Reference



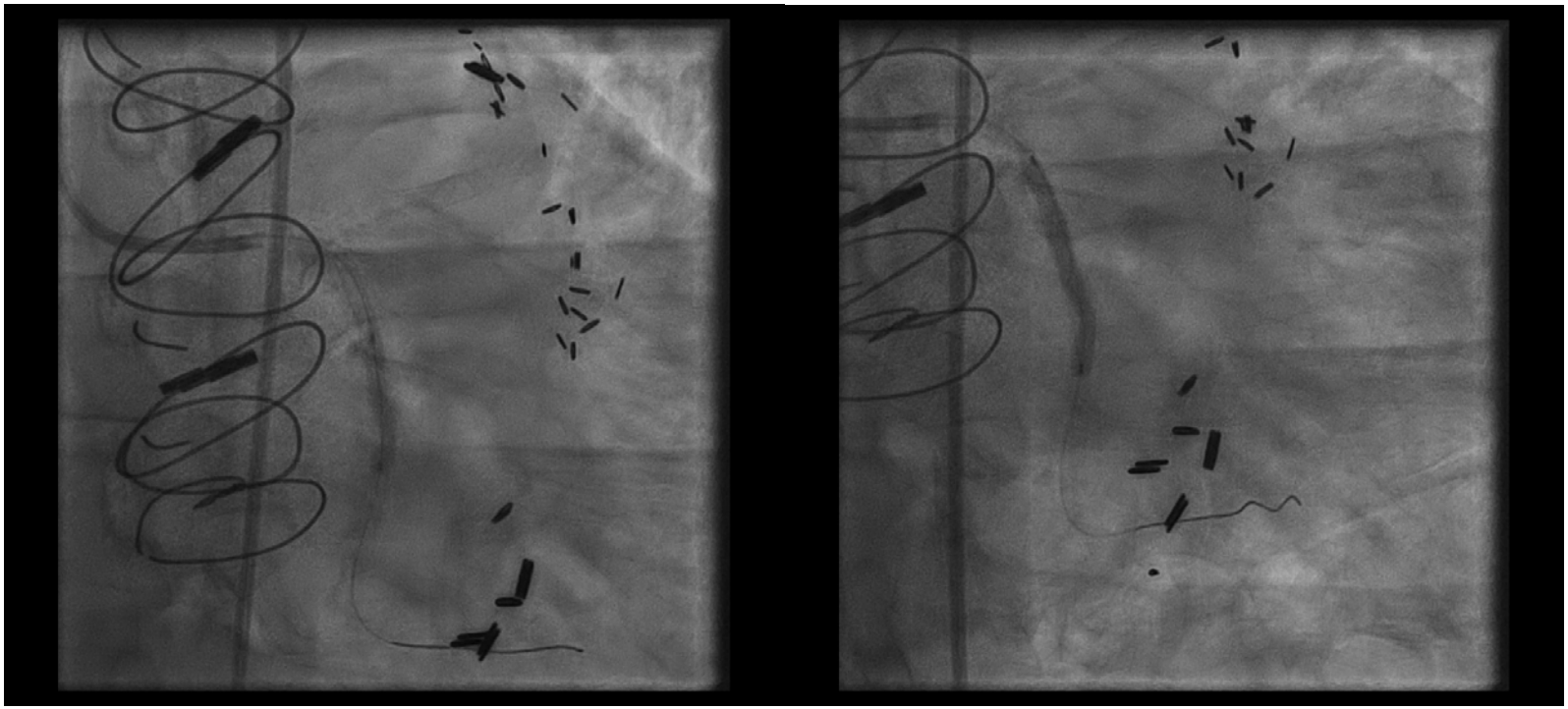
Measurements



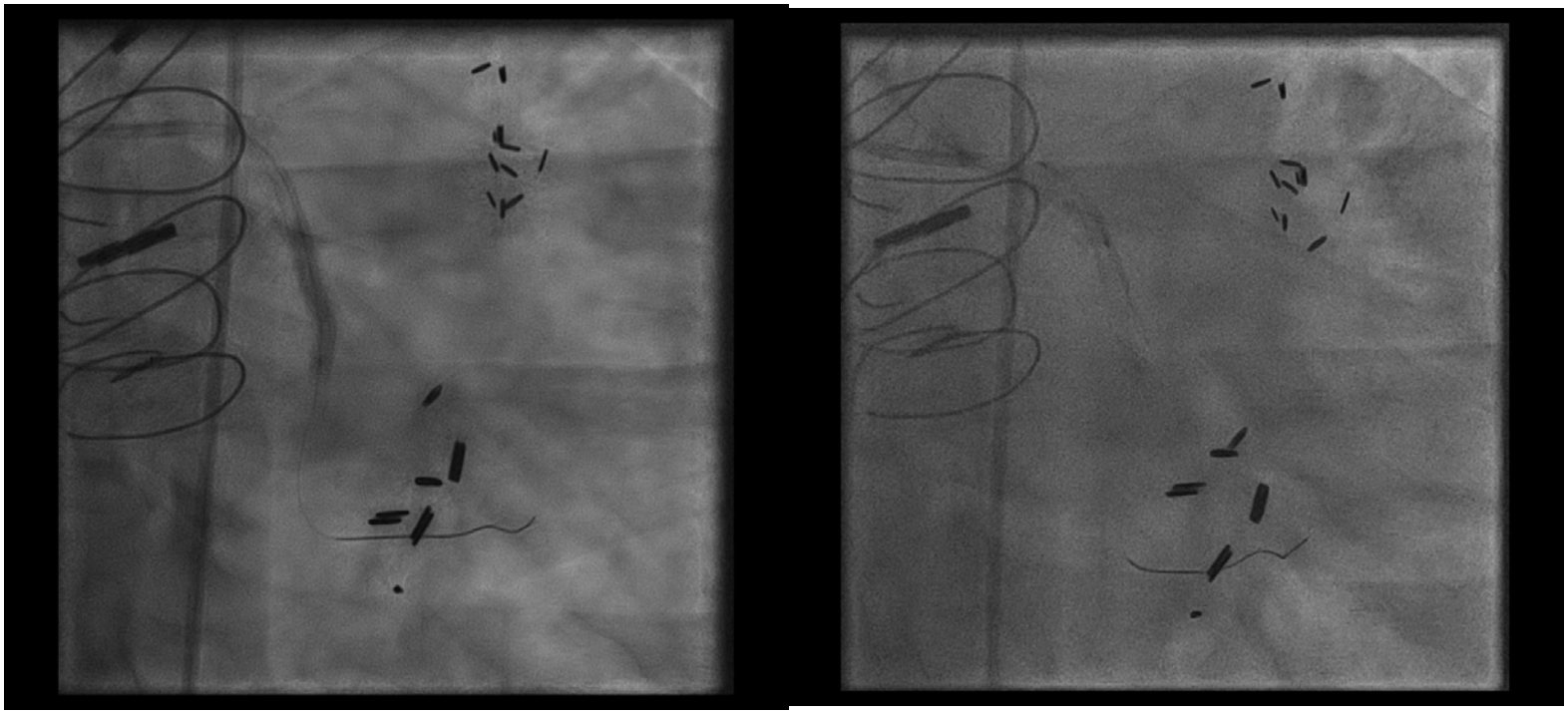
Laser Atherectomy



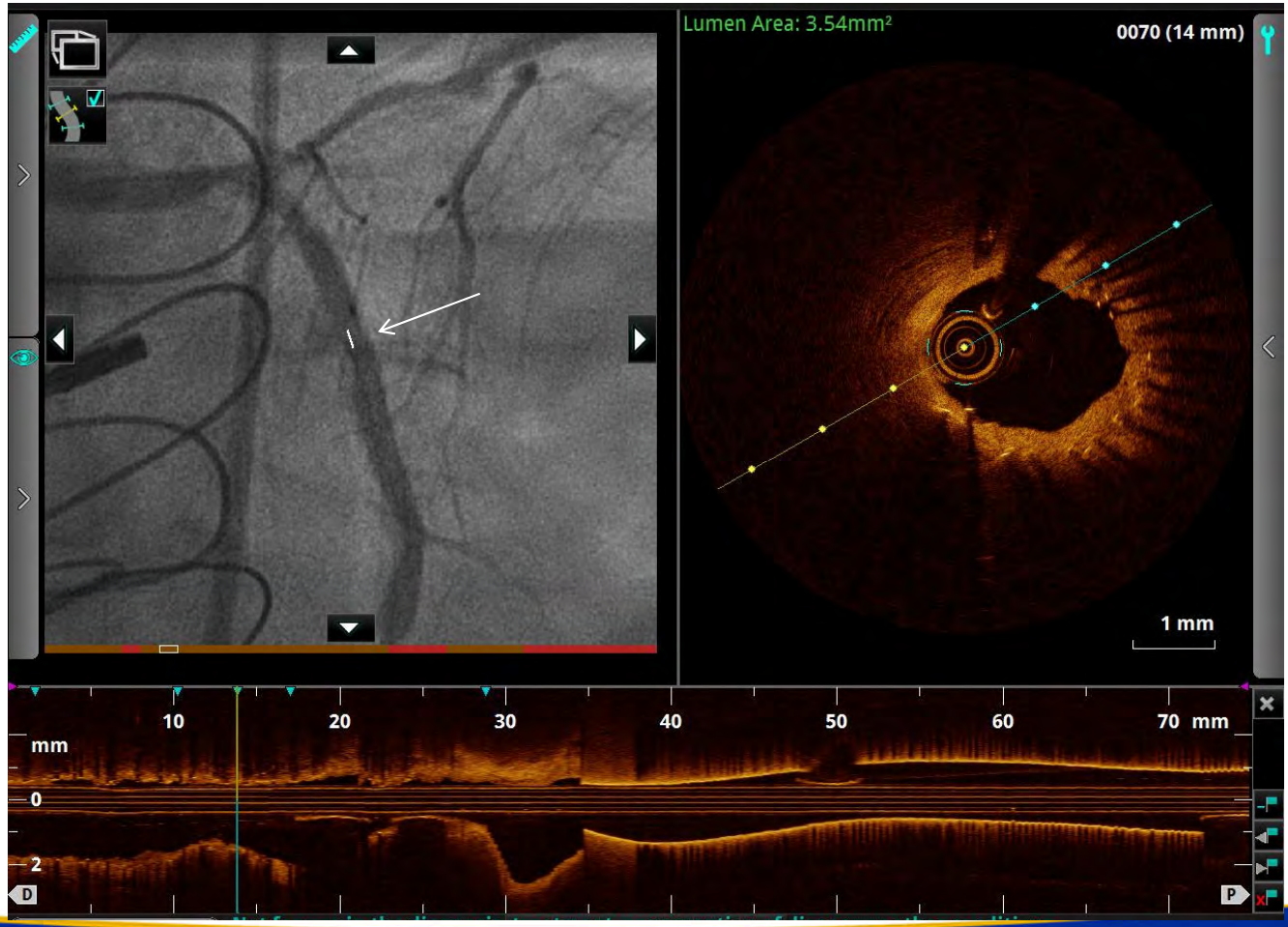
3.00 NC Balloon at high Pressure and 3.00 X 33 Stent



3.0 X 15 Stent & 3.0 X 20 Balloon

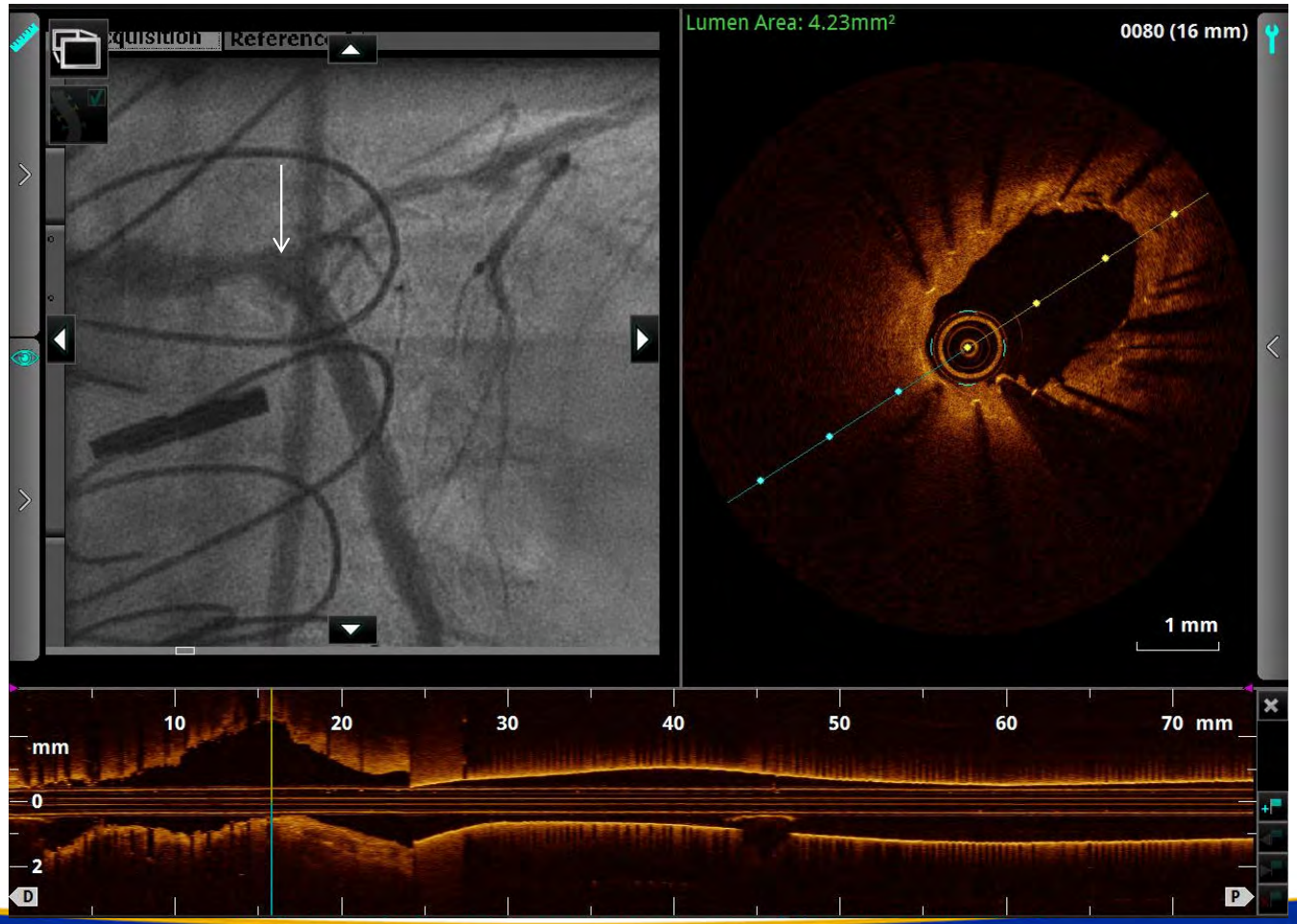


Calcified Nodule Covered

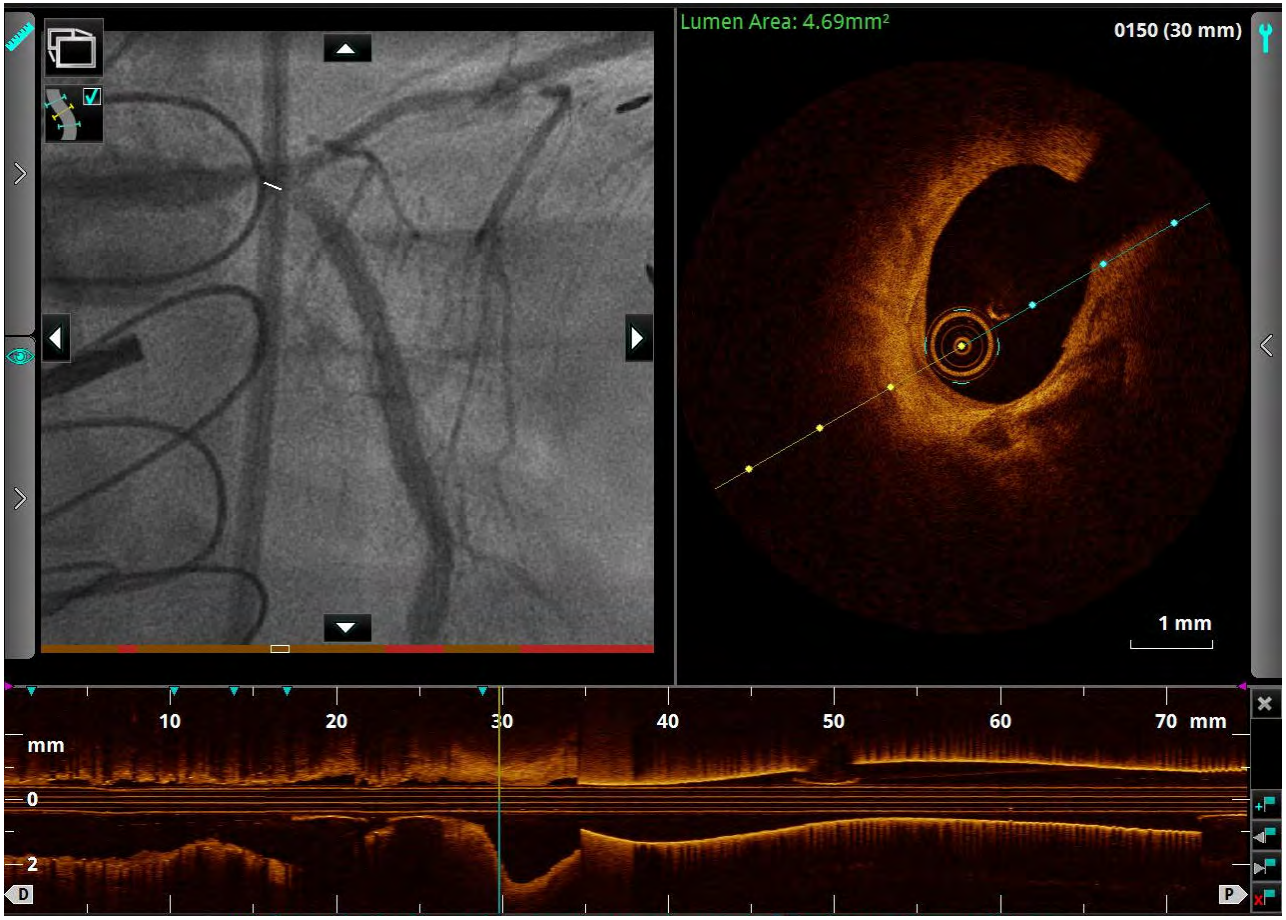


Ca^{++} Fracture with MSA $3.38mm^2$

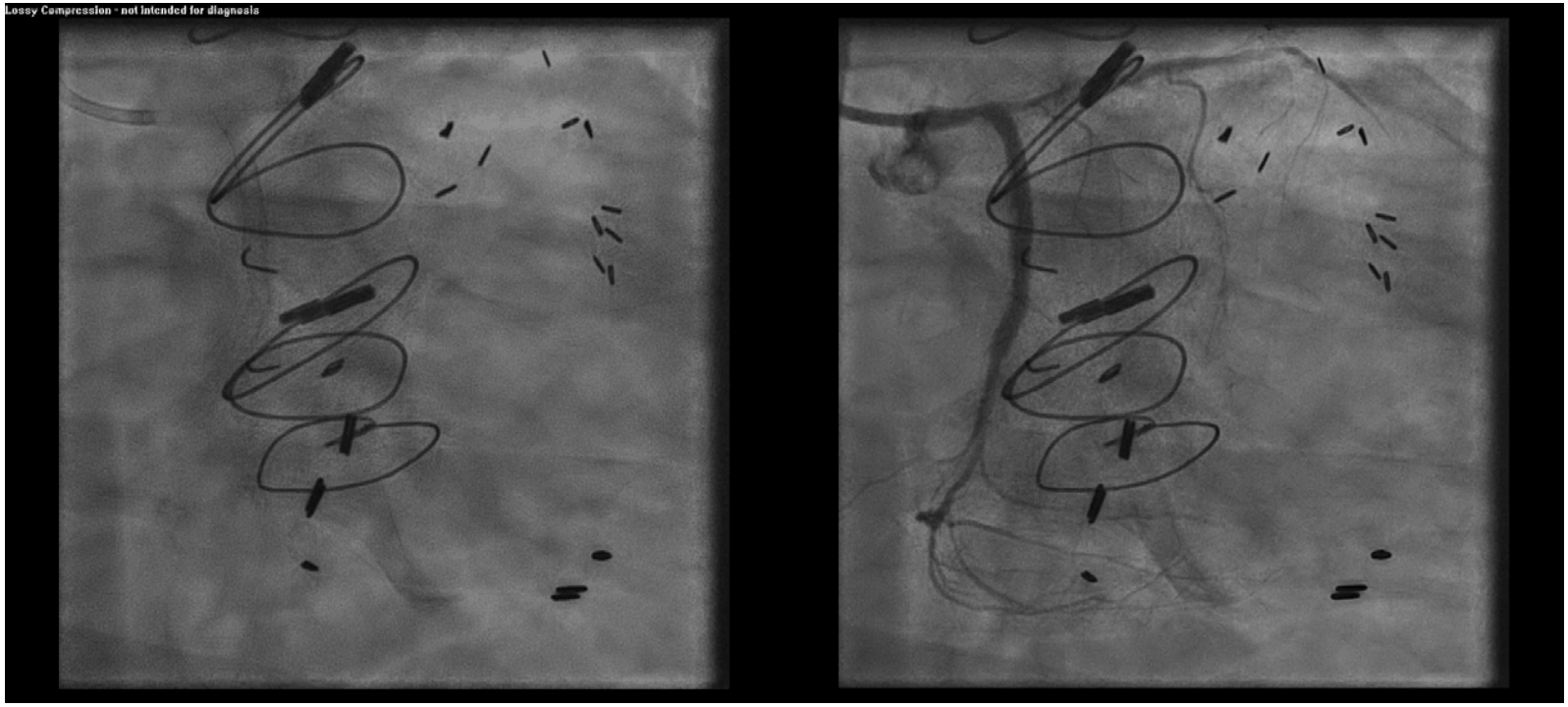
Proximal Edge



Left Main



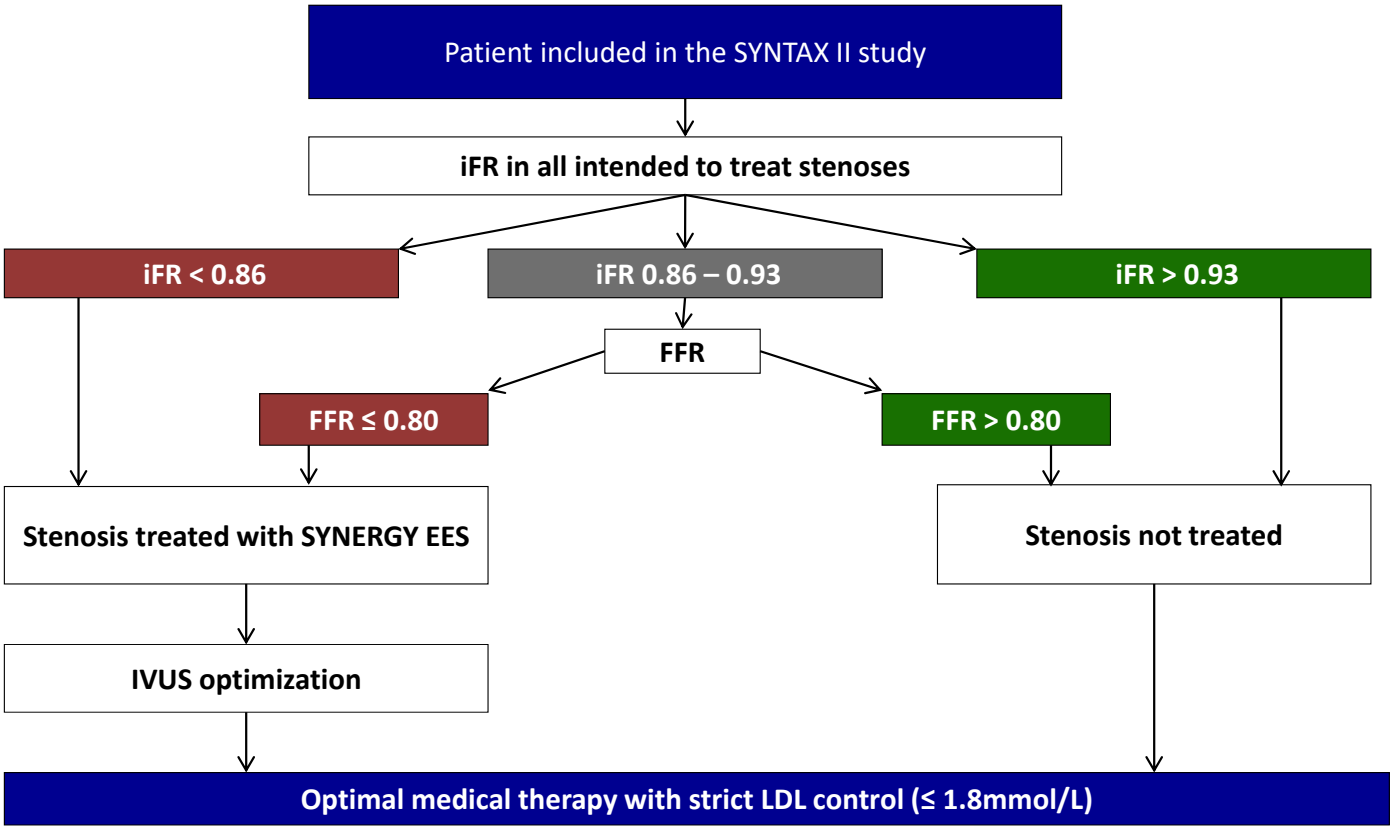
Final Angiograms



What is State-of-the-Art PCI in 2022?

Study Flow Chart

SYNTAX II



What is State of the art PCI?

SYNTAX II

Physiology was performed in **98%** of patients

	SYNTAX I	SYNTAX II
iFR/FFR	Likely <10%	98%
IVUS	13.5%	87%

73% of lesions assessed without adenosine

Post-stent IVUS was performed in **84%** of patients

- iFR hybrid approach was used due to timing of the clinical trial
- This still led to 73% of lesions assessed without adenosine

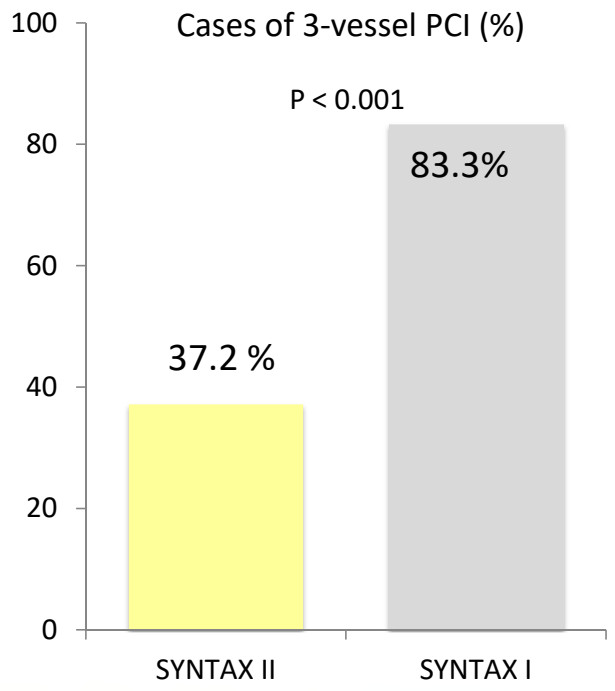
Serruys et al., N Engl J Med. 2009 Mar 5;360(10):961-72
Escaned et al., European Heart Journal (2017) 00, 1–11 doi:10.1093/eurheartj/ehx512

Marked Simplification of PCI

SYNTAX II

46% of 3VD patients downgraded to 2VD or 1VD

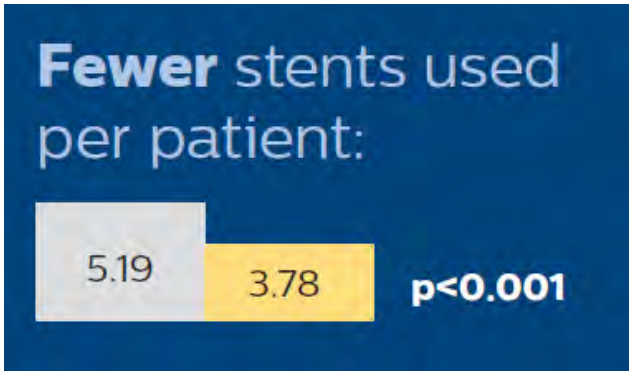
Angiography alone is not enough to determine treatment pathway in complex PCI



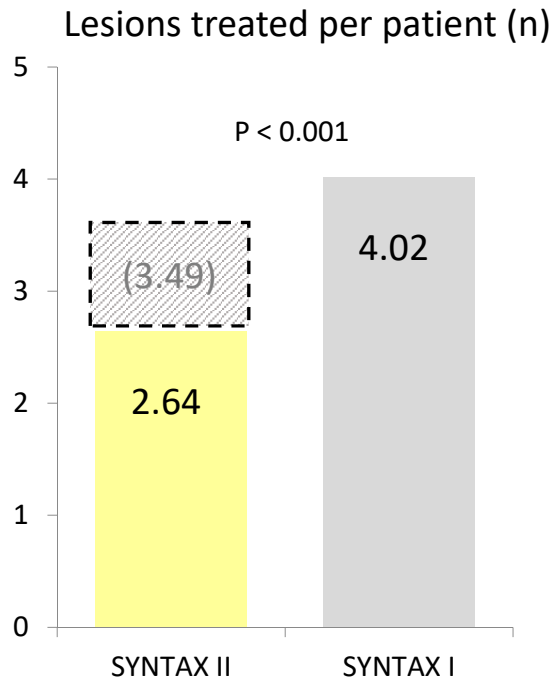
Escaned et al., European Heart Journal (2017) 00, 1–11 doi:10.1093/eurheartj/ehx512

Marked Simplification of PCI

SYNTAX II



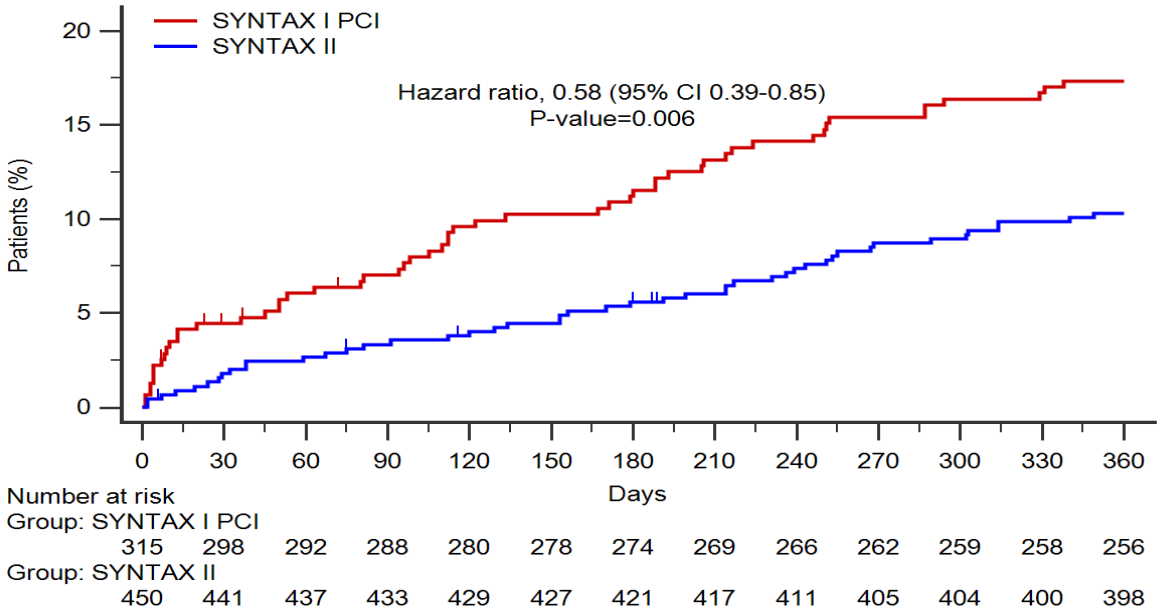
In SYNTAX II, an average of 3.49 lesions per patient were initially determined to receive stent by angiography. Only 74.6% were found to be significant by physiology. This reduced average lesions treated per patient to 2.64



Adapted from: Escaned et al., European Heart Journal (2017) 00, 1–11 doi:10.1093/eurheartj/ehx512

1-Year MACCE Rate

SYNTAX II



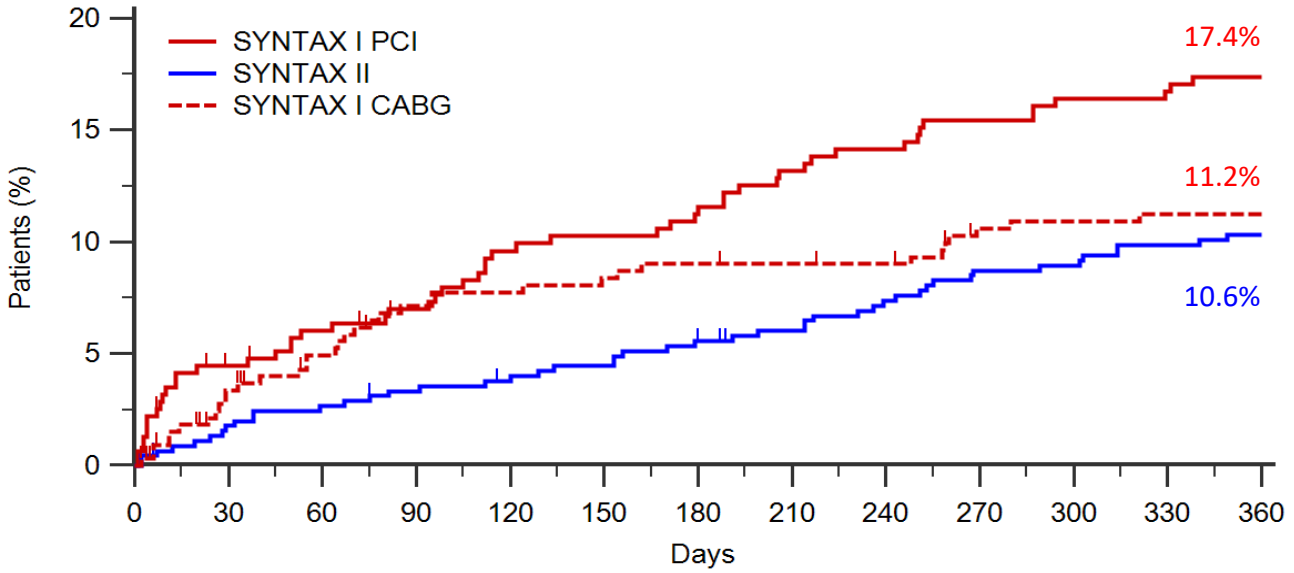
Significantly lower MACCE rate in SYNTAX II:

17.4% 10.6% **p=0.006**

Escaned et al., European Heart Journal (2017) 00, 1–11
doi:10.1093/eurheartj/ehx512

SYNTAX II

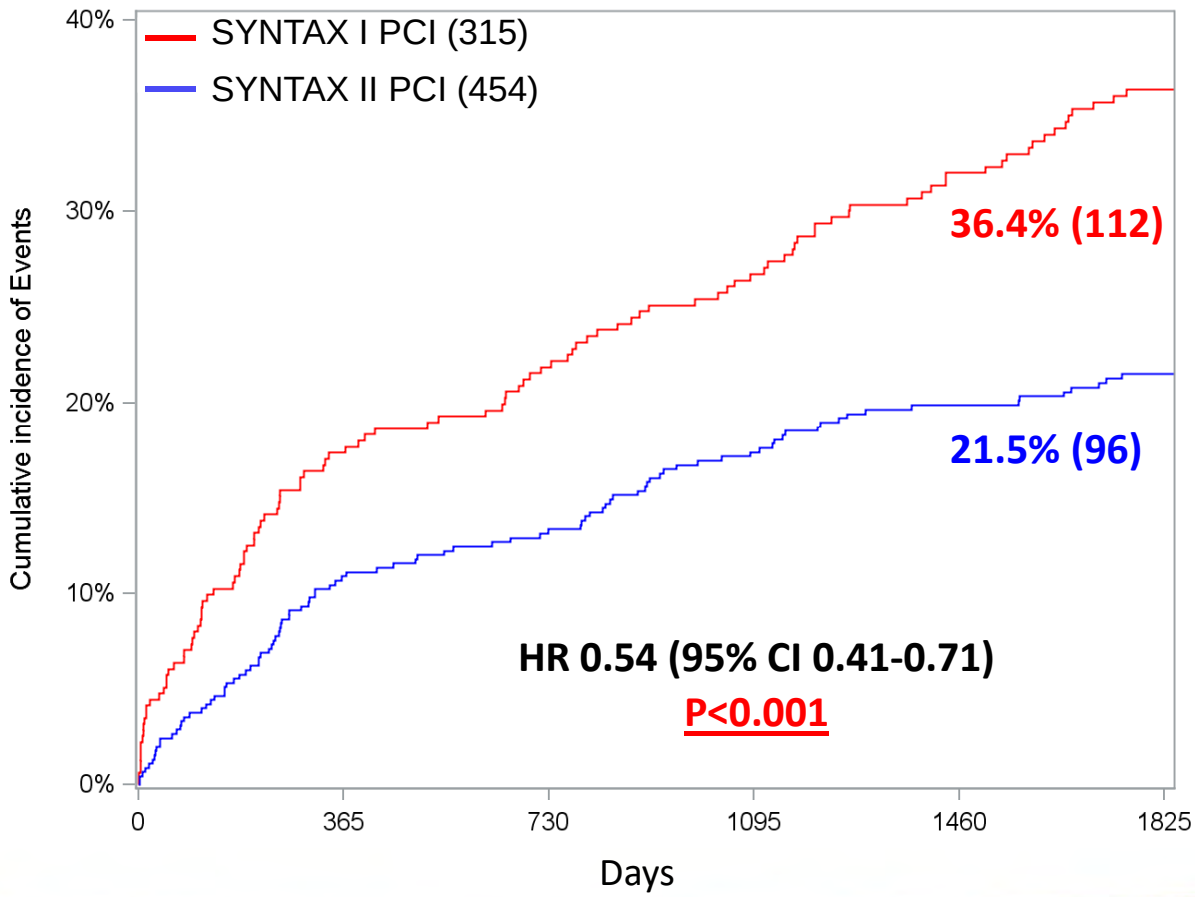
MACCE rates: SYNTAX II and SYNTAX I PCI/CABG



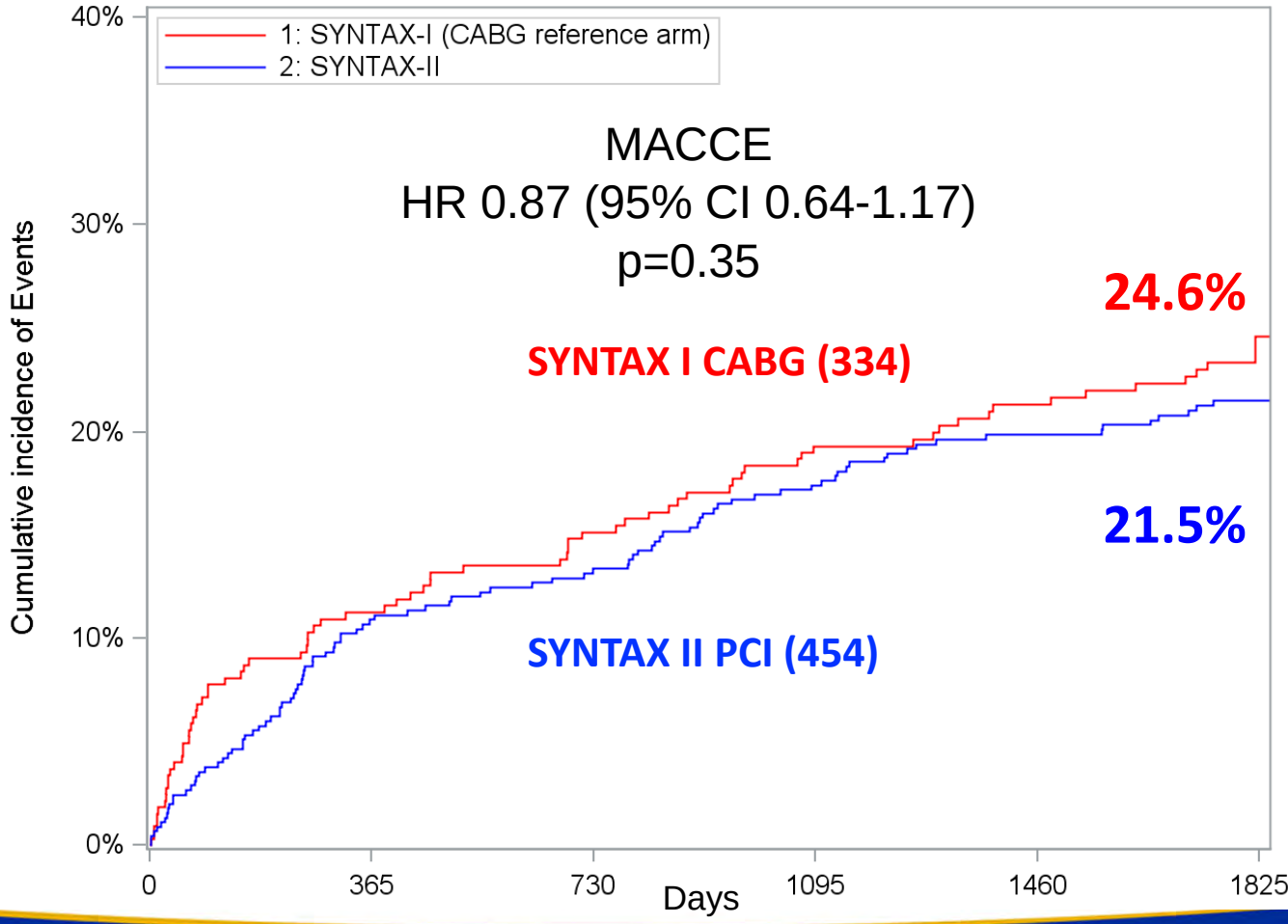
SYNTAX I PCI	315	298	292	288	280	278	274	269	266	262	259	258	256
SYNTAX II	450	441	437	433	429	427	421	417	411	405	404	400	398
SYNTAX I CABG	334	313	304	295	293	291	289	288	287	279	278	277	277

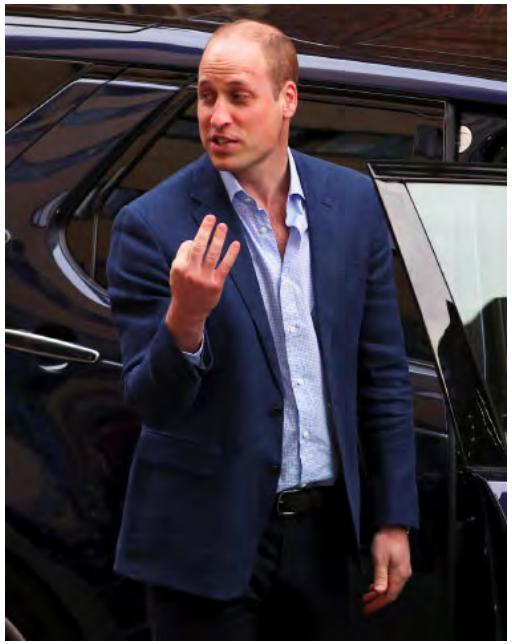
Escaned et al., European Heart Journal (2017) 00, 1–11 doi:10.1093/eurheartj/ehx512

SYNTAX II 5 year FU: Primary Endpoint (MACCE)



5-year MACCE in CABG and PCI Arms in SYNTAX II



Banning A, Escaned J et al Eur Heart J (in press)

Looks Can Be Deceiving…