Artificial Intelligence for Imaging and Physiology Interpretation

Akiko Maehara, MD

Columbia University, Cardiovascular Research Foundation, New York, NY

DISCLOSURE

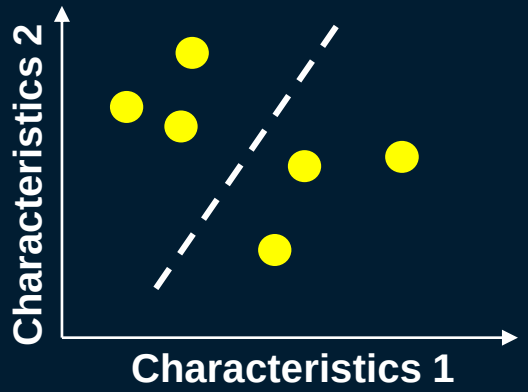
- Consultant: Boston Scientific, Abbott Vascular, Philips
- Advisory Board: SpectraWave
- Speaker Honoraria: Nipro

Type of Machine Learning

Supervised

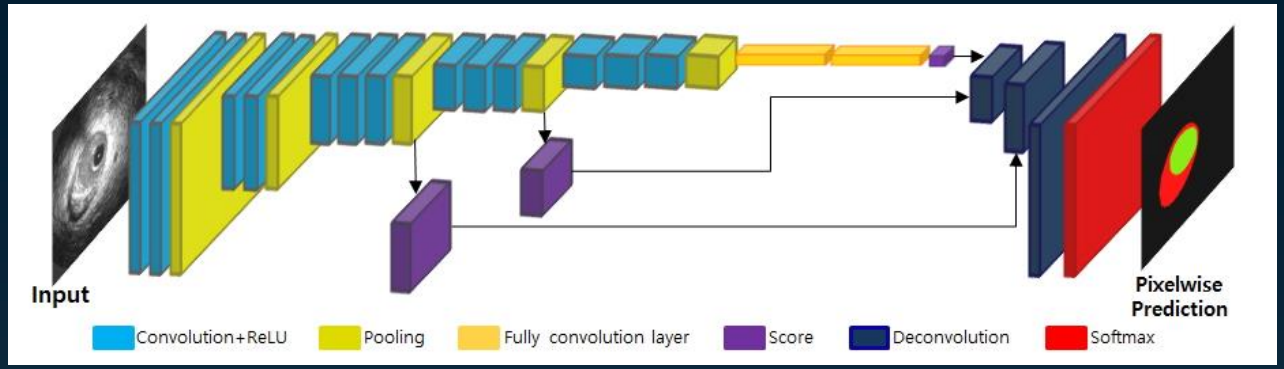
Use of expert input and classify data accurately

Unsupervised



Discover hidden patterns in data without expert input

AI for Imaging: Convolutional Neural Network (CNN)



Min HS, et al. JACC Interv 2021;14:1021-9.

1. Convolution layer

Filtering to extract unique features

2. ReLU layer (Rectified Linear Unit)

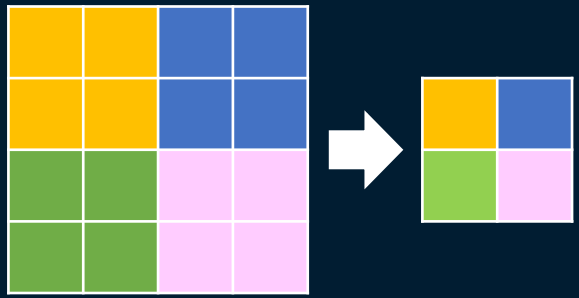
Convert the data to be more appropriate to use

$f(x)=0$, if $x<0$

$=x$, if $x\geq 0$

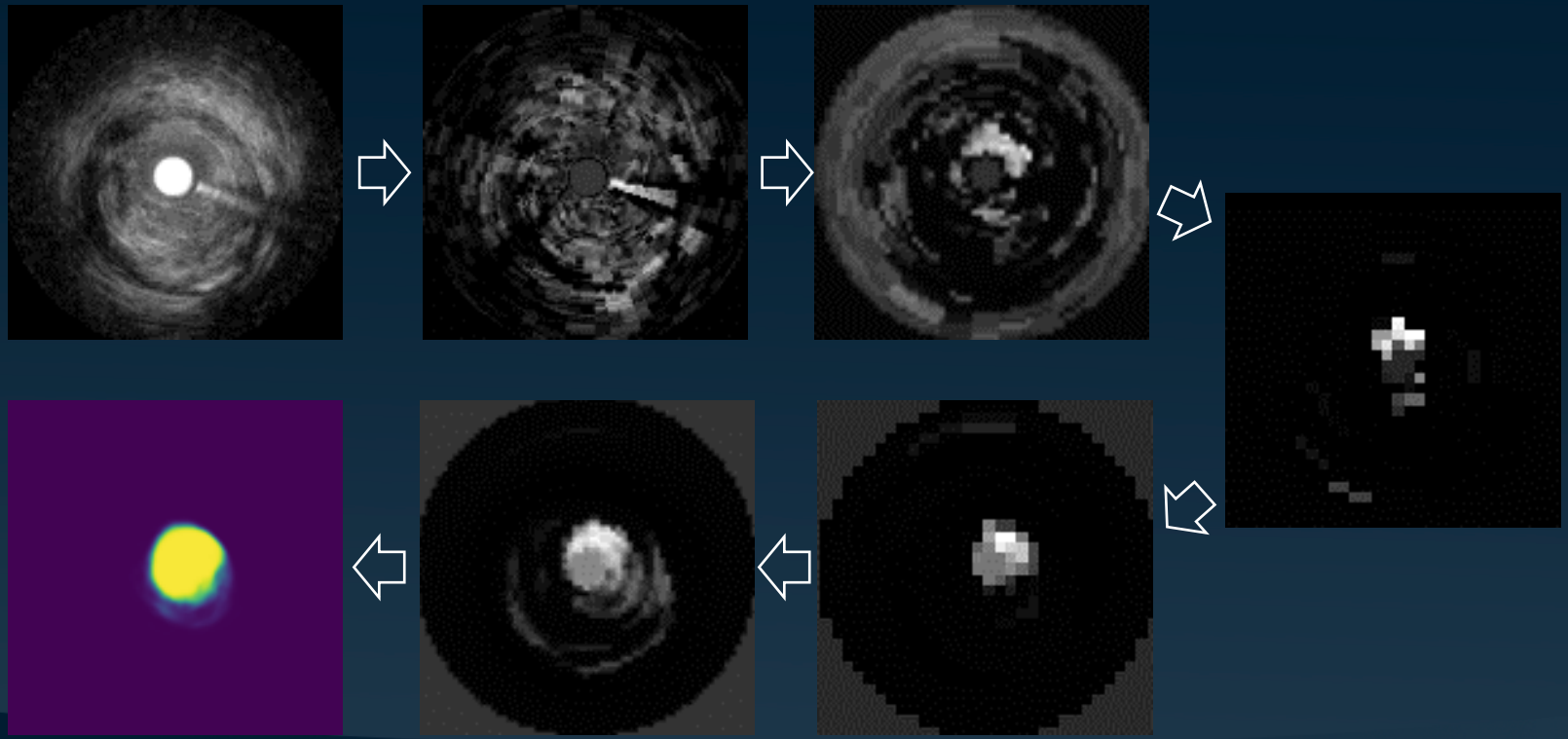
3. Pooling layer

Downsizing data



AI (CNN) Segmentation for IVUS

Contractive path

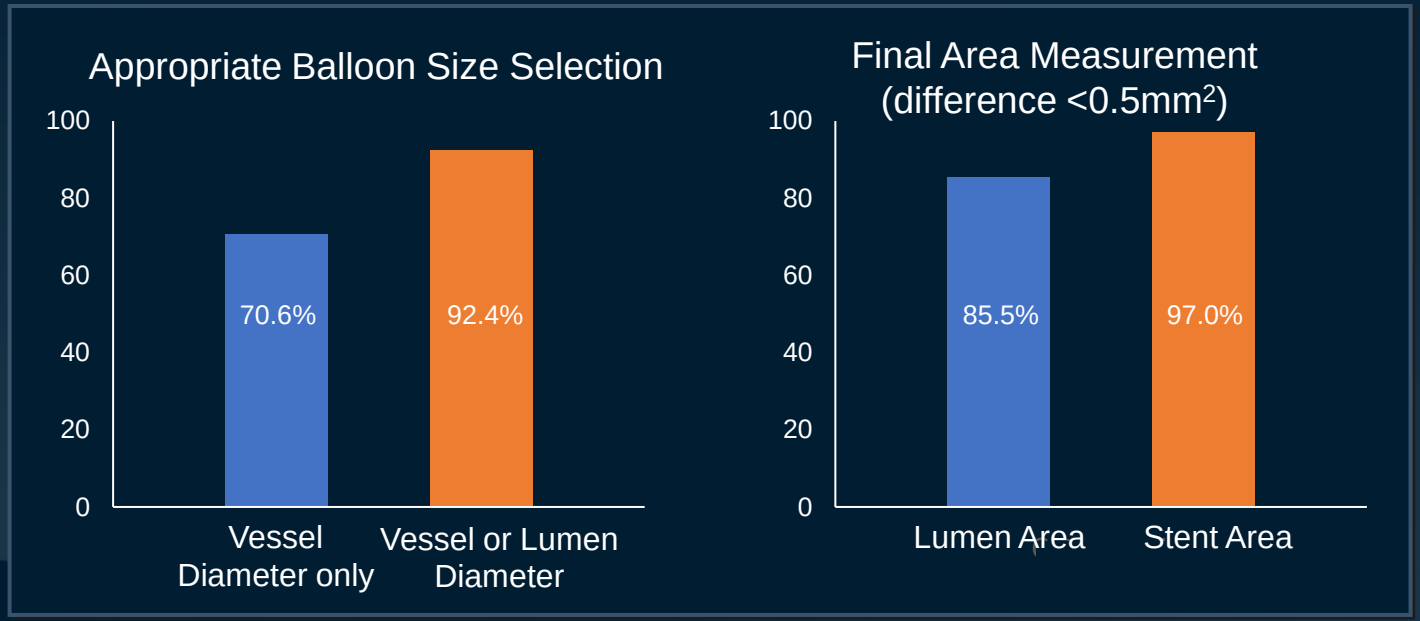


Expansive path

Matsumura M, et al. JACC ADVANCES 2023; 2:1-11.

Set up a Goal That Clinically Makes Sense

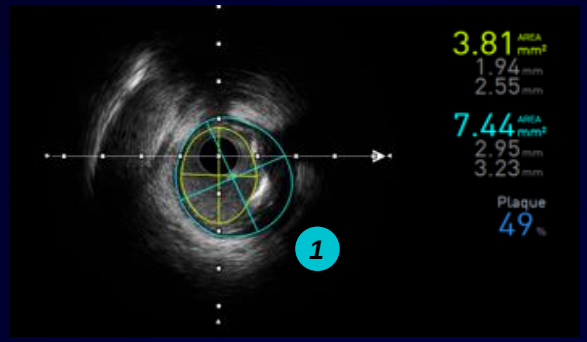
Goal: Agreement of 1) Appropriate balloon sizing between expert vs AI
2) Evaluation of good stent expansion.
Sample: 8076 IVUS frames from 234 patients for training (83%) and validation (17%), external test data of 437 frames in 92 patients

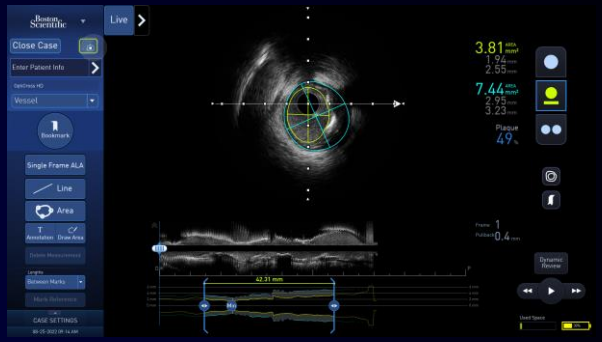


Matsumura M, et al. JACC ADVANCES 2023; 2:1-11.

AVVIGO+ Automated Lesion Assessment ALA™ System

1 **Vessel and Lumen Borders**





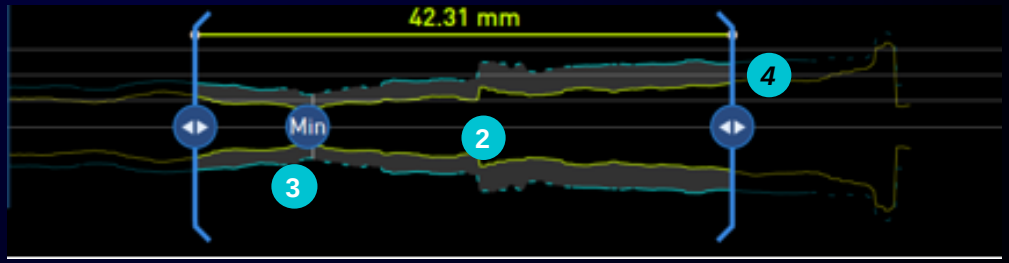
2 **Vessel Profile**

Graphical representation of the average vessel and lumen diameters

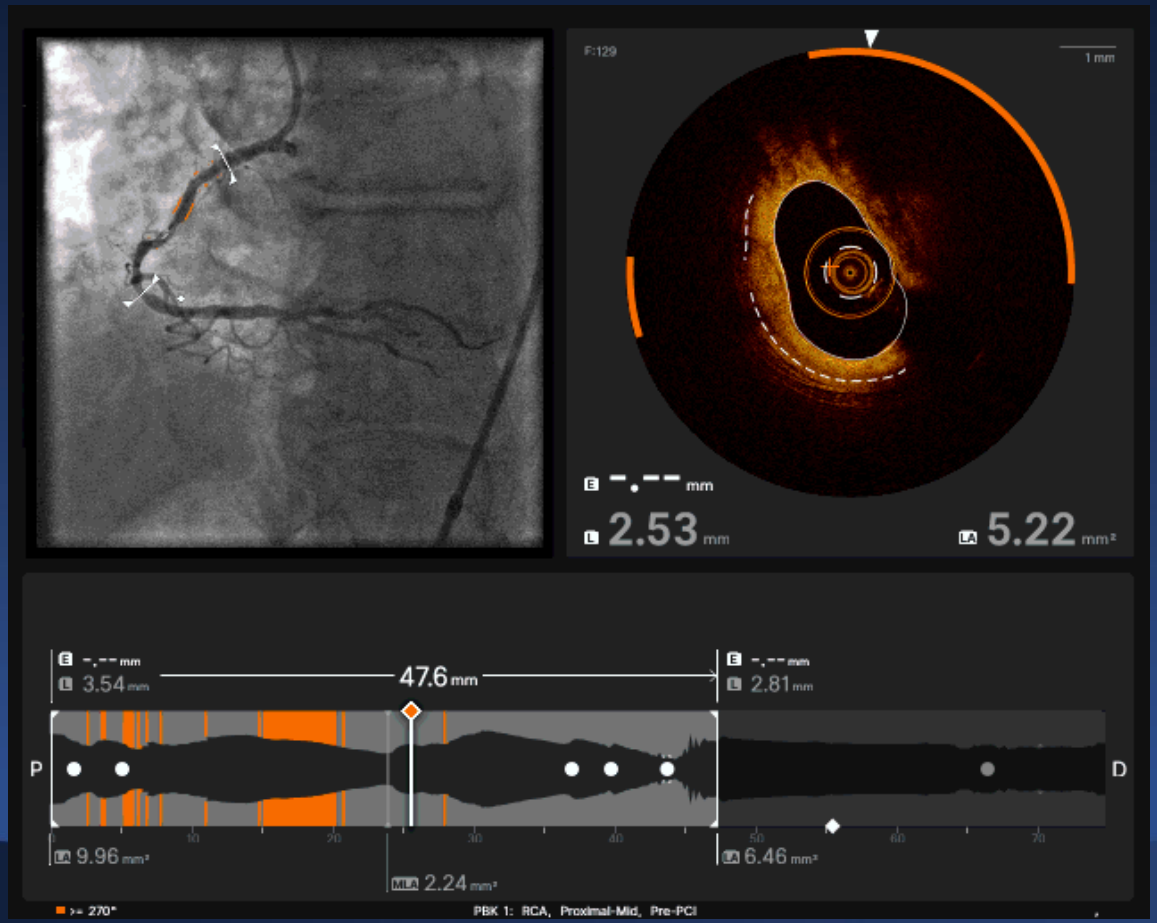
3 **Min Key Frame marker: MLA**

4 **Distal & Proximal Key Frame markers**

Proximal and distal key frame markers represented at ≤50% plaque burden from minimum frame.



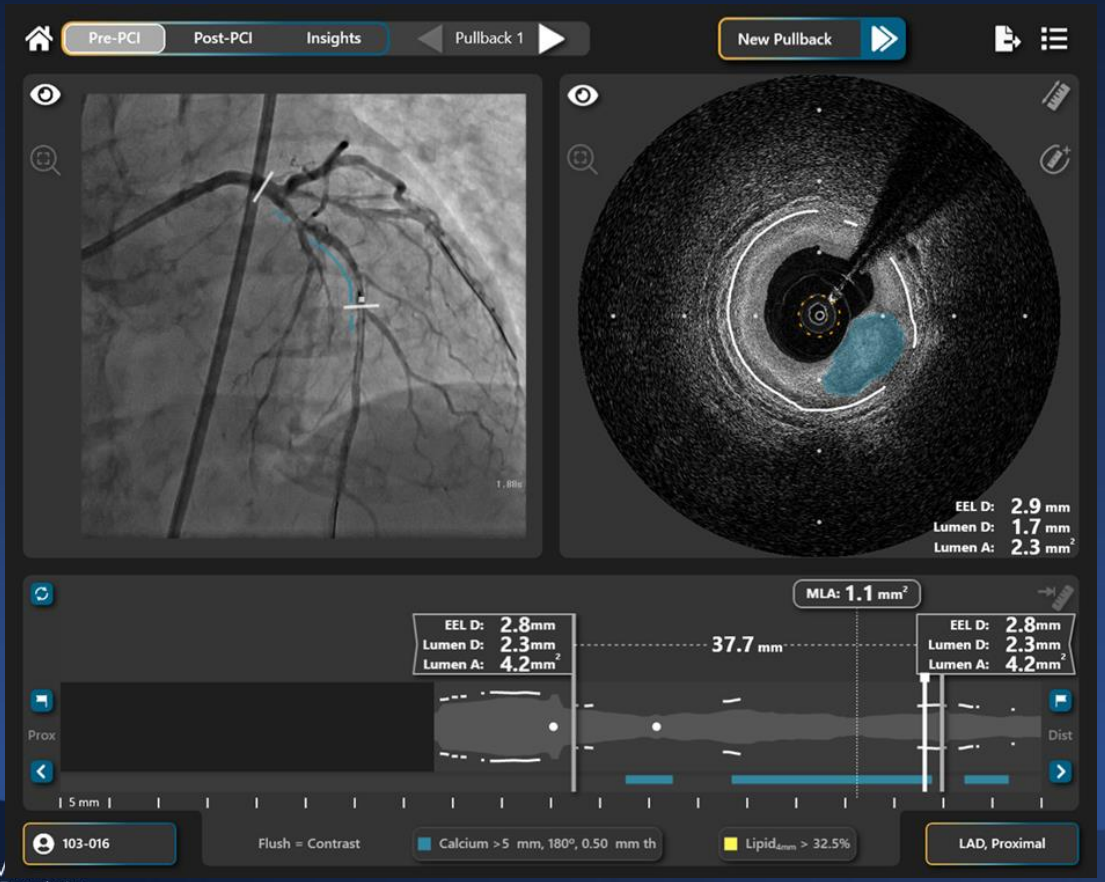
Abbott Ultreon 2.0

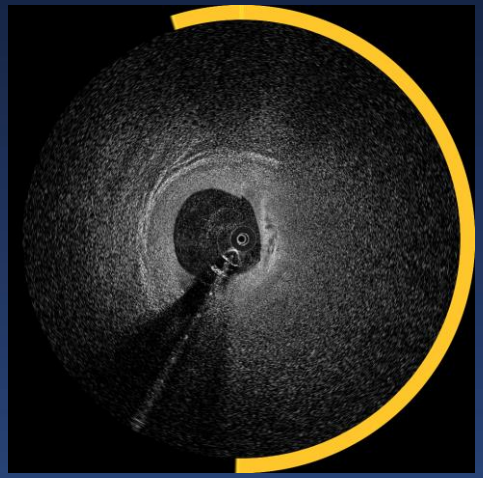


Cardiovascular Research Foundation

Columbia University Medical Center
NewYork-Presbyterian

SpectraWave



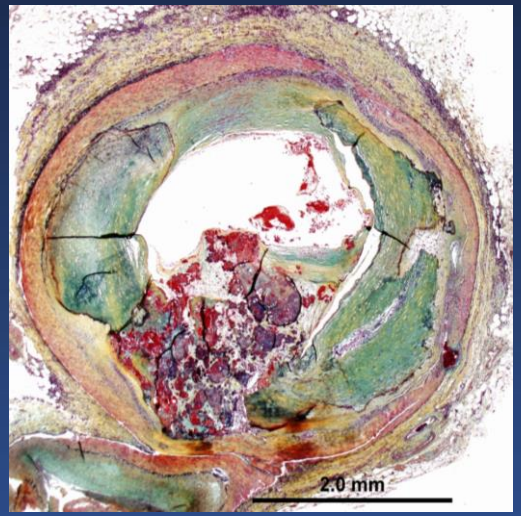


“Vulnerable Plaque” which causes thrombotic event or rapid lesion progression (silent thrombosis & healing)

Plaque Rupture

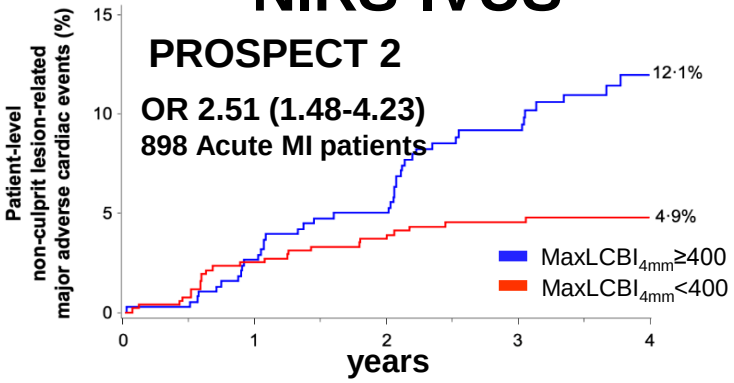
Plaque Erosion

Calcified Nodule

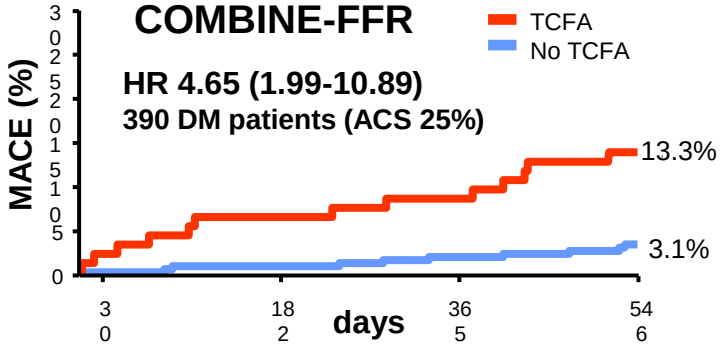


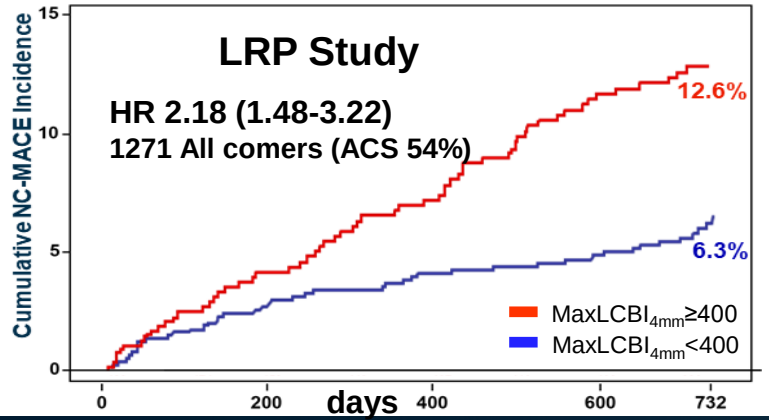
The Importance of NIRS/IVUS or OCT High-Risk Plaque in the Secondary Prevention Cohort

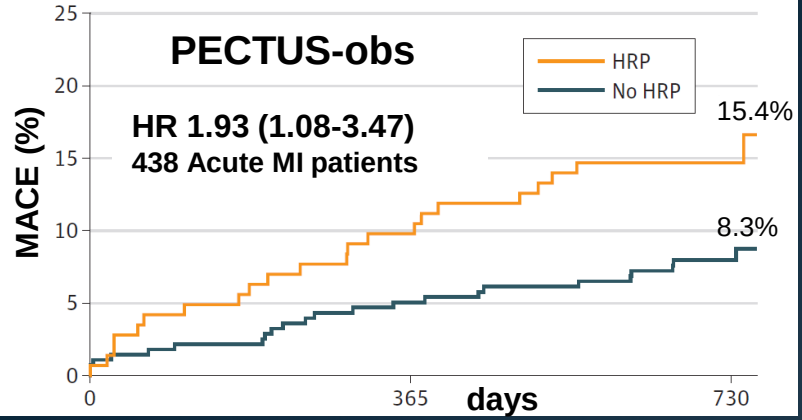
NIRS-IVUS



OCT







Waksman R, Lancet 2019;394:1629-1637; Erlinge D, Lancet 2021;397:985-95; Kedhi E, EHJ 2021 42:4671-4679; Mole JQ , JAMA Cardiol 2023: e232910

Vulnerable Plaque - Meta Analysis -

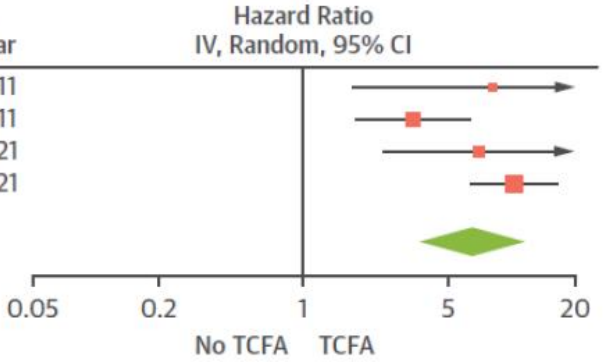
9 prospective, 21 retrospective; 4 OCTs 3 VH-IVUS, 2 NIRS-IVUS, 21 CT, 30369 pts

Lesion-Level

Thin Cap Fibroatheroma

Study or Subgroup	Log [Hazard Ratio]	SE	Weight	Hazard Ratio IV, Random, 95% CI	Year
Calvert, 2011	2.0992	0.7769	13.0%	8.16 [1.78, 37.41]	2011
Stone, 2011	1.209	0.3255	30.9%	3.35 [1.77, 6.34]	2011
Kedhi, 2021	1.9459	0.5398	20.4%	7.00 [2.43, 20.16]	2021
Kubo, 2021	2.3428	0.2419	35.6%	10.41 [6.48, 16.73]	2021
Total (95% CI)			100.0%	6.55 [3.40, 12.60]	

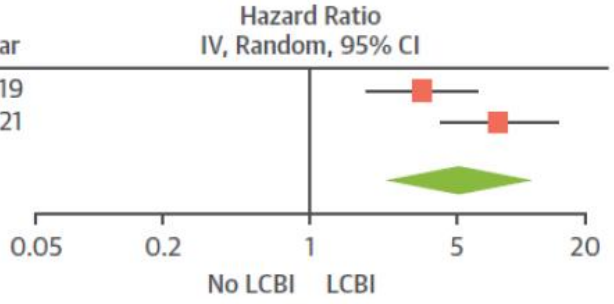
Heterogeneity: $Tau^2 = 0.25$; $Chi^2 = 7.86$, df = 3 ($P = 0.05$); $I^2 = 62\%$
Test for overall effect: Z = 5.63 ($P < 0.00001$)



Large Lipid Core Burden Index

Study or Subgroup	Log [Hazard Ratio]	SE	Weight	Hazard Ratio IV, Random, 95% CI	Year
Waksman, 2019	1.2208	0.309	50.8%	3.39 [1.85, 6.21]	2019
Erlinge, 2021	2.058	0.3276	49.2%	7.83 [4.12, 14.88]	2021
Total (95% CI)			100.0%	5.12 [2.25, 11.62]	

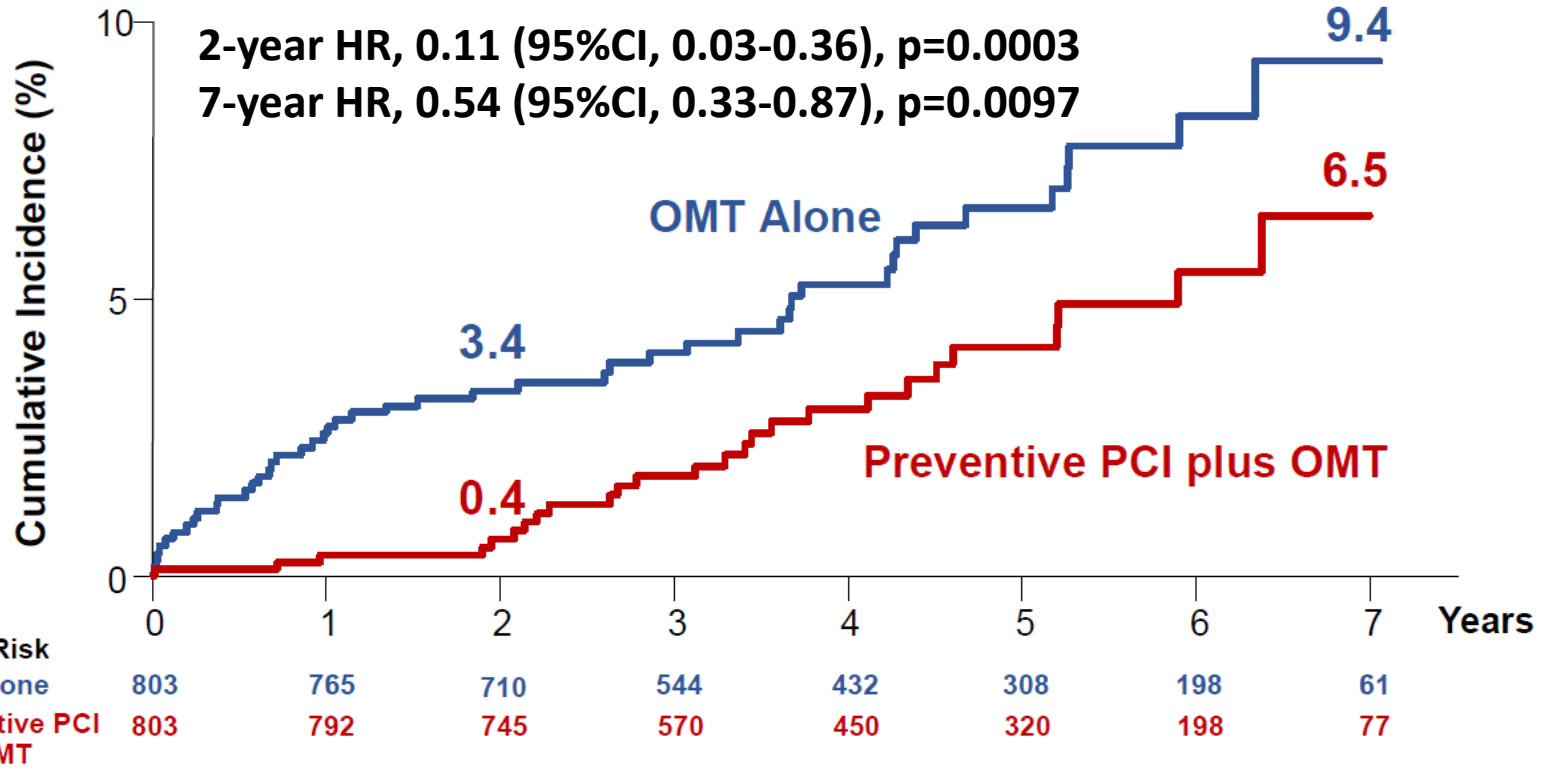
Heterogeneity: $Tau^2 = 0.25$; $Chi^2 = 3.46$, df = 1 ($P = 0.06$); $I^2 = 71\%$
Test for overall effect: Z = 3.90 ($P < 0.0001$)



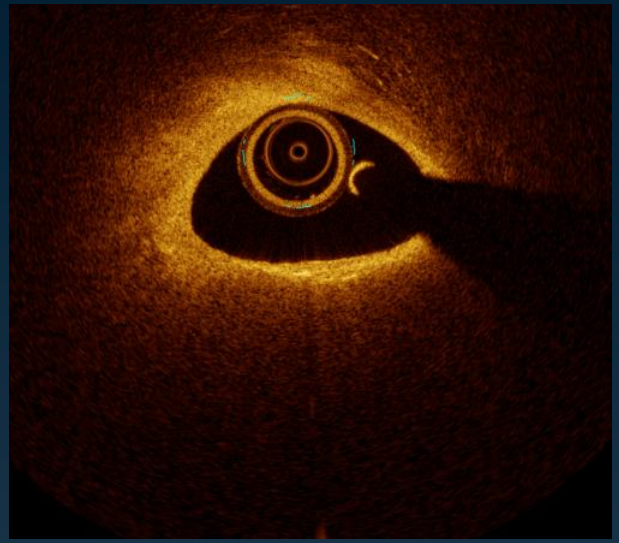
Gallone G. et al. JACC Img 2023; 16: 1584-1604.

Primary Composite Outcome:
Target Vessel Failure at 7 Year F/U

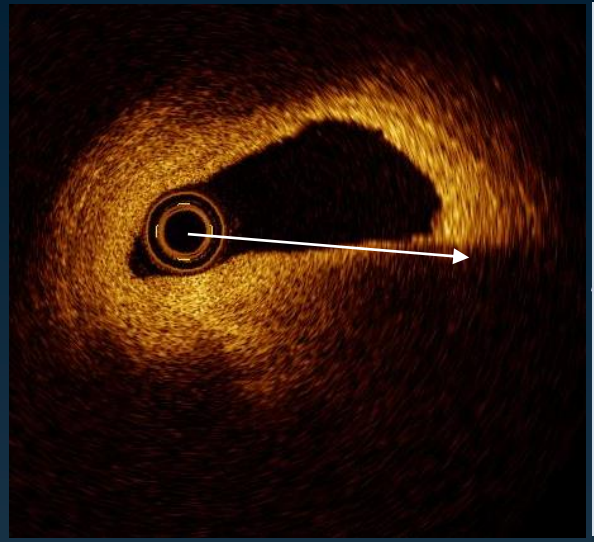
PREVENT



Is this TCFA (Thin Cap Fibroatheroma)?



Tangential Signal Drop-Off



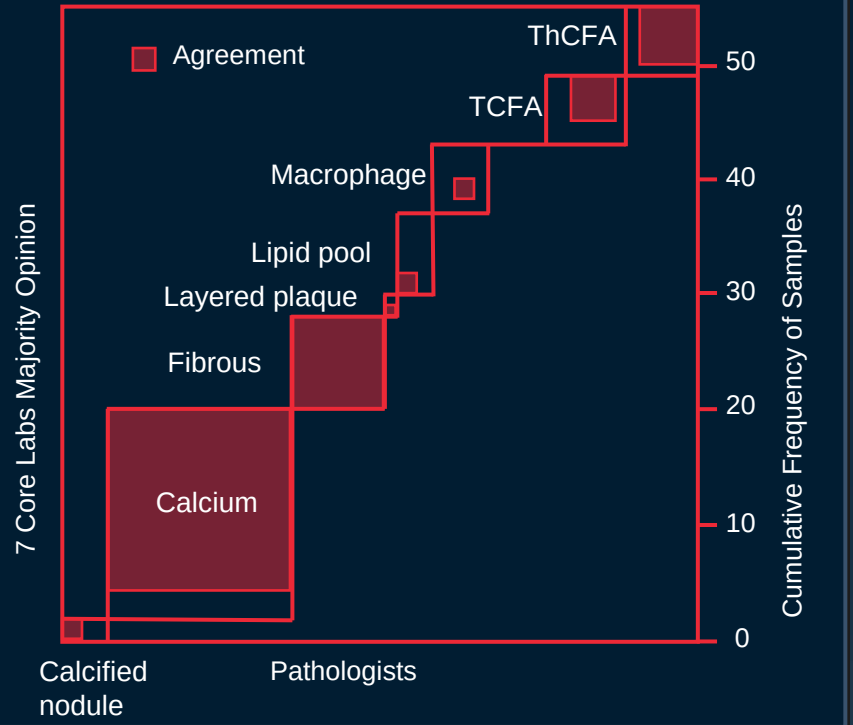
Courtesy of Dr.Kenichi Fujii

Significant Inter-Core Lab Variability of OCT Diagnosis

Participant 7 Core Lab: Drs. Kini/Vengrenyuk (Mount Sinai), H Garcia-Garcia (Medstar), L Räber (Bern), IK-Jang (MGH), Akasaka (Japan), Dijkstra (Leiden), Maehara (CRF)

Median Kappa of 7 core lab (each core lab vs pathologist)

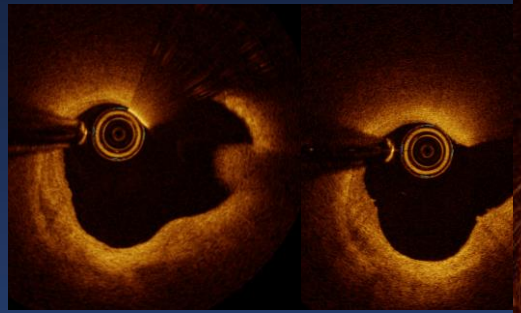
Plaque Type	Kappa
Fibrous	0.93
Calcium	0.83
Thick Cap Fibroatheroma (ThCFA)	0.63
TCFA	0.22
Necrotic Core	0.22
Macrophage/Form Cell	0.39
Lipid Pool	0.35
Calcified Nodule	0.50

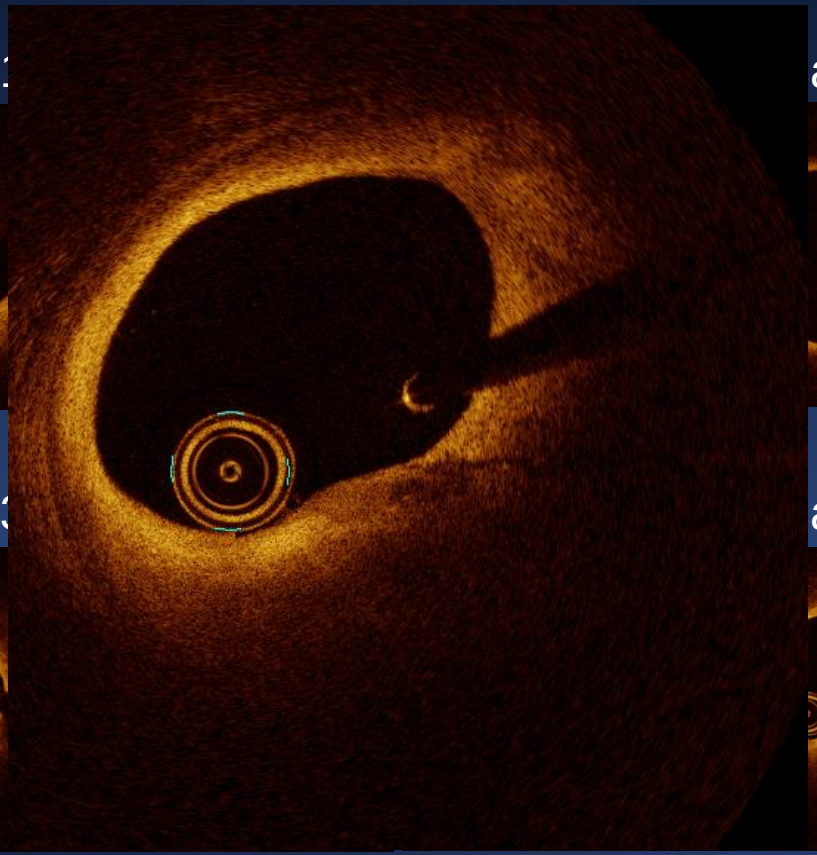


Gruslova A, Feldman M, et al. JACC Img. 2024: 17 448-450.

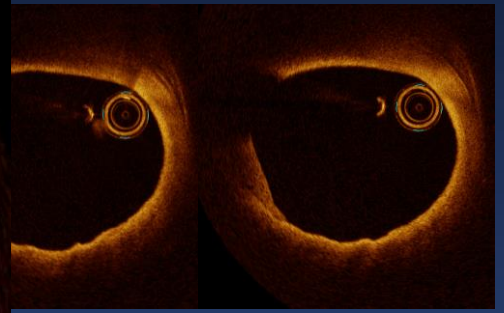
Trivial Findings in MINOCA

Case 1

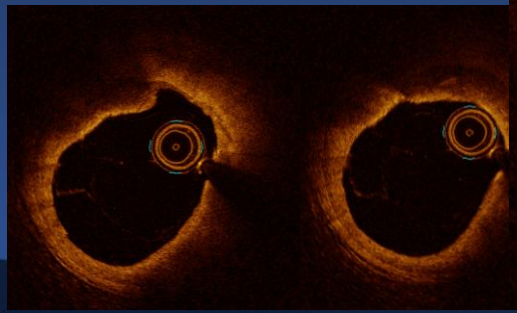




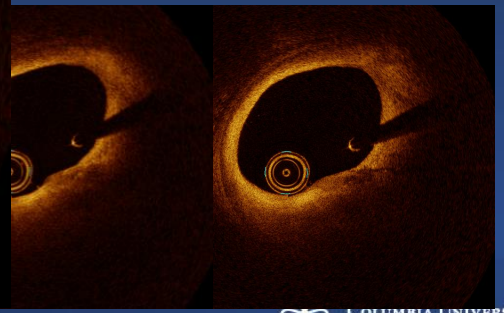
ase 2



Case 3



ase 4



Cardiovascular Research Foundation

Reynolds HR, et al. Circulation 2021;143:624-640.

Columbia University Medical Center
NewYork-Presbyterian

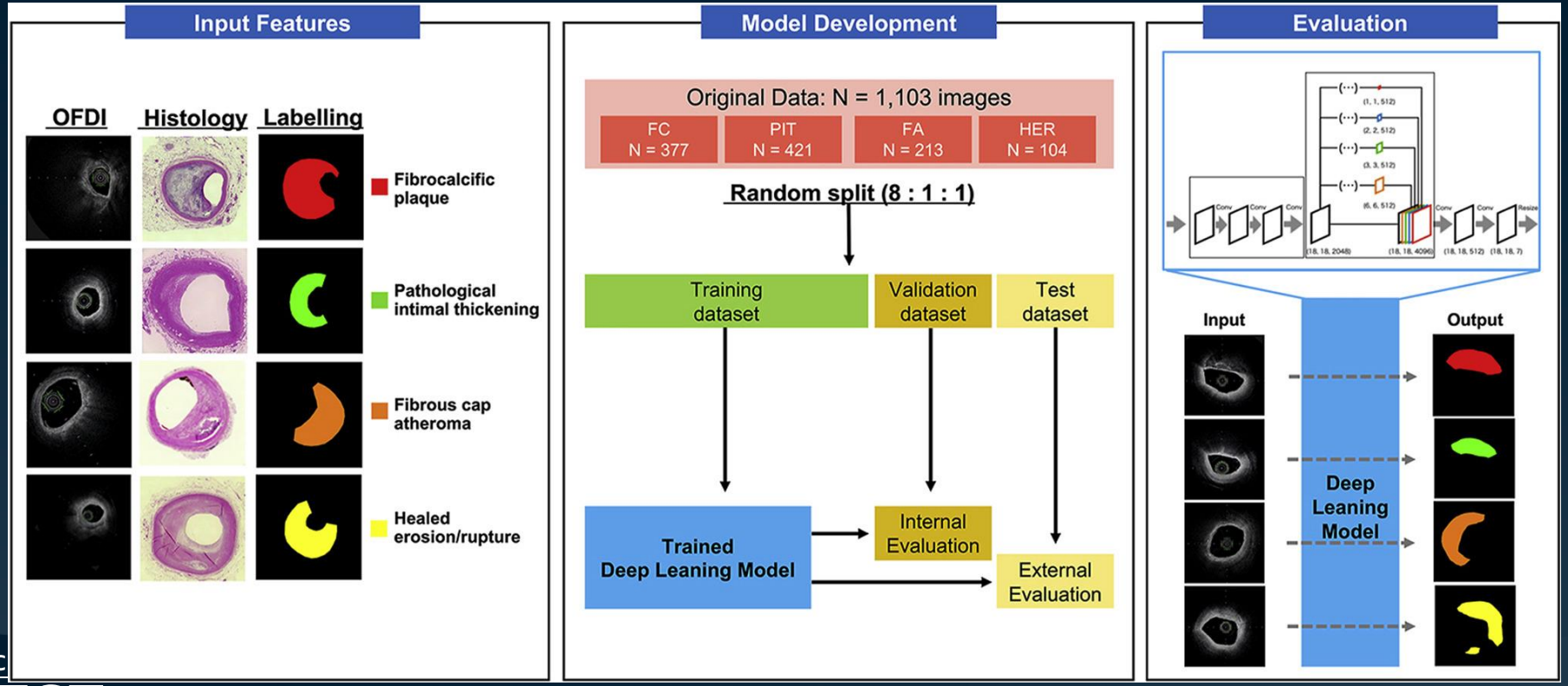
Summary of AI Diagnosis of OCT Plaque

Author, published y	# of sample	Tissue type Endpoint	Ground truth	Findings
Shibutani, 2021	1103 slices in 45 autopsy	Fibroatheroma, PIT, fibrous, healed plaque	Pathology	AUC for fibroatheroma: 0.86 PCI: 0.85
Holmberg, 2021	62slices in 7 autopsy, 222 slices 51 pts	TCFA, fibroatheroma, PIT, fibrous, calcium	Pathology & expert analysis	Overall accuracy in clinical pts: 85.8%
Min, 2020	602 lesions in 602 pts	TCFA	Expert analysis	Accuracy for TCFA: 91.3%
Lee, 2020	6556 slices in 49 pts	Fibrolipidic, fibrocalcific	Expert analysis	Sensitivity/specificity for lipid:84.8%/97.8%
Chu, 2021	11673 slices in 509 pullbacks, 300 slices (ext)	Lipid pool, cholesterol crystal, macrophage fibrous, calcium	Expert analysis	Accuracy for lipid 90.5%
Niioka, 2022	44947 slices in 1791 pts	TCFA	Expert analysis	AI TCFA predicts clinical outcome

Shibutani H, Atherosclerosis 2021; 328: 100-105; Holmberg O, Frontiers in CM 2021;8:779807; Min HS, Eurointervention 2020;16:404-12; Lee J, Nature Research OPEN 2020;10:2596; Chu M, Eurointervention 2021;17:41-50; Niioka H, Nature Research OPEN 2022;12:14067

AI Diagnosis of OCT Plaque Using Pathology as Ground Truth

Fibrous Cap Atheroma: Sensitivity/specificity 75%/93% by AI, 60%/89% by expert



Shibutani H, Atherosclerosis 2021; 328: 100-105

AI Diagnosis of OCT VP to Predict Clinical Outcome

Patients with non-culprit lesion OCT
n=1791

Test data 1173 frames, 102 pts

Development of AI algorithm

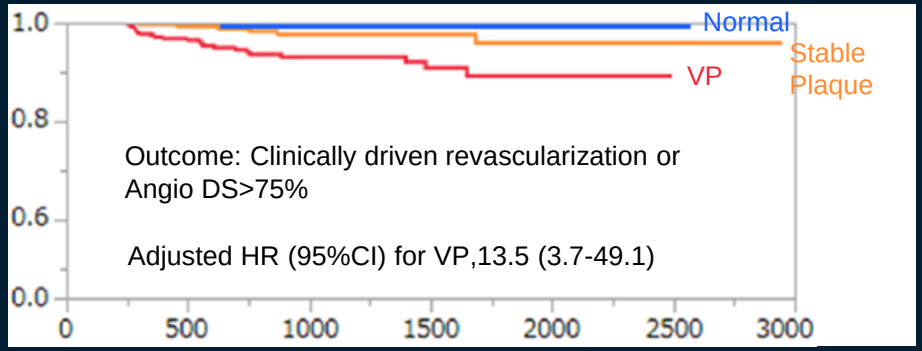
Training data
35,958 frames, 1351 pts

Validation data
8,989 frames, 338 pts

Accuracy
94.0%

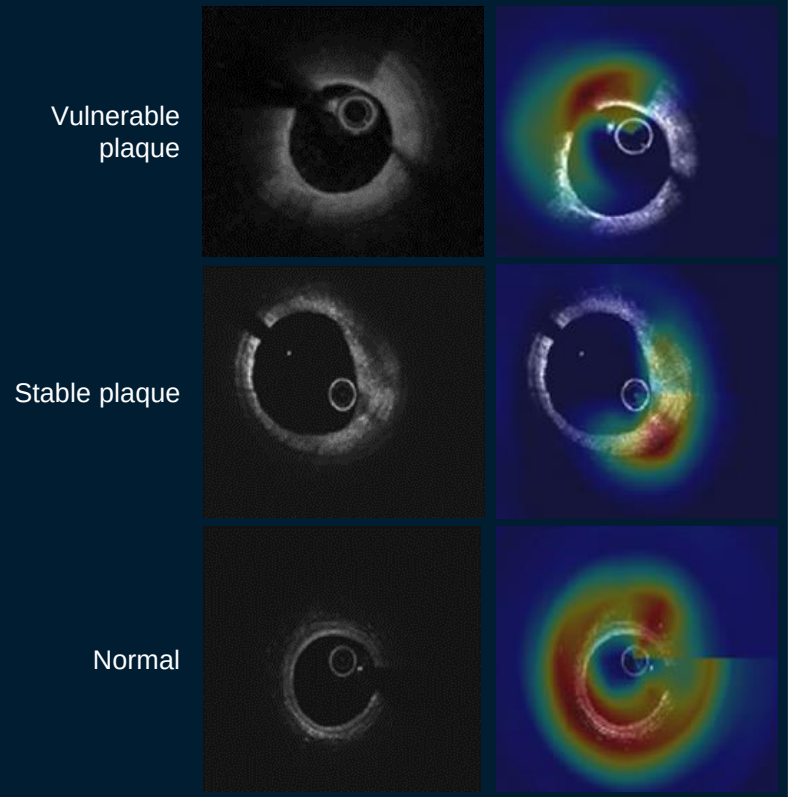
239 incomplete follow-up

Prediction of Clinical Outcome
1450 pts



Niioka H, et al. Nature Scientific Reports Open 2022;12,14067

Grad-CAM* Highlight important region for predicting concept

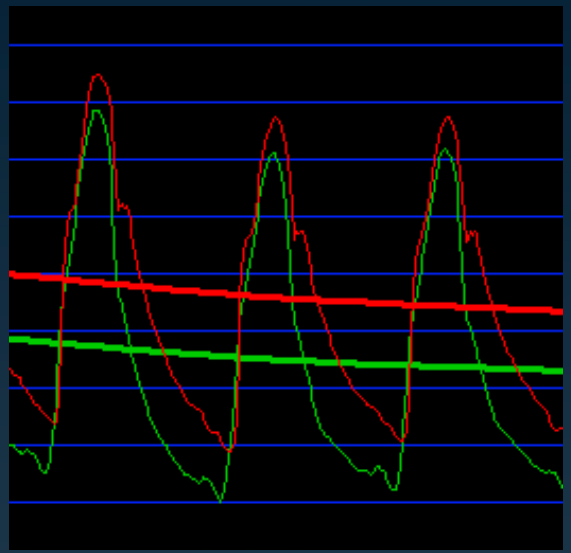


*Grad-CAM denotes gradient-weighted Class Activation Mapping

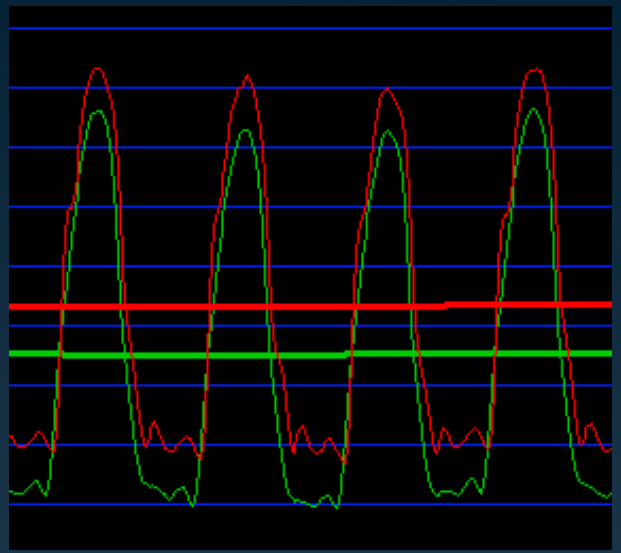
Physiology Measurement

CONTRAST Study: 4946 pressure waves in 763 patients
Pressure drift 17.5%

Good

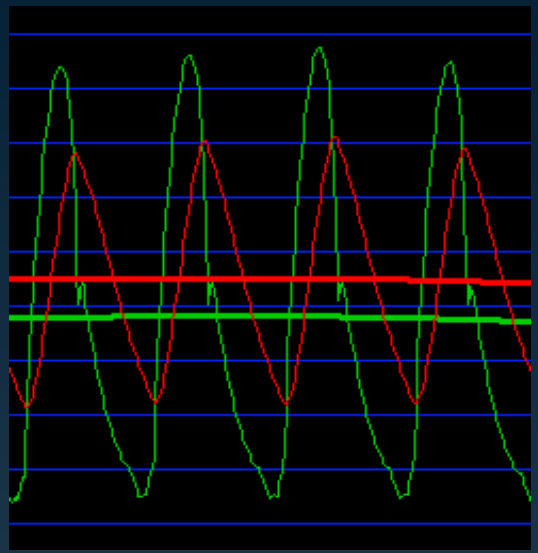


Aortic Damping



222/4217 (5.3%)

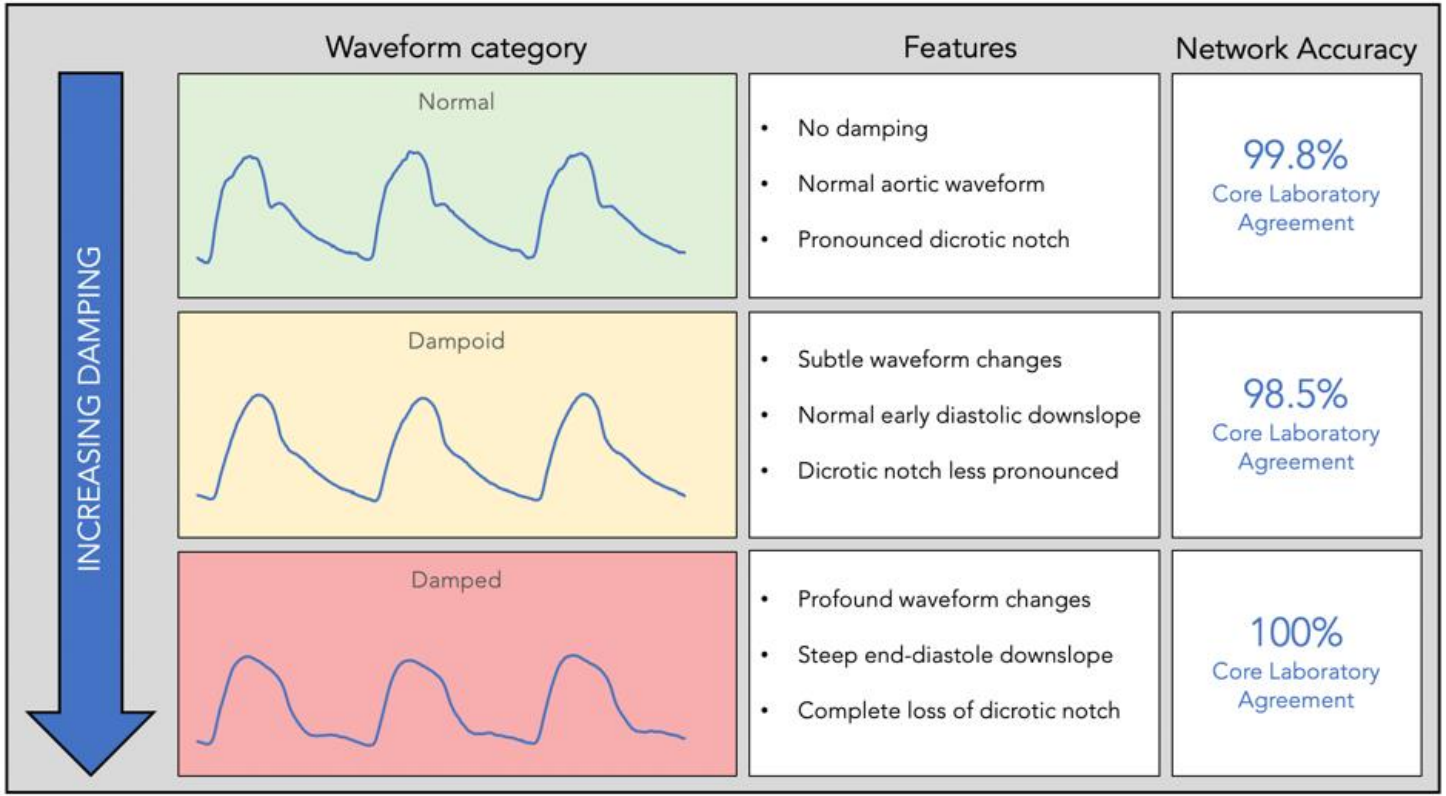
Distorted Wave



168/4217 (4.0%)

Matsumura M, et al. JACC Interv 2017; 10: 1392-401.

AI network provides very close agreement with corelab data interpretation



Howard J, Davies JE et al. J Am Coll Cardiol Intv. 2019 Oct, 12 (20) 2093-2101.

Basic Fluid Dynamics Equations

Poiseuille Equation

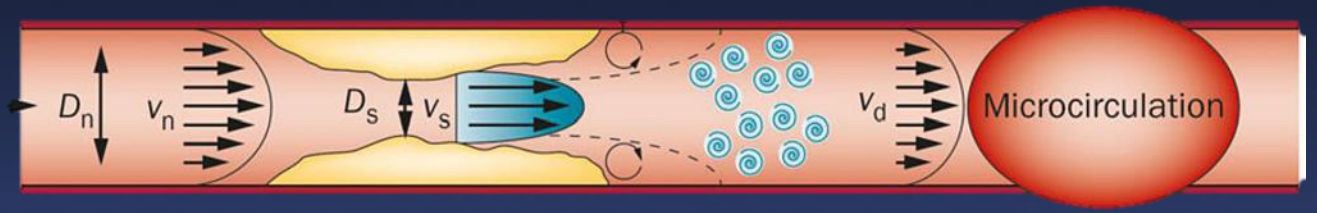
$$\Delta P = \frac{8\pi\mu L}{As}\ \frac{An}{As} \times V$$

Viscosity

Borda-Carnot Equation

$$\Delta P = \frac{\rho}{2}\left(\frac{An}{As} - 1\right)^2 \times V^2$$

Flow separation



Total Pressure Loss by Epicardial Stenosis

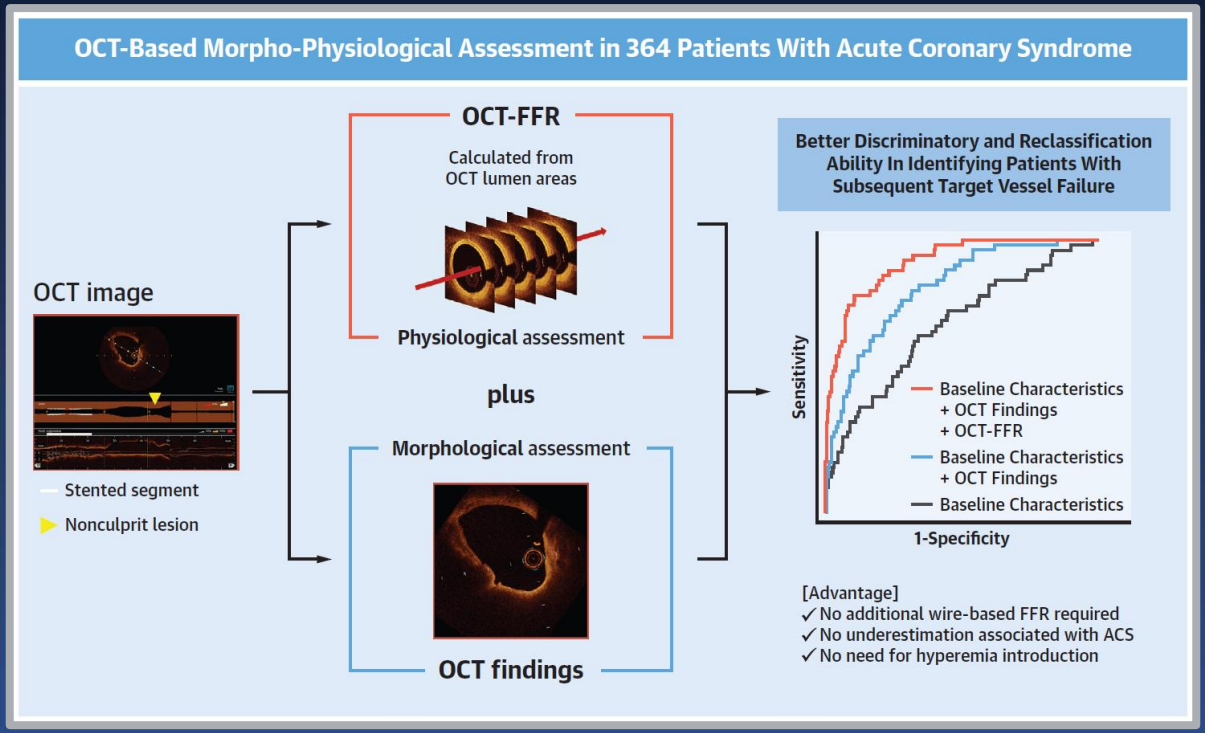
$$= \frac{8\pi\mu L}{As}\ \frac{An}{As} \times V + \frac{\rho}{2}\left(\frac{An}{As} - 1\right)^2 \times V^2$$

$$= F\,V + S\,V^2$$

L: Slice interval
μ: Blood viscosity
As: Lesion lumen area
An: Normal lumen area
ρ: Blood density
V: Flow velocity

Seike F, et al. Circ Interv 2022; 15, 851-860.

OCT-FFR to Predict MACE in ACS Patients



Variables	HR (95%CI)
Clinical	
LVEF	0.96 (0.93-0.98)
Discharge Statin	0.33 (0.16-0.67)
Stent segment	
Vessel OCT FFR per 0.1	0.38 (0.29-0.49)
Thrombus	1.86 (1.05-3.29)
Ref segment	
LRP Prox Ref	1.77 (1.01-3.12)
Ref Lumen Area	0.77 (0.67-0.89)
NCL-TCFA	2.56 (1.43-4.60)

Kakizaki S, et al. JACC Interv 2022; 15, 2035-2048.

Future Direction and Take Home Message

1. Using supervised CNN (convolutional neural network), imaging and physiology AI diagnoses have been progressed.
2. AI improved accuracy, reproducibility, and speed.
3. AI derived integrated information provides better PCI optimization and improve outcome.