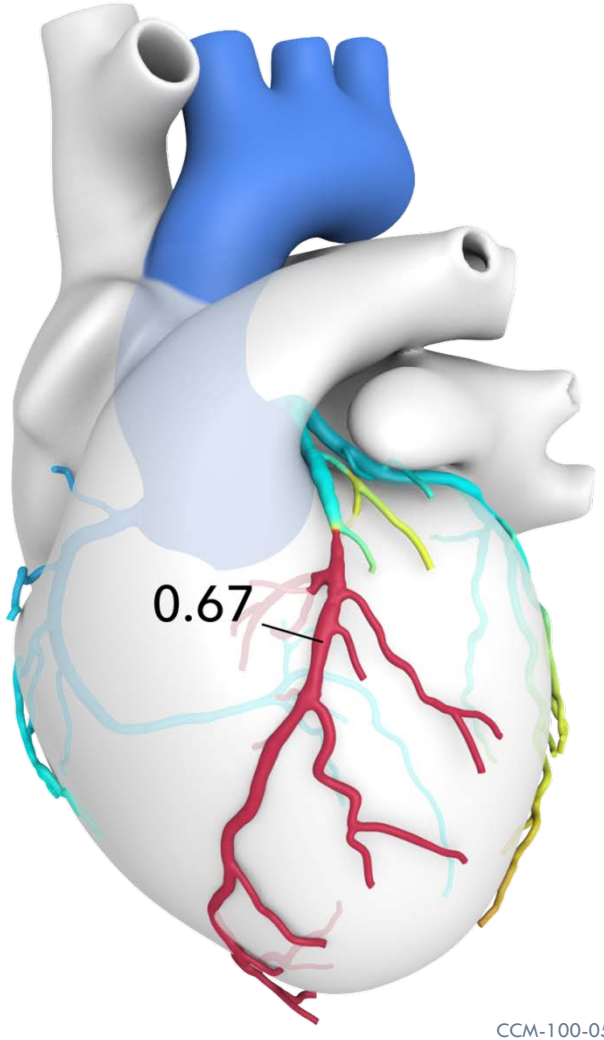
Cardiac CT FFR: The New Gold Standard



CCM-100-051-G

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Adjunct Prof. of Computational Science & Engineering, U.T. Austin

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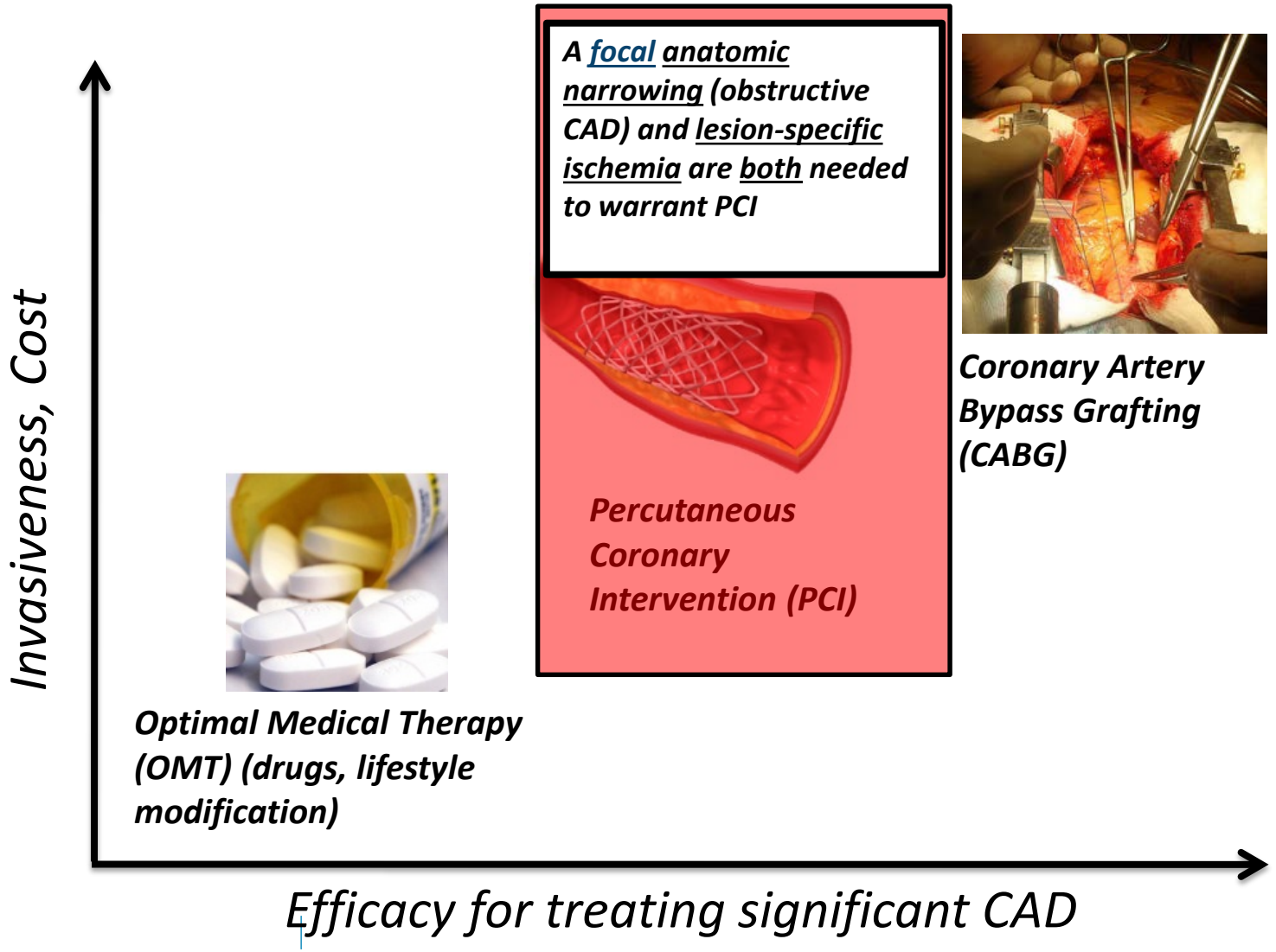
Disclosures

- Founder, Shareholder, Employee of HeartFlow, Inc., Redwood City, California

Alternate treatments for Coronary Artery Disease (CAD)

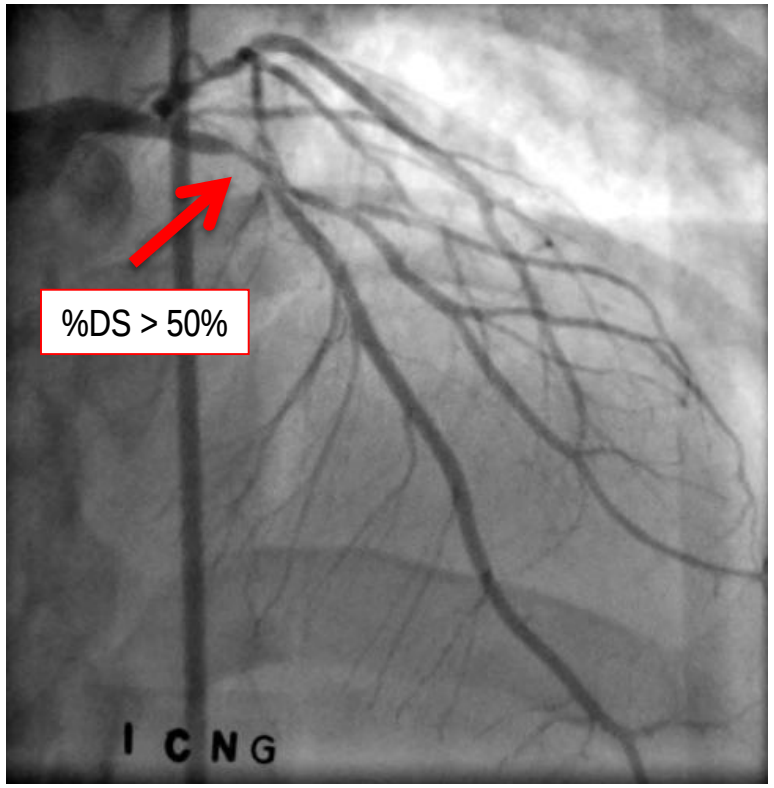


Diagnosing Anatomic and Functionally-Significant CAD

	ANATOMY ***Identify obstructive CAD***	***FUNCTION*** ***Identify lesion-specific ischemia that may benefit from PCI***
Invasive	**?**	**?**

Coronary Angiography (CAG) is the gold-standard for identifying obstructive CAD

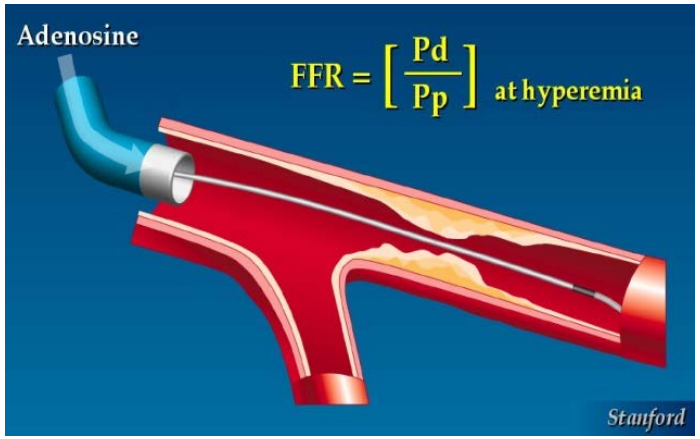
Normal coronary artery



Diseased coronary artery

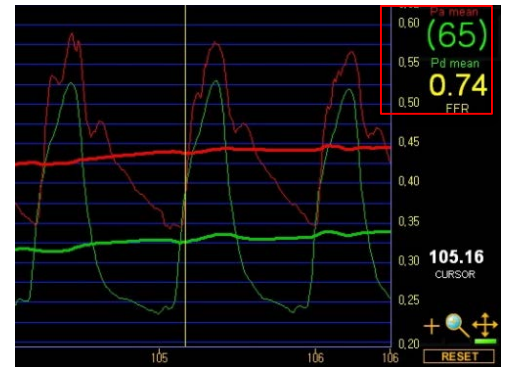
FFR is the gold-standard test to identify lesion-specific ischemia resulting from obstructive CAD

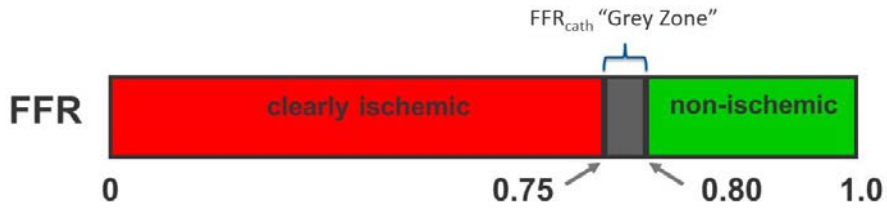
- **Fractional Flow Reserve (FFR)**
  - Defines the functional significance of coronary lesions*
  - Measured with pressure wire during coronary angiography
  - Adenosine used to elicit maximum hyperemia (i.e. to simulate exercise in the cardiac catheterization)



Angiography

FFR





*Pijls NH et al. J Am Coll Cardiol. 2007
Pijls NH et al. J. Am. Coll. Cardiol. 2010

Robust clinical evidence has established FFR as the gold-standard test to identify lesion-specific ischemia

FAME

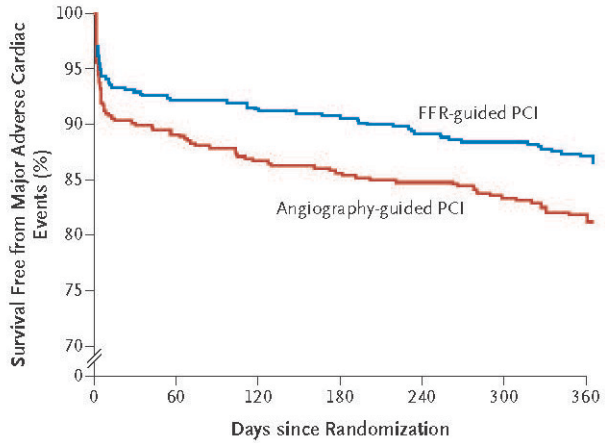
Defer PCI for lesions with FFR>0.8

The NEW ENGLAND JOURNAL of MEDICINE
ESTABLISHED IN 1812 JANUARY 15, 2009 VOL. 360 NO. 3

Fractional Flow Reserve versus Angiography for Guiding Percutaneous Coronary Intervention

CONCLUSIONS

Routine measurement of FFR in patients with multivessel coronary artery disease who are undergoing PCI with drug-eluting stents significantly reduces the rate of the composite end point of death, nonfatal myocardial infarction, and repeat revascularization at 1 year. (ClinicalTrials.gov number, NCT00267774.)



Tonino et al. NEJM 2009, 360: 213

FAME-2

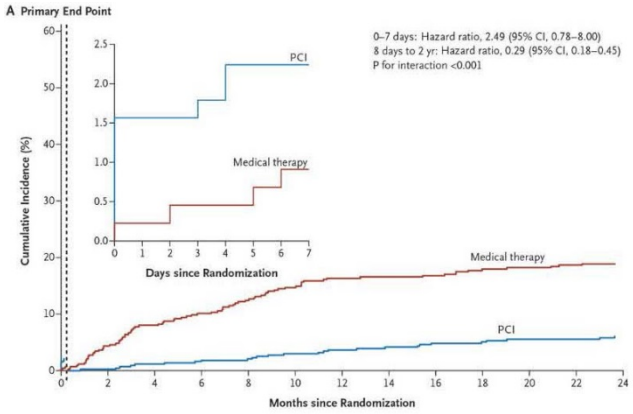
Perform PCI for lesions with FFR≤0.8

The NEW ENGLAND JOURNAL of MEDICINE
ORIGINAL ARTICLE

Fractional Flow Reserve–Guided PCI versus Medical Therapy in Stable Coronary Disease

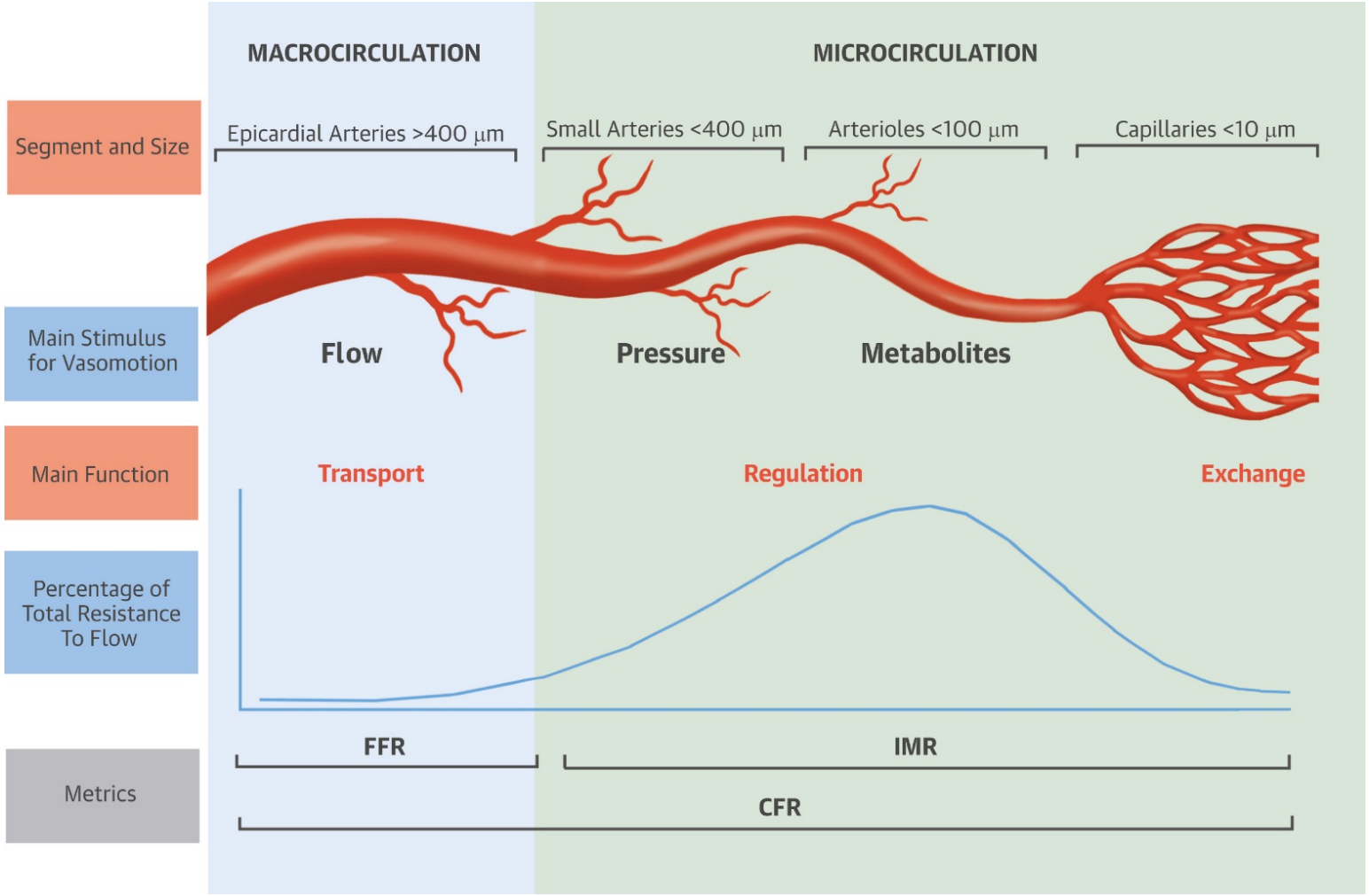
CONCLUSIONS

In patients with stable coronary artery disease and functionally significant stenoses, FFR-guided PCI plus the best available medical therapy, as compared with the best available medical therapy alone, decreased the need for urgent revascularization. In patients without ischemia, the outcome appeared to be favorable with the best available medical therapy alone. (Funded by St. Jude Medical; ClinicalTrials.gov number, NCT01132495.)



De Bruyne et al. NEJM 2012, 367: 991

FFR uniquely isolates CAD in epicardial arteries causal of ischemia, i.e. that is treatable by revascularization



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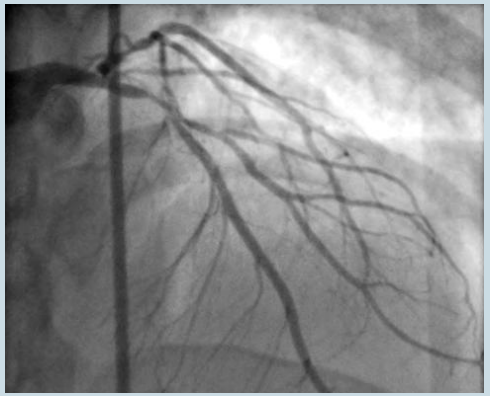
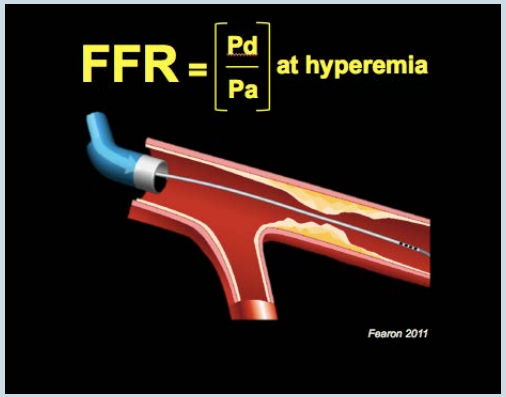
Bernard De Bruyne, Keith G. Oldroyd, Nico H.J. Pijls, Microvascular (Dys)Function and Clinical Outcome in Stable Coronary Disease, Journal of the American College of Cardiology, Volume 67, Issue 10, 2016, 1170–1172

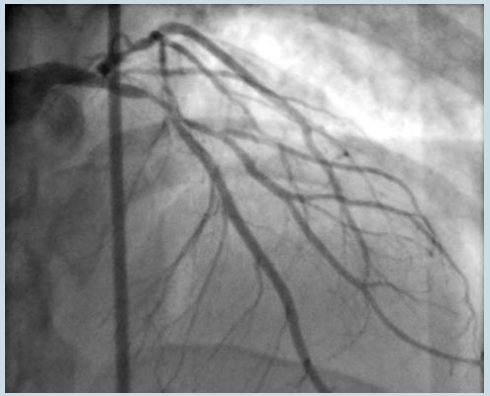
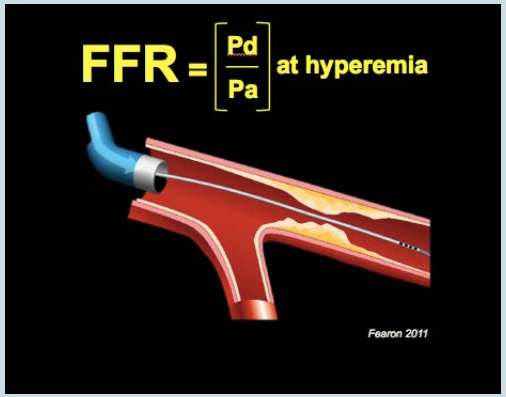
Diagnosing Anatomic and Functionally-Significant CAD

	ANATOMY	***FUNCTION***
	Identify obstructive CAD	***Identify lesion-specific ischemia that may benefit from PCI***
Invasive		

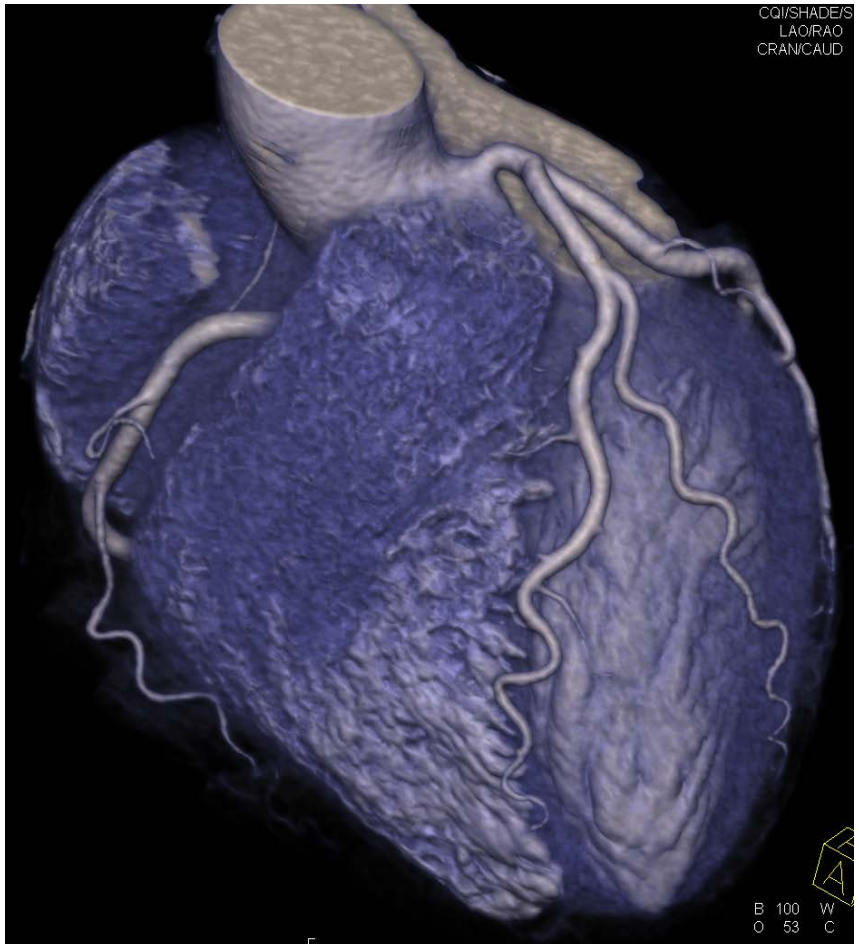
- Angiography and FFR require invasive cardiac catheterization
- Most patients that enter the cath lab do not have obstructive coronary artery disease on angiography let alone positive FFR

Can we identify obstructive CAD and lesion-specific ischemia ***BEFORE*** *patients go the cath lab?*

Diagnosing Anatomic and Functionally-Significant CAD

	ANATOMY ***Identify obstructive CAD***	***FUNCTION*** ***Identify lesion-specific ischemia that may benefit from PCI***
Invasive		
Non-invasive		?

Does this patient have coronary artery disease?



Very little. May or may not benefit from medical therapy

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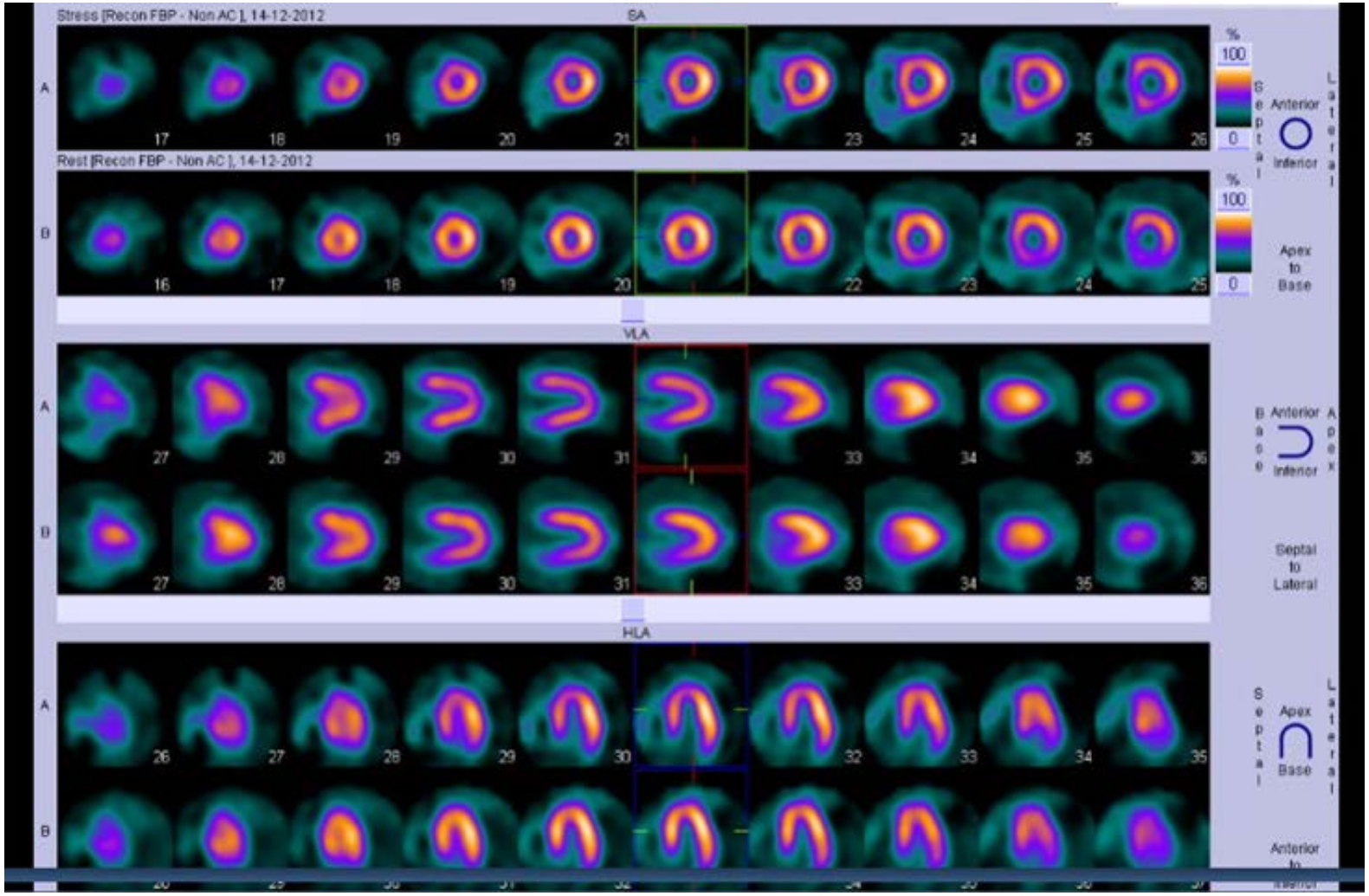
Images provided by J. Leipsic

Does this patient have coronary artery disease and if so how should it be treated?

cCTA read by core lab as having a **severe proximal LAD lesion**

Does this patient have coronary artery disease and if so how should it be treated?



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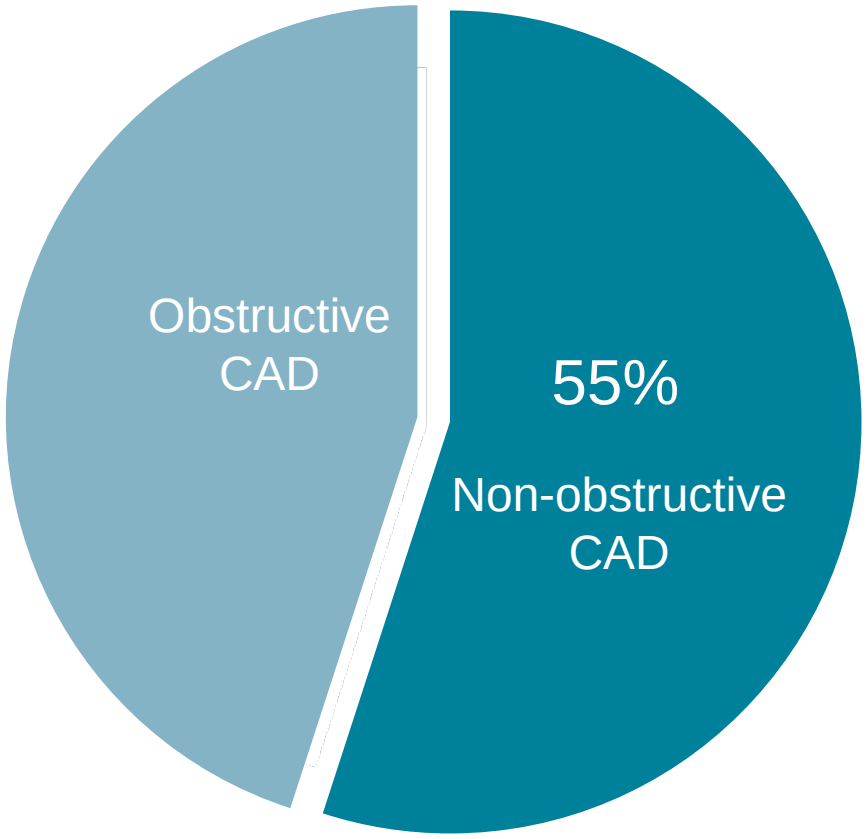
SPECT read by core lab as negative

Noninvasive Stress Testing Leads to Overutilization of Invasive Procedures

Findings During Invasive Coronary Angiograms



Because standard non-invasive stress testing is low yield

Over half of patients
who undergo invasive angiograms
have no disease

and could have avoided ICA
if better non-invasive screening
were available

Data includes nearly 400,000 patients at over 650 US hospitals

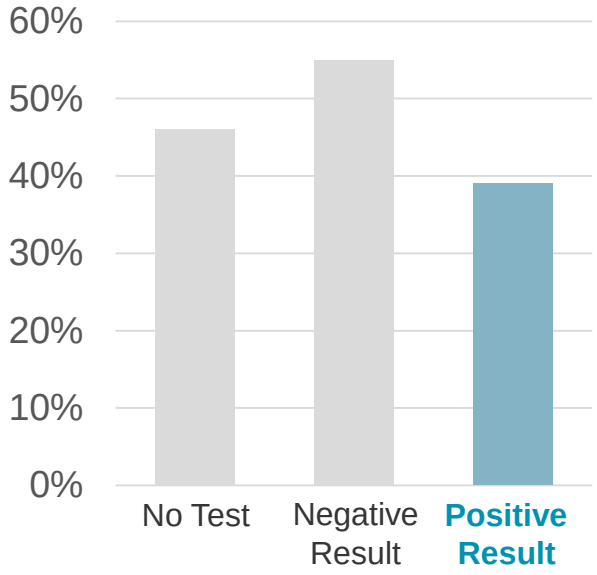
Patel et al, NEJM 2010.
Patel et al, AHJ 2014.

Stress Testing Does Not Provide Actionable Information

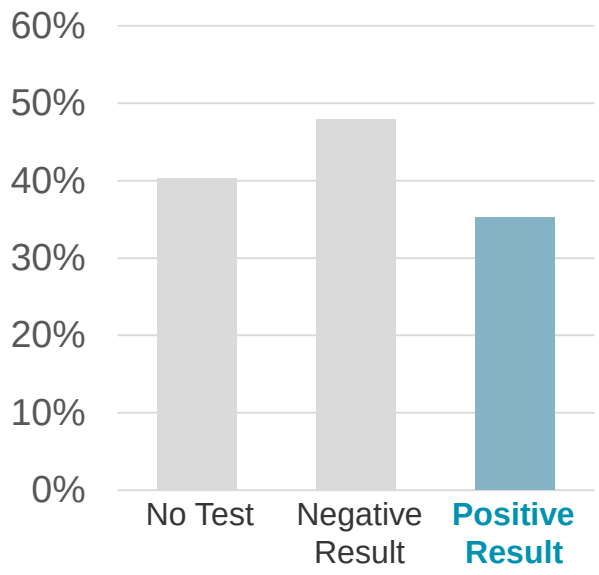
A recent study of **over 15,000 ICA patients** found that

- Patients with a positive stress test were the least likely to
  - Have Obstructive CAD
  - Receive a Revascularization

ICA findings of Obstructive CAD by prior stress test results

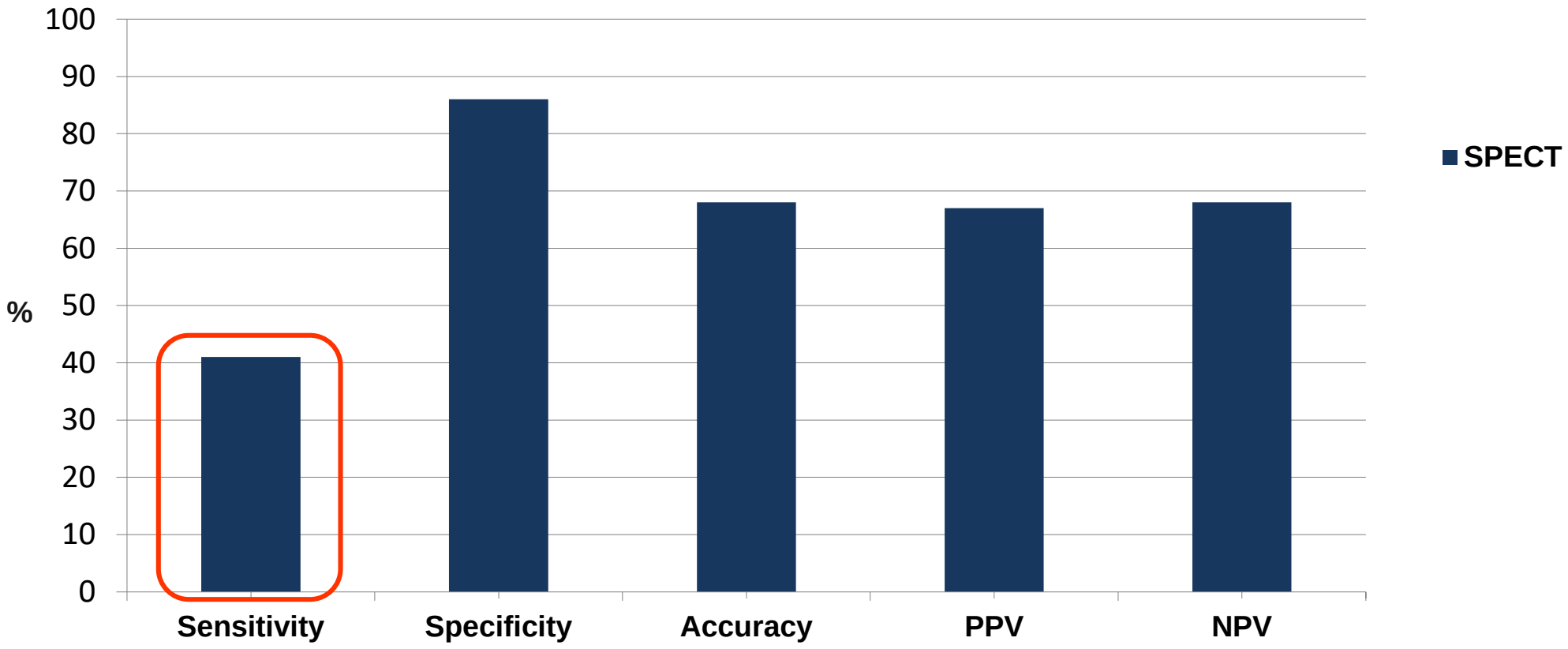


Revascularization Rates by prior stress test results



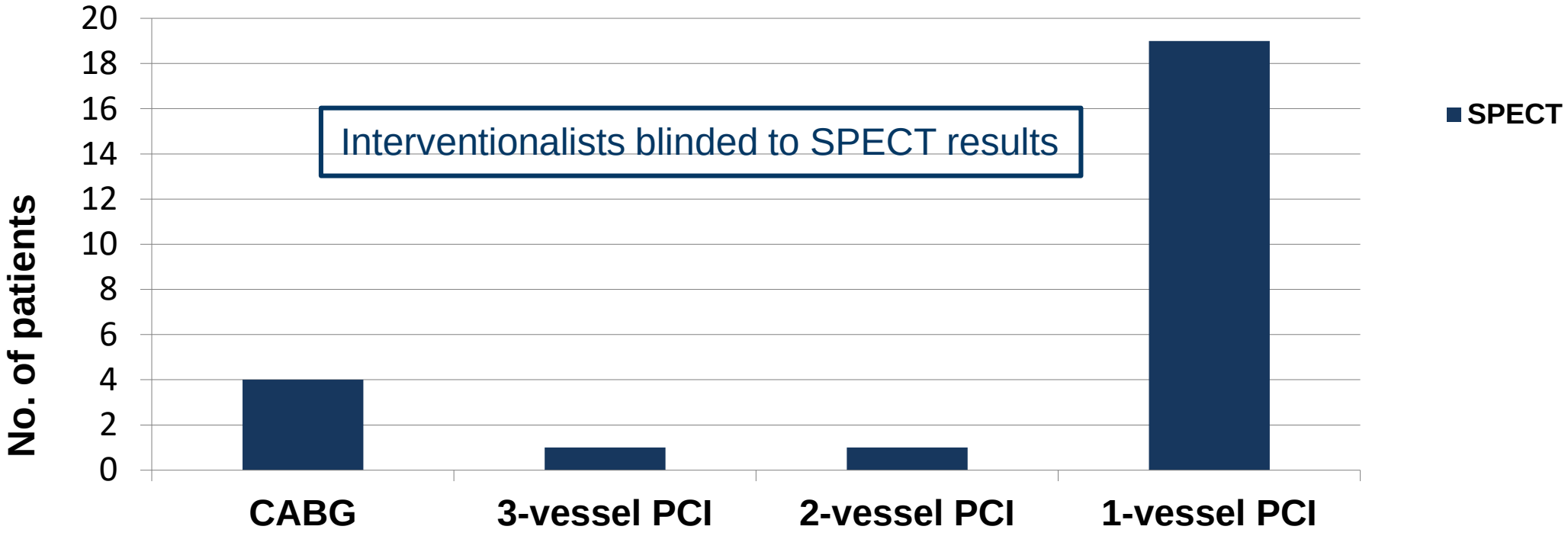
Vavalle et al, JAMA Cardiology 2016.

Per-Patient Diagnostic Performance of SPECT vs FFR
(143 Patients enrolled after positive cCTA)



Reference: FFR ≤ 0.80

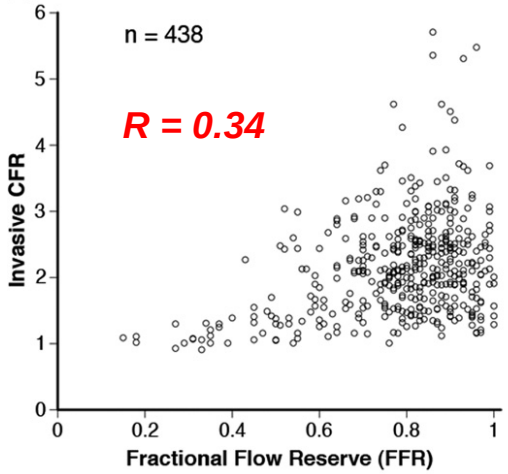
Revascularization outcome for Patients with a False Negative SPECT vs FFR



- 59/143 Patients enrolled had a positive FFR
- 25 patients were revascularized and had a negative SPECT study

Why are perfusion tests (SPECT, MRMPI, PET) discordant with FFR?

- FFR quantifies ratio of flow through diseased vessel to flow through hypothetically normal vessel
  - ***Identifies lesions that, if stented, will result in increased blood flow***
  - Supported by robust clinical evidence demonstrating utility in planning PCI
- Perfusion imaging quantifies ratio of hyperemic flow to baseline flow, i.e. coronary flow reserve (CFR)
  - Provides measure of global myocardial ischemia useful for assessing long-term prognosis of patients, but does not identify lesions that may benefit from PCI
- FFR and CFR are different physiologic metrics that do not correlate well



Johnson, N.P., Kirkeeide, R.L., Gould, K.L.
"Is Discordance of Coronary Flow Reserve and Fractional Flow Reserve Due to Methodology or Clinically Relevant Coronary Pathophysiology?"
JACC Cardiovascular Imaging, Vol. 5 , No. 2 , 2012

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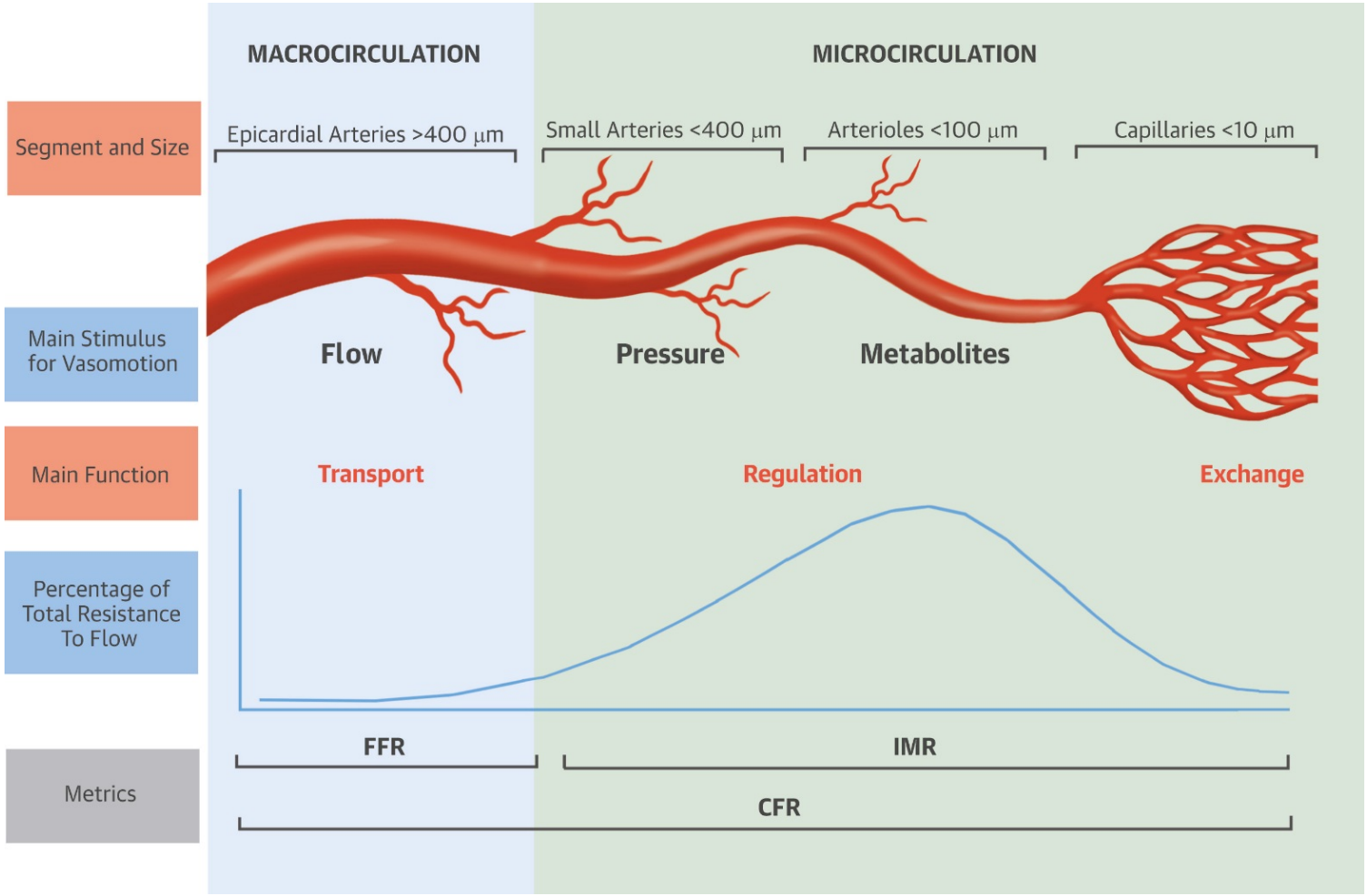

A1: They measure global myocardial ischemia, not lesion-specific ischemia

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Bernard De Bruyne, Keith G. Oldroyd, Nico H.J. Pijls, Microvascular (Dys)Function and Clinical Outcome in Stable Coronary Disease, Journal of the American College of Cardiology, Volume 67, Issue 10, 2016, 1170–1172

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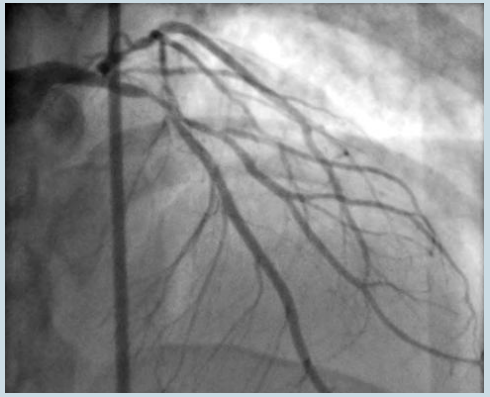
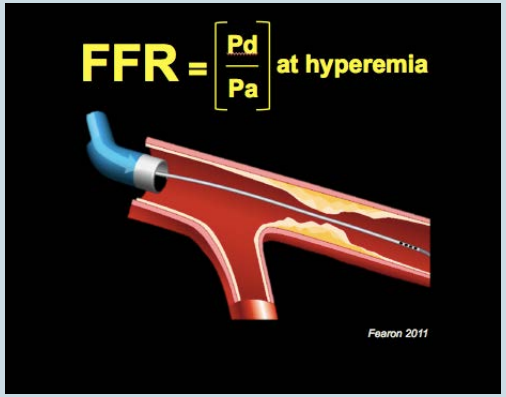
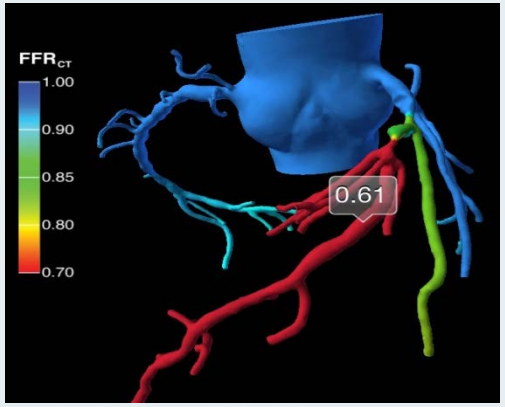
Invasive		
Noninvasive		

FFR_{CT} Results

Interactive Results

HeartFlow®

CCM-100-081-B

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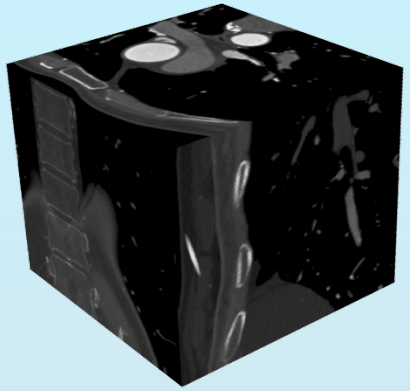
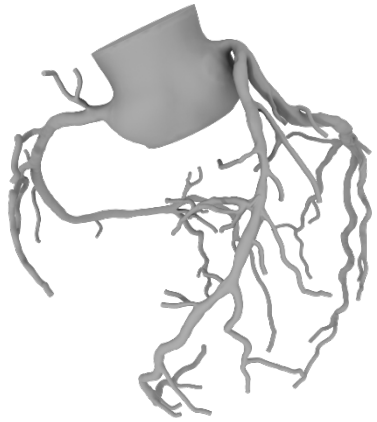
Refer to product Instructions For Use for patient populations in which FFR_{CT} has been clinically evaluated, relevant clinical data, and product warnings.

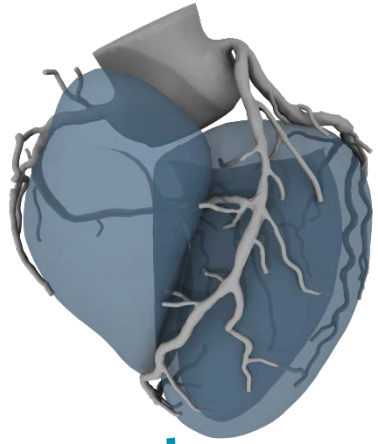
The FFR_{CT} Analysis Process



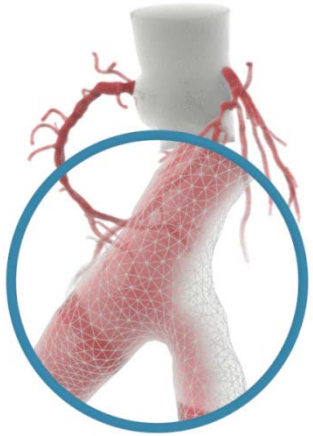
CT data submitted



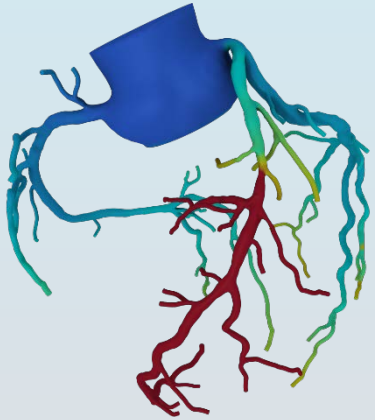
Anatomic model



Physiologic model

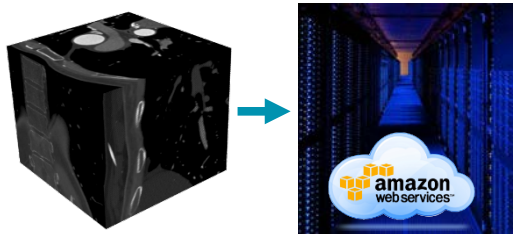


Functional assessment with Computational Fluid Dynamics



HeartFlow Analysis delivered

FFR_{CT} Process



- A standard cardiac **CT scan** is performed and the data is uploaded to secure application on Amazon Web Services (AWS)

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FFR_{CT} Process

- A standard cardiac **CT scan** is performed and the data is uploaded to HeartFlow via AWS
- **Deep learning** methods are used to create a **personalized, digital 3D model of the coronary arteries.** Model is then inspected and corrected by trained image analysts.

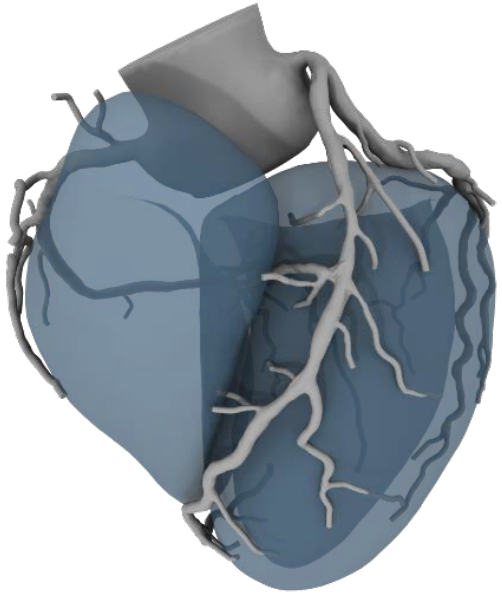

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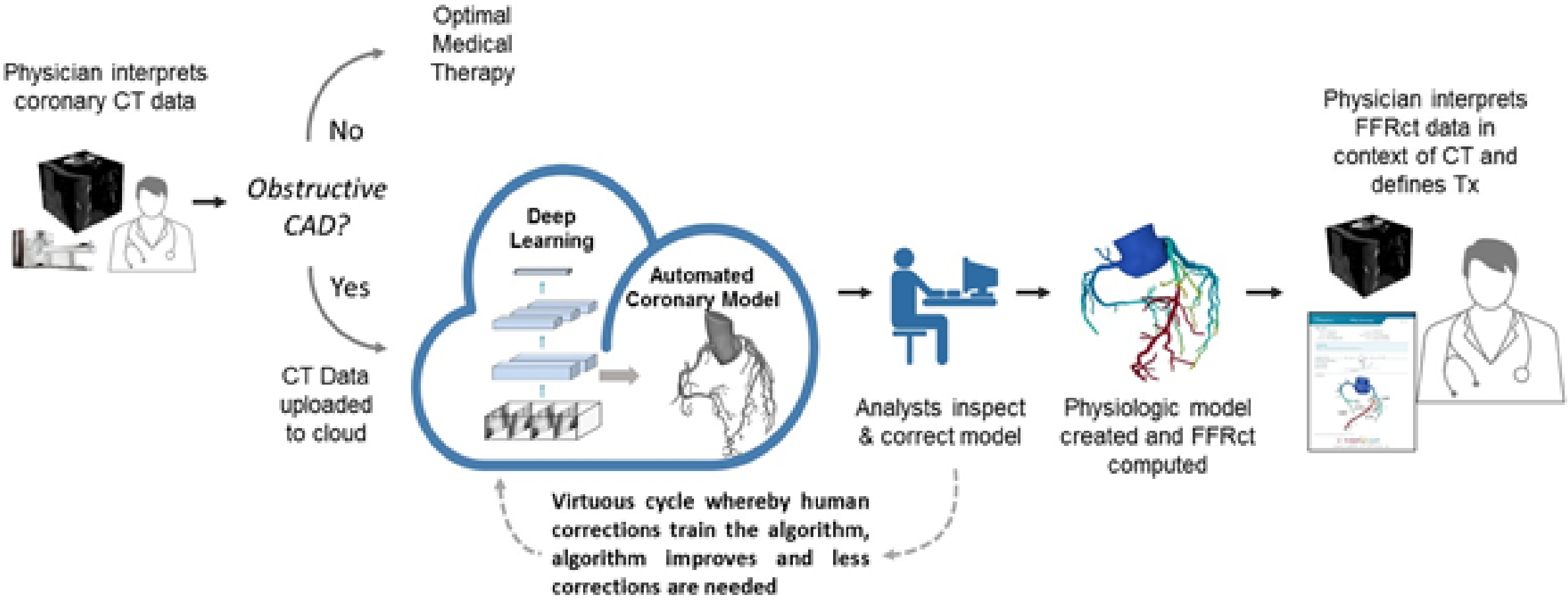
*Image not representative of actual product.

Automation via Deep Learning Image Analysis



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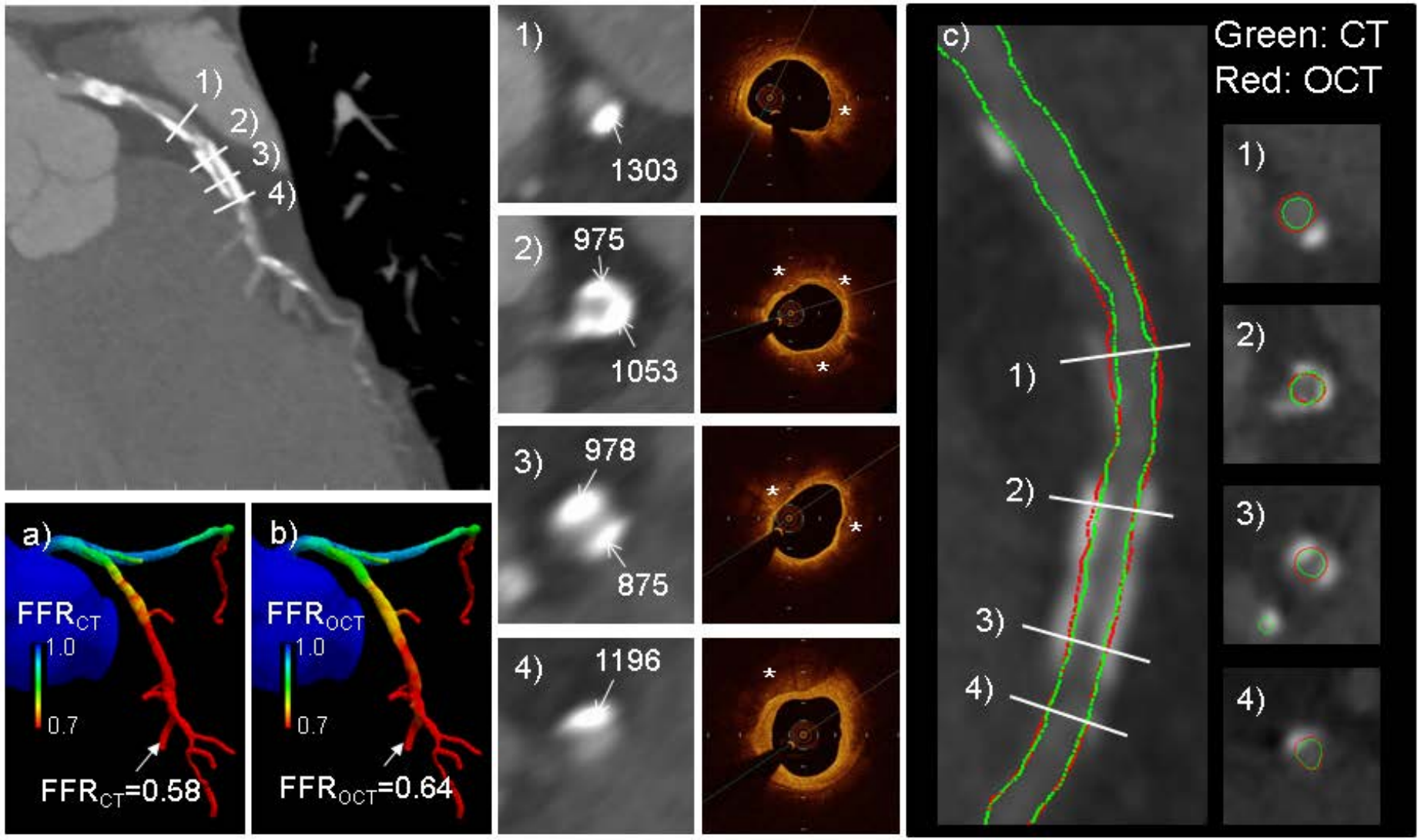
Large quantities of rigorously annotated data mandatory for deep learning

FFR_{CT} lumen accuracy validated with OCT data



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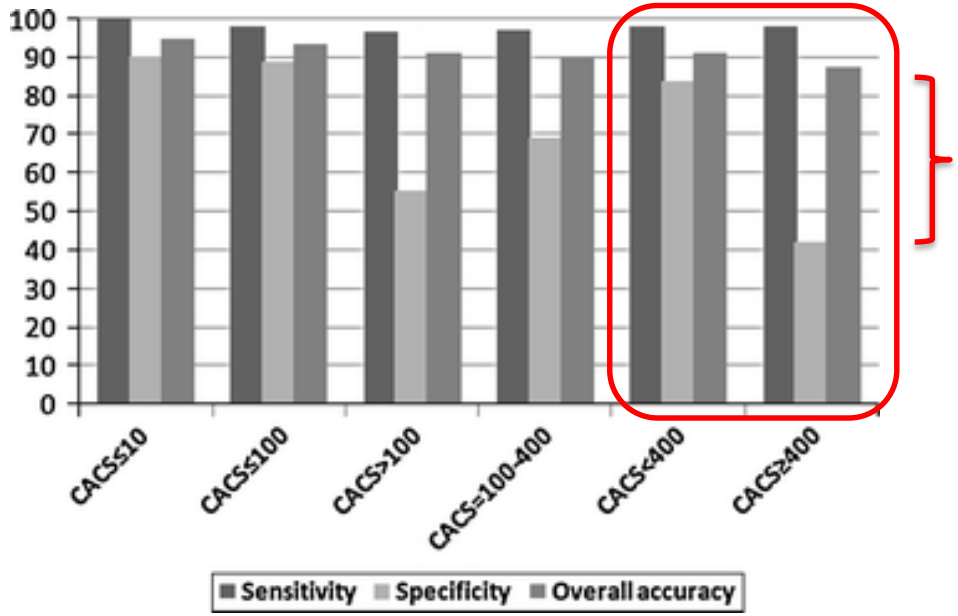
Uzu et.al. Eurointervention, 2018

Limitations of coronary CTA with high calcium

- Coronary CTA often limited to patients with low-intermediate risk
  - High NPV of coronary CTA can rule out obstructive CAD and lesion-specific ischemia
  - PPV of coronary CTA to rule-in obstructive CAD declines significantly with increasing disease burden, especially with calcified vessels

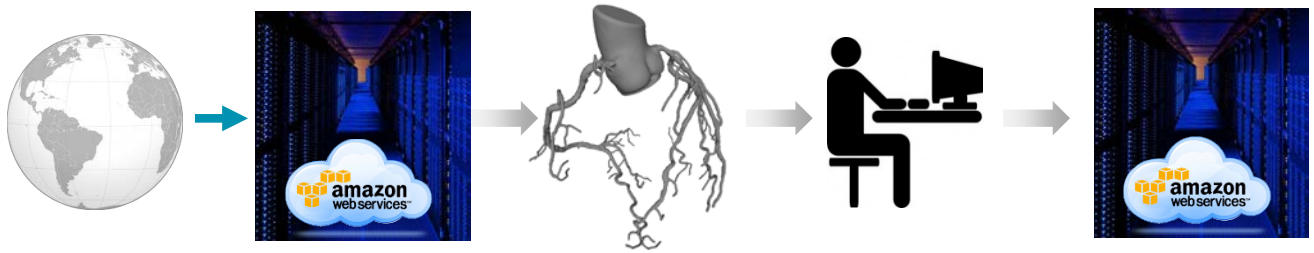


Decreased specificity of cCTA for Calcium score > 400

Abdulla, J., Pedersen, K.S., Budoff, M. et al. Int J Cardiovasc Imaging (2012) 28: 943.

FFR_{CT} technology can account for calcium blooming

FFR_{CT} Process



- A standard cardiac **CT scan** is performed and the data is uploaded to HeartFlow via AWS
- **Deep learning** methods are used to create a **personalized, digital 3D model of the coronary arteries.** Model is then inspected and corrected by trained image analysts.
- **Powerful computer algorithms** solve equations of blood flow to assess the impact of coronary artery disease

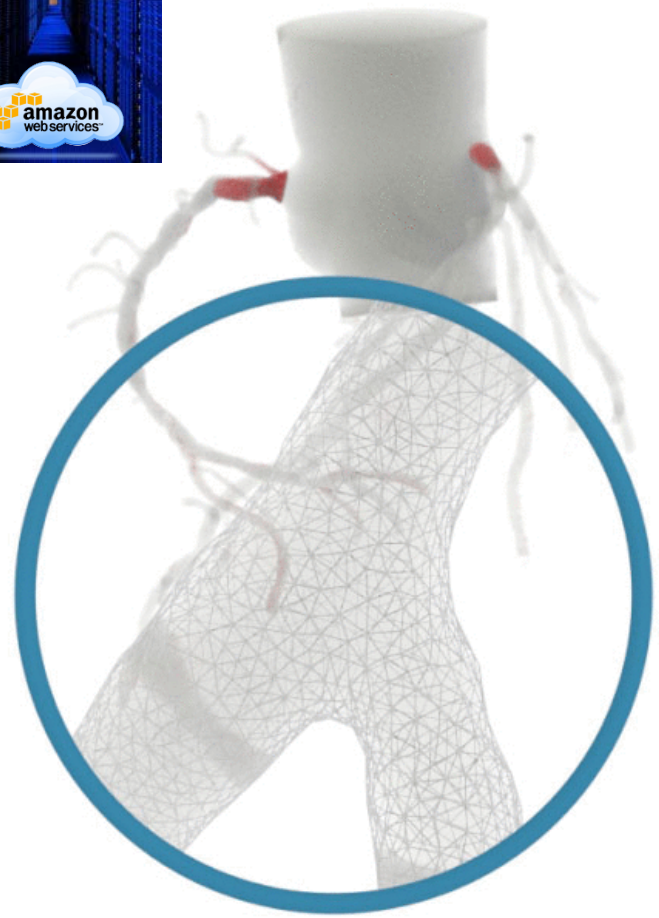


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*Image not representative of actual product.

Computational fluid dynamic analysis can be used to quantify blood flow and pressure

3D Modeling of Blood Flow Requires Solving the Governing Partial Differential Equations

Mass Conservation (1 equation):

$$\frac{\partial v_x}{\partial x}+\frac{\partial v_y}{\partial y}+\frac{\partial v_z}{\partial z}=0$$

This law states that blood is an incompressible fluid

Momentum Balance (3 equations):

$$\rho\frac{\partial v_x}{\partial t}+\rho\left(v_x\frac{\partial v_x}{\partial x}+v_y\frac{\partial v_x}{\partial y}+v_z\frac{\partial v_x}{\partial z}\right)=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 v_x}{\partial x^2}+\frac{\partial^2 v_y}{\partial y^2}+\frac{\partial^2 v_z}{\partial z^2}\right)$$

$$\rho\frac{\partial v_y}{\partial t}+\rho\left(v_x\frac{\partial v_y}{\partial x}+v_y\frac{\partial v_y}{\partial y}+v_z\frac{\partial v_y}{\partial z}\right)=-\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v_x}{\partial x^2}+\frac{\partial^2 v_y}{\partial y^2}+\frac{\partial^2 v_z}{\partial z^2}\right)$$

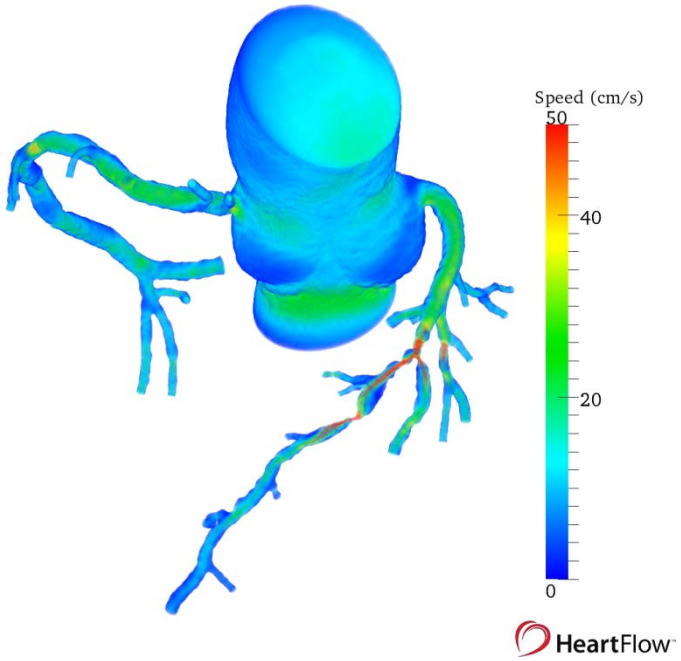
$$\rho\frac{\partial v_z}{\partial t}+\rho\left(v_x\frac{\partial v_z}{\partial x}+v_y\frac{\partial v_z}{\partial y}+v_z\frac{\partial v_z}{\partial z}\right)=-\frac{\partial p}{\partial z}+\mu\left(\frac{\partial^2 v_x}{\partial x^2}+\frac{\partial^2 v_y}{\partial y^2}+\frac{\partial^2 v_z}{\partial z^2}\right)$$

These equations come from the application of Newton's 2nd law, F=ma to a fluid

where ρ is the fluid density, and μ is the fluid viscosity (both assumed known).

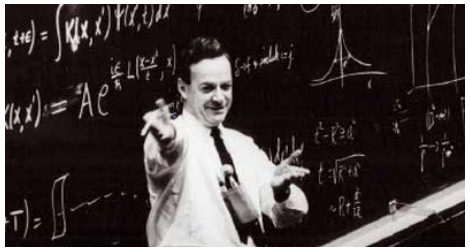
We solve these for $v_x(x,y,z,t), v_y(x,y,z,t), v_z(x,y,z,t), p(x,y,z,t)$

for every point in the 3D model and over whatever time interval we are interested in.



"*People who wish to analyze nature without using mathematics must settle for a reduced understanding*"

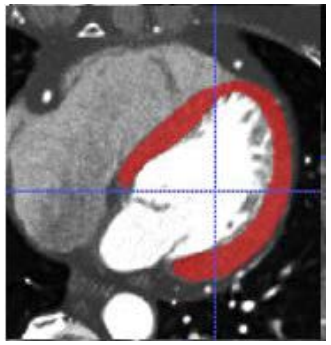
- Richard Feynman, PhD, Nobel Laureate in Physics



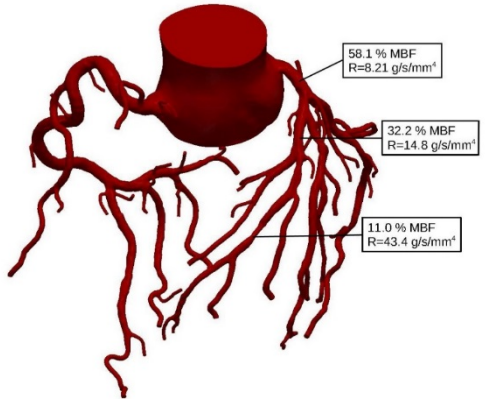
Physiologic Model of FFR_{CT}

1. Total baseline flow from myomass

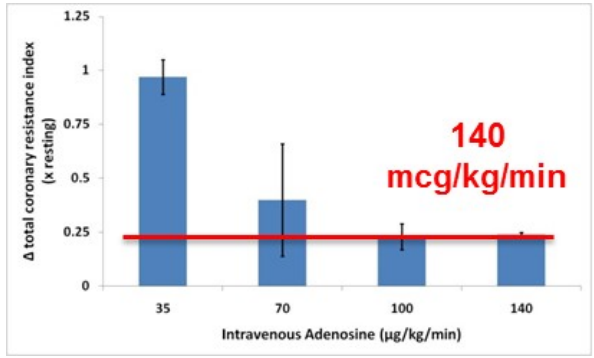
$Q_c^{baseline} \propto M_{myo}^{3/4}$



2. Distribute baseline flow based on vessel size, compute terminal resistances



3. Reduce terminal resistances to model hyperemia



<u>Modeling coronary blood flow</u>:

1. Compute total baseline myocardial blood flow from segmented LV myocardium
2. Distribute baseline flow proportionally based on vessel size to define baseline microvascular resistance
3. Reduce terminal resistance values from initial values until maximal vasodilatory threshold reached

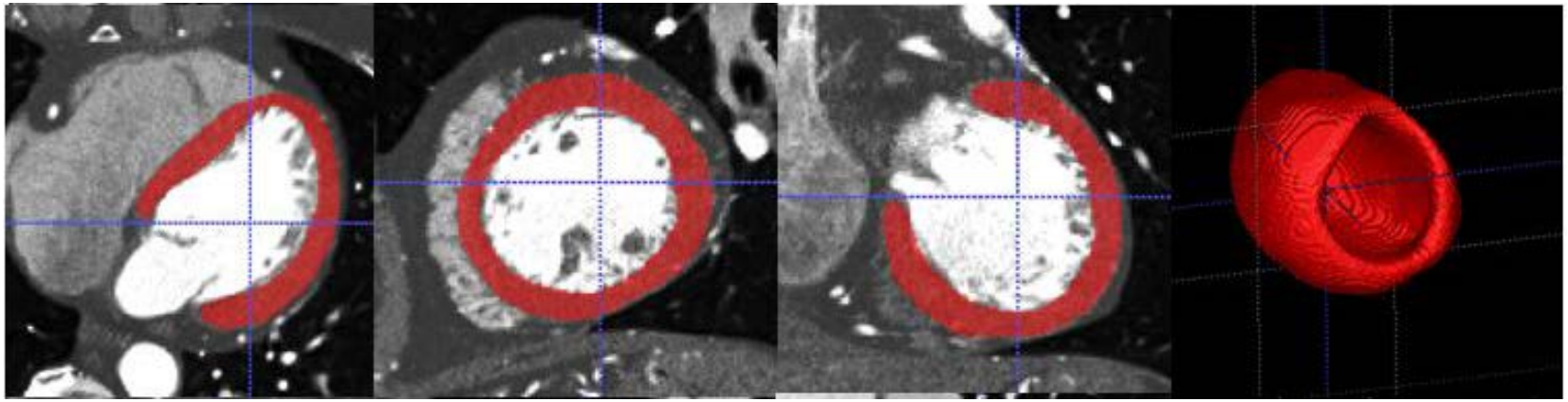
Taylor et al. JACC 2013, 61:2, 2233-41.

Scientific Principle #1

Baseline coronary blood flow is proportional to myocardial mass

In FFR_{CT}, allometric scaling laws are applied to estimate total baseline coronary flow, from myocardial mass

$$Q_c^{rest} \propto M_{myo}^{3/4}$$



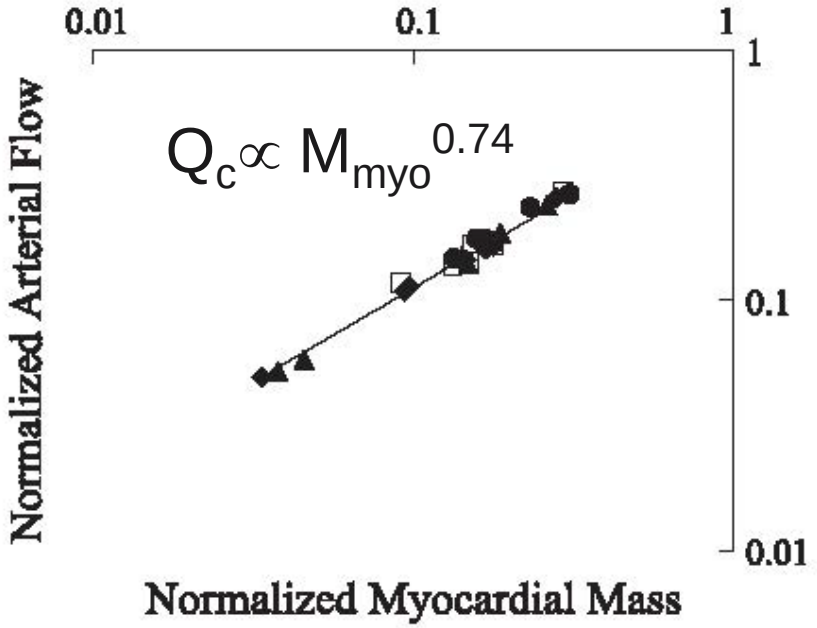
Left Ventricle Myocardial Volume can be extracted from CT data and used to compute average total coronary blood flow at rest

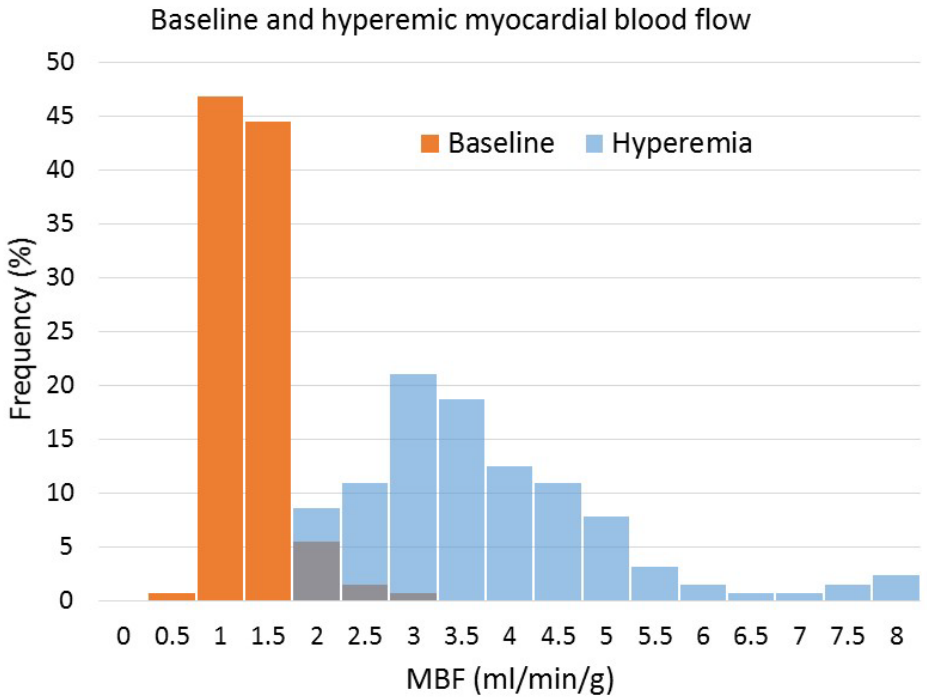
Taylor et al. JACC 2013, 61:2, 2233-41.

Scientific Principle #1

Baseline coronary blood flow is proportional to myocardial mass

Data from animal studies and perfusion imaging demonstrates that baseline coronary blood flow is indeed proportional to myocardial mass





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Choy et. al., J Appl Physiol, 2008.

Adapted from Danad et. al., Eur J Nucl Med Mol Imaging. 2012

Scientific Principle #1

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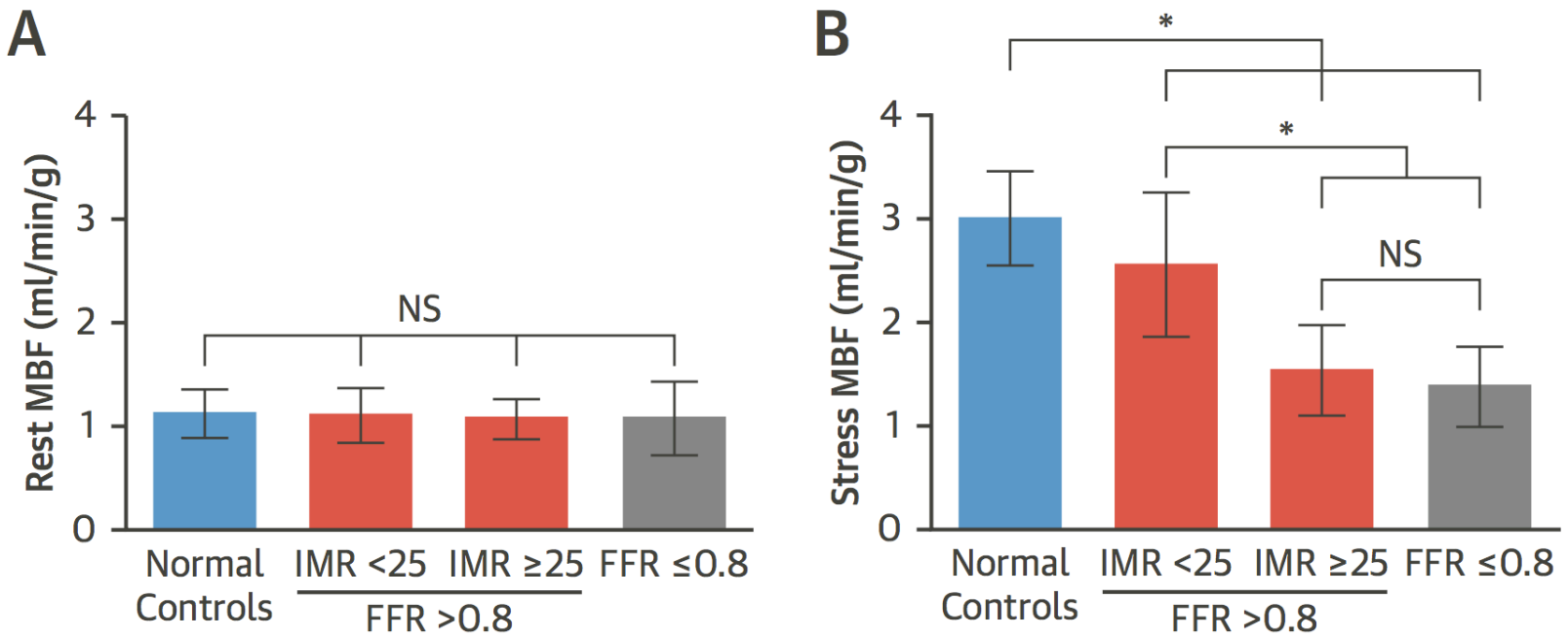

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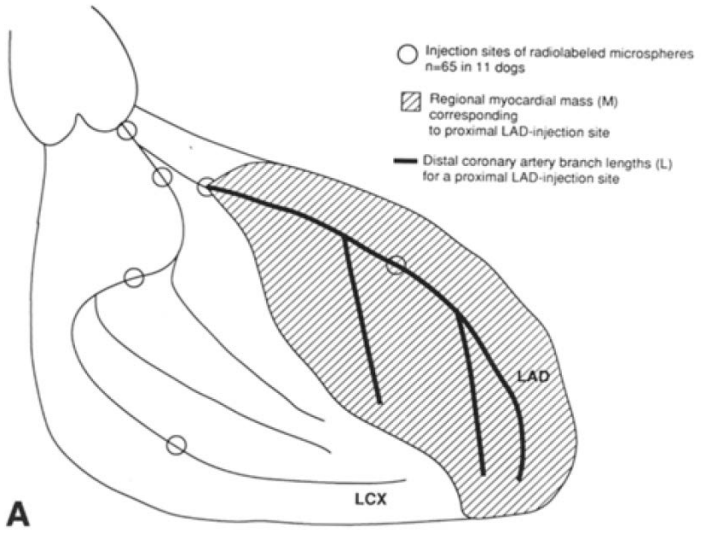
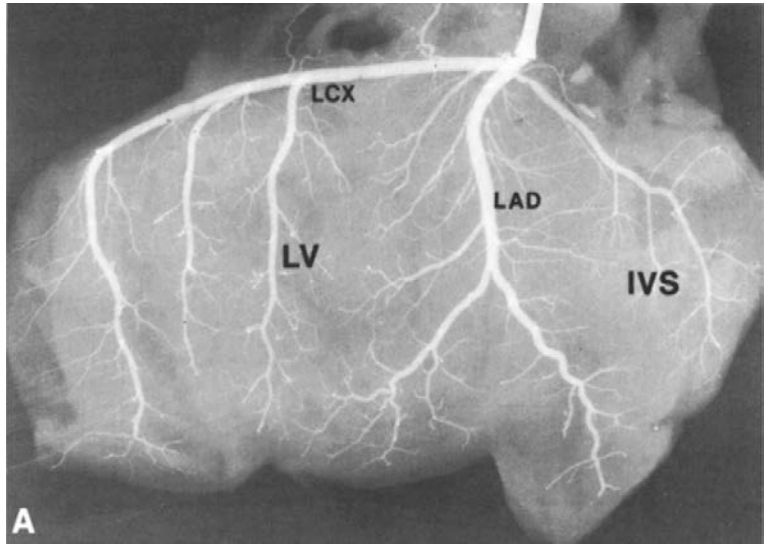
Liu et. al., J Am Coll Cardiol 2018;71:969–79

Scientific Principle #2

Resistance of microcirculatory vascular bed at rest is inversely proportional to size of feeding vessel





"there is a curvilinear relation between coronary artery lumen area and dependent regional myocardial mass comparable to that in humans, reflecting fundamental physical principles underlying the structure of the coronary artery tree".

Seiler, C., R.L. Kirkeeide, and K.L. Gould, *Measurement from arteriograms of regional myocardial bed size distal to any point in the coronary vascular tree for assessing anatomic area at risk.* J Am Coll Cardiol, 1993. **21**(3): p. 783-97.

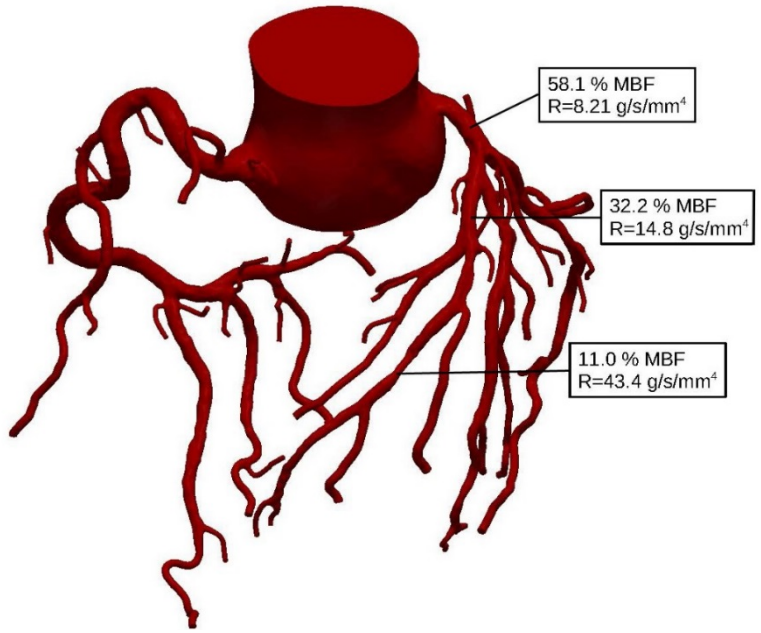
Myocardial Perfusion territory ⇒ Coronary Artery Flow ⇒ Coronary Artery Size

Therefore, coronary artery size is related to coronary artery flow

Scientific Principle #2

Resistance of microcirculatory vascular bed at rest is inversely proportional to size of feeding vessel

1. Healthy and diseased vessels adapt to amount of flow they carry
2. Power law relationships of form $Q \propto d^k$ apply to different vascular beds – including coronary arteries
3. Since mean pressure (P) is essentially constant down the length of the coronary arteries at rest, $R \propto \mathbf{d^{-k}}$

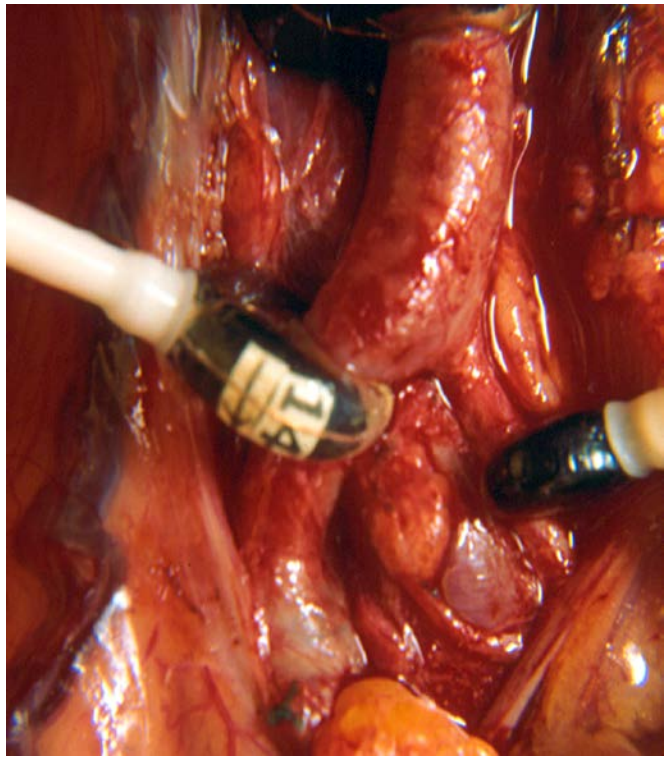


Vascular Bed	Power law exponent, k	Species	Reference
Coronary	2.7±1.3 (N=57)	Human	Hutchins et al., Circ Res, 38;572-576, 1976
Coronary	2.7 (N=5)	Porcine	Zhou et al. Phys Med Biol,47: 977–993, 2002
Cerebral	2.9±1.2 (N=47)	Human	Ingebrigtsen et al. Neurosurg 101:108–113, 2004
Cerebral	2.9±0.7 (N=157)	Human	Rossitti and Lofgren, Stroke 24:371-377, 1993
Brachial	2.75 (N=56)	Human	Wang et al. Ultrasound Med Biol, in press, 2011

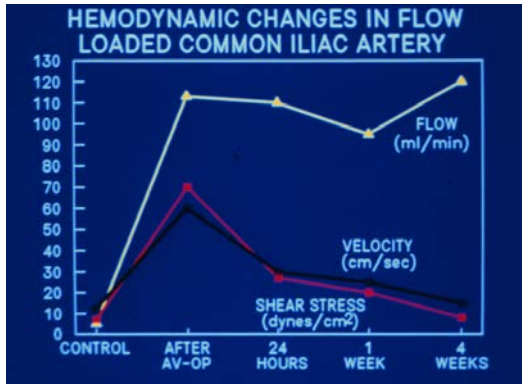
Scientific Principle #2

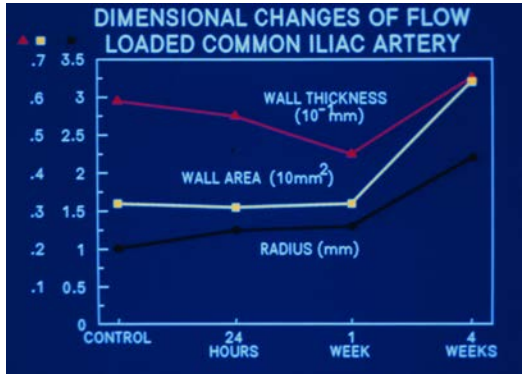
Resistance of microcirculatory vascular bed at rest is inversely proportional to size of feeding vessel

Evidence for shear stress autoregulation theory - Zarins et al. AV-fistula models



Rabbit iliac artery enlarged after AVF





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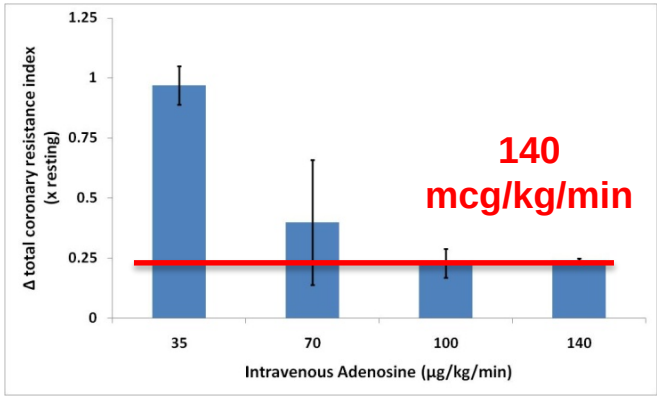
Zarins CK, Zatina MA, Giddens DP, Ku DN, Glagov S. Shear stress regulation of artery lumen diameter in experimental atherogenesis. J Vasc Surg 5(3): 413-420, 1987

Scientific Principle #3

Predictable microcirculatory response to adenosine

1. When the heart lacks O_2, breakdown of ATP results in release of Adenosine → vasodilation
2. Exogenous administration of Adenosine elicits the maximum hyperemic response by forcing complete smooth muscle cell relaxation
3. Standard of care for induction of hyperemia in non-invasive tests and the cath lab

Adenosine relaxes smooth muscle cells lining arterioles resulting in vasodilation



Intravenous administration of adenosine elicits remarkably consistent vasodilatory response in normal subjects at sufficient doses

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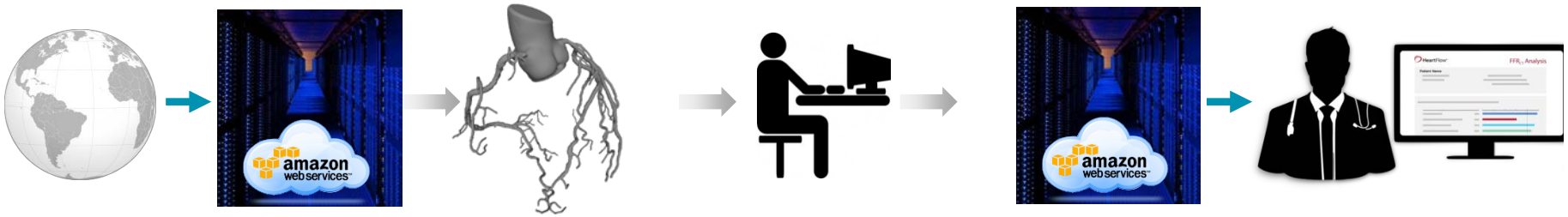
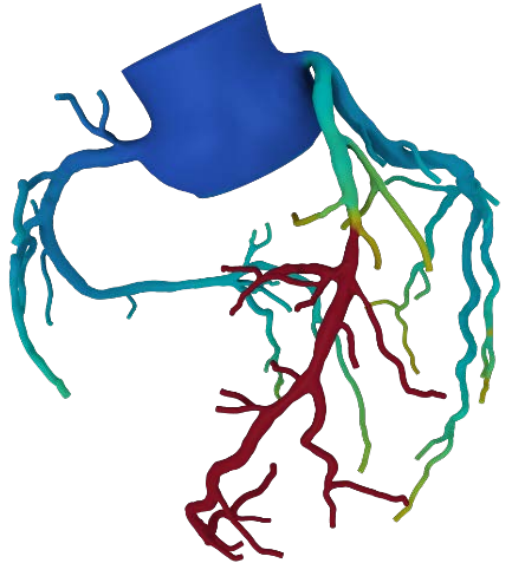
Adapted from Wilson, et. al., Circulation 1990

FFR_{CT} Process



- A standard cardiac **CT scan** is performed and the data is uploaded to HeartFlow via AWS
- HeartFlow proprietary software, using **deep learning**, creates a **personalized, digital 3D model of the coronary arteries.** Model is then inspected and corrected by HeartFlow analysts
- **Powerful computer algorithms** solve incompressible Navier-Stokes equations to assess the impact of coronary artery disease
- Physicians **interrogate the model and interpret the FFR_{CT} results** to assess, vessel-by-vessel, if sufficient blood is reaching the heart



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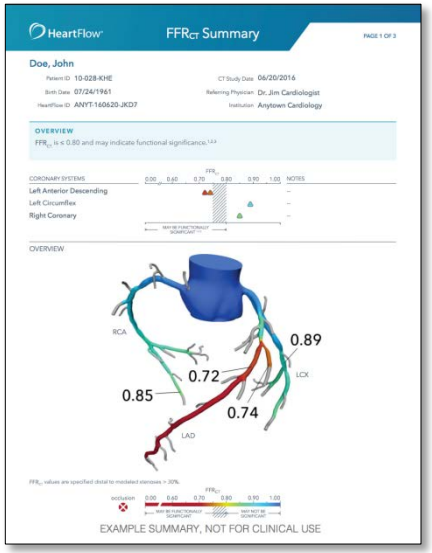
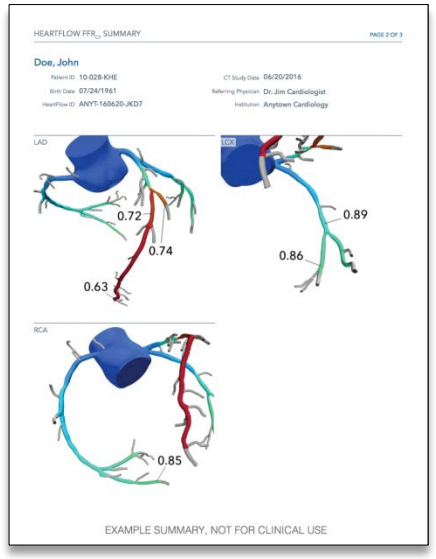
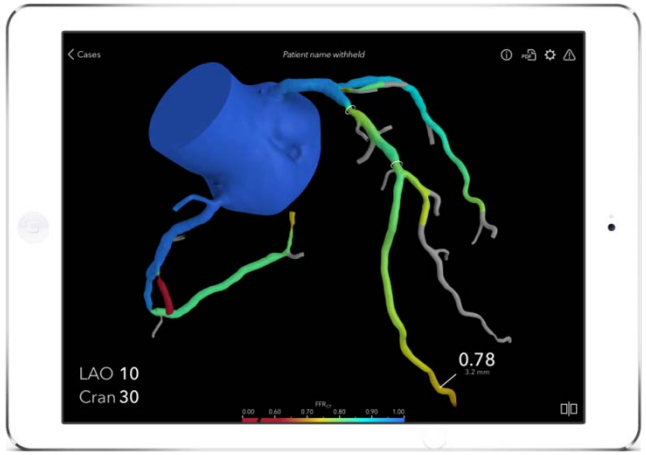
Accessing FFR_{CT} results







High Accuracy of FFR_{CT} Compared to Invasive FFR gold standard

DISCOVER-FLOW

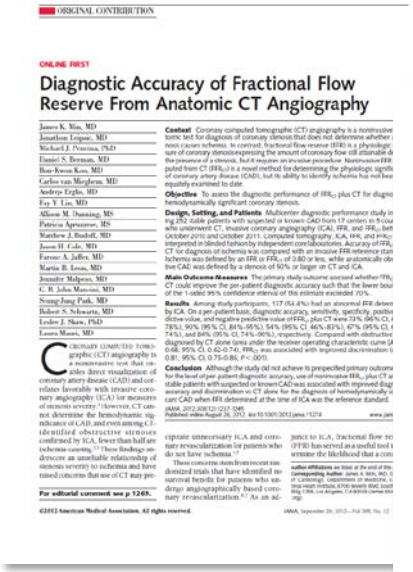
- Completed 2011
- N=103 patients


Diagnosis of Ischemia-Causing Coronary Stenoses by Noninvasive Fractional Flow Reserve Computed From Coronary Computed Tomographic Angiogra

Results From the Prospective Multicenter DISCOVER-FLOW (Diagnosis of Ischemia-Causing Stenoses Obtained Via Noninvasive Fractional Flow Reserve) Study

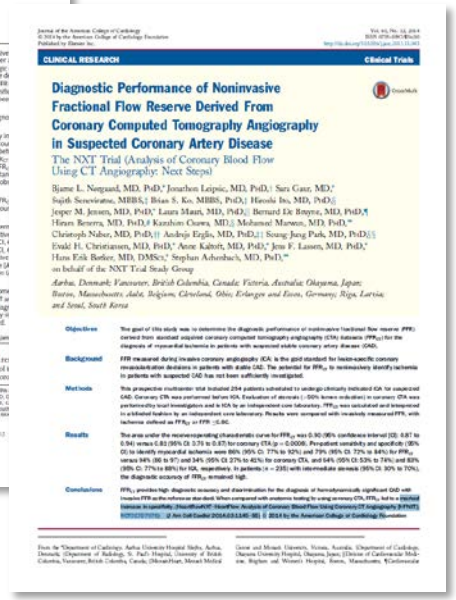
DeFACTO

- Completed 2012
- N=252 patients


Diagnostic Accuracy of Fractional Flow Reserve From Anatomic CT Angiography

NXT

- Completed 2013
- N=254 patients


Diagnostic Performance of Noninvasive Fractional Flow Reserve Derived From Coronary Computed Tomography Angiography in Suspected Coronary Artery Disease

The NXT Trial (Analysis of Coronary Blood Flow Using CT Angiography: Next Steps)

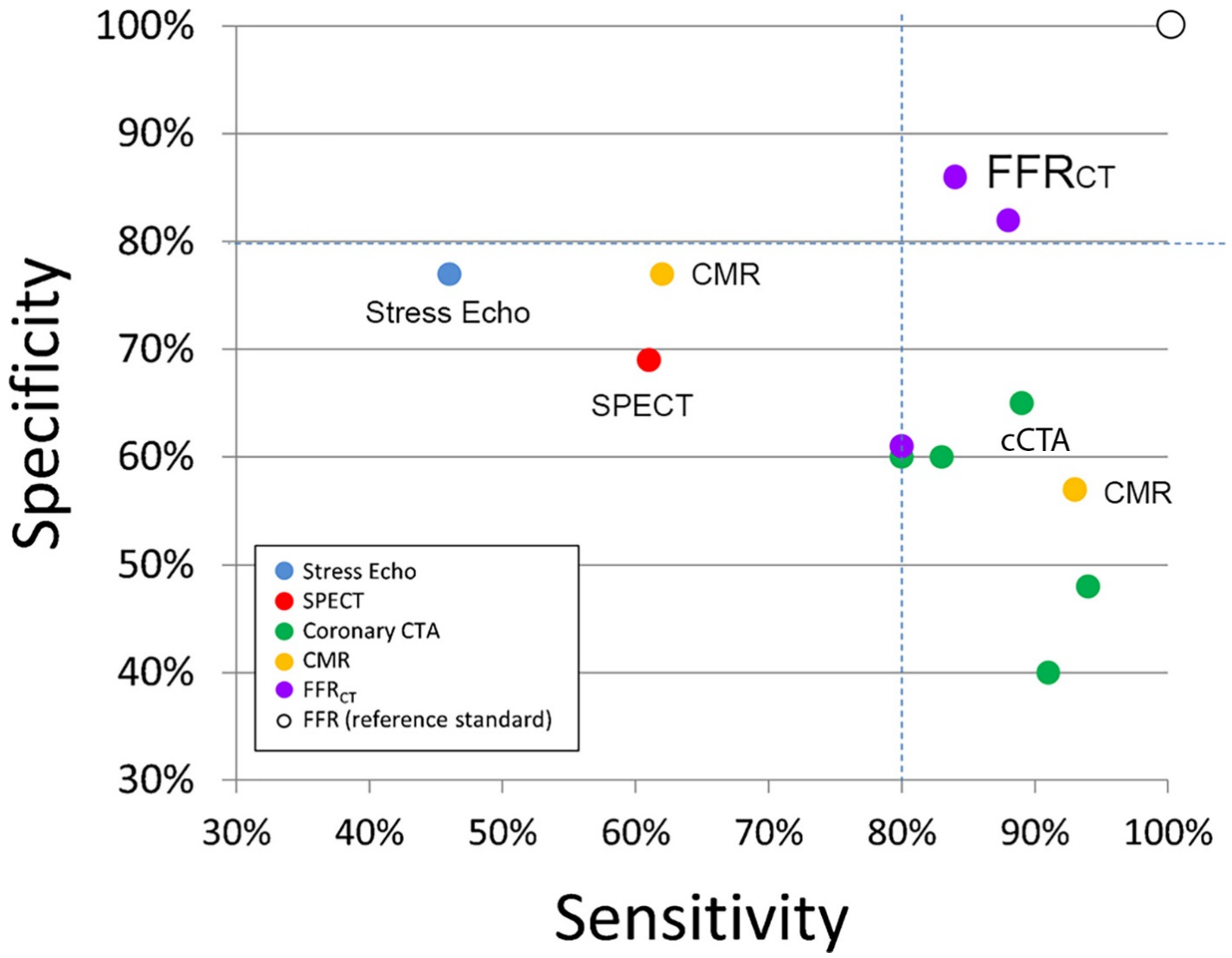
NXT Per-Vessel Performance

- Specificity: 86%
- Sensitivity: 84%
- Accuracy: 86%

NXT data supported 2014 FDA Clearance

Koo et al, JACC 2011.
Min et al, JAMA 2012.
Norgaard et al, JACC 2014.

Performance of Coronary Diagnostic Tests for Lesion-specific Ischemia



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Nørgaard, et al., Euro Radiology 2015; 25(8): 2282-90. Based on Figure 3.

Factors affecting concordance between FFR_{CT} and FFR

Patient-based

1. **Low-Intermediate vs. high pre-test likelihood of disease**
2. **Patient's responsiveness to vasodilator during measured FFR**

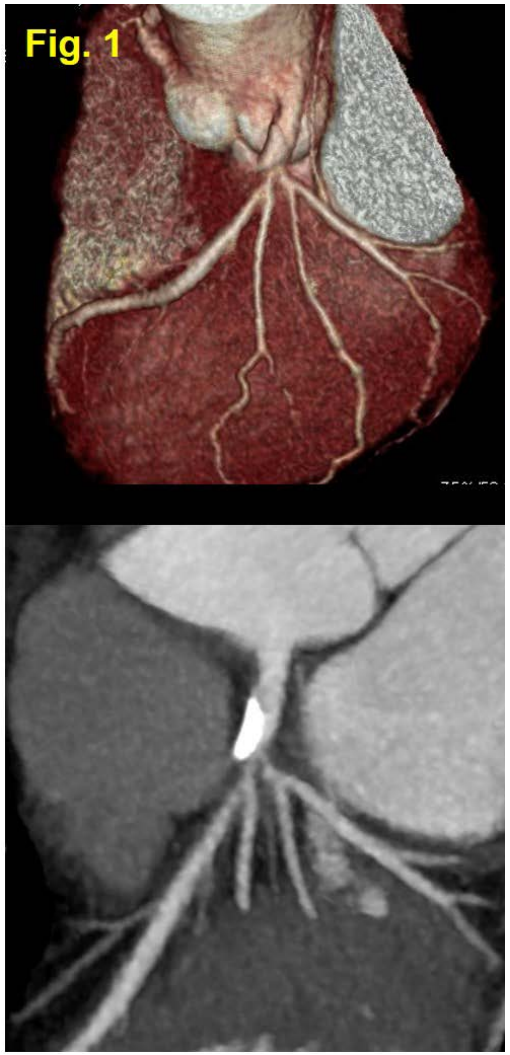
Experimental

1. **Differences in patient state between time of cCTA and cardiac catheterization, esp. nitrate protocol**
2. **Image quality**
3. **Quality of FFR measurement, e.g. calibration protocol**

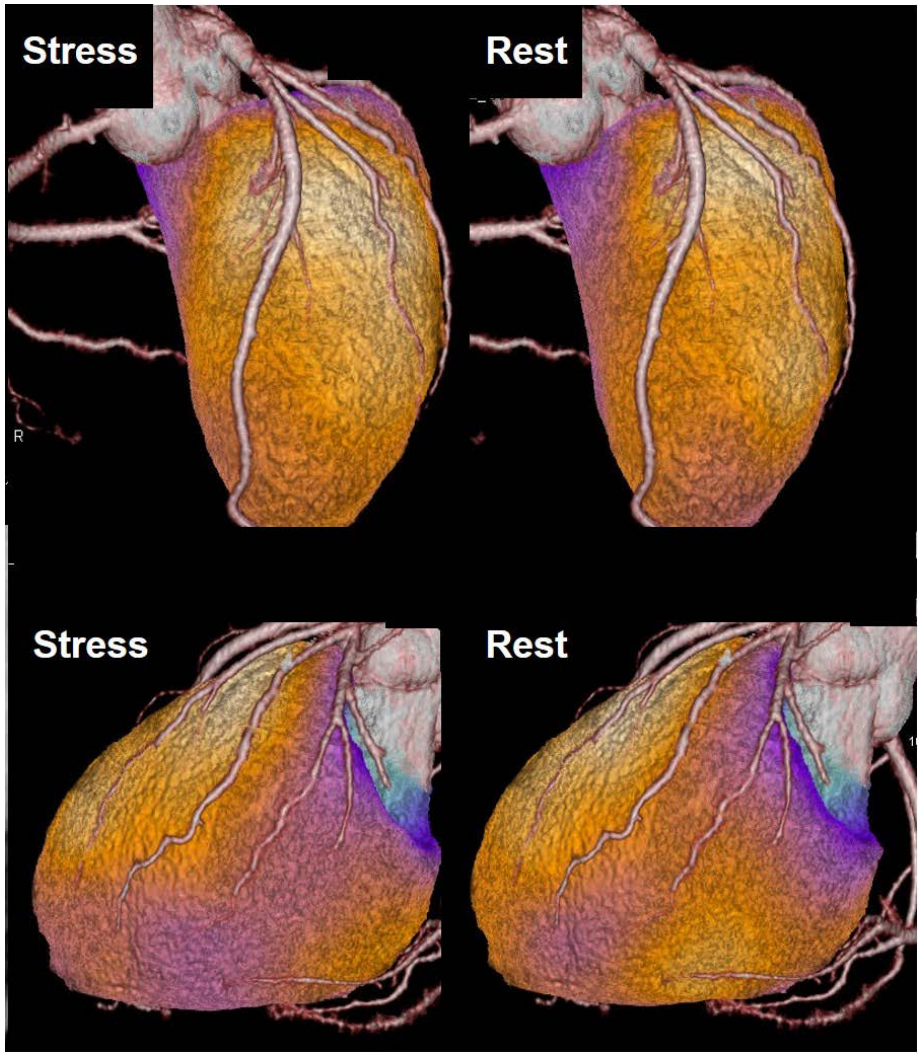
Methodologic

1. **Fidelity of CT-derived anatomic model to actual patient**
2. **Quality of (population-derived) physiologic model and appropriateness of application to individual patient**
3. **Flow calculation method, e.g. 3D vs 1D**
4. **Process for matching FFR_{CT} prediction with measurement locations**

Does this patient have coronary artery disease and if so how should it be treated?

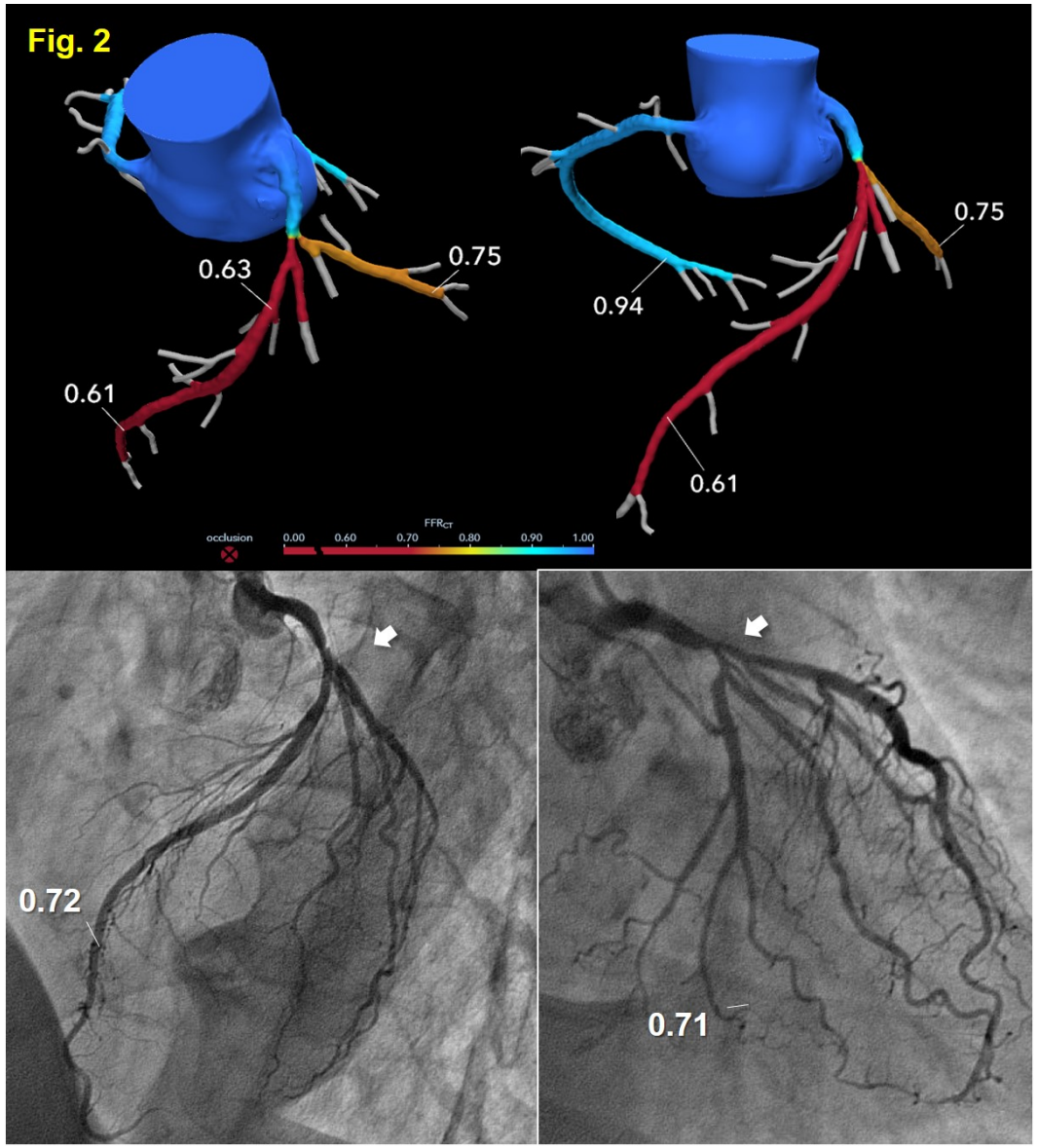


CT positive



SPECT read as negative

Does this patient have coronary artery disease and if so how should it be treated?



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PLATFORM - Prospective clinical utility trial

PLATFORM

FFR_{CT}-Guided Strategy

vs.

Usual Care

ORIGINAL INVESTIGATIONS

1-Year Outcomes of FFR_{CT}-Guided Care in Patients With Suspected Coronary Disease

The PLATFORM Study

FASTTRACK
ESC Hot Line

Douglas, et al. EHJ 2015.
Hlatky, et al. JACC 2015.
Douglas, et al. JACC 2016.

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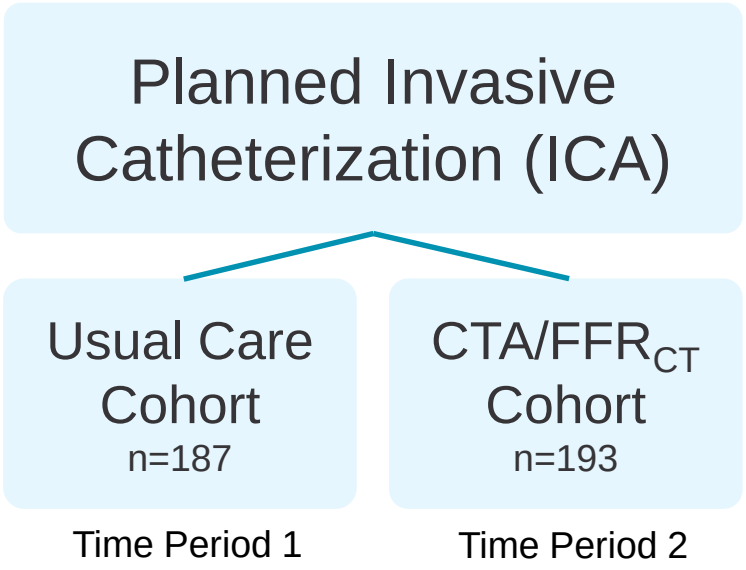
Trial Design

- **P**rospective **L**ongitudin**A**l **T**rial of **F**FR$_{CT}$: **O**utcome and **R**esource I**M**pacts
  - Prospective, controlled, pragmatic comparative effectiveness trial utilizing a comparative cohort design
  - Comparing the effectiveness of two distinct clinical strategies
  - 584 patients with suspected CAD (pre-test likelihood of 20-80%) were enrolled at 11 centers in 6 EU countries

- **Primary Endpoint:** For patients with a planned ICA
  - Are patients evaluated using a **CTA/FFR$_{CT}$ guided strategy** less likely to undergo ICAs that show **no obstructive CAD**?



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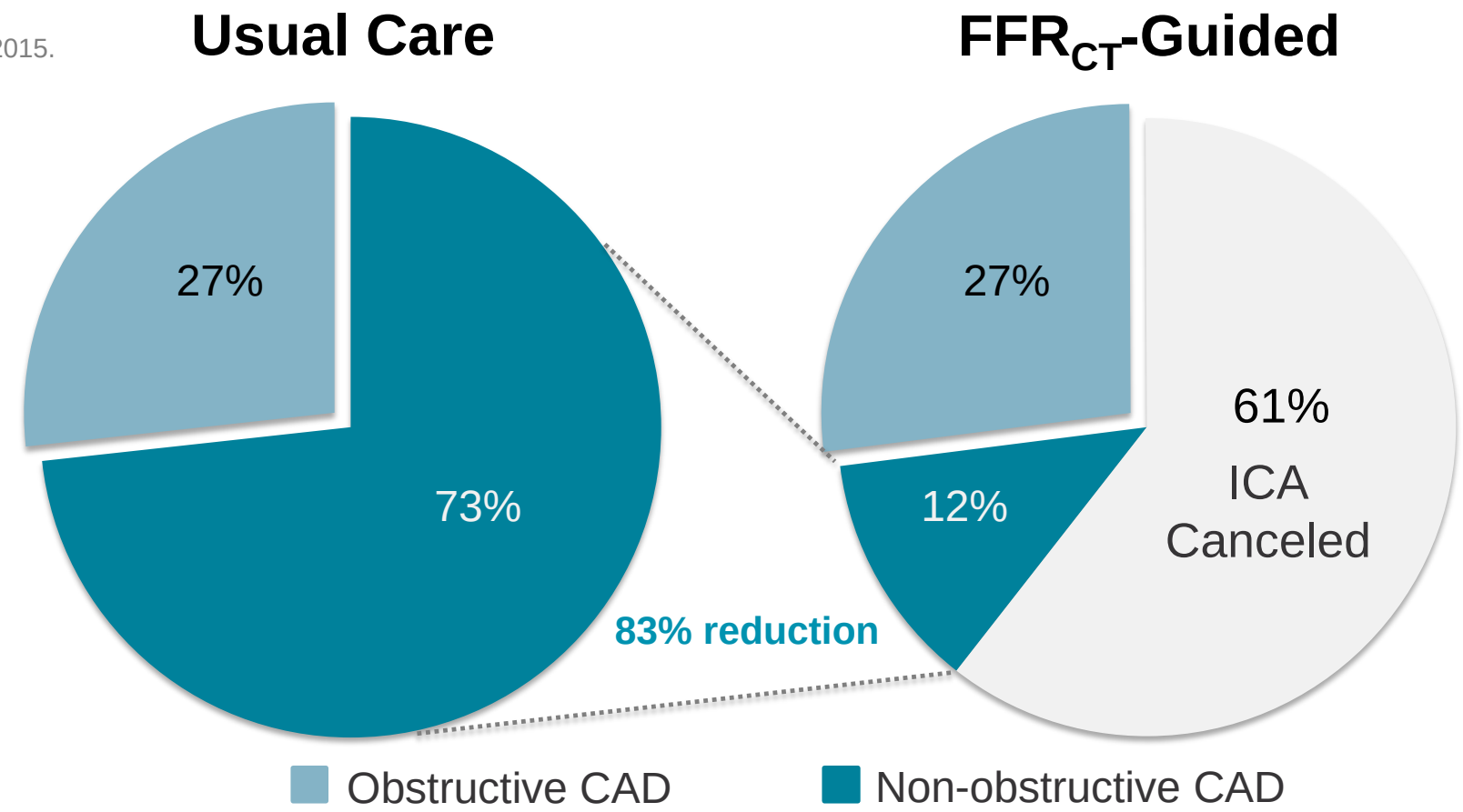
Dramatic Reduction in Invasive Catheterization (ICA) with No Obstructive Disease

Douglas, et al. EHJ 2015.



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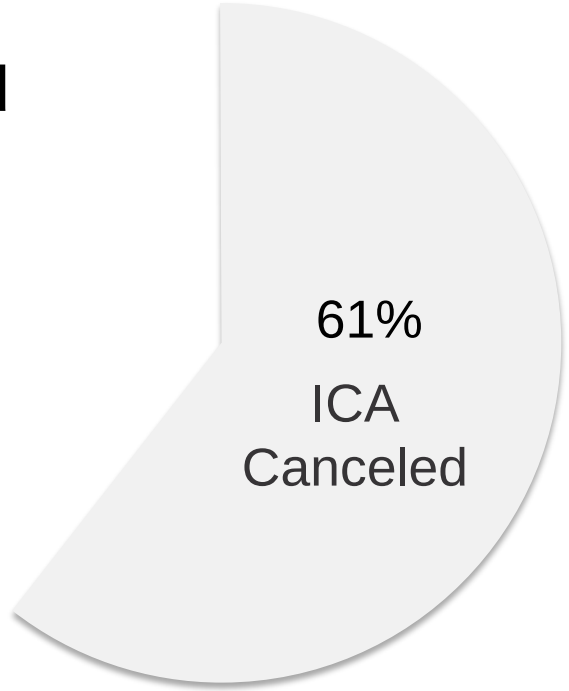
Proven Safety with Durable Results **through 1 Year**

Douglas, et al. JACC 2016.

No adverse clinical events occurred in any of the 117 patients whose ICA was canceled based on the findings from a FFR_{CT} guided strategy.



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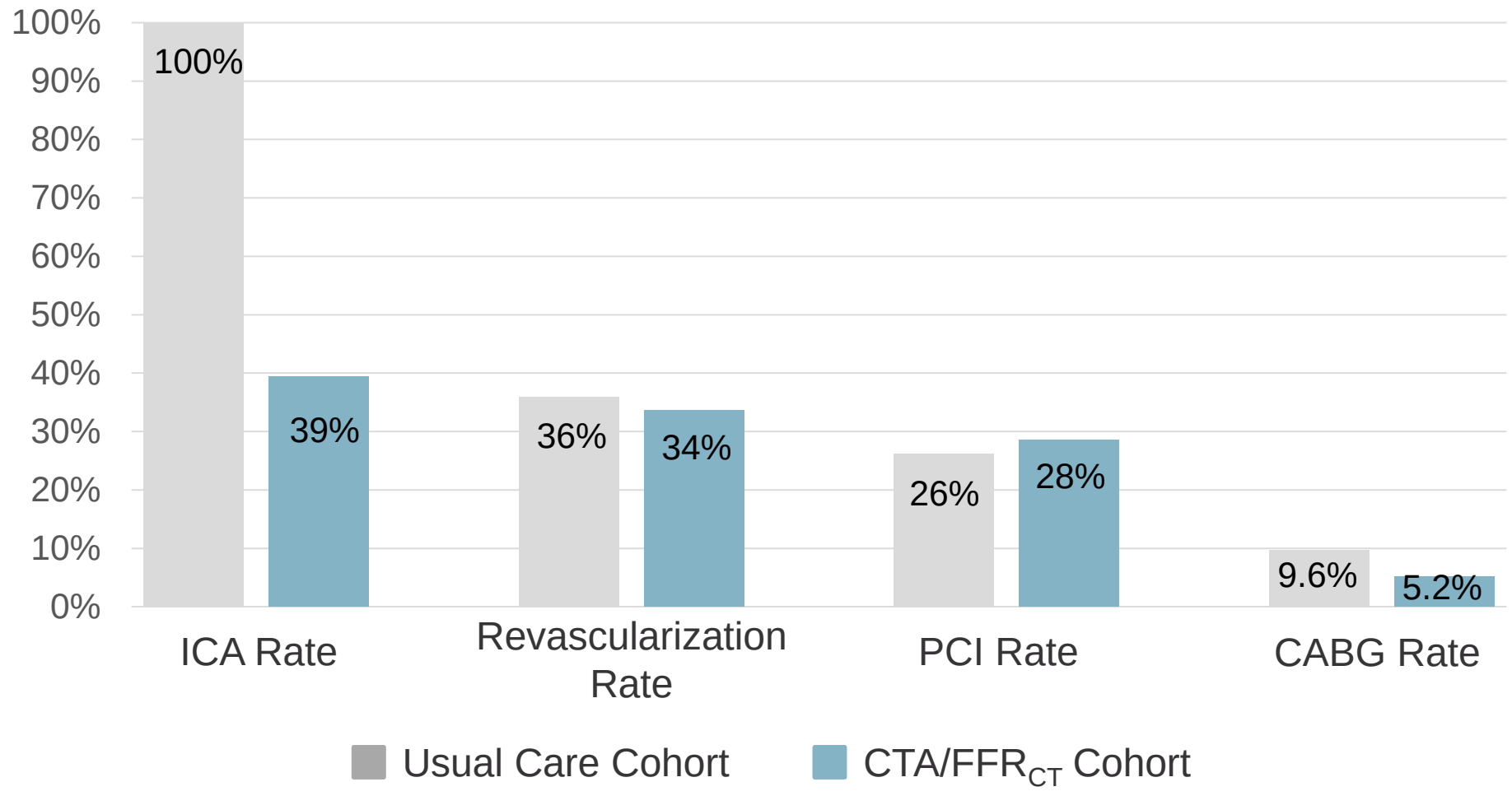
No Difference in Revascularization Rates in Patients with a Planned ICA



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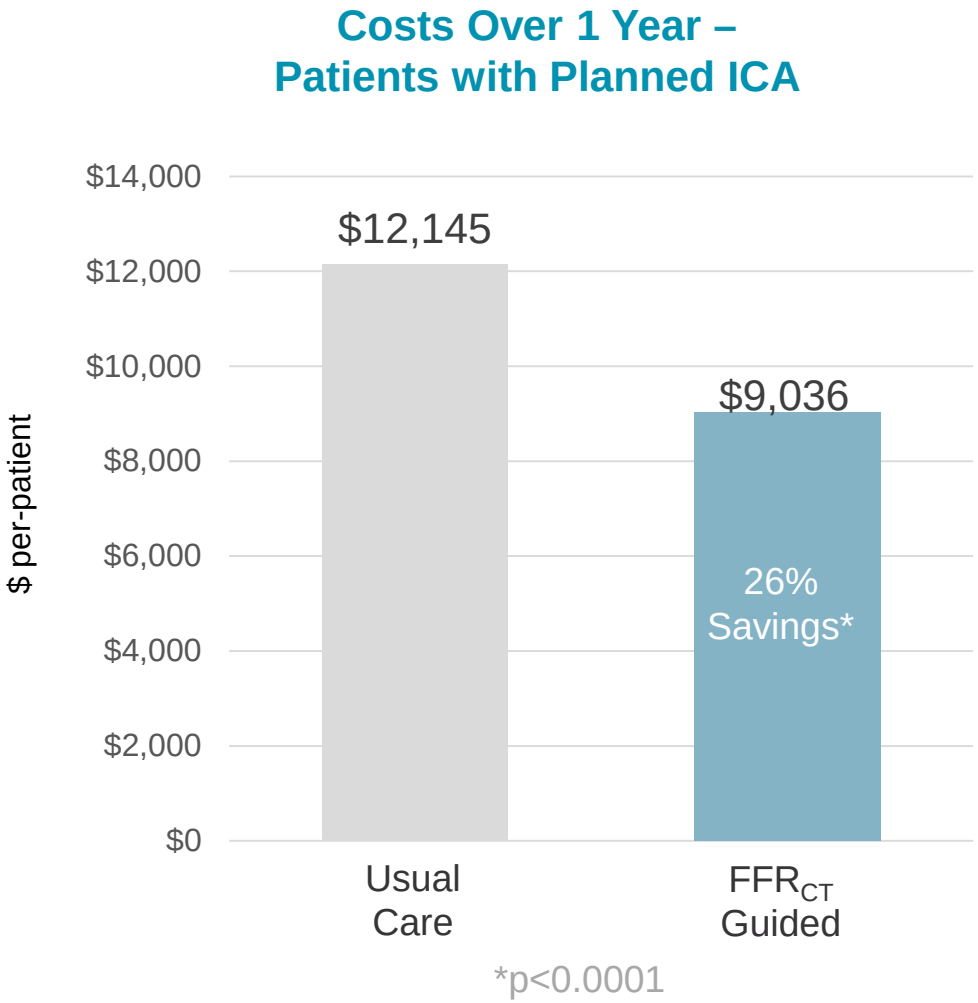
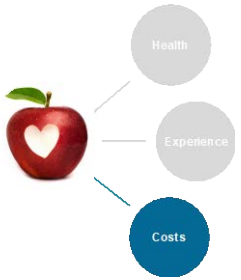
Douglas, et al. JACC 2016.

Significant Savings to the Healthcare System



Cost savings of 26% to the health system after accounting for the cost of the HeartFlow Analysis.



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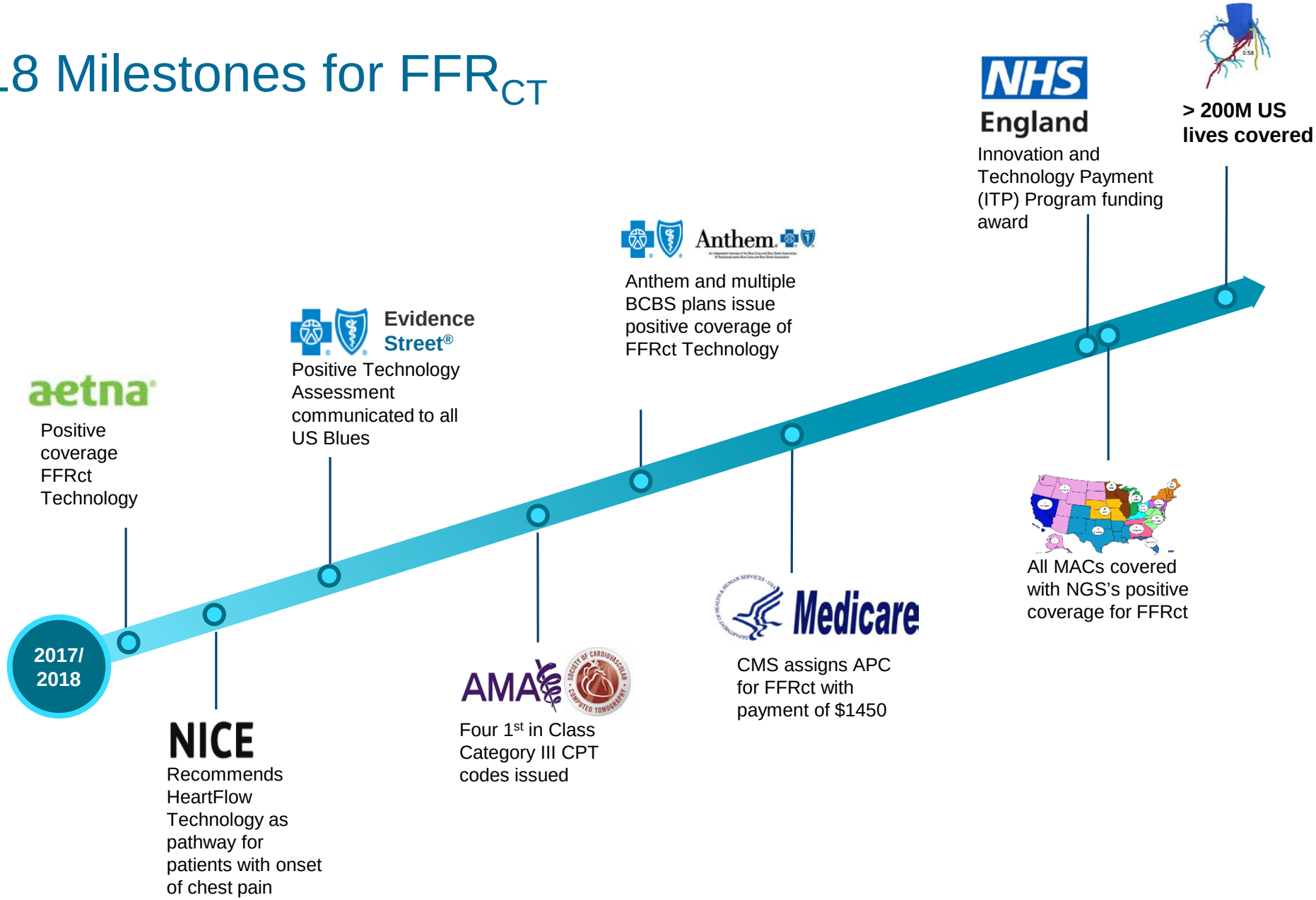
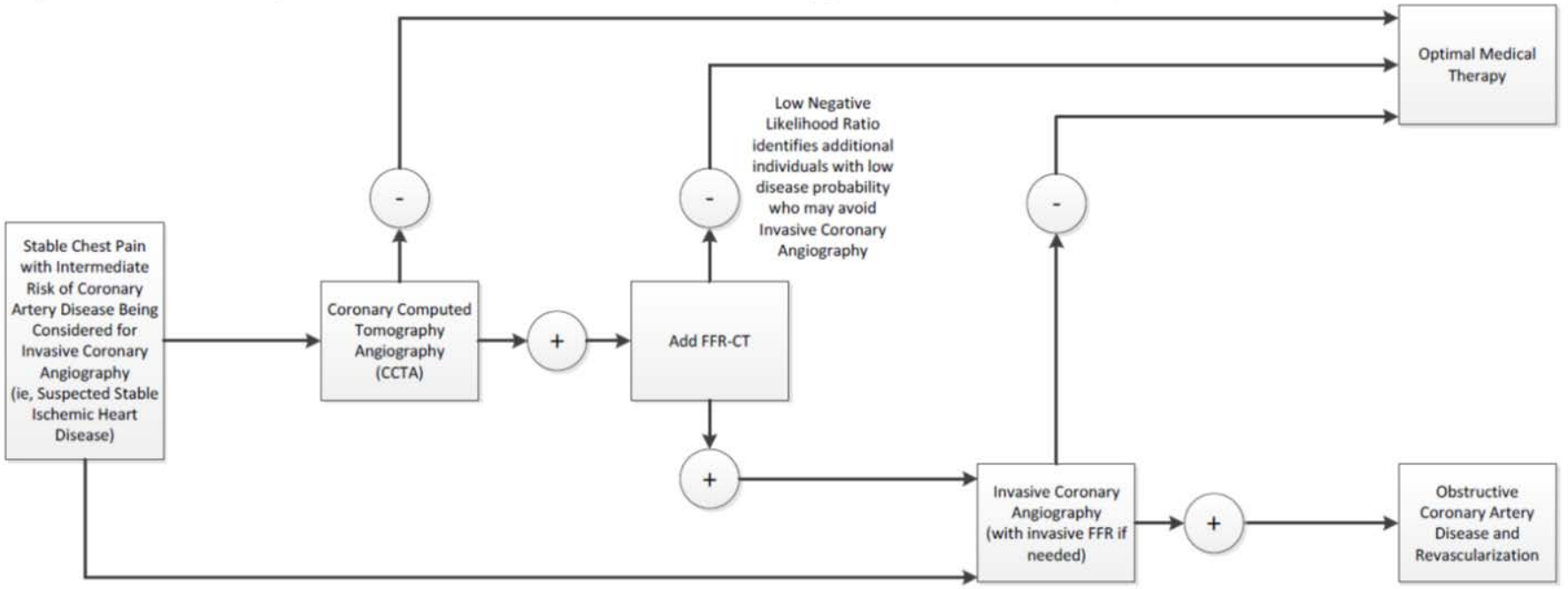
Douglas, et al. JACC 2016.

2017/18 Milestones for FFR_{CT}



BCBS Evidence Street Pathway

Figure 1. Pathway for Clinical Use of FFR-CT to Support Clinical Utility



FFR-CT: fractional flow reserve using coronary computed tomography angiography.

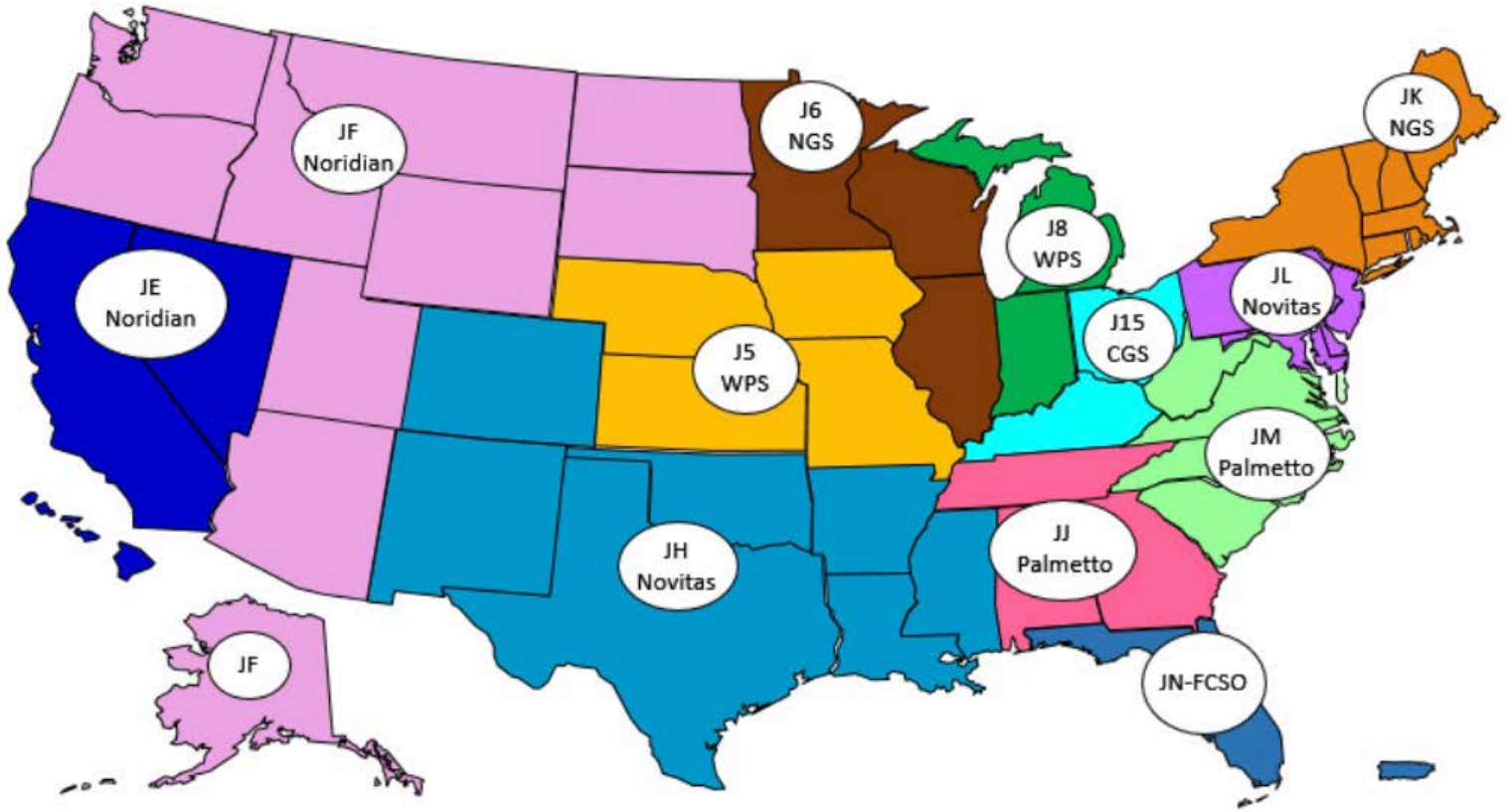
BlueCross BlueShield Association

Evidence Street®
Where the Market Meets Evidence

"Coronary Computed Tomography Angiography With Selective Noninvasive Fractional Flow Reserve," BCBSA Evidence Street Review, June 2017.

Medicare Administrative Contractors (MACs)

- CMS final rule assigned CPT 0503T to a New Tech APC for payment of $1450.50 effective January 1, 2018
- Since then, Palmetto, NGS, WPS have issued positive coverage decisions
- Novitas (OK MAC) has been paying for FFR_{CT} on a claim-by-claim basis



>140M Commercial Covered Lives

Nearly all major US health plans provide coverage for the FFR_{CT} Analysis.

HCSC
Health Care Service Corporation

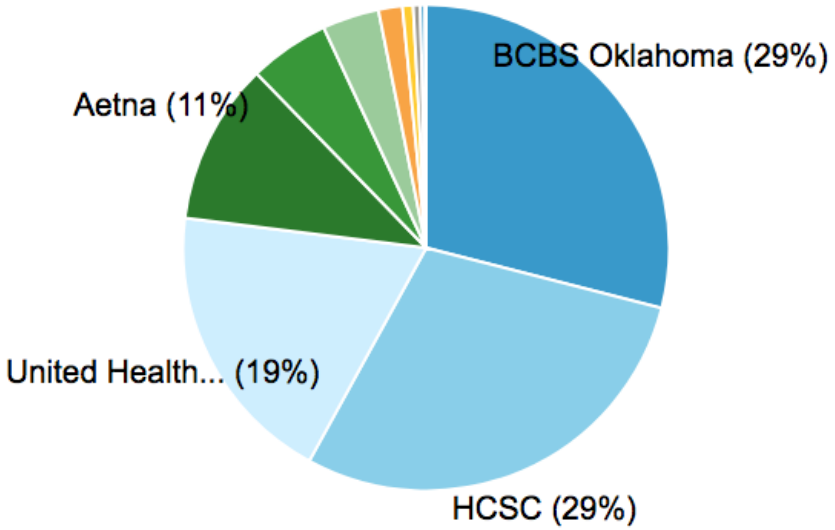
aetna

Cigna

eviCore healthcare
innovative solutions

AIM SpecialtyHealth

Oklahoma Payer Mix



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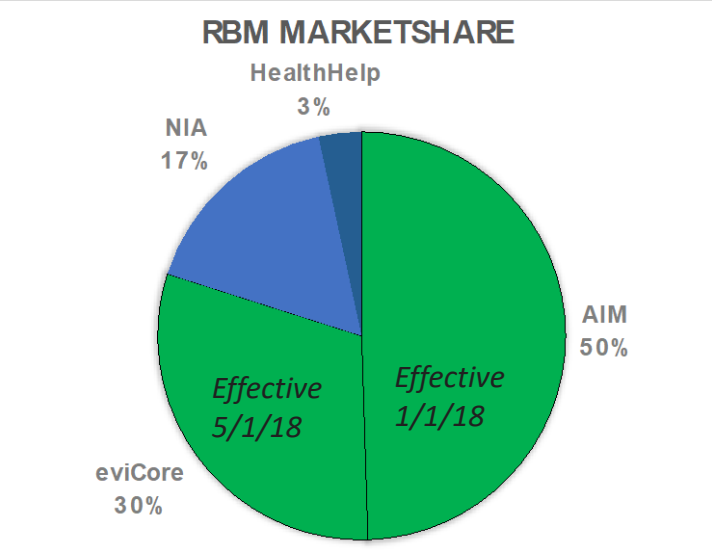
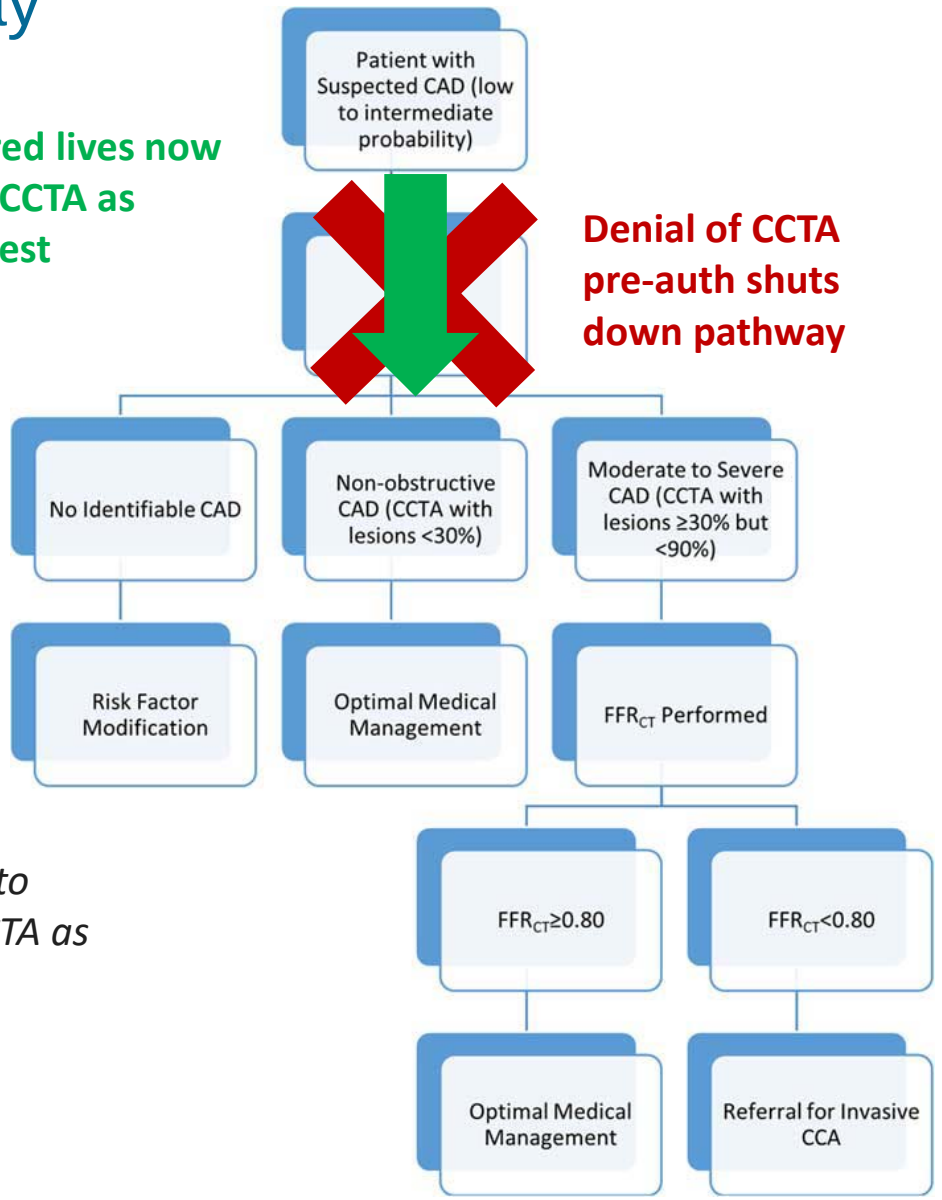
RBMs: Enabling the Clinical Pathway

80% covered lives now authorize CCTA as frontline test



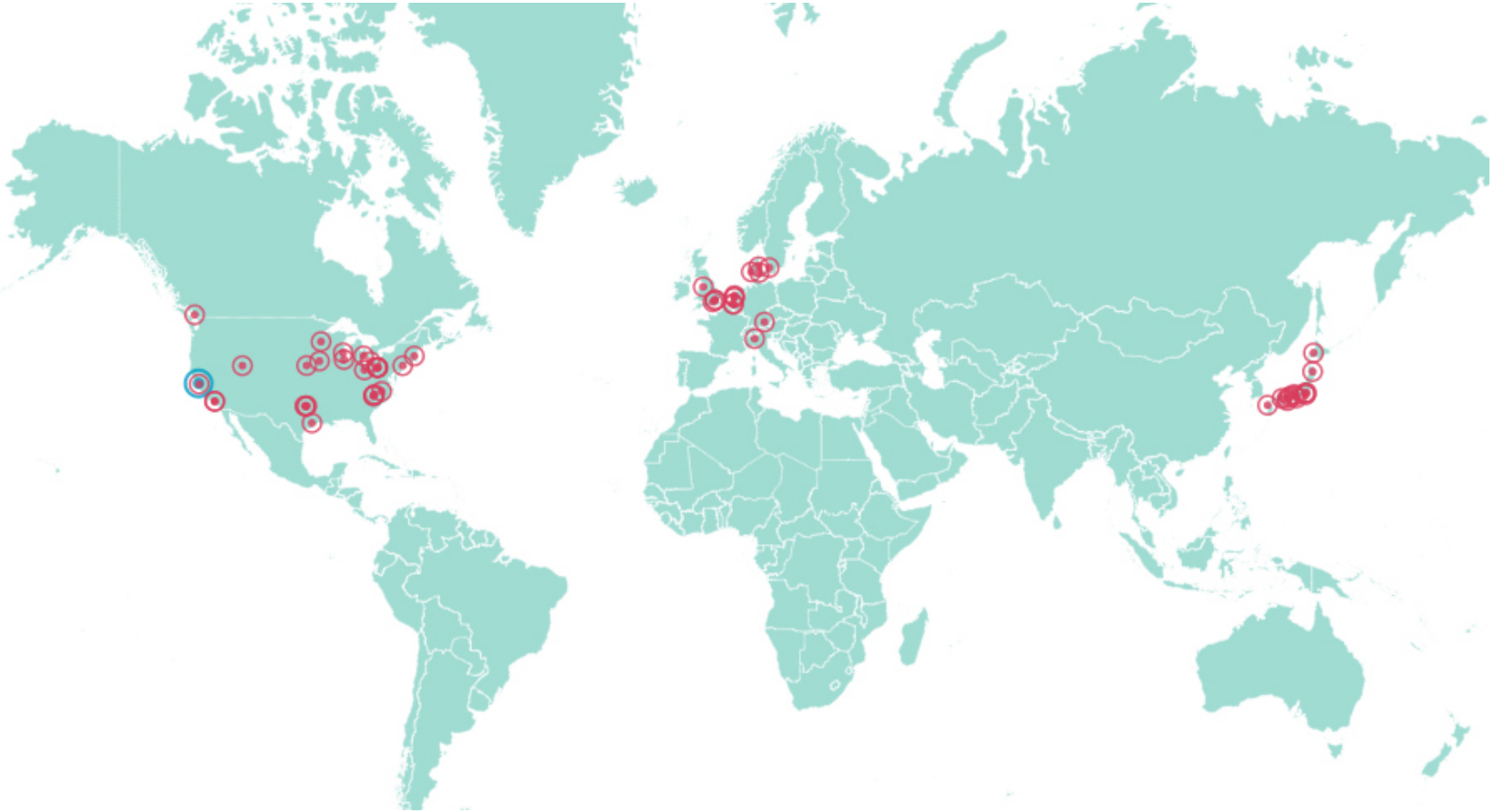
Former RBM policies required stress test prior to coronary CTA. Updated policies now enable CCTA as first test for diagnosing CAD.



Denial of CCTA pre-auth shuts down pathway

J Thorac Imaging 2017

Worldwide Adoption of FFR_{CT}



Approximately 20,000 Patients

have received FFR_{CT} worldwide

What has been learned?

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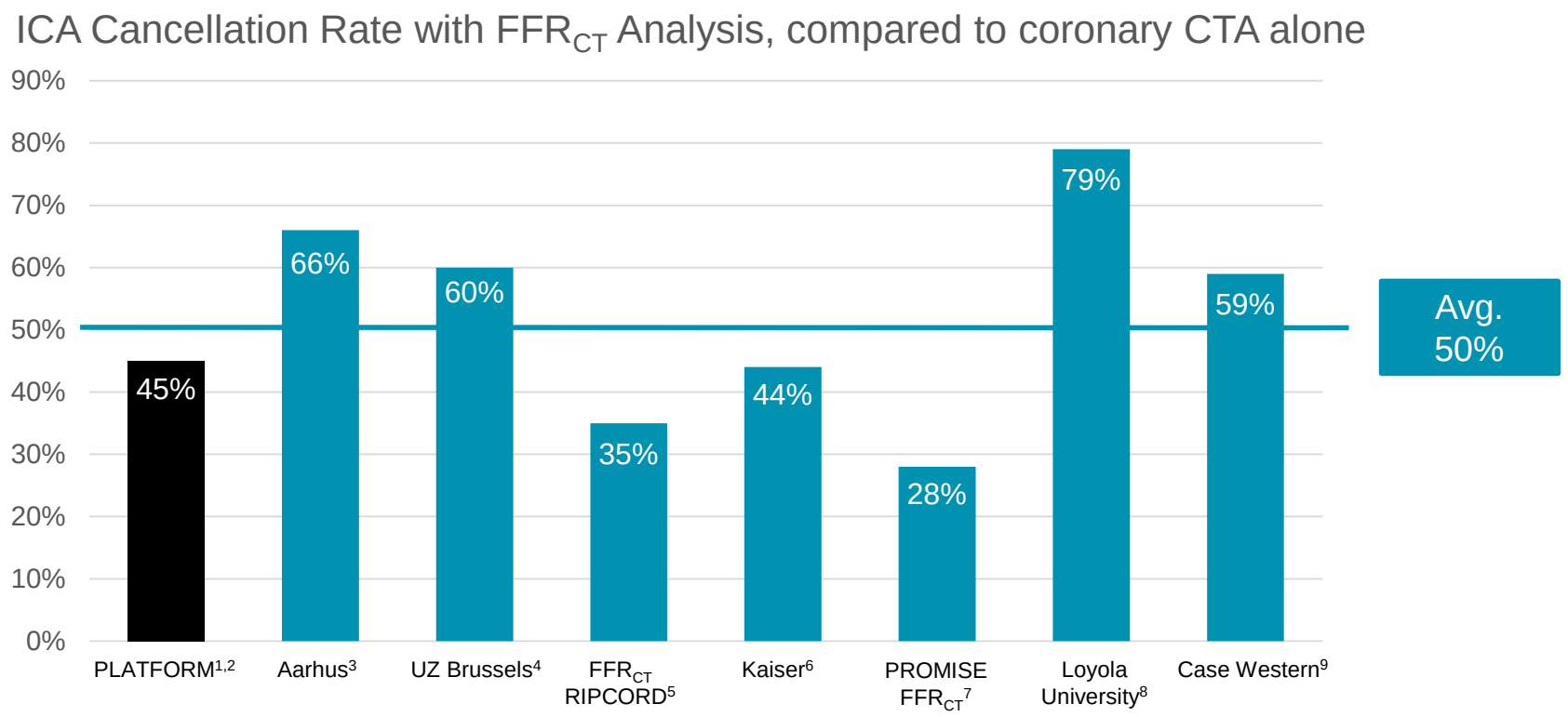
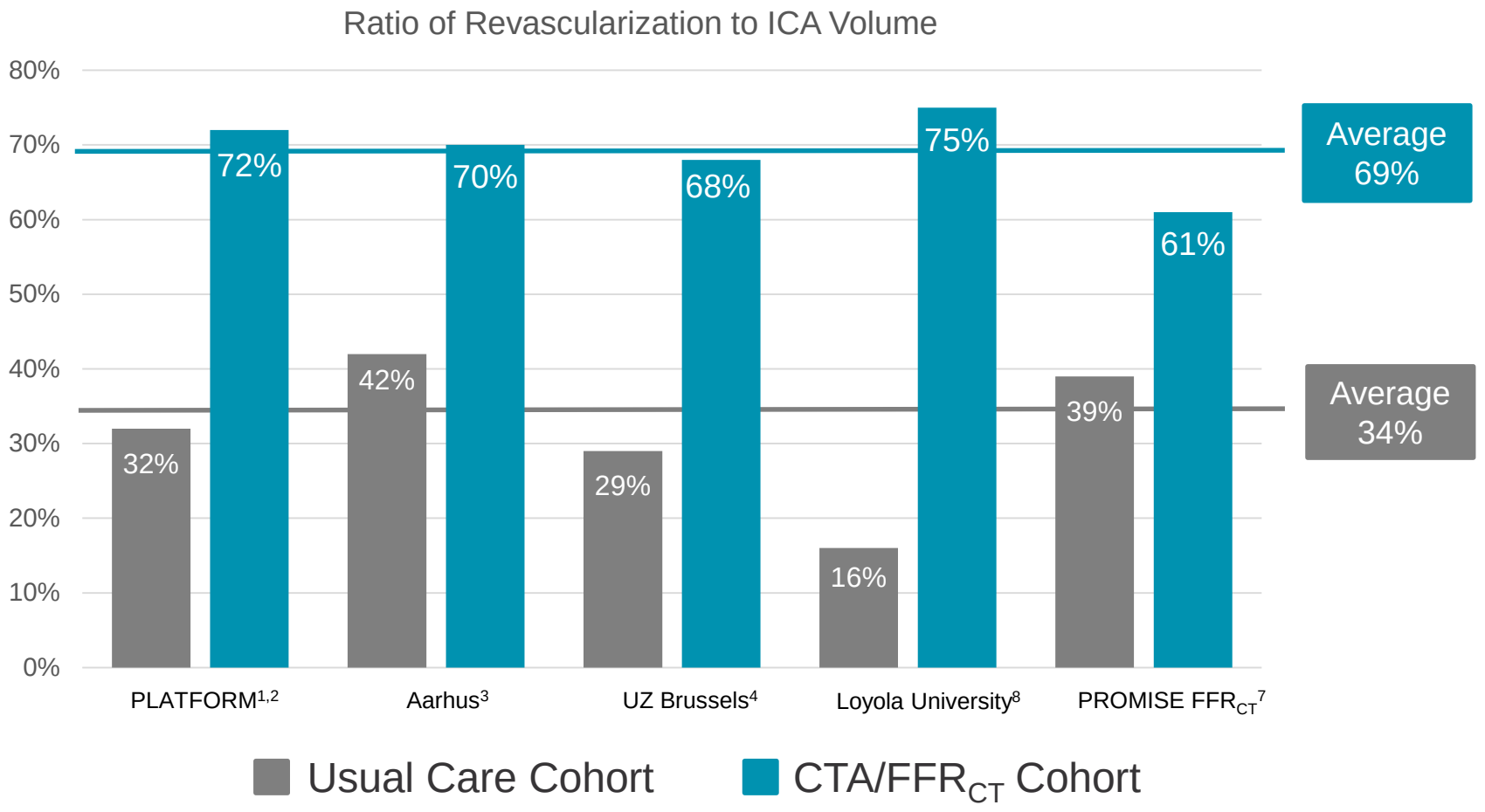
Lesson 1: Use of FFR_{CT} decreases cath rate and increases cath lab efficiency

Adding FFR_{CT} Reduces the Rate of ICAs by 50% on Average



- PLATFORM: Within the FFR_{CT}-guided pathway, 45% of patients who would have been referred to ICA based on coronary CTA results were deferred based on FFR_{CT}

Lesson 1: Use of FFR_{CT} decreases cath rate and increases cath lab efficiency



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n= 745 patients

Lesson 2: Safe to defer patients w/ FFR_{CT} > 0.80

- PLATFORM
  - No adverse clinical events occurred in any of the **117** patients whose ICA was canceled based on the findings from a FFR_{CT} guided strategy.
- Aarhus Real-world clinical experience
  - No adverse cardiac events occurred in any of the **123** patients with ICA cancelled during a median (range) follow-up of 12 (6-18) months
- Advance Registry
  - Zero adverse events seen in patients whose ICA was cancelled (n=**1406**)

Douglas et al. JACC 2016
Norgaard et. al. JACC: CV Imaging 2016

Lesson 3: FFR_{CT} identifies CT-false positive patients

NXT

Per-patient

FFR	Coronary CTA stenosis ≥50%	Coronary CTA stenosis <50%
≤0.80	75 (30%)	5 (2%)
>0.80	115 (45%)	59 (23%)

FFR	FFR_{CT} ≤0.80	FFR_{CT} >0.80
≤0.80	69 (27%)	11 (4%)
>0.80	37 (15%)	137 (54%)

FFR_{CT} reclassified **68%** of CT false positives as true negatives

Nørgaard et al, JACC Vol. 63, No. 12, 2014

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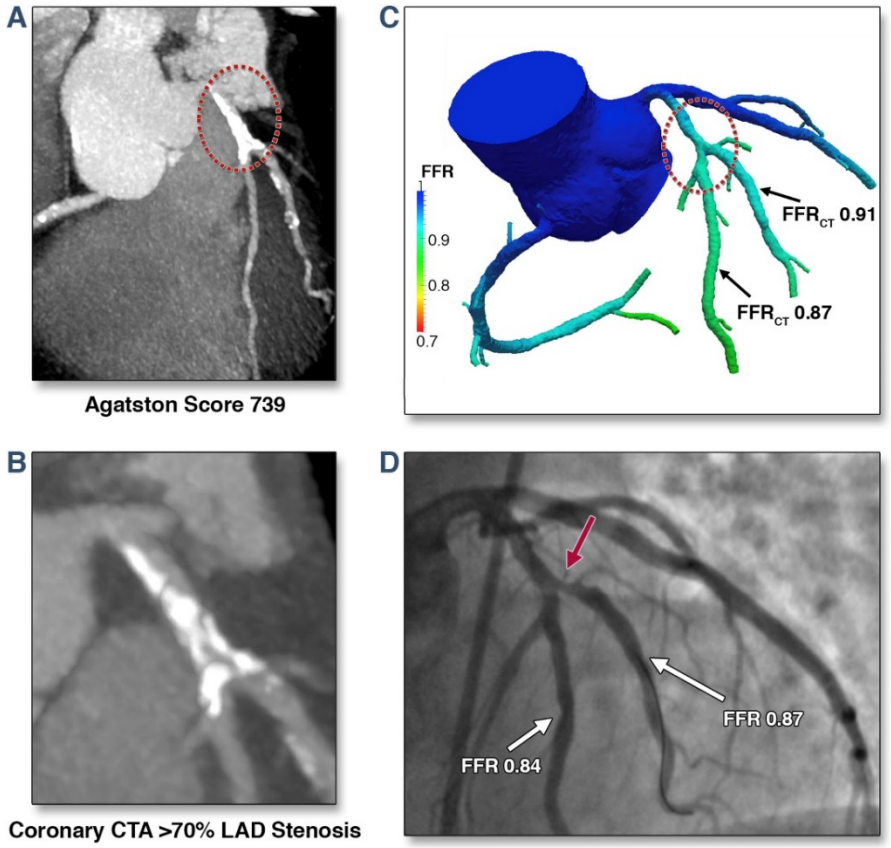
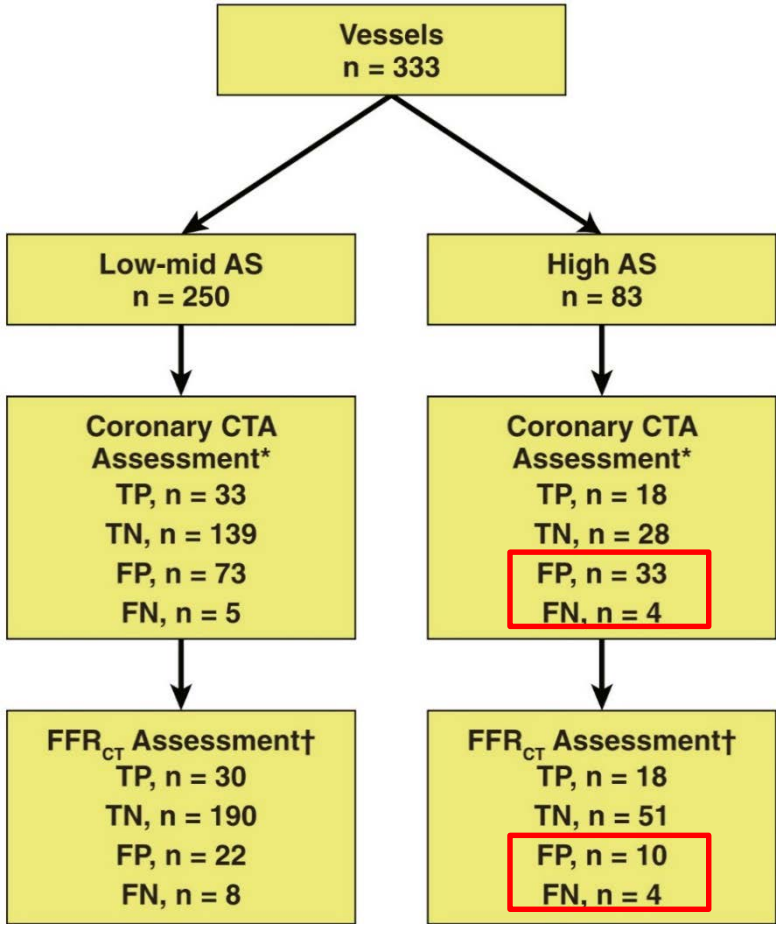
Lesson 4: FFR_{CT} performs well with high calcium

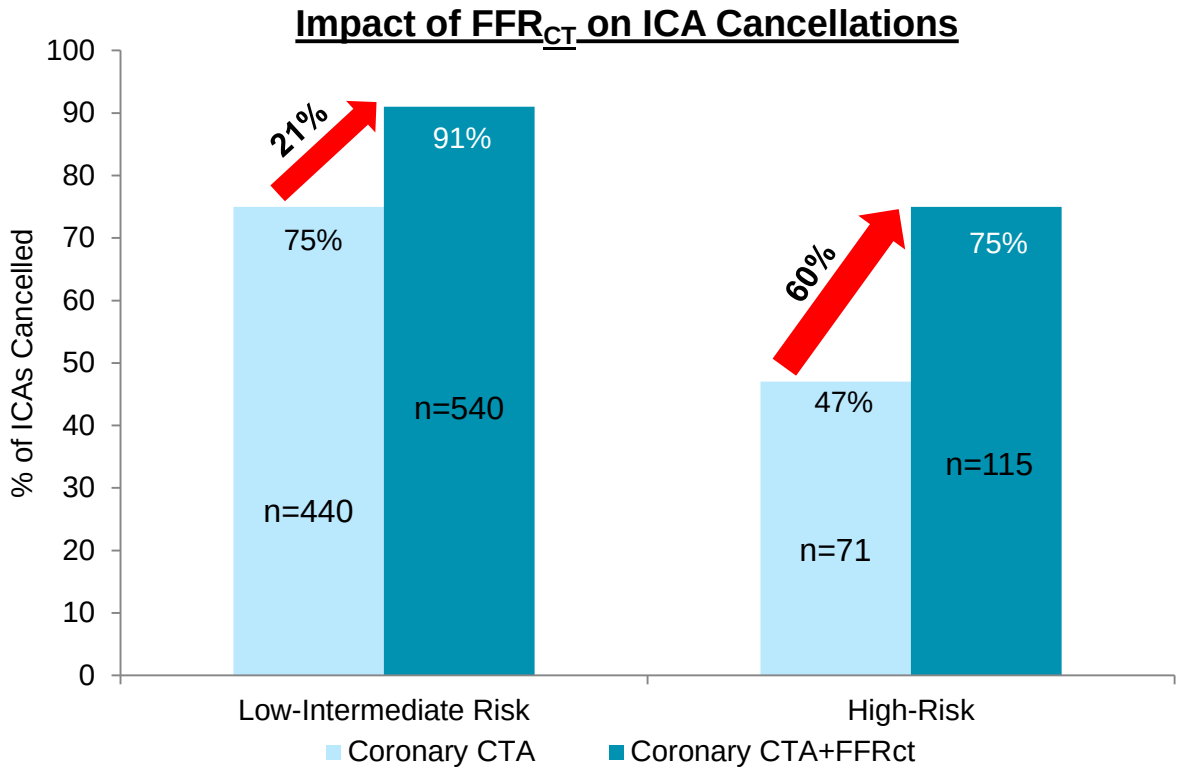




Nørgaard et. al., Influence of Coronary Calcification on the Diagnostic Performance of CT Angiography Derived FFR in Coronary Artery Disease, JACC: Cardiovascular Imaging, Volume 8, Issue 9, Pages 1045-1055

3-fold reduction in false positives by adding FFR_{CT} to coronary CTA, even with high Agatson calcium score

Lesson 5: Increased value of FFR_{CT} in patients with high disease burden



- **A frontline cCTA and FFR_{CT} testing strategy cancelled 75% of ICAs in the high-risk group**
- **The incremental impact of FFR_{CT} was greater in high-risk as compared with the low-intermediate risk group**
  - 60% in high-risk versus 21% in low-intermediate risk

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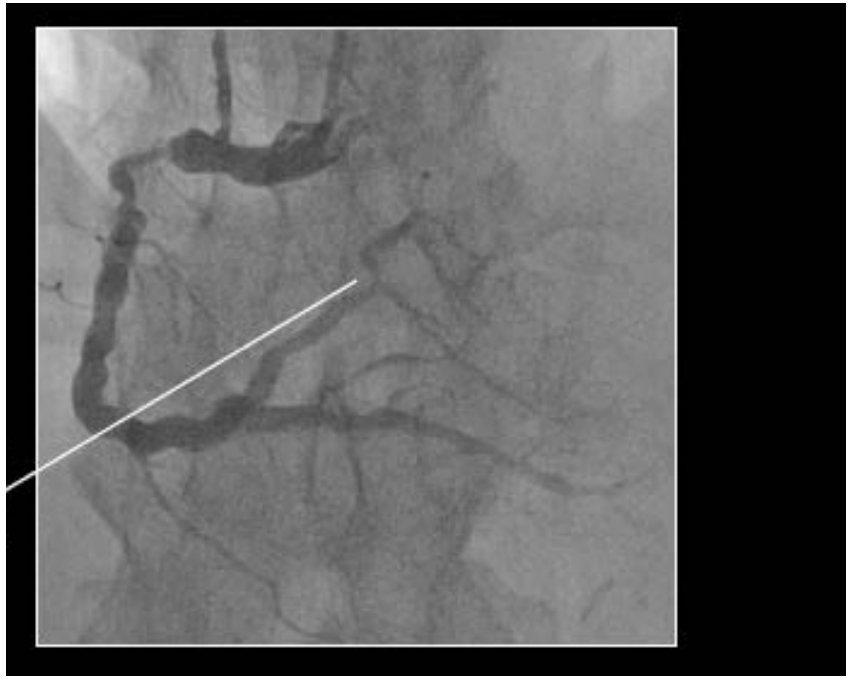
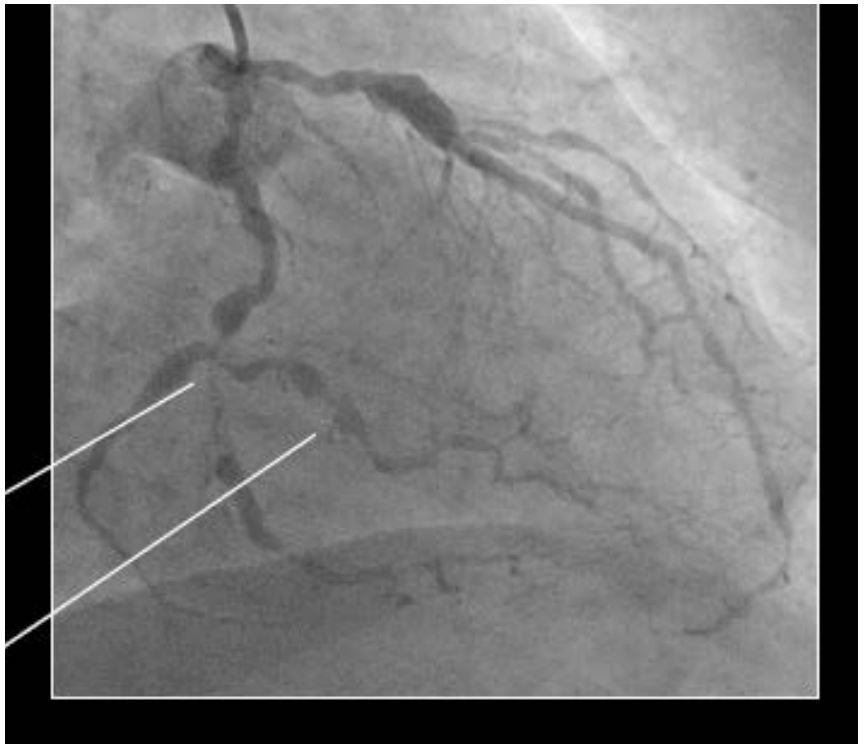
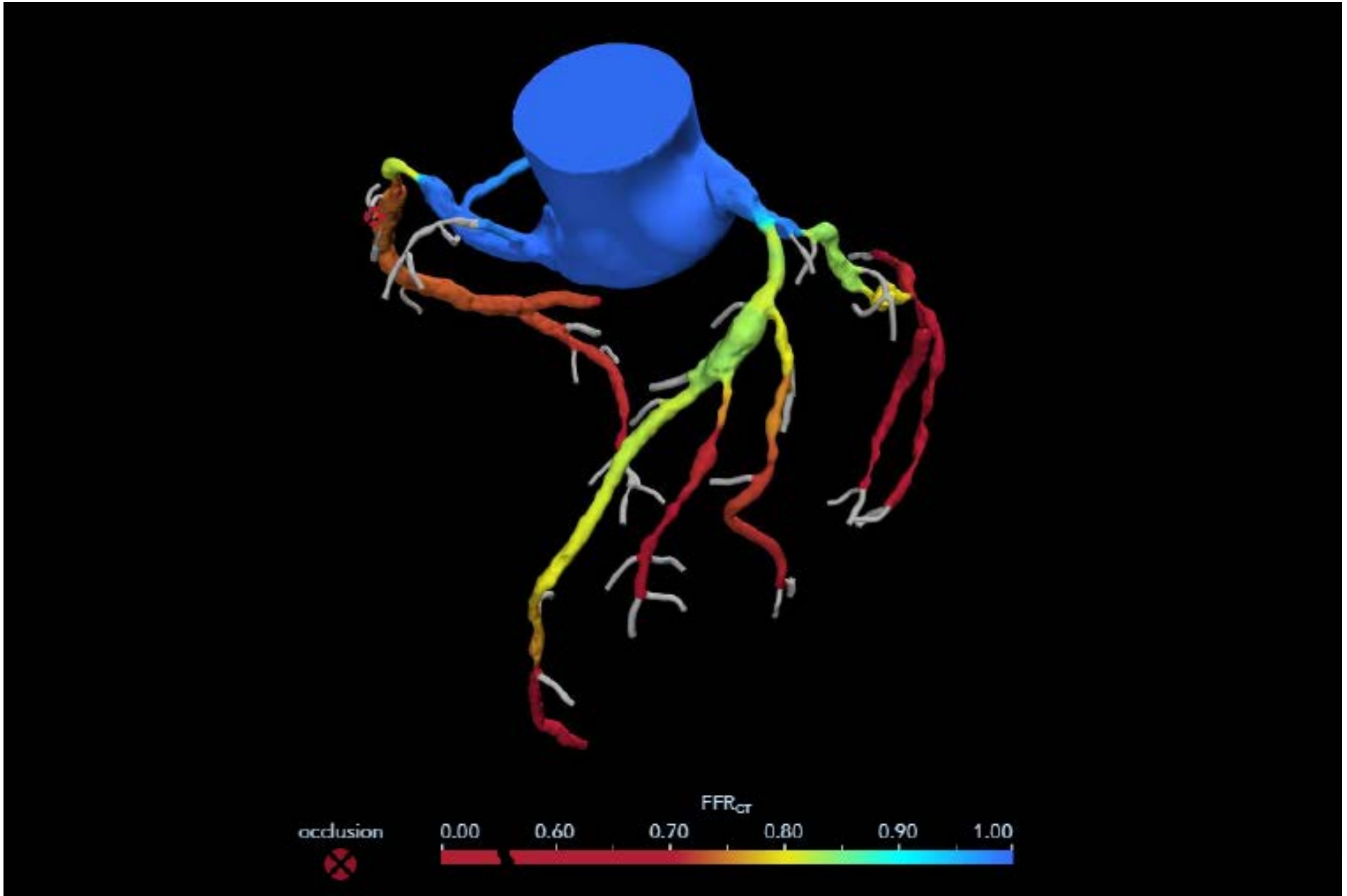
Jensen et. al., Computed tomography derived fractional flow reserve testing in stable patients with typical angina pectoris: influence on downstream rate of invasive coronary angiography, 2017

Case: Complex MVD





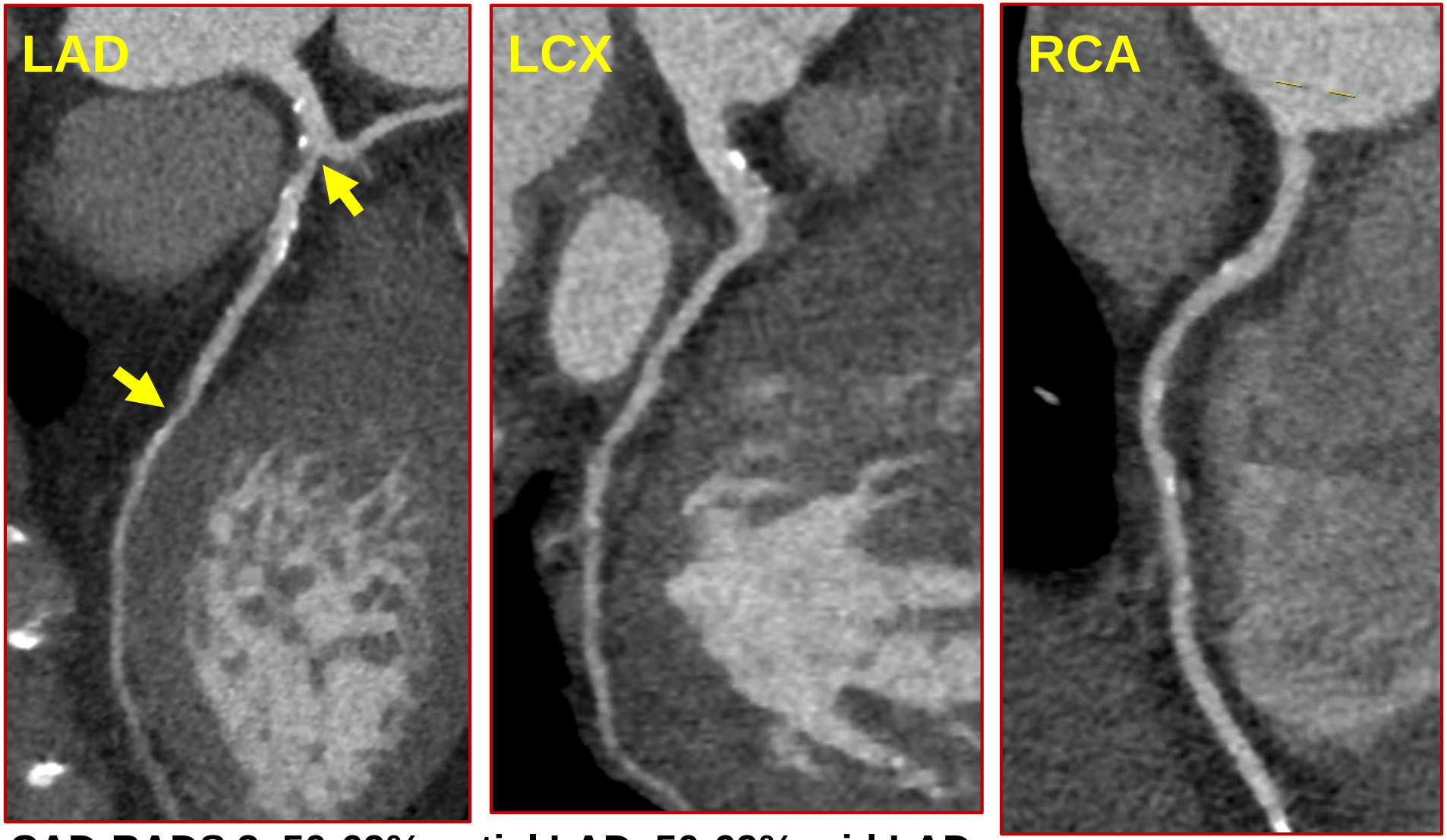
Case: FFRct



Case 1 - Oklahoma Heart

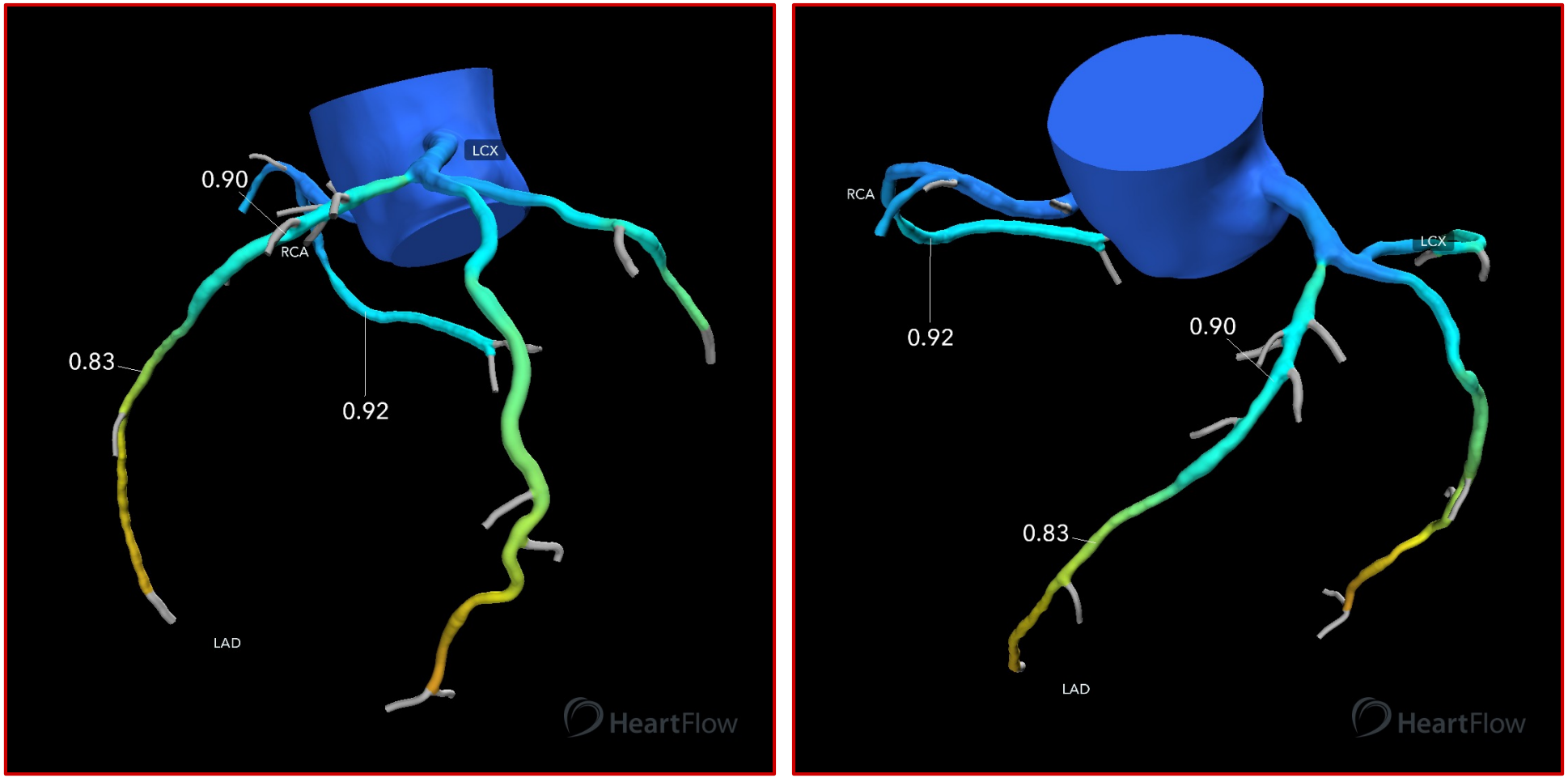
- 69 year-old man
- Chronic recurrent exertional chest tightness and breathlessness
- Known cardiomyopathy and nonstenotic coronary arteries on cath 6 years ago
- Sinus with left bundle branch block on resting ECG
- Recent SPECT showed anterior wall nontransmural infarct pattern

Case 1 - Oklahoma Heart



CAD-RADS 3, 50-69% ostial LAD, 50-69% mid LAD

Case 1 - Oklahoma Heart

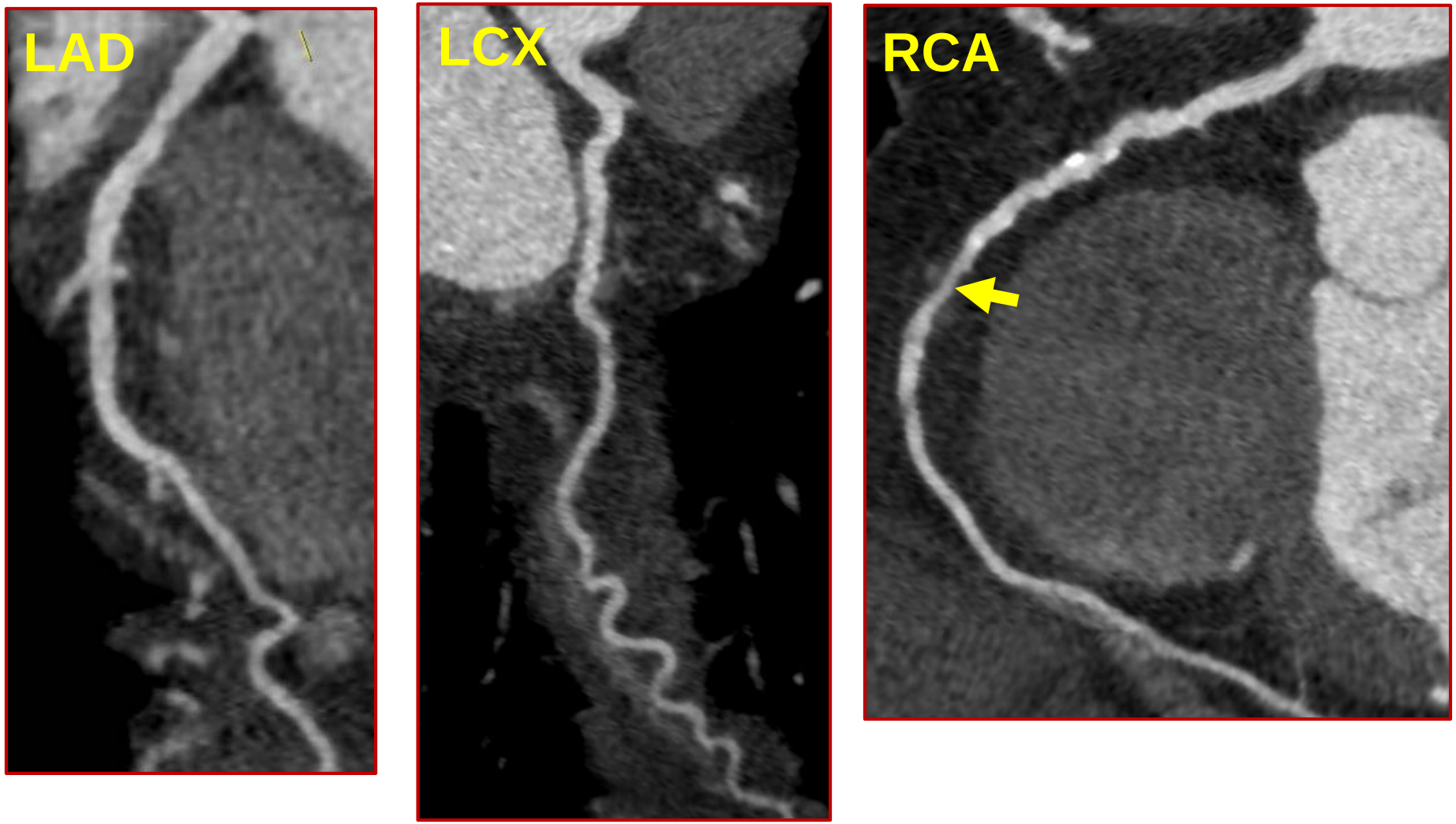


SPECT result felt to be probably artifactual, no cardiac events at 6 months

Case 2 - Oklahoma Heart

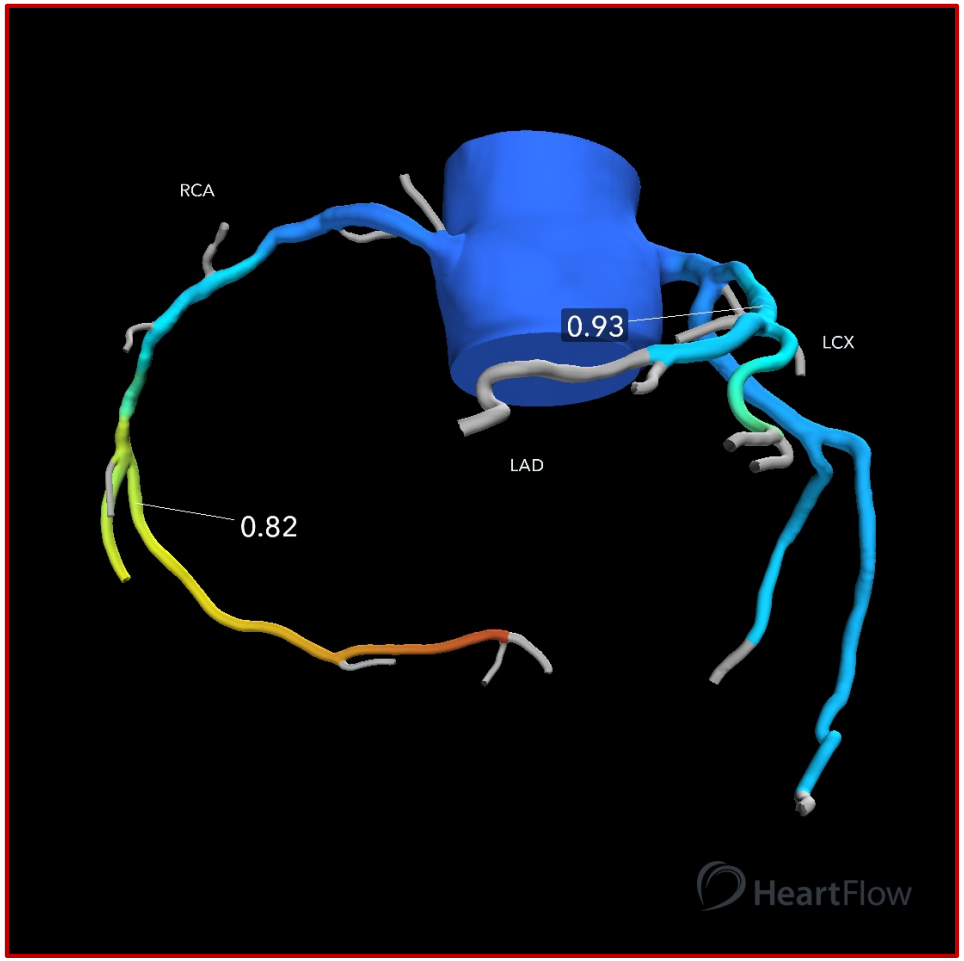
- 74 year-old woman
- Hypertension and GERD
- Nonexertional central chest ache with radiation to both arms, difficult to tell if fits her typical reflux
- Normal resting ECG

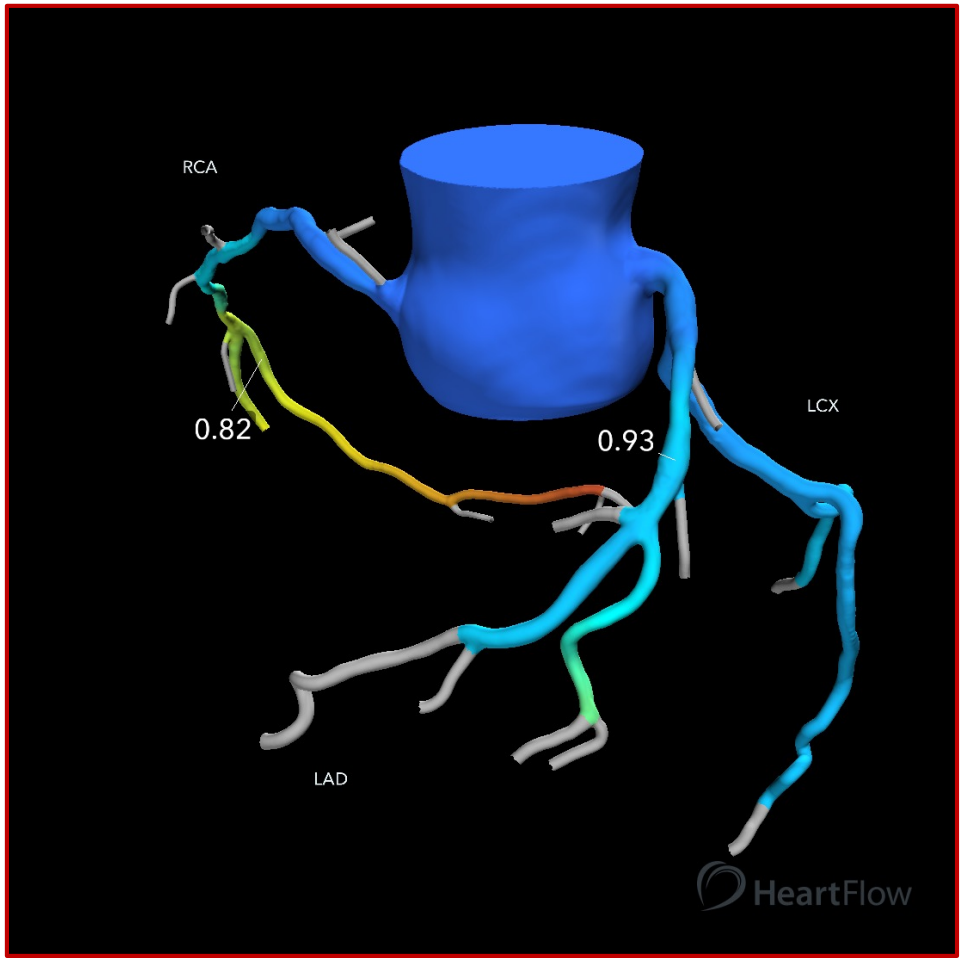
Case 2 - Oklahoma Heart



CAD-RADS 3, 50-69% mid RCA

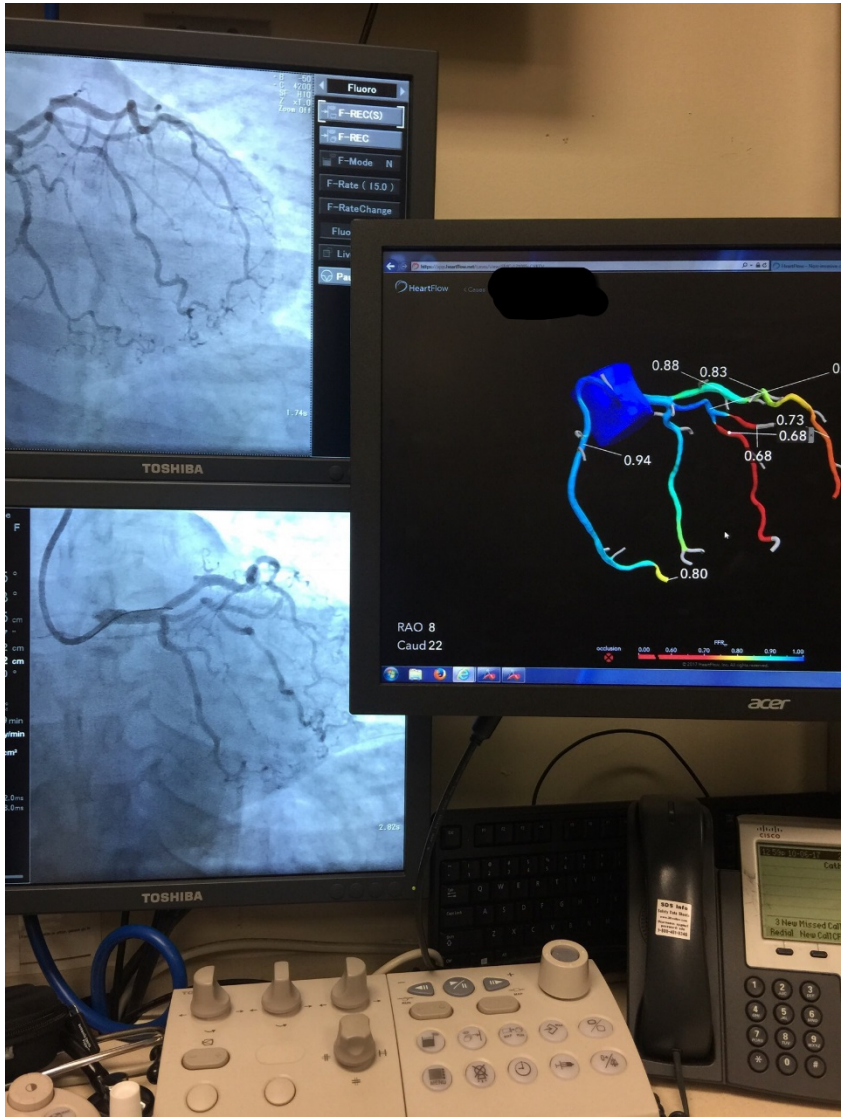
Case 2 - Oklahoma Heart





- Referred for MPS 1 months later: Equivocal inferior wall reversible defect
- Office visit at 7 months: Chest pain free
- Follow-up to date 12 months: No cardiac events

Bringing FFR_{CT} into the cath lab



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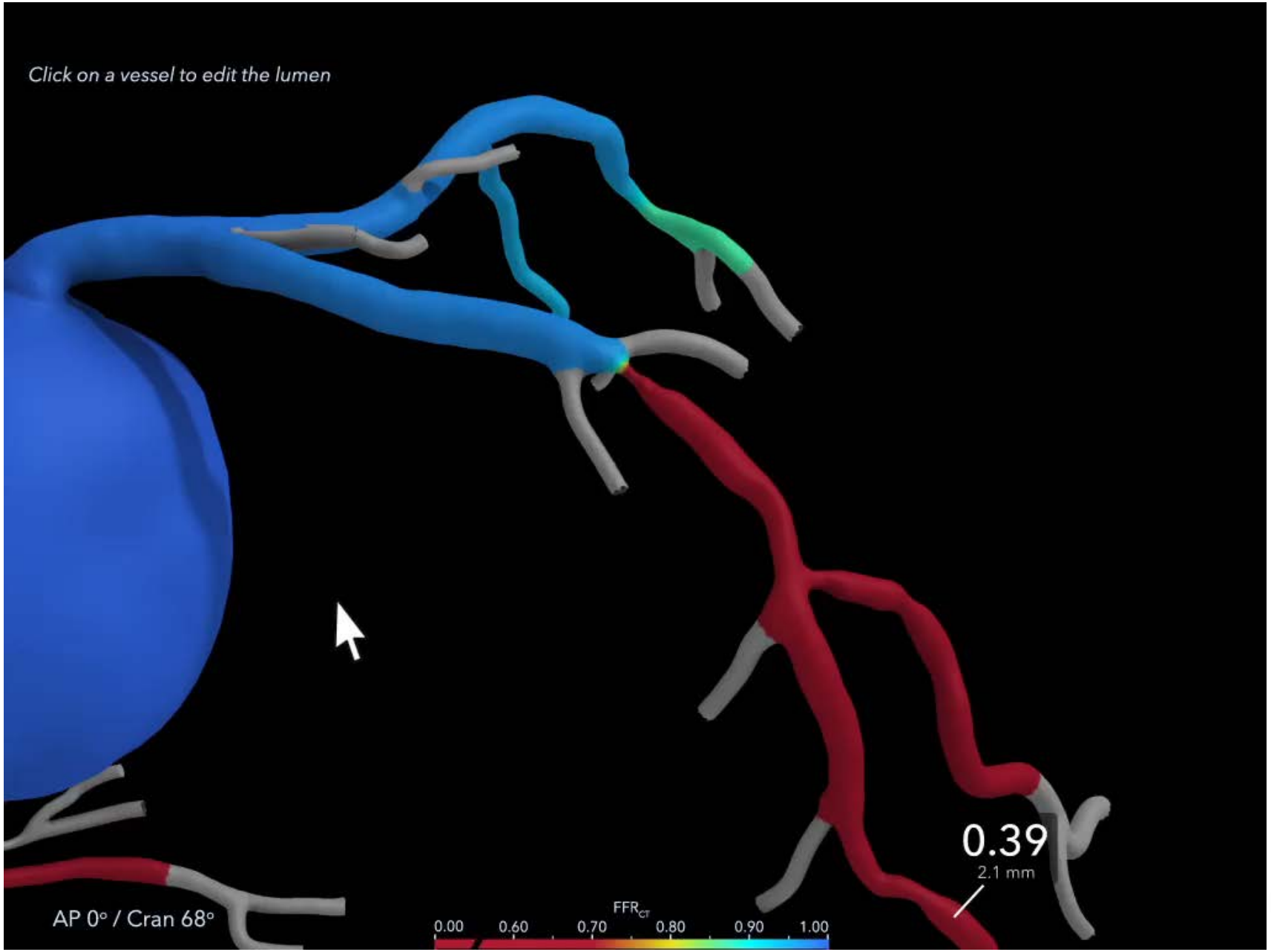
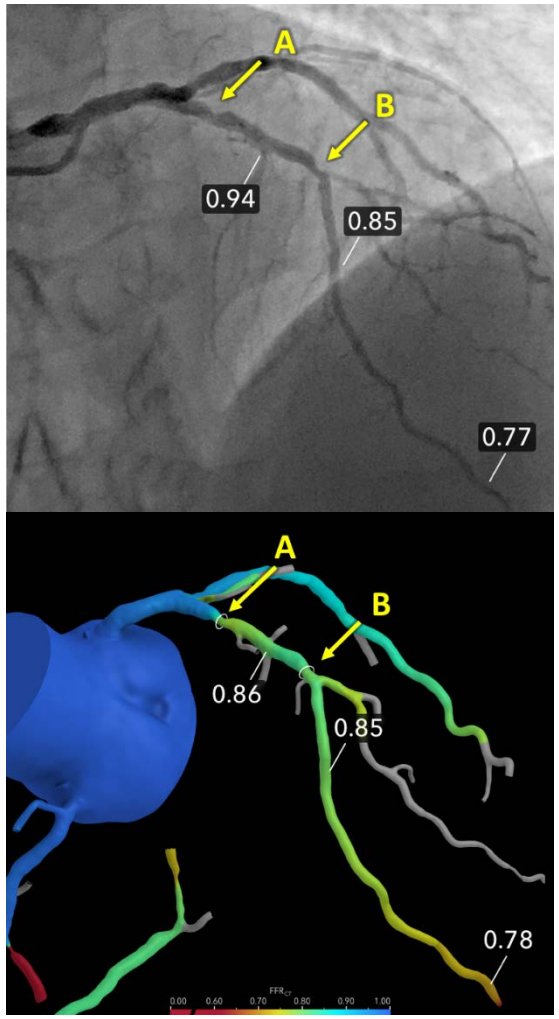
Virtual Intervention Planner

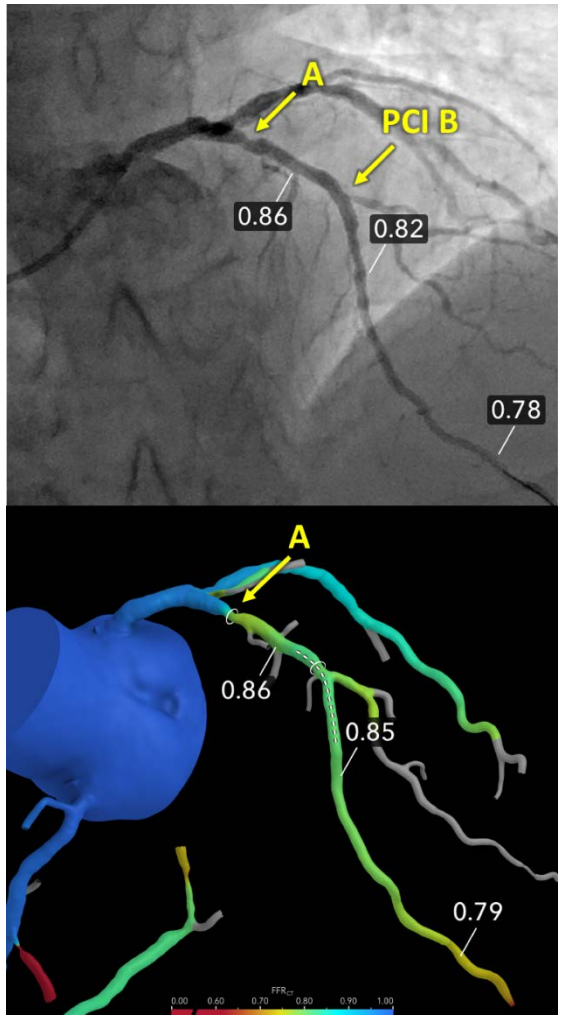


Recent Highlights : Presented at SCCT 2017

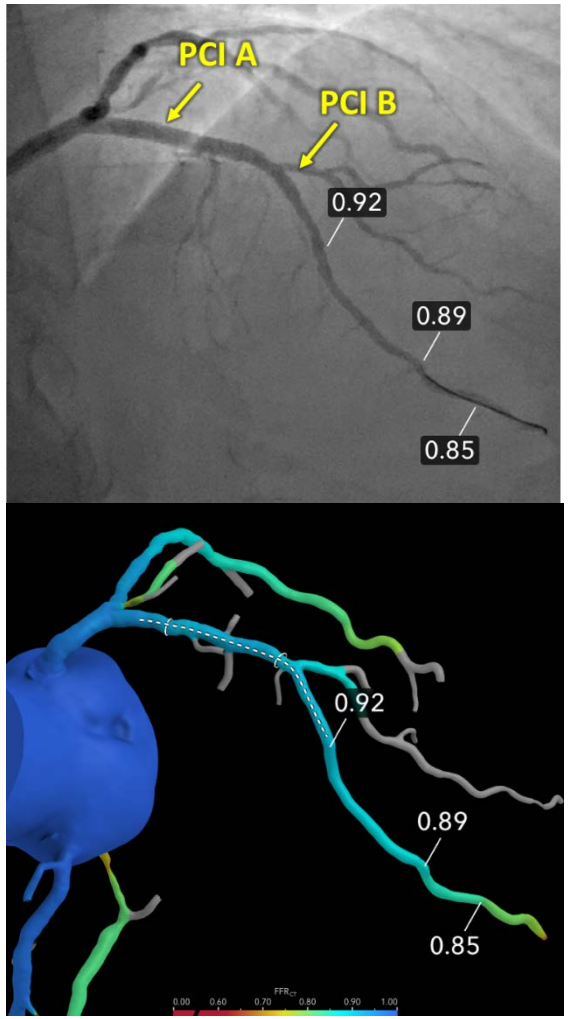
Before PCI



After Mid lesion



After Mid+Prox lesion



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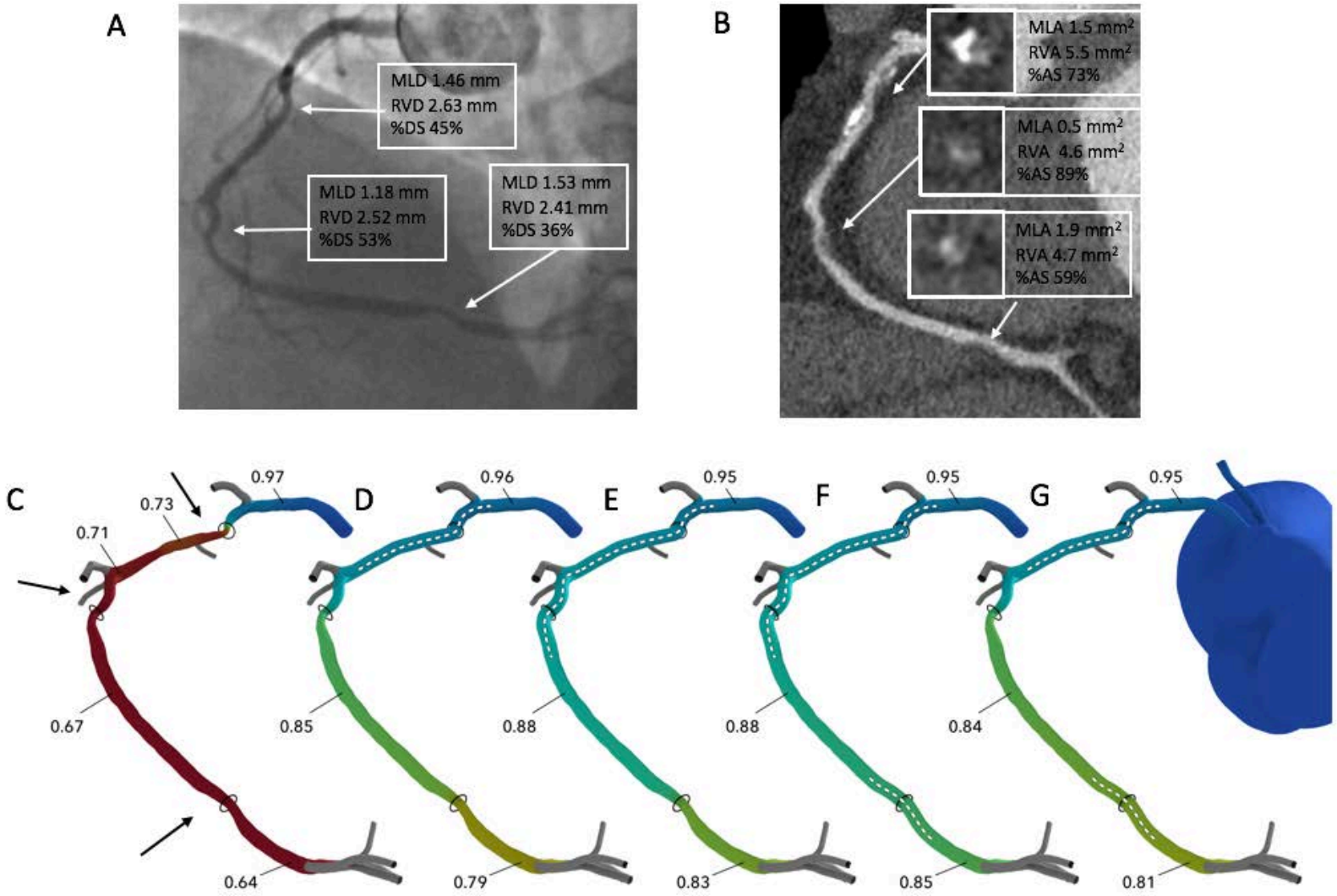
Ihdayhid et. al. JACC CV Interventions, 2017

Recent Highlights: Presented at TCT 2017



Sonck et. al, Eurointervention, 2017

Summary

- FFR_{CT}
  - validated in 4 prospective multicenter clinical trials and over 1200 patients
  - reduces negative diagnostic cardiac catheterizations, but not PCI
  - could result in significant cost savings while improving patient care
  - used clinically in 20,000 patients
  - Planning for large RCTs underway
- Technology platform will enable
  - Fast turn-around for ER patients
  - New data to aid in decision-making
  - Virtual intervention planning
  - Identification of plaques at higher risk of rupture (EMERALD study)