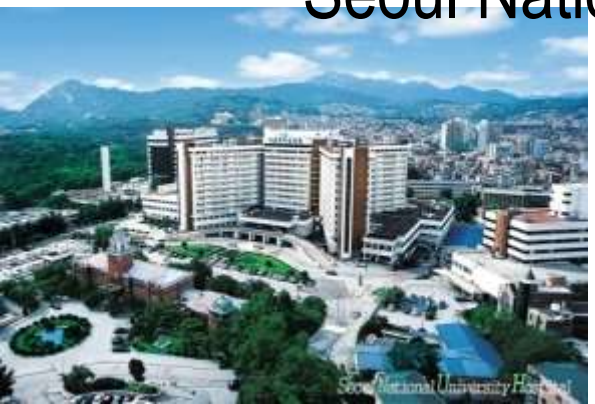
FFR_{CT} in Progression

Bon-Kwon Koo, MD, PhD

Seoul National University Hospital, Seoul, Korea

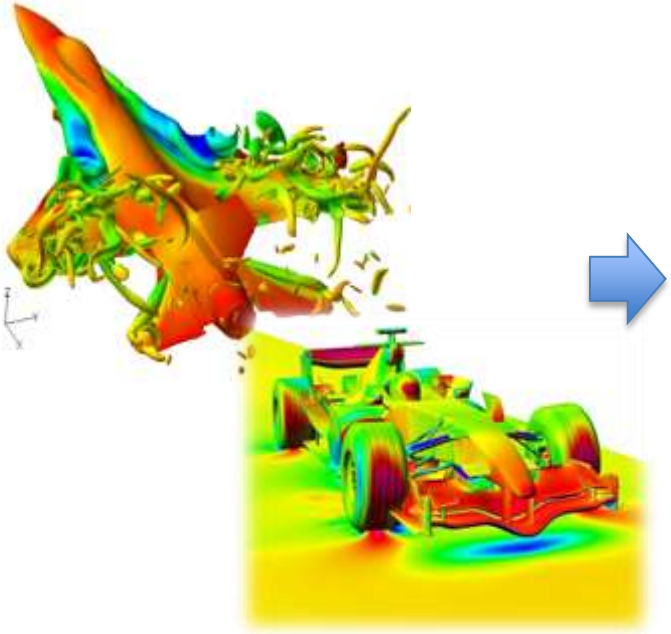


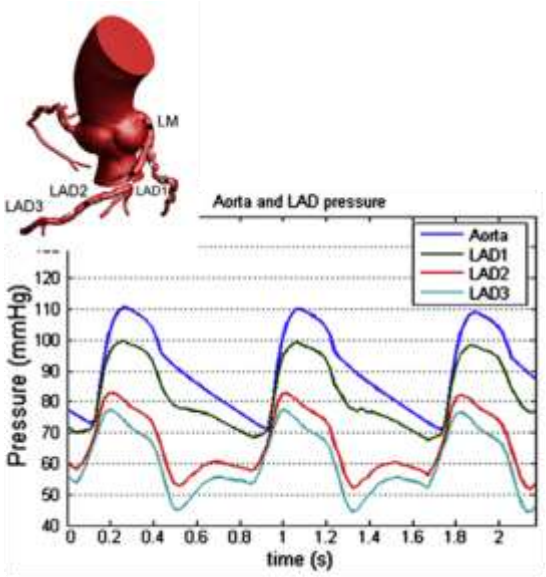
SNUH *Seoul National University Hospital*
Cardiovascular Center

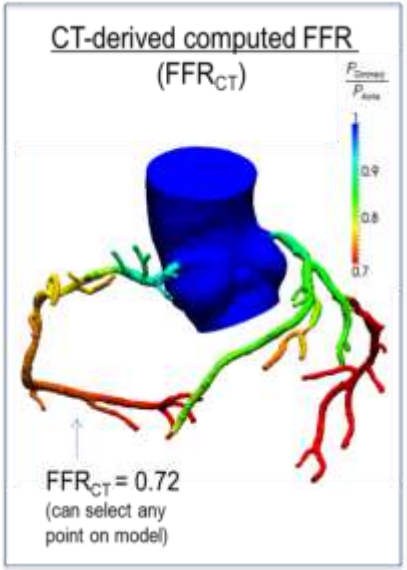
CT-derived FFR (FFR_{CT})

: Computed FFR from static coronary CT image using **computational fluid dynamics**

A novel model: Coronary artery disease





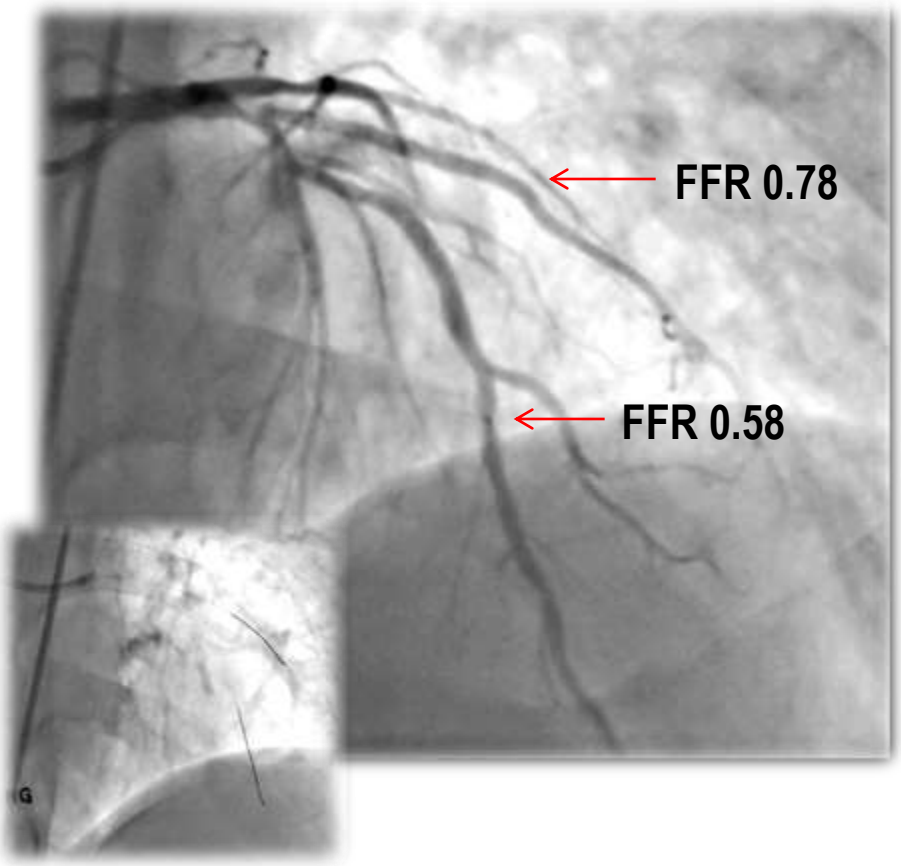


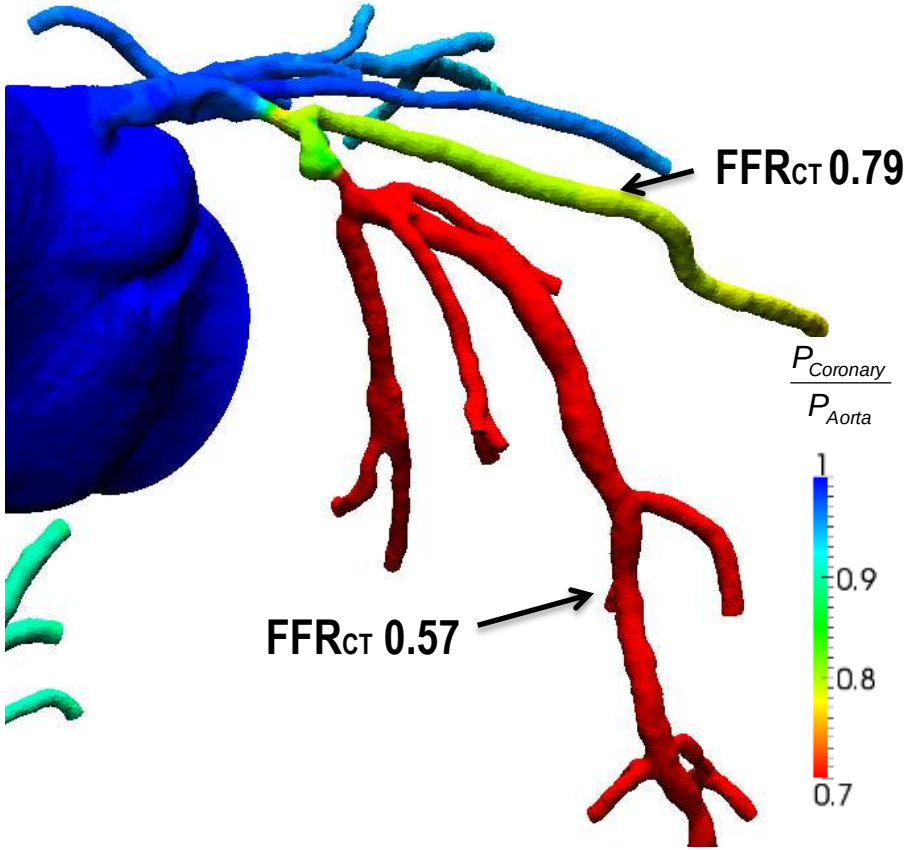
Calculated data:

- Velocity and pressure of blood in human coronary arteries
- **Fractional Flow Reserve**

Courtesy of C. Taylor, HeartFlow

FFR vs. CT-derived computed FFR

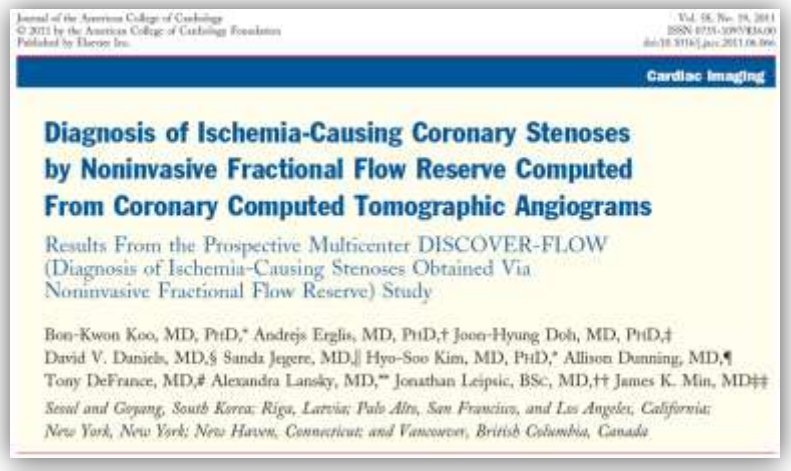




Without invasive procedure
Without pressure wire, without adenosine

Clinical Evidences on Diagnostic Performance

- **DISCOVER-FLOW**
  - 5 center FIH clinical trial
  - Completed 2011
  - N=103 patients
  - Published in JACC
- **DeFACTO**
  - 17 center clinical trial
  - Completed 2012
  - N=252 patients
  - Published in JAMA
- **NXT**
  - 10 center clinical trial
  - Completed August, 2013
  - N=251 patients
  - Published in JACC



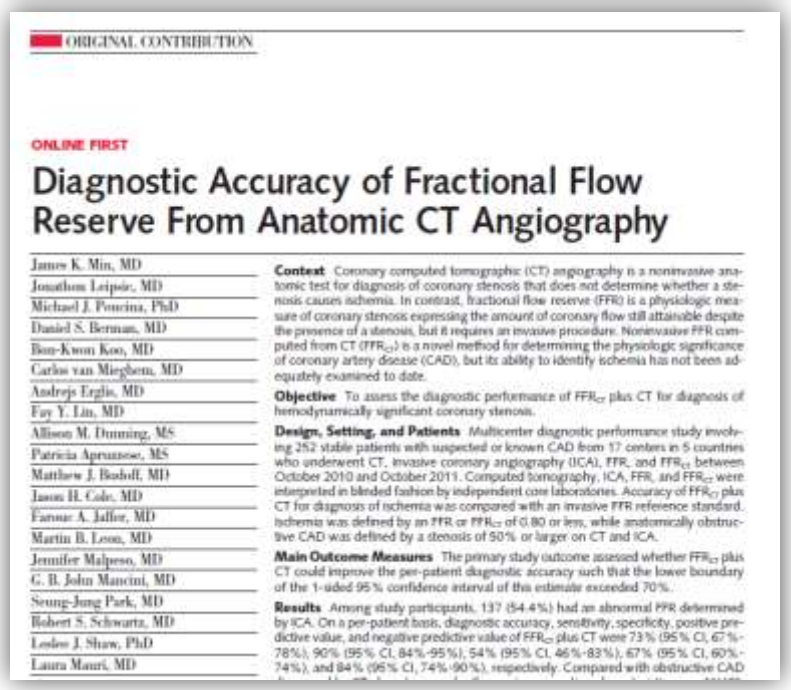
Cardiac Imaging

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

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

Bon-Kwon Koo, MD, PhD,* Andrejs Erglis, MD, PhD,† Joon-Hyung Doh, MD, PhD,‡ David V. Daniels, MD,§ Sanda Jegere, MD,‖ Hyo-Soo Kim, MD, PhD,* Allison Dunning, MD,¶ Tony DeFrance, MD,# Alexandra Lansky, MD,** Jonathan Leipsic, BSc, MD,†† James K. Min, MD‡‡

Seoul and Goyang, South Korea; Riga, Latvia; Palo Alto, San Francisco, and Los Angeles, California; New York, New York; New Haven, Connecticut; and Vancouver, British Columbia, Canada



ORIGINAL CONTRIBUTION

ONLINE FIRST

Diagnostic Accuracy of Fractional Flow Reserve From Anatomic CT Angiography

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Robert S. Schwartz, MD
Leslee J. Shaw, PhD
Laura Mauri, MD

Context Coronary computed tomographic (CT) angiography is a noninvasive anatomic test for diagnosis of coronary stenosis that does not determine whether a stenosis causes ischemia. In contrast, fractional flow reserve (FFR) is a physiologic measure of coronary stenosis expressing the amount of coronary flow still attainable despite the presence of a stenosis, but it requires an invasive procedure. Noninvasive FFR computed from CT (FFR_{CT}) is a novel method for determining the physiologic significance of coronary artery disease (CAD), but its ability to identify ischemia has not been adequately examined to date.

Objective To assess the diagnostic performance of FFR_{CT} plus CT for diagnosis of hemodynamically significant coronary stenosis.

Design, Setting, and Patients Multicenter diagnostic performance study involving 252 stable patients with suspected or known CAD from 17 centers in 5 countries who underwent CT, invasive coronary angiography (ICA), FFR, and FFR_{CT} between October 2010 and October 2011. Computed tomography, ICA, FFR, and FFR_{CT} were interpreted in blinded fashion by independent core laboratories. Accuracy of FFR_{CT} plus CT for diagnosis of ischemia was compared with an invasive FFR reference standard. Ischemia was defined by an FFR or FFR_{CT} of 0.80 or less, while anatomically obstructive CAD was defined by a stenosis of 50% or larger on CT and ICA.

Main Outcome Measures The primary study outcome assessed whether FFR_{CT} plus CT could improve the per-patient diagnostic accuracy such that the lower boundary of the 1-sided 95% confidence interval of this estimate exceeded 70%.

Results Among study participants, 137 (54.4%) had an abnormal FFR determined by ICA. On a per-patient basis, diagnostic accuracy, sensitivity, specificity, positive predictive value, and negative predictive value of FFR_{CT} plus CT were 73% (95% CI, 67%-78%), 90% (95% CI, 84%-95%), 54% (95% CI, 46%-83%), 67% (95% CI, 60%-74%), and 84% (95% CI, 74%-90%), respectively. Compared with obstructive CAD

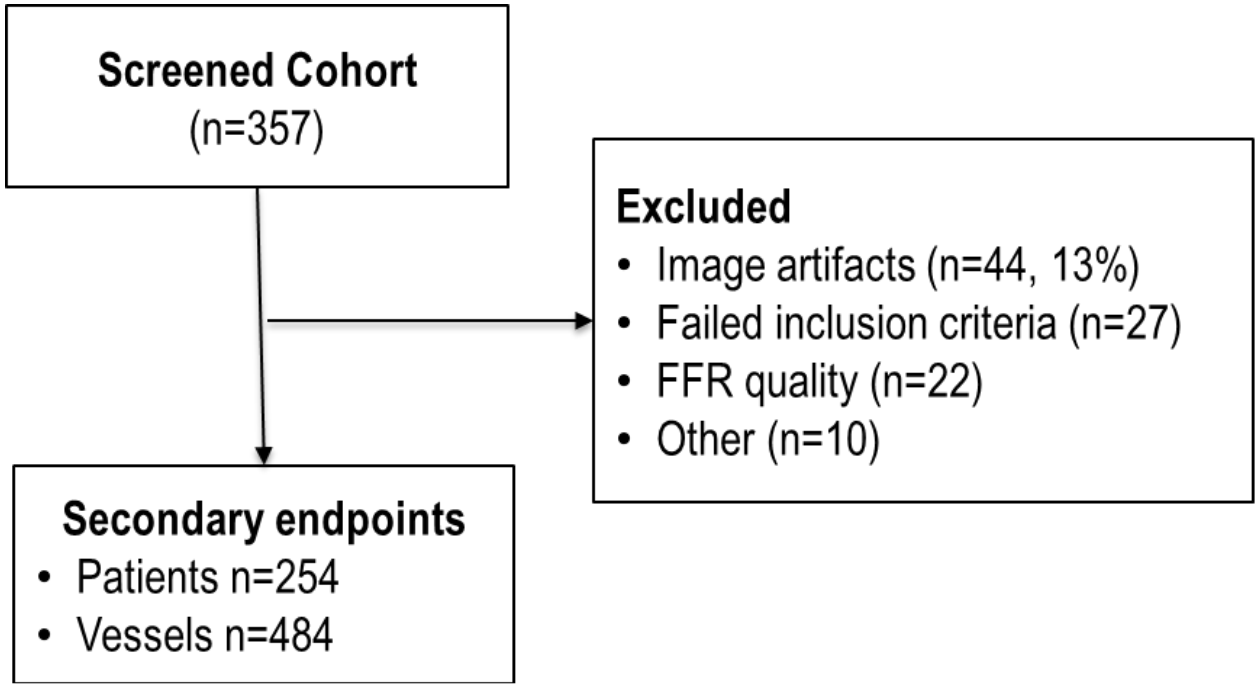
NXT study

Incorporates learning from previous FFR_{CT} trials:

- Newest generation of FFR_{CT} analysis software
- Strict CT acquisition protocol according to societal guidelines

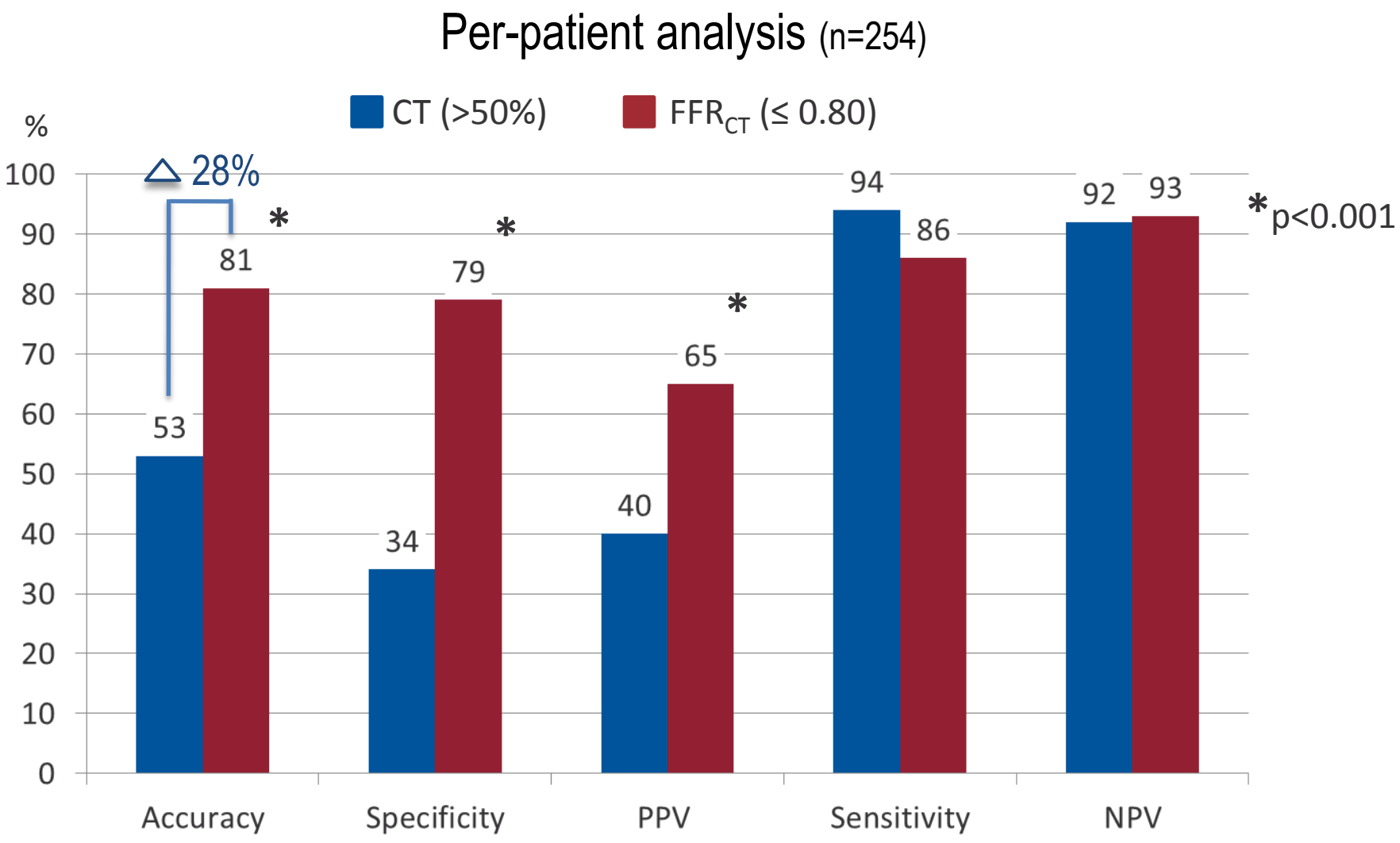
CT Characteristics

Nitrates	99.6%
Beta Blockers	78%
Heart Rate (bpm)	63
Range	37-110
Prospective	54%
mean dose (mSv)	3
Retrospective	46%
mean dose (mSv)	14
Calcium score*	
Mean	302
>400	26%



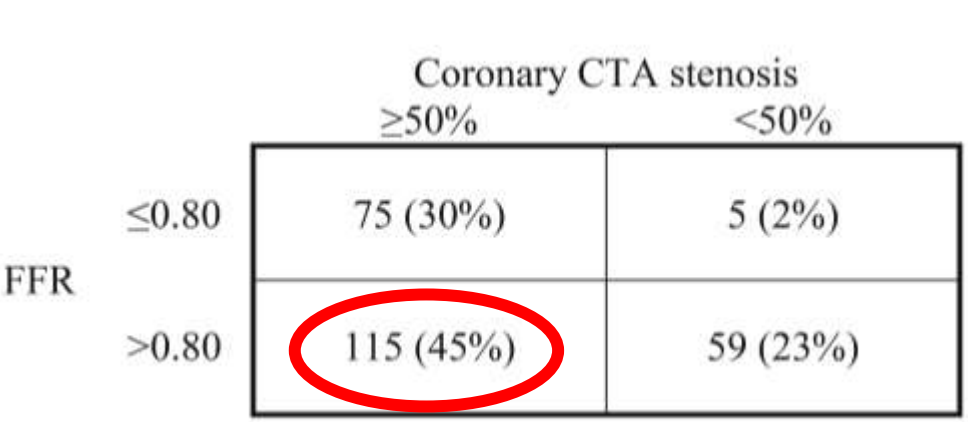
Nørgaard B, JACC 2014

NXT study

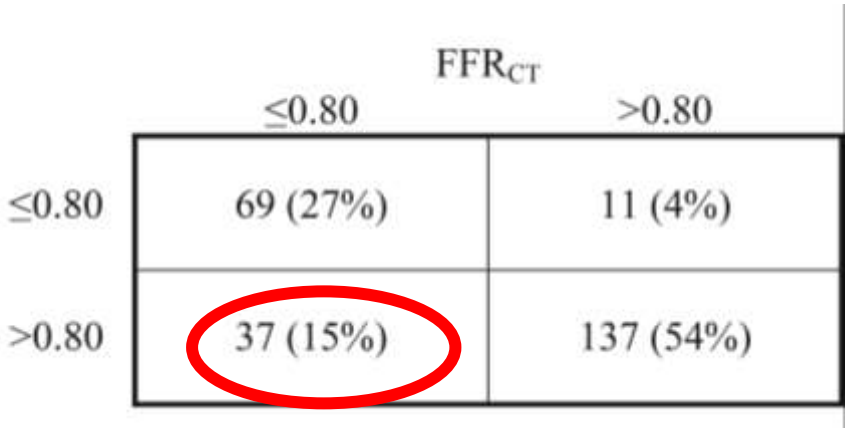


Nørgaard et al, JACC 2014

FFR_{CT} reclassification



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



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

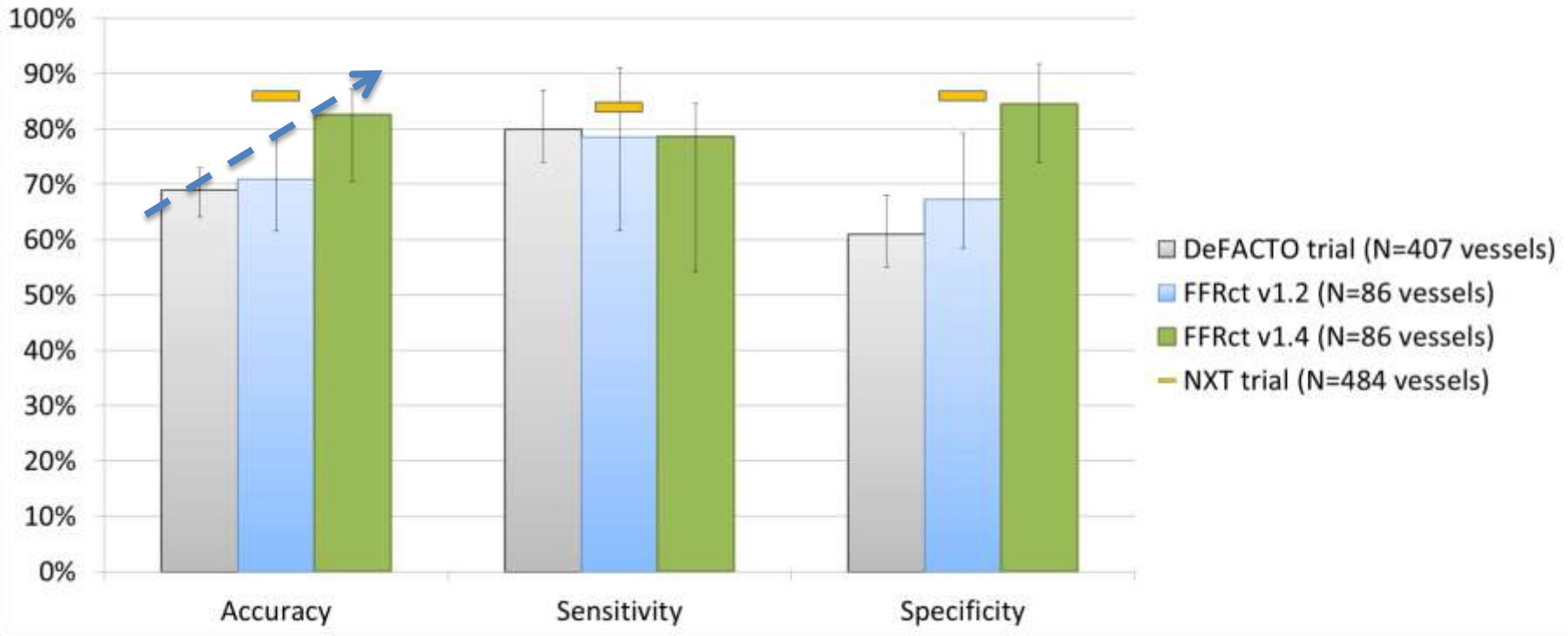
FFR_{CT} reclassified **68%** of CT false positives as true negatives

Nørgaard et al, JACC 2014

Diagnostic performance of FFR_{CT}

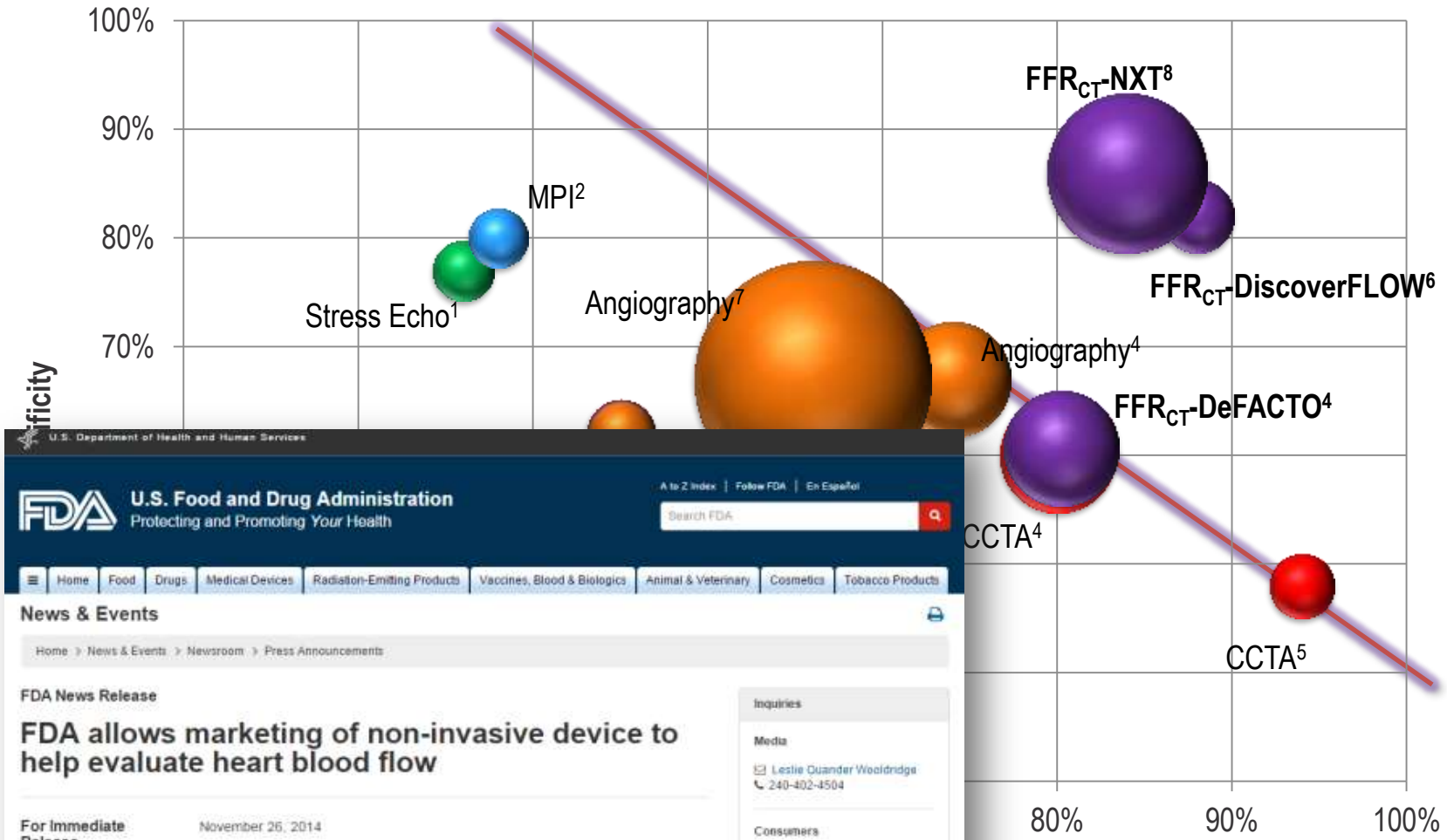
	Patient No	Sensitivity	Specificity	PPV	NPV	Accuracy
DISCOVER-FLOW	103	93%	82%	85%	91%	**87%**
DeFACTO	252	90%	54%	67%	84%	**73%**
NXT	251	86%	79%	65%	92%	**81%**
	Total: 606	90%	72%	72%	89%	**80%**

Impact of CT image quality and updated FFR_{CT} algorithms on FFR_{CT} performance



Norgaard et al, SCCT 2014

Non-invasive tests/FFR_{CT}/Angiography vs. FFR



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FDA News Release

FDA allows marketing of non-invasive device to help evaluate heart blood flow

For Immediate Release: November 26, 2014

Release: The U.S. Food and Drug Administration today allowed marketing of the HeartFlow FFR-CT software, which permits health care professionals to non-invasively evaluate blood flow in the coronary arteries of patients showing signs and symptoms of coronary artery disease.

Inquiries

Media

Leslie Quander Wooldridge
240-402-4504

Consumers

888-INFO-FDA

Share

4. Min et al. JAMA 2012;308:1237-1245

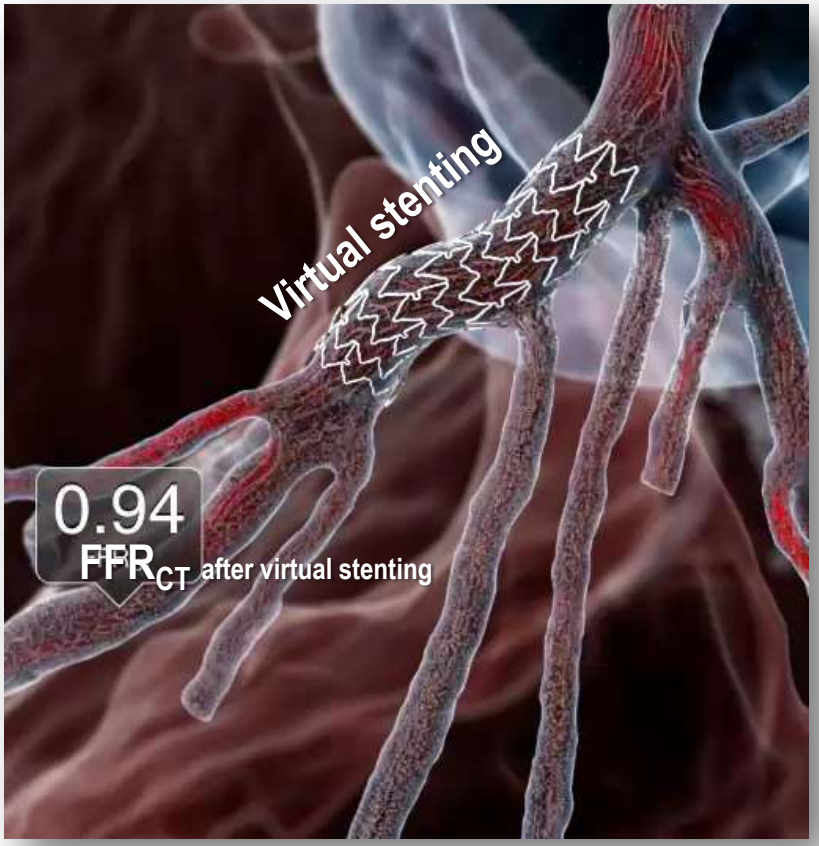
om et al. JACC 2008;52:636–43
al. JACC 2011;58:1989-97
al. JACC 2012

8. Norgaard et a. JACC 2014

FFR_{CT}: Applications ***in Future***

Image-based computerised modelling of coronary circulation: **Future direction**

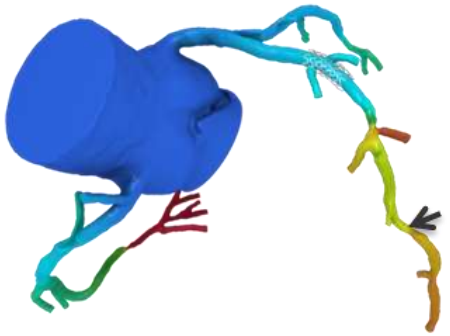
Planning the treatment strategy using **Virtual revascularization & CT-derived computed FFR**



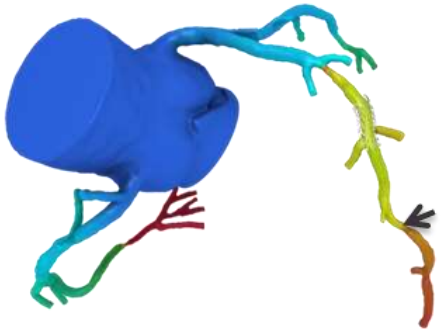
Planning the treatment strategy using
Virtual revascularization & CT-derived computed FFR

Before Stenting

Stent proximal lesion only

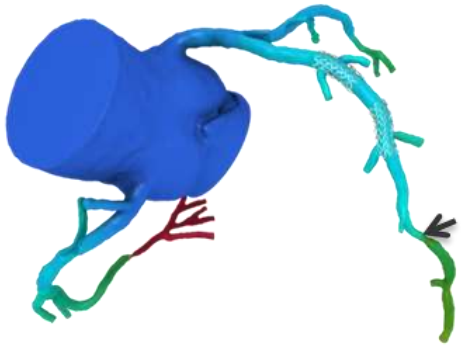


Stent distal lesion only

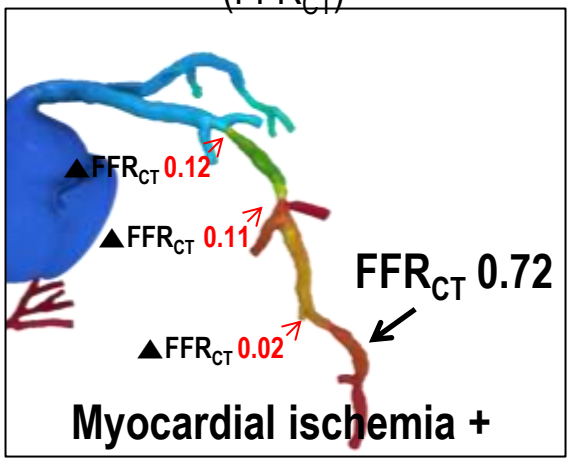


After Stenting

Stent both

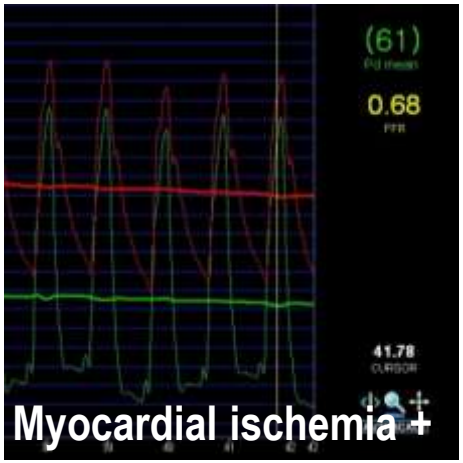
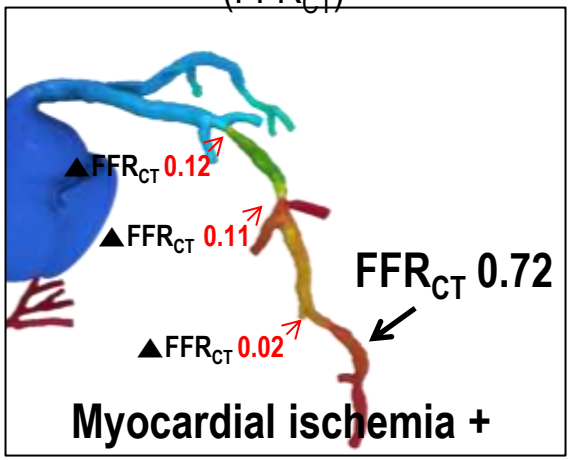
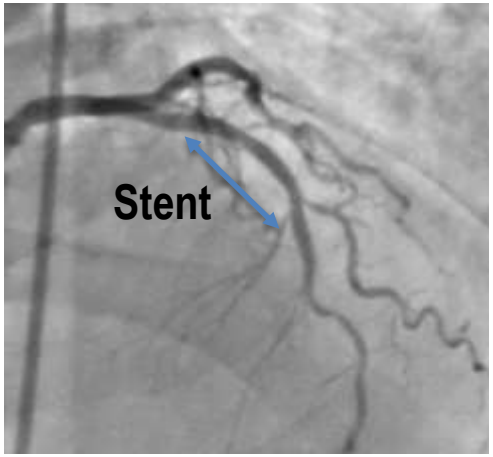
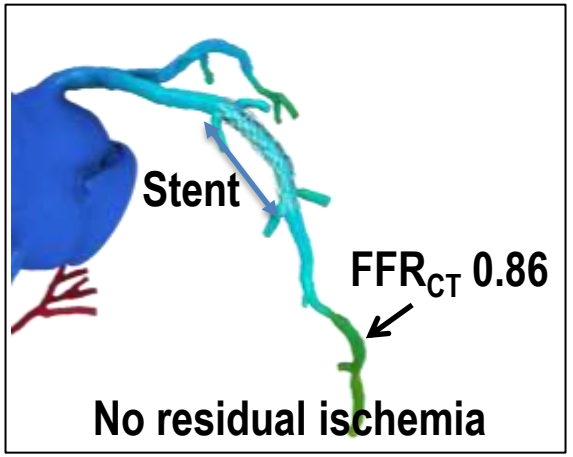


CT-derived computed FFR (FFR_{CT})



Kim KH, Koo BK, et al. JACC interv 2014

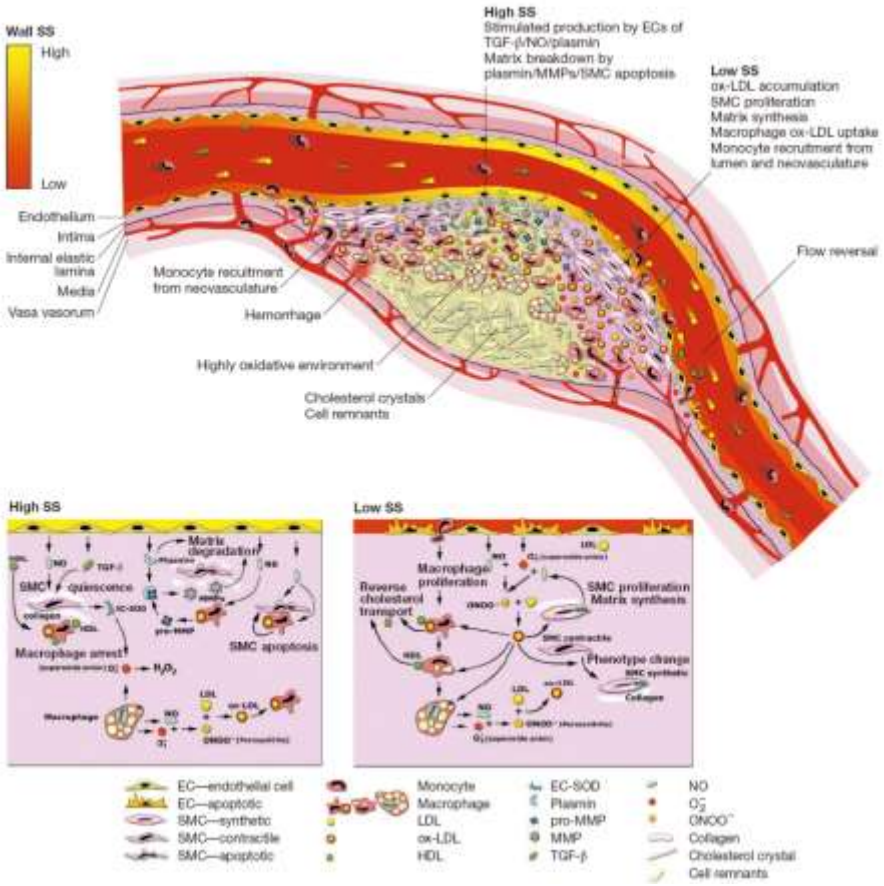
Planning the treatment strategy using
Virtual revascularization & CT-derived computed FFR

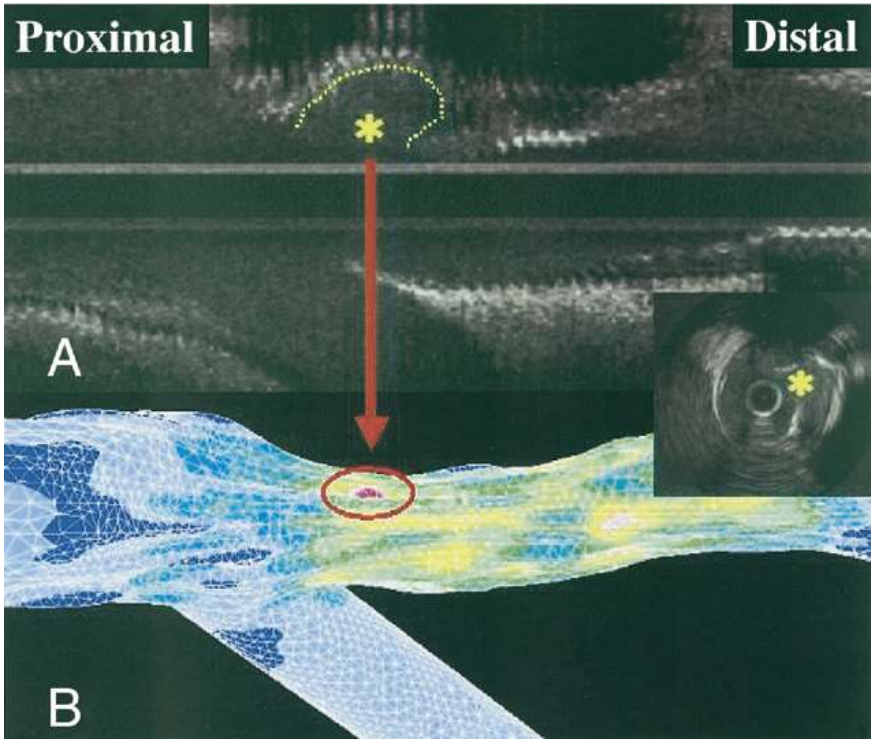
	Angiography	Invasive FFR	CT-derived computed FFR (FFR_{CT})
Before Stenting			
After Stenting			

Kim KH, Koo BK, et al. JACC interv 2014

Coronary hemodynamics: WSS, WSSG, traction, pressure, axial stress.....

: Key determinanats of plaque development, growth, vulnerability and rupture





Fukumoto, et al. JACC 2008

Slager, et al. Nature Clin Pract 2005

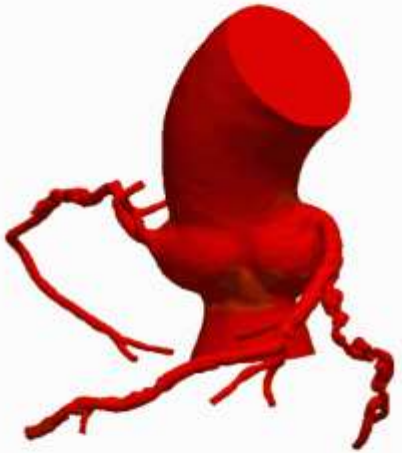
Hemodynamic force measurement using computational fluid dynamics and cCTA in a patient

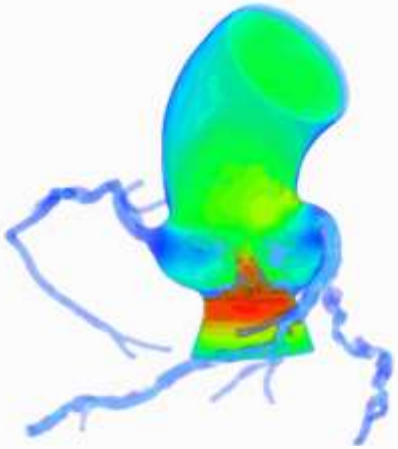
Pressure

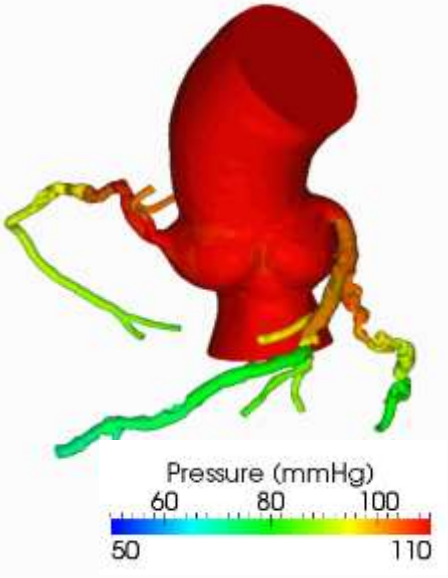
Velocity

Rest

Hyperemia







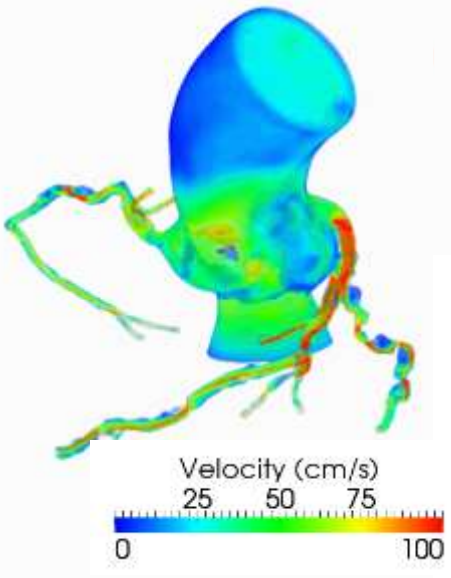
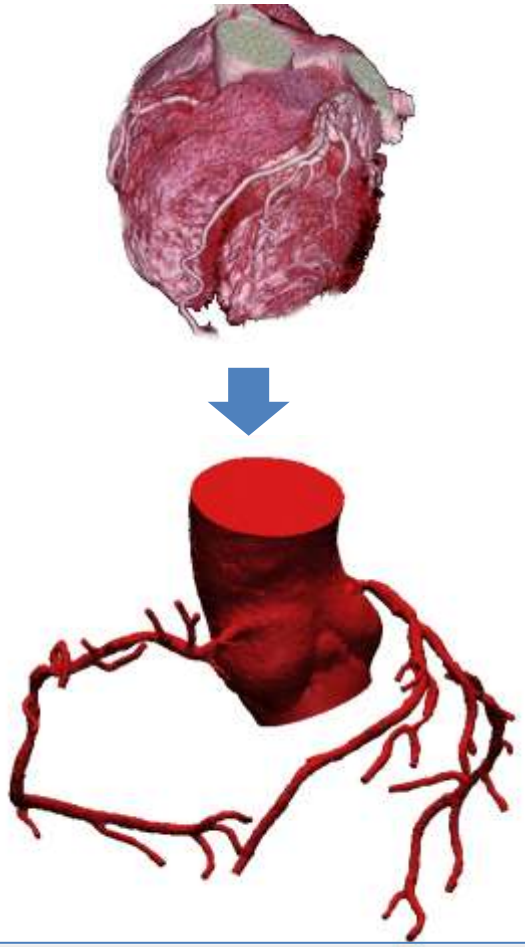


Image-based computerised modelling of coronary circulation: ***Potentials***

3-D geometry from CCTA



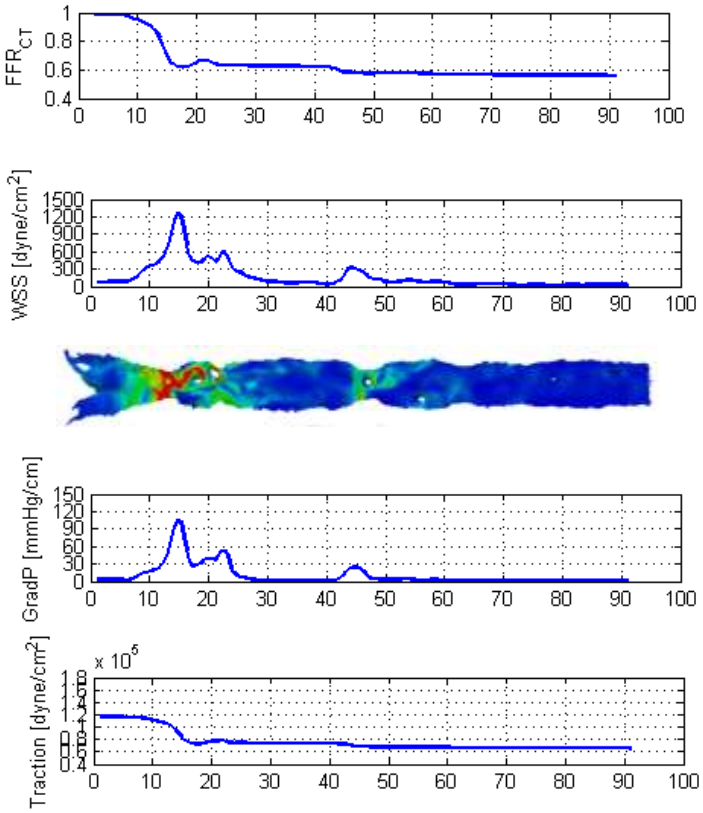
Hemodynamics

- **Pressure**
  - Pressure difference
  - Pressure gradient
  - Pressure recovery
  - FFR
- Flow velocity
- Flow rate
- Shear rate
- Shear stress – average, peak, gradient
- Traction
- Oscillatory shear index
- Particle residence time
- Turbulent kinetic energy
- ……..

- Static
- Pulsatile
- Resting
- Hyperemic
- Exercise – mild, moderate, peak

Image-based computerised modelling of coronary circulation: ***Potentials***

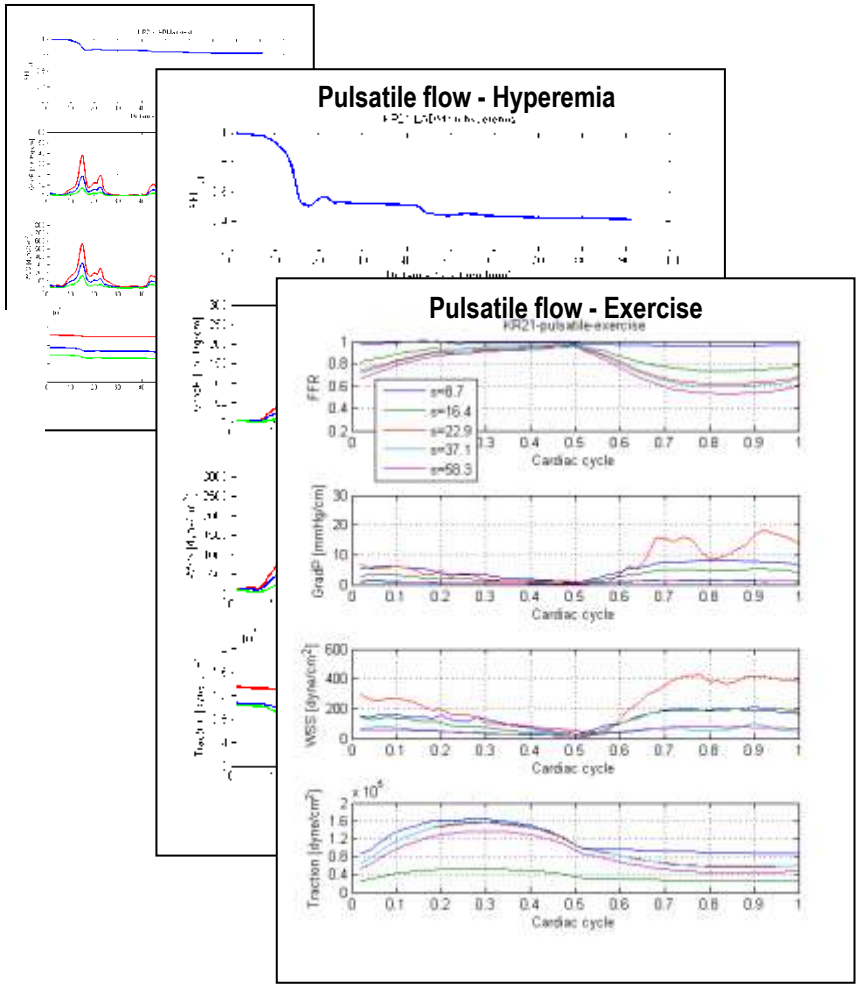
Static flow - hyperemic



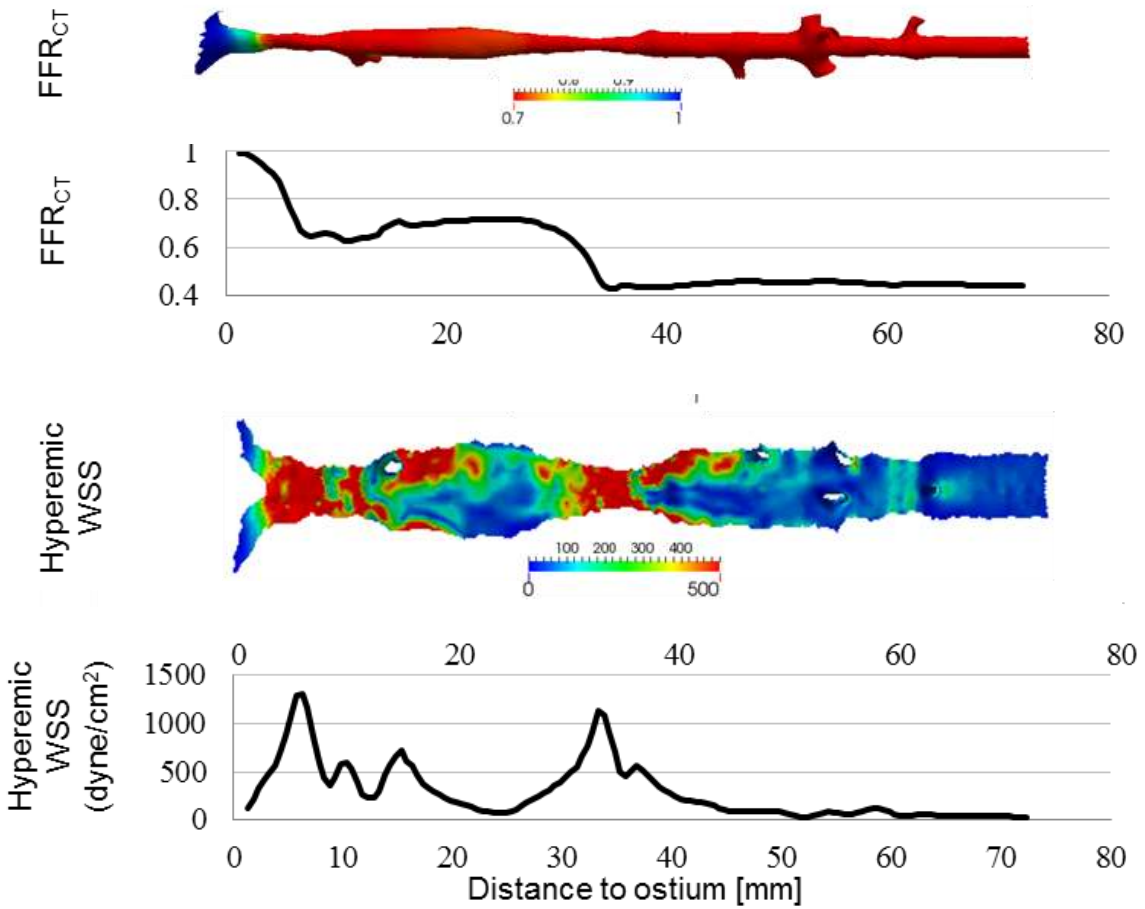
Pulsatile flow - rest

Pulsatile flow - Hyperemia

Pulsatile flow - Exercise

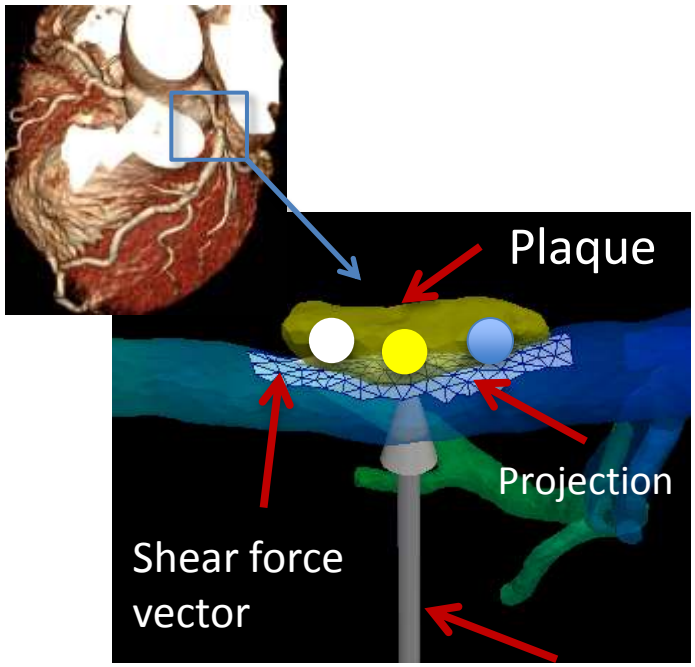


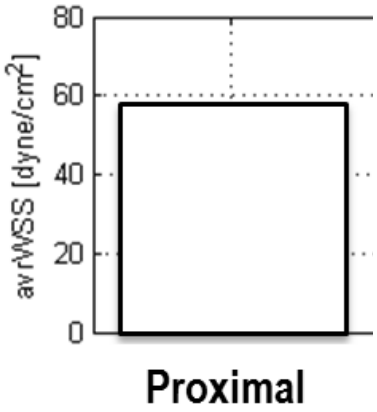
Measurement of hemodynamic parameters in a patient using cCTA and computational fluid dynamics

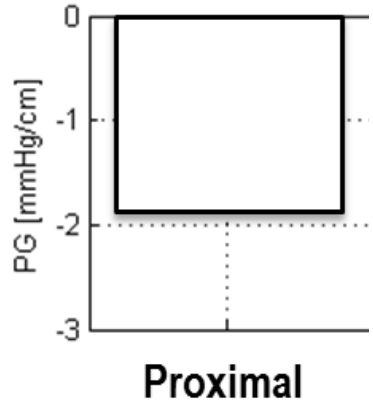


Koo BK. International Symposium on Biomechanics 2014

Regional distribution of hemodynamic forces
: Pressure gradient vs. WSS



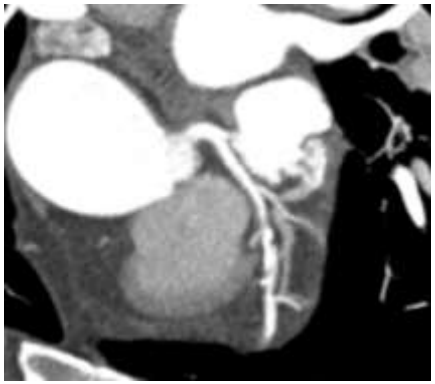




Park JB, Koo BK, et al. Submitted

Future perspective

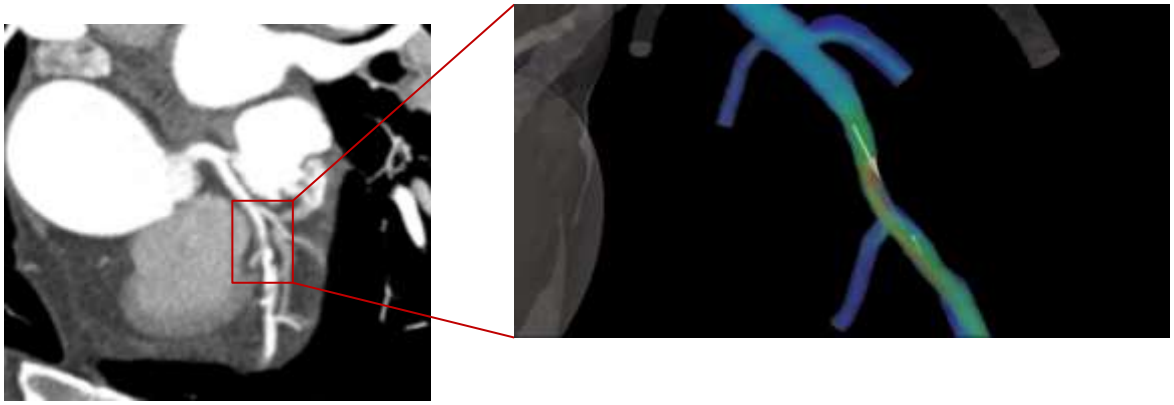
2011-04 CT, Asymptomatic



2012-06 Acute MI

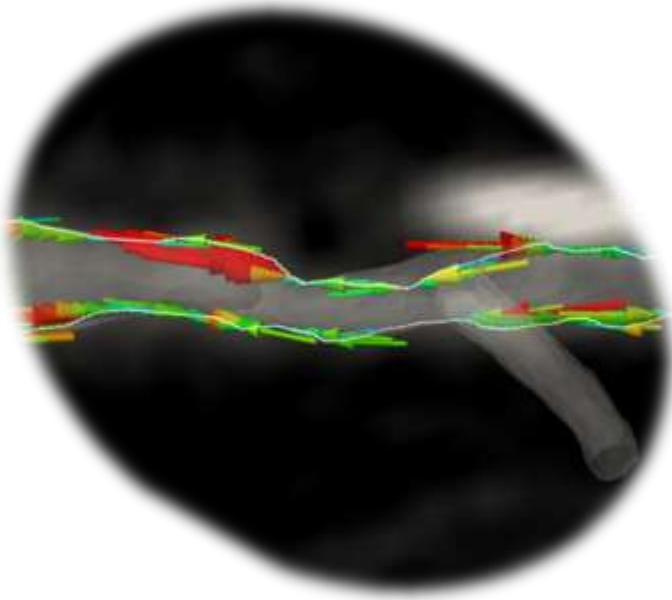
Future perspective

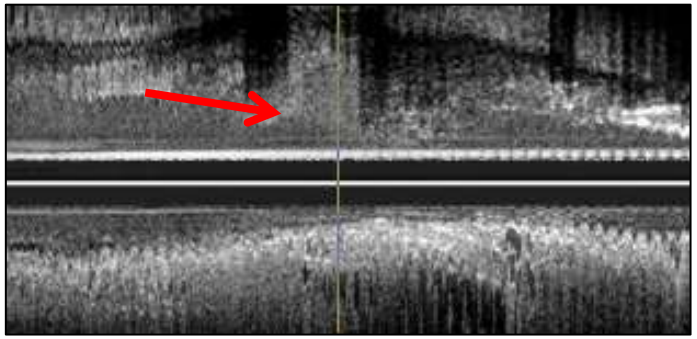
2011-04 CT, Asymptomatic



2012-06 Acute MI

	Plaque stress
Upstream	**9960 dyne/cm^2**
Downstream	1740 dyne/cm^2





FFR_{CT} in Progression

- Clinical data suggest that non-invasive FFR_{CT} can be used to predict the functional significance of coronary stenosis.
- FFR_{CT} technology is evolving and its diagnostic performance will also get better.
- Further technical development will expand its applicability.
  - PCI planner
  - Comprehensive hemodynamic assessment ……..