FFR before, during and after stenting

without pressure wire, without adenosine♪

European Bifurcation Club

EBC

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ESC/EACTS GUIDELINES

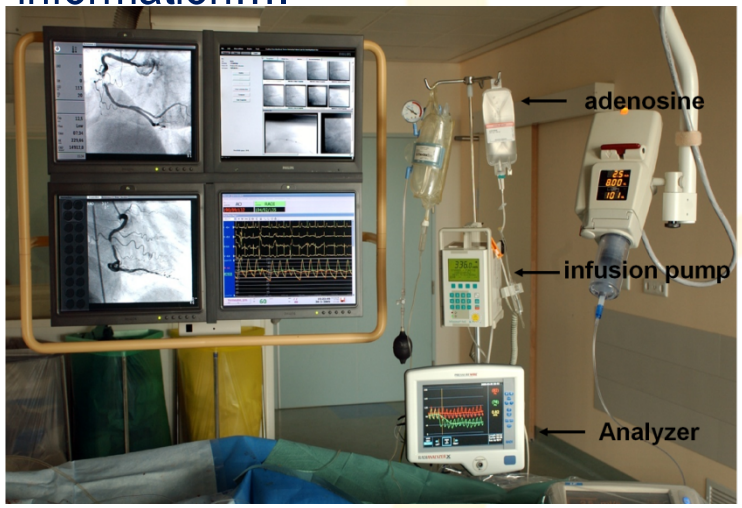
Guidelines on myocardial revascularization

The Task Force on Myocardial Revascularization of the European Society of Cardiology (ESC) and the European Association for Cardio-Thoracic Surgery (EACTS)

	Class[a]	Level[b]
FFR-guided PCI is recommended for detection of ischaemia-related lesion(s) when objective evidence of vessel-related ischaemia is not available.	I	A
DES[d] are recommended for reduction of restenosis/re-occlusion, if no contraindication to extended DAPT.	I	A
Distal embolic protection is recommended during PCI of SVG disease to avoid distal embolization of debris and prevent MI	I	B

FFR has become the gold standard to detect the ischemia-related lesion and is good for the patients…….

But, requires invasive/expensive procedure and cannot provide anatomical information….



Integration of anatomy and function

FFR without invasive procedure, without pressure wire, without adenosine???

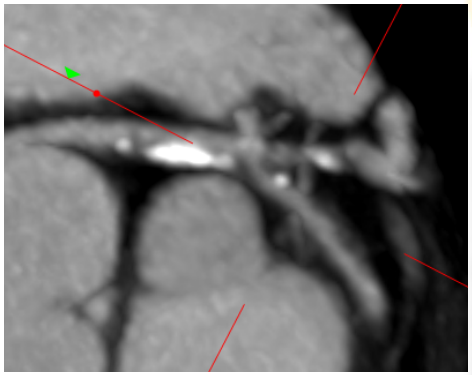
M/63 Stable angina

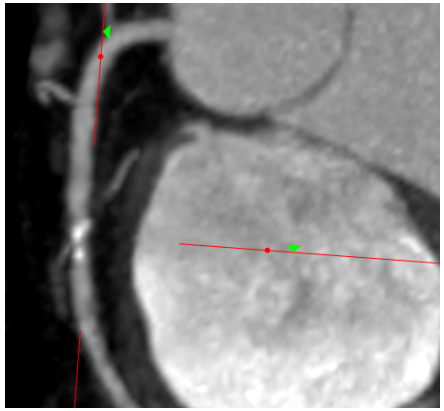
Risk factors: Hypertension, Hypercholesterolemia♪

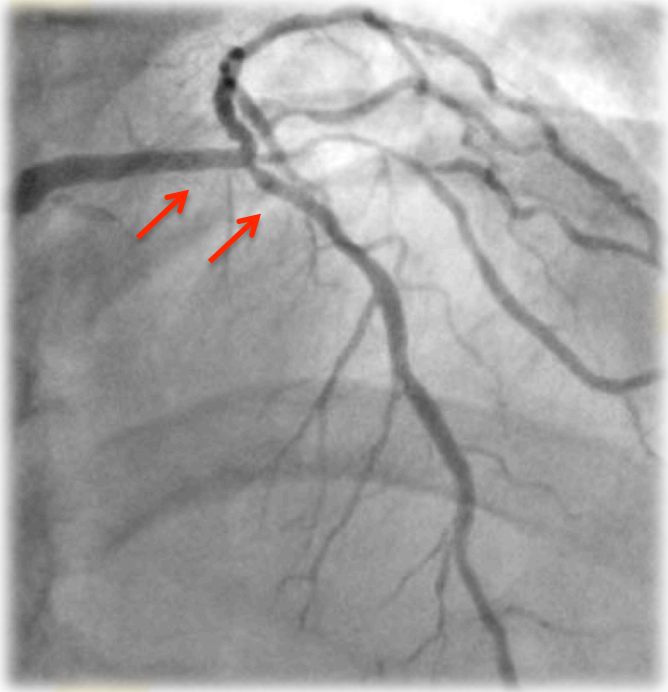
CT angiography: Significant stenosis at LAD ostium and mid RCA
Invasive angiography: Stenosis at left main to LAD ostium and mid RCA♪

Which lesion is causing myocardial ischemia?

Left main? LAD? RCA? All?♪

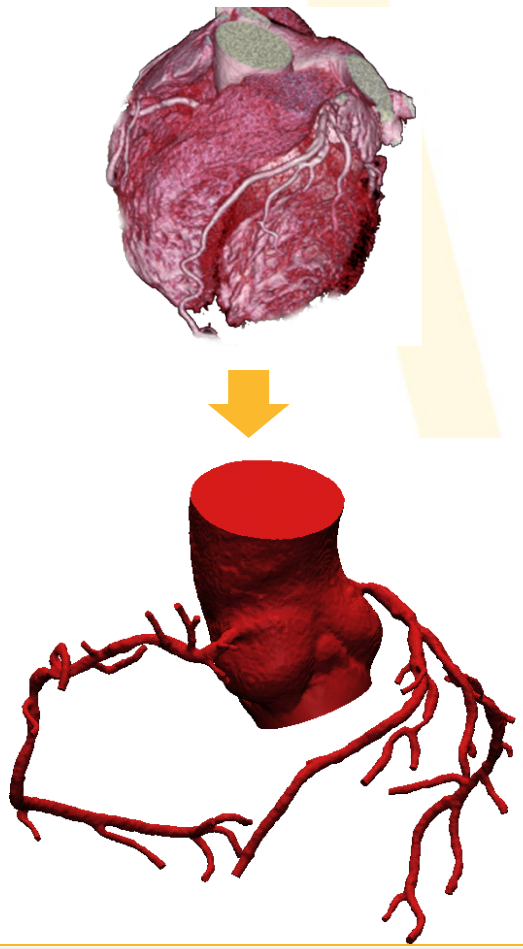




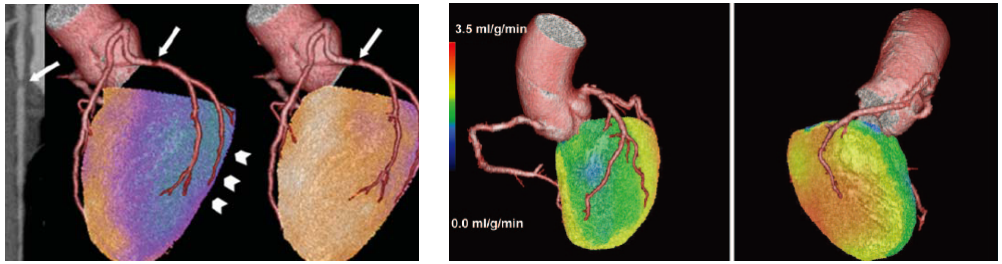


Non-invasive FFR (functional assessment of CAD)

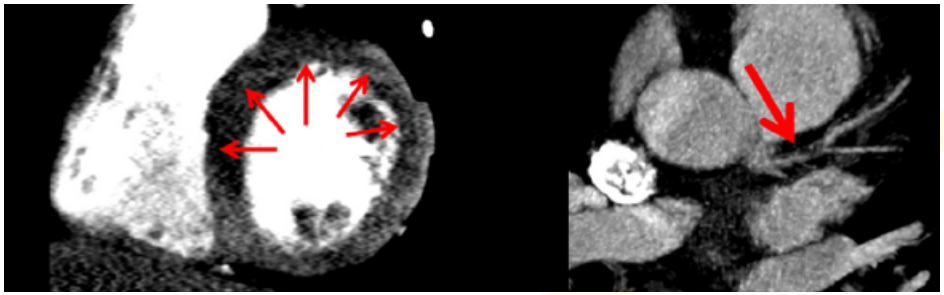
3-D Model based on CCTA



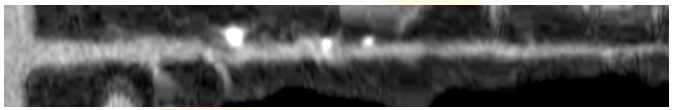
Hybrid imaging: CCTA + SPECT/PET

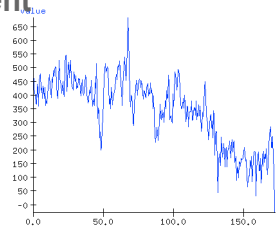


Stress CT perfusion imaging



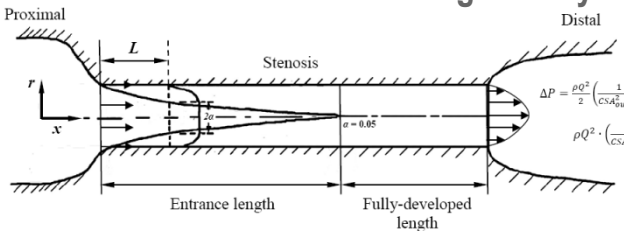
Transluminal attenuation gradient





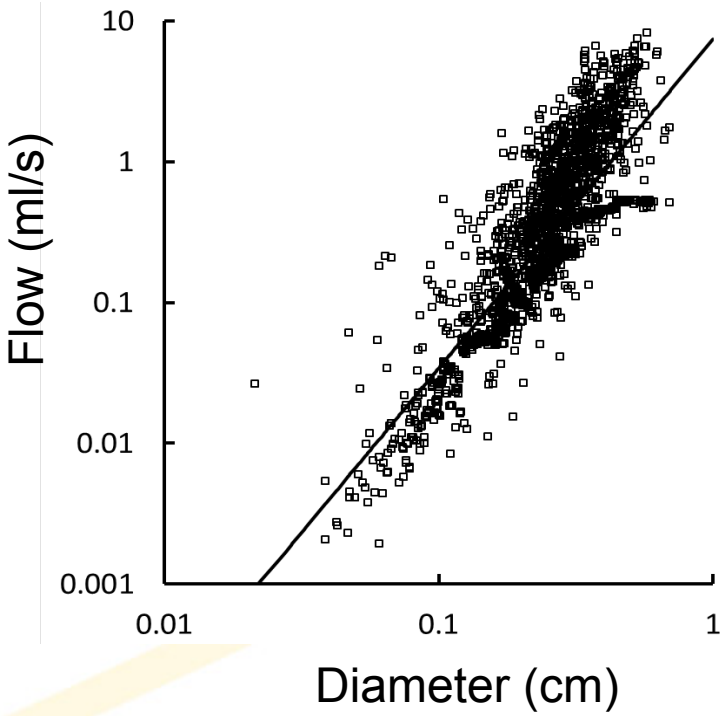
TAG = -15.42 (HU/10mm)

Estimation from geometry of stenosis



$$\Delta P = \frac{\rho Q^2}{2}\left(\frac{1}{CSA_{outlet}^2} - \frac{1}{CSA_{inlet}^2}\right) + \frac{\rho Q^2}{2 \cdot CSA_{stenosis}^2}\frac{96}{5}\int_{0.05}^{1}\frac{(1+4\alpha+9\alpha^2+4\alpha^3)}{\alpha(3+2\alpha)(3+2\alpha+\alpha^2)^2}d\alpha + \int_0^{L_{vessel}-L_{entrance}}\frac{8\pi\mu}{CSA^2}Q dx + \rho Q^2 \cdot \left(\frac{1}{CSA_{stenosis}} - \frac{1}{CSA_{distal}}\right)\cdot\left(\frac{1}{CSA_{stenosis}} - \frac{1}{3}\cdot\frac{1}{CSA_{distal}}\right) \quad [A12]$$

Flow-Diameter Scaling Law

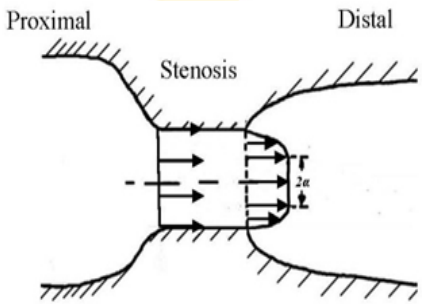


Terminal resistance comes from the reconstruction of microstructure

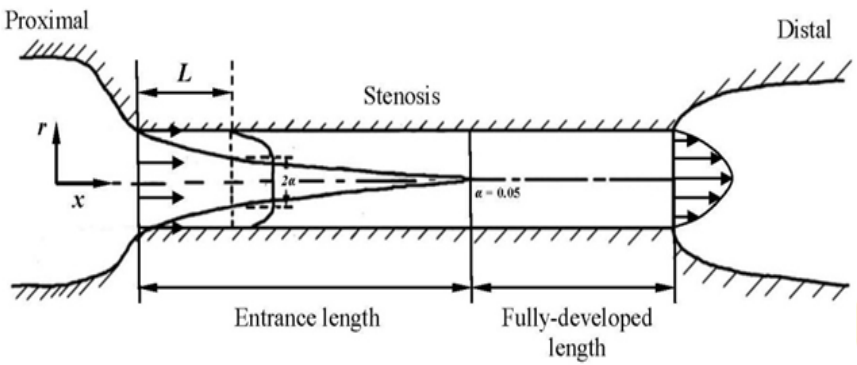
$$Q_s = 7.4 \cdot D_s^{\frac{7}{3}} \; (\mathrm{R}^2 = 0.75)$$

Courtesy of Professor Kassab, USA♪

FFR from theoretical Model



$$\text{FFR} = \frac{P_{distal}}{P_a} = \frac{P_a - \Delta P}{P_a}$$



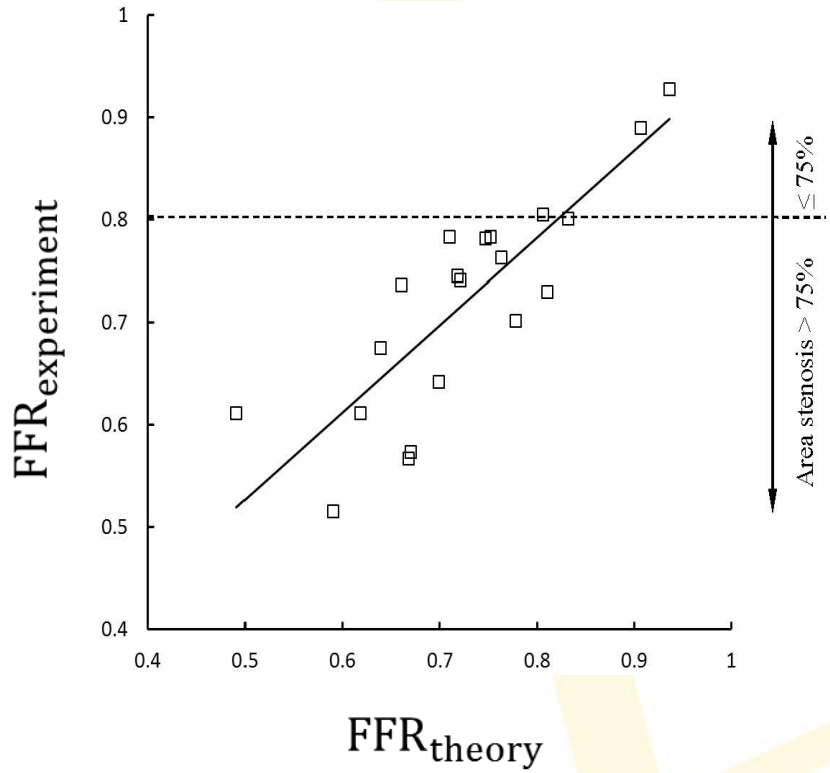
$$\Delta P = \Delta P_{convective} + \Delta P_{diffusive} + \Delta P_{expansion}$$

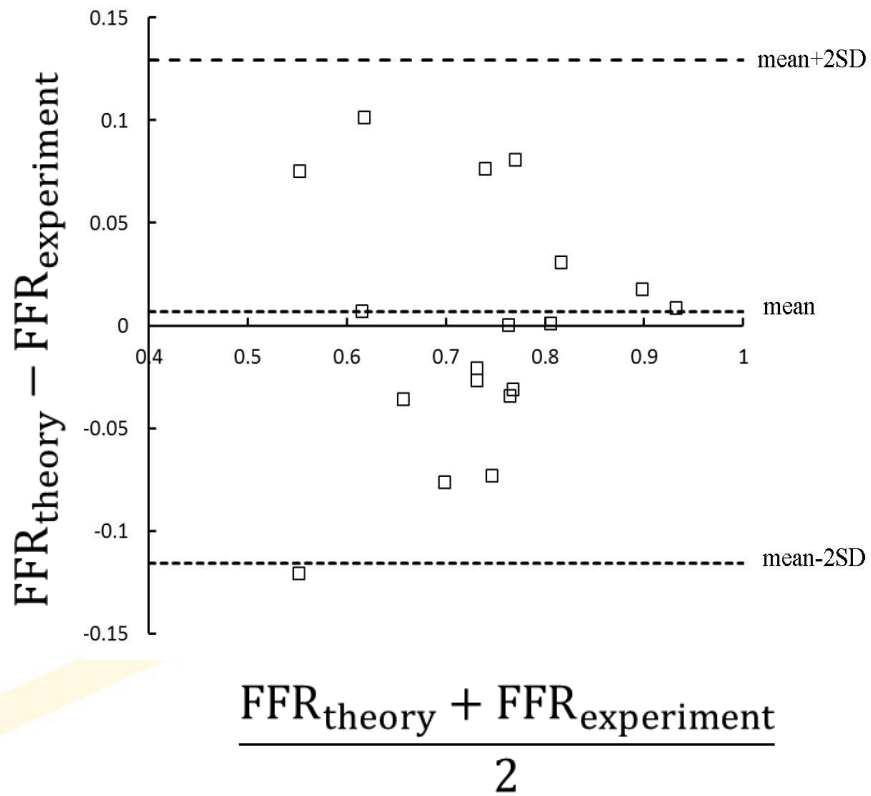
We provide a validated analytical equation for short (top) or long (bottom) lesion:

$$\Delta P = f(\text{Q, Lesion Dimension, Proximal and Distal CSA})$$

Courtesy of Professor Kassab, USA♪

Calculated vs. Measured FFR



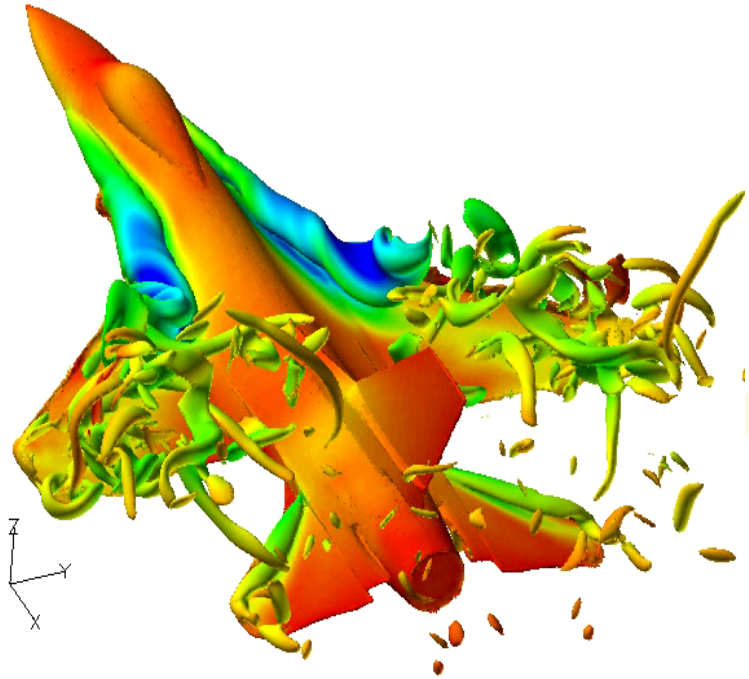


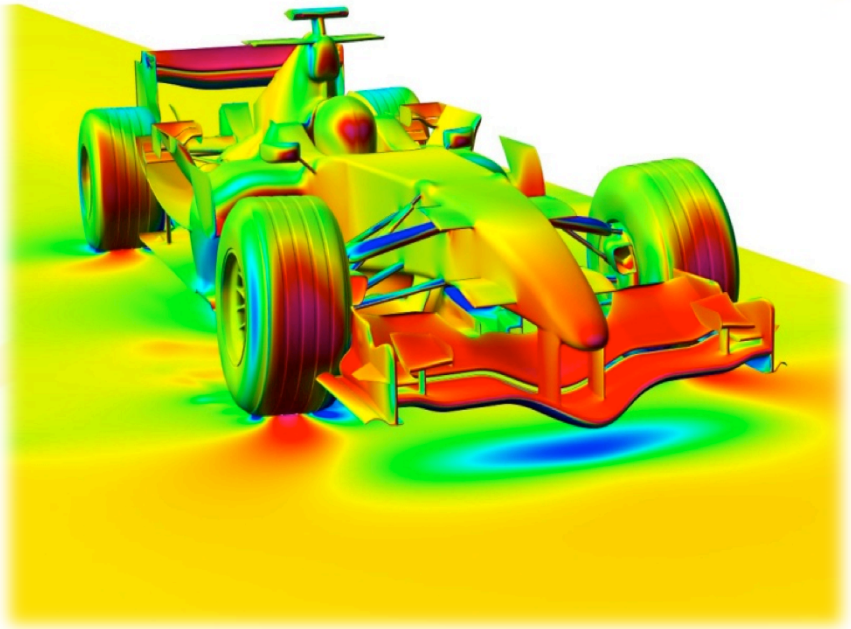
Can predict below and above 0.75 threshold with accuracy between 92% and 95%.

Courtesy of Professor Kassab, USA

Computational Fluid Dynamics (CFD)

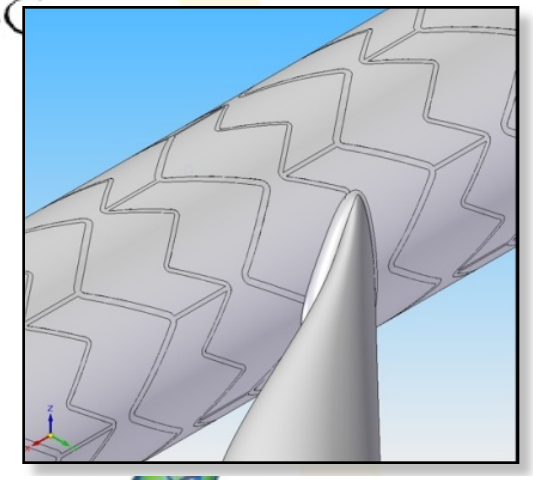
- Computational fluid dynamics (CFD) quantifies fluid pressure and velocity, based on physical laws of mass conservation and momentum balance
- CFD is widely used in the aerospace and automotive industries for design and testing

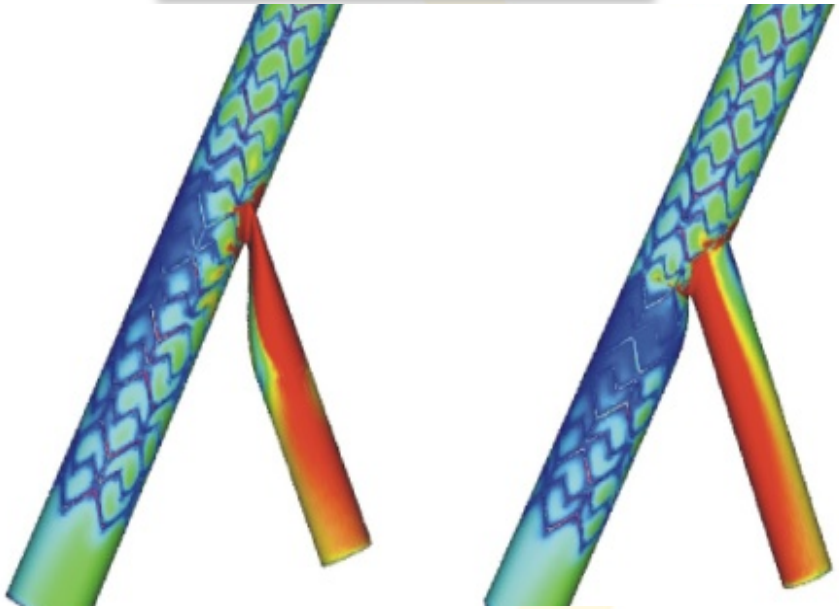




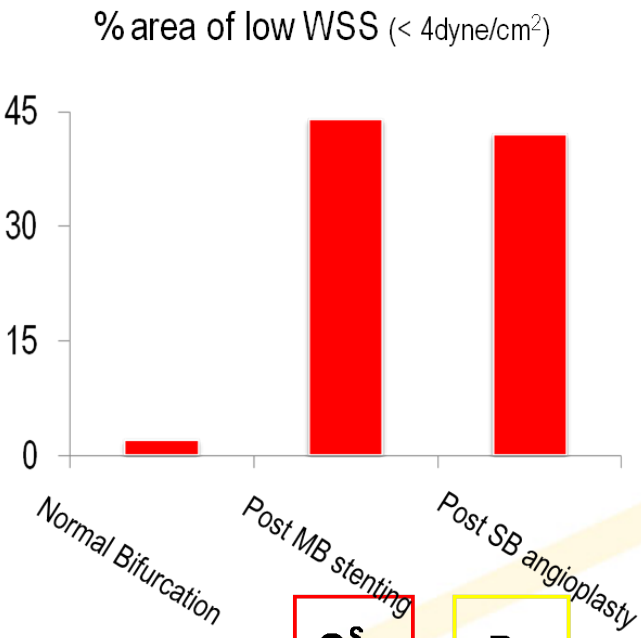
Courtesy of Charles Tayler, PhD♪

CFD in simple and idealized coronary models

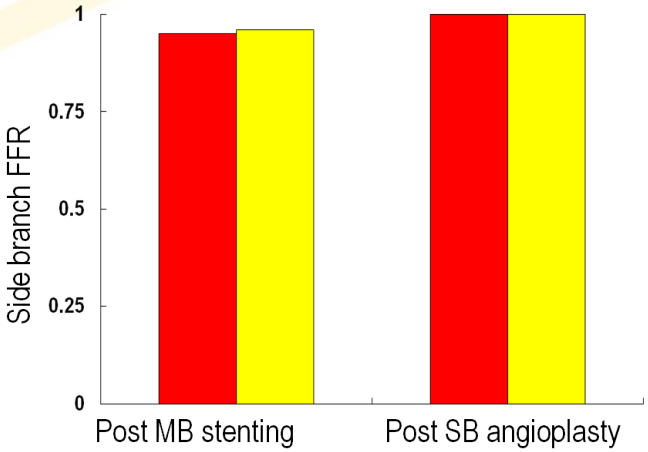




Post MB stenting Post SB angioplasty

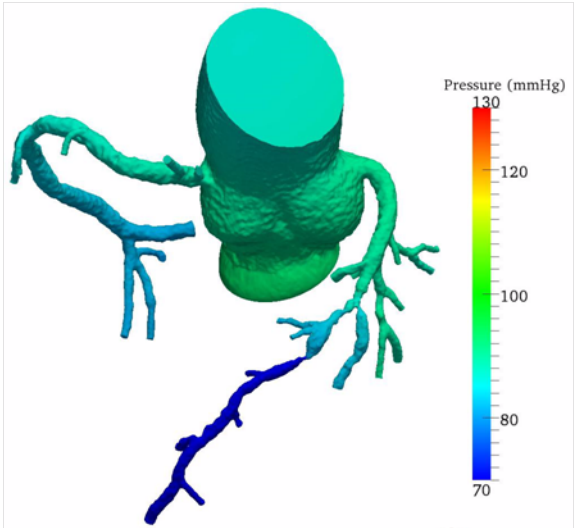


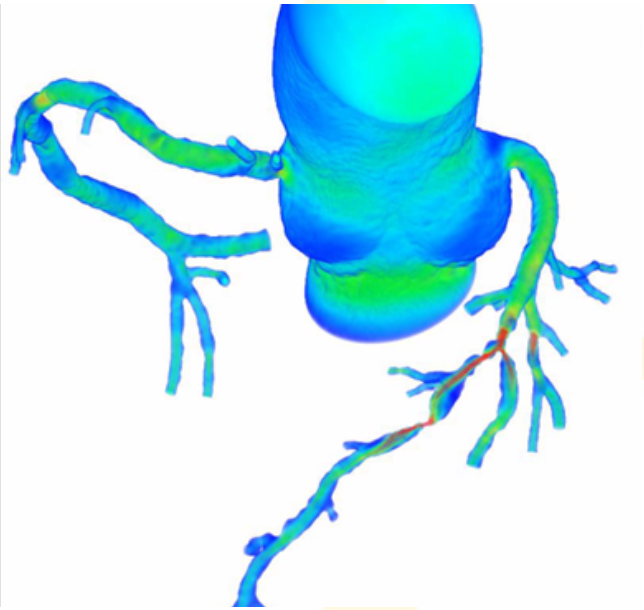
$$FFR = \frac{Q^{S}_{max}}{Q^{N}_{max}} = \frac{P_d}{P_a}$$

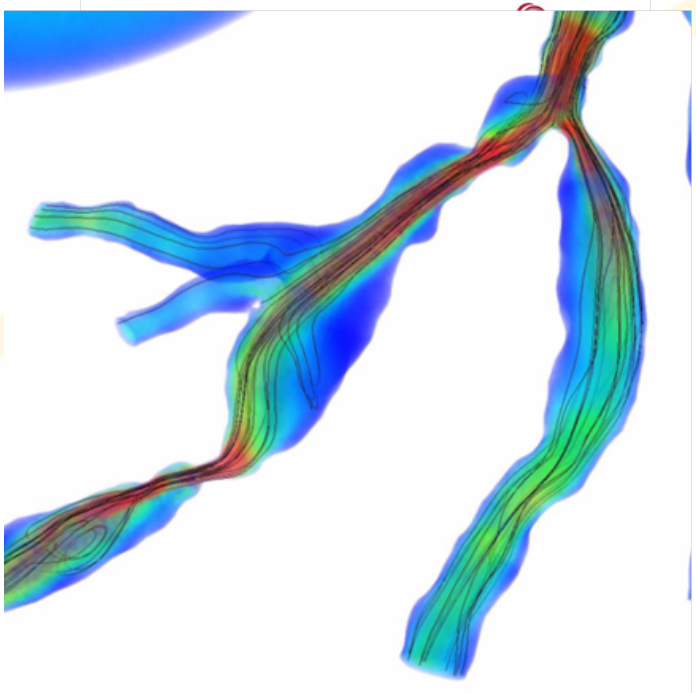


Koo BK, European bifurcation club, 2009♪

Potential of patient-specific CFD analysis







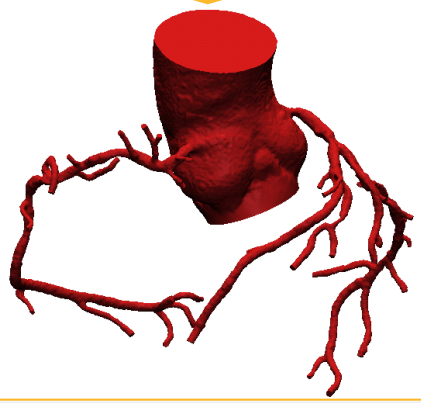
Koo BK, European Bifurcation Club,2010♪

Non-invasive FFR (FFR_{CT})

Computational Model based on CCTA

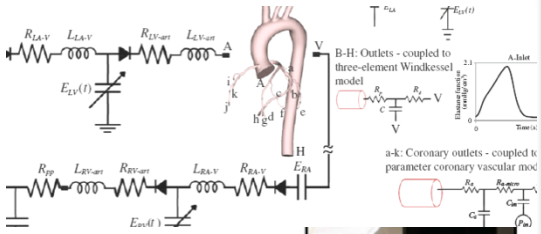
3-D anatomic model from CCTA

No additional imaging
No additional medications♪



Blood Flow Solution

Blood flow equations solved on supercomputer

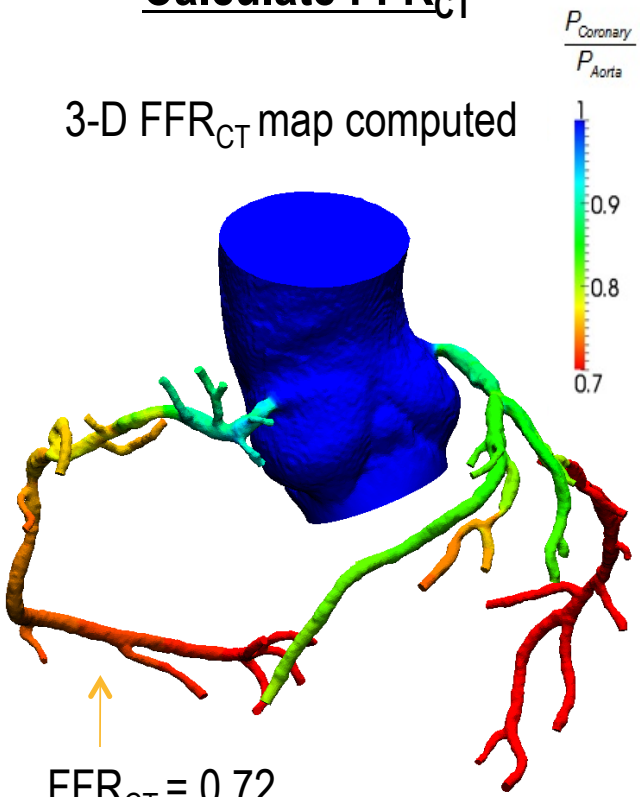


$$\rho \bar{v}_{,t} + \rho \bar{v} \cdot \nabla \bar{v} = -\nabla p + \nabla \cdot \tau$$
$$\nabla \cdot \bar{v} = 0$$

Physiologic models
-Myocardial demand
-Morphometry-based boundary condition
-Effect of adenosine on microcirculation

Calculate FFR_{CT}

3-D FFR_{CT} map computed



FFR_{CT} = 0.72
(can select any point on model)

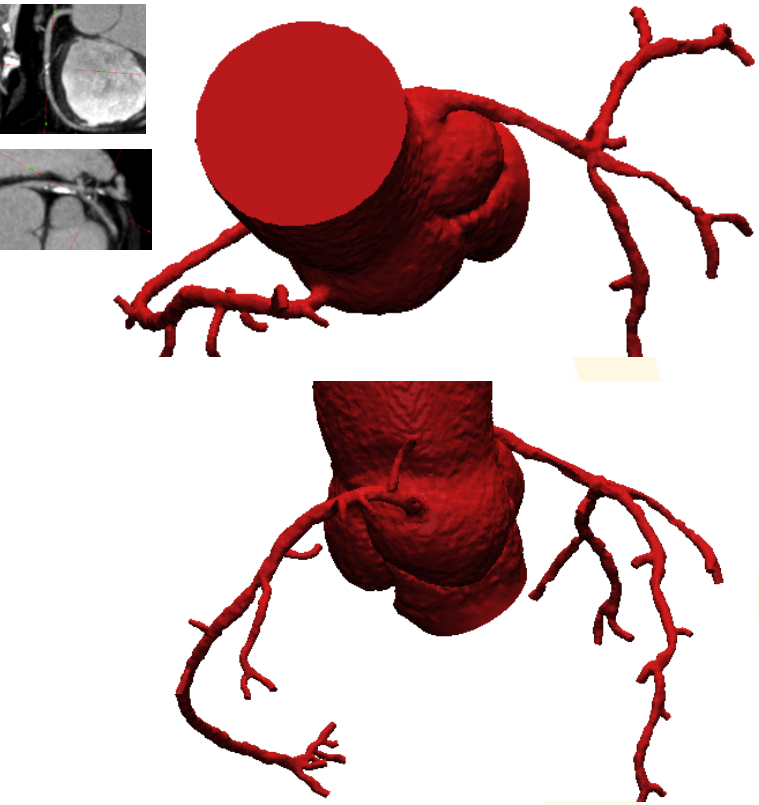
Koo BK, EuroPCR 2011♪

M/63 Stable angina

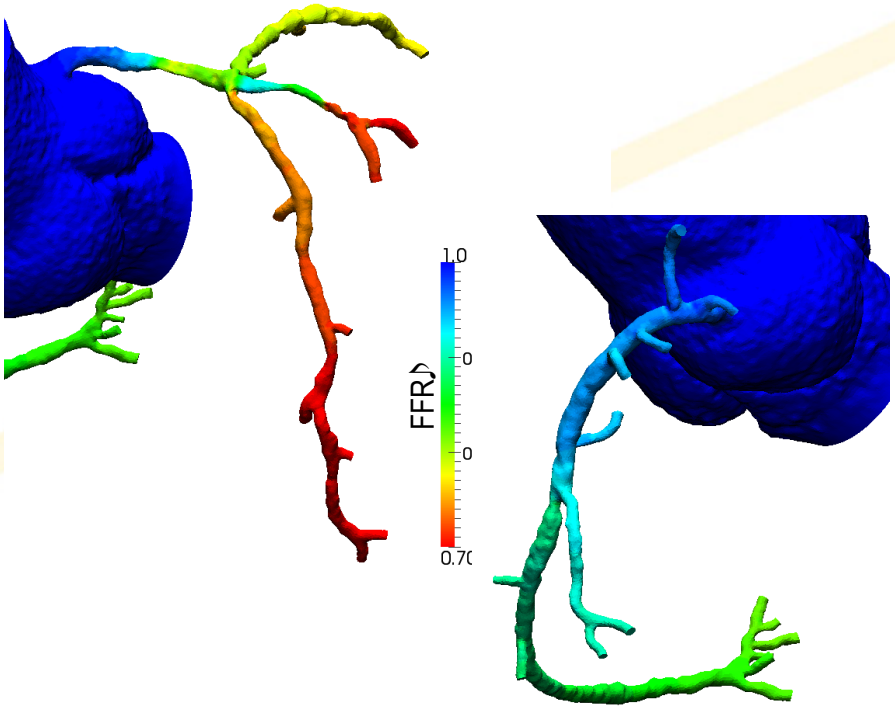
Risk factors: Hypertension, Hypercholesterolemia♪

Application of FFR_{CT}

Reconstruction of coronary anatomy using CCTA

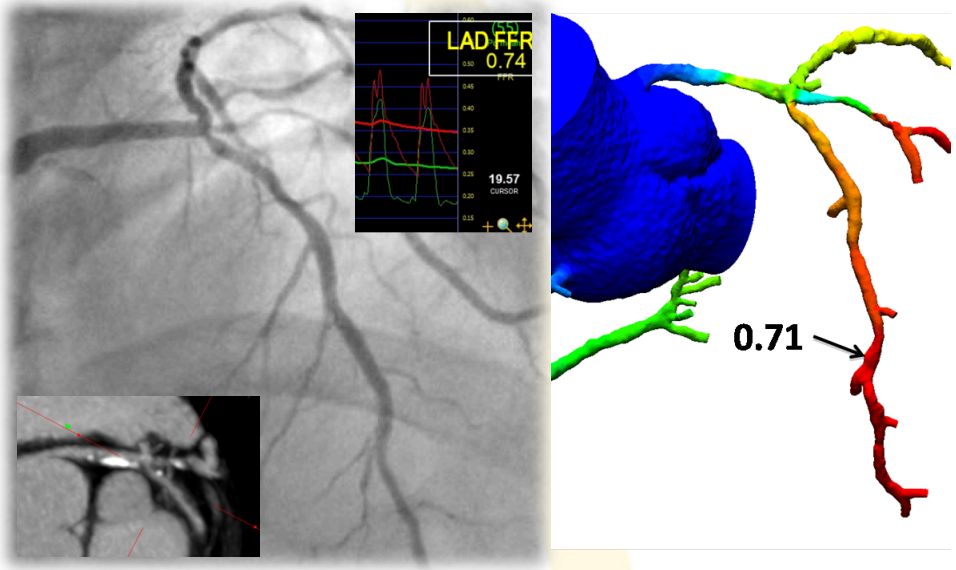


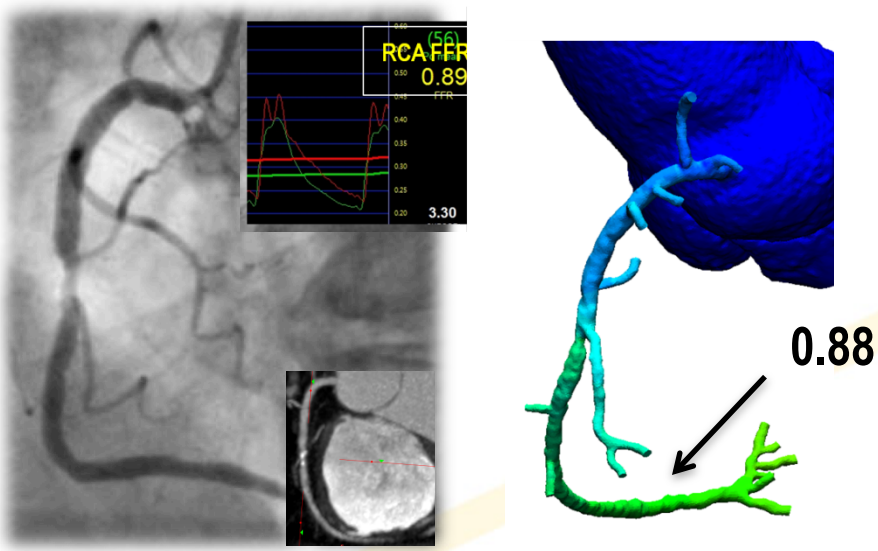
Measurement of non-invasive computed FFR (FFR_{CT}) using computational fluid dynamics



Koo BK, Euro PCR 2011♪

Invasive FFR vs. Non-invasive FFR_{CT}♪





CCTA: 2 vessel disease

Non-invasive FFR_{CT}: 1 vessel disease

} **Non-invasive assessment prior to the cath lab♪**

Angiography: 2 vessel disease

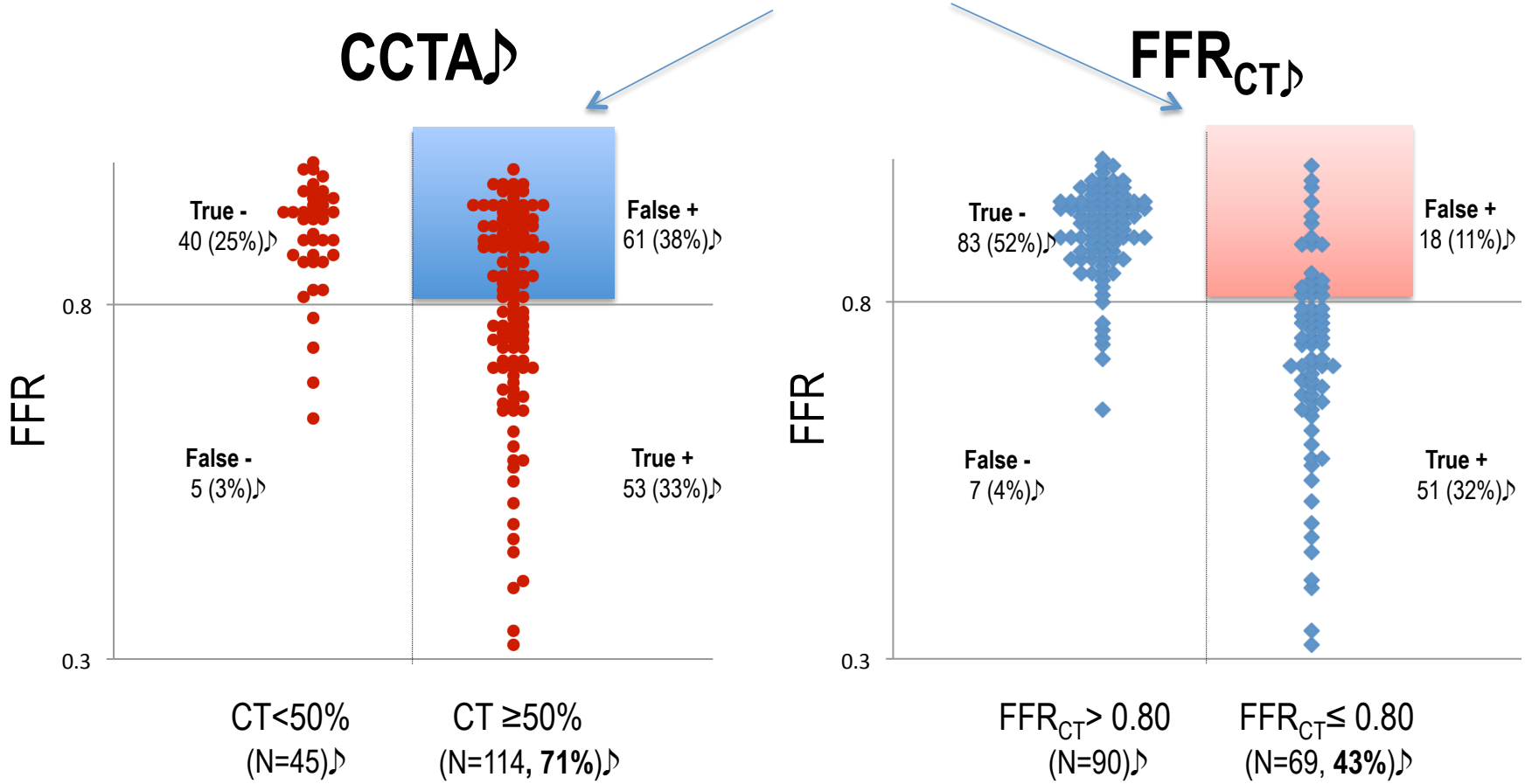
Invasive FFR: 1 vessel disease♪

} **Invasive assessment in the cath lab♪**

Koo BK, Euro PCR 2011♪

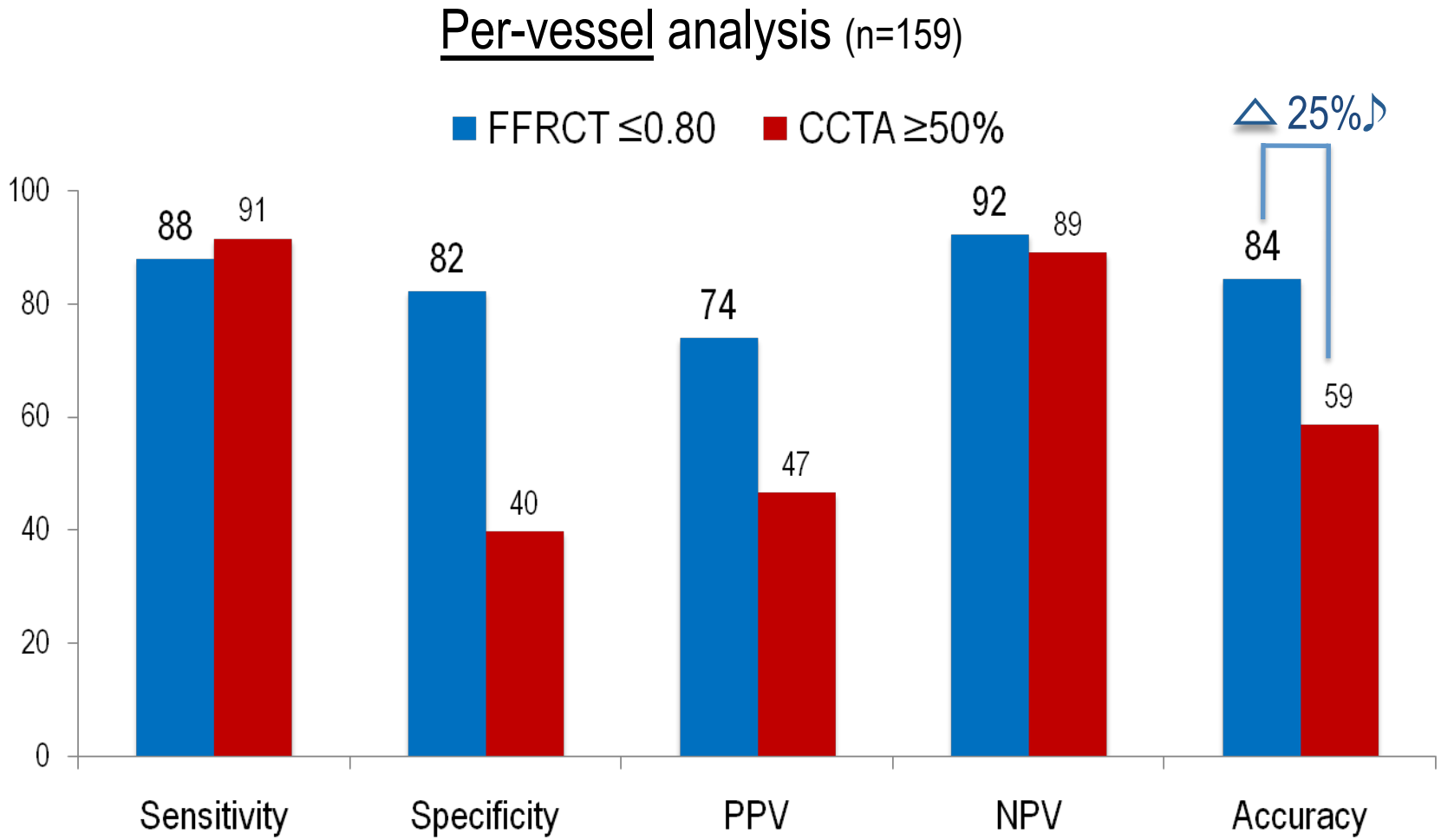
DISCOVER-FLOW study (n=159)

Reduction of false positives: 70%



Koo BK, et al. J Am Coll Cardiol 2011 in press

Diagnostic performance of FFR_{CT} and CCTA



PPV: positive predictive value, NPV: negative predictive value

Koo BK, et al. J Am Coll Cardiol 2011 in press

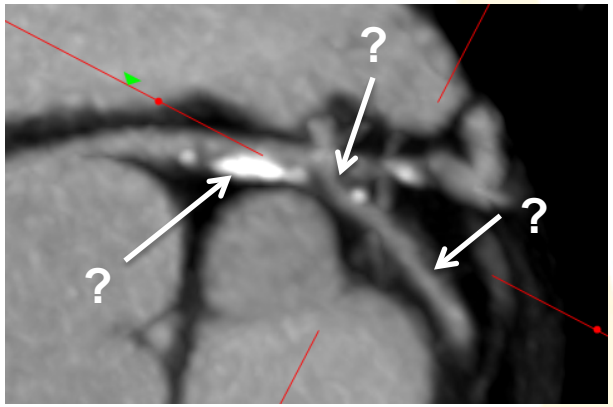
M/63 Stable angina
Risk factors: Hypertension, Hypercholesterolemia♪

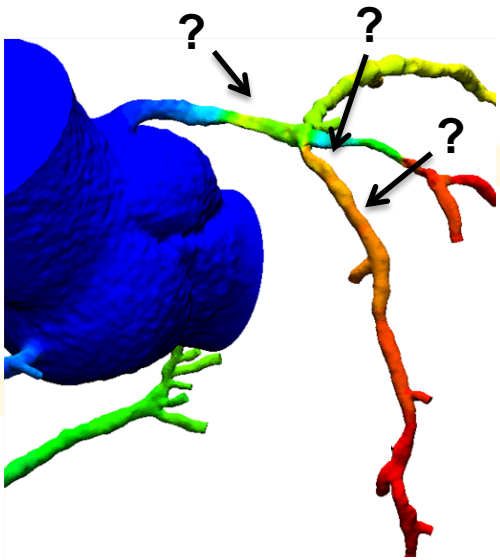
What is the best treatment plan for the patient?♪

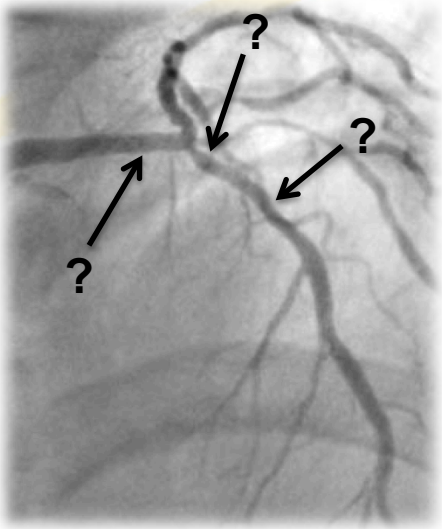
Which lesions are flow limiting?

How many stents are needed?

What effect does a stent have on flow through other lesions?

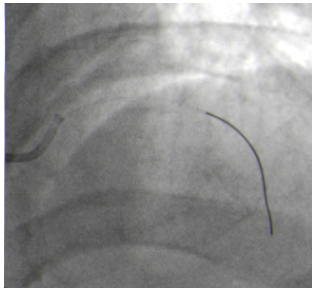




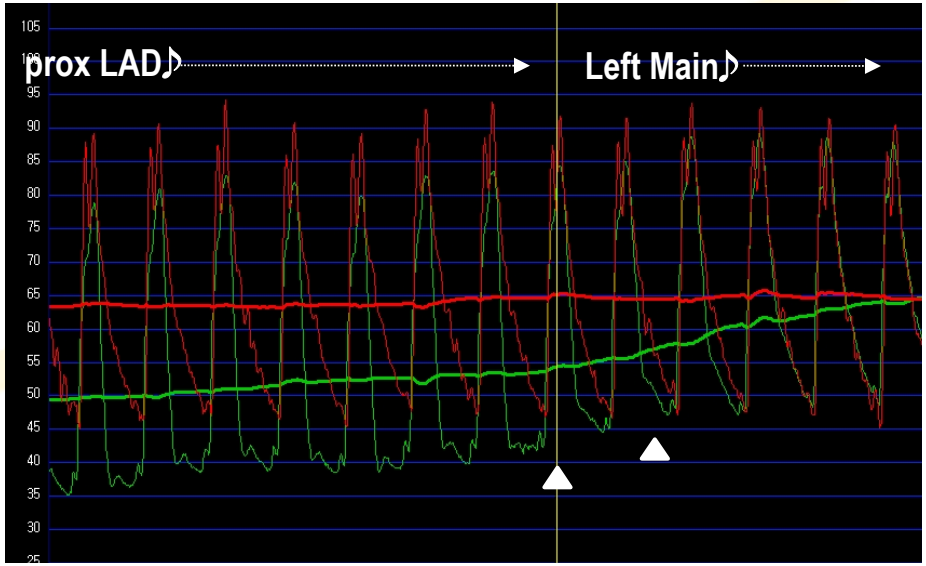


Koo BK, Euro PCR 2011♪

What is the best treatment plan for the patient?♪



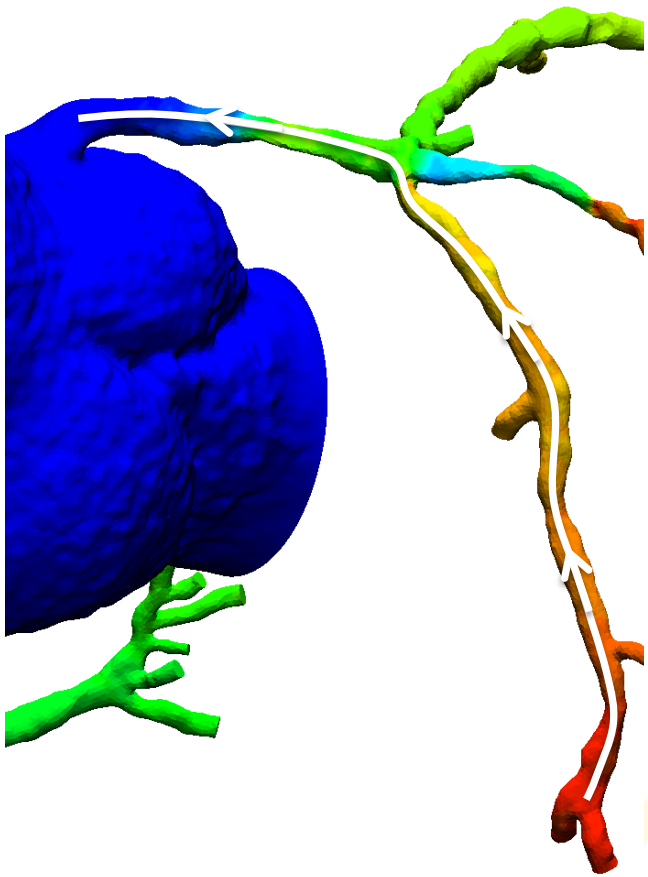
Pressure pull-back tracing♪

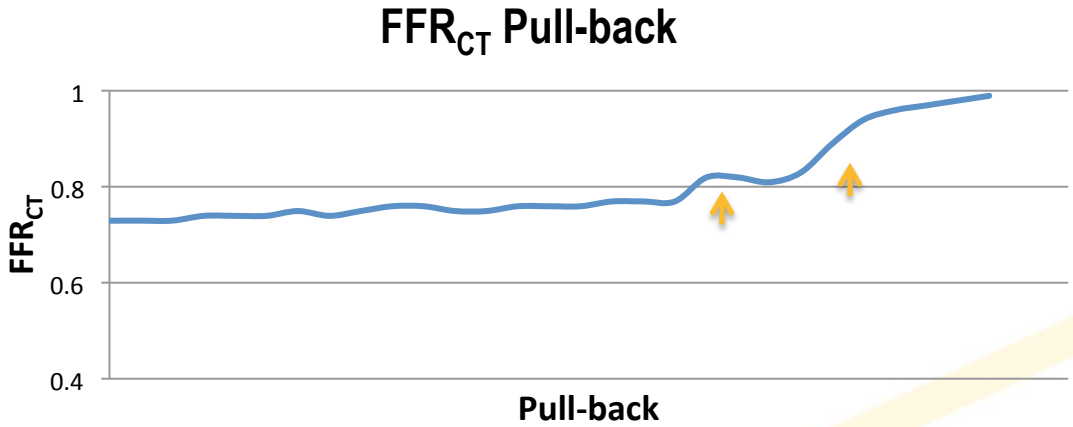


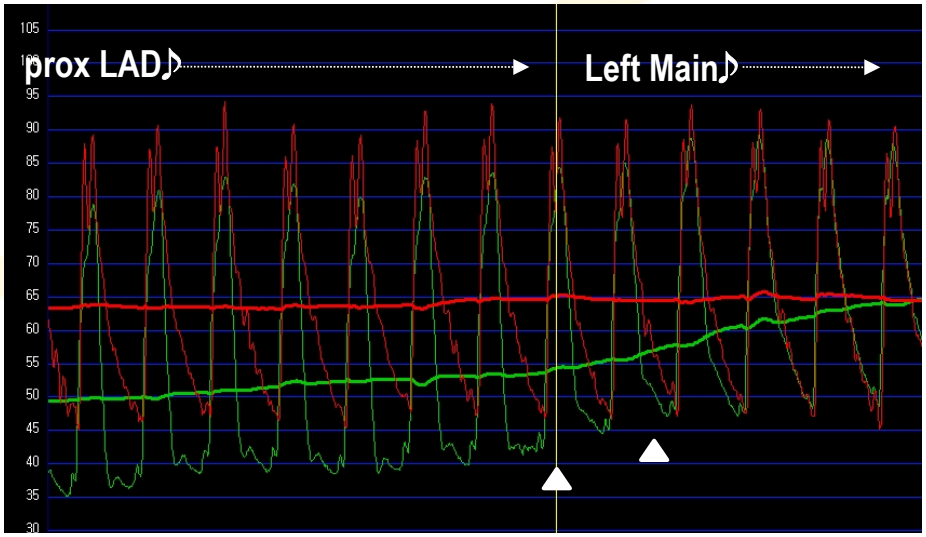
Pd♪ 49mmHg♪ 57mmHg♪ 63mmHg♪

Koo BK, Euro PCR 2011♪

FFR_{CT} pull-back vs. Pressure wire pull-back





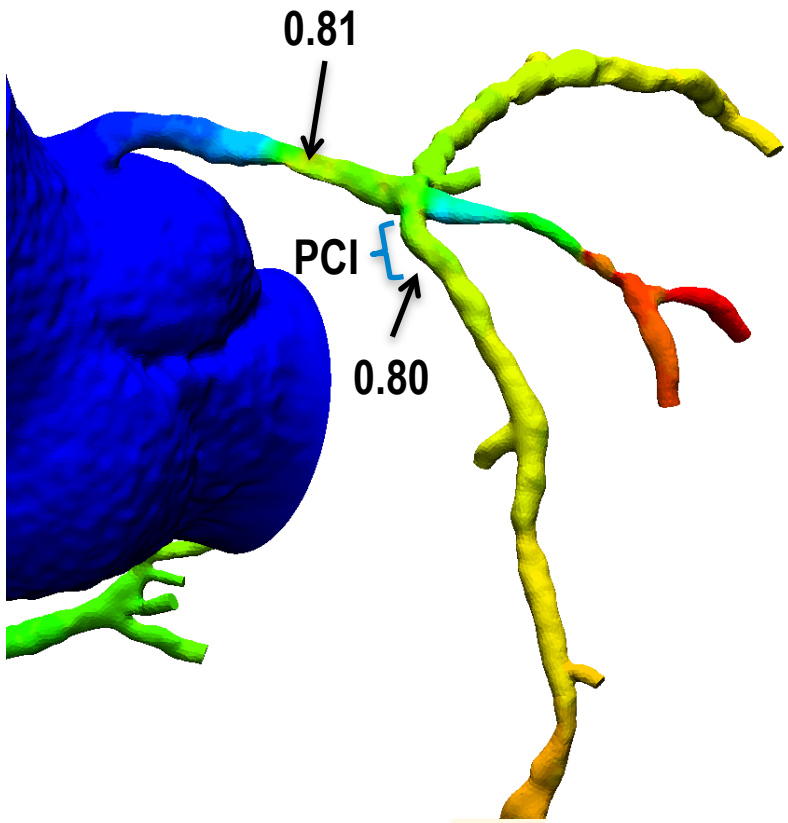


Koo BK, Euro PCR 2011♪

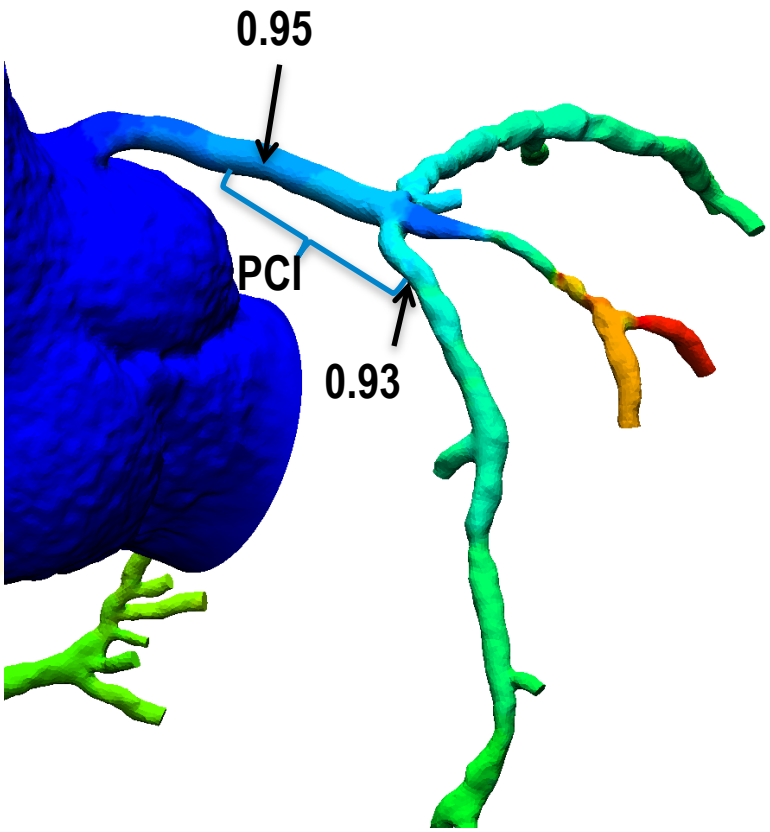
Treatment planning prior to invasive procedures

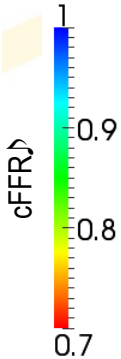
Virtual PCI and post-PCI FFR_{CT}♪

After LAD os PCI



After Left main and LAD os PCI





Koo BK, Euro PCR 2011♪

Summary♪

- FFR can be determined prior to invasive procedures using a novel technologies using CT scans.
- This case showed that computed FFR can predict the functional significance of coronary stenoses and can also be helpful in planning the treatment strategy.
- Further studies are needed……..

Acknowledgement

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