A Reason Why Visual-Functional Mismatch Happens:
Insights from Mathematical Models

Imaging & Physiology Summit 2015

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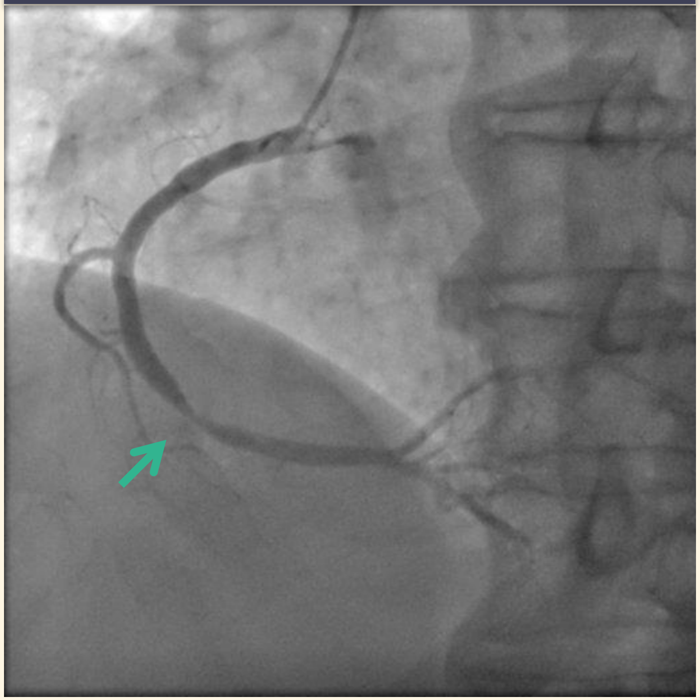
Imaging and Physiology Sometimes Do Not Agree

- Visual-Functional Mismatch

- Reverse Mismatch

Visual-Functional Mismatch

Imaging



Physiology

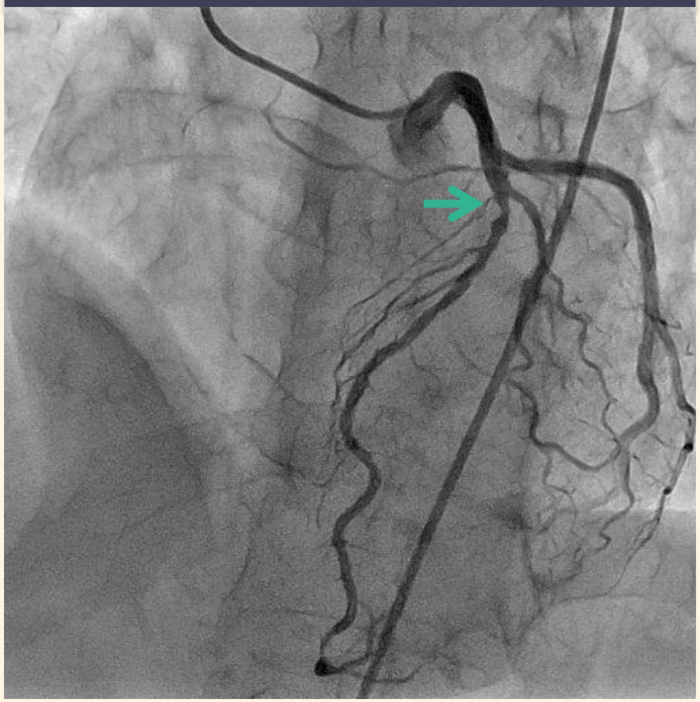
Visual Estimation: 90%

FFR: 0.92

Intervention was Deferred

Reverse Mismatch

Imaging



Physiology

Visual Estimation: 50%

FFR: 0.79

Intervention was Conducted

Imaging and Physiology Sometimes Do Not Agree

- Mismatch

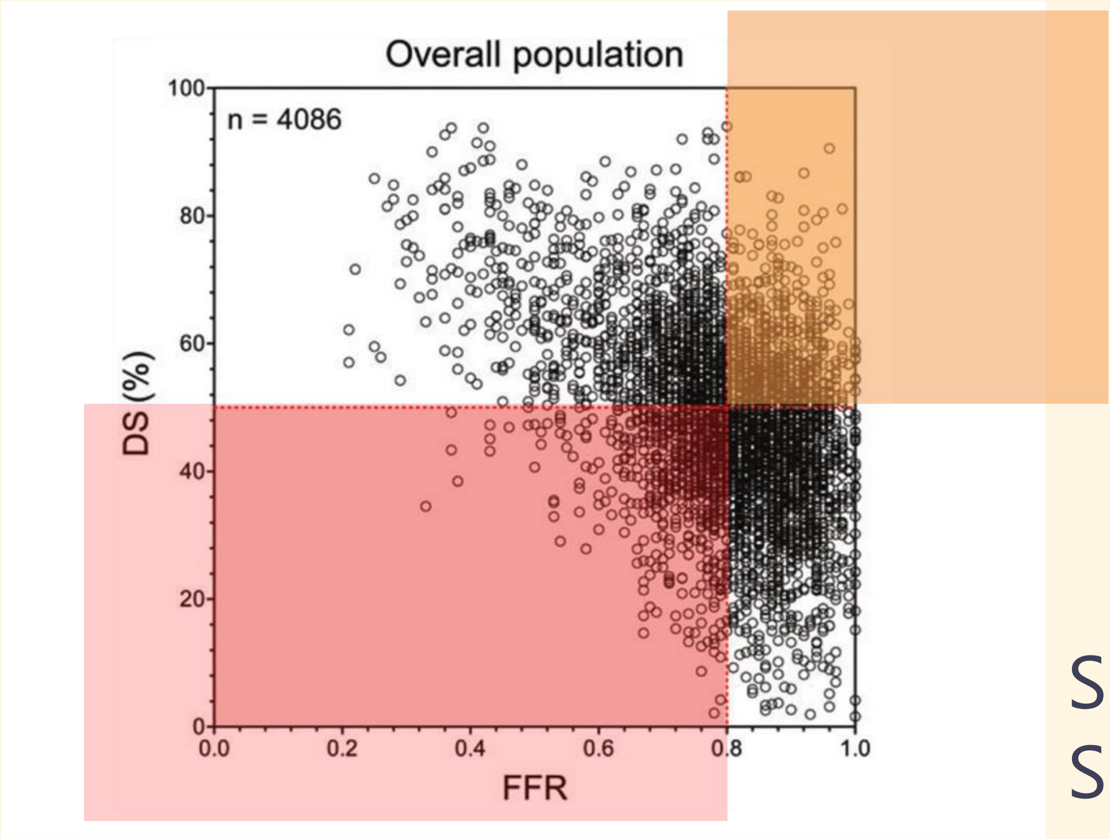
  = Significant Stenosis, But Negative FFR

- Reverse Mismatch

  = Insignificant Stenosis, But Positive FFR

Angiography-FFR Mismatch

Mismatch



Sensitivity: 0.61
Specificity: 0.67

Reverse Mismatch

Discordance Between Angiography and FFR = 35%

Eur Heart J. 2014;35(40):2831-2838.

IVUS and OCT

Meta-Analysis
15 Studies, 2,581 Patients and 2,807 Lesions

	OCT-MLA	IVUS-MLA
Pooled Sensitivity	0.81 [0.74-0.87]	0.68 [0.65-0.71]
Pooled Specificity	0.77 [0.71-0.83]	0.68 [0.66-0.70]

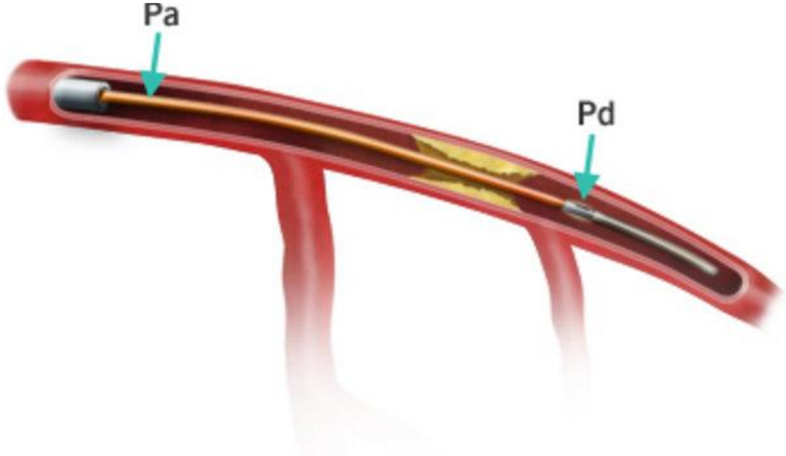
Despite improvement, IVUS and OCT do not predict functional stenosis, even with dedicated cutoff.

Am Heart J. 2015;169(5):663-673.

Why Mismatch Happen?

Going Back to the Original Definition of FFR_{myo}

Daily Practice: Pressure is Measured



$$FFR_{myo} = \frac{P_d - P_v}{P_a - P_v} \doteqdot \frac{P_d}{P_a}$$

Pressure

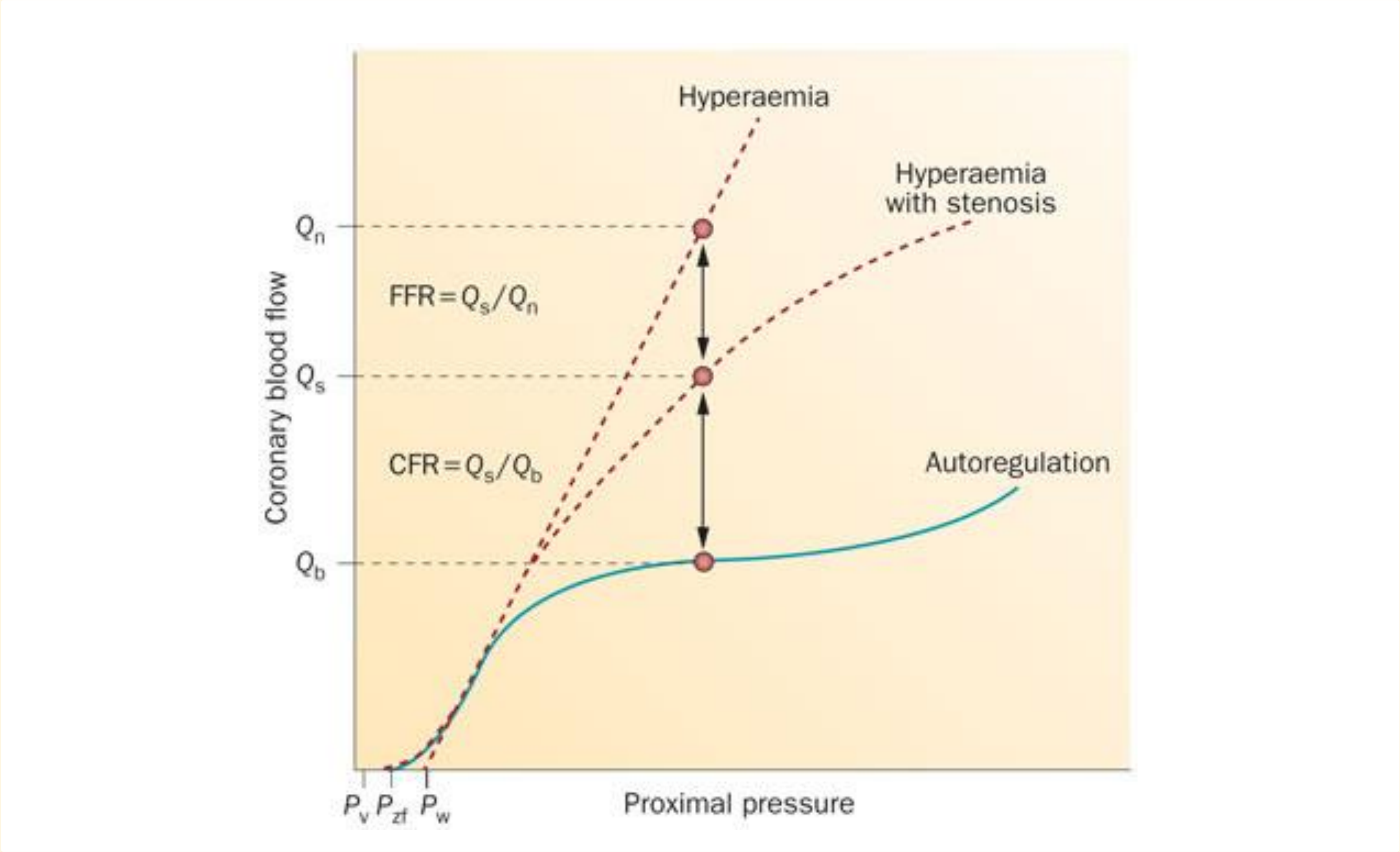
Original Definition: Flow is Required

$$FFR_{myo} = \frac{maximum\ myocardial\ blood\ flow\ distal\ to\ an\ epicardial\ stenosis}{maximum\ myocardial\ blood\ flow\ if\ no\ epicardial\ stenosis\ present} = \frac{Q}{Q^N}$$

Flow

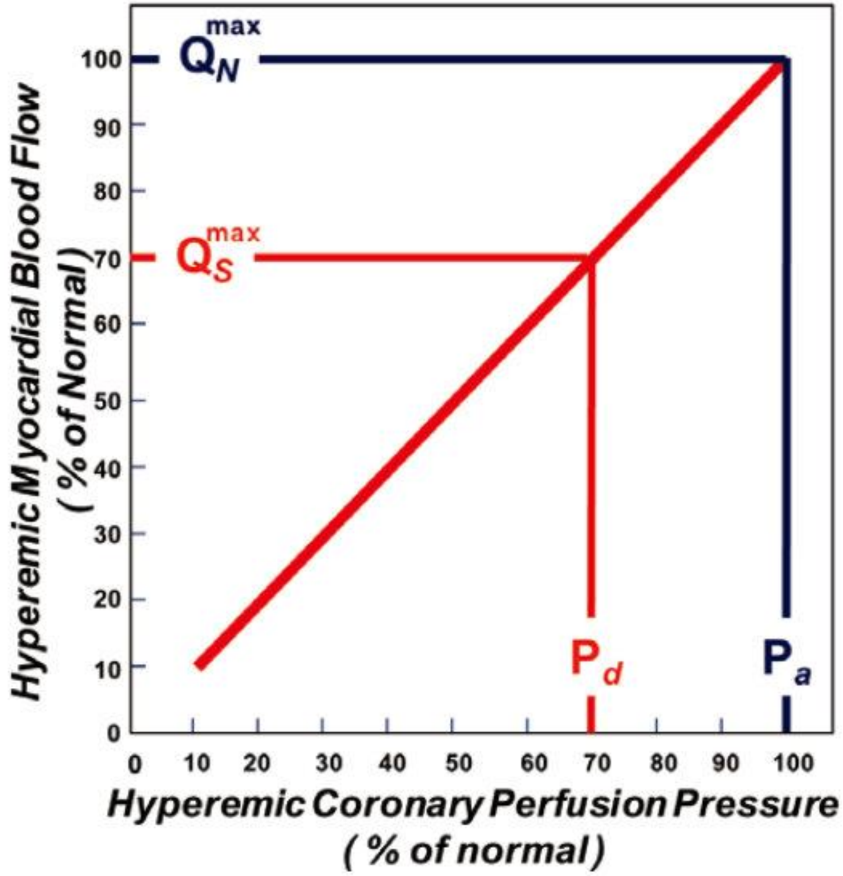
Pijls NH, De Bruyne B *Circulation*. 1993;87(4):1354-1367.

No Autoregularion@Hyperemia



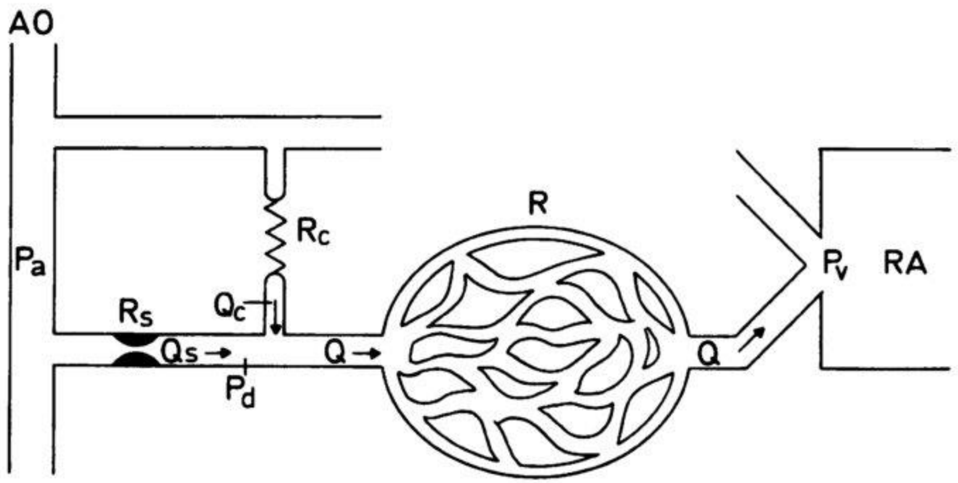
Nat Rev Cardiol. 2012;9(4):243-52.

Flow is Proportional to Pressure @Hyperemia



Pijls NHJ. *Circ J*. 2012;77(3):561-569.

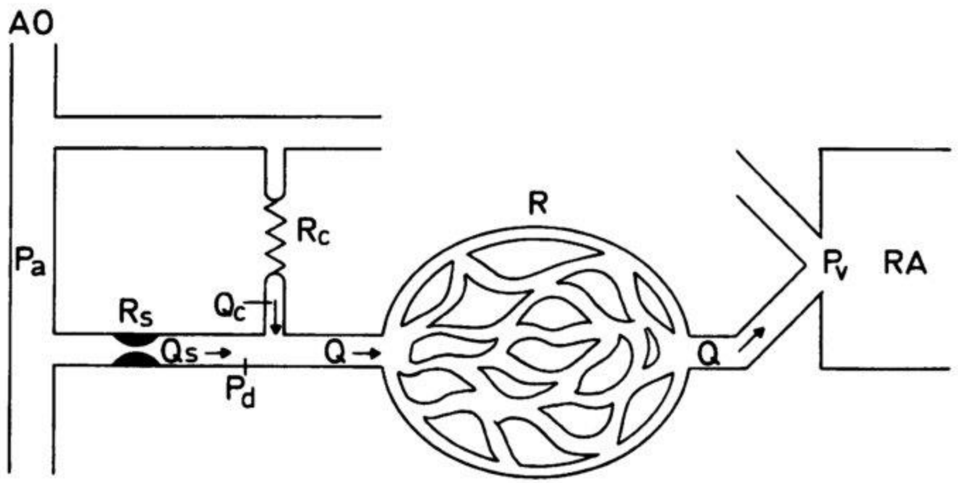
How Pressure is Converted to Flow:
P = Q x R



$$FFR_{myo} = \frac{Q}{Q^N} = \frac{\frac{P_d - P_v}{R}}{\frac{P_a - P_v}{R}} = \frac{P_d - P_v}{P_a - P_v} \fallingdotseq \frac{P_d}{P_a}$$

Pijls NH, De Bruyne B *Circulation*. 1993;87(4):1354-1367.

FFR_{myo}: Expressed in Terms of Resistance



$$FFR_{myo} = \frac{R(R_s + R_c)}{R_s R_c + R(R_s + R_c)}$$

FFR_{myo} expressed in terms of resistance clearly indicates that FFR_{myo} is determined not only by the stenosis (R_s), but also by the myocardial bed (R) and the collateral circulation (R_c).

P = Q x R

1. Flow

$$FFR_{myo} = \frac{Q}{Q^N} \quad (A)$$

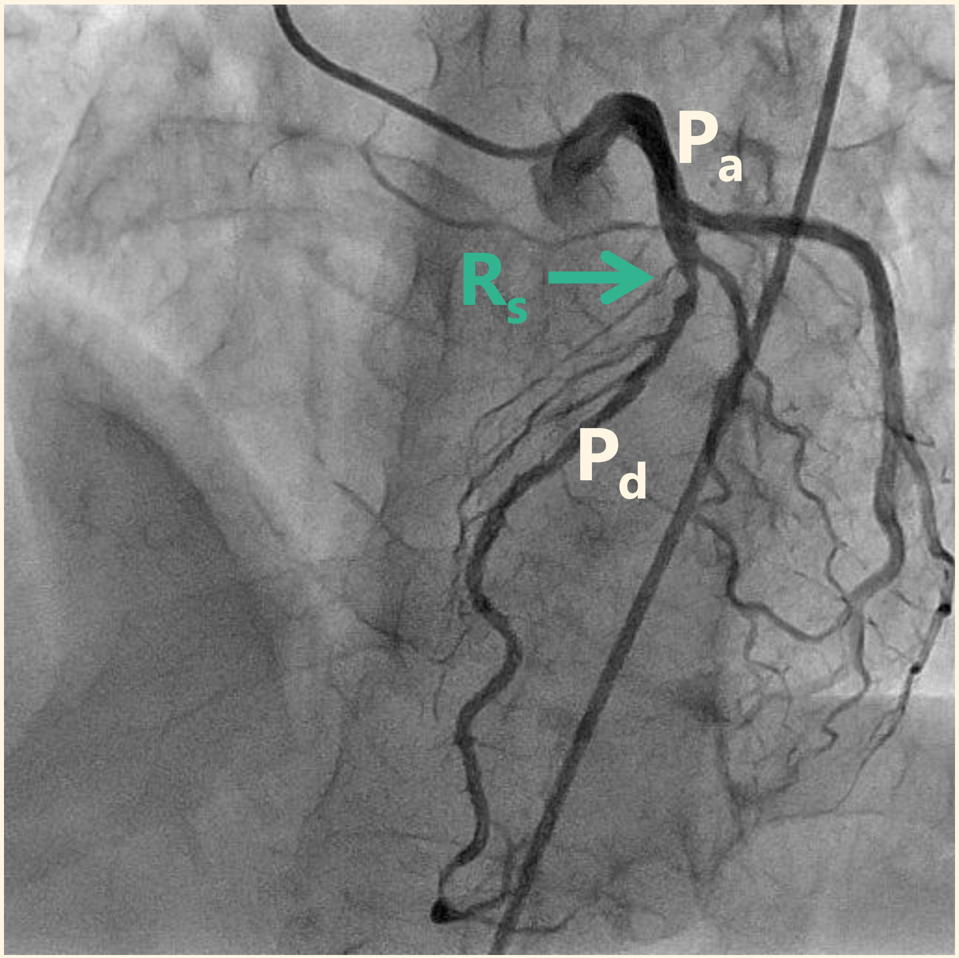
2. Pressure

$$FFR_{myo} = \frac{P_d}{P_a} \quad \text{(B)}$$

$$FFR_{myo} = \frac{R(R_s + R_c)}{R_s R_c + R(R_s + R_c)} \quad (C)$$

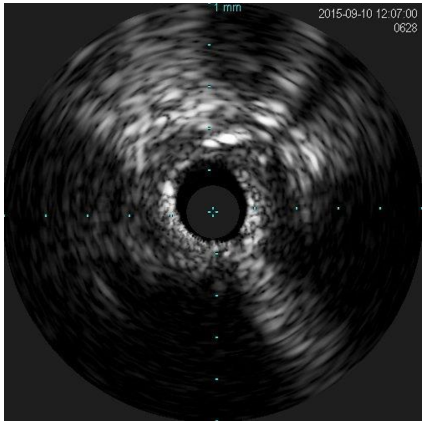
3. Resistance

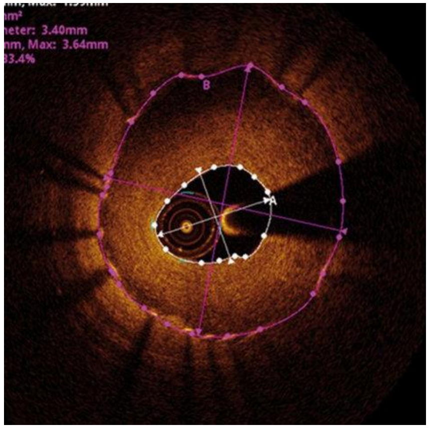
QCA, IVUS, and OCT Analyze Only R_s



FFR: Pressure

$$FFR_{myo} = \frac{P_d}{P_a}$$

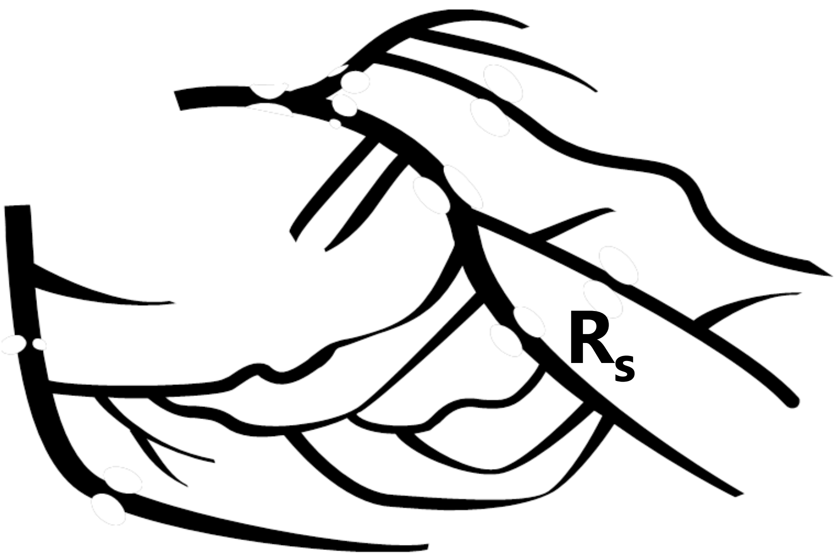




FFR: Resistance

$$FFR_{myo} = \frac{R(\boldsymbol{R_s} + R_c)}{\boldsymbol{R_s}R_c + R(\boldsymbol{R_s} + R_c)}$$

Complex Circulation Model



Epicardial Stenosis = R_{s1}, $R_{s2,,,,,,}R_{sn}$
Myocardial Vascular Bed = R_1, $R_{2,,,,,,}R_m$
Collateral Circulation= R_{c1}, $R_{c2,,,,,,}R_{cl}$

Flow

$$FFR_{myo} = \frac{Q}{Q^N} \quad (A)$$

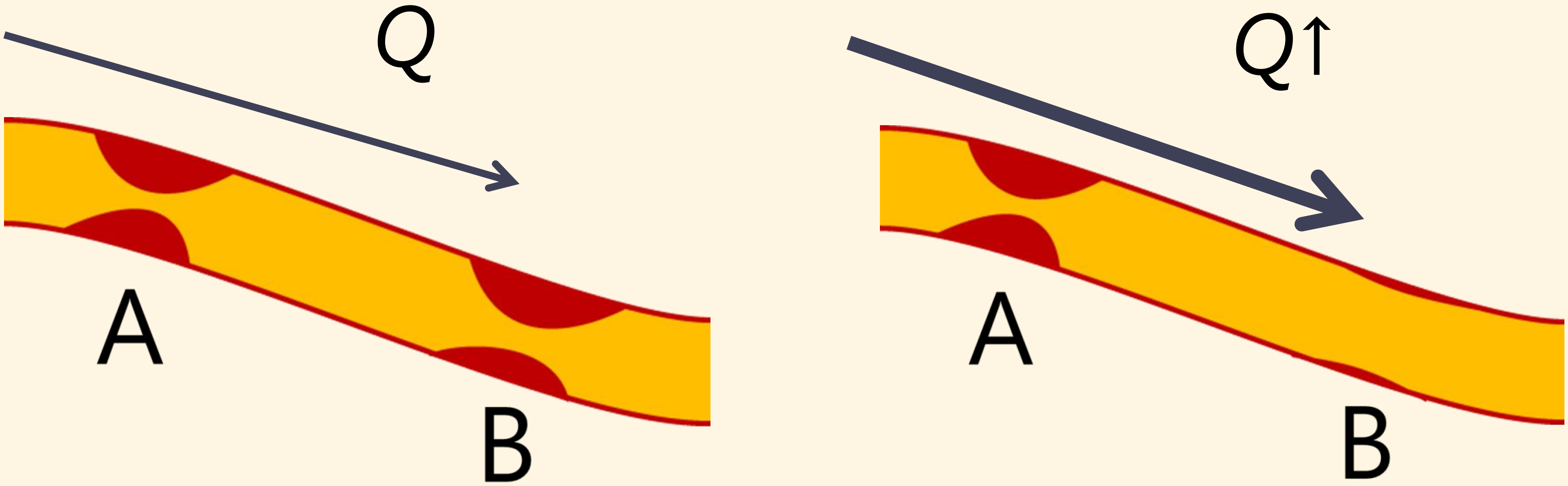
Pressure

$$FFR_{myo} = \frac{P_d}{P_a} \quad (\mathrm{B})$$

$$FFR_{myo} = f(R_{s1},\cdots,R_{sn},R_1,\cdots,R_m\,,R_{c1},\cdots,R_{cl}) \quad (C')$$

Resistance

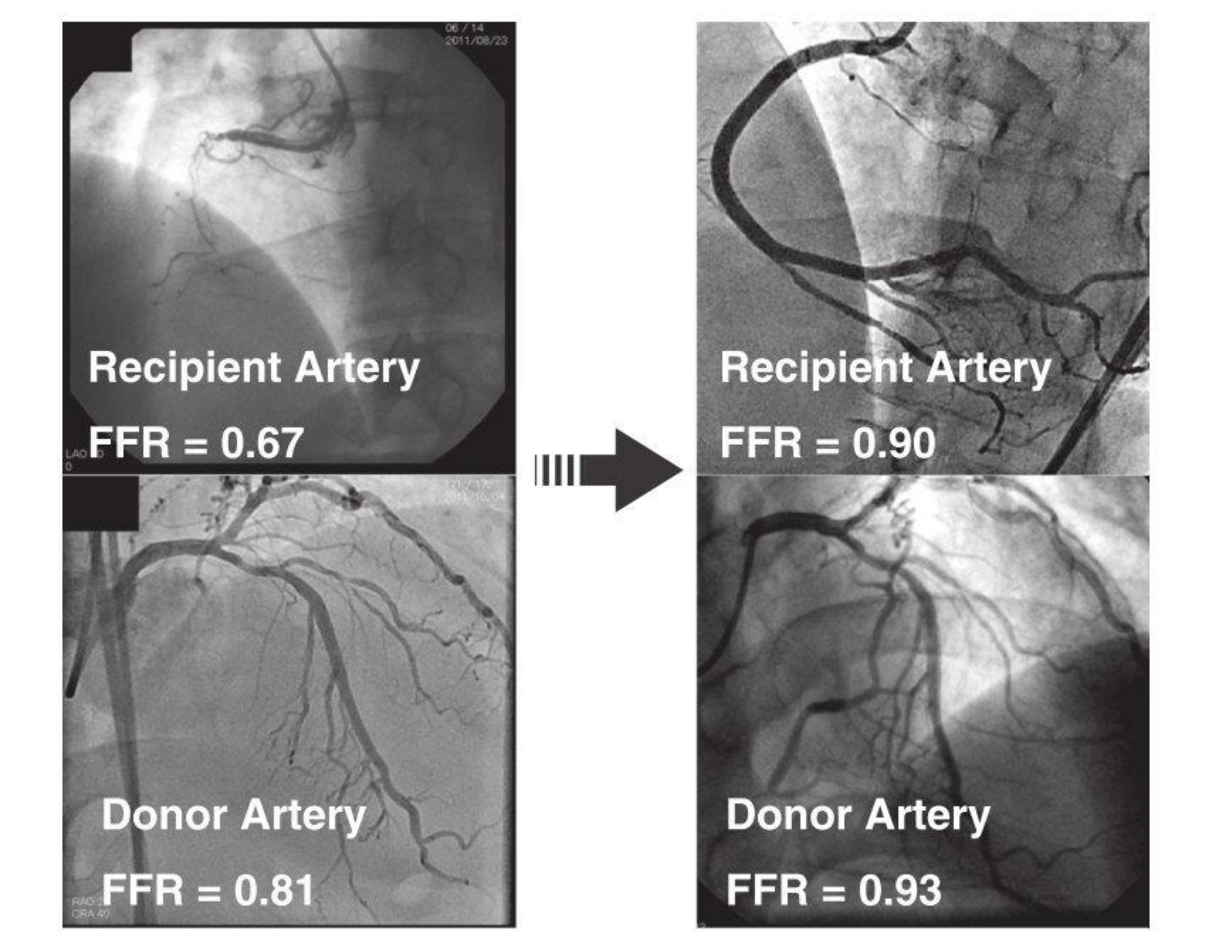
Example 1. Tandem Lesion



FFR(A) pre ≠ FFR(A) post

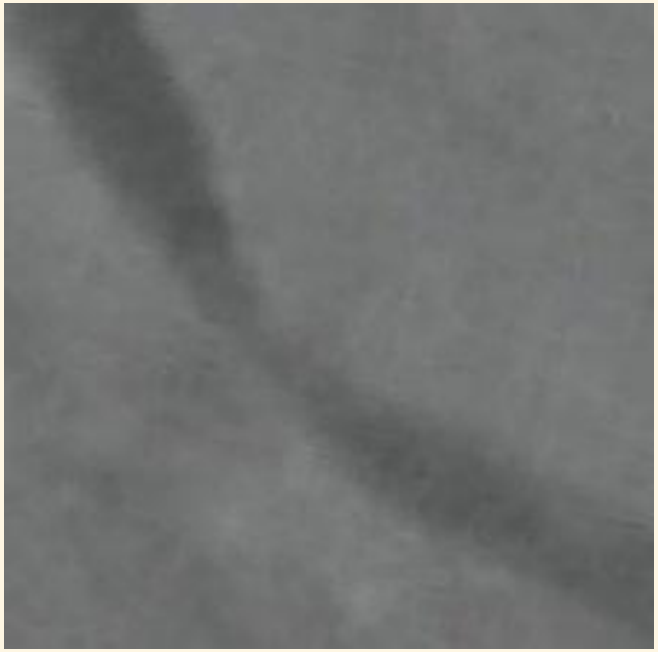
De Bruyne B, Pijls NHJ, et al. *Circulation*. 2000;101(15):1840-1847.

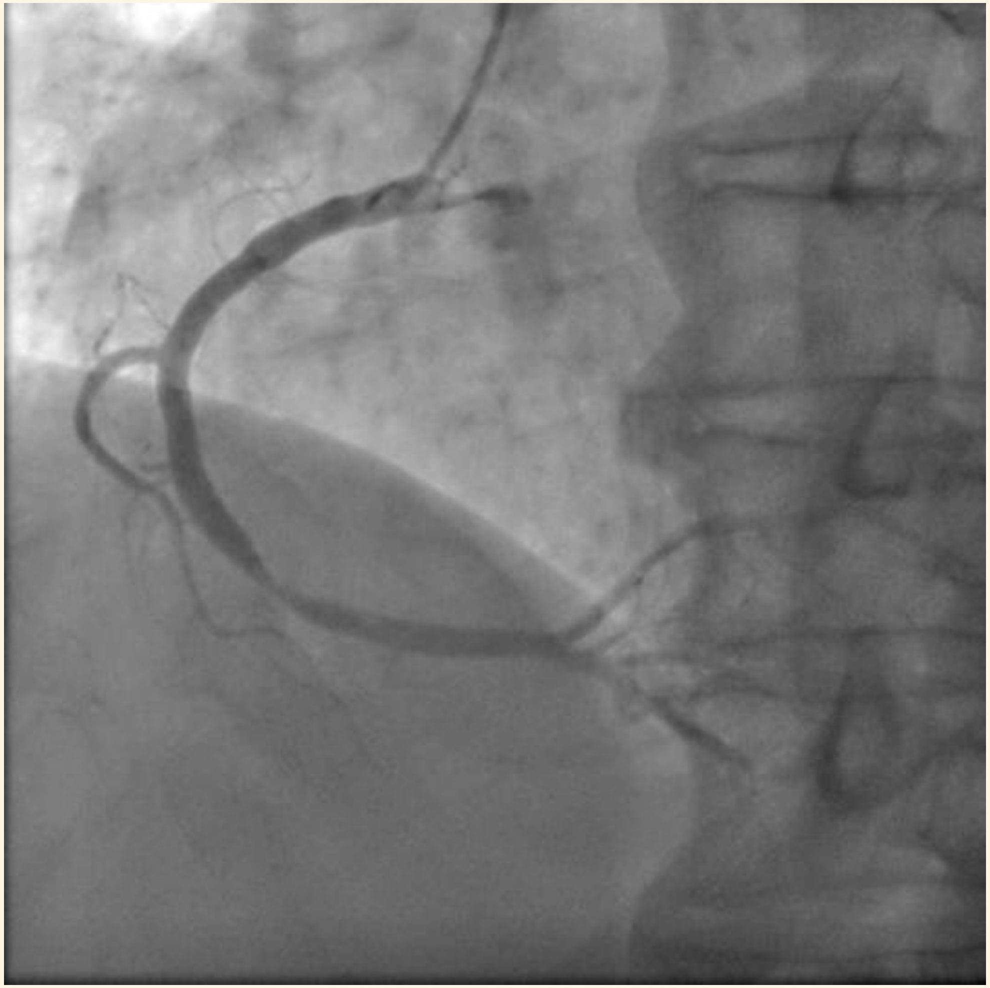
Example 2. CTO Lesion



Matsuo H, et al. Catheter Cardiovasc Interv. 2013;82(4):E459-64.

Example 3. Lesion Location





Pressure Drop Across a Stenosis

Darcy–Weisbach Equation

$$\Delta \mathrm{P} = \mathrm{f} \cdot \frac{L}{D} \cdot \frac{\rho V^2}{2}$$

Hagen-Poiseuille equation

$$\Delta \mathrm{P} = \frac{128 \mu L}{\pi D^4} \cdot Q$$

Pressure Drop Across a Stenosis

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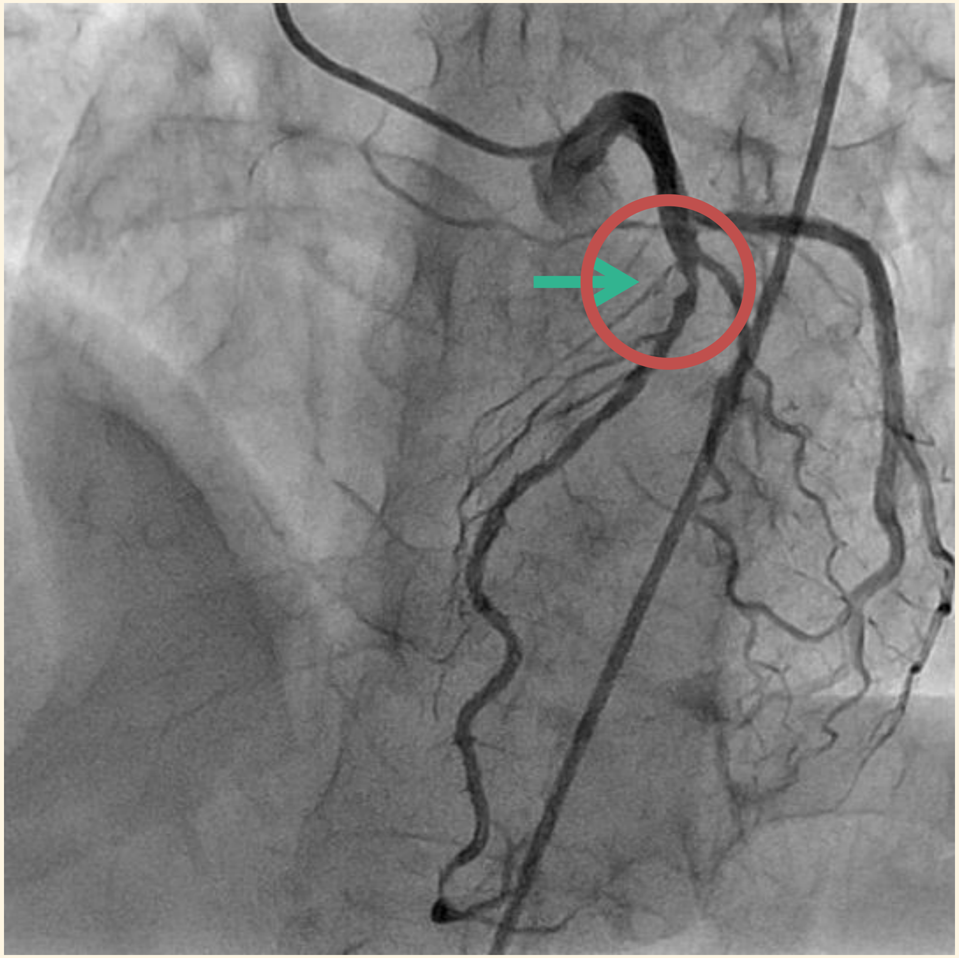
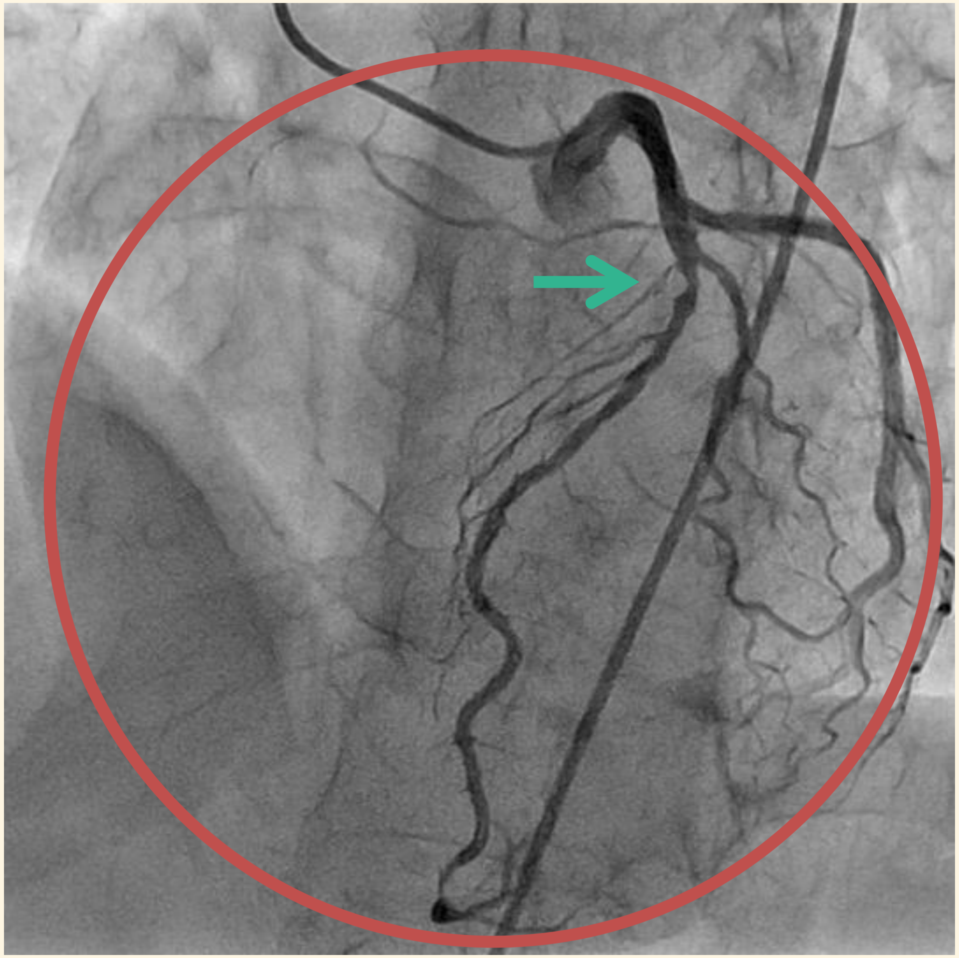


You Have to Consider the Whole Circulation System, If You Want to Know the FFR of Any Given Lesion.



You Have to Consider the Whole Circulation System, If You Want to Know the FFR of Any Given Lesion.

Can't see the wood for the trees

Summary

- QCA, IVUS, and OCT assesse only the target epicardial lesion, but FFR_{myo} is influenced by the other parts of the heart. This is very clear when FFR is expressed in terms of resistance:

$$FFR_{myo} = \frac{R(\boldsymbol{R_s} + R_c)}{\boldsymbol{R_s} R_c + R(\boldsymbol{R_s} + R_c)}$$

- You need to see the whole circulation system, if you want to know the functional severity of any given stenosis.

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