Fractional Flow Reserve (s): How it (they) Work(s)

Christian Seiler, Bern, Switzerland
Fractional Flow Reserve (FFR)

„Maximal blood flow in a stenotic artery to normal maximal flow“

Tonino et al. N Engl J Med 2009; 360: 213-
Assumptions for FFR by Ohm’s Law

$$\Delta P = Q_{\text{cor}} \times R_{\text{cor}}$$
Assumptions for FFR by Ohm‘s Law

\[ \Delta P = Q_{myo} \times R_{myo} \]

- CVP=0mmHg
- constant and minimal
Coronary Hyperemia

Determined by myocardial O$_2$ demand
→ approximated by heart rate \( \times \) blood pressure

- Physical exercise (NO)
- Acetylcholine
- **Adenosine** (i.c. or i.v.)
- Dipyridamole
- Dobutamine
- Cold pressor test
FFR = 0.52

RCA
„…Blood Flow in a **Stenotic** Artery“?

\[ Q_{\text{myo}} = Q_{\text{cor}} + Q_{\text{coll}} \]
Distribution of Human Coronary Collateral Function (n=1'740)

Collateral Flow Index, CFI (mmHg/mmHg)

No CAD  
n=188

CAD, VD1  
n=499

CAD, VD2  
n=649

CAD, VD3  
n=404
„…Blood Flow in a **Stenotic** Artery“?

\[ FFR_{myo} = FFR_{cor} + CFI \]

CFI: collateral flow index
\[
\frac{(P_d - \text{CVP})}{(P_a - \text{CVP})} = \\
\frac{(P_d - P_{\text{occl}})}{(P_a - P_{\text{occl}})} + \frac{(P_{\text{occl}} - \text{CVP})}{(P_a - \text{CVP})}
\]

- \(P_d\): distal coronary pressure
- \(P_a\): aortic pressure
- \(P_{\text{occl}}\): coronary occlusive pressure
- \(\text{CVP}\): central venous pressure
Seiler et al. J Am Coll Cardiol 1998; 32: 1272-
Seiler. Collateral circulation of the heart. Springer 2009
Fractional Flow Reserve(s)

Coronary microvascular resistance ≠ minimal or constant
Adenosine not feasible for full vasodilation
Adenosine i.c. dosage too variable
Central venous pressure ≠ 0
Conventional $\text{FFR}_{\text{myo}}$ not stenosis specific
$\text{FFR}_{\text{myo}}$ ≠ $\text{FFR}_{\text{coro}}$
Collateral flow ≠ 0

Hypothesis
↓ † and infarct in FAME1-FFR group: ↑ collateral function vs angiogr. group
Baseline myocardial blood flow (ml/min/g)

Count

Baseline Myocardial Perfusion by PET

Oxygen-15 labelled water PET  
n=169 healthy humans

Baseline myocardial blood flow (ml/min/g)
Baseline and Hyperemic Myocardial Perfusion by Contrast Echo

Baseline

Hyperemia (adenosine)

<table>
<thead>
<tr>
<th></th>
<th>Myocardial perfusion (ml/min/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>hcm</td>
<td>1.5</td>
</tr>
<tr>
<td>athl</td>
<td>2.0</td>
</tr>
<tr>
<td>hhd</td>
<td>3.0</td>
</tr>
<tr>
<td>sed</td>
<td>4.0</td>
</tr>
</tbody>
</table>

hcm  hypertrophic cardiomyopathy
athl athlete's heart
hhd  hypertensive heart disease
sed  sedentary; normal heart

Indermühle et al. Eur Heart J 2006; 27: 1571-
Indermühle et al. SMW 2009; 139: 691-
74 yrs, atypical chest pain, coronary angiography xi/09 → LAD stenosis
cardio-stress-MR negative, myocardial scintigraphy positive,
coronary angiography xi/10
Baseline

Dobutamine / Atropine
Baseline Myocardial Perfusion by PET

Oxygen-15 labelled water PET
n=169 healthy humans

Baseline myocardial blood flow (ml/min/g)
Myocardial Perfusion by Contrast Echo

Vogel et al. J Am Coll Cardiol 2005; 45: 754-
Lower Limit of Myocardial Perfusion
1-min Coronary Occlusion: ECG Signs of Ischemia and Myocardial Blood Flow

Contrast echo derived myocardial blood flow, ml/min/g

n=28 with CAD and percutaneous coronary intervention

ECG

ST↑<0.1mV
ST↑≥0.1mV

0.374 ml/min/g
Instantaneous flow velocity

Flow velocity trend

Time (s)
FFR = 0.95
Myocardial Perfusion or Blood Flow (MBF) by Contrast Echo

\[ MBF = \frac{rBV \cdot \beta}{\rho_T} \]

\[ rBV = \frac{V_{IV}}{V} = \frac{\hat{y}}{y_{LV}} \]

Vogel et al. J Am Coll Cardiol 2005; 45: 754-
Patient with chest pain syndrome

Assess pretest probability of obstructive CAD

Low
Consider ECG treadmill testing
If inconclusive

Intermediate
Interpretable ECG

Uninterpretable ECG
Stress echo or nuclear SPECT
If inconclusive
Cardiac CTA and calcium score

High
Consider cardiac catheterization or nuclear SPECT

Cardiac CTA is not likely to be diagnostic in patients with:
- Arrhythmias
- Prior CAD
- Prior stents
\[ P_{ao} - \text{CVP} = R \times Q \]

\[ 8 \mu \pi^{-1} \text{L} / r^4 \]
Design of the coronary artery tree structure

\[ E = W + B \]

Energy content of blood
\[ B = b \times \pi L r^2 \]

Viscous energy loss
\[ W = Q^2 \times 8 \mu L / \pi r^4 \]

Area at risk for infarction (regional myocardial mass M)