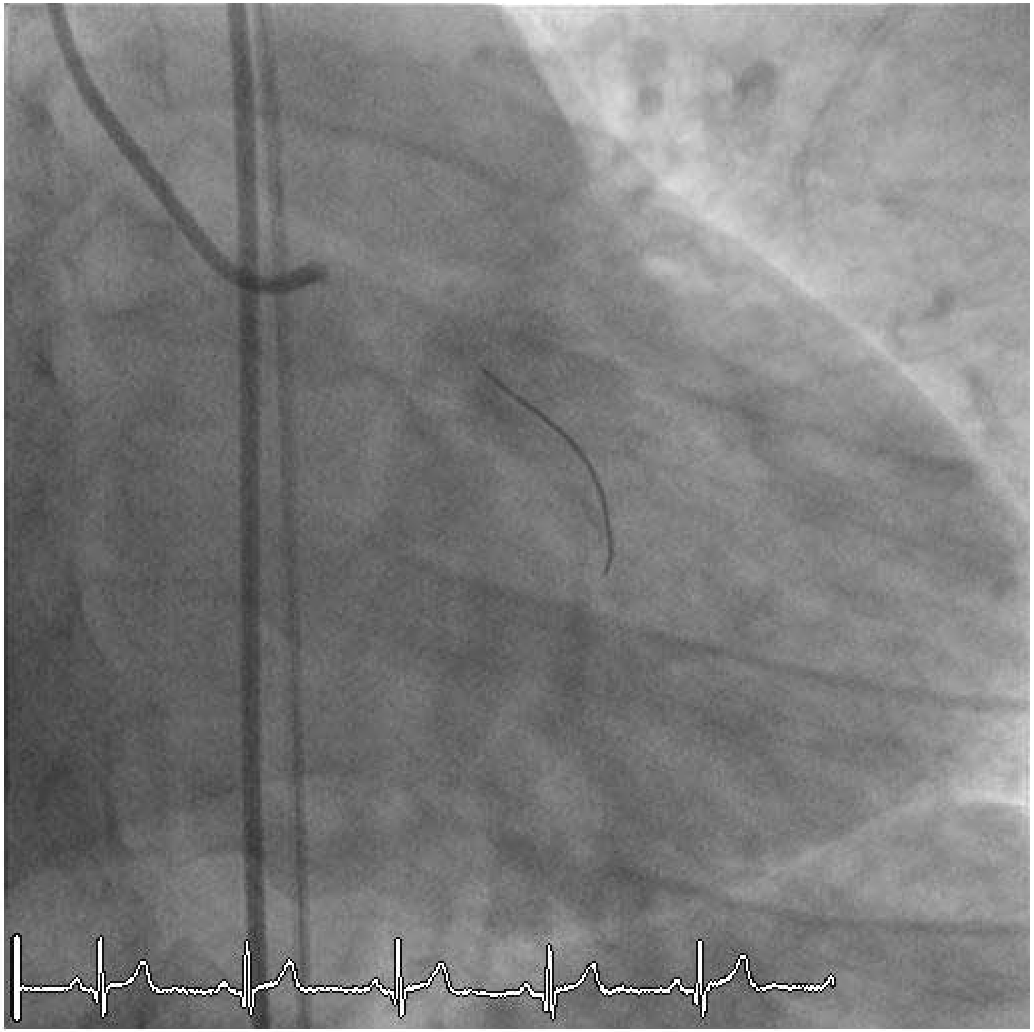
Fractional Flow Reserve (s): How it (they) Work(s)

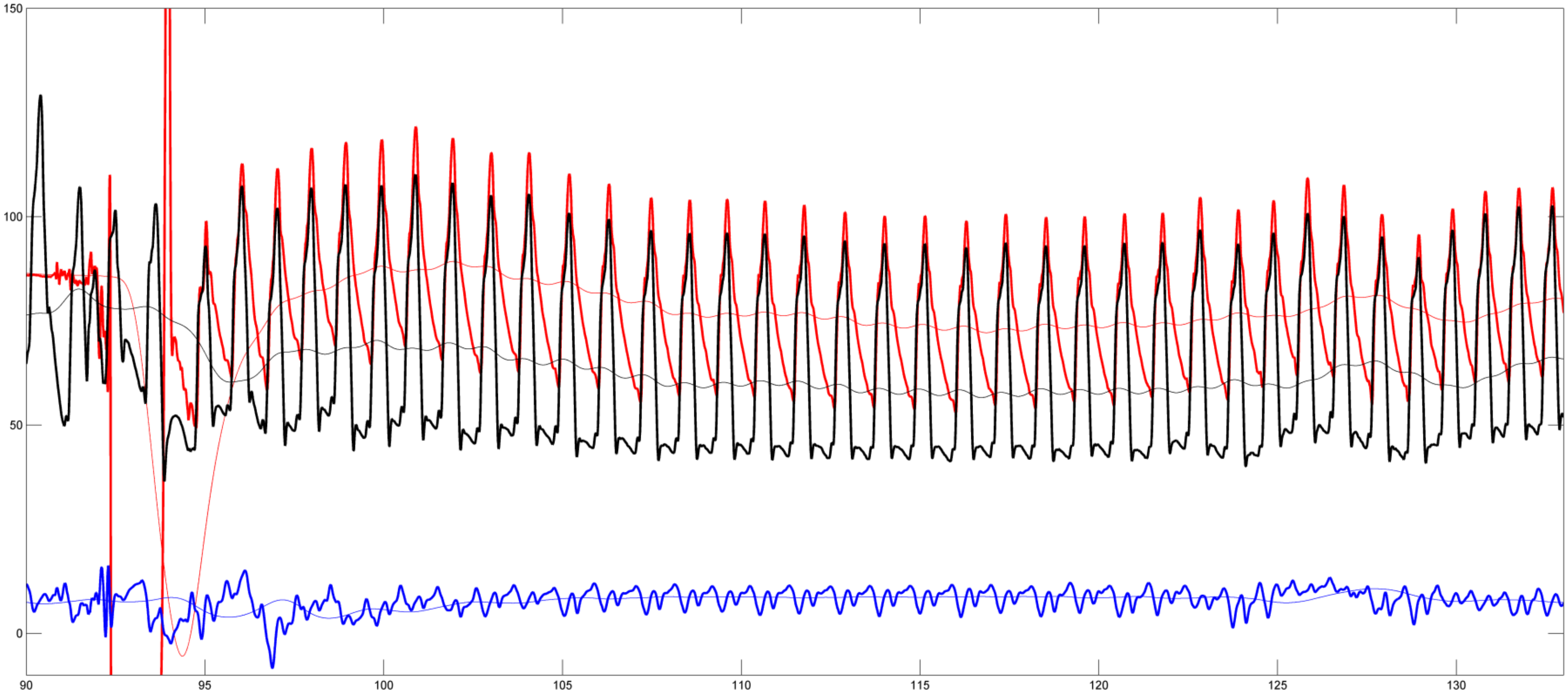
Christian Seiler, Bern, Switzerland

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-





150
100
50
0
90
95
100
105
110
115
120
125
130

Assumptions for F**F**R by Ohm's Law

$$\Delta \mathbf{P} = \mathbf{Q_{cor}} \times R_{cor}$$

Assumptions for FFR by Ohm‘s Law

$$\Delta \mathbf{P} = \mathbf{Q_{myo}} \times R_{myo}$$

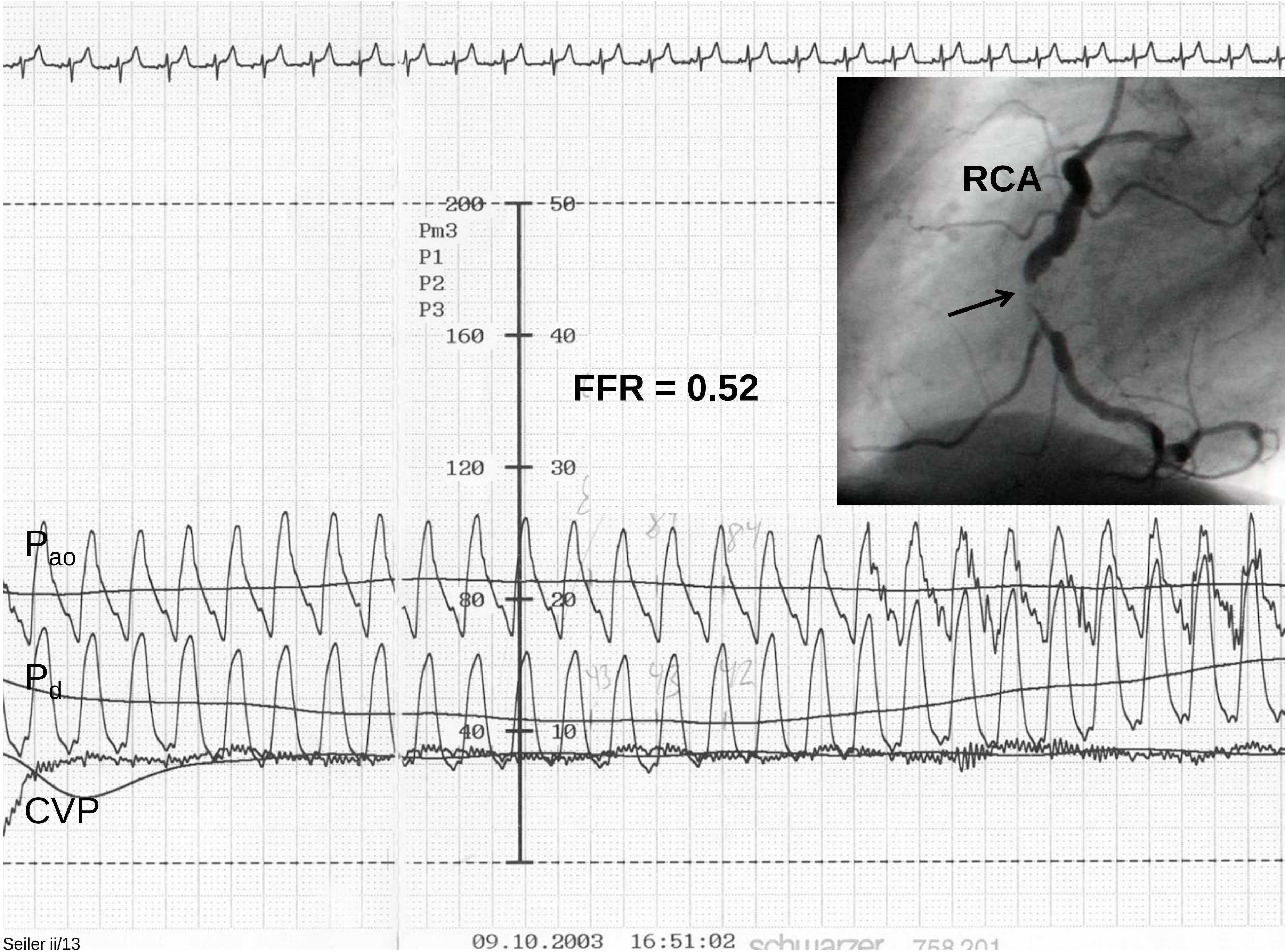
$\downarrow$ CVP=0mmHg

$\downarrow$ constant and minimal

Coronary Hyperemia

Determined by myocardial O_2 demand
$\rightarrow$ approximated by heart rate $_x$ blood pressure

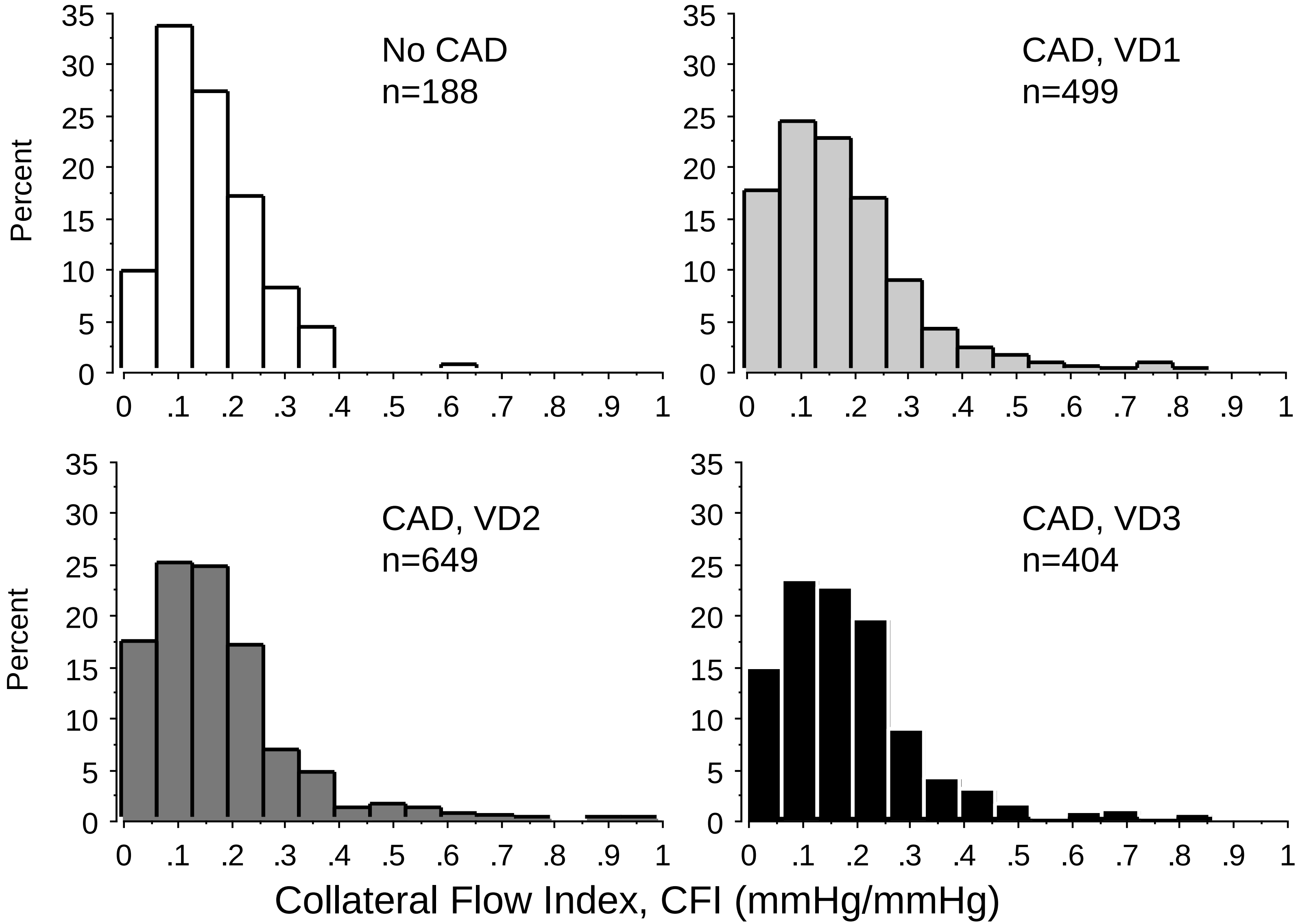
-Physical exercise (NO)
-Acetylcholine
-**Adenosine (i.c. or i.v.)**
-Dipyridamole
-Dobutamine
-Cold pressor test


RCA
FFR = 0.52
200
50
Pm3
P1
P2
P3
160
40
120
30
80
20
40
10
P_{ao}
P_d
CVP
09.10.2003 16:51:02 schwarzer 758 201

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

$$Q_{myo} = \mathbf{Q_{cor}} + Q_{coll}$$

Distribution of Human Coronary Collateral Function (n=1‘740)



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

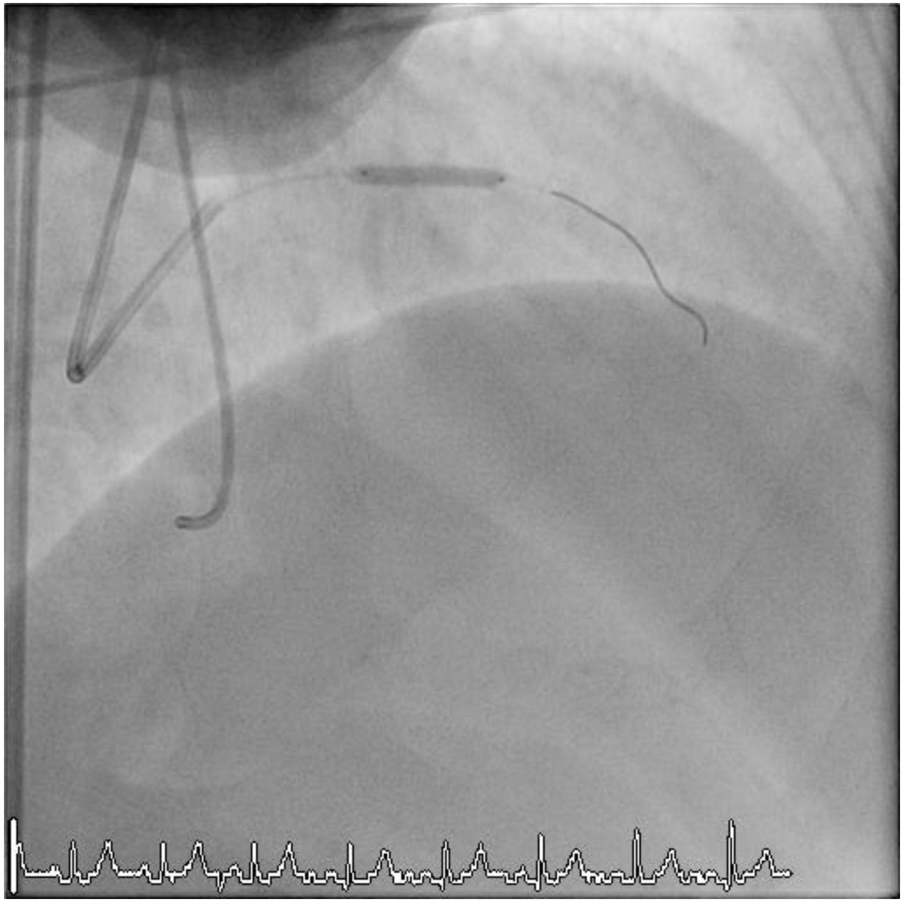
$$FFR_{myo} = FFR_{cor} + \mathbf{CFI}$$

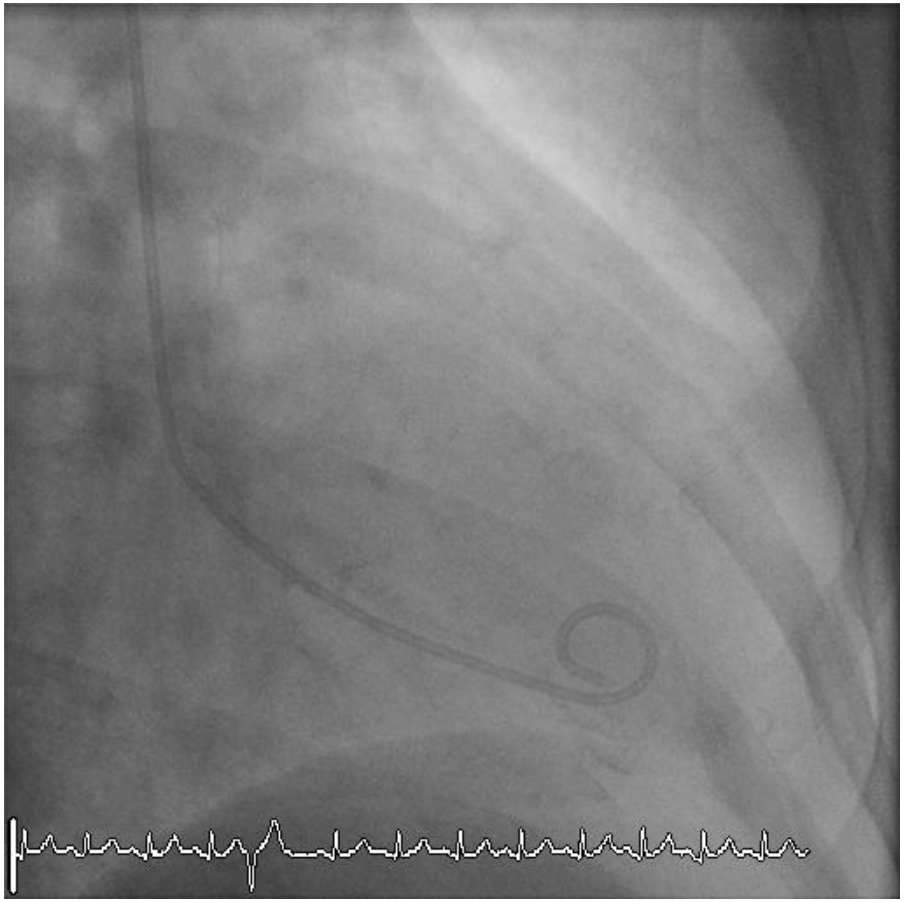
CFI: collateral flow index

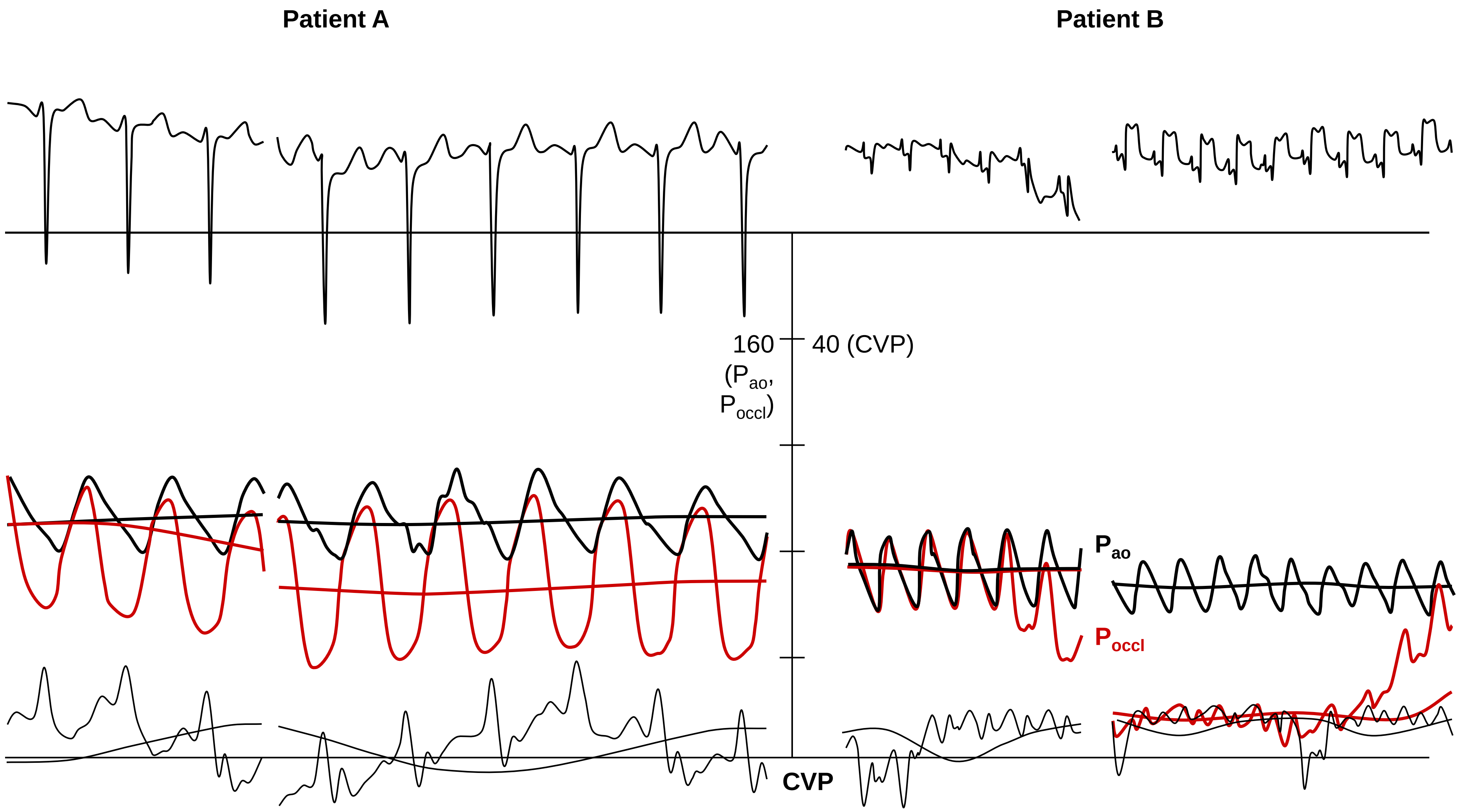
$$(P_d\text{-}CVP)/(P_a\text{-}CVP) =$$

$$(P_d\text{-}\mathbf{P_{occl}})/(P_a\text{-}\mathbf{P_{occl}})$$
$$+ (\mathbf{P_{occl}}\text{-}CVP)/(P_a\text{-}CVP)$$

P_d	distal coronary pressure
P_a	aortic pressure
P_{occl}	coronary occlusive pressure
CVP	central venous pressure







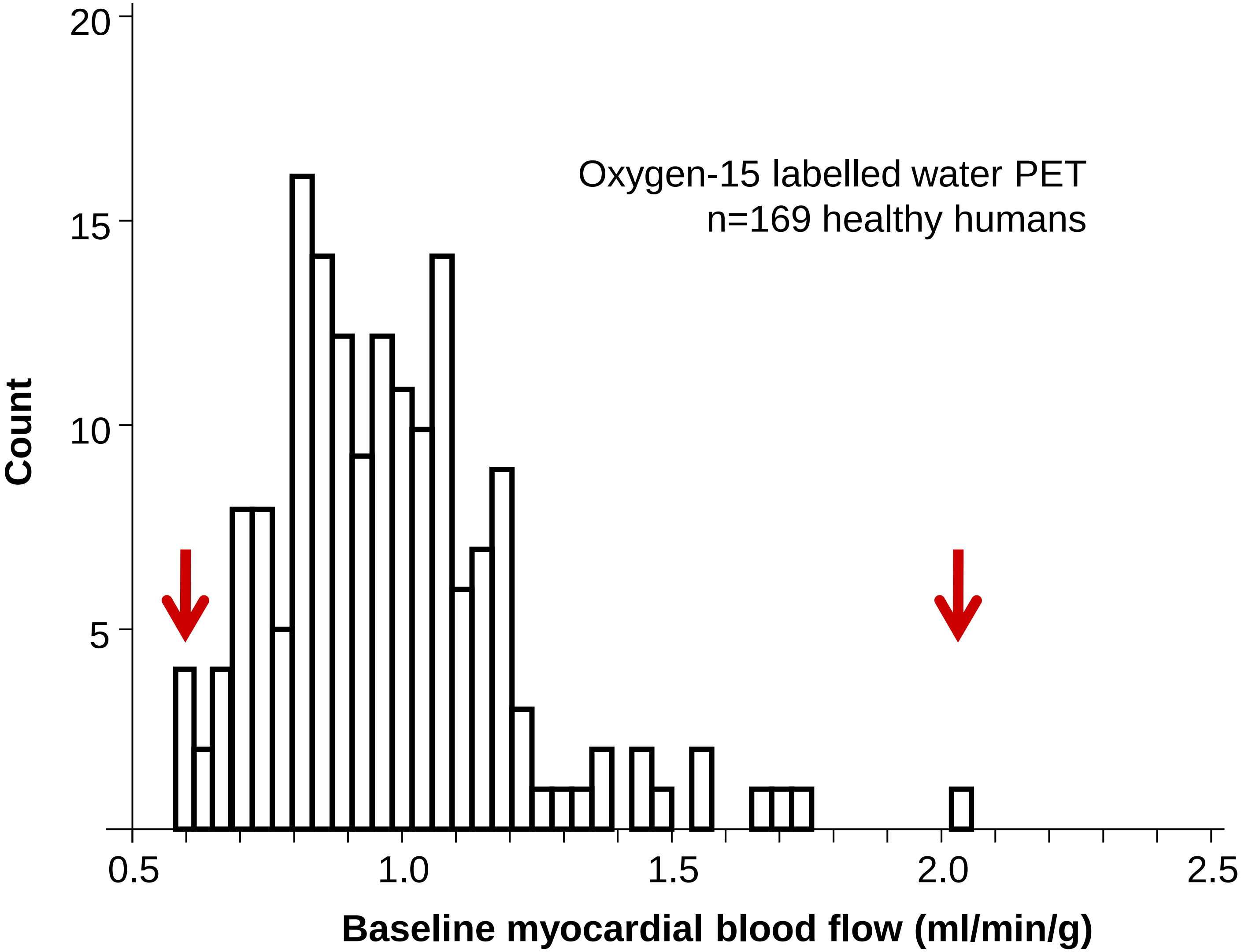
Seiler et al. J Am Coll Cardiol 1998; 32: 1272-
Seiler. Collateral circulation of the heart. Springer 2009

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 FFR_{myo} not stenosis specific
$FFR_{myo} \neq FFR_{coro}$
Collateral flow ≠ 0

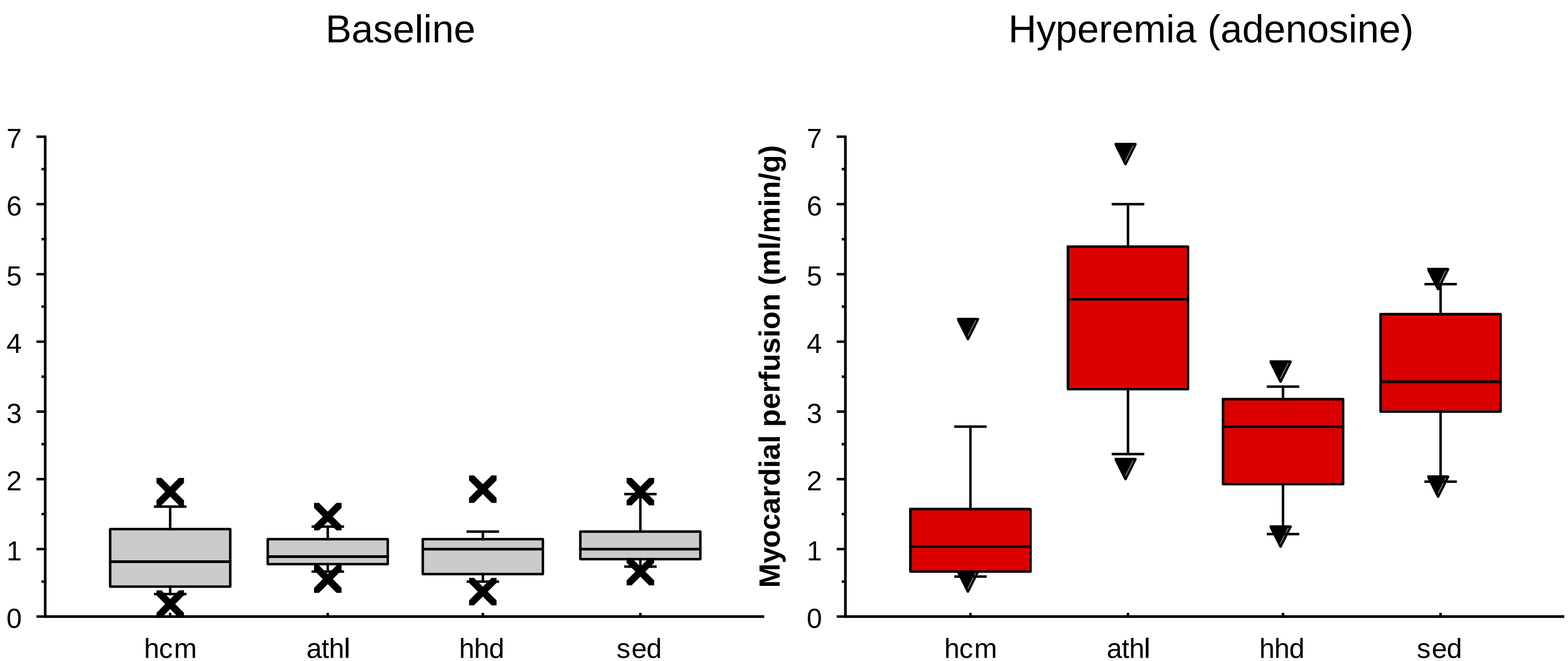
Hypothesis
↓ ✞ and infarct in FAME1-FFR group: ↑ collateral function vs angiogr. group

Baseline Myocardial Perfusion by PET



Chareonthaitawee et al. Cardiovasc Res 2001; 50: 151-

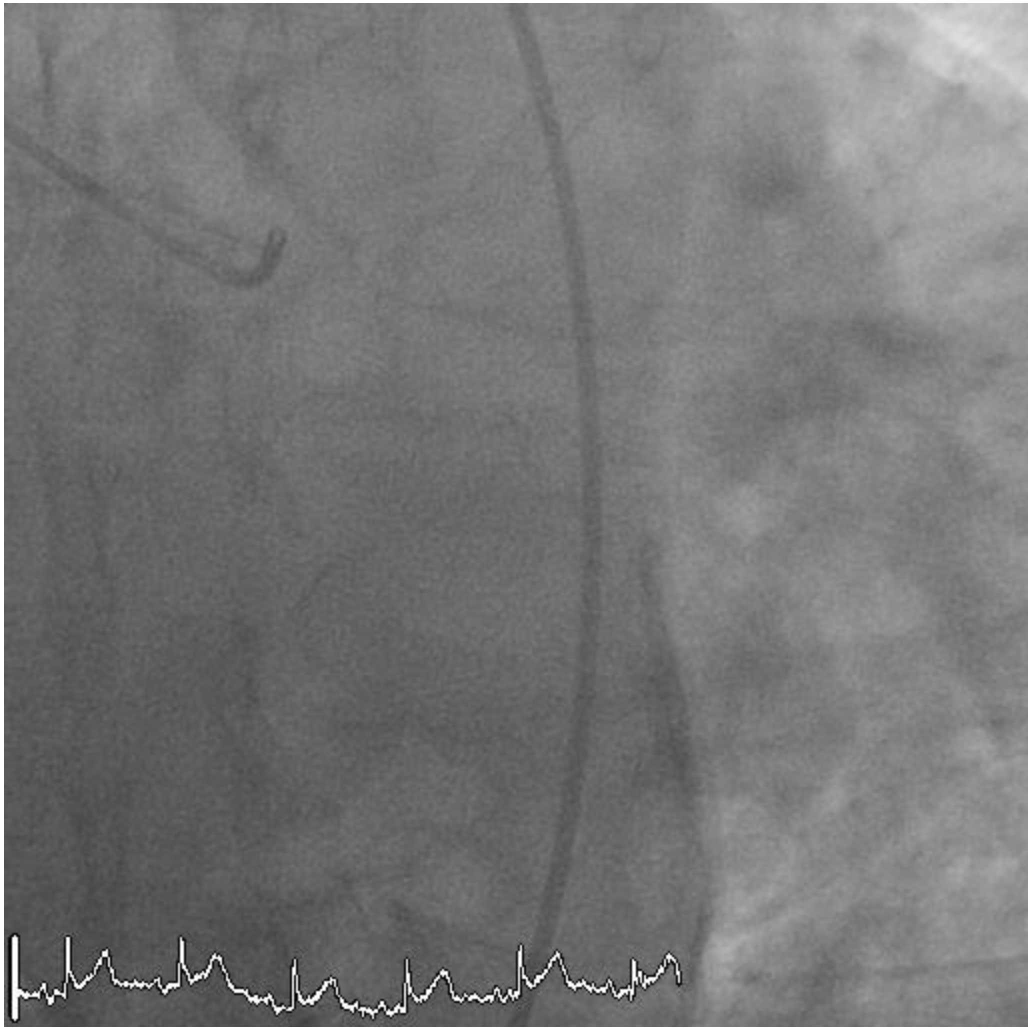
Baseline and Hyperemic Myocardial Perfusion by Contrast Echo

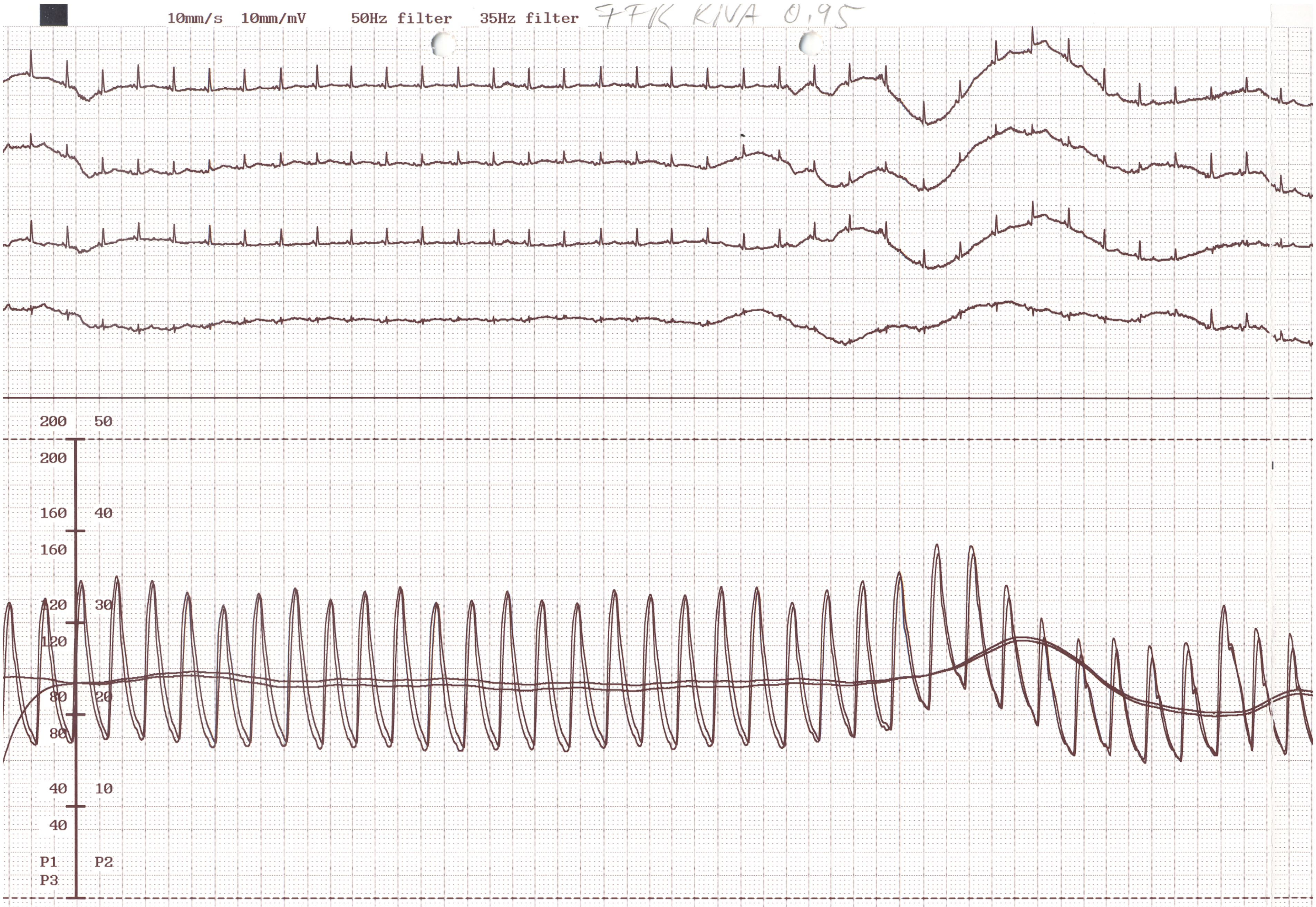


hcm	hypertrophic cardiomyopathy
athl	athlete‘s heart
hhd	hypertensive heart disease
sed	sedentary; normal heart

Indermühle et al. Eur Heart J 2006; 27: 1571-
Indermühle et al. SMW 2009; 139: 691-

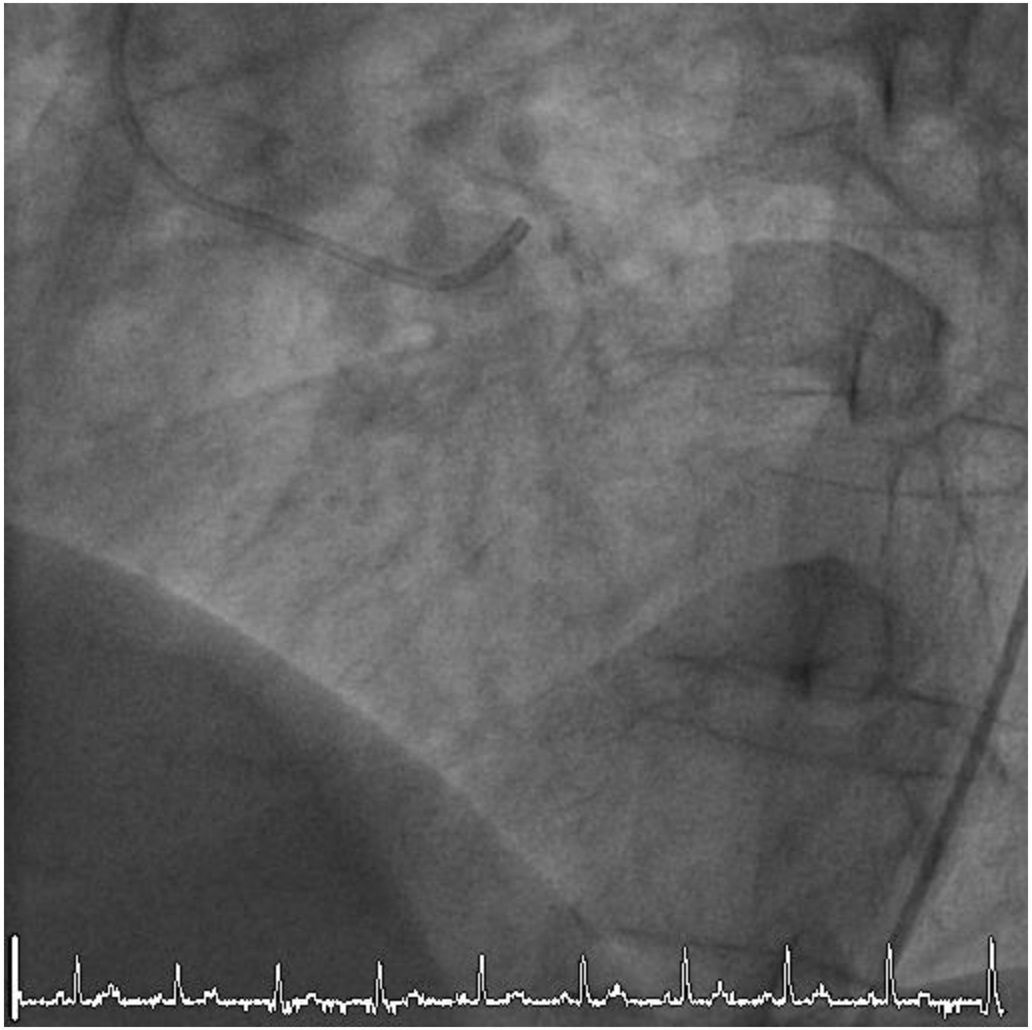
♂ 74 yrs, atypical chest pain, coronary angiography xi/09 → LAD stenosis
cardio-stress-MR negative, myocardial scintigraphy positive,
coronary angiography xi/10



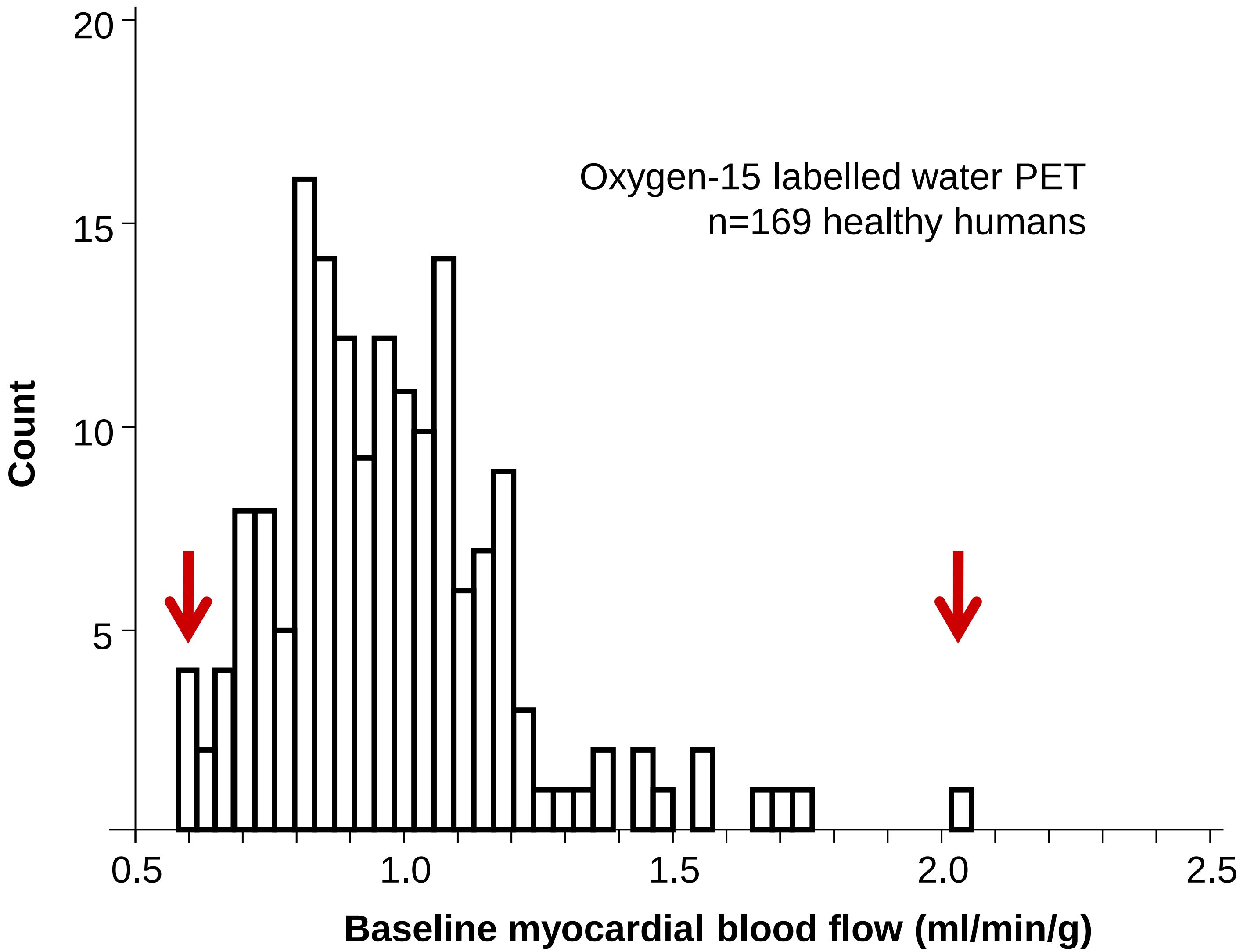

10mm/s 10mm/mV 50Hz filter 35Hz filter
7FK KIVA 0,95
200 50
200
160 40
160
120 30
120
80 20
80
40 10
40
P1 P2
P3

Baseline

Dobutamine / Atropine



Baseline Myocardial Perfusion by PET

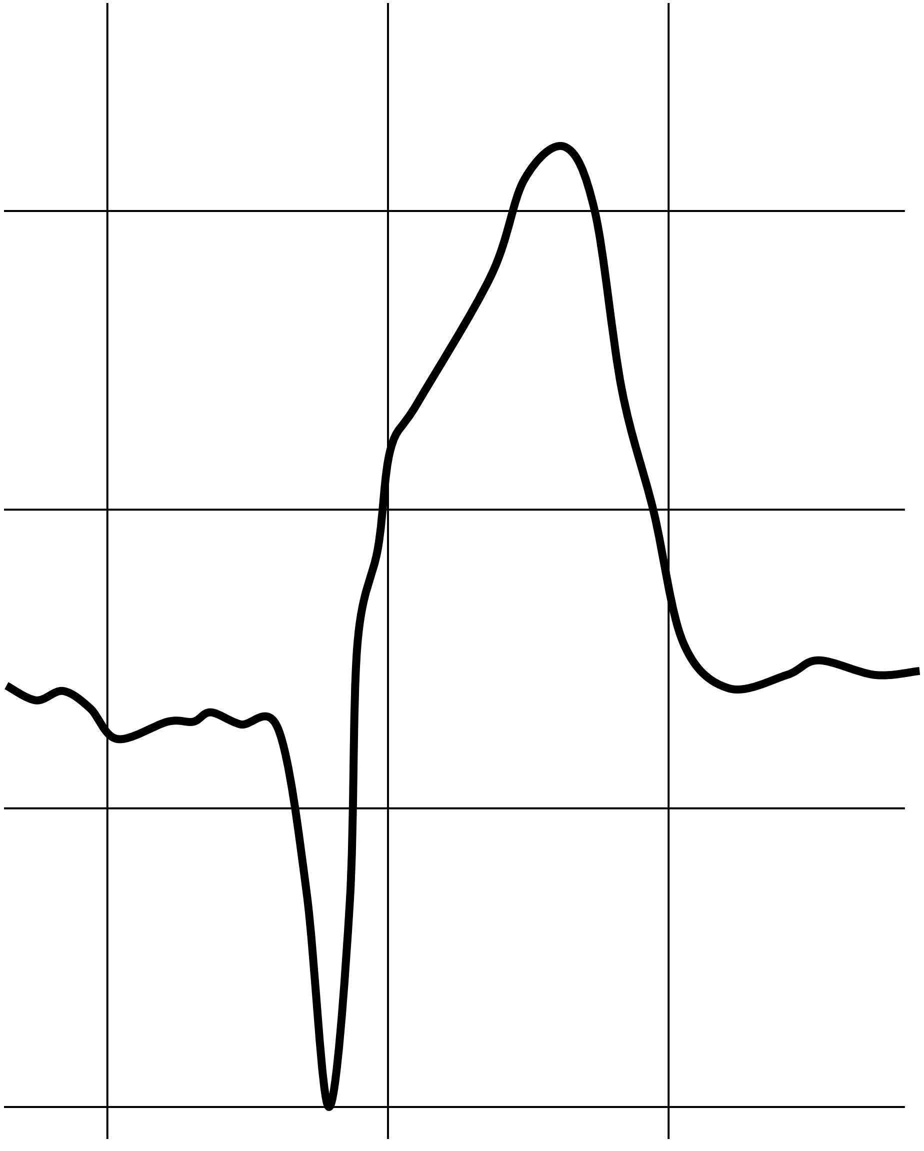


Chareonthaitawee et al. Cardiovasc Res 2001; 50: 151-

Myocardial Perfusion by Contrast Echo

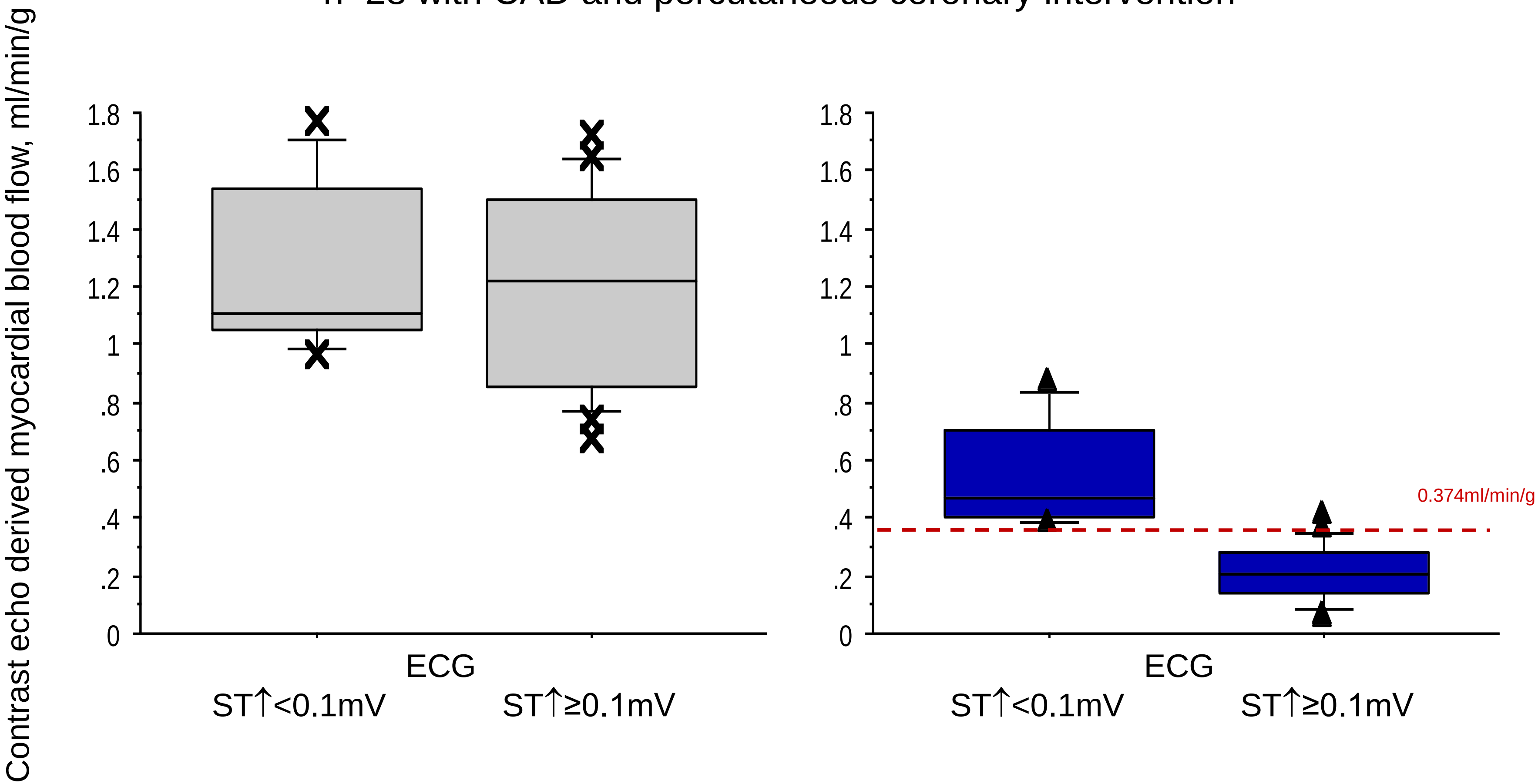
Vogel et al. J Am Coll Cardiol 2005; 45: 754-

Lower Limit of Myocardial Perfusion

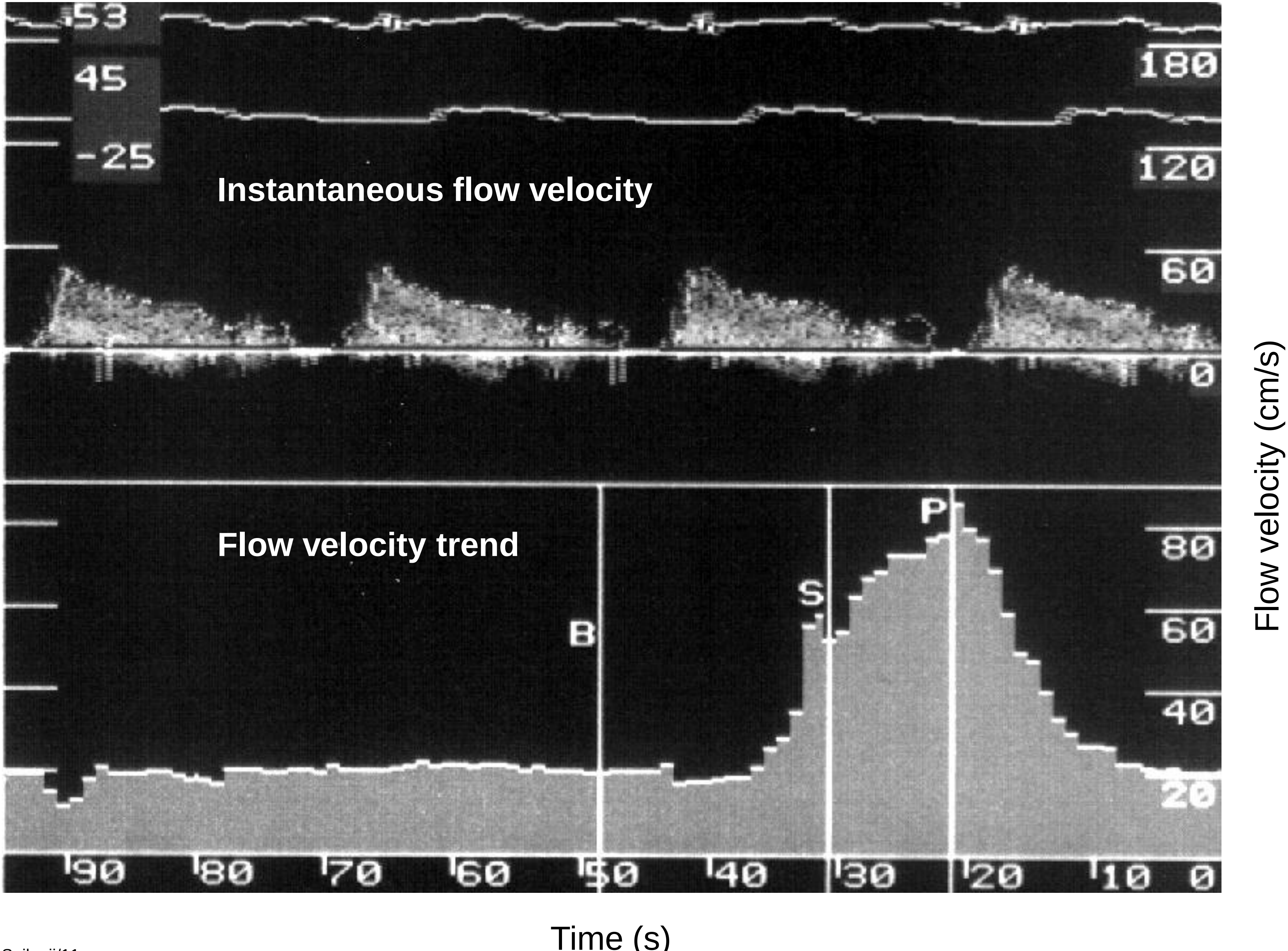


1-min Coronary Occlusion: ECG Signs of Ischemia and Myocardial Blood Flow

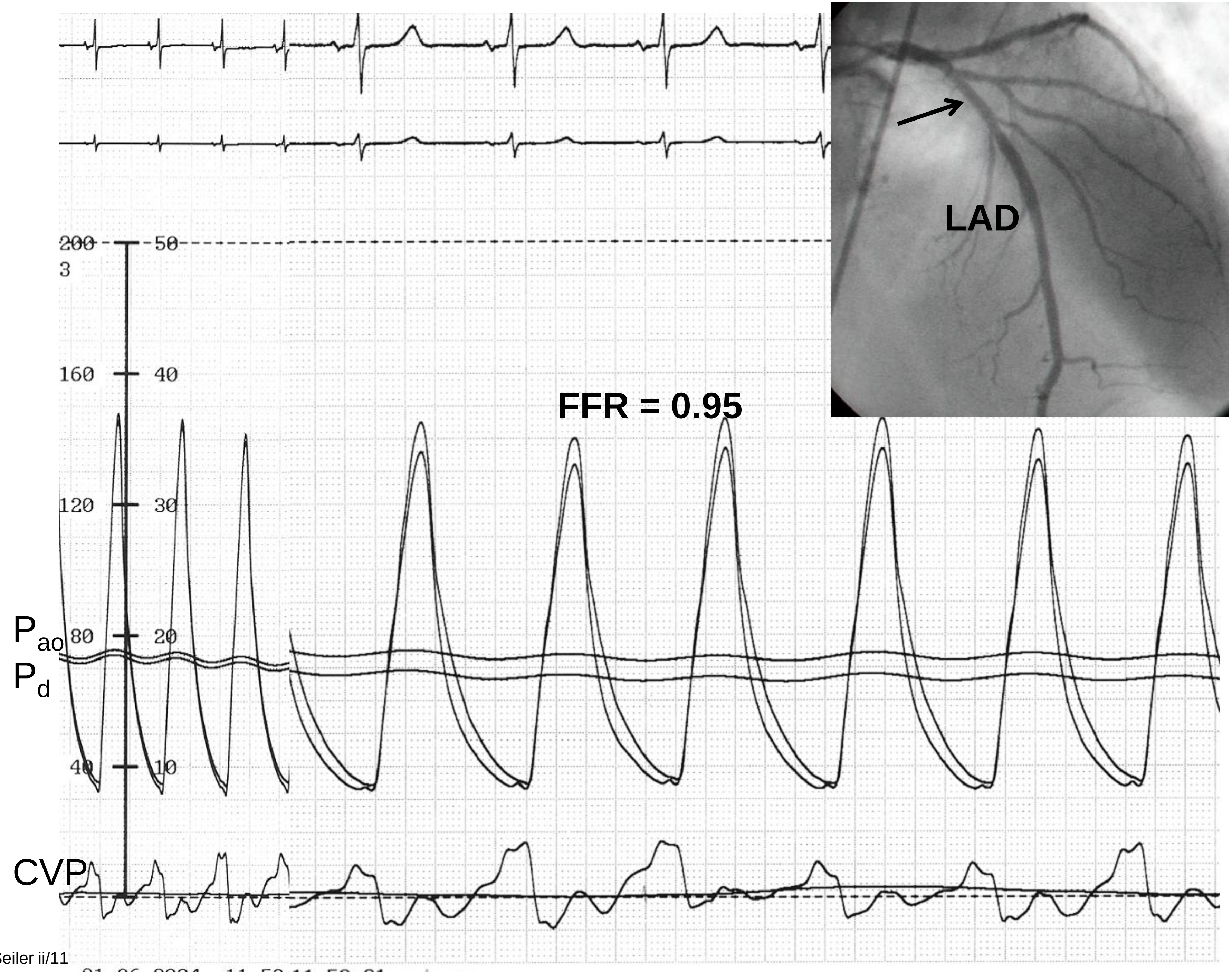
n=28 with CAD and percutaneous coronary intervention



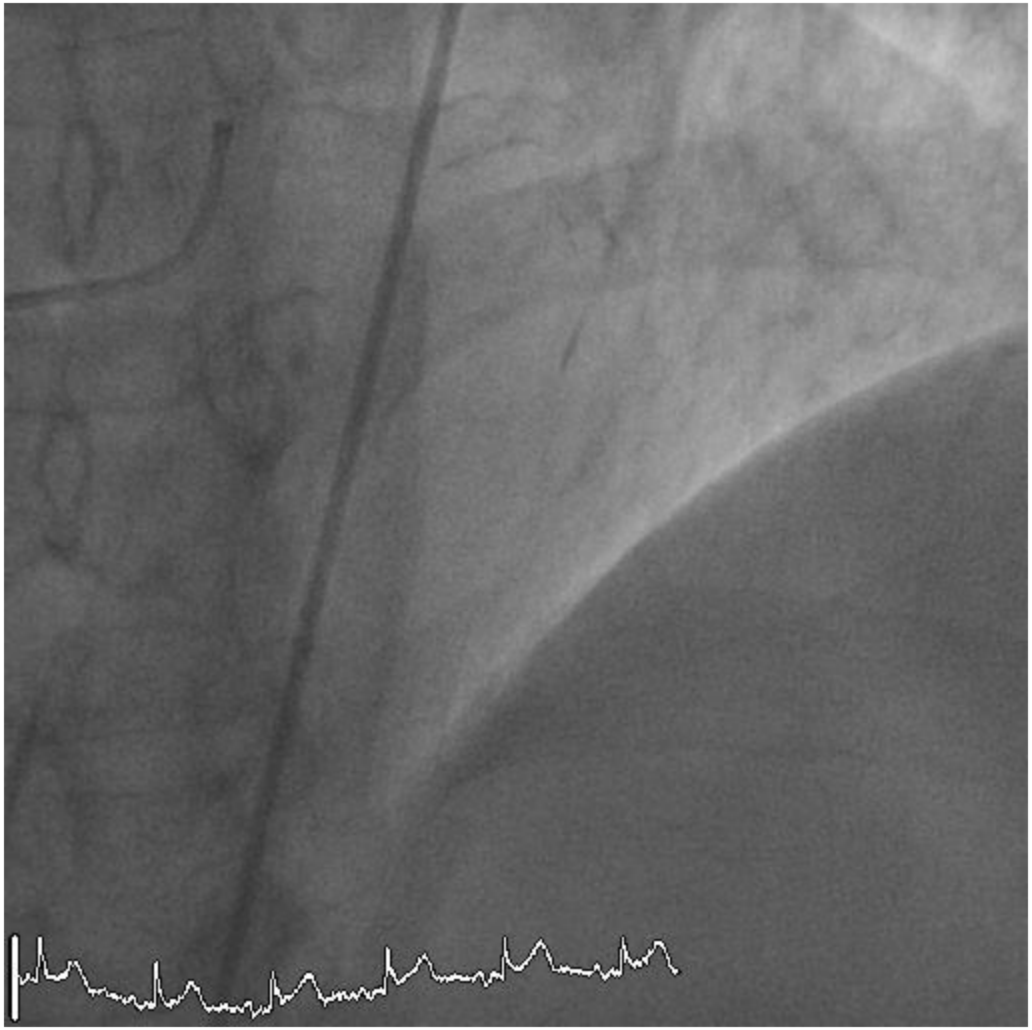
Vogel et al. Heart 2007; 93: 115-

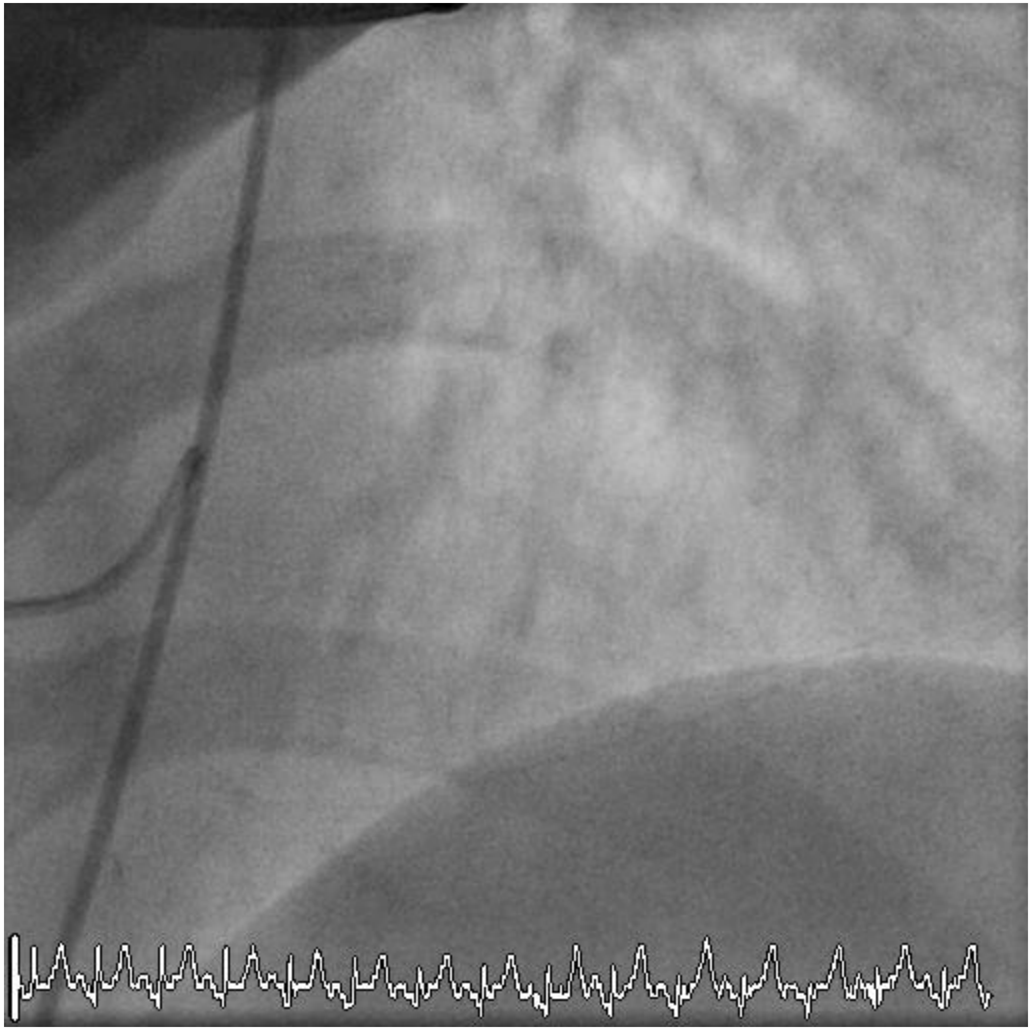

53
45
-25
180
120
60
0
Instantaneous flow velocity
Flow velocity trend
B
S
P
80
60
40
20
90
80
70
60
50
40
30
20
10
0
Flow velocity (cm/s)
Time (s)

Seiler ii/11

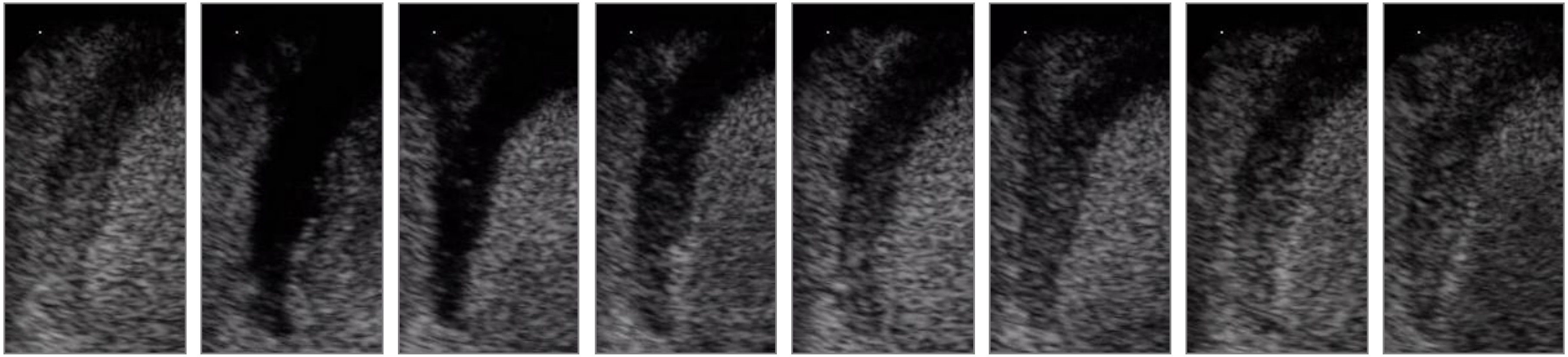


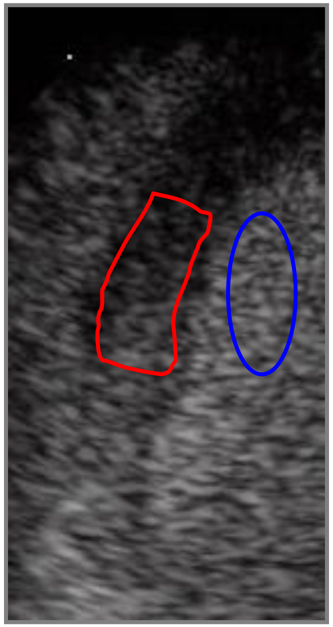
LAD
FFR = 0.95
200
3
50
160
40
120
30
80
20
40
10
P_ao
P_d
CVP
21.06.2004 11:50 11:53:21





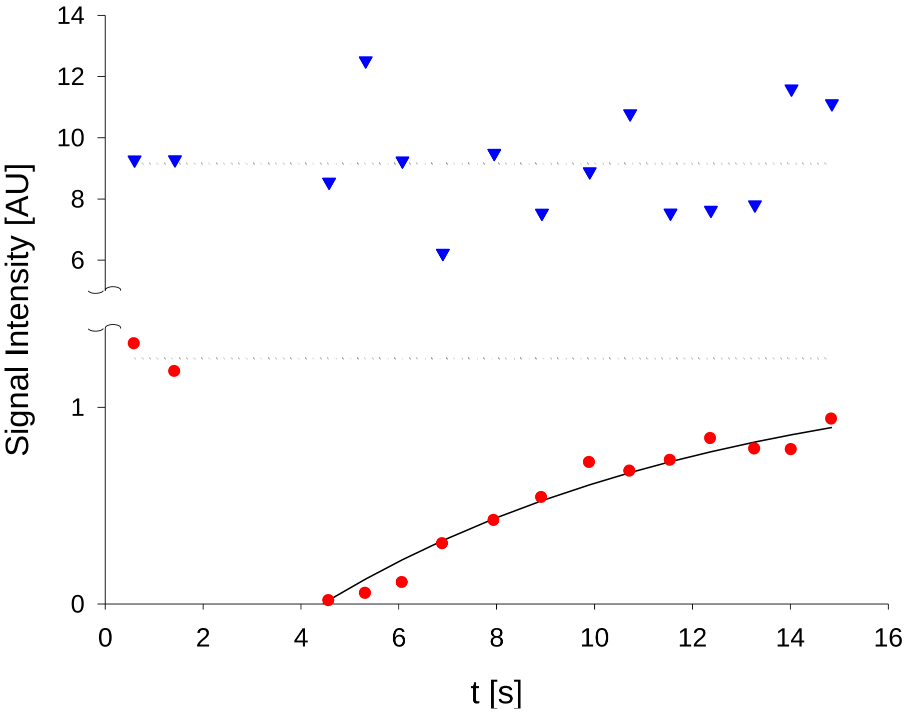
Myocardial Perfusion or Blood Flow (MBF) by Contrast Echo



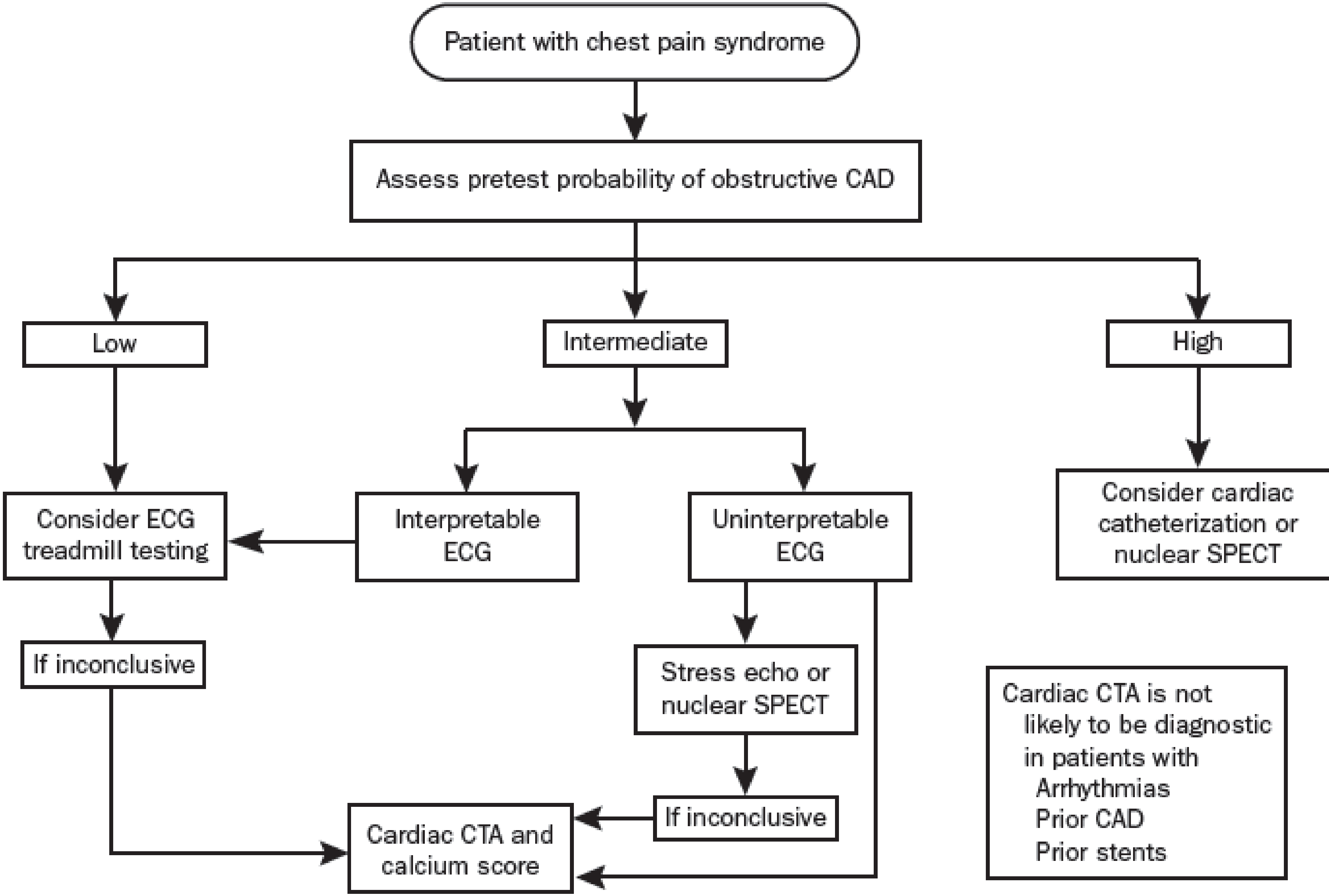


$$MBF = \frac{rBV \cdot \beta}{\rho_T}$$

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

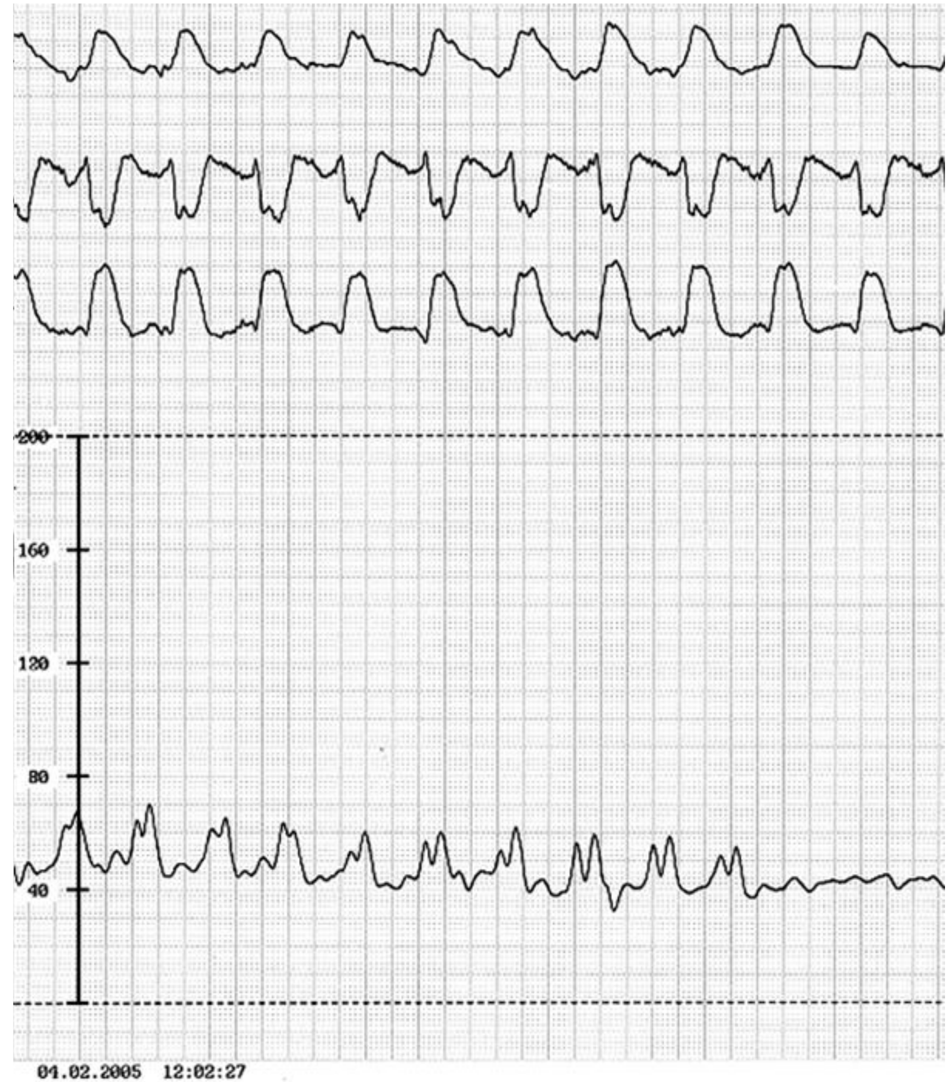


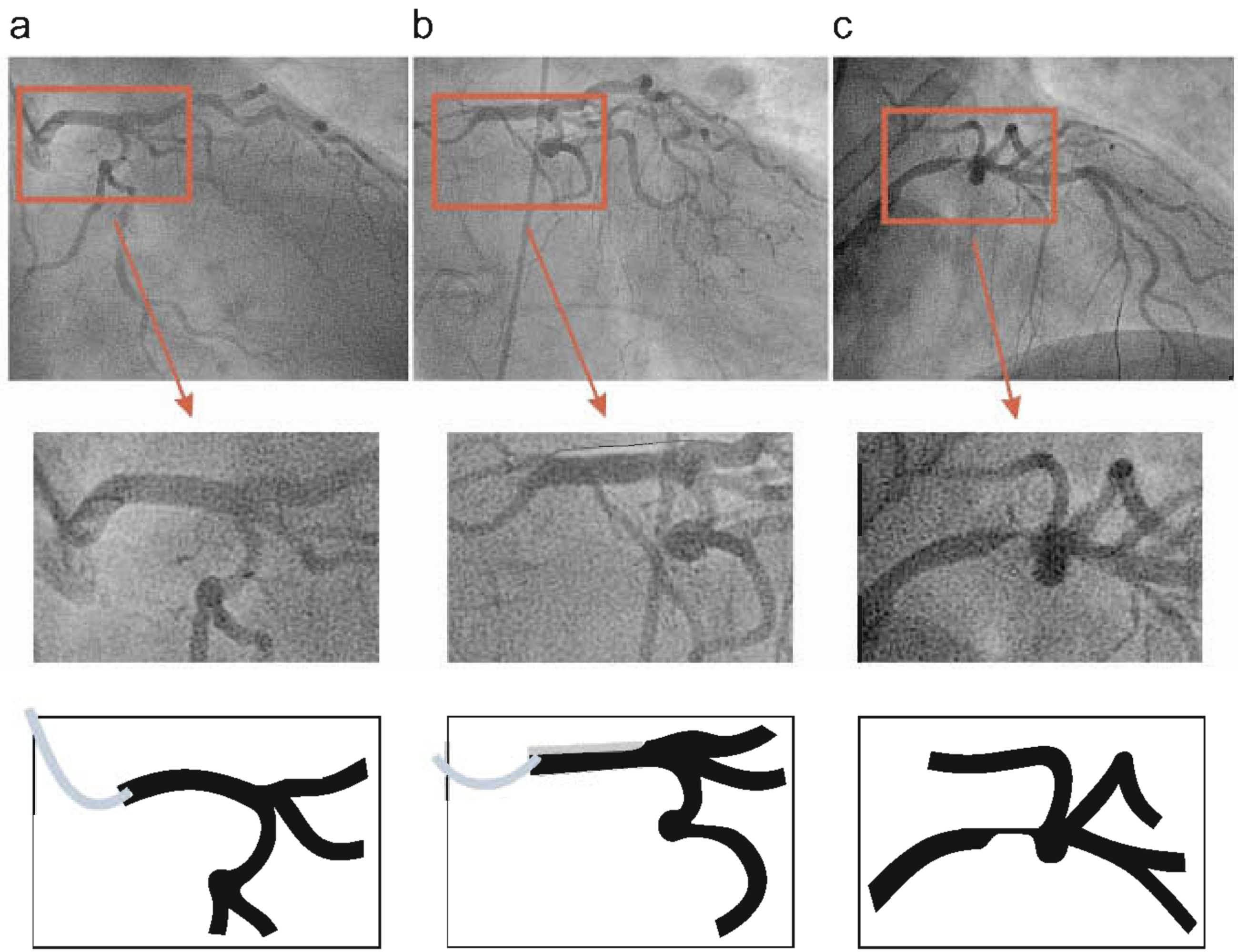
Vogel et al. J Am Coll Cardiol 2005; 45: 754-



Winchester et al. Mayo Clin Proc 2010; 85: 358-


I
II
aVL
P1
200
160
120
80
40
04.02.2005 11:03:52

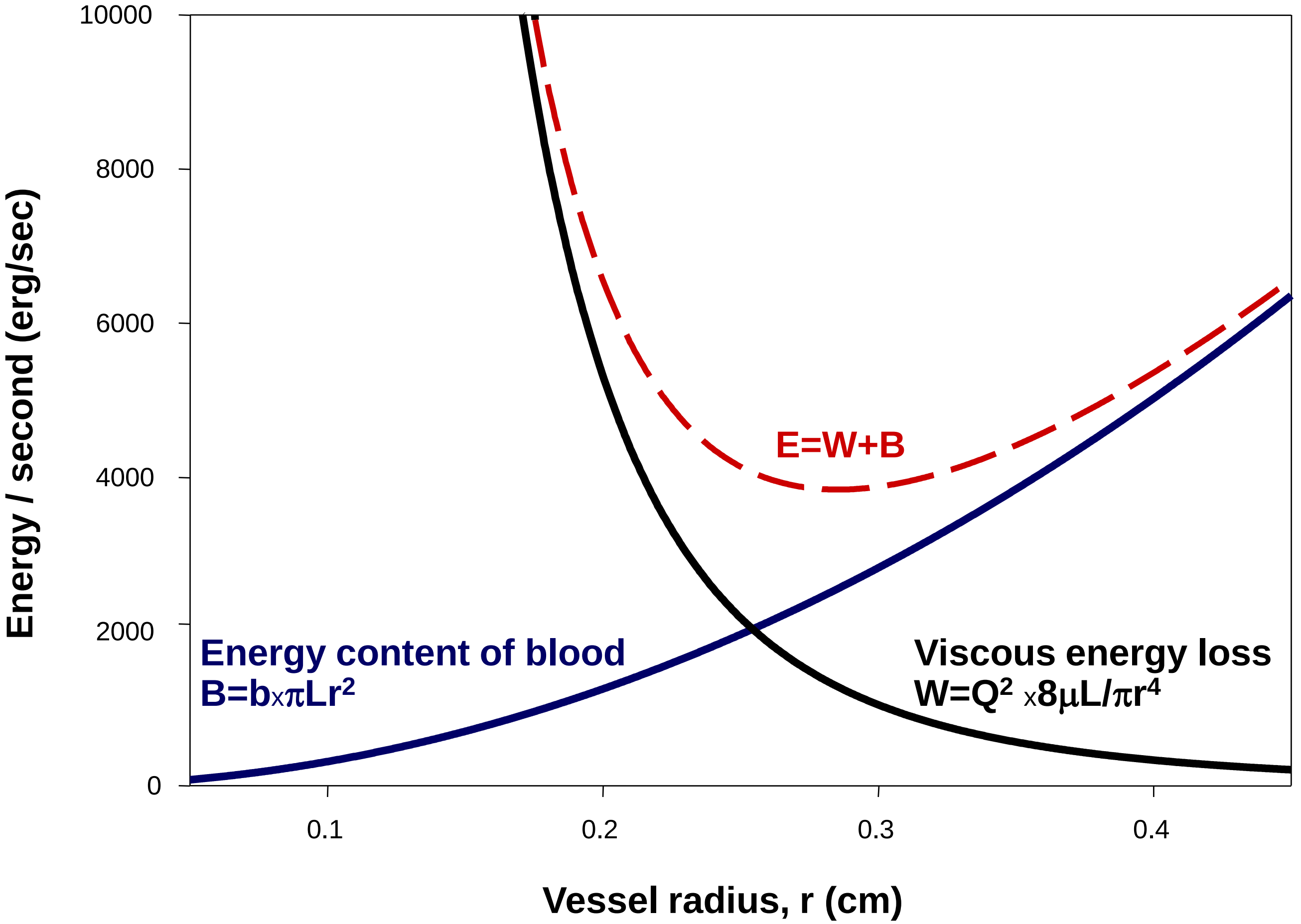

200
160
120
80
40
04.02.2005 12:02:27



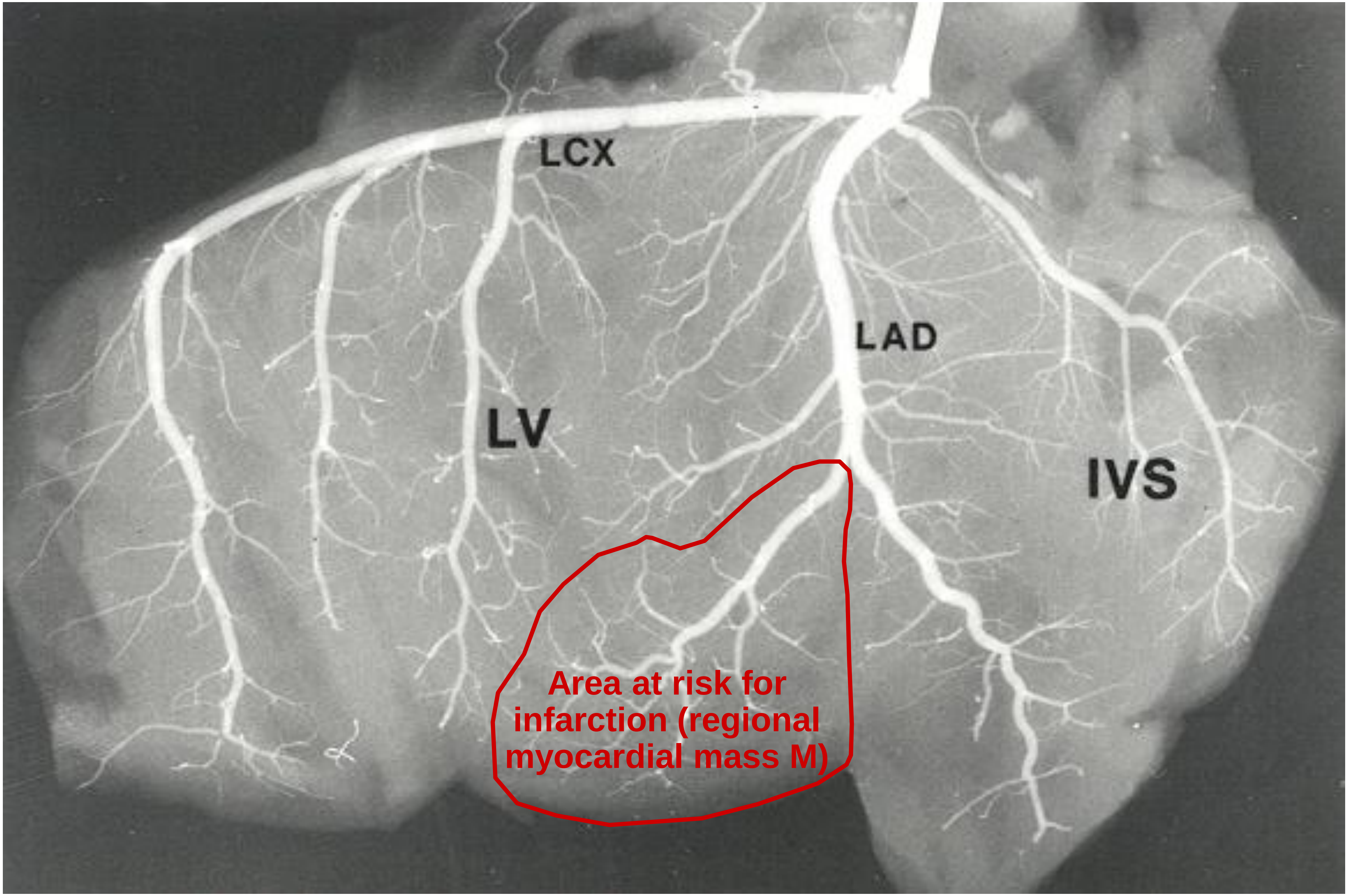
a
b
c

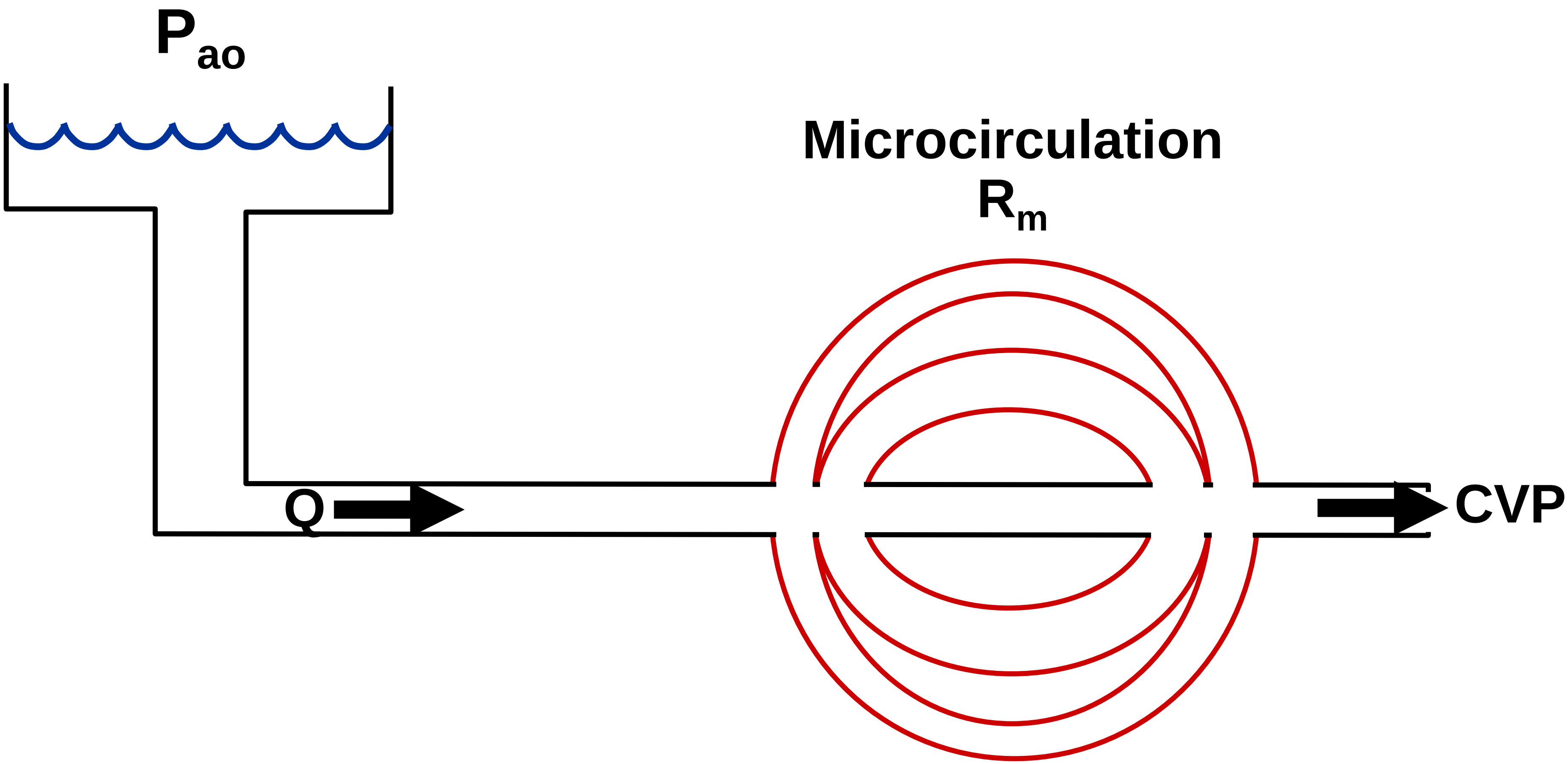
$$P_{ao} - CVP = \underbrace{R}_{8\mu\pi^{-1}\,L\,/\,r^4} \times Q$$

Design of the coronary artery tree structure

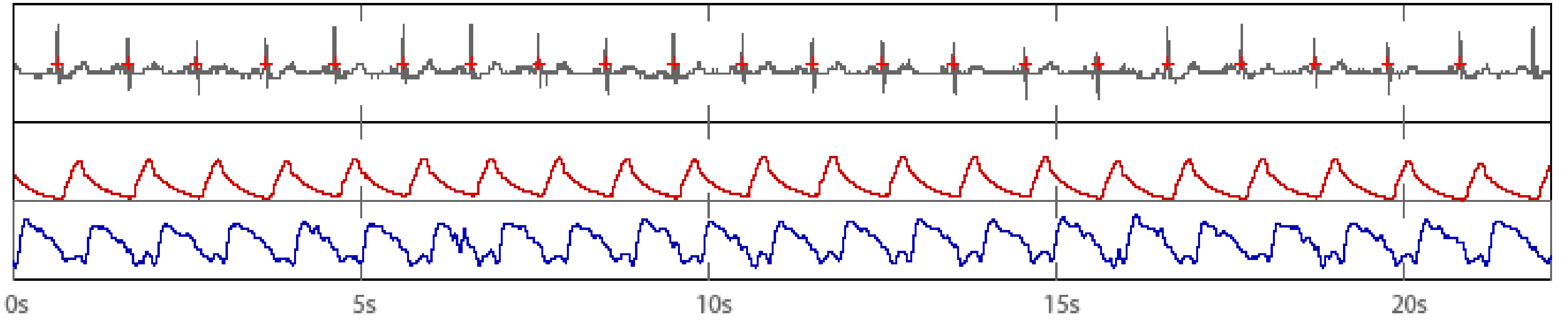


Seiler et al. Circulation 1992; 85: 1987-2003

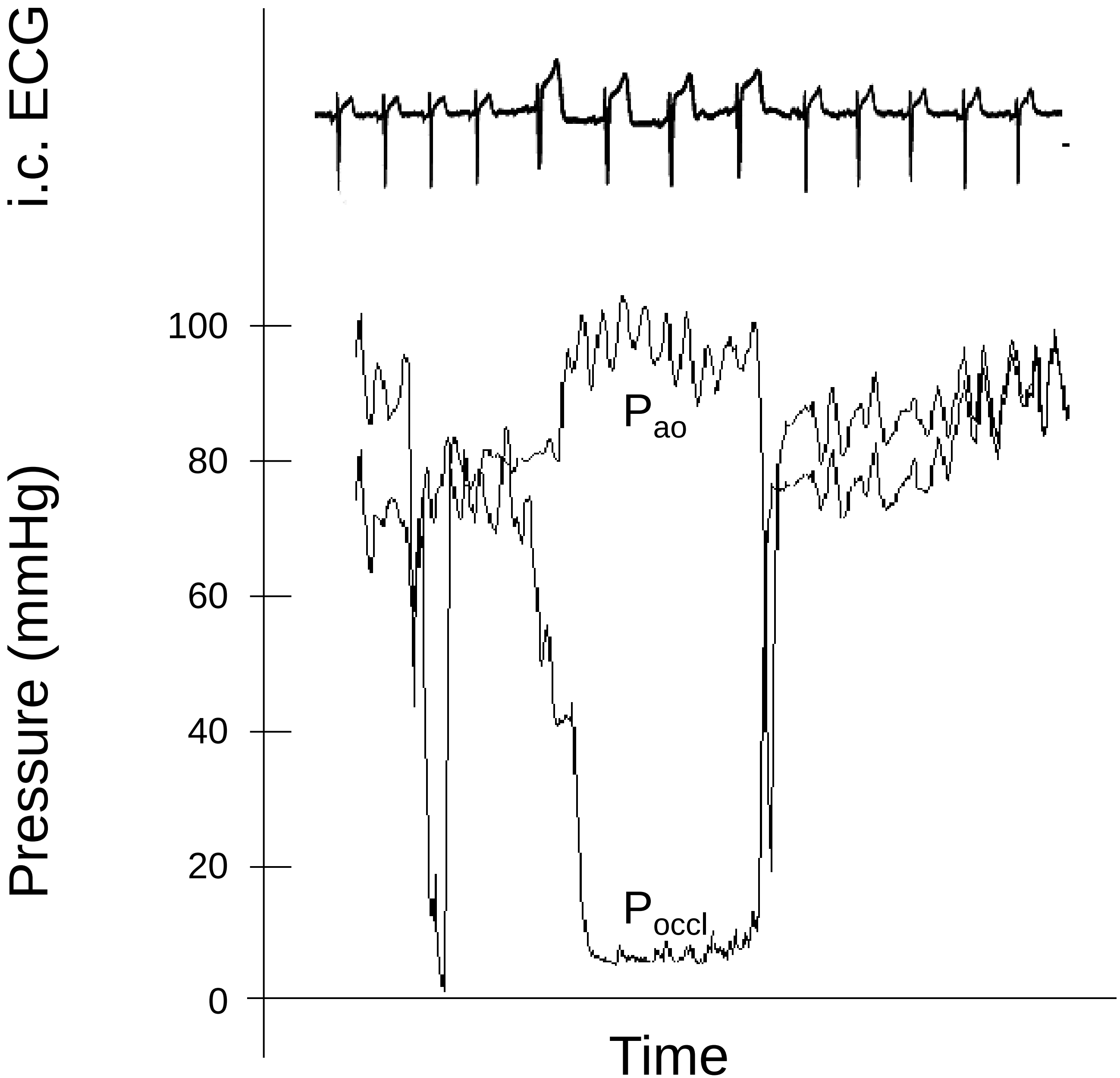

LCX
LAD
LV
IVS
Area at risk for infarction (regional myocardial mass M)

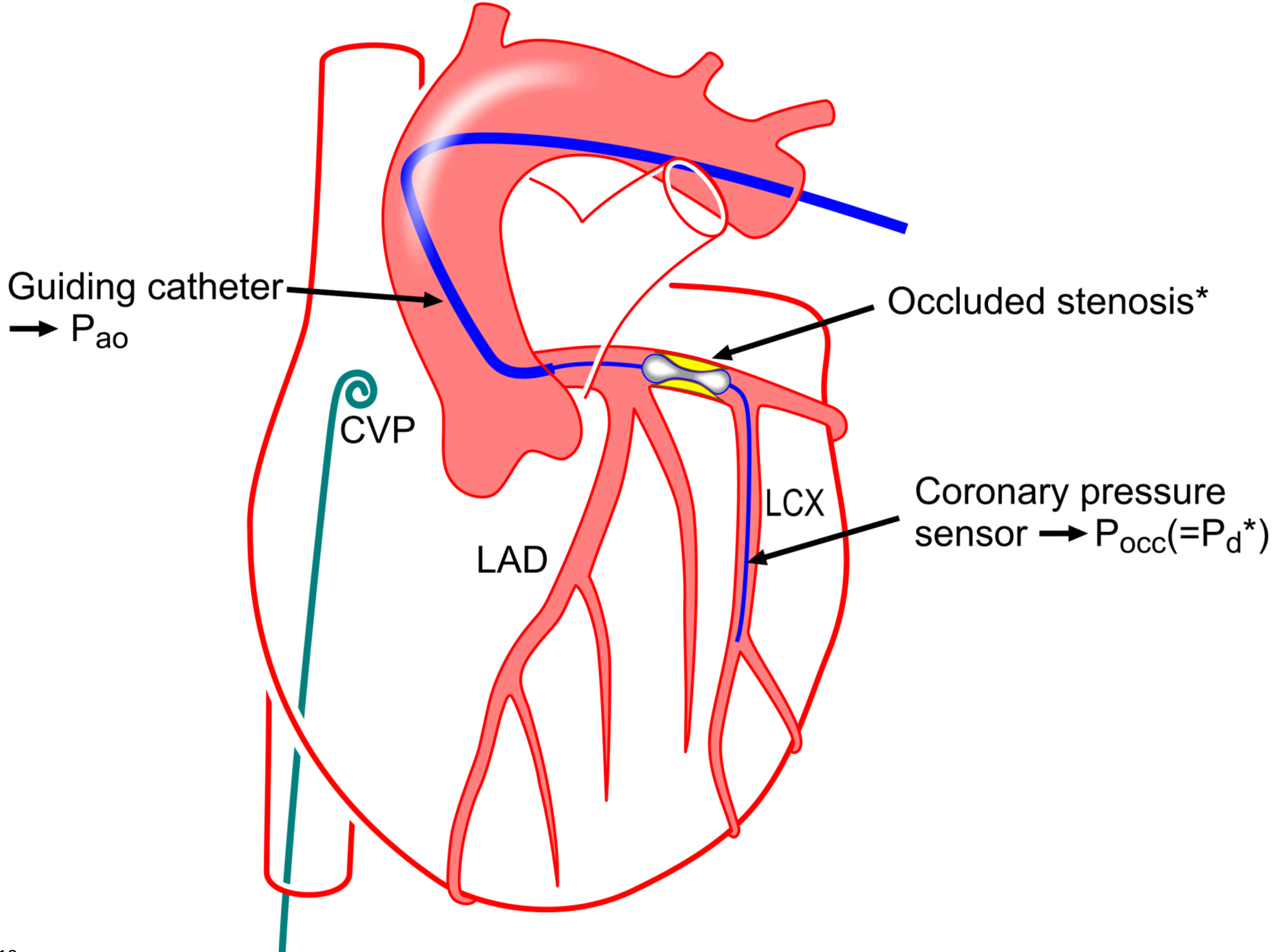


P_{ao}
Microcirculation
R_m
Q
CVP



0s
5s
10s
15s
20s


i.c. ECG
Pressure (mmHg)
100
80
60
40
20
0
P_{ao}
P_{occl}
Time


Guiding catheter
→ P_{ao}
Occluded stenosis*
CVP
LCX
LAD
Coronary pressure
sensor → $P_{occ}(=P_d^*)$

Seiler ii/13