CORONARY PHYSIOLOGY IN THE CATHLAB:

FFR AND COLLATERAL FLOW

Educational Training Program ESC
European Heart House
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CATHARINA-ZIEKENHUIS

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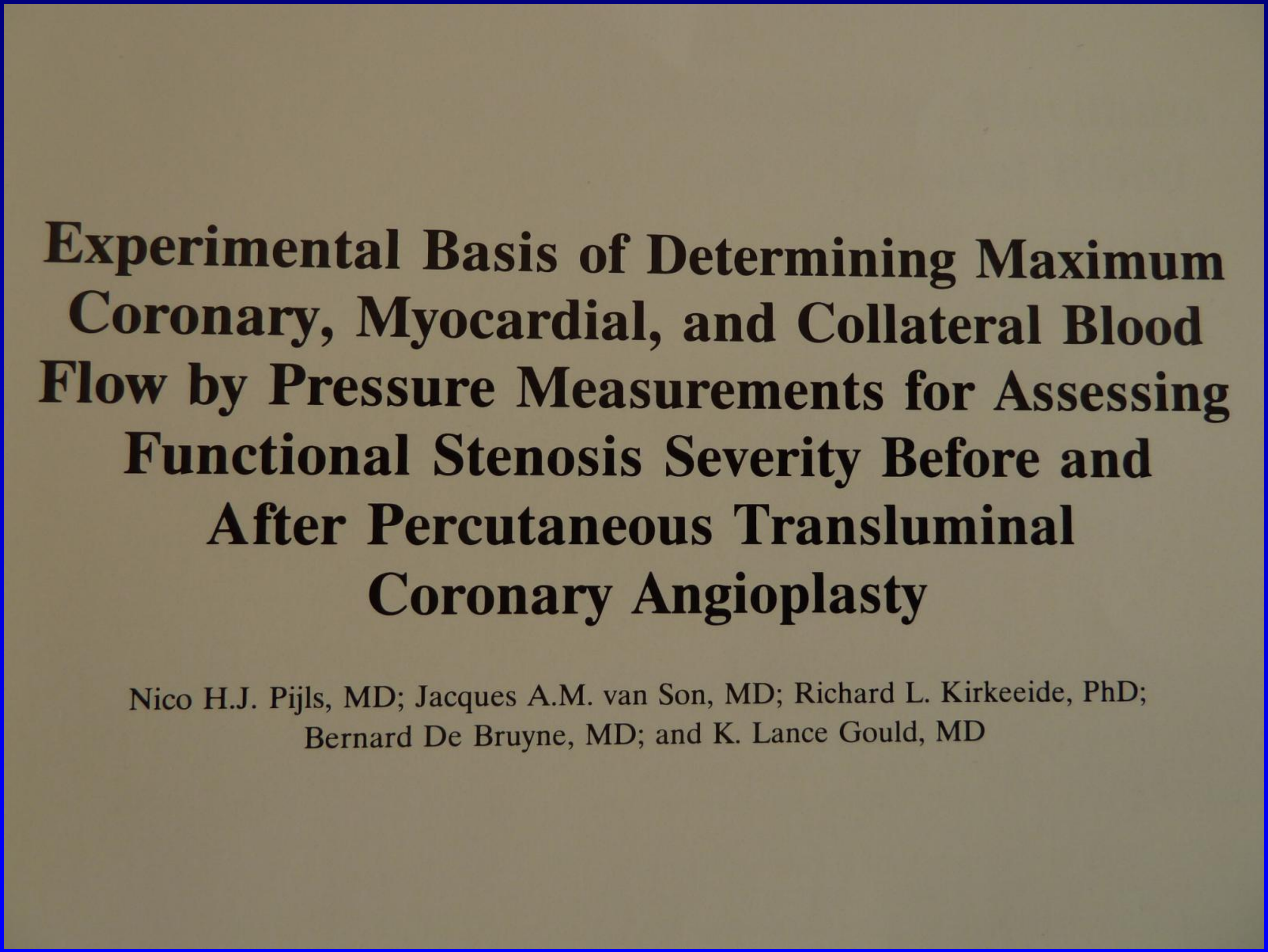
Very, very long ago, there existed…………



Experimental Basis of Determining Maximum Coronary, Myocardial, and Collateral Blood Flow by Pressure Measurements for Assessing Functional Stenosis Severity Before and After Percutaneous Transluminal Coronary Angioplasty

Nico H.J. Pijls, MD; Jacques A.M. van Son, MD; Richard L. Kirkeeide, PhD; Bernard De Bruyne, MD; and K. Lance Gould, MD

Introduction of FFR in Circulation:may 1993

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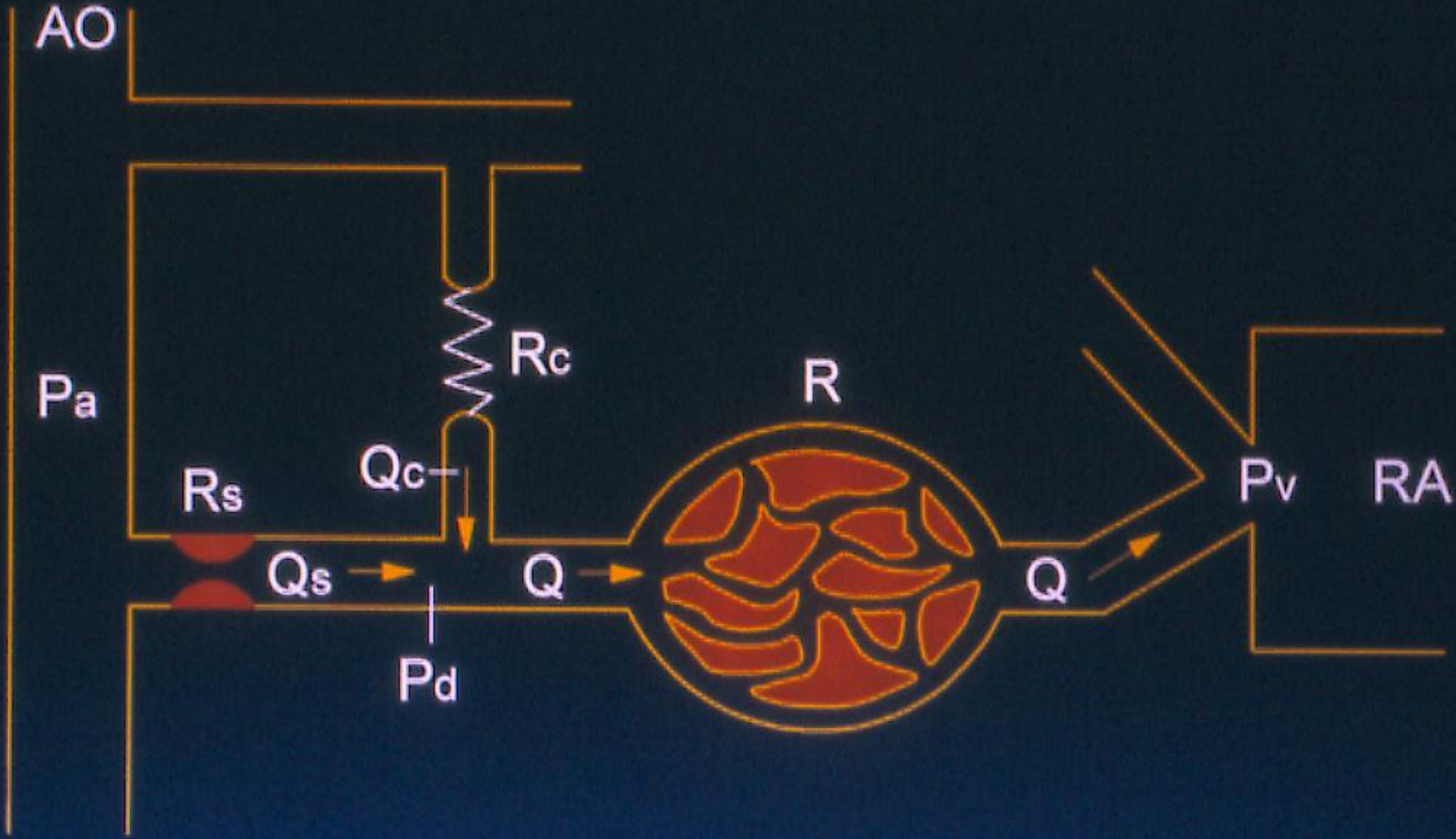

Including collaterals in the model……..

$$Q_{myo} = Q_{cor.artery} + Q_{collateral}$$

Quantitave assessment of the contribution of ***coronary arterial*** and ***collateral flow*** to total ***myocardial flow*** is possible by coronary pressure measurements, but not trivial

Pijls & De Bruyne:
Circulation 1993
Coronary Pressure, sec edition, Kluwer 2000

I $$\frac{P_a - P_v}{P_w - P_v} = 1 + \frac{R_c}{R} = \text{constant}$$

IIa $$FFR_{cor} = \frac{P_d - P_w}{P_a - P_w} = 1 - \frac{\Delta P}{P_a - P_w}$$

IIIa $$FFR_{myo} = \frac{P_d - P_v}{P_a - P_v} = 1 - \frac{\Delta P}{P_a - P_v}$$

IVa $$Q_c = (FFR_{myo} - FFR_{cor}) \cdot Q^N$$

23 exp.bas-4 equations

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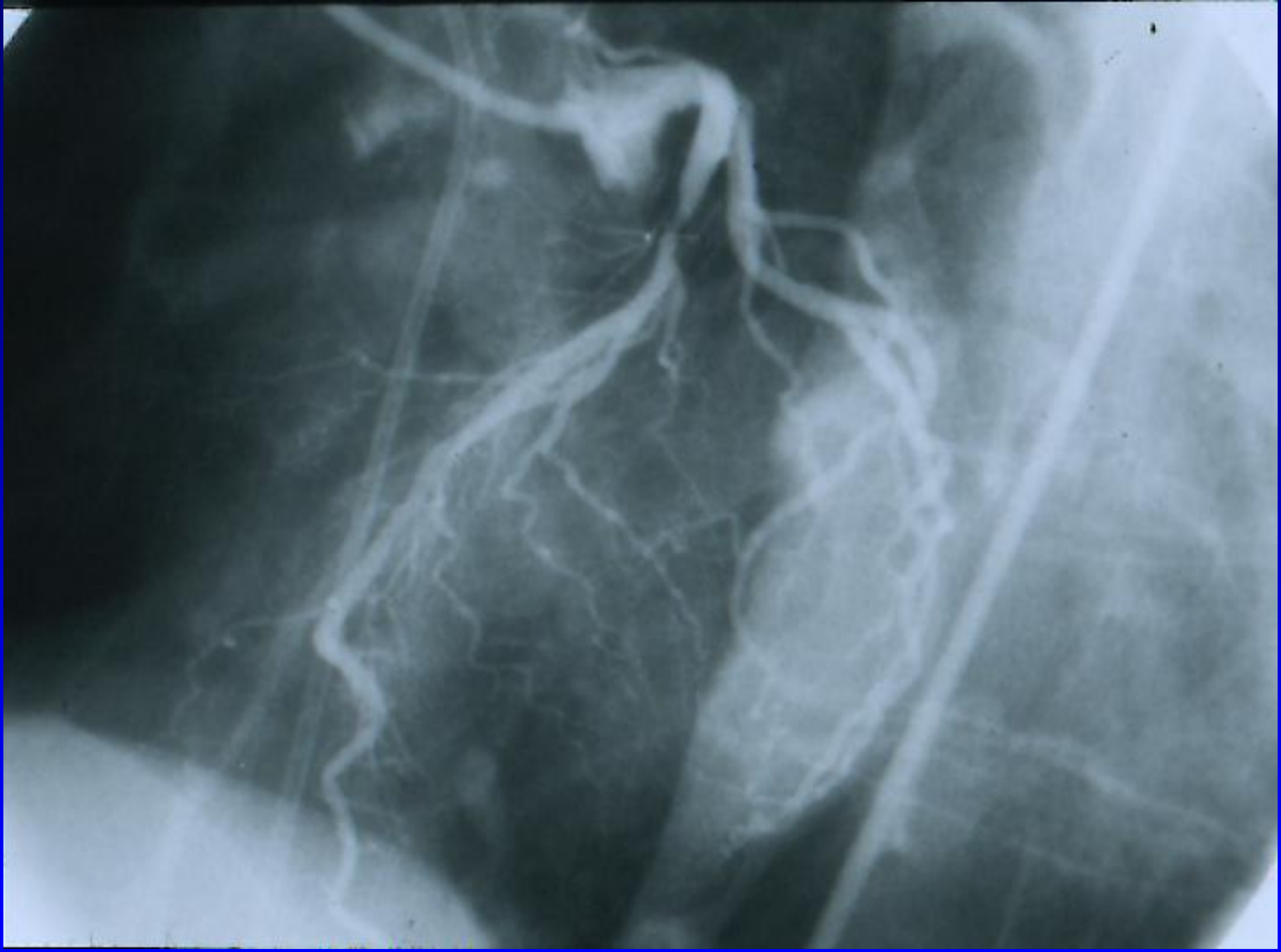
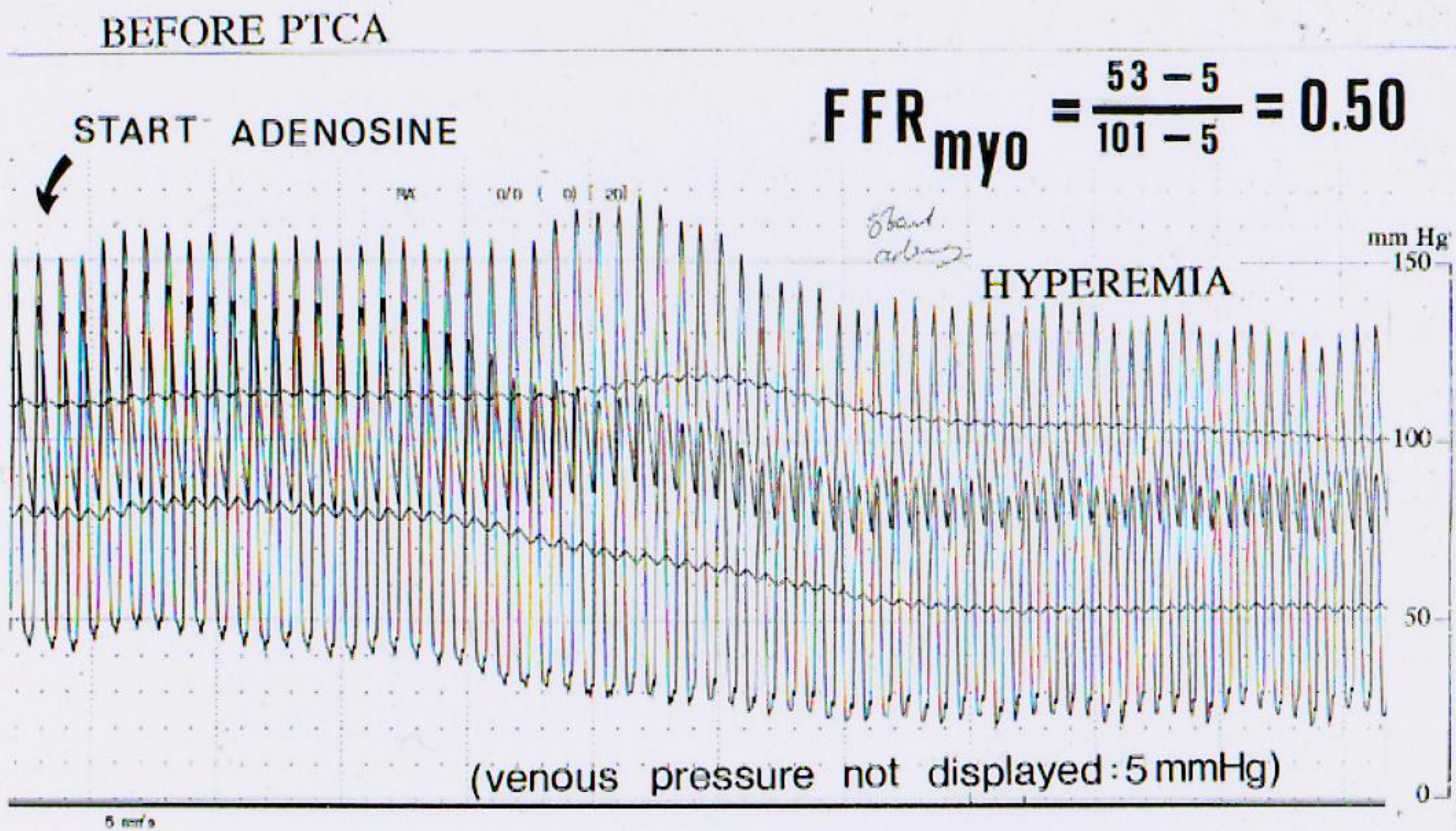
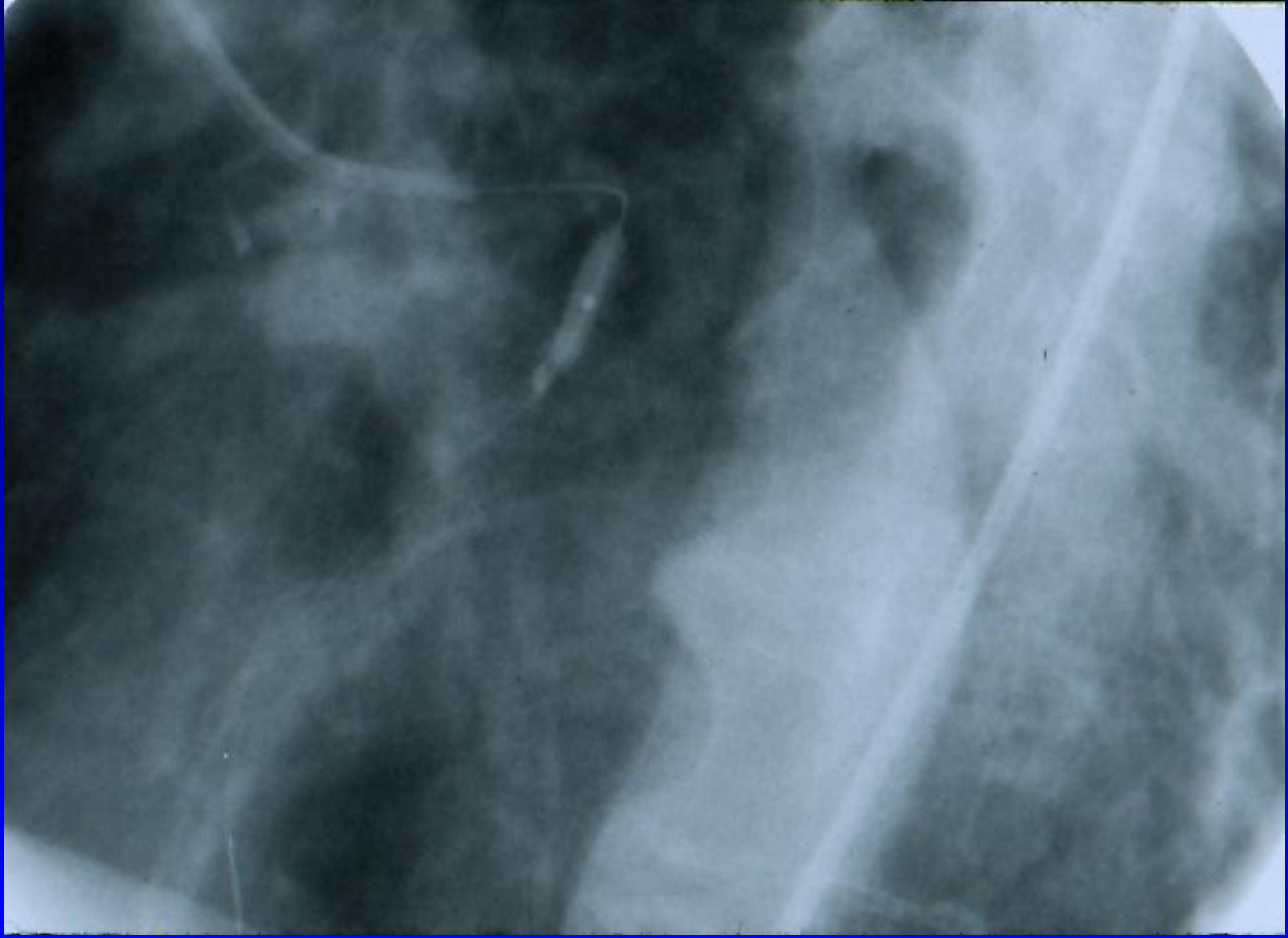


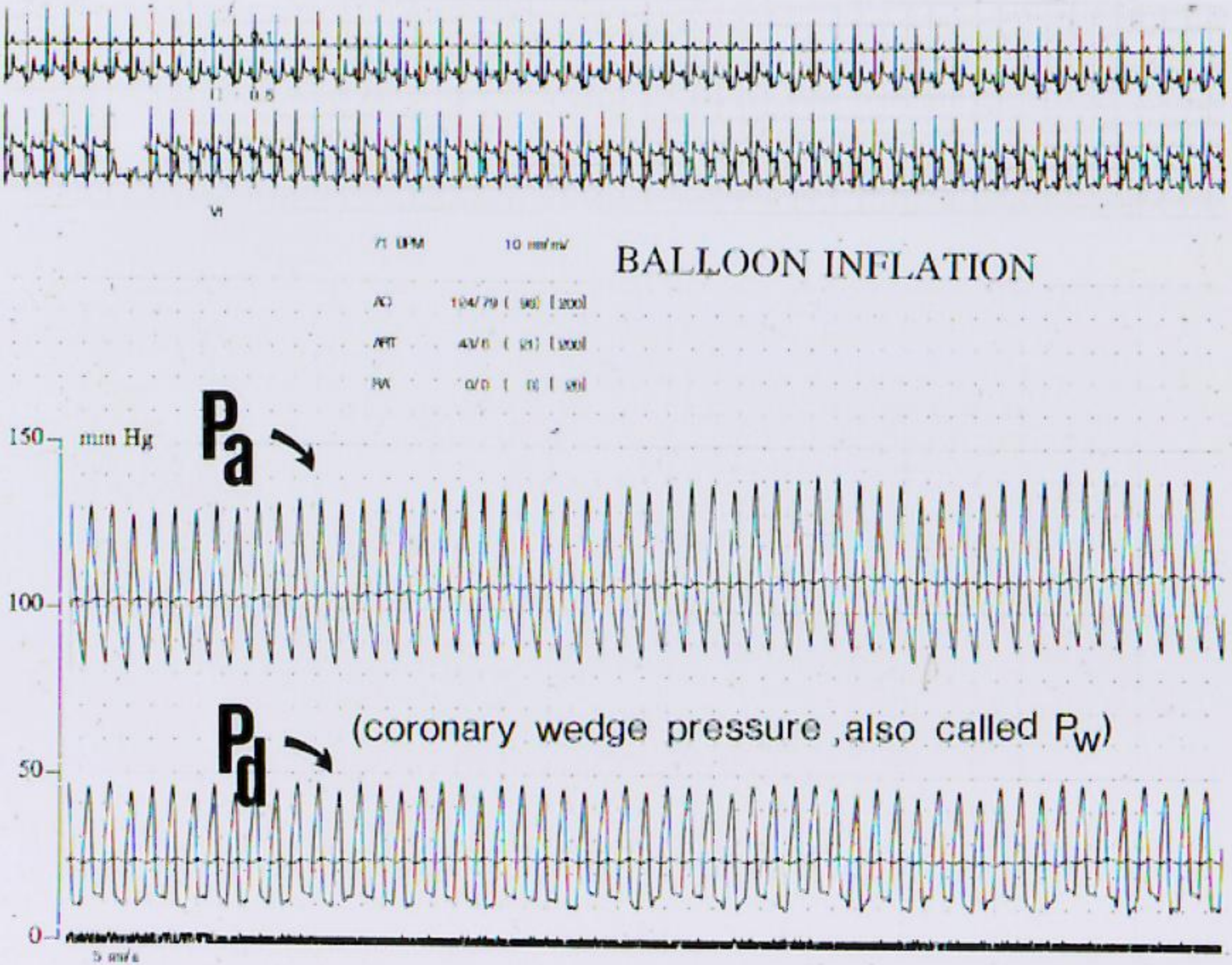
Circulation 1993; Coronary Pressure 2000

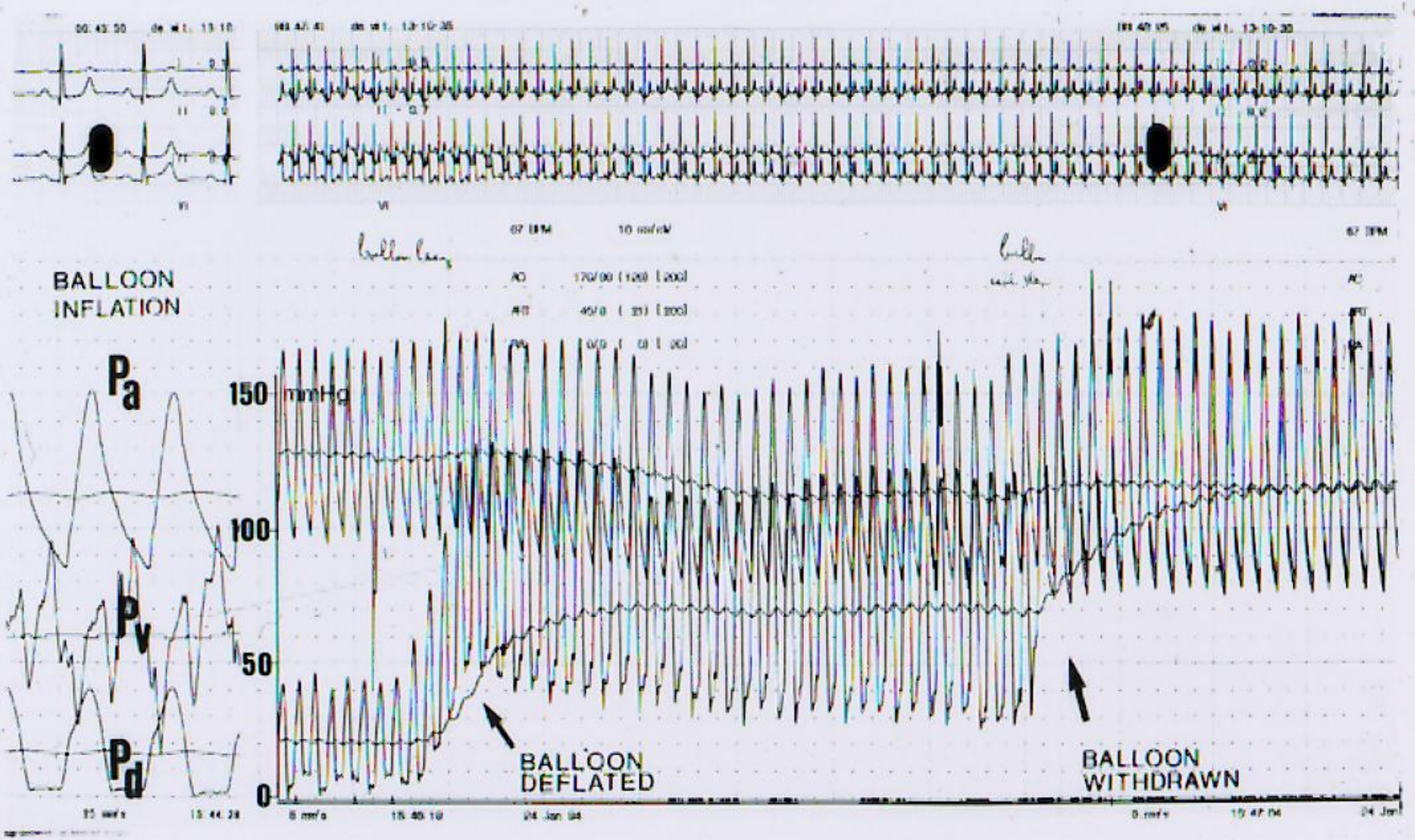


13 vb5-PTCA - de Wit-Stek (4)



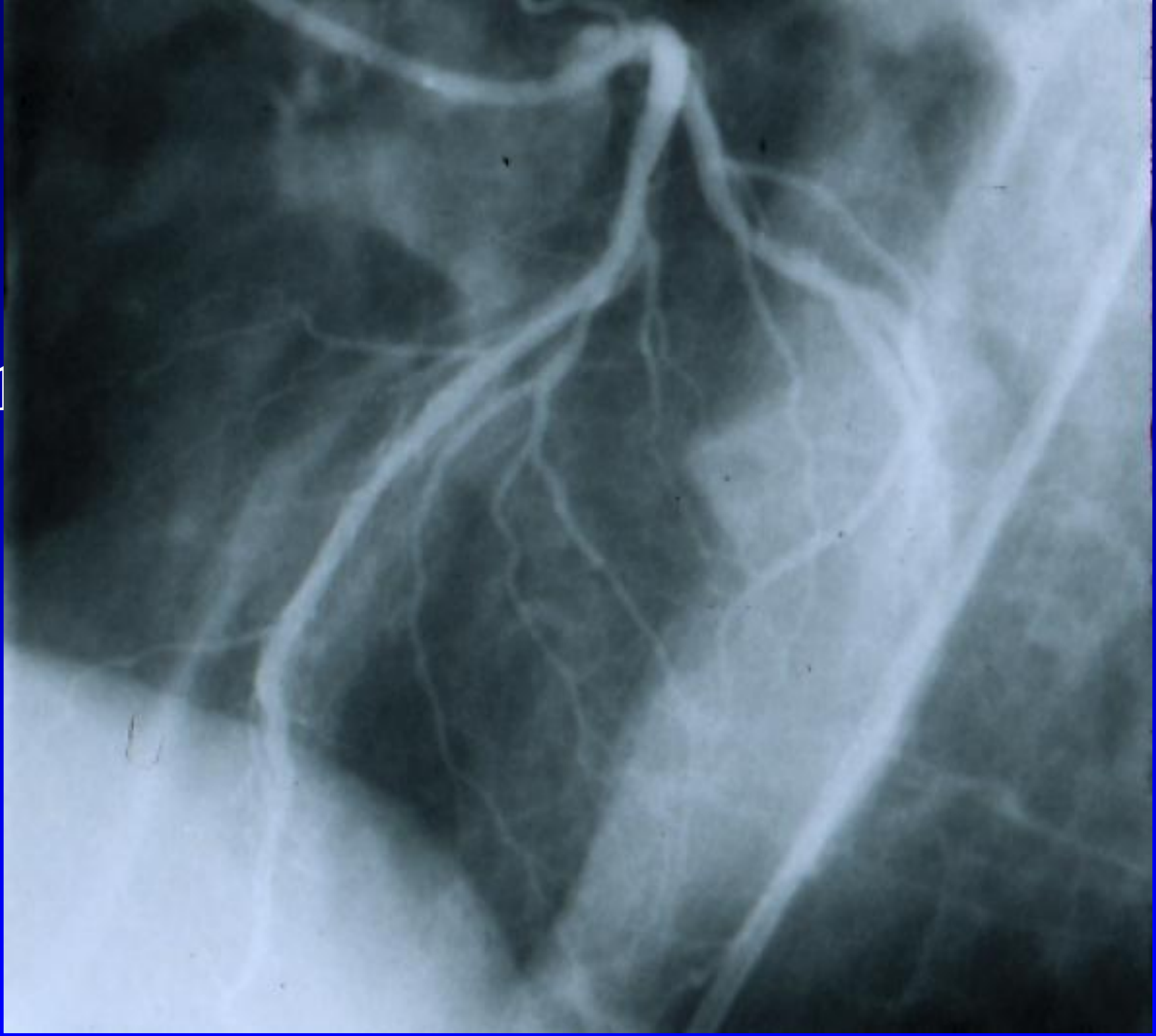
14 vb5-PTCA - de Wit-Stek (5)

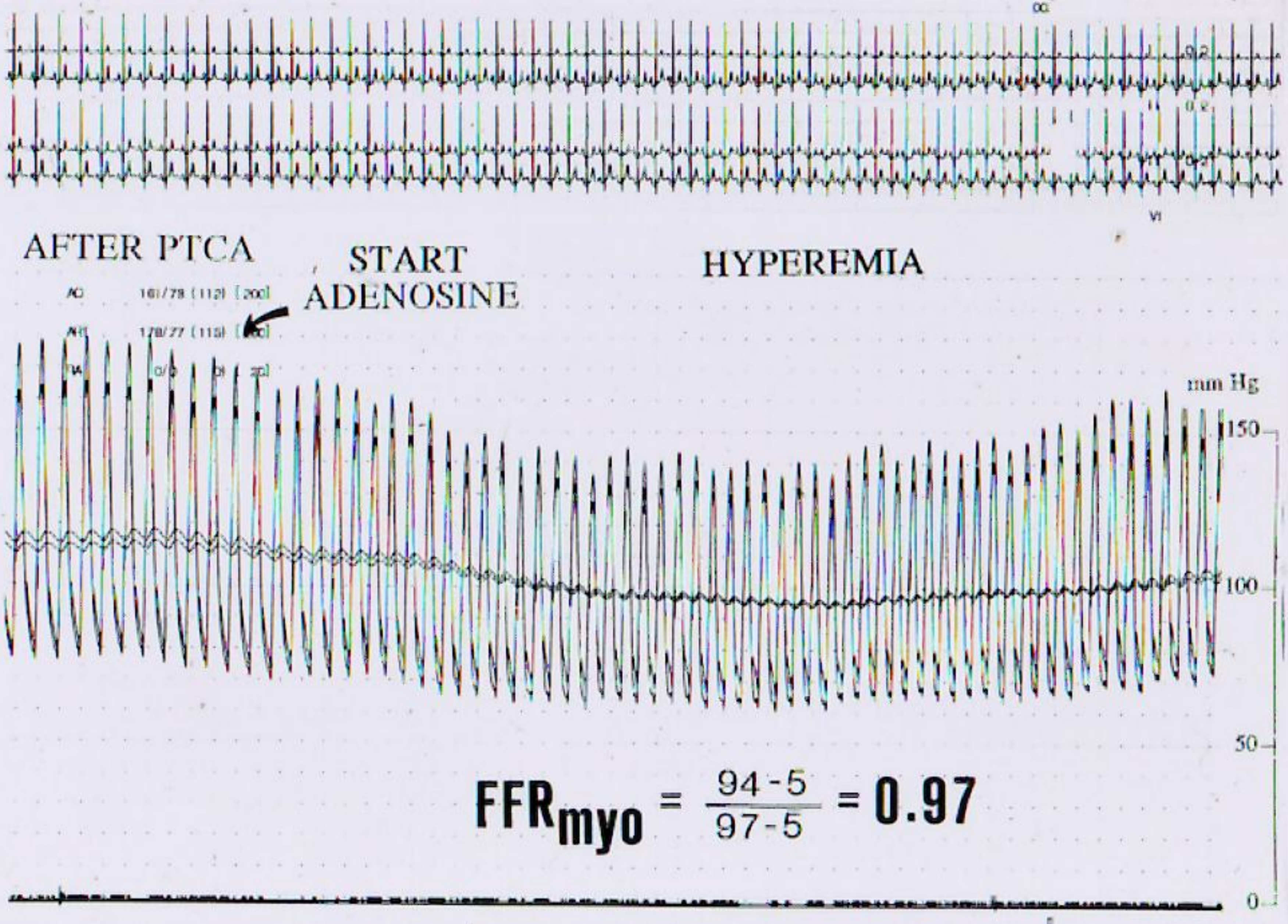

BALLOON INFLATION
150
mm Hg
Pa
100
Pd
(coronary wedge pressure ,also called Pw)
50
0



16 vb5-PTCA - de Wit-Stek (7)

• 1




AFTER PTCA
START
ADENOSINE
HYPEREMIA
mm Hg
150
100
50
0
FFRmyo = (94 - 5) / (97 - 5) = 0.97

	before	occlusion	after
Pa	90	101	98
Pd	42	-	82
Pv	2	5	2
Pw	(14)	18	(15)

	before PTCA	at occlusion	after PTCA
FFRmyo	0.50	0.18	0.97
FFRcor	0.39	-	0.96
Qc/Q^N	0.11	0.18	0.01

note: the values in this matrix are inependant of pressure or other hemodynamic variables. Such a matrix completely describes the distribution of flow in that part of the coronary circulation related to the respective artery.

	before PTCA	at occlusion	after PTCA
FFRmyo	0.50	0.18	0.97
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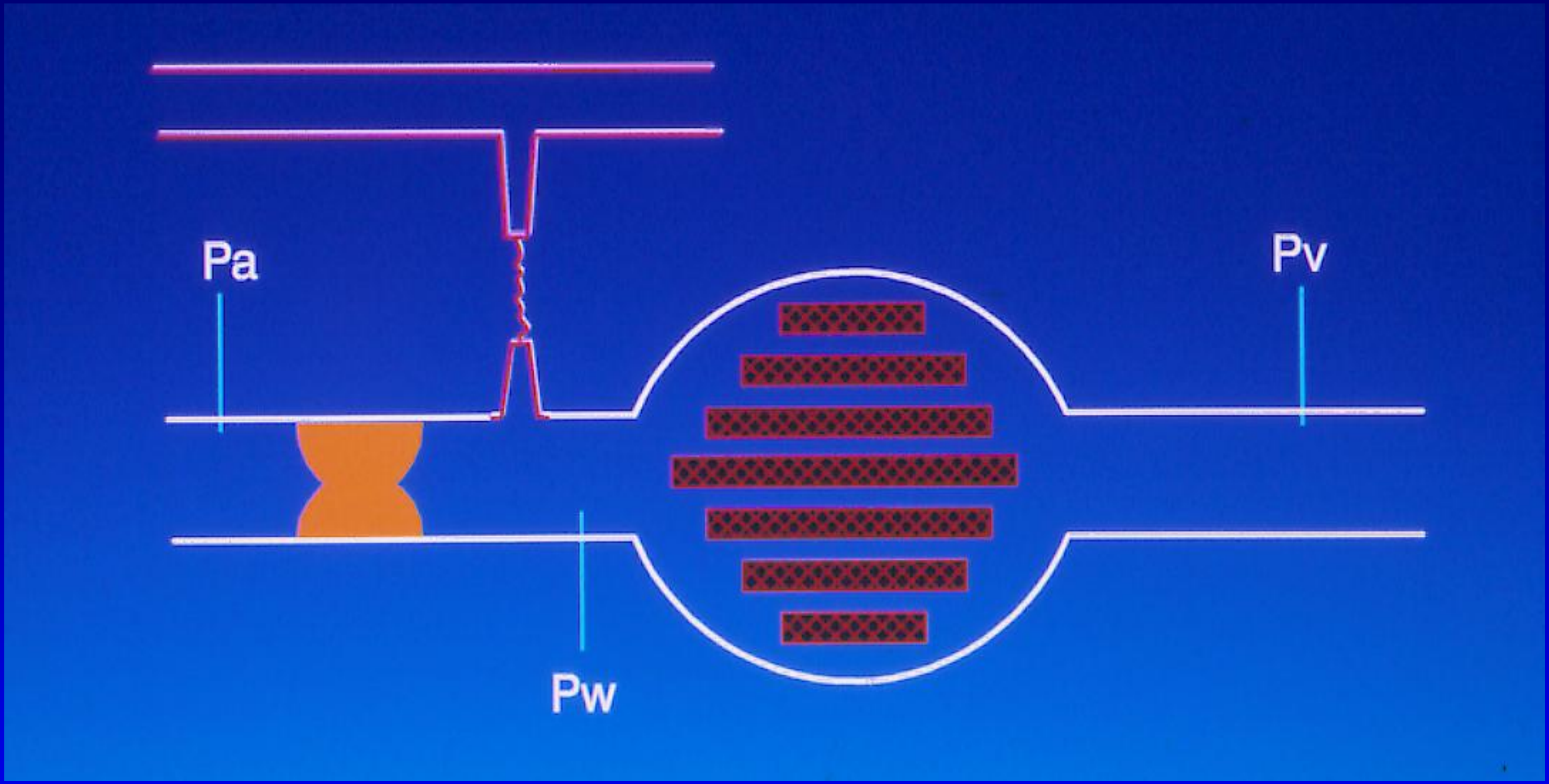


Fractional collateral flow =

$$\text{FFR } coll = \frac{Pd - Pw}{Pa - Pw}$$

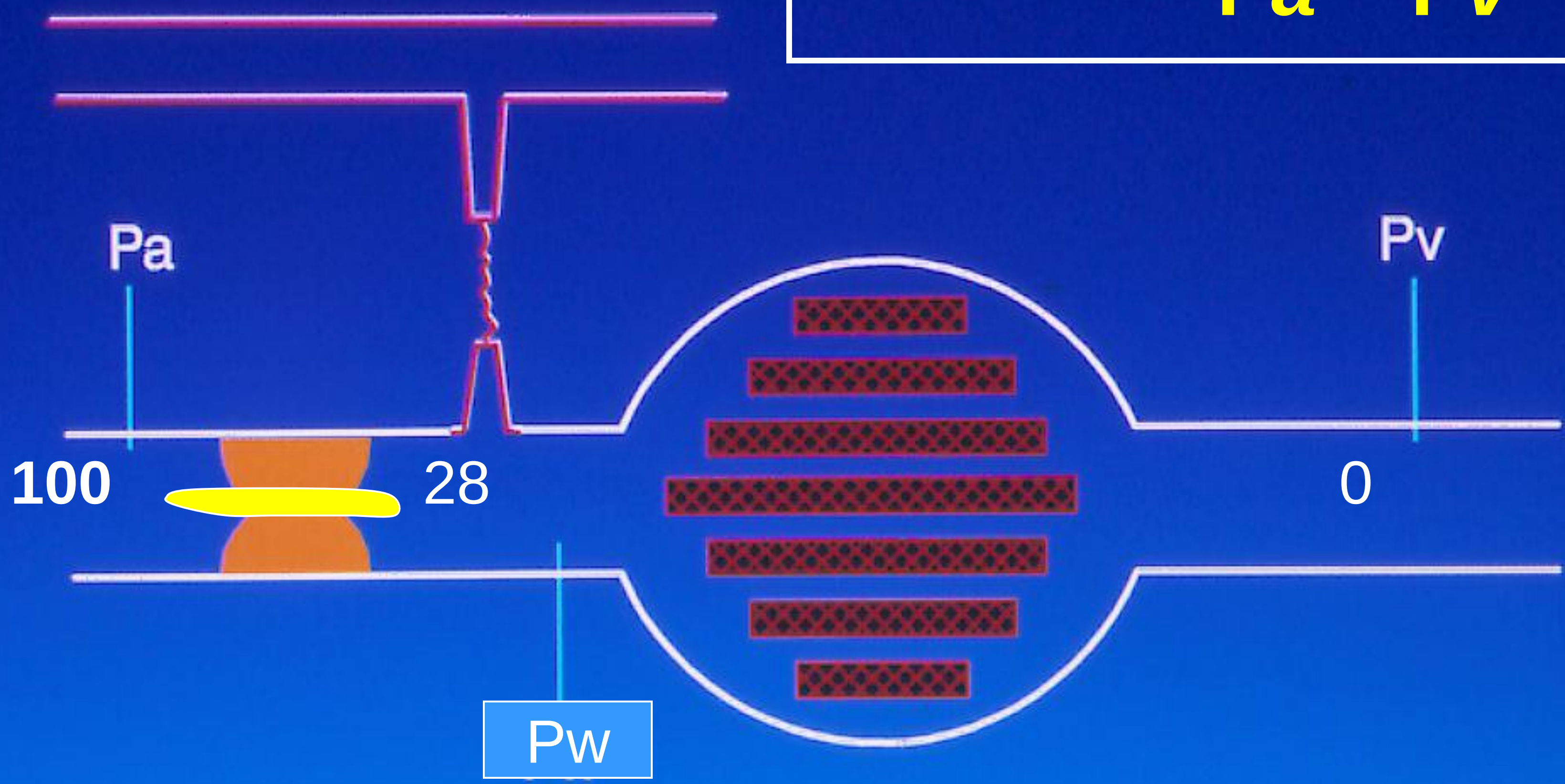
(later also called CFIp
by Seiler et al)

To determine collateral flow by pressure measurement, temporary occlusion of the coronary artery is necessary !

(prerequisite to measure coronary wedge pressure)

During balloon occlusion of the coronary artery:

$$FFR_{coll} = \frac{P_w - P_v}{P_a - P_v}$$

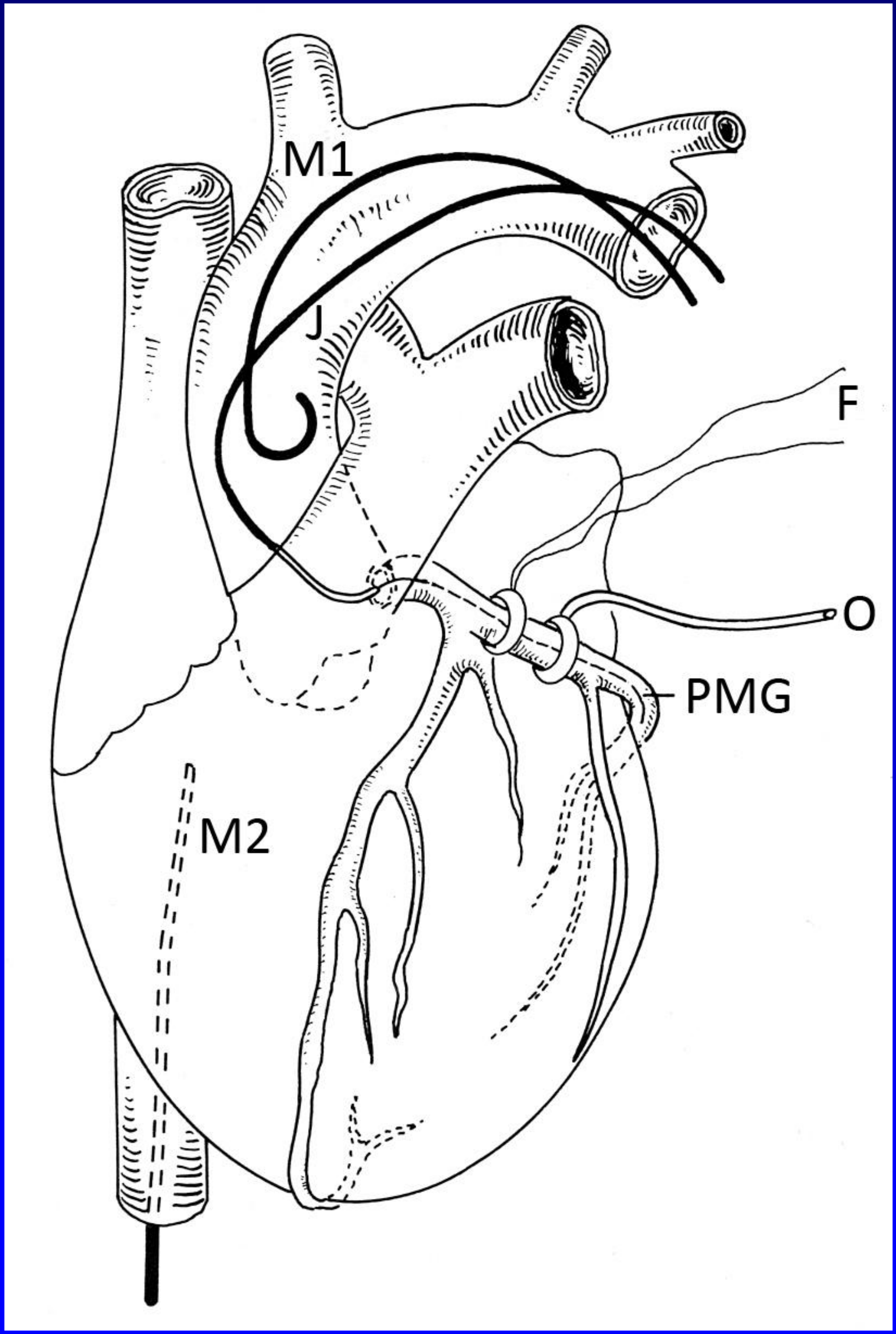


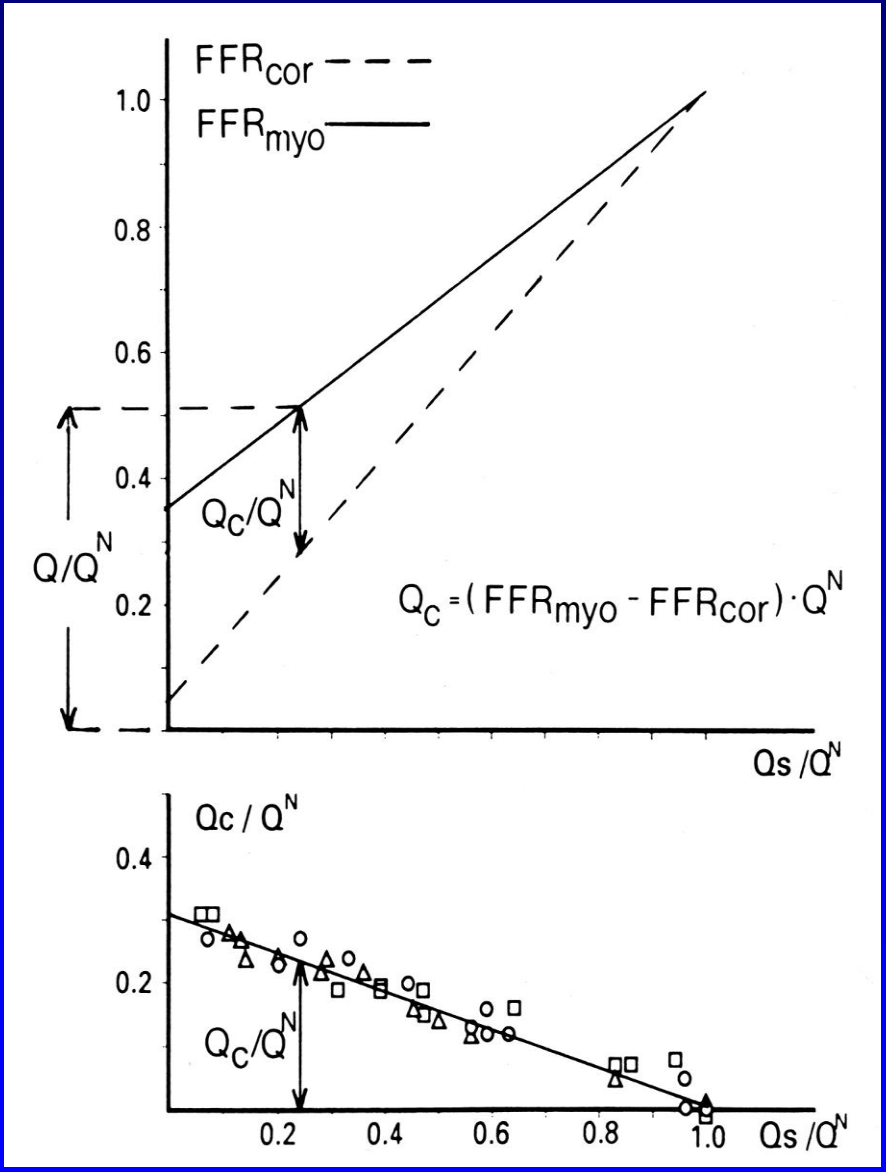
FFR coll = 0.28 (also called CFIp)

Circulation 1993;87:1354-1367

Coronary Pressure, 2nd ed, 2000

FFR $_{coll}$:
experimental validation in chronic dog studies





Experimental basis of FFR

Horizontal axis:
FFR$_{cor}$ measured by true flow

Vertical axis:
FFR$_{myo}$ and *FFR$_{coll}$ measured by Hyperemic pressure ratio*

Pijls et al, Circulation, 1993

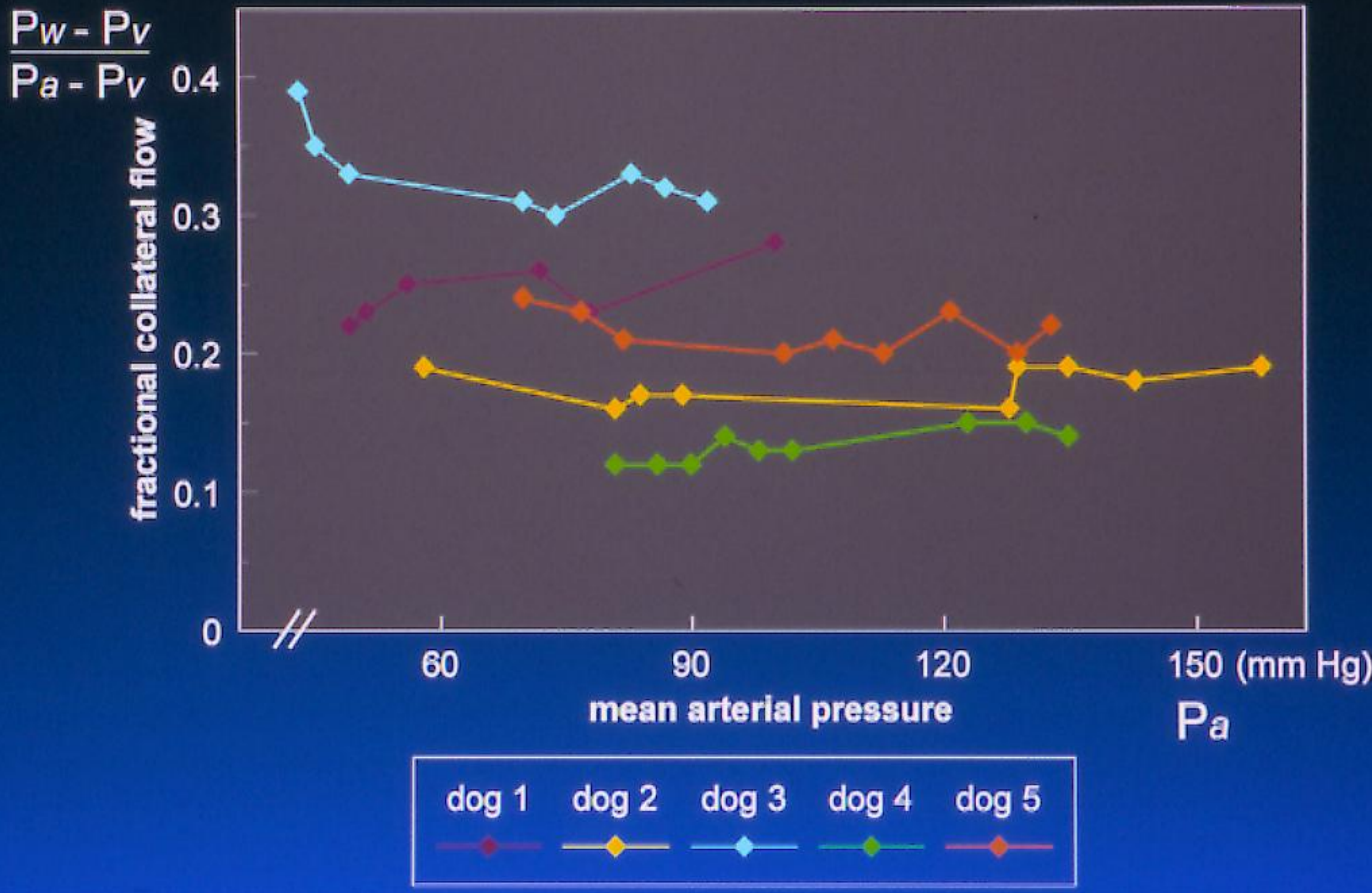
Do we have to bother about P_v ?

→ ***Yes,*** in case of studies to collateral function, we have to take into account Pv

$$FFR_{coll} = \frac{Pw - Pv}{Pa - Pv}$$

$$\frac{75 - 5}{100 - 5} = 0.74 \quad \Bigg| \quad \frac{75}{100} = 0.75 \quad \Bigg| \quad \frac{20-5}{100-5} = 0.15 \quad \Bigg| \quad \frac{20}{100} = 0.20$$

FFR myo **FFR coll**



FFR$_{collaterals}$ *is independent of changes in blood pr*

Reproducibilty of FFR$_{collaterals}$

Pressure-Derived Parameters for Assessing Coronary Collateral Circulation

Reproducibility:

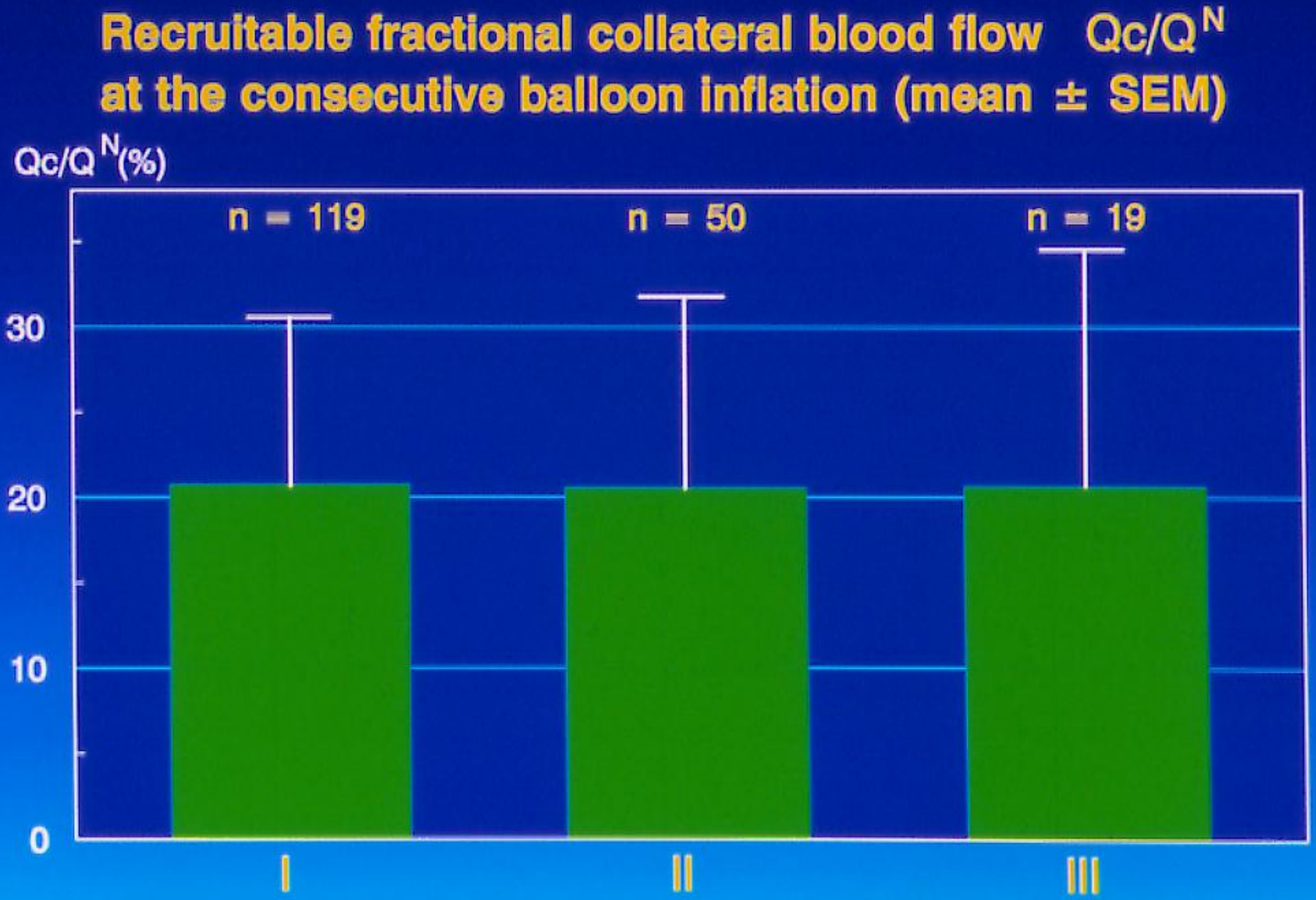
- 50 patients
- recruitable collateral flow assessment at 2 consecutive balloon occlusions with an interval of 15 minutes, by:

$$Q_c/Q^n = \frac{P_w - P_v}{P_a - P_v}$$

- first occlusion: 0.21 ± 0.10
- second occlusion: 0.20 ± 0.11

coefficient of variation: 2 ± 4%

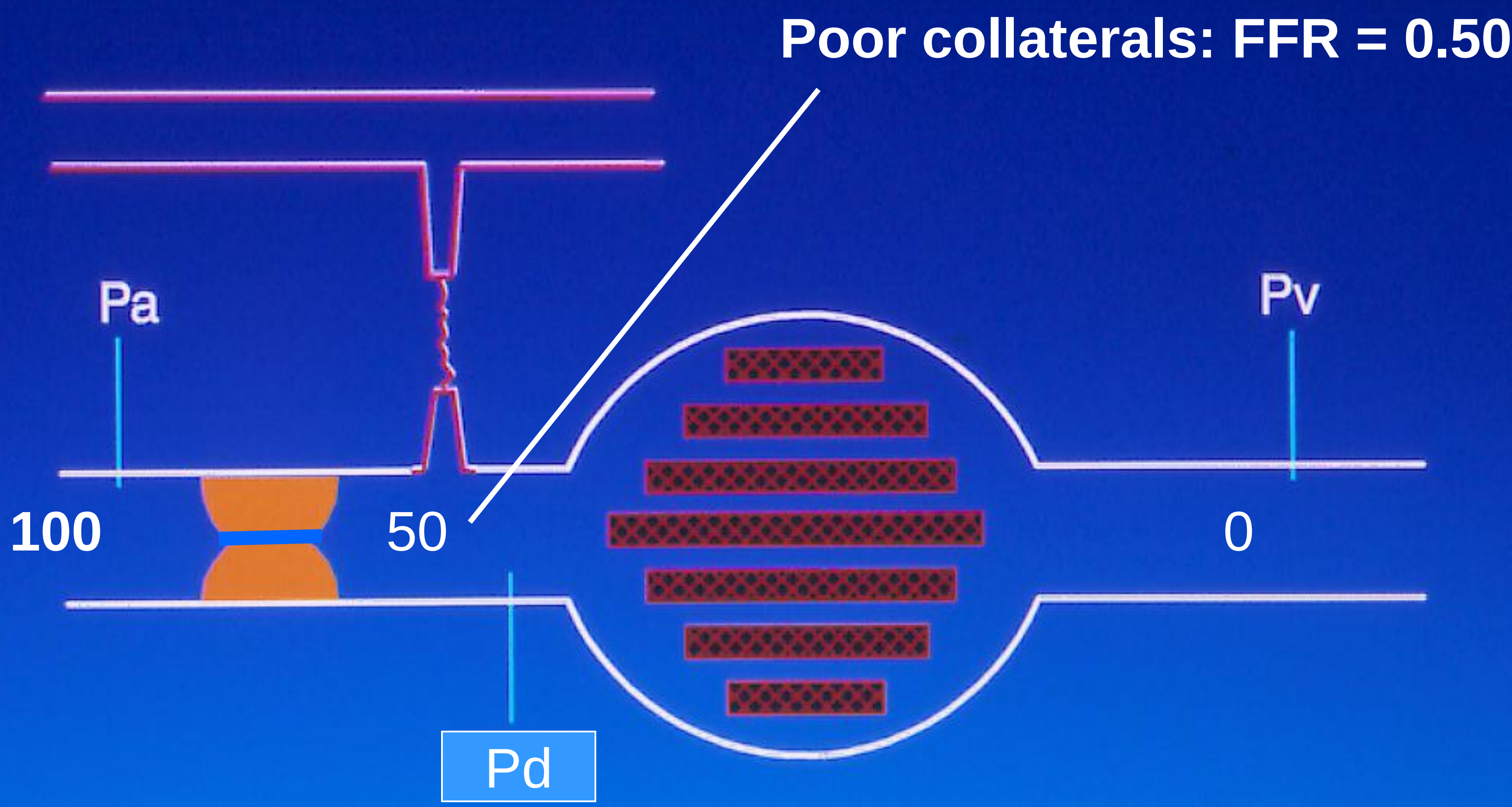
Pijls et al, JACC 1995



20 col-figuur consec. infl.

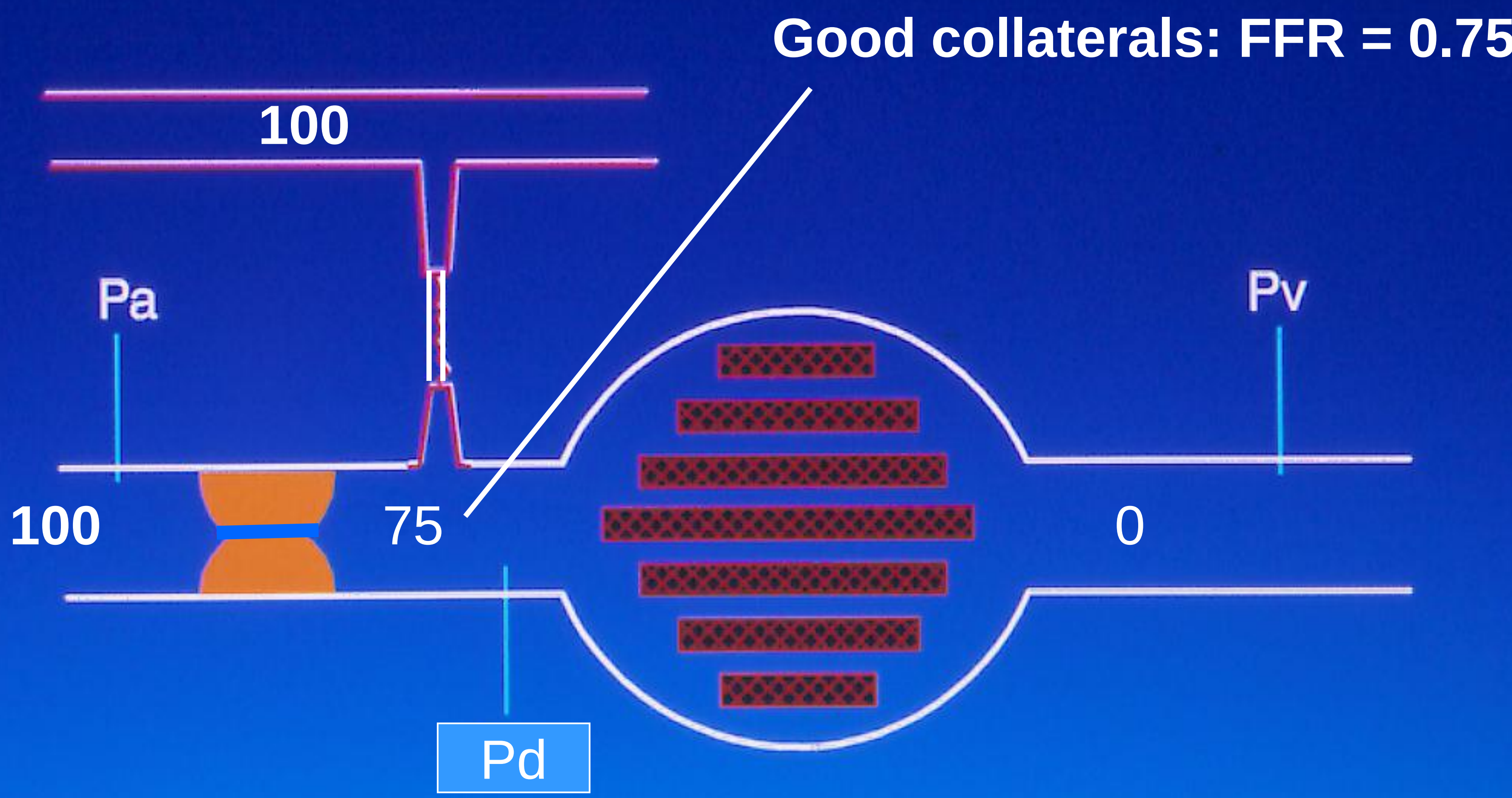
One of the reasons why an apparently severe stenosis might have a high FFR Value, is the presence of good collaterals…………

“One identical stenosis, but......”



Poor collaterals ⟶ low FFR

……………different extent of collaterals"



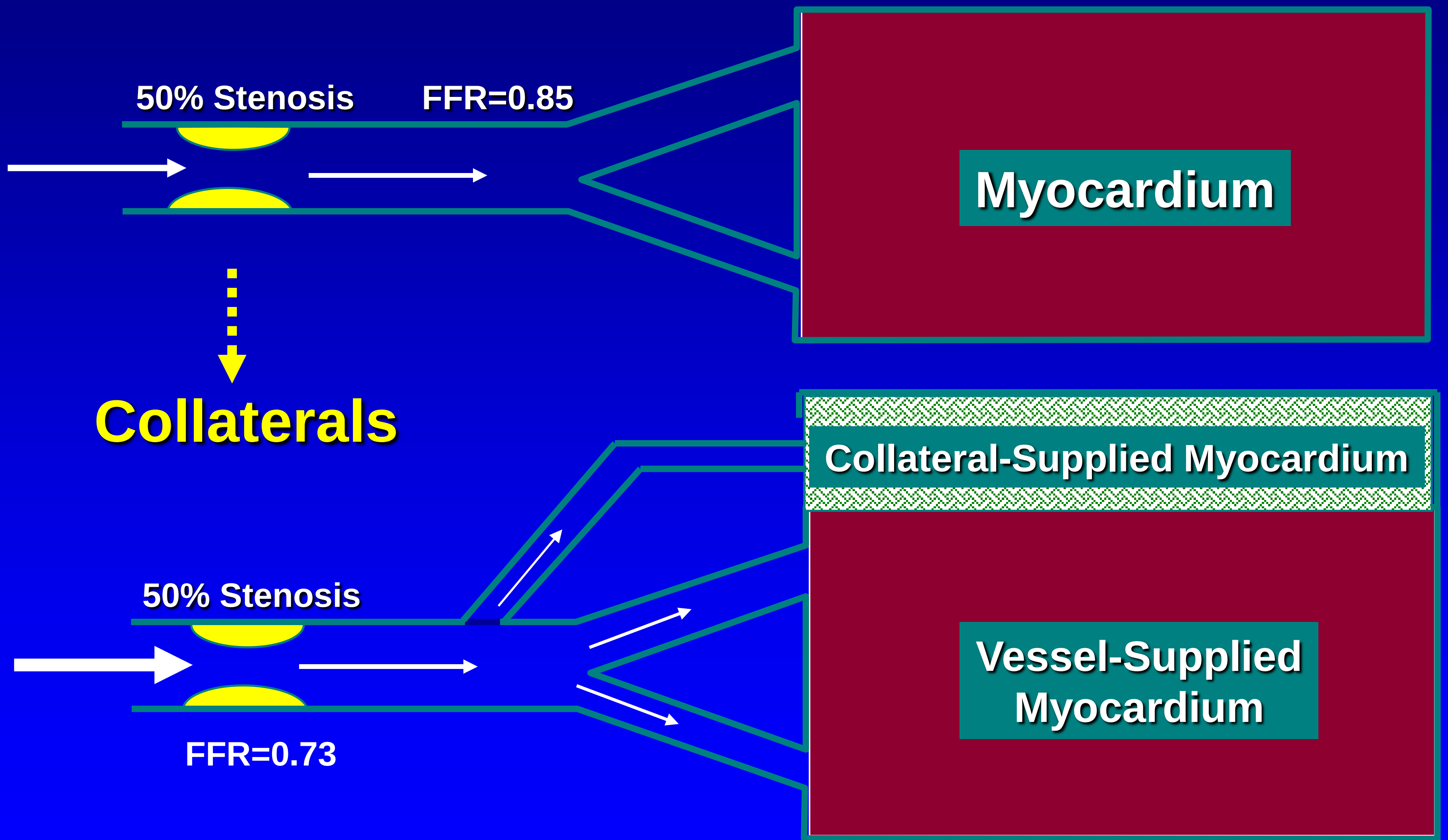
Good collaterals ⟶ higher FFR

FEATURES OF FFR

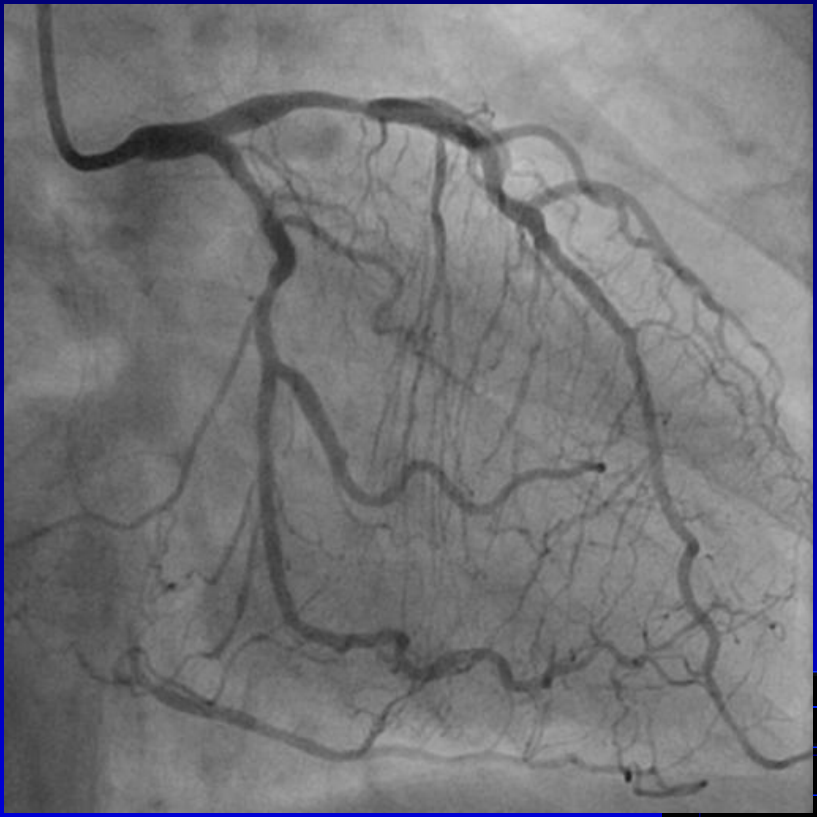
- *Normal value = 1.0* for every patient and every artery
- FFR is *not influenced by changing hemodynamic conditions* (heart rate, blood pressure, contractility)
- FFR specifically relates the influence of the epicardial stenosis to myocardial perfusion area and blood flow
- **FFR accounts for collaterals**
- FFR has a *circumscript threshold value* (~ 0.75 – 0.80) to indicate ischemia
- FFR is *easy* to measure (success rate 99 %) and extremely *reproducible*
- Pressure measurement has un *unequaled spatial resolution*

This also means that a rather mild stenosis in a collateral-giving artery, might have a lower than expected FFR, if the perfusion territory is enlarged due to extensive collaterals !

Disconnect between Anatomy and Physiology



…During Maximal Hyperemia

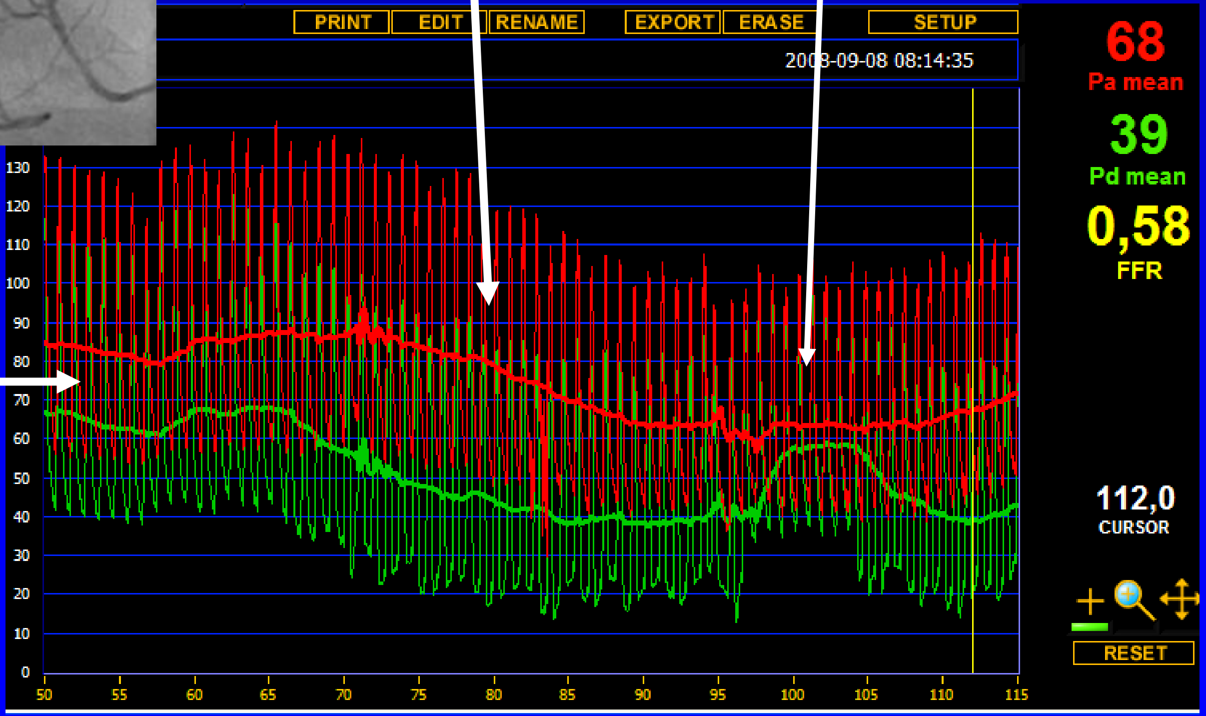


moderate LAD-stenosis with large perfusion area → *low FFR, functionally highly significant*

hyperemia

pull-back

resting



FFR is more than just Pd/Pa at hyperemia……..

It is a complete description of coronary, myocardial, And collateral blood flow in terms of pressure

FFR is a beautiful physiological index describing the relation between

- ***epicardial stenosis severity***
- ***coronary blood flow***
- ***extent of perfusion territory***
- ***and myocardial ischemia***

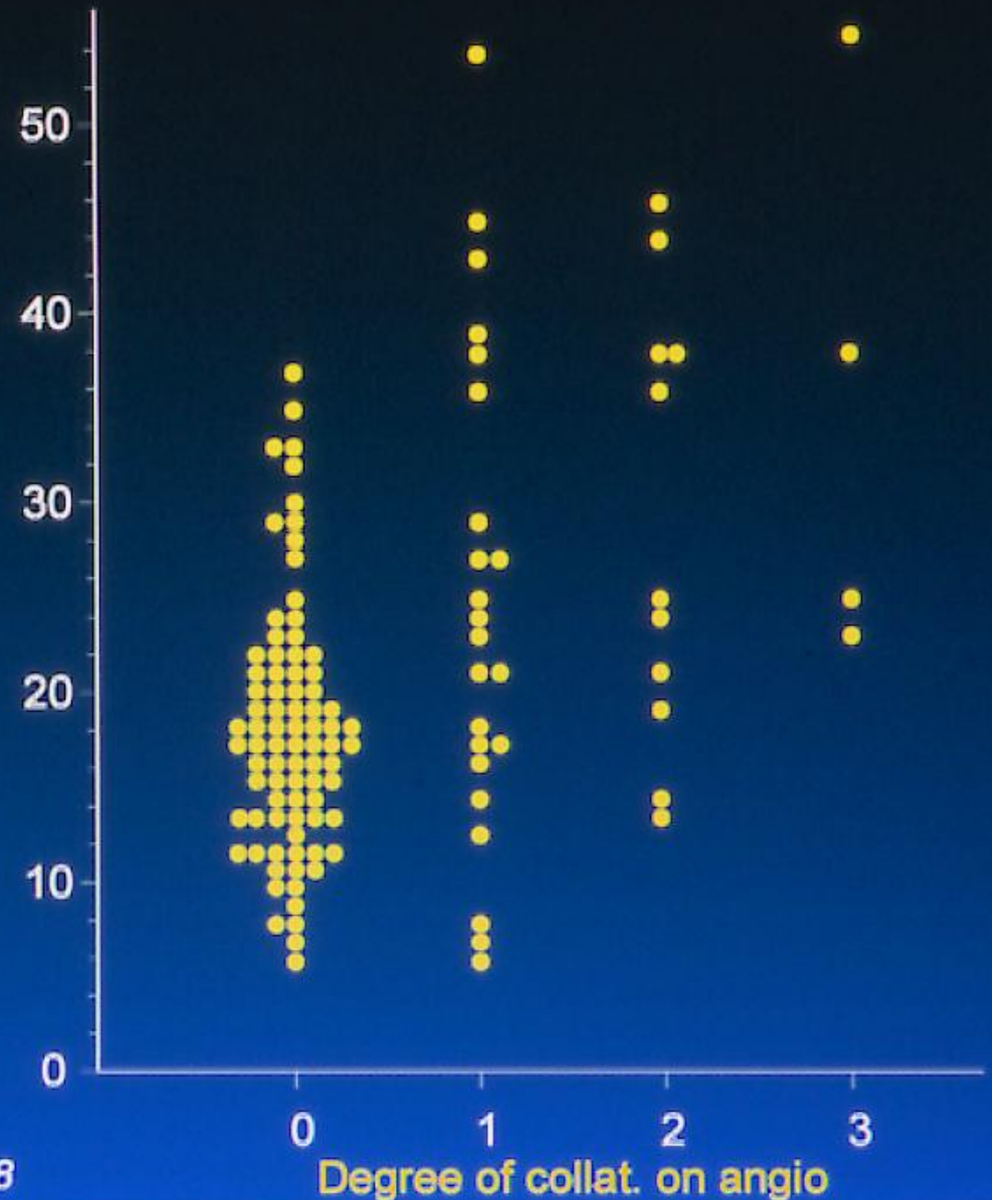
- ***FFR in fact incorporates a large part of coronary physiology***

Relation between FFR_{coll} and angiographic grading?

$$\frac{P_w - P_v}{P_a - P_v} = Q_c / Q^N (\%)$$

FFR_{coll}

(or CFI_p)



from Pijls et al, JACC 1995; 25 : 1522-8

angiographic grading according to renthrop

Collateral Flow assessment by FFR and OUTCOME

Recruitable Collateral Flow & Clinical Outcome:

- n=120 patients, undergoing PTCA
- quantitation of recruitable collateral flow by coronary pressure measurements
- group I: $Q_c/Q^n \geq 0.25$ or $P_w/P_a \geq 0.30$: n=34
- group II: $Q_c/Q^n < 0.25$ or $P_w/P_a < 0.30$: n=85
- 2-year follow-up:
  group I: 1 acute ischemic event (3%)
  group II: 15 acute ischemic events (18%)

Pw/Pa at occlusion ≥ 0.30 ⟶ 5x smaller chance for myocardial infarction or death in the next 5 years

Pijls & De Bruyne, Coronary Pressure, sec edition, 2000: pg 348-349

Recruitable Collateral Flow & Clinical Outcome:

- n=120 patients, undergoing PTCA <u>***single vessel disease!***</u>
- quantitation of recruitable collateral flow by coronary pressure measurements
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FFR and Collateral Flow: CONCLUSIONS

- FFR $_{coll}$ (also called CFI_p) can be easily obtained during PCI
- is reproducible and independent of blood pressure
- has relevant relation to outcome
- is suitable tool for studies to collateral blood flow

Disadvantages:

- only applicable during PCI, not at diagnostic angio because of necessity of P_w
- for studies, P_v should be included
- careful calibration and equalization is mandatory

EINDE

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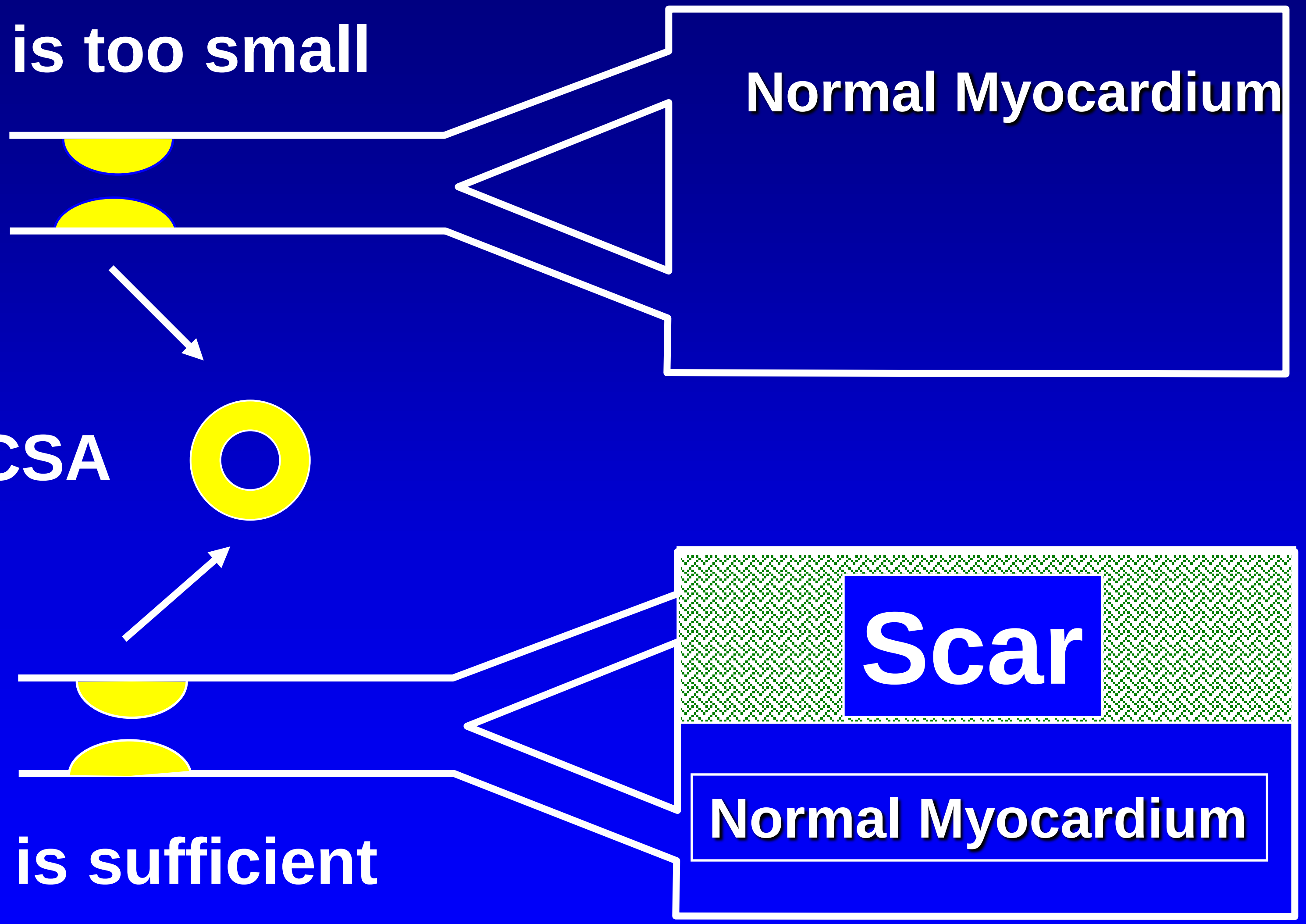
similar stenosis but different extent of perfusion area

4 mm^2 is too small

IVUS
identical CSA
4 mm^2

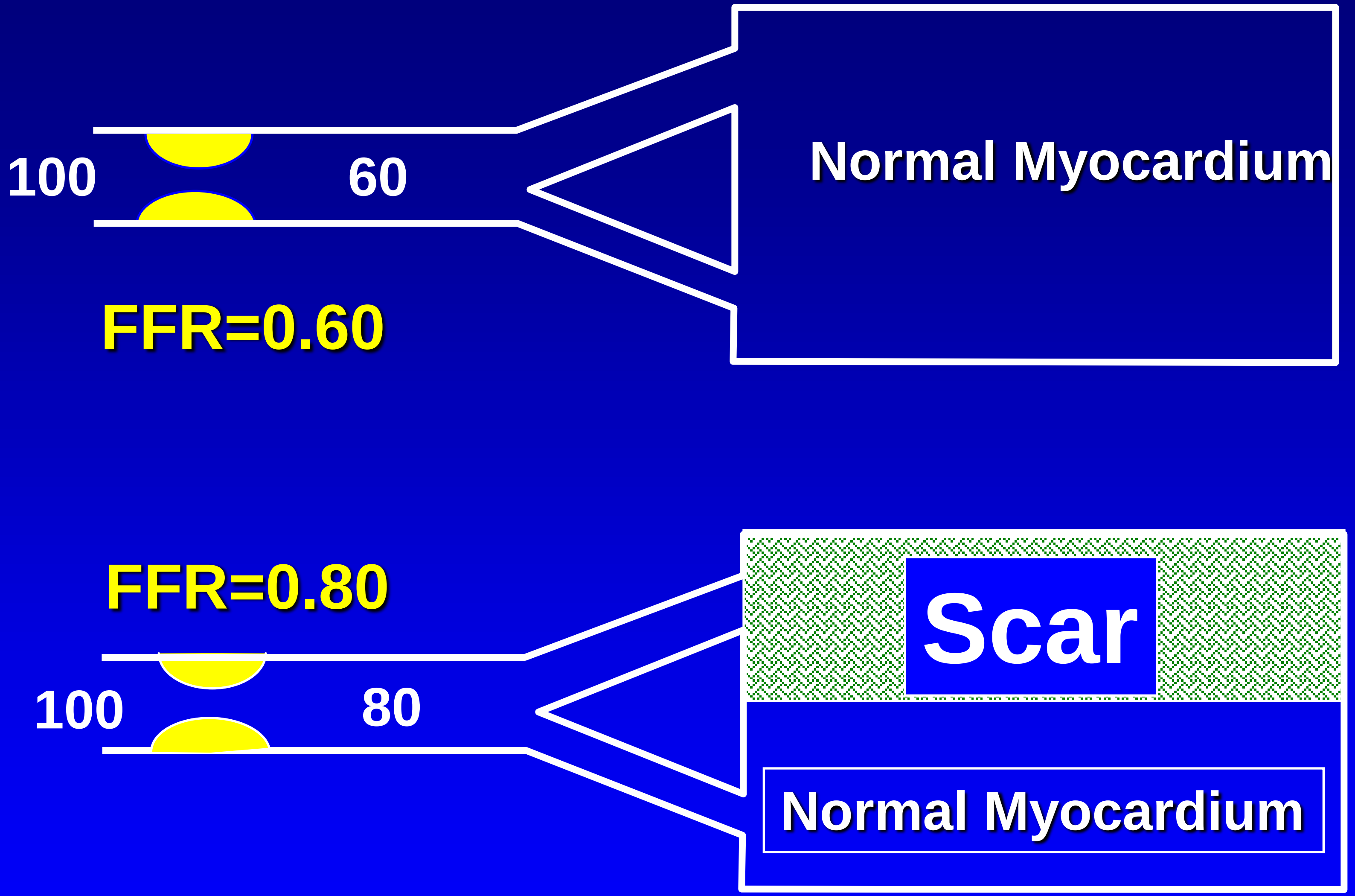


4 mm^2 is sufficient

identical CSA, but different significance of stenosis

With permission of
Dr Haitma Amin,
Bahrain

FFR accounts for the extent of the perfusion area:



Anatomic stenosis severity by IVUS or QCA is identical but physiologic severity has decreased.

→ ***FFR accounts for these changes !!!***

Recruitable Collateral Blood Flow at Consecutive Inflations

	# 1	# 2	# 3
Q_c/Q^N (%)	21 ± 11	21 ± 12	22 ± 14

19 col-tabel consec. infl.

Pressure-Derived Parameters for Assessing Coronary Collateral Circulation

Cut-off value for Protection against ischemia:

Meier (n=57): *Circulation 1987*	P_w = 30 mm Hg accuracy 92%	≈ P_w/P_a = 0.31
Pijls (n=120) *JACC 1995*	Q_c/Q^n = 0.25 accuracy 94%	≈ P_w/P_a = 0.30
Piek (n=106) *JACC 1997*	accuracy 84%	≈ P_w/P_a = 0.30

34 col-cut-off values fcf

Pressure-Derived Parameters for Assessing Coronary Collateral Circulation

Advantages:

- quantitative assessment of coronary collateral blood flow
- easily applicable in the clinical catheterization laboratory
- independent of blood pressure and other hemodynamic variations
- excellent reproducibility
- relevant clinical implications: $P_w/P_a \geq 0.30$ indicates protection against acute ischemic events (relative risk 6 x lower than in other patients)

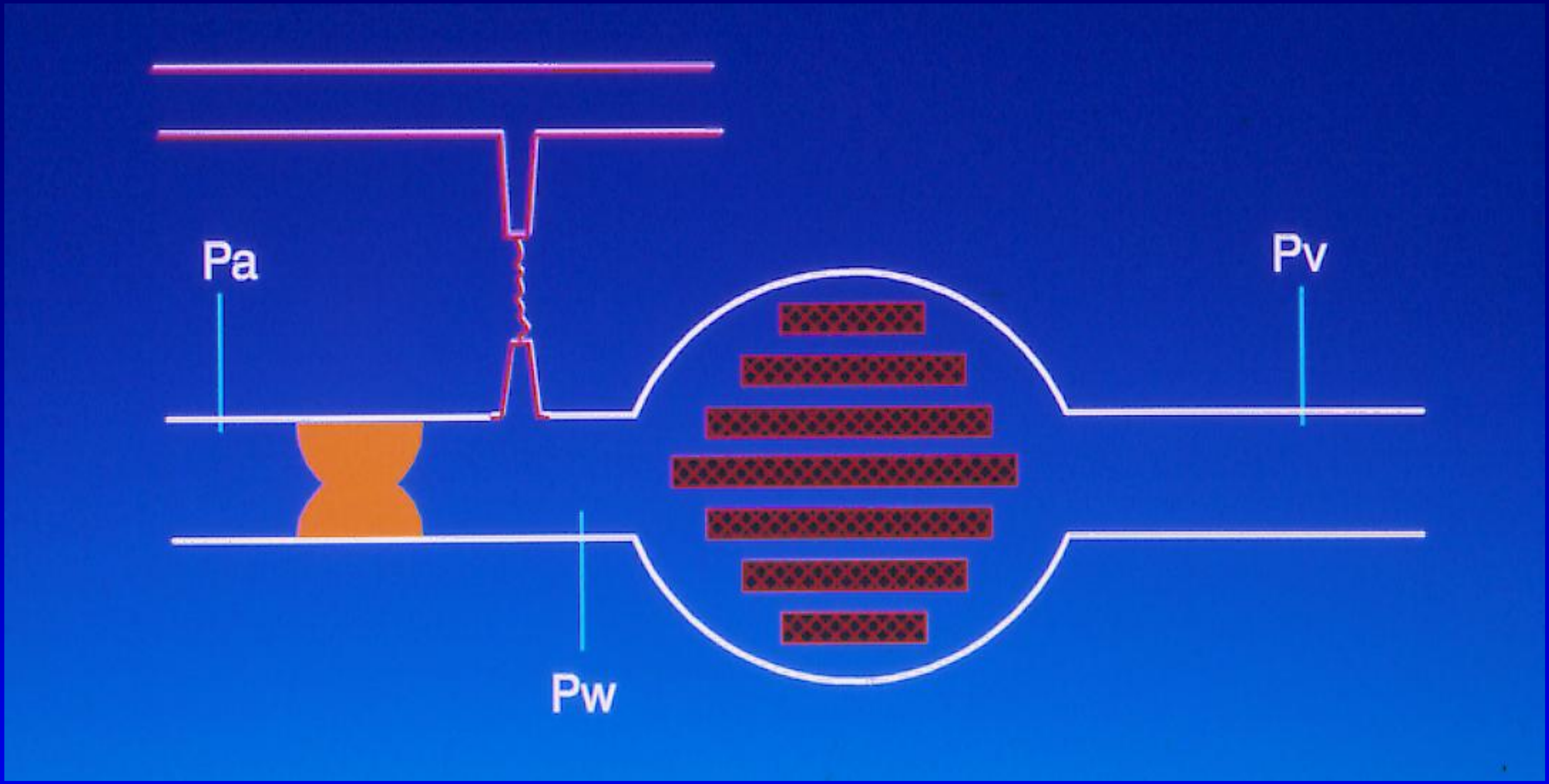
35 col-fcf:advantages

Pressure-Derived Parameters for Assessing Coronary Collateral Circulation

Limitations:

- Coronary wedge pressure (P_w) is always necessary
  ➡ *only applicable at PTCA*

- Measurement of central venous pressure (P_v) is mandatory in case this pressure is expected to be elevated

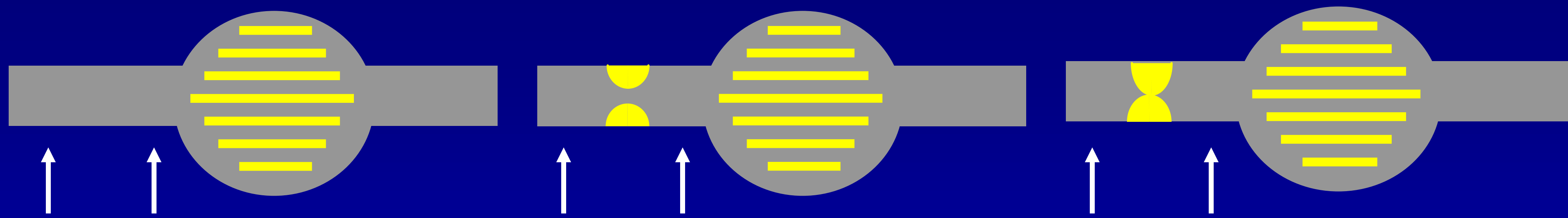


Fractional collateral flow (also called CFI*p*) =

$$FFR\ coll = \frac{Pw - Pv}{Pa - Pv}$$

Venous pressure not negligible anymore !

normal → increasing stenosis → total occlusion



100 100 100 70 100 25 (P*wedge*)

<u>Maximum myocardial perfusion:</u>

	100%	→	*70%*	→	*25%*
FFR:	1.0	→	0.7	→	0.25
H-SRv:	0	→	?	→	∞ *or negative*
Resting indexes	*1.0*		*unpredictable*		*0.25*

Predictive value of the different parameters to predict ischemia:

- Chest pain during balloon inflation: 67%
- Visible collaterals on angiogram: 76%
- Coronary wedge pressure: 84%
- Calculated collateral blood flow (Q_c/Q^N): 95%

14 col-predicted values

Recruitable collateral flow during balloon inflation:

$$Q_c / Q^N = \frac{P_w - P_v}{P_a - P_v}$$

Q_c = recruitable collateral blood flow at balloon inflation

Q^N = normal maximum myocardial blood flow

Pa = mean aortic pressure at balloon inflation

Pv = mean right atrial pressure at balloon inflation

Pw = coronary wedge pressure at balloon inflation

Circulation 1993;87:1354-1367

28 col-recr. fcf at occl.

Pressure-Derived Parameters for Assessing Coronary Collateral Circulation

History:

Schaper: 1967	pressure gradient / arterial blood pressure ratio as a function of time after gradual occlusion by ameroid constrictor in dogs
Meier, De Bruyne, Rutishauser, 1987/88	systematic investigations to the relation between coronary wedge pressure (P_w) and extent of the coronary collateral circulation