Μελέτη της Πνευμονικής κυκλοφορίας (RHC): από τις καταγραφές στη κλινική εφαρμογή

Διάγνωση/παρακολούθηση
Πνευμονικής Υπέρτασης

Ιστορία

D. Georgopoulos, Professor of Medicine,
Department of Intensive Care Medicine,
University Hospital of Heraklion,
University of Crete, Greece

Werner Forssmann

1904 –1979

1929 Gerda Ditzen

Forssmann W (1929) Die Sondierung des Rechten Herzens. *Klein Wochenschr 8:2085*

In conclusion I should point out that this method has opened the prospect of many possible metabolic researches and studies of the function of the heart, some of which I have already begun

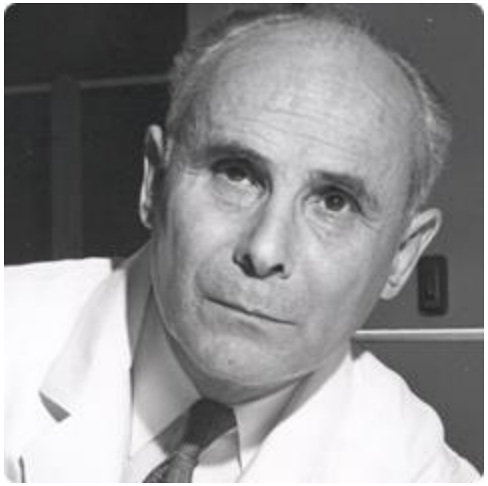
Forssmann W (1931) Ueber Kontrastdarstellung der Hohlen des lebenden rechten Herzens und der Lungenschlagader. *Miinchener Med Wochenschr 78:489*

Werner Forssmann

1904 –1979

Werner Forssmann: „The typical man before his time!"
– Erste Herzkatheterisierung im Selbstversuch
Anästhesiol Intensivmed Notfallmed Schmerzther 2008; 43(2): 162-165

Ένας άνθρωπος μπροστά από την εποχή του



André Cournand

1895 – 1988

1944

14446 P

Recording of Right Heart Pressures in Man.*

A. Cournand, H. D. Lauson, R. A. Bloomfield, E. S. Breed, and E. de F. Baldwin.
(Introduced by W. W. Palmer.)

From the Departments of Medicine, College of Physicians and Surgeons, Columbia University; of Physiology, Medicine and Surgery, New York University College of Medicine; and Bellevue Hospital, New York City.

Utilizing the right heart catheterization technic of Cournand and Ranges,[1] the cyclic pressure changes in the right auricle and right ventricle have been recorded with the Hamilton manometer[2] in 50 individuals.

Catheterization of the right auricle was performed as previously described.[1,3] The

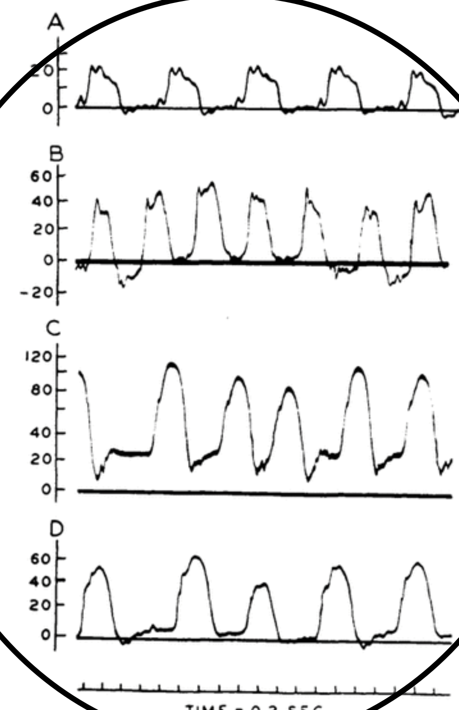


Fig. 1.

All tracings were retouched to improve contrast in reproduction. Pressures in mm of mercury.

A. Right ventricular pressure pulses from a normal young female. One respiratory cycle is shown.

B. Record from young male with extensive pulmonary fibrosis and normal-sized heart. Cardiac output and arterial pressures normal. Note marked increase in systolic pressures; large respiratory variation due to dyspnea at rest; sharp drop of systolic and diastolic levels associated with beginning of inspiration; artifacts on systolic peaks.

C. Patient with mitral stenosis and insufficiency and aortic insufficiency and auricular fibrillation in congestive failure. Note extreme elevation of systolic pressures in right ventricle. The high diastolic pressures correspond to marked increase in right auricular and peripheral venous pressures. Note respiratory variation associated with dyspnea. Cardiac output subnormal and total blood volume about twice normal. Arterial pressure was 210/90.

D. Same patient after clinical improvement due to bed rest and digitalization.

patients experienced little or no discomfort during the procedure. The level of the catheter in the heart by lateral X-ray was taken as zero pressure. Introduction of the catheter with a slightly curved tip into the right ventricle under fluoroscopic control was not difficult as a rule, and was signaled first by a rise above auricular pressure, then by large oscillations at cardiac rate in the saline manometer connected to the catheter.

Addition of the long narrow catheter (No. 8 or 9) to the manometer system decreases the natural frequency. Frequencies obtained with this system have varied from about 25 to 50 vibrations per second. Although not ideal, this range has proved fairly adequate

* This investigation was carried on under a contract, recommended by the Committee on Medical Research, between the Office of Scientific Research and Development and Columbia University, with the collaboration of New York University. Additional support was provided by the Commonwealth Fund.

1 Cournand, A., and Ranges, H., Proc. Soc. Exp. Biol. and Med., 1941, **46**, 462.

2 Hamilton, W. F., Brewer, G., and Brotman, I., *Am. J. Physiol.*, 1934, **107**, 427.

3 Cournand, A., Riley, R. L., Breed, E. S., and Baldwin, E. de F., Interim Report, O.S.R.D. Contract OEMcmr 107, 1943.

MEASUREMENT OF CARDIAC OUTPUT IN MAN USING THE TECHNIQUE OF CATHETERIZATION OF THE RIGHT AURICLE OR VENTRICLE

BY A. COURNAND, R. L. RILEY, E. S. BREED, E. DEF. BALDWIN, AND D. W. RICHARDS, JR., WITH THE TECHNICAL ASSISTANCE OF M. S. LESTER AND M. JONES

(From the Department of Medicine of Columbia University, College of Physicians and Surgeons, and the Tuberculosis Service, Bellevue Hospital (Columbia University Division), New York City)

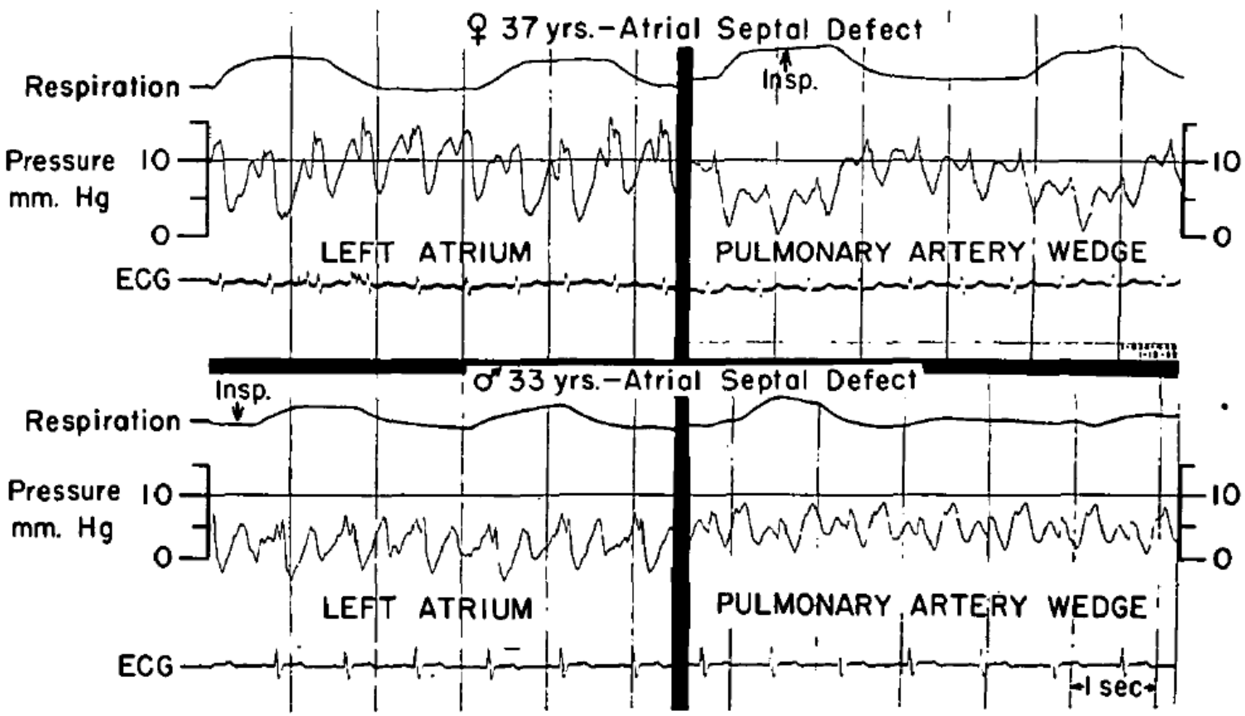
(Received for publication June 27, 1944)

Dickinson Richards

1895 – 1973

The Relationship between Pulmonary Artery Wedge Pressure and Left Atrial Pressure in Man

By Daniel C. Connolly, M.D., John W. Kirklin, M.D., and Earl H. Wood, M.D., Ph.D.



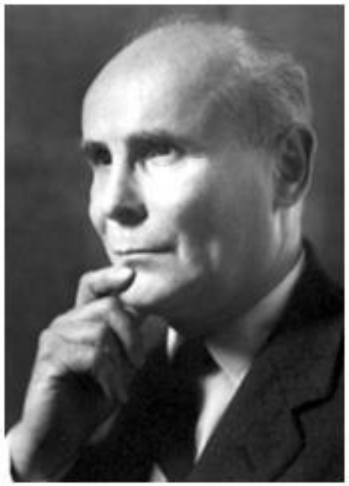
Circulation Research, Vol. II, September 1954

1956

Werner
Forssmann

Nobel 1956

Who is this guy?



André Frédéric Cournand
Prize share: 1/3

Werner Forssmann
Prize share: 1/3

Dickinson W. Richards
Prize share: 1/3

Honorary Professor of Surgery and Urology
University of Mainz (1956)
National University of Cordoba (1961)

Cardiology Journal
2010, Vol. 17, No. 6, pp. 650–651

ISSN 1897–5593

HISTORY OF CARDIOLOGY

William Ganz: From refugee to world fame

1919-2009

1919: Kassa (Κόσιτσε, Slovakia)

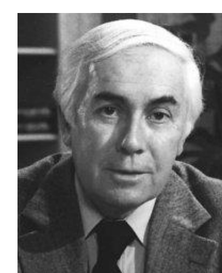
1937: School of medicine, Charles University, Prague

1944: Escape to Budapest (Before sent to Auschwitz)

1947: Charles University (Prague)

1966: Escape in Vienna with only the clothes he was wearing (47 years old!!!)

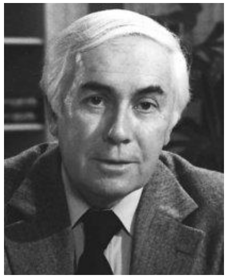
1966: USA - Cedars Sinai Medical Centre (chief of cardiology Jeremy Swan)



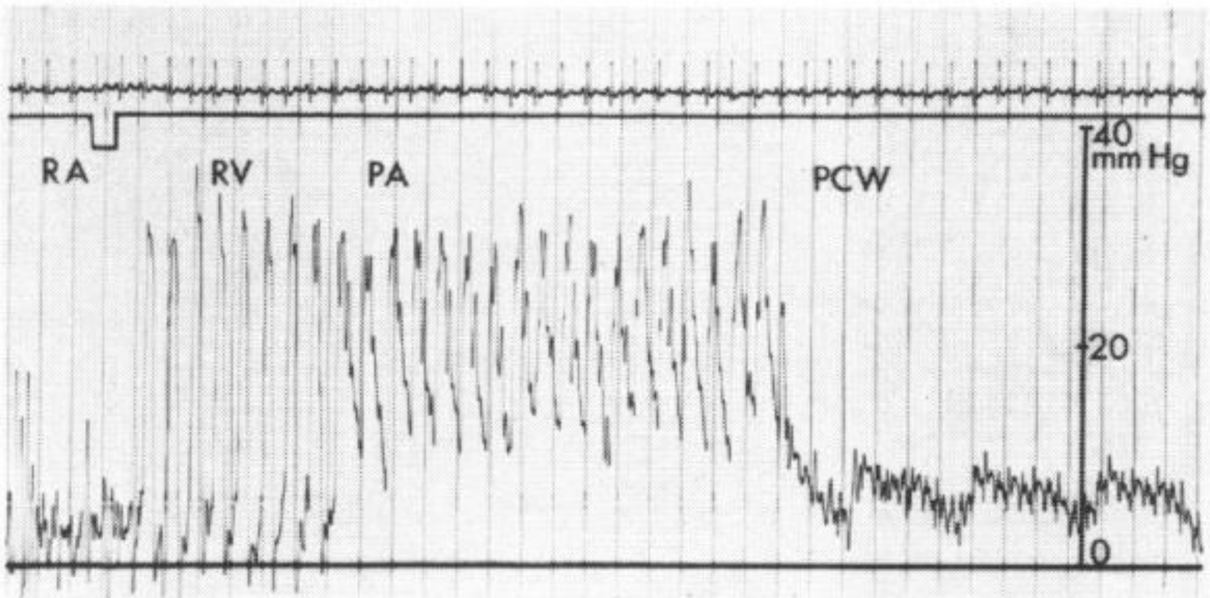
Swan and Ganz:

Is it possible to introduce the catheter in pulmonary artery without x-ray?

Sunday



Santa Monica Bay



RA
RV
PA
PCW
40
mm Hg
20
0

CATHETERIZATION OF THE HEART IN MAN WITH USE OF A FLOW-DIRECTED BALLOON-TIPPED CATHETER*

H. J. C. SWAN, M.B., PH.D., F.R.C.P., WILLIAM GANZ, M.D., C.SC., JAMES FORRESTER, M.D., HAROLD MARCUS, M.D., GEORGE DIAMOND, M.D., AND DAVID CHONETTE

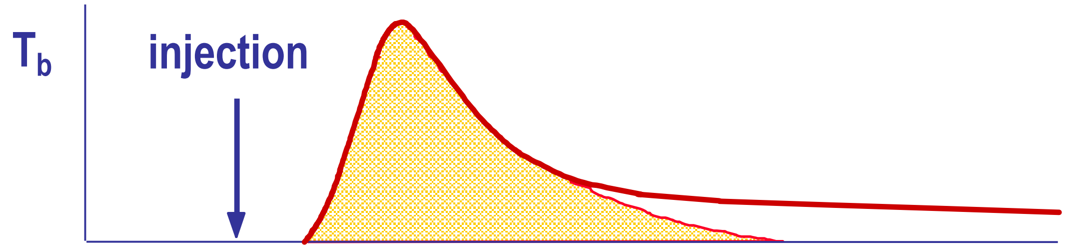
Abstract Pressures in the right side of the heart and pulmonary capillary wedge can be obtained by cardiac catheterization without the aid of fluoroscopy. A No. 5 Fr double-lumen catheter with a balloon just proximal to the tip is inserted into the right atrium under pressure monitoring. The balloon is then inflated with 0.8 ml of air. The balloon is carried by blood flow through the right side of the heart into the smaller radicles of the pulmonary artery. In this position when the balloon is inflated wedge pressure is obtained. The average time for passage of the catheter from the right atrium to the pulmonary artery was 35 seconds in the first 100 passages. The frequency of premature beats was minimal, and no other arrhythmias occurred.

New Engl J Med 1970

Clinical communications

Thermodilution cardiac output determination with a single flow-directed catheter

James S. Forrester, M.D.
William Ganz, M.D.
George Diamond, M.D.
Thomas McHugh, M.D.
David W. Chonette, M.S.
H. J. C. Swan, M.D., Ph.D.
Los Angeles, Calif.

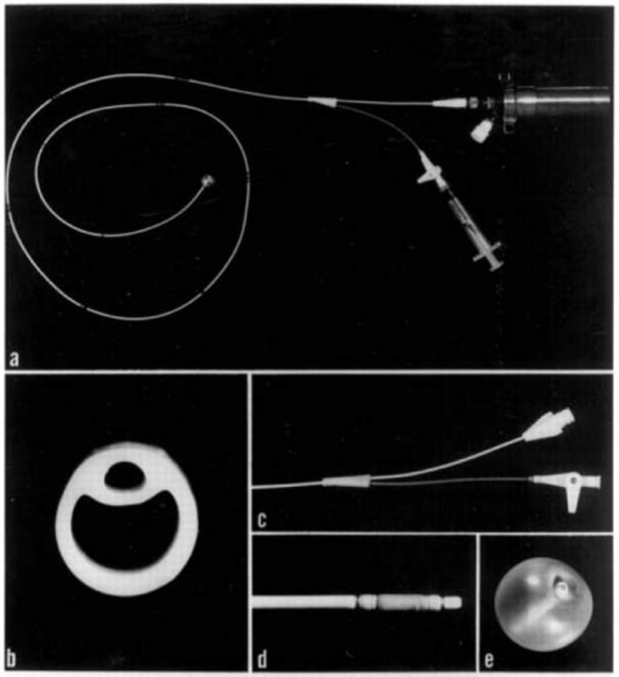


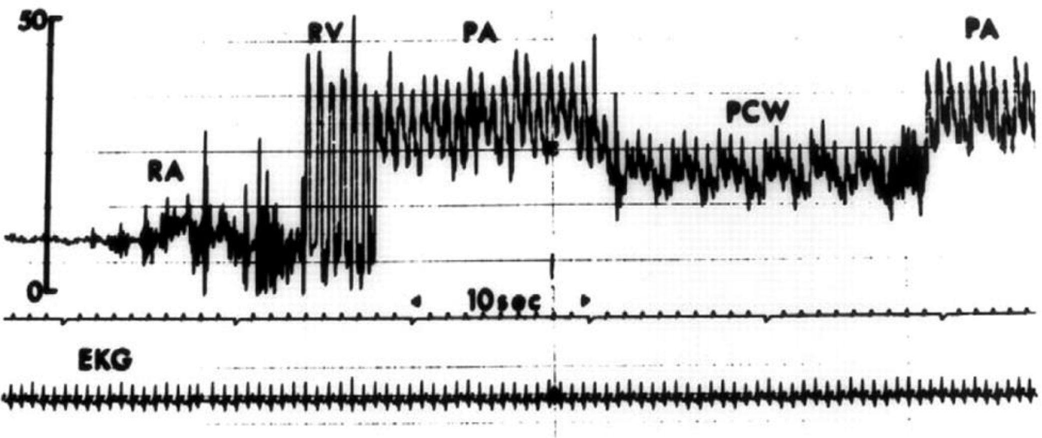
$$Q = \frac{V(T_B - T_I)\, K_1 K_2}{T_B(t)^{dt}}$$

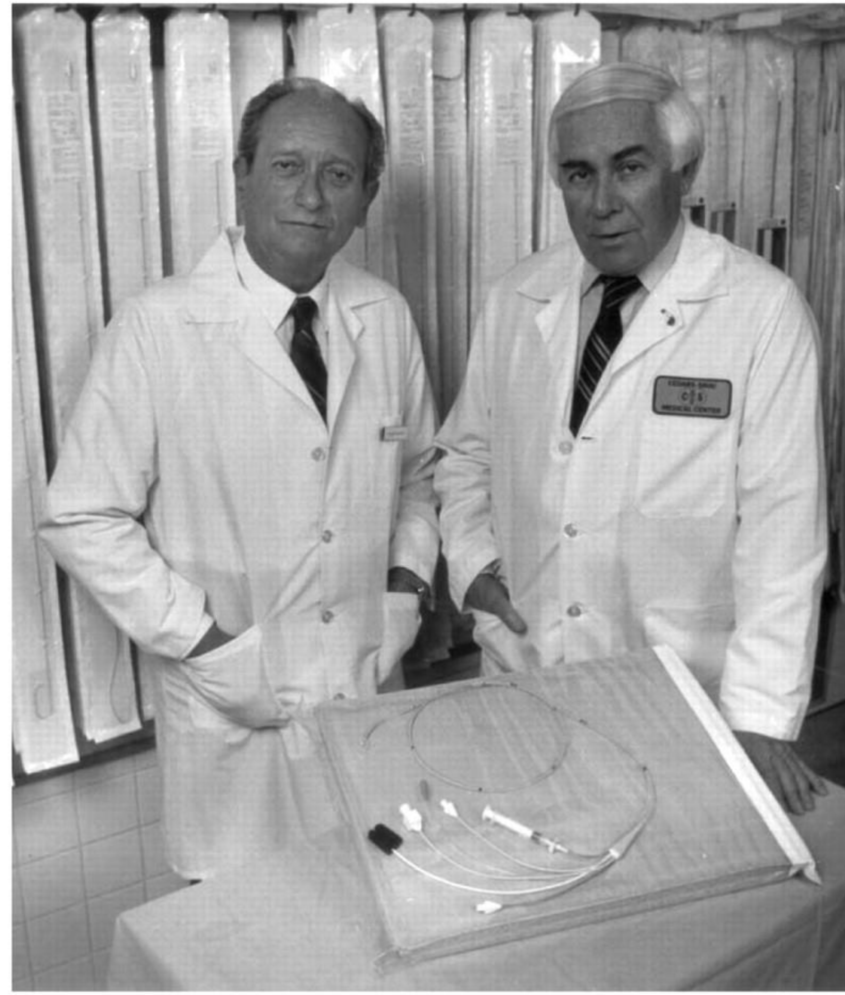
Q= cardiac output, V= volume injected, T_B = blood temperature, T_I = injectate temperature, K_1 and K_2 = computational constants, and $T_B(t)^{dt}$ = change in blood temperature as a function of time.

American Heart Journal March, 1972 Vol. 83, No. 3, pp. 306-311

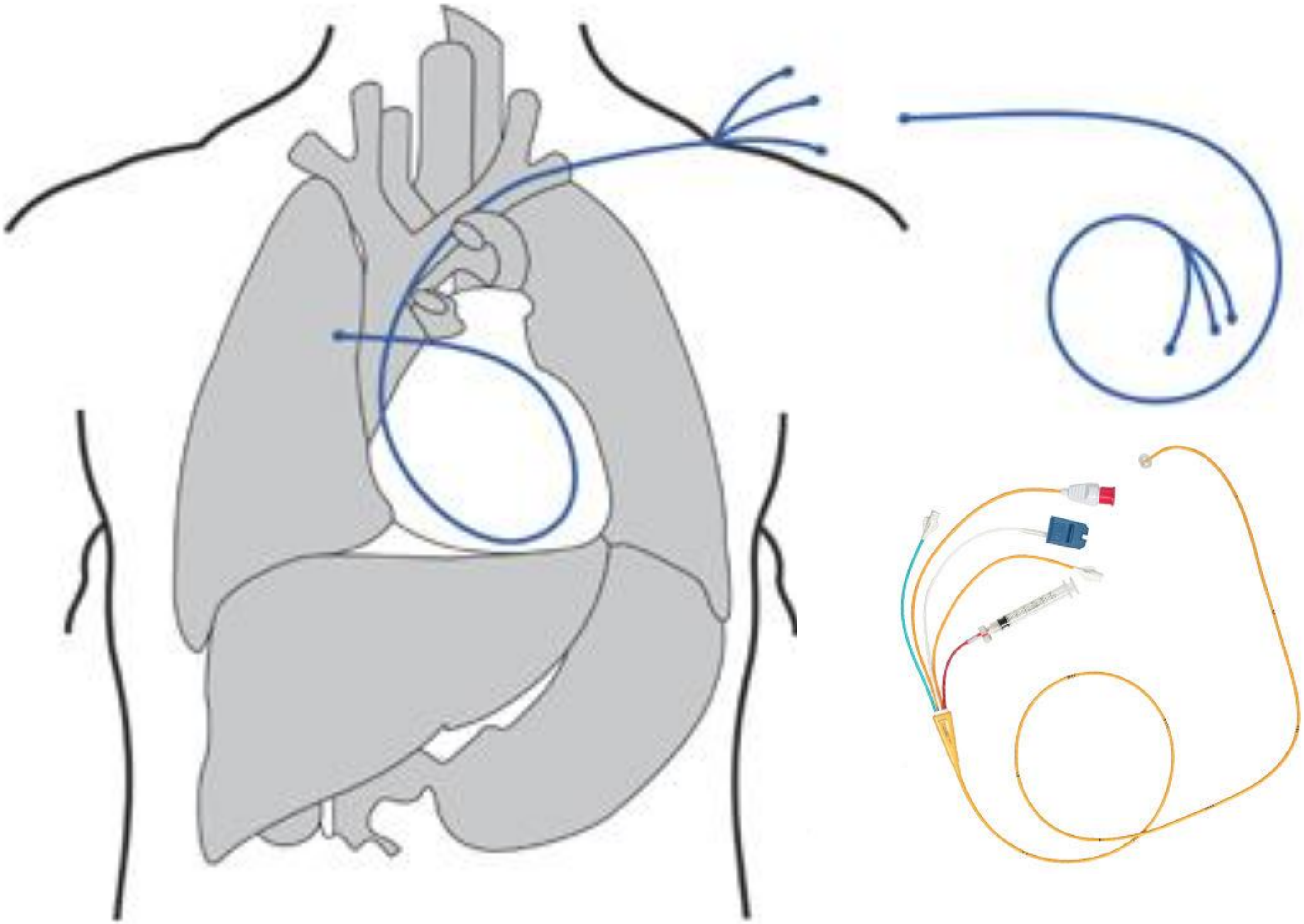
The Pulmonary Artery Catheter

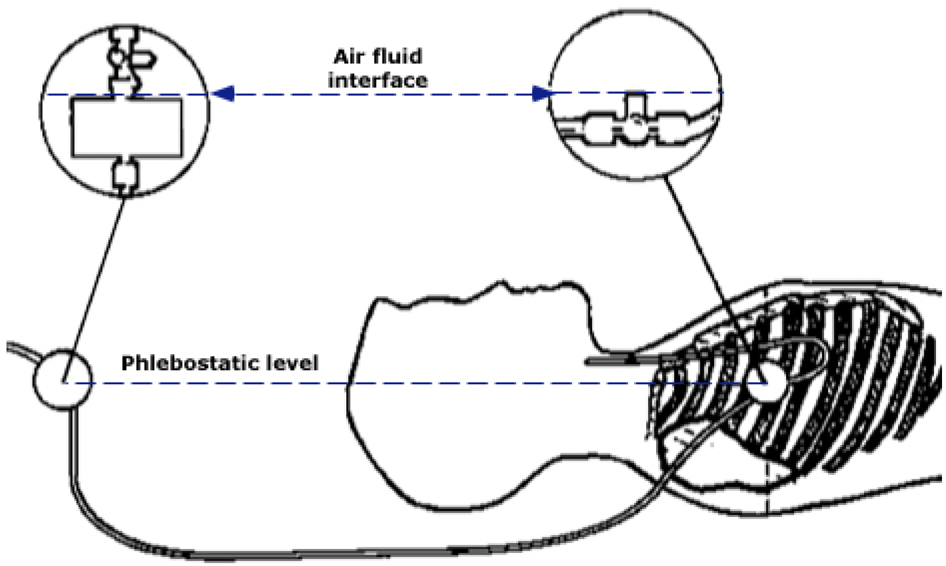


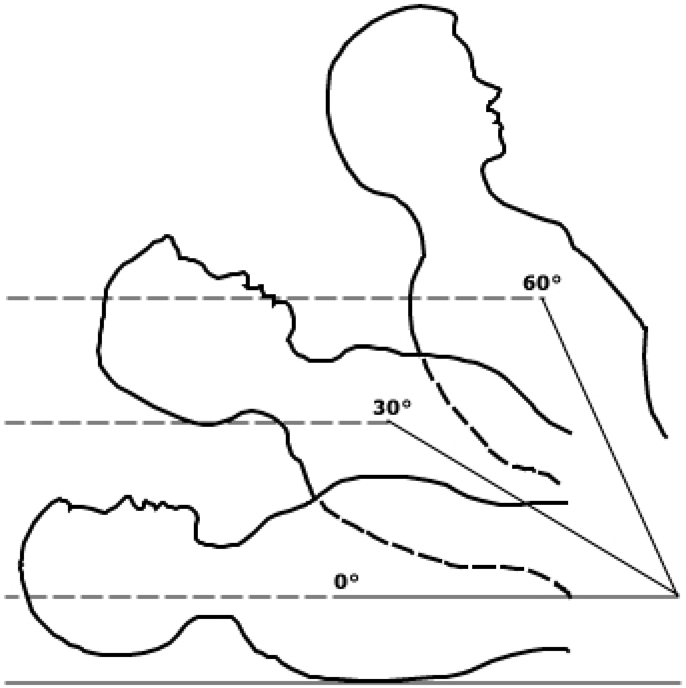


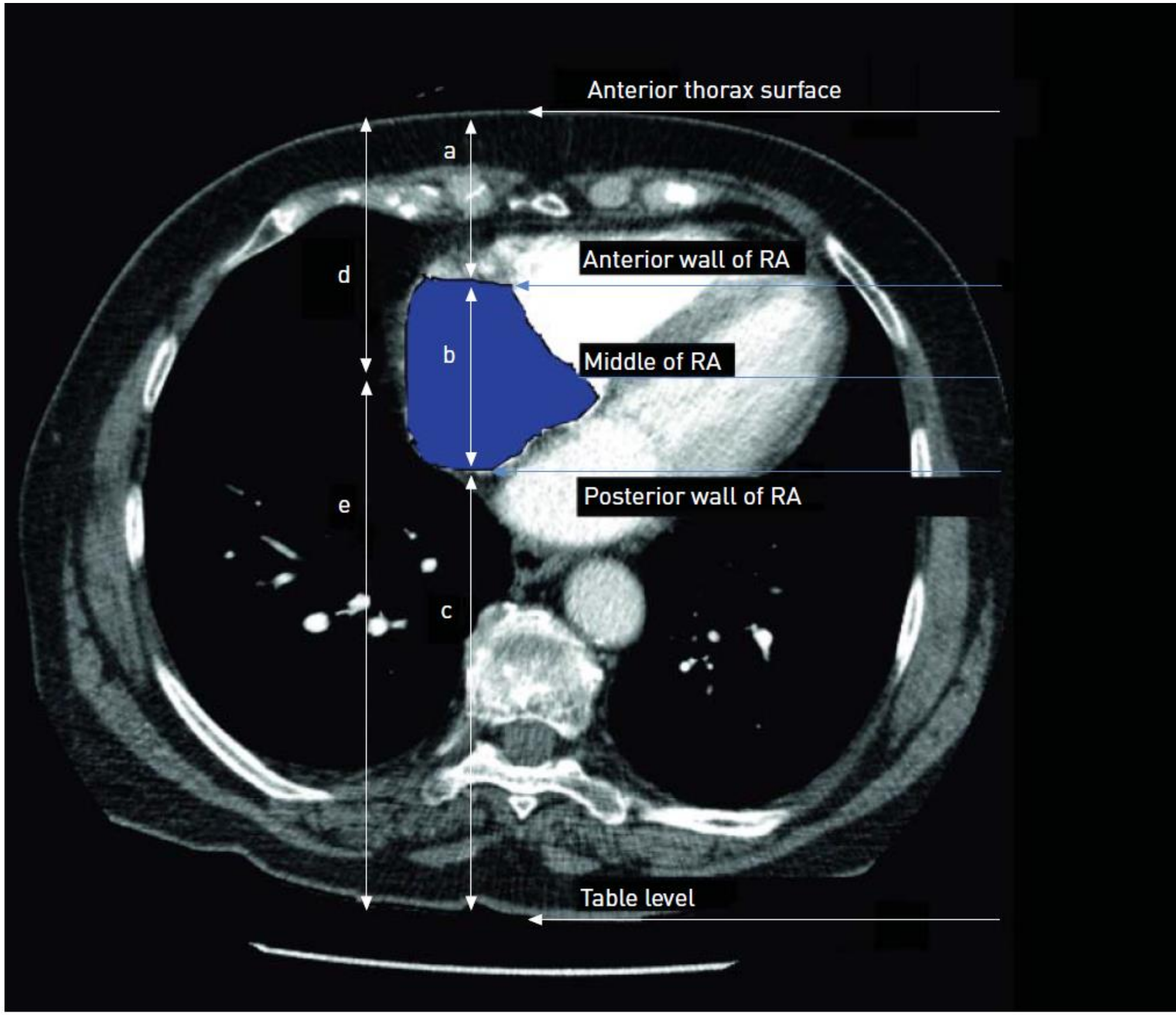


William Ganz and H.J.C. Swan



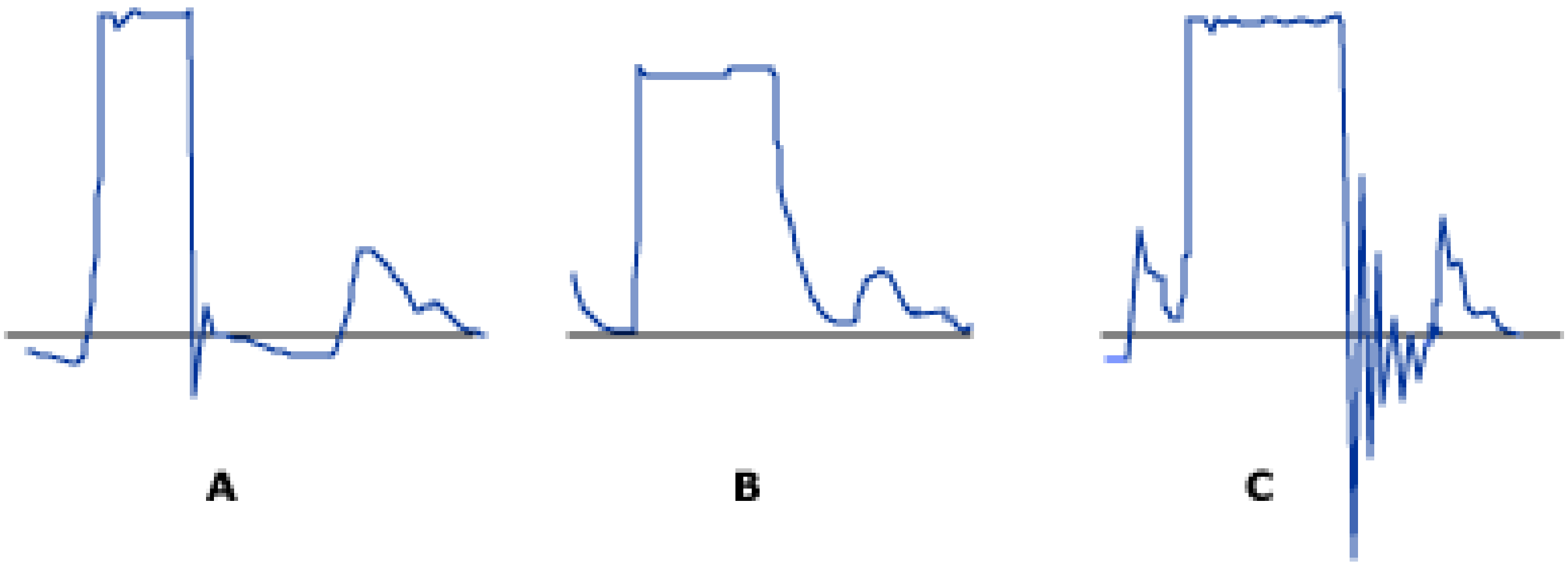

Air fluid
interface
Phlebostatic level



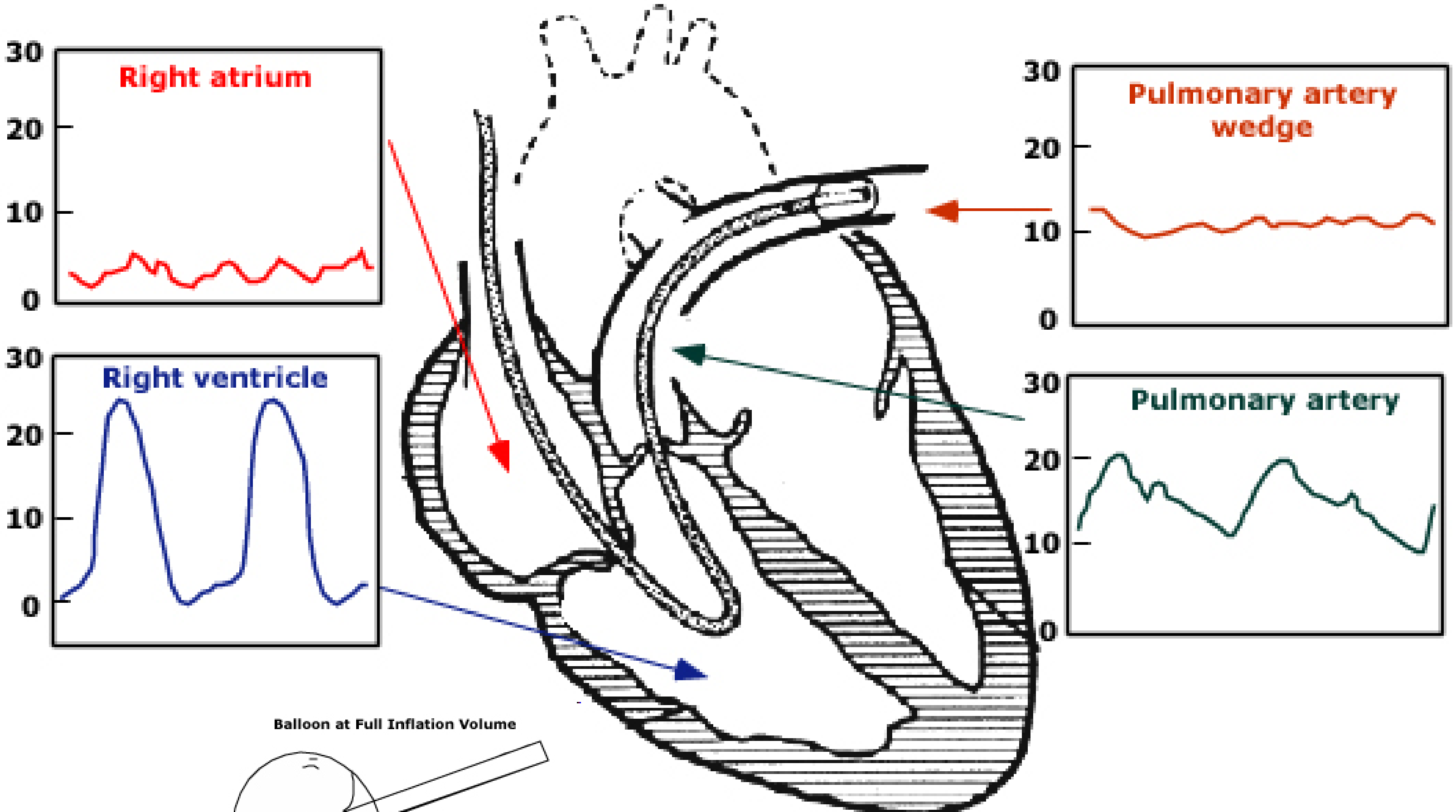


Kovacs et al. Eur Respir J 2013; 42: 1586–1594

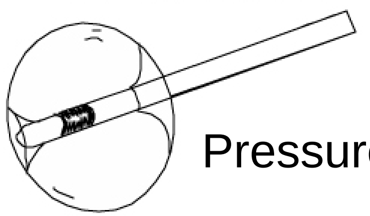
The "fast flush" test



Optimal Overdamped Underdamped

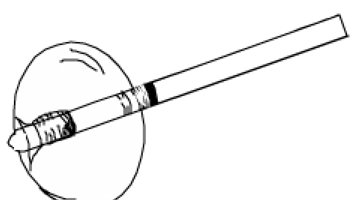


Balloon at Full Inflation Volume

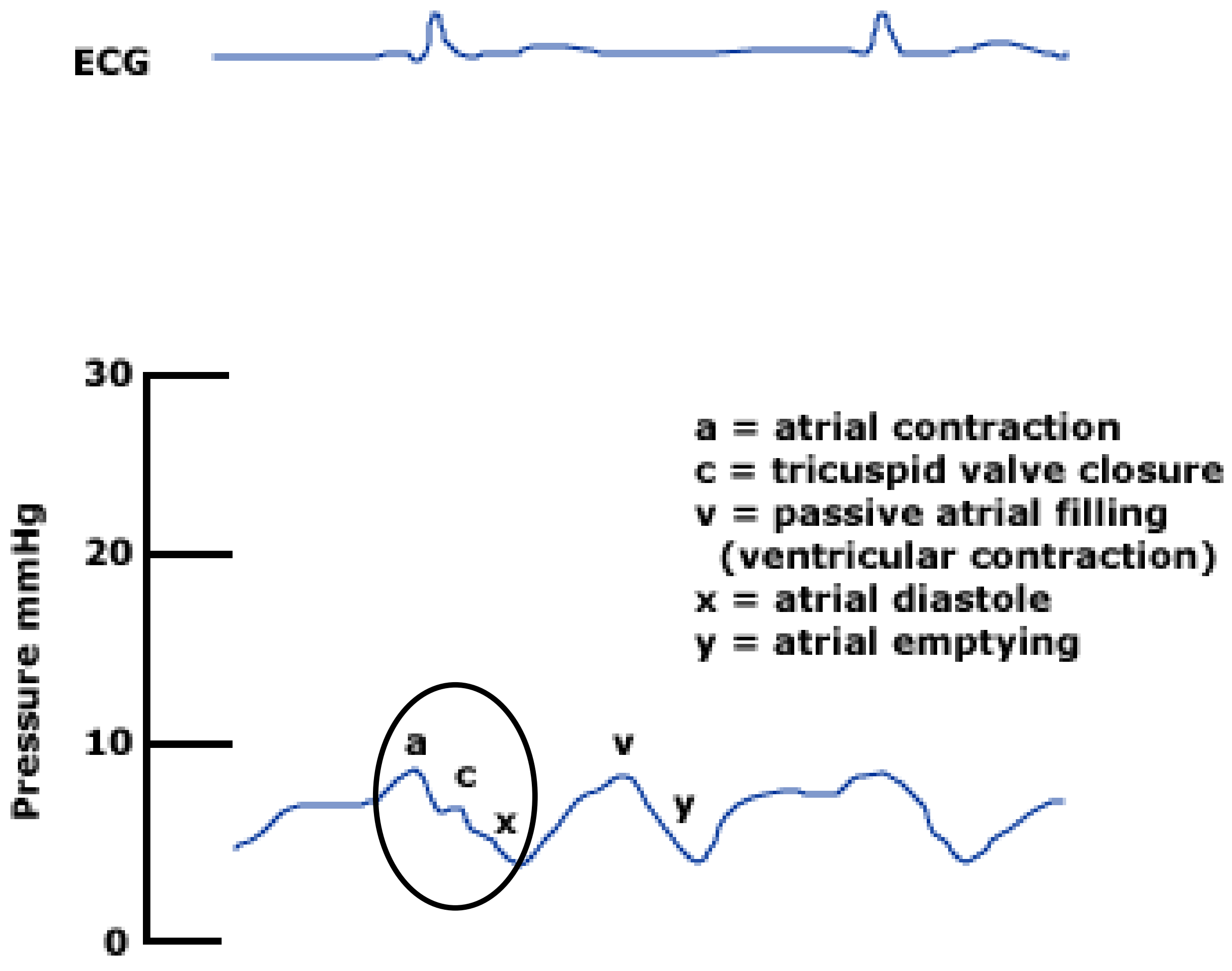


Pressures may be overestimated

Balloon at Less Than Full Inflation Volume



Right atrium



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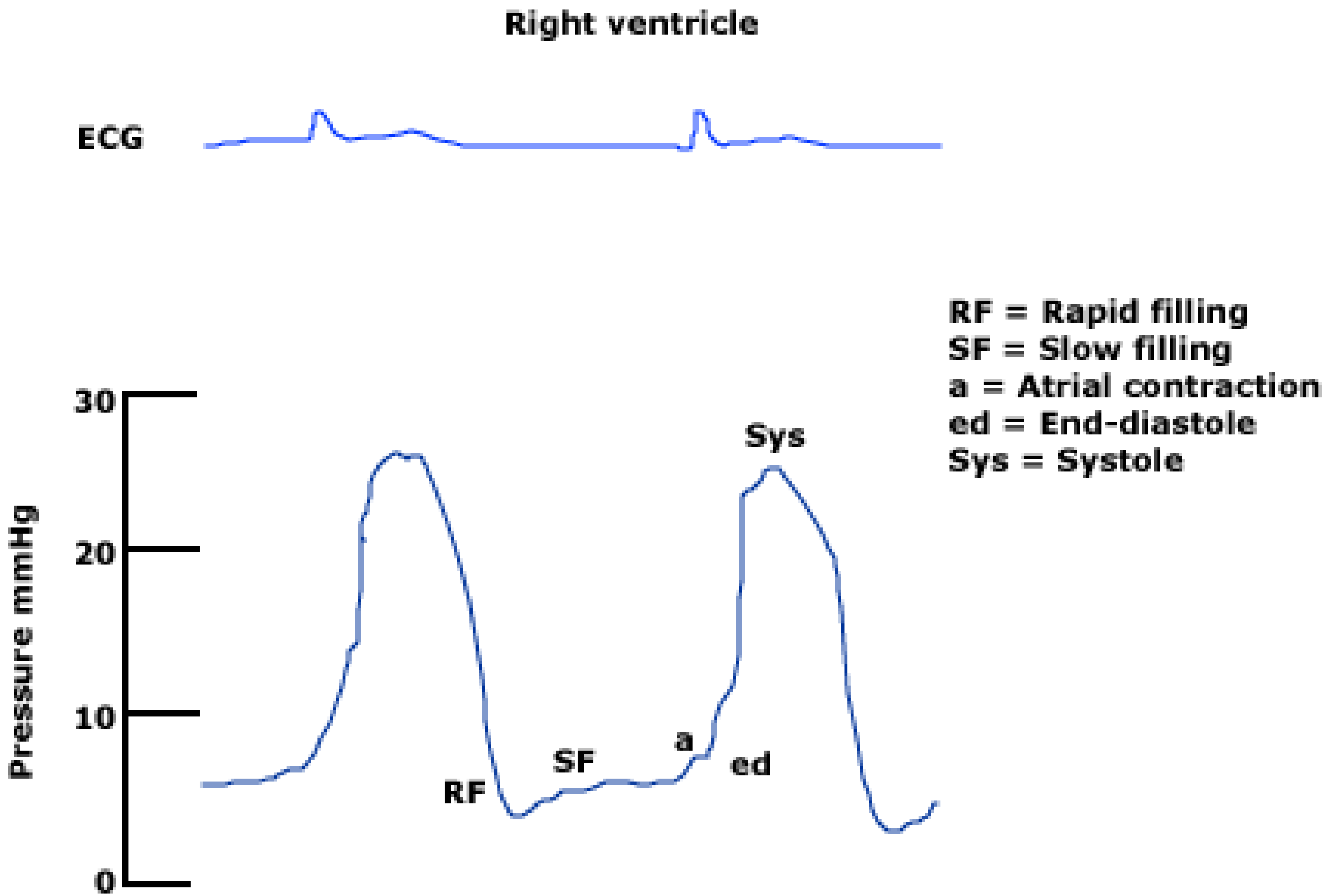
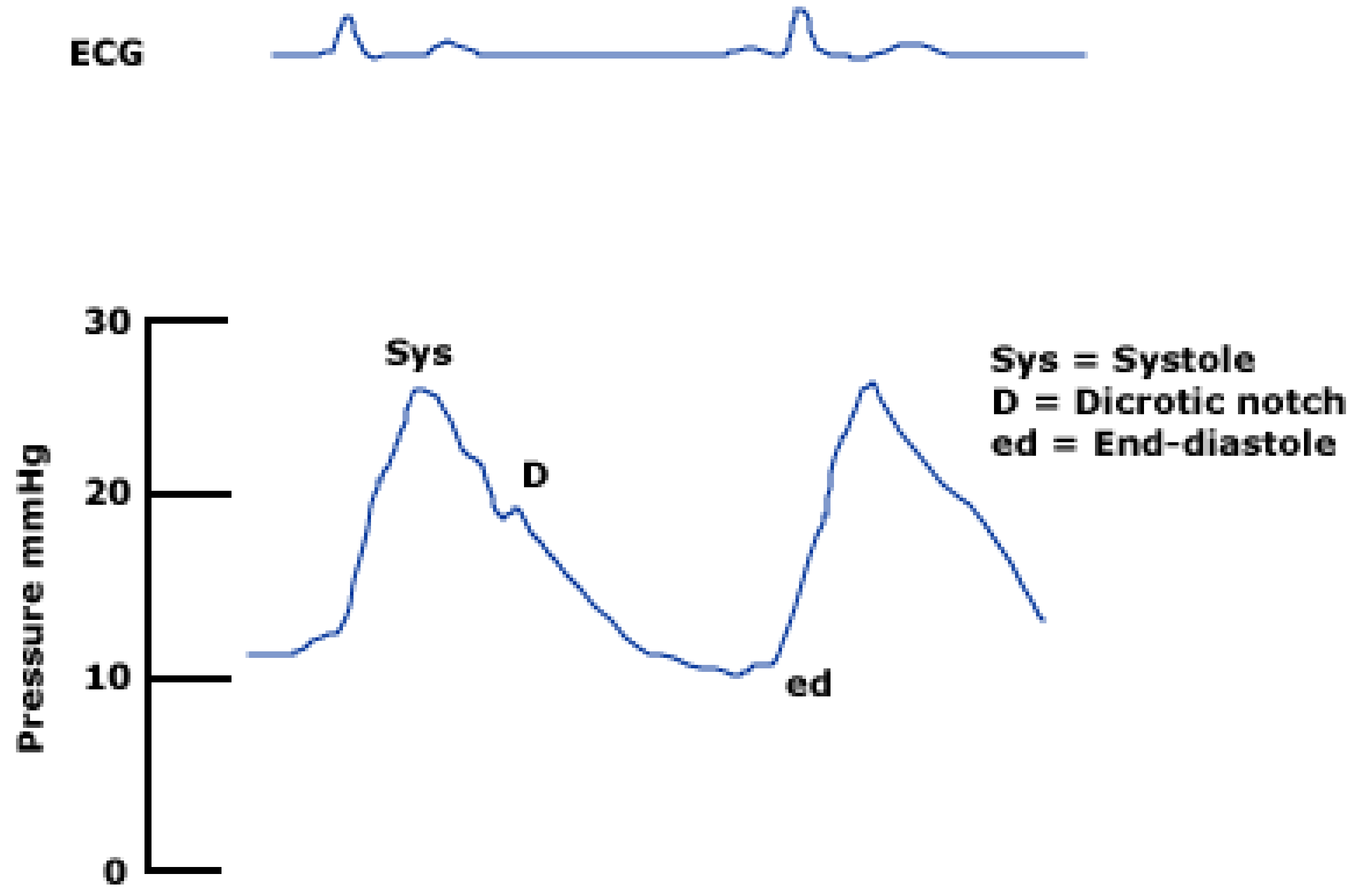
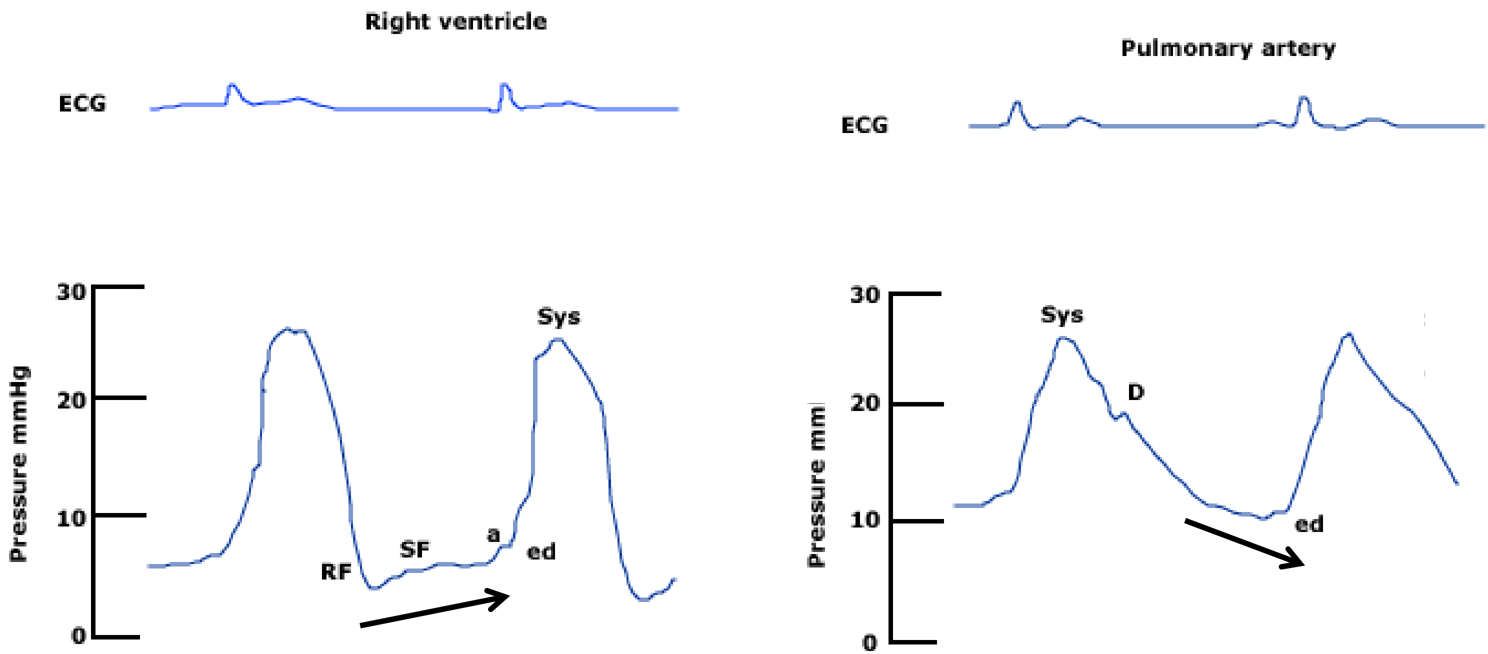


Right ventricle
ECG
RF = Rapid filling
SF = Slow filling
a = Atrial contraction
ed = End-diastole
Sys = Systole
Pressure mmHg
30
20
10
0
Sys
RF
SF
a
ed

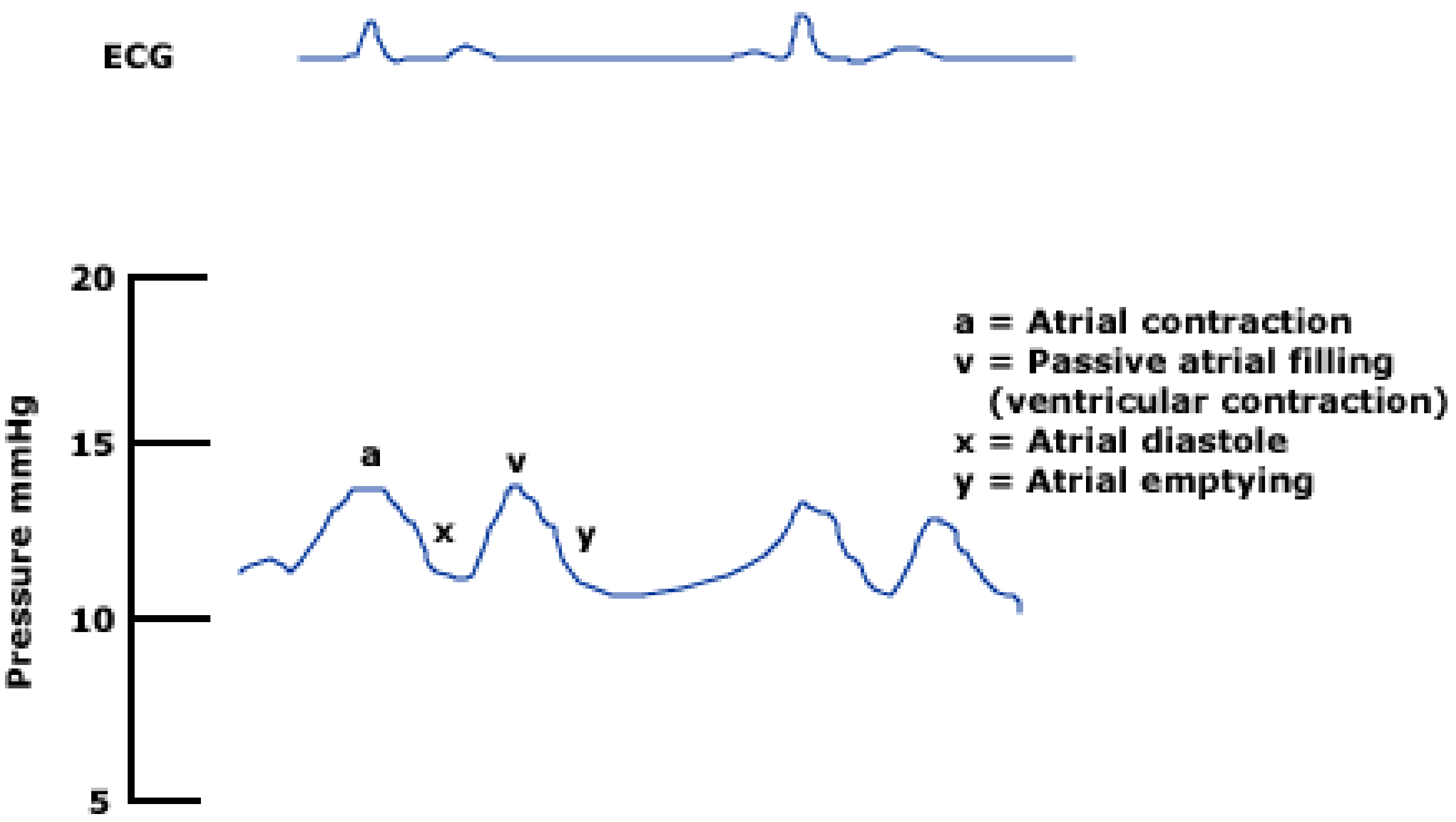
Pulmonary artery



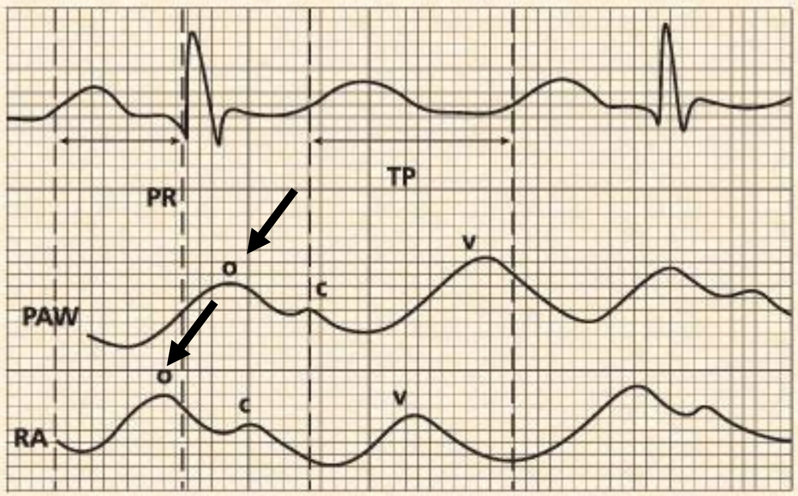


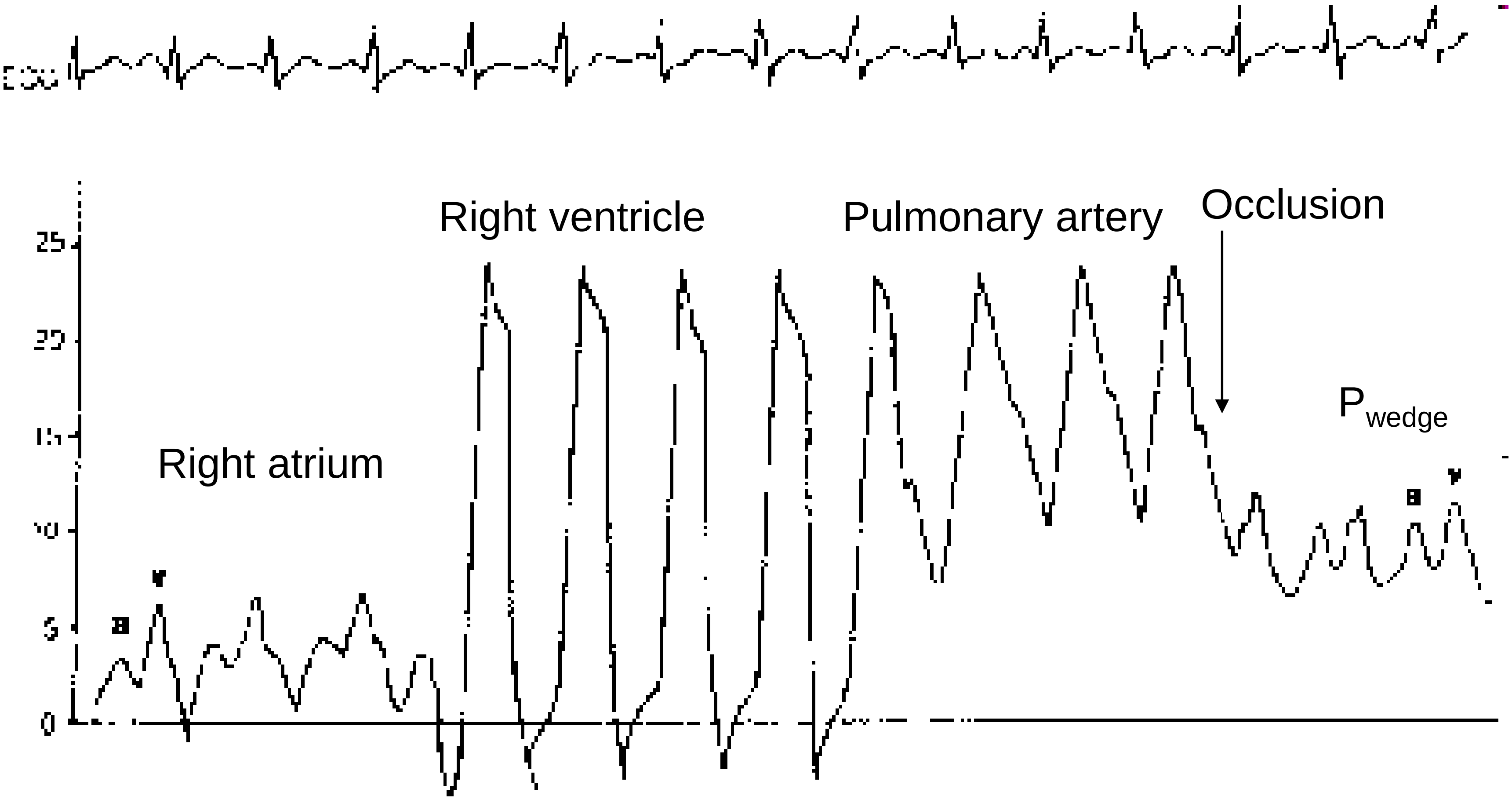
Right ventricle
ECG
30
20
10
0
Pressure mmHg
Sys
RF
SF
a
ed
Pulmonary artery
ECG
30
20
10
0
Pressure mm
Sys
D
ed

Pulmonary artery wedge



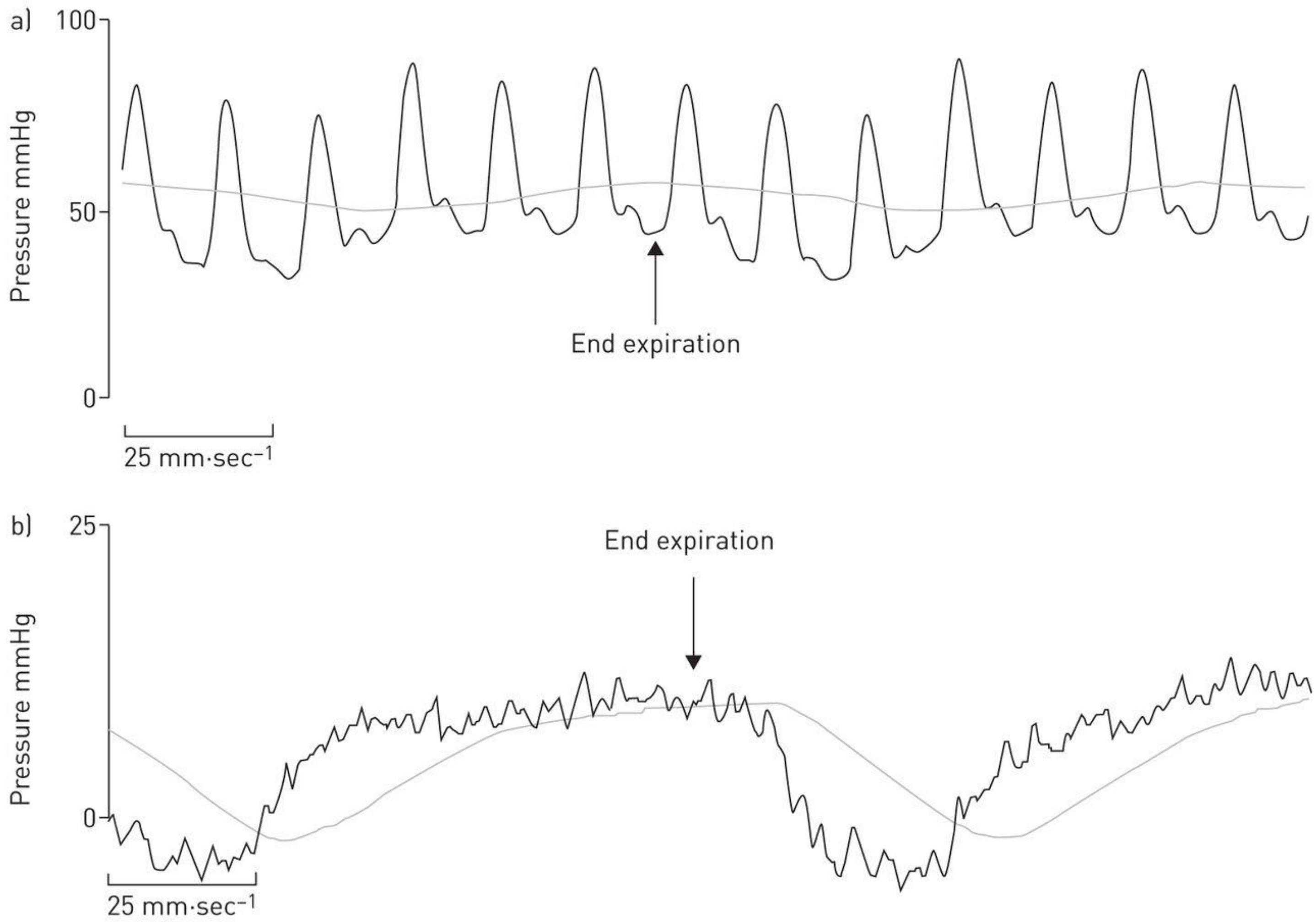
Normal Atrial Pressure Values and Waveform Patterns





ECG
25
20
15
10
5
0
Right atrium
a
v
Right ventricle
Pulmonary artery
Occlusion
P_{wedge}
a
v

Representative pressure tracings of a) pulmonary arterial pressure and b) pulmonary arterial wedge pressure (PAWP).



Stephan Rosenkranz, and Ioana R. Preston Eur Respir Rev
2015;24:642-652

Clinical communications

Thermodilution cardiac output determination with a single flow-directed catheter

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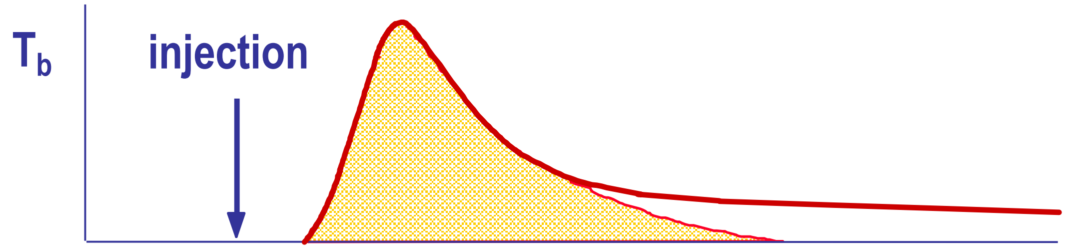

$$Q = \frac{V(T_B - T_I)\, K_1 K_2}{T_B(t)^{dt}}$$

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American Heart Journal March, 1972 Vol. 83, No. 3, pp. 306-311

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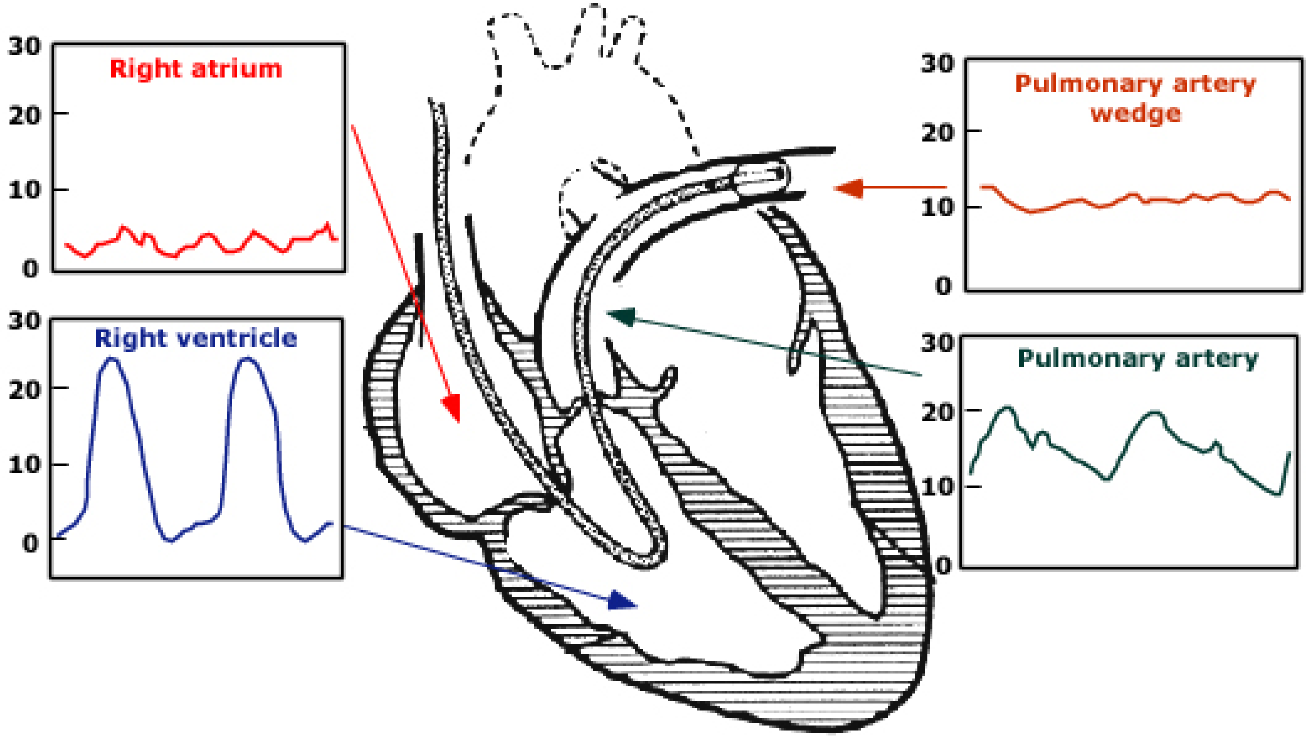


PRESSURES FLOWS (CO)

RESISTANCE

Resistance = Driving pressure for flow (change in pressure)/flow

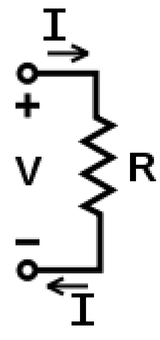
PRESSURES FLOWS

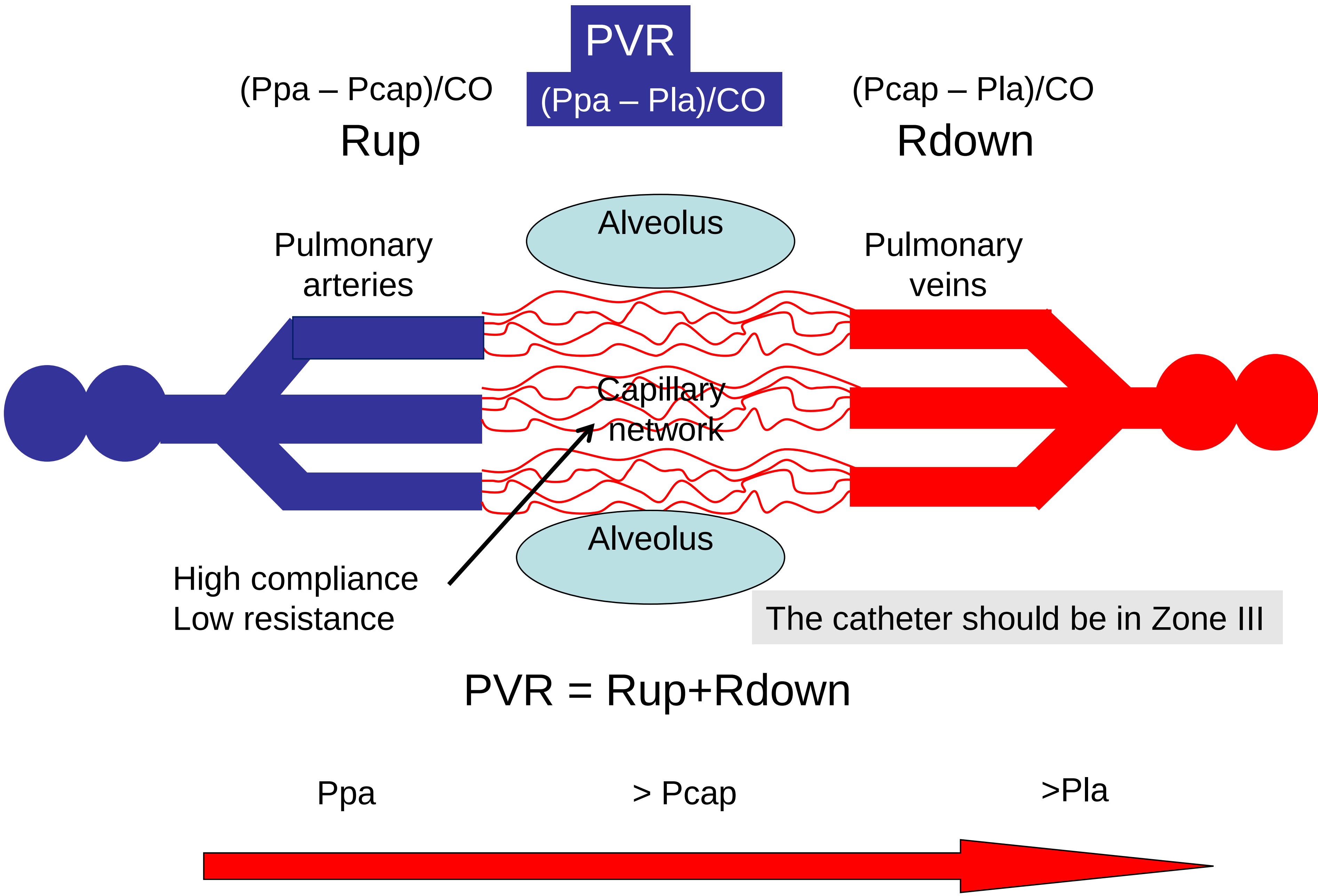
RESISTANCE

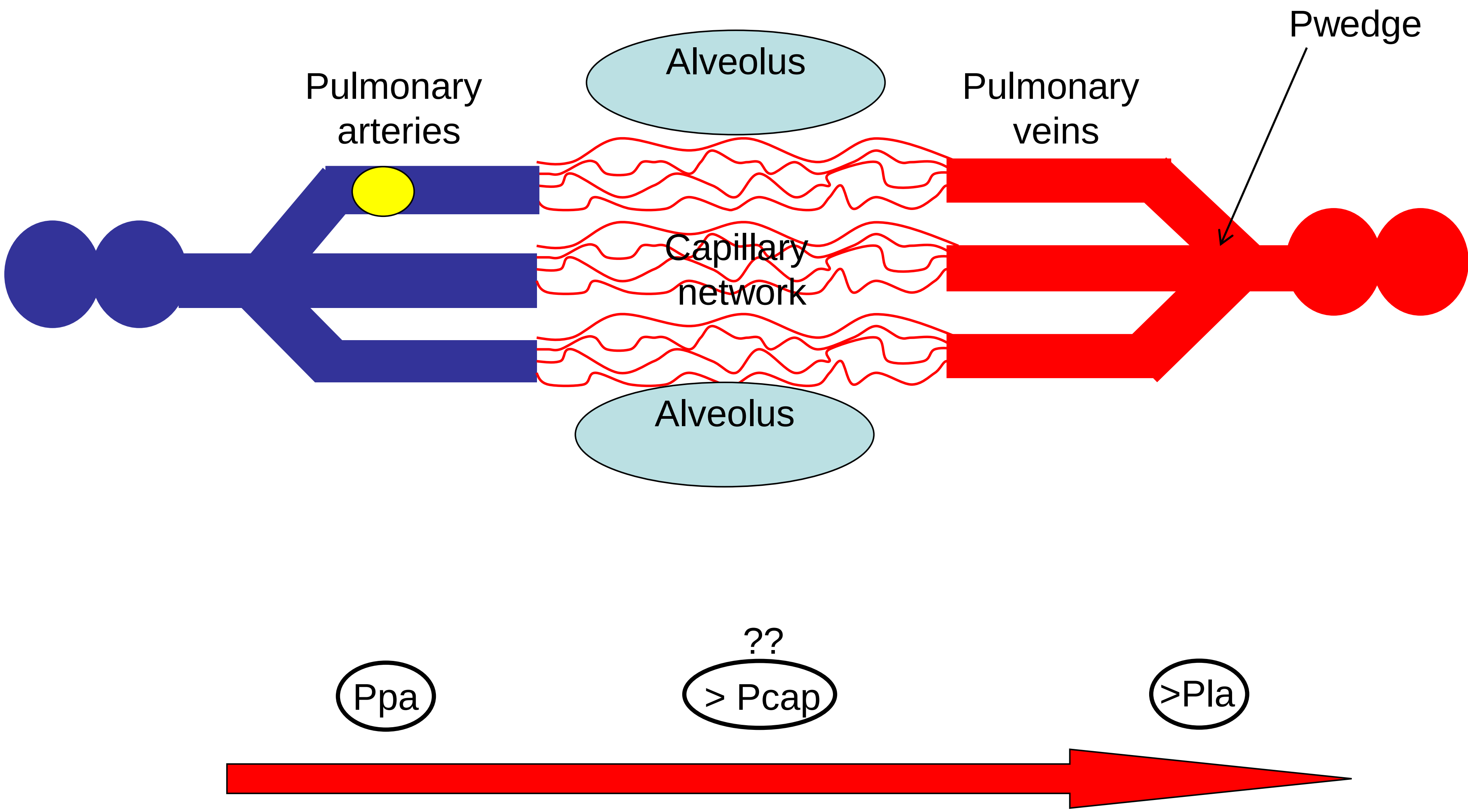
Resistance = Driving pressure for flow (change in pressure)/flow

$$R = \Delta P/CO$$

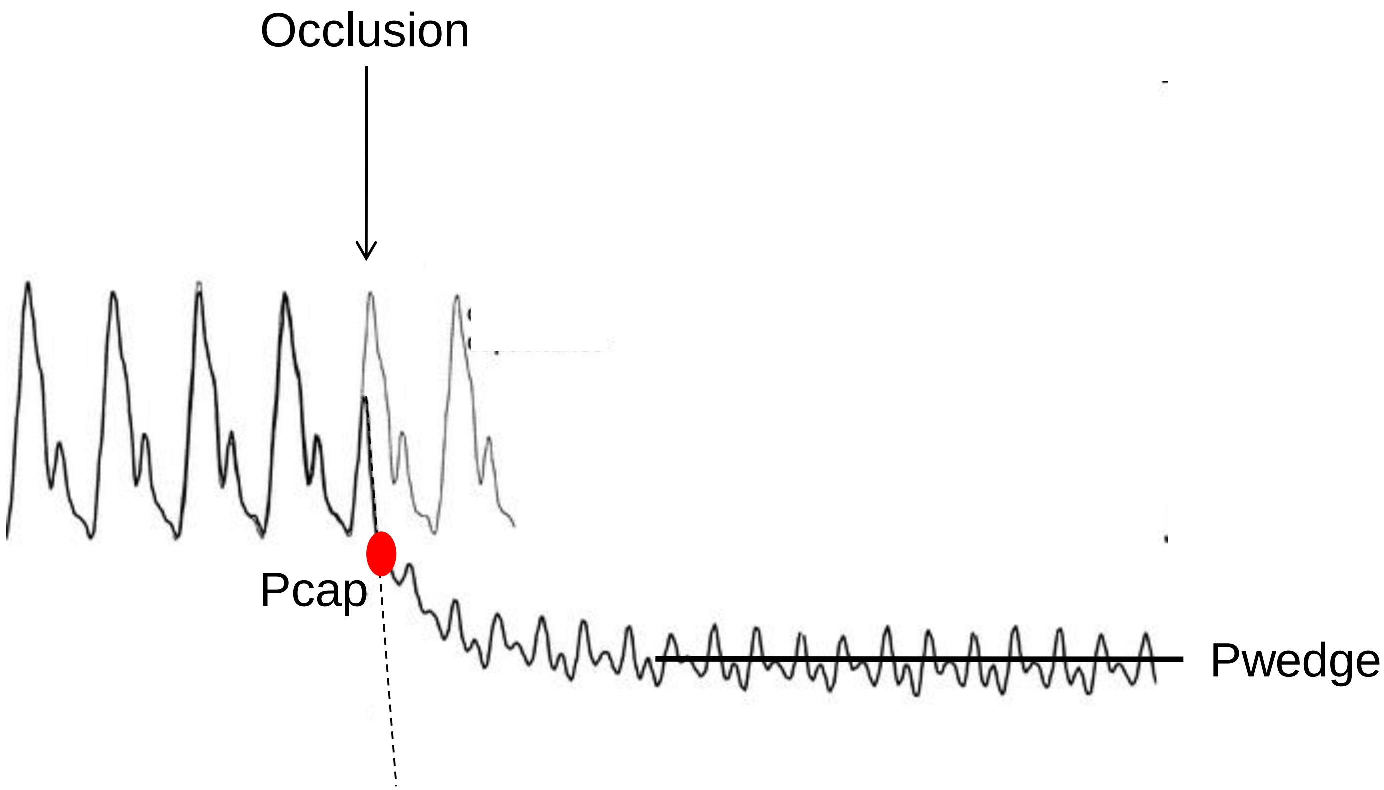
Current (I) ≈ Flow
Volt (V) ≈ Pressure

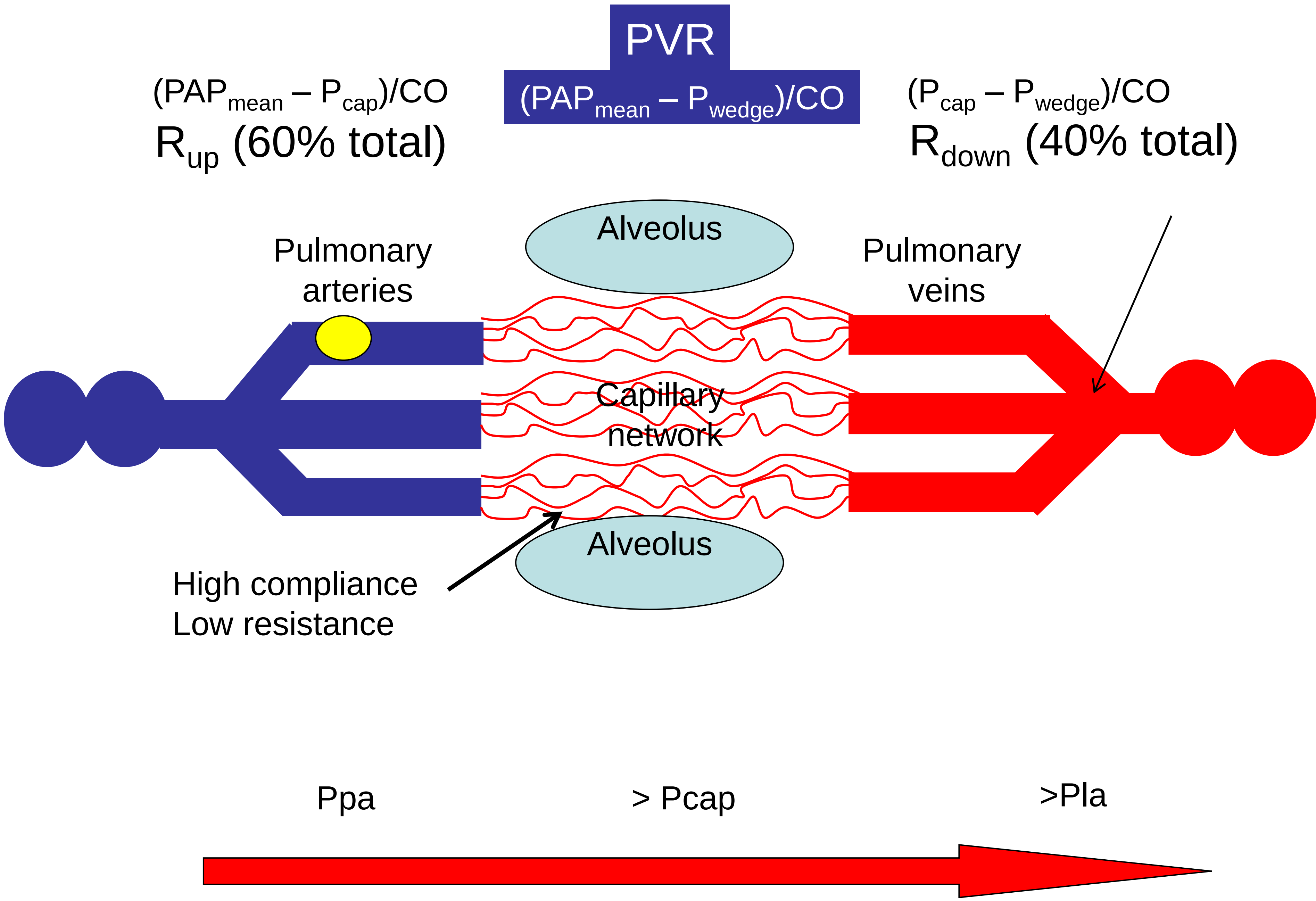



PVR
(Ppa – Pcap)/CO
(Ppa – Pla)/CO
(Pcap – Pla)/CO
Rup
Rdown
Alveolus
Pulmonary arteries
Pulmonary veins
Capillary network
Alveolus
High compliance
Low resistance
The catheter should be in Zone III
PVR = Rup+Rdown
Ppa
> Pcap
>Pla

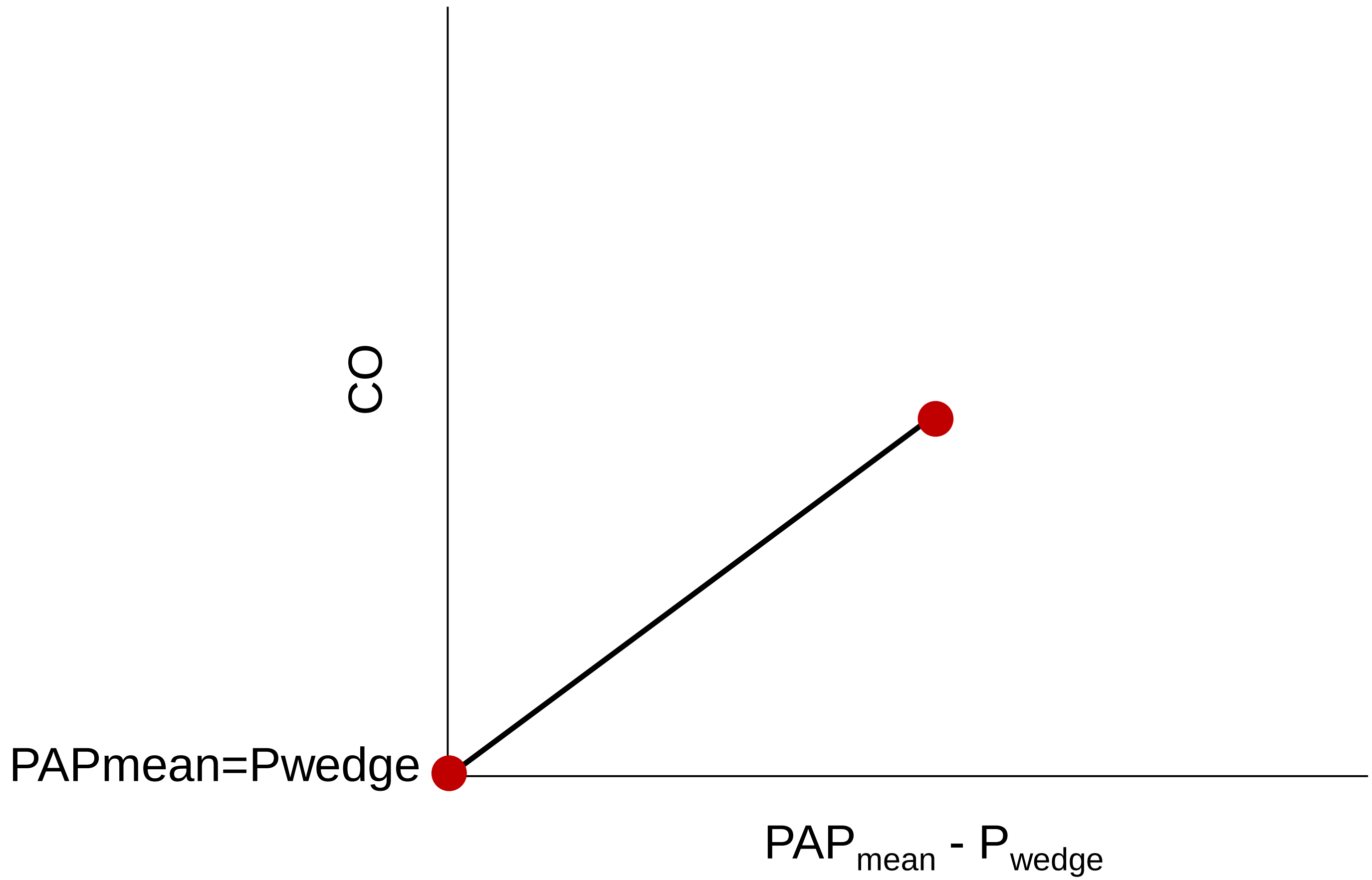


Pwedge
Alveolus
Pulmonary arteries
Pulmonary veins
Capillary network
Alveolus
??
Ppa
> Pcap
>Pla

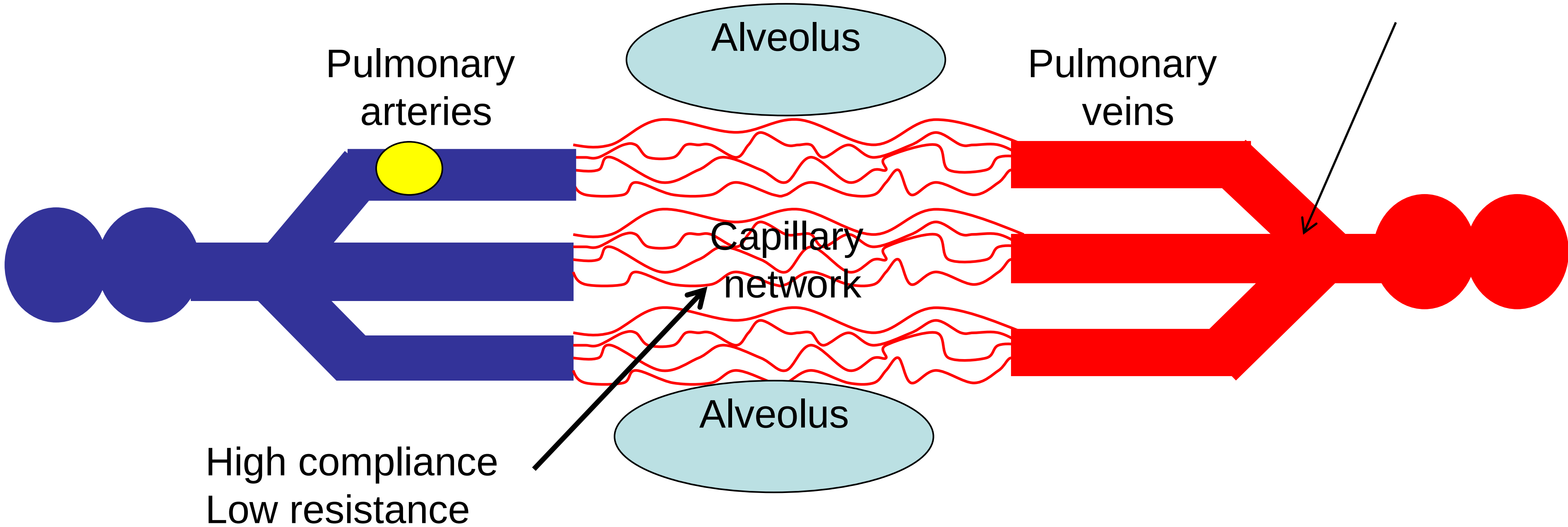

Occlusion
Pcap
Pwedge

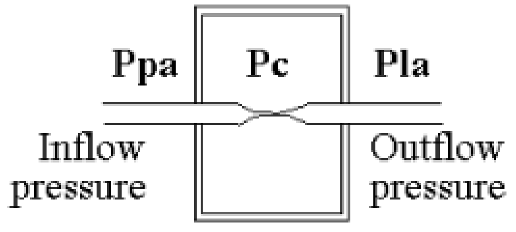

PVR
$(PAP_{mean} - P_{wedge})/CO$
$(PAP_{mean} - P_{cap})/CO$
R_{up} (60% total)
$(P_{cap} - P_{wedge})/CO$
R_{down} (40% total)
Alveolus
Pulmonary arteries
Pulmonary veins
Capillary network
Alveolus
High compliance
Low resistance
Ppa
> Pcap
>Pla

$$PVR = (PAP_{mean} - P_{wedge})/CO$$



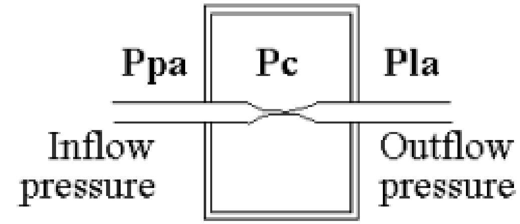
PVR = 1/slope

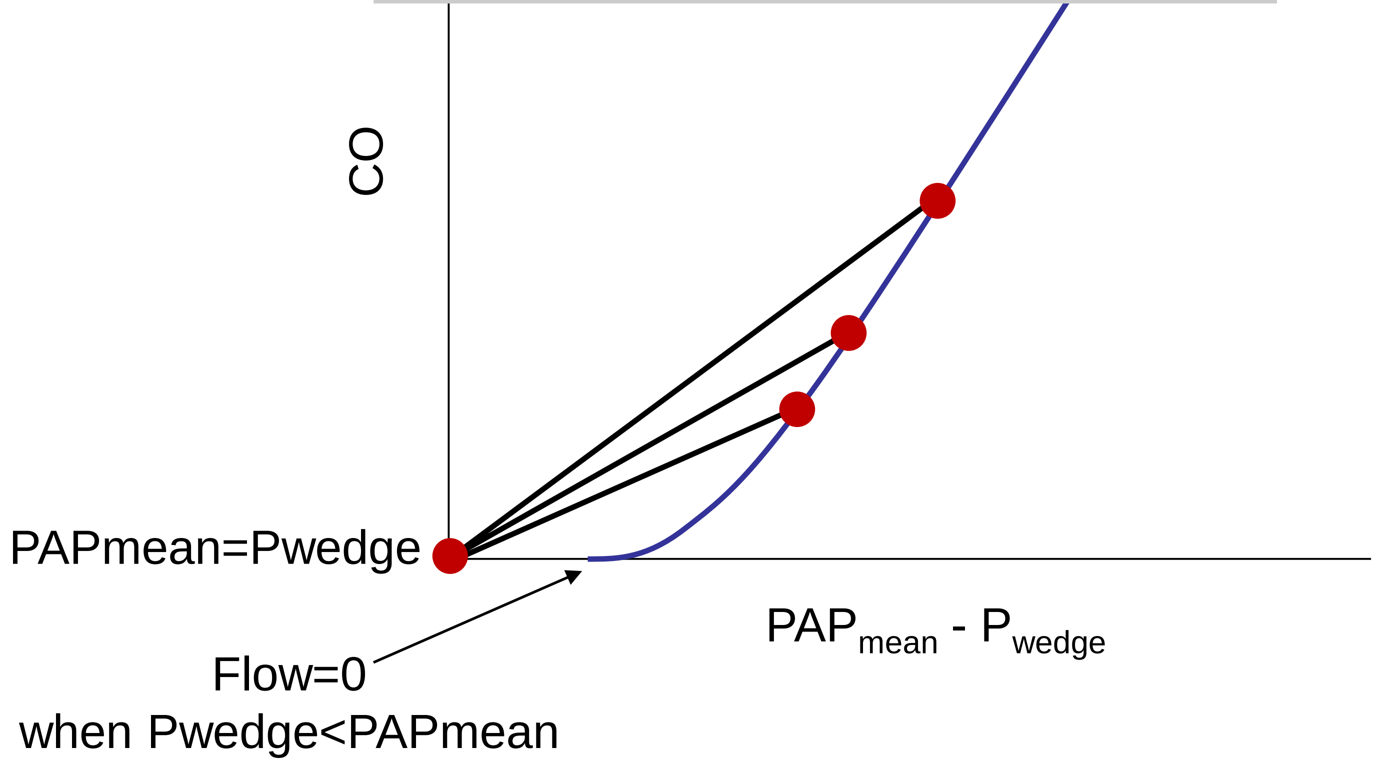

Alveolus
Pulmonary
arteries
Pulmonary
veins
Capillary
network
Alveolus
High compliance
Low resistance


Ppa
Pc
Pla
Inflow
pressure
Outflow
pressure

$$PVR = (PAP_{mean} - P_{wedge})/CO$$

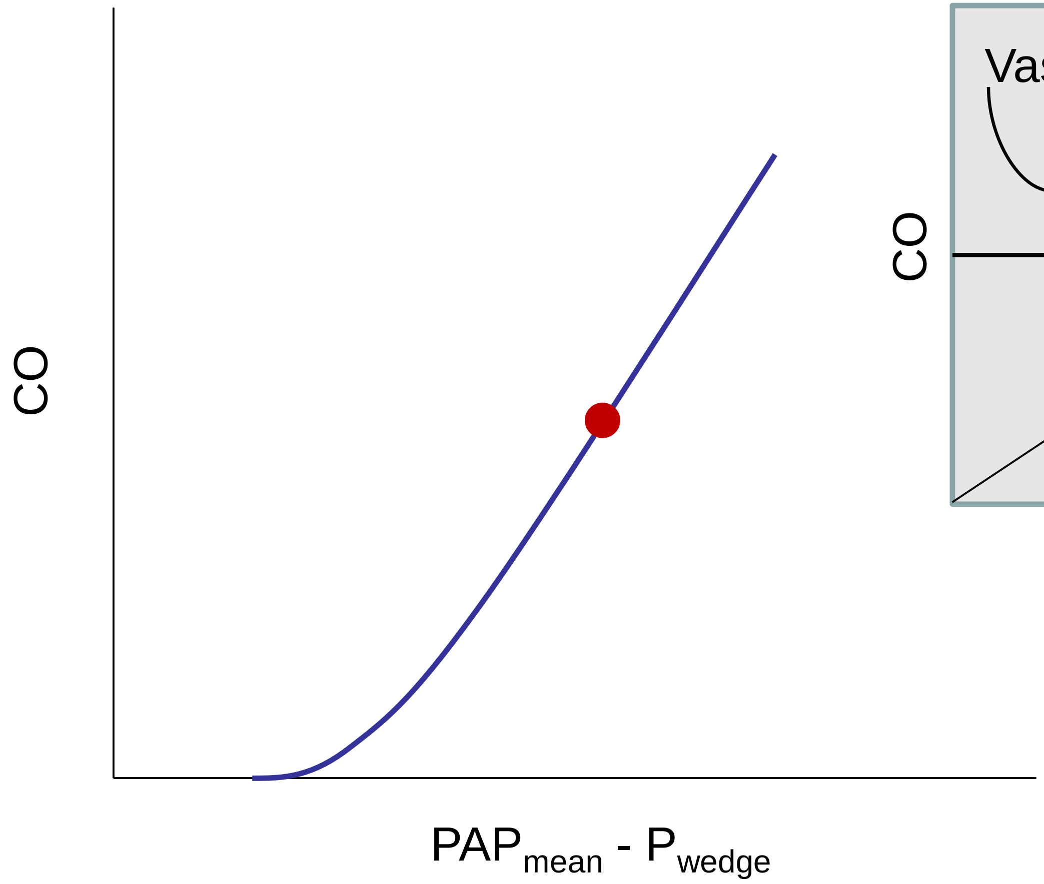
Message:
PVR is heavily depended on flows (cardiac output)

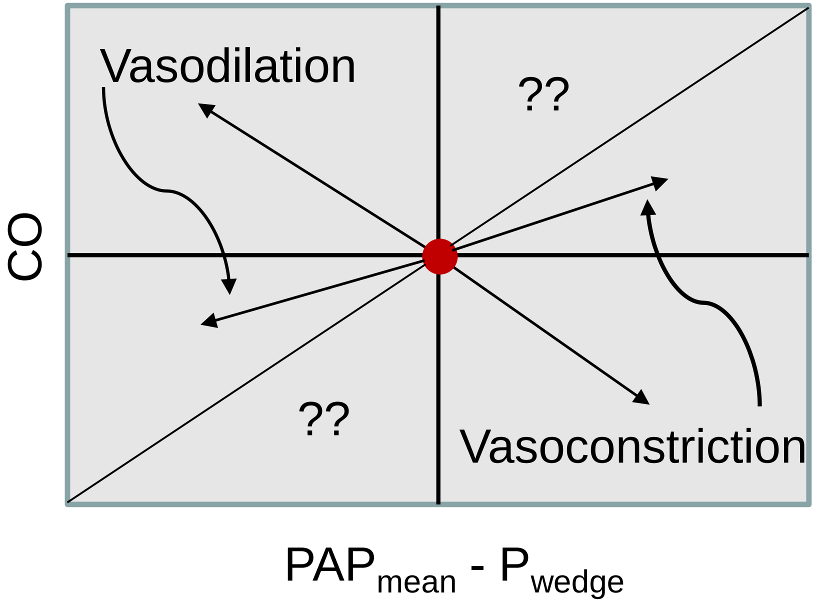


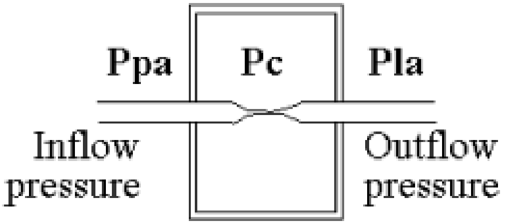


PVR = 1/slope

$$PVR = (PAP_{mean} - P_{wedge})/CO$$







Does the patient have Pulmonary hypertension?

Mean pulmonary arterial pressure (PAPm) ⩾25 mmHg at rest as assessed by right heart catheterization

The normal PAPm at rest is 14 ± 3 mmHg with an upper limit of normal of approximately 20 mmHg

Patients presenting with a pulmonary artery pressure (PAP) between 21 and 24 mmHg should be carefully followed when they are at risk for developing PAH

Eur Respir J 2015; 46: 903–975

Classification of PH

PAPm ⩾25 mmHg

1. Pulmonary arterial hypertension (Group 1) and PVR>3 WU
2. Pulmonary hypertension due to left heart disease (Group 2)
3. Pulmonary hypertension due to lung disease and/or hypoxia (Group 3)
4. Chronic thromboembolic pulmonary hypertension and other pulmonary artery obstruction (Group 4)
5. Pulmonary hypertension with unclear and/or multifactorial mechanisms (Group 5)

Eur Respir J 2015; 46: 903–975

Classification of PH

1. Pulmonary arterial hypertension (Group 1)

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3. Pulmonary hypertension due to lung disease and/or hypoxia (Group 3)

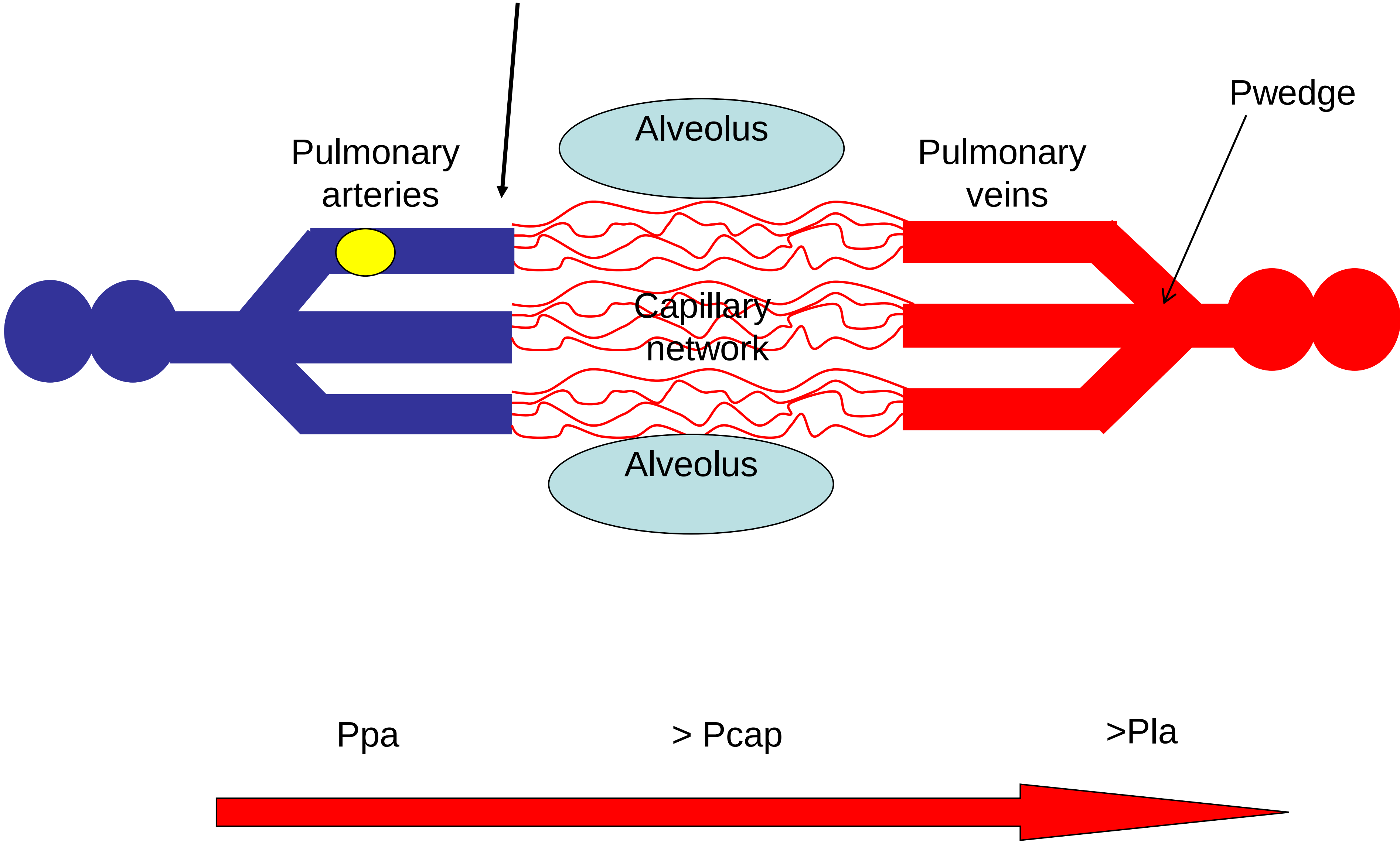
4. Chronic thromboembolic pulmonary hypertension and other pulmonary artery obstruction (Group 4)

5. Pulmonary hypertension with unclear and/or multifactorial mechanisms (Group 5)

Eur Respir J 2015; 46: 903–975

Group 1, 3, 4, 5
Pre-capillary Pulmonary Hypertension

PAPm ≥25 mmHg
Pwedge ≤15 mmHg



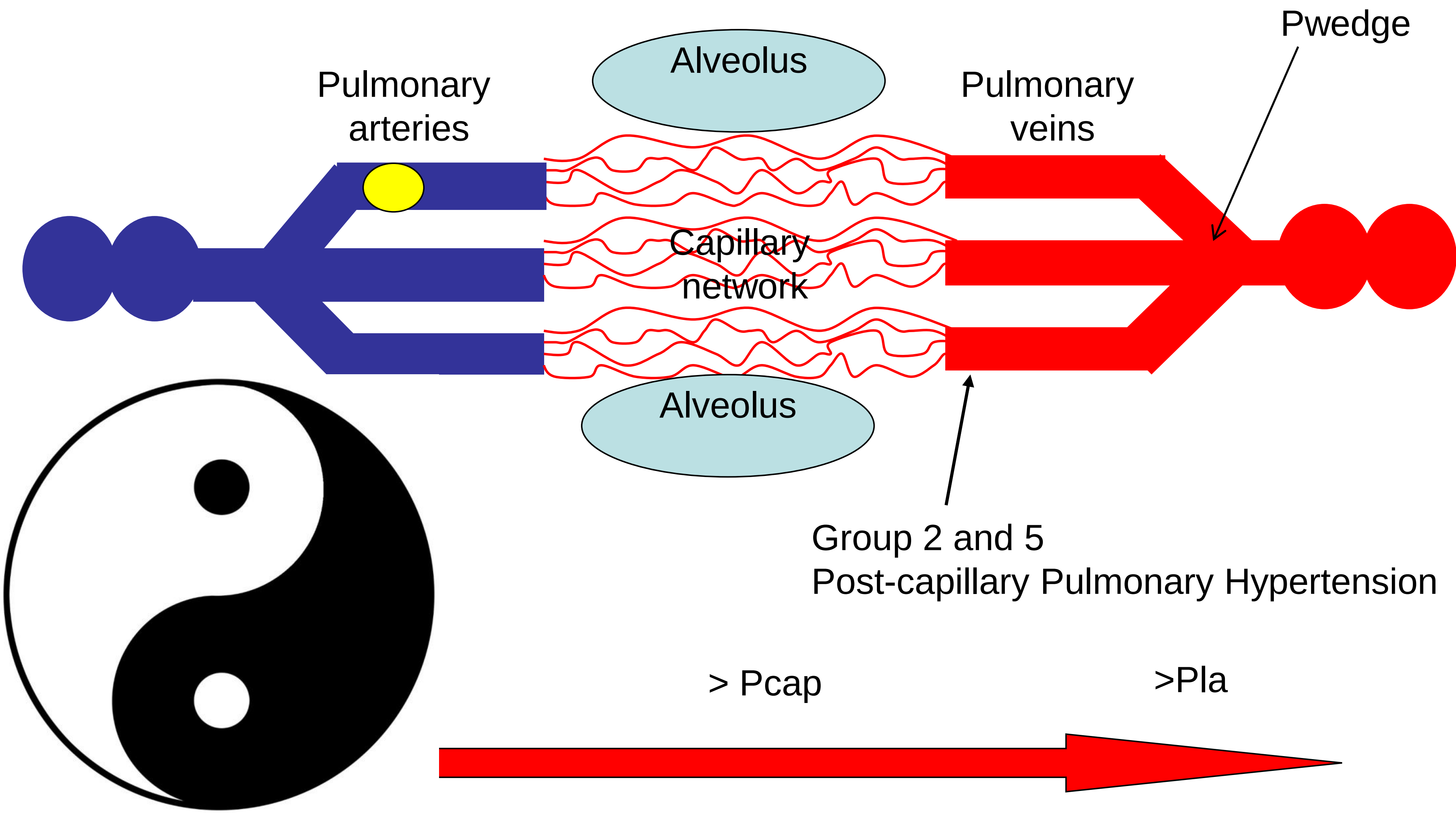
Classification of PH

1. Pulmonary arterial hypertension (Group 1)
2. Pulmonary hypertension due to left heart disease (Group 2)
3. Pulmonary hypertension due to lung disease and/or hypoxia (Group 3)
4. Chronic thromboembolic pulmonary hypertension and other pulmonary artery obstruction (Group 4)
5. Pulmonary hypertension with unclear and/or multifactorial mechanisms (Group 5)

Eur Respir J 2015; 46: 903–975

PAPm ≥25 mmHg

Pwedge >15 mmHg



[Original Research Pulmonary Vascular Disease]

CHEST

Clinical Relevance of Fluid Challenge in Patients Evaluated for Pulmonary Hypertension

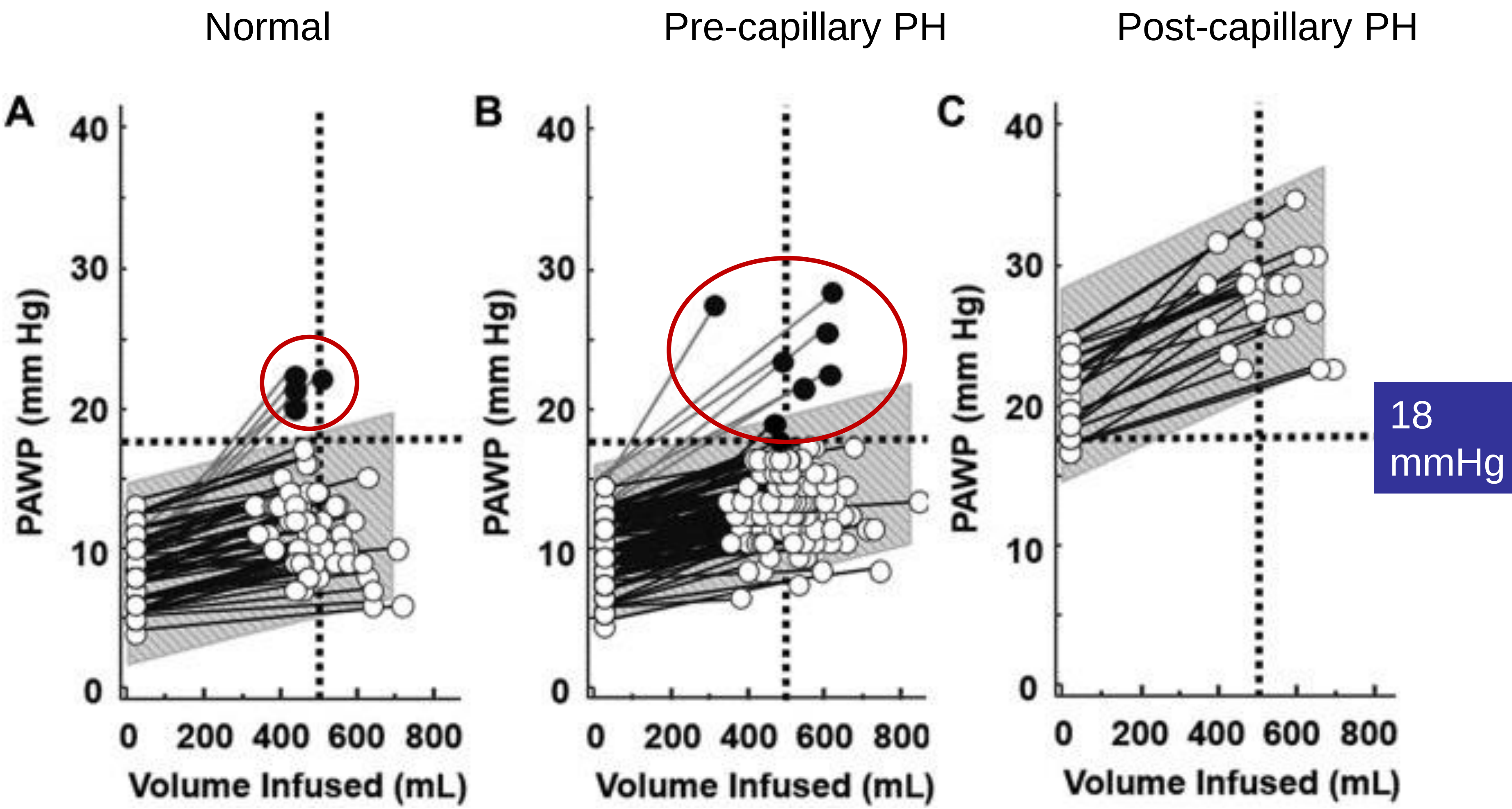
CHEST 2017; 151(1):119-126

Michele D'Alto, MD, PhD; Emanuele Romeo, MD, PhD; Paola Argiento, MD, PhD; Yoshiki Motoji, MD, PhD; Anna Correra, MD; Giovanni Maria Di Marco, MD; Agostino Mattera Iacono, MD; Rosaria Barracano, MD; Antonello D'Andrea, MD, PhD; Gaetano Rea, MD; Berardo Sarubbi, MD, PhD; Maria Giovanna Russo, MD; and Robert Naeije, MD, PhD

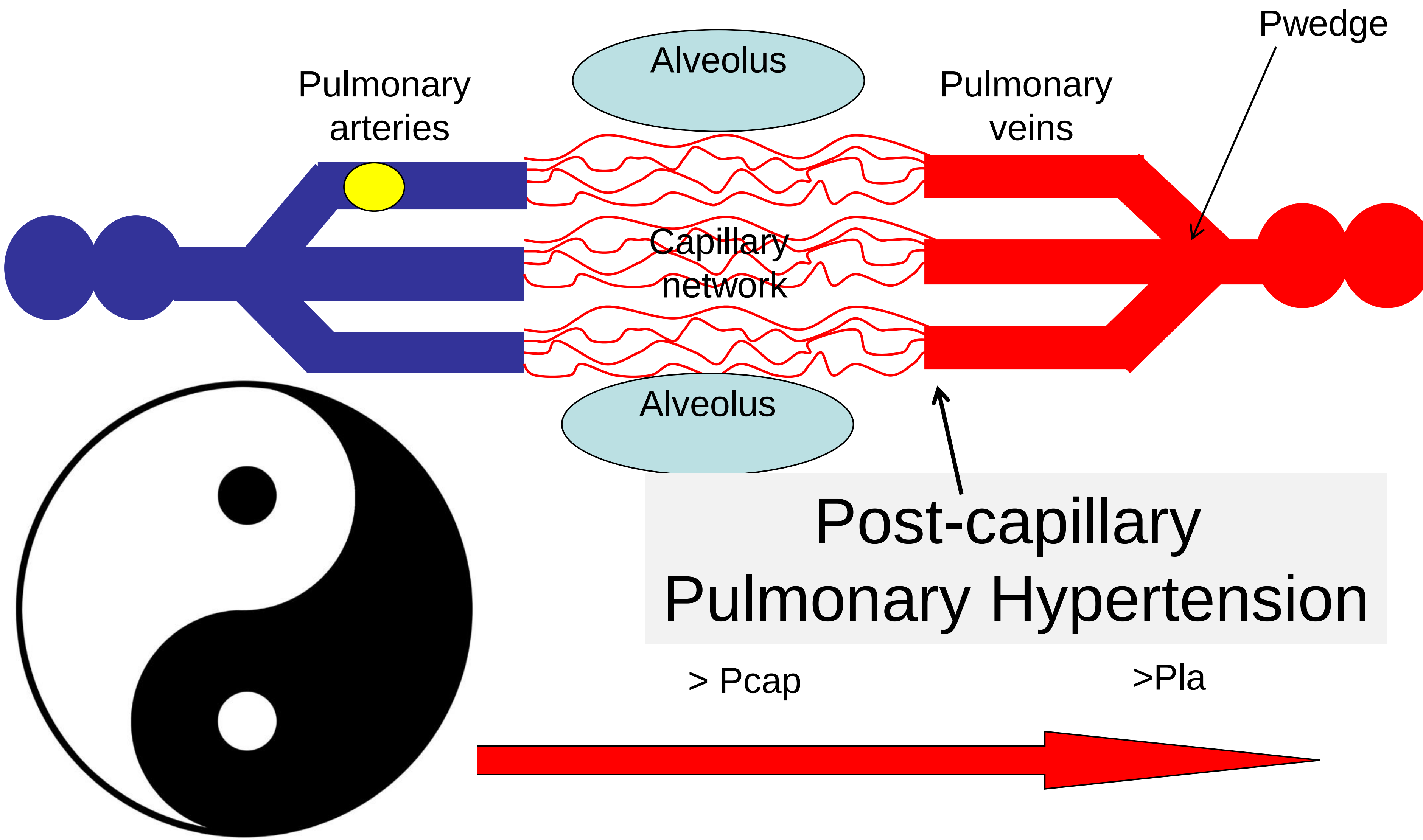
212 patients referred for PH underwent a right-sided heart catheterization.

Hemodynamic measurements were obtained at baseline and immediately after intravenous administration of 7 mL/kg of saline over 5 to 10 min.

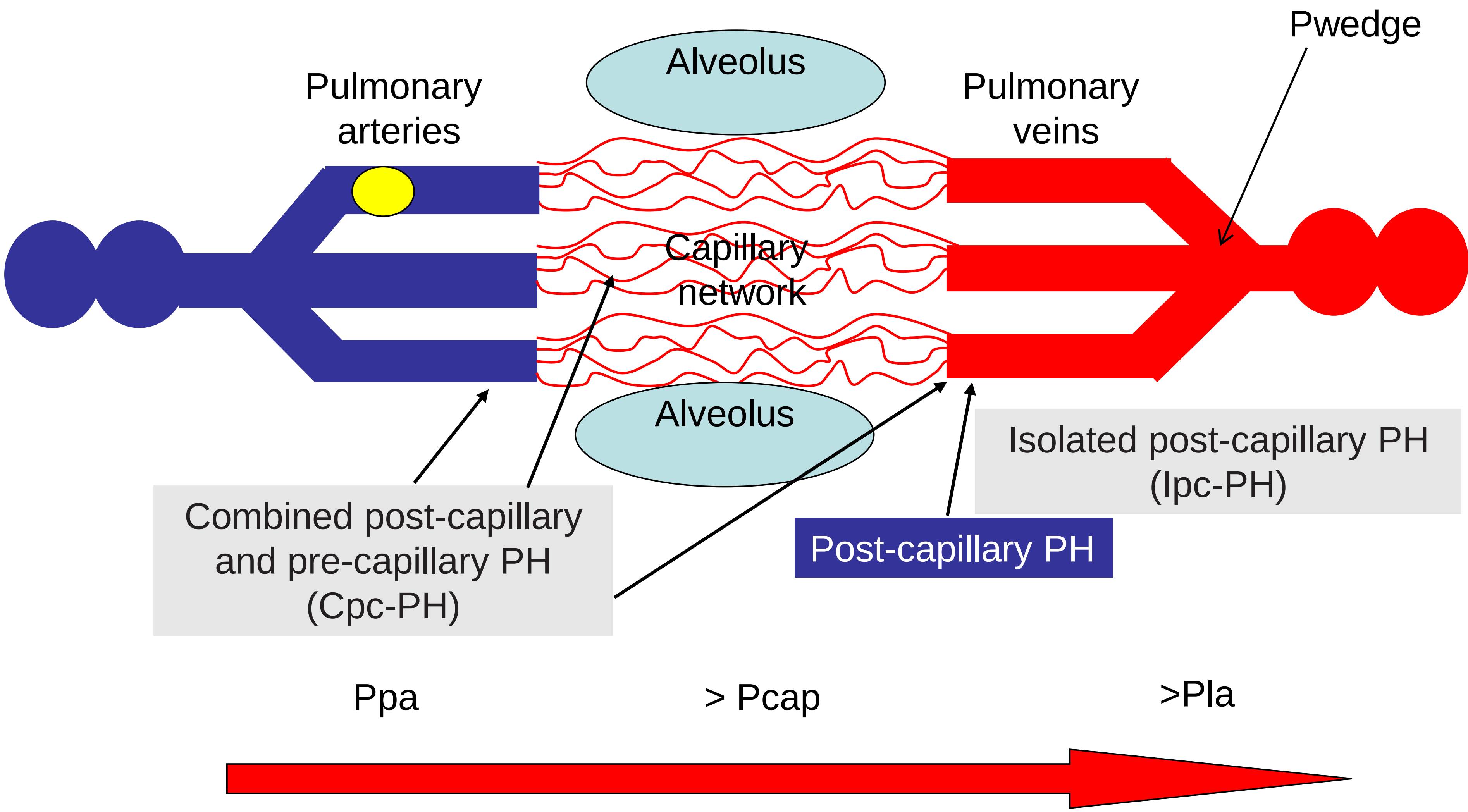
After fluid challenge, 5 of 66 patients with no PH (8%) and 8 of 124 with precapillary PH (6%) had the diagnosis reclassified as post-capillary PH.

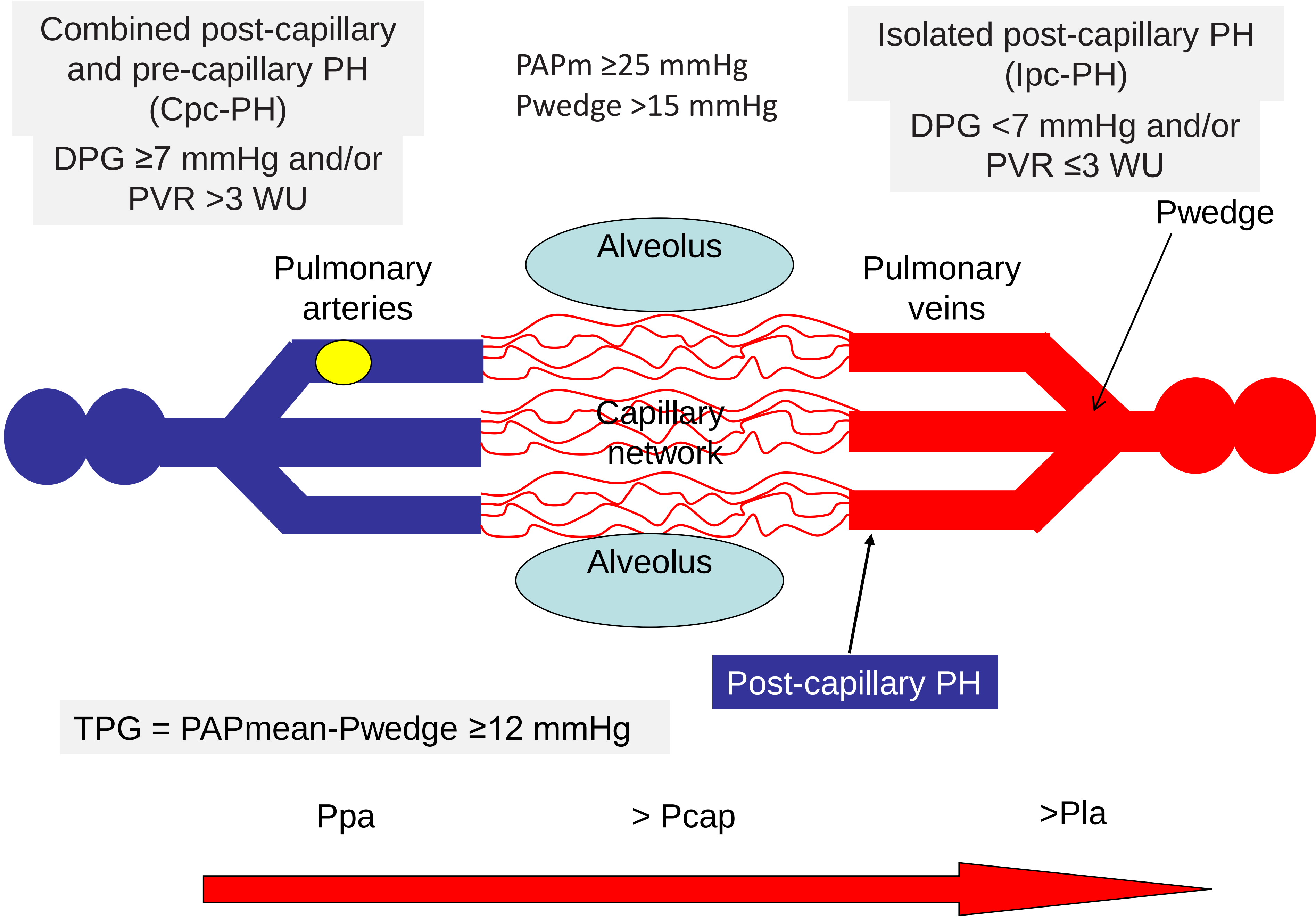


8% (diagnosed as normal) and
6% (diagnoses with Pre-capillary PH)



PAPm ≥25 mmHg
Pwedge >15 mmHg




Combined post-capillary and pre-capillary PH (Cpc-PH)
DPG ≥7 mmHg and/or PVR >3 WU
PAPm ≥25 mmHg
Pwedge >15 mmHg
Isolated post-capillary PH (Ipc-PH)
DPG <7 mmHg and/or PVR ≤3 WU
Pwedge
Alveolus
Pulmonary arteries
Pulmonary veins
Capillary network
Alveolus
Post-capillary PH
TPG = PAPmean-Pwedge ≥12 mmHg
Ppa
> Pcap
>Pla

SERIES "PHYSIOLOGY IN RESPIRATORY MEDICINE"
Edited by R. Naeije, D. Chemla, A. Vonk Noordegraaf and
A.T. Dinh-Xuan
Number 1 in this Series

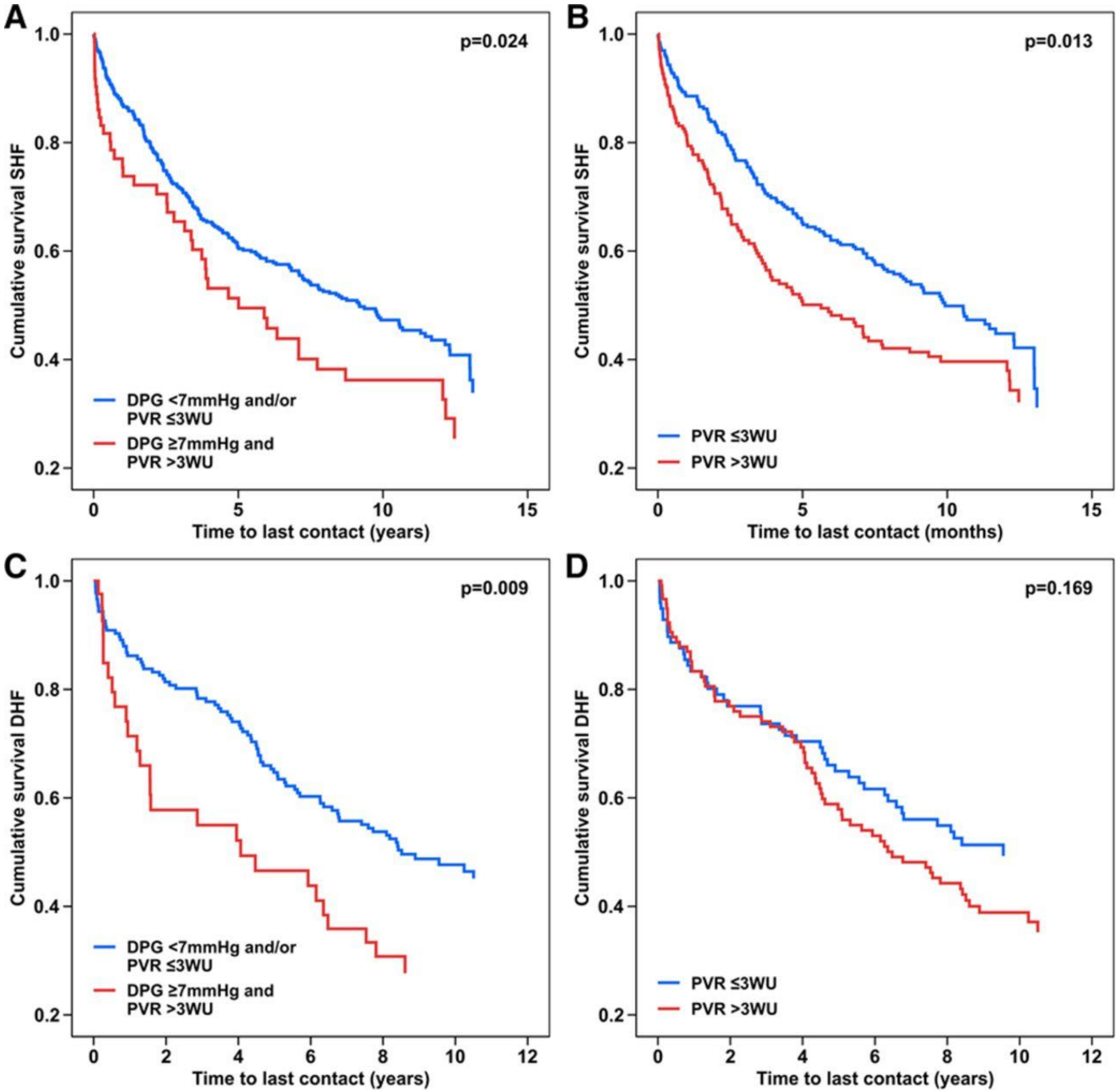
The transpulmonary pressure gradient for the diagnosis of pulmonary vascular disease

Robert Naeije*, Jean-Luc Vachiery[#], Patrick Yerly[#] and Rebecca Vanderpool*

Eur Respir J 2013; 41: 217–223

TPG depends on 1) cardiac output, 2) recruitment and distension of the pulmonary vessels, 3) stroke volume and 4) arterial compliance

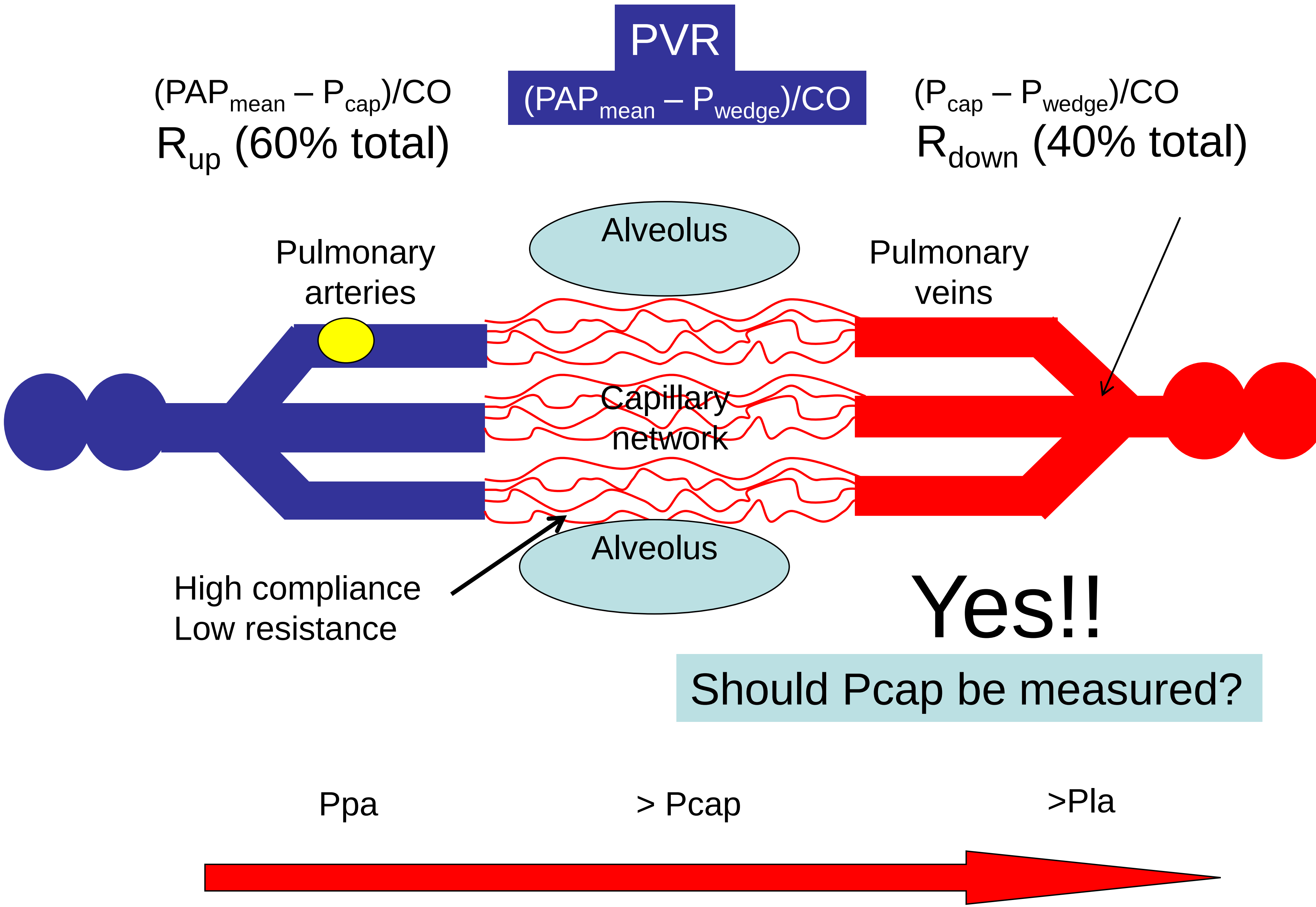
DPG is superior to the TPG for the diagnosis of "out of proportion" pulmonary hypertension



reduced ejection fraction/
systolic heart failure

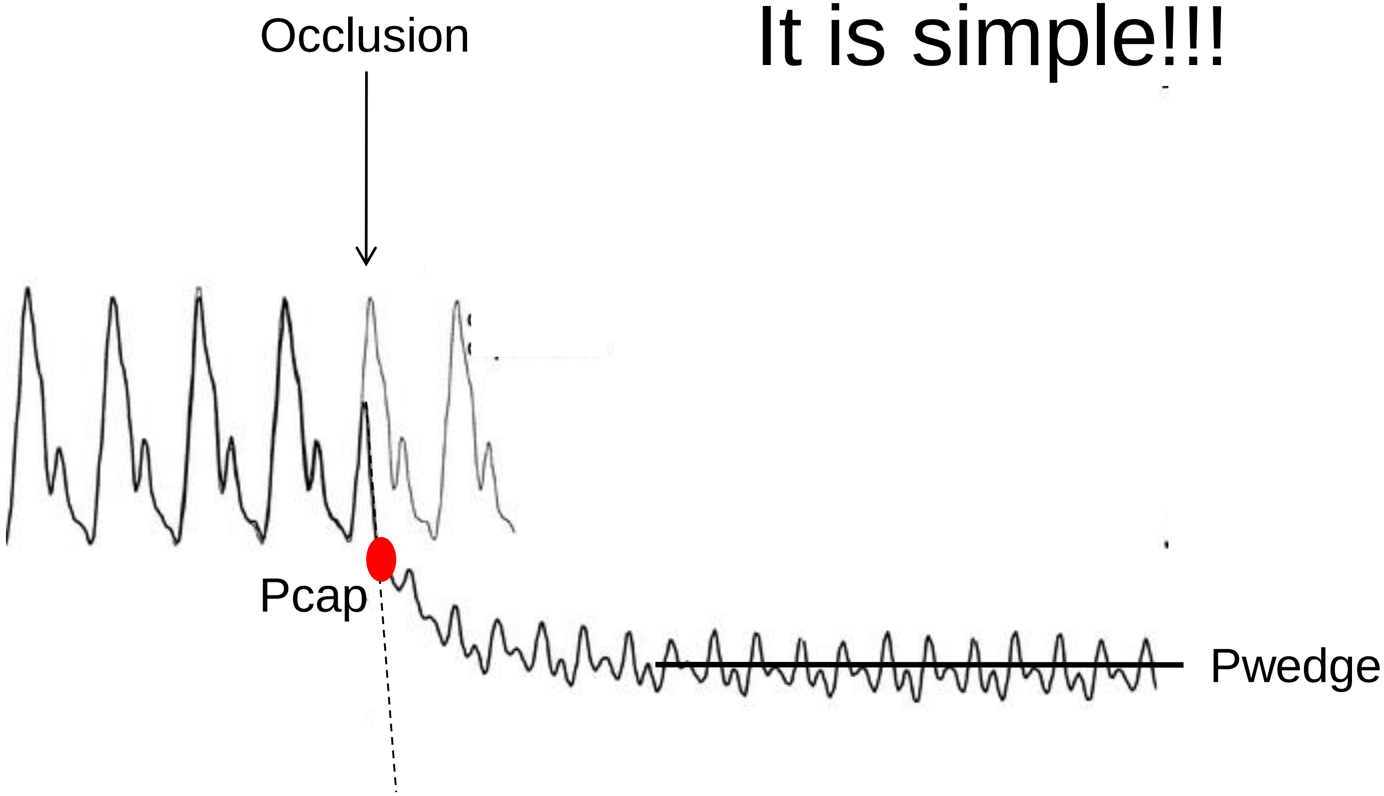
preserved ejection fraction/
diastolic heart failure

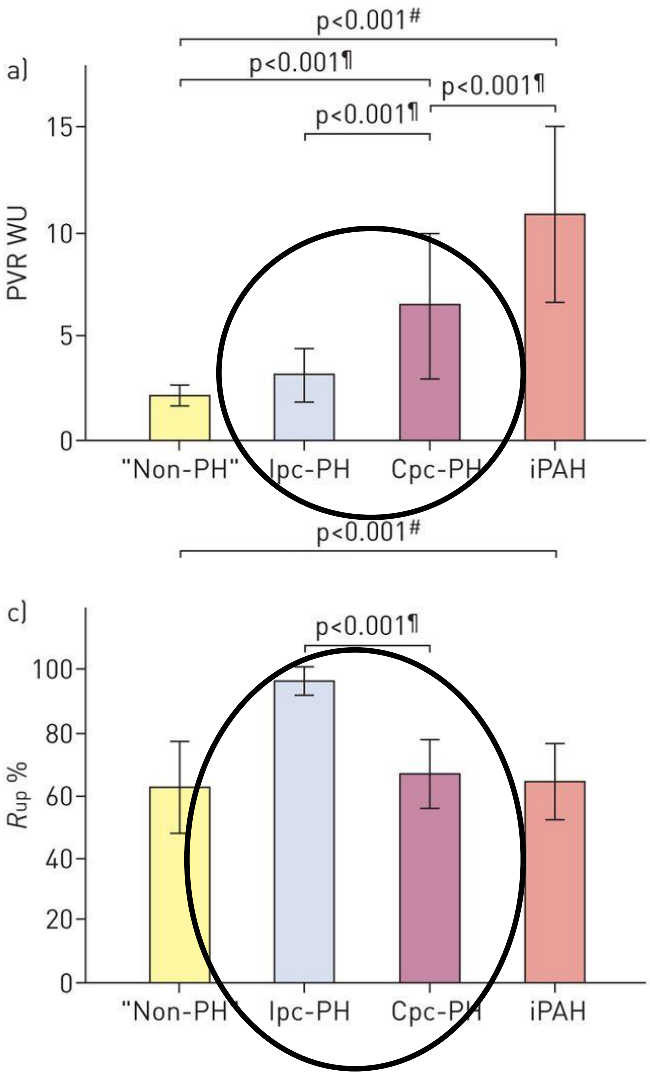
Robert Naeije et al. Circ Heart Fail. 2017;10:e004082



PVR
$(PAP_{mean} - P_{wedge})/CO$
$(PAP_{mean} - P_{cap})/CO$
R_{up} (60% total)
$(P_{cap} - P_{wedge})/CO$
R_{down} (40% total)
Alveolus
Pulmonary arteries
Pulmonary veins
Capillary network
Alveolus
High compliance
Low resistance
Yes!!
Should Pcap be measured?
Ppa
> Pcap
>Pla

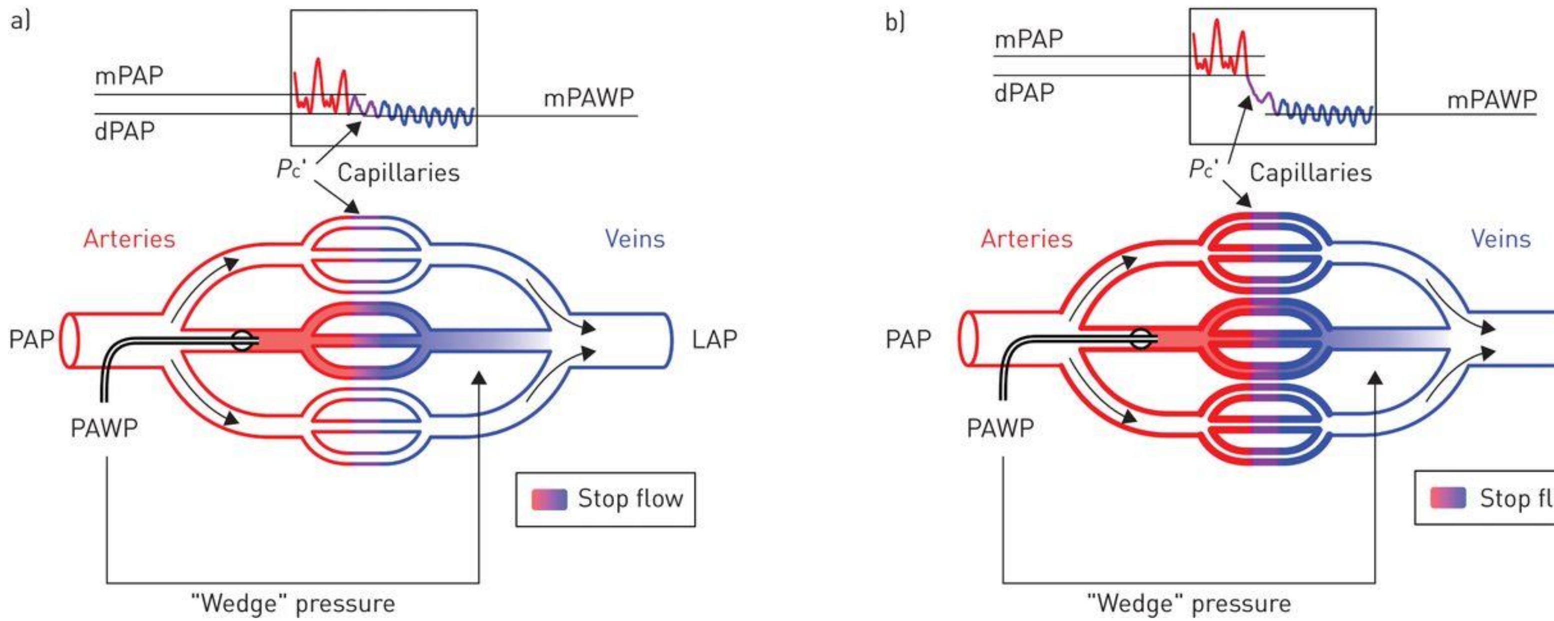
It is simple!!!





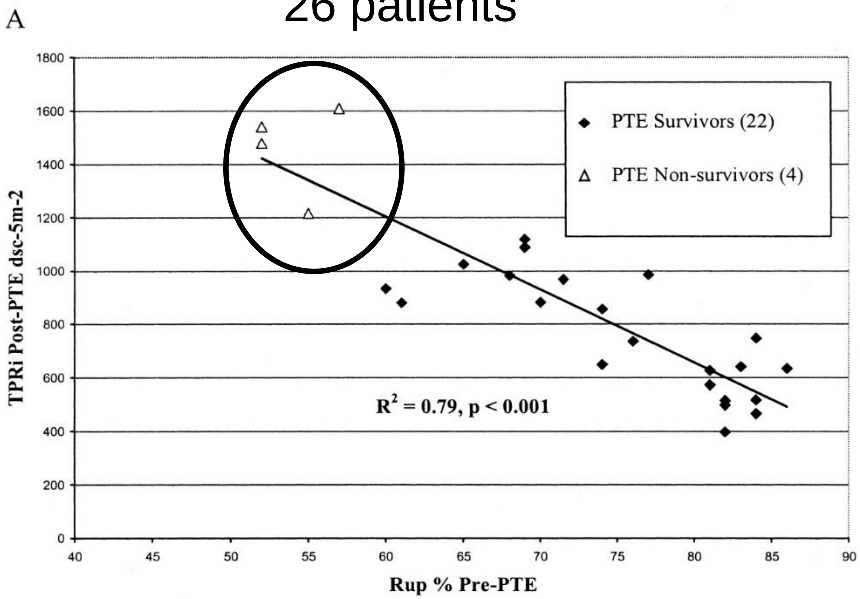
Christian Gerges et al. Eur Respir J 2018;51:1800067

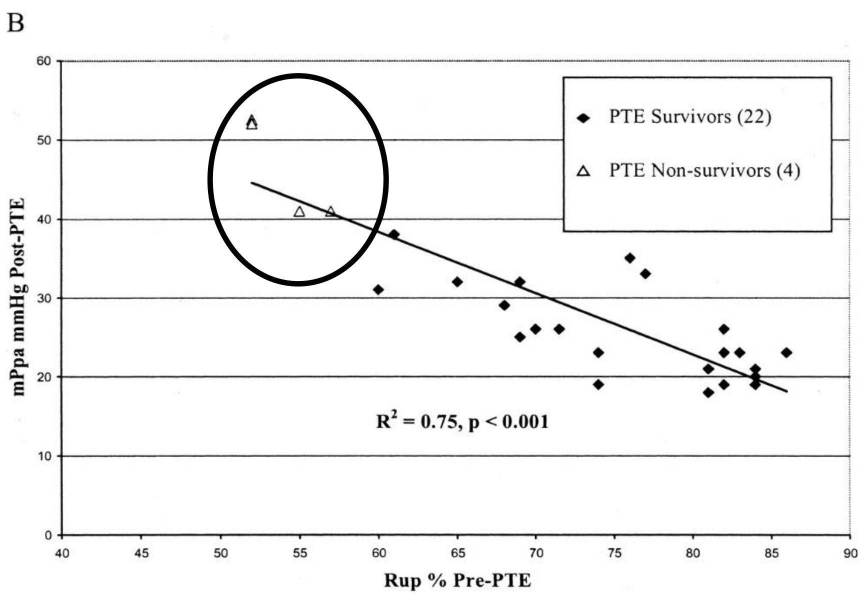
Models of the pulmonary circulation with corresponding phenotypes of pressure decay curves in a) isolated post-capillary pulmonary hypertension (Ipc-PH) and b) combined post- and pre-capillary PH (Cpc-PH).



Christian Gerges et al. Eur Respir J 2018;51:1800067

26 patients



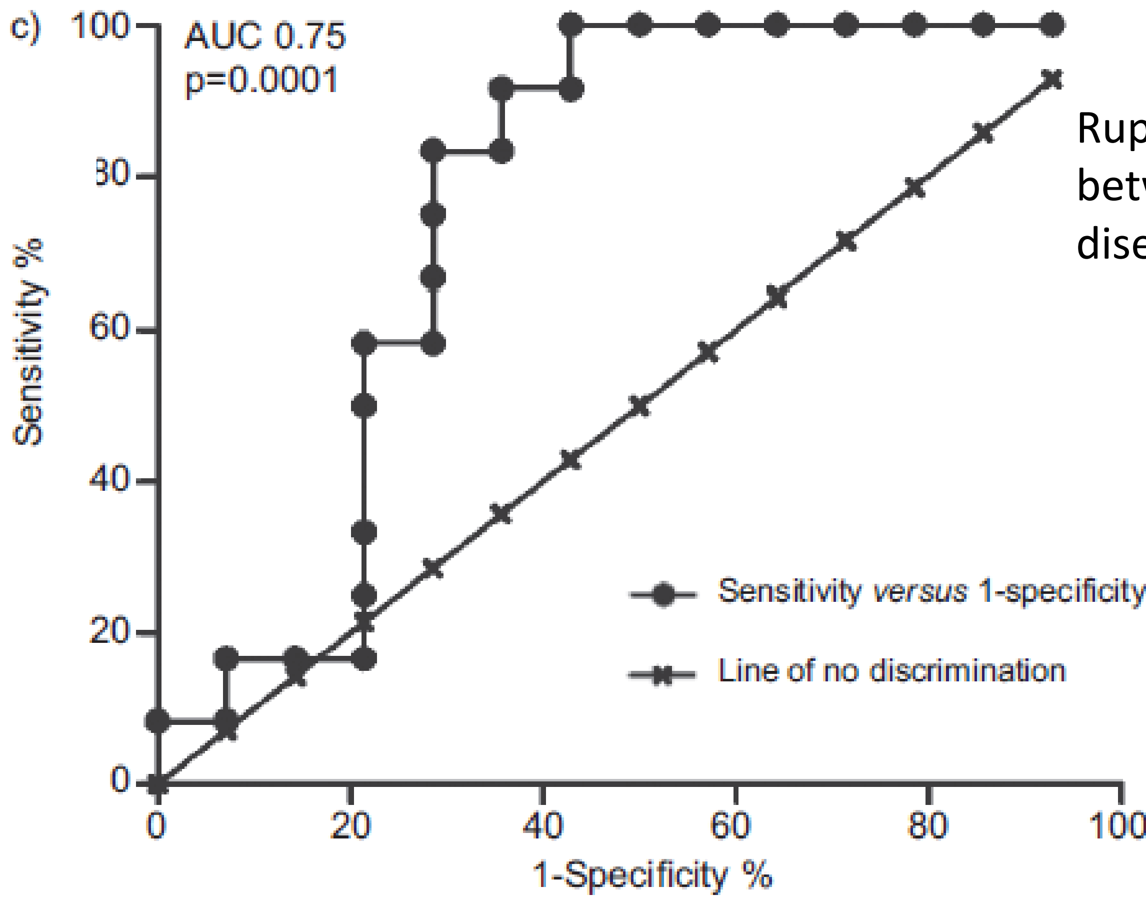


Group 4 and Rup

Patients with R*up* values <60% appear to have the highest postoperative risk

Nick H.S. Kim et al. Circulation. 2004;109:18-22

14 operable CTEPH, 15 inoperable CTEPH



Rup is capable of distinguishing between operable and inoperable disease

Cutoff point of 79.3%:
100% sensitivity
57.1% specificity

Cutoff point of 83.8%:
83.3% sensitivity
71.4% specificity

Toshner et al. Eur Respir J 2012; 40: 612–617

Vaso-reactivity test

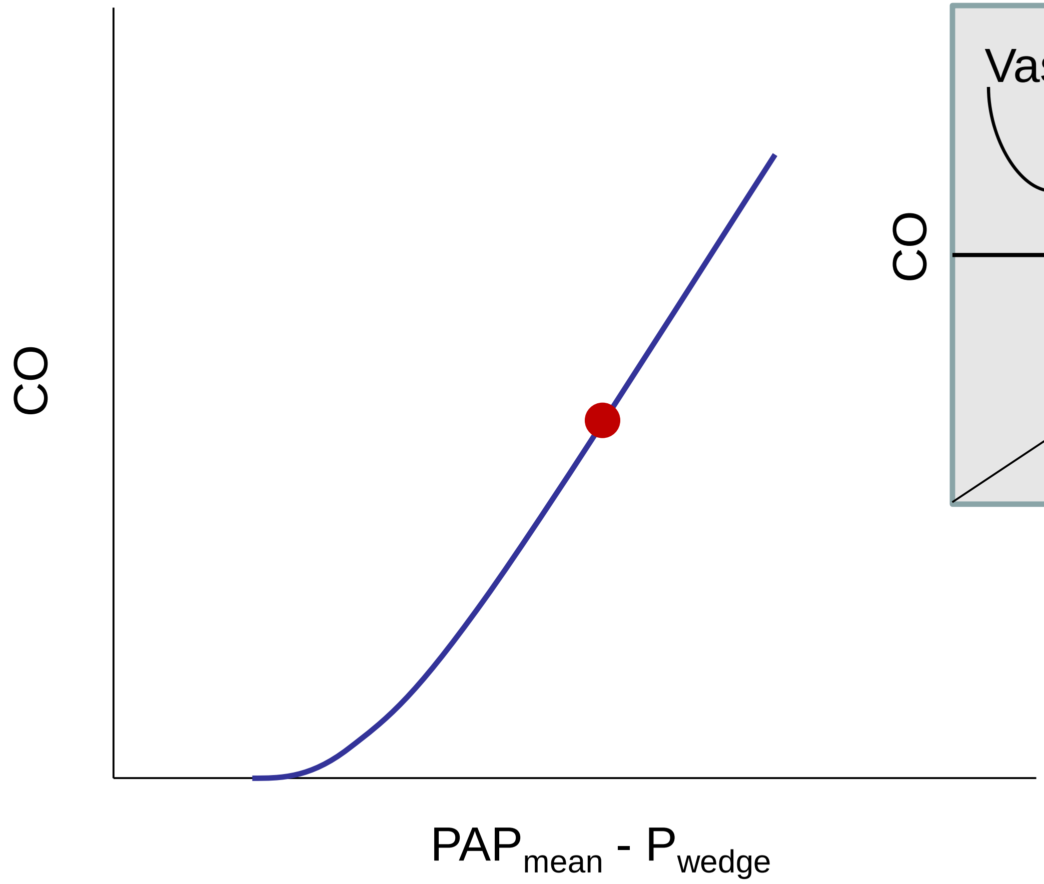
Pulmonary vasoreactivity testing is recommended only for patients with:

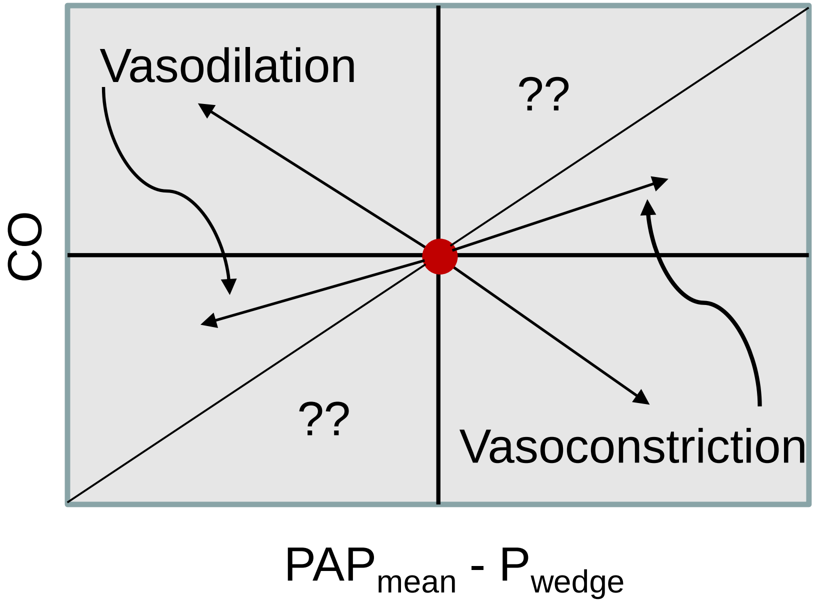
1) IPAH
2) HPAH or
3) drug-induced PAH

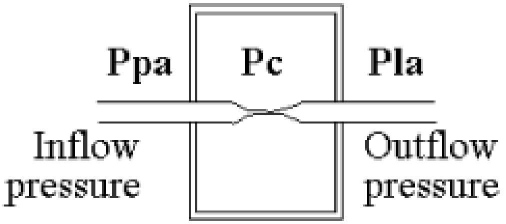
1. Inhaled nitric oxide (NO)
2. Epoprostenol
3. Adenosine
4. Inhaled iloprost

Positive response to vasoreactivity testing:
A reduction of mean PAP ≥10 mmHg to reach an absolute value of mean PAP ≤40 mmHg with an increased or unchanged cardiac output

$$PVR = (PAP_{mean} - P_{wedge})/CO$$

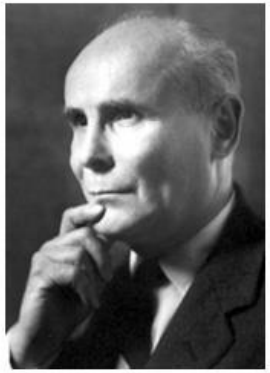






RHC and follow up

Determinants of prognosis[a] (estimated 1-year mortality)	Low risk <5%	Intermediate risk 5–10%	High risk >10%
Clinical signs of right heart failure	Absent	Absent	Present
Progression of symptoms	No	Slow	Rapid
Syncope	No	Occasional syncope[b]	Repeated syncope[c]
WHO functional class	I, II	III	IV
6MWD	>440 m	165–440 m	<165 m
Cardiopulmonary exercise testing	Peak VO_2 >15ml/min/kg (>65% pred.) VE/VCO_2 slope <36	Peak VO_2 11–15 ml/min/kg (35–65% pred.) VE/VCO_2 slope 36–44.9	Peak VO_2 <11 ml/min/kg (<35% pred.) VE/VCO_2 slope ≥45
NT-proBNP plasma levels	BNP <50 ng/l NT-proBNP <300 ng/l	BNP 50–300 ng/l NT-proBNP 300–1400 ng/l	BNP >300 ng/l NT-proBNP >1400 ng/l
Imaging (echocardiography, CMR imaging)	RA area <18 cm^2 No pericardial effusion	RA area 18–26 cm^2 No or minimal, pericardial effusion	RA area >26 cm^2 pericardial effusion
Haemodynamics	RAP <8 mmHg CI ≥2.5 l/min/m^2 SvO_2 >65%	RAP 8–14 mmHg CI 2.0–2.4 l/min/m^2 SvO_2 60–65%	RAP >14 mmHg CI <2.0 l/min/m^2 SvO_2 <60%

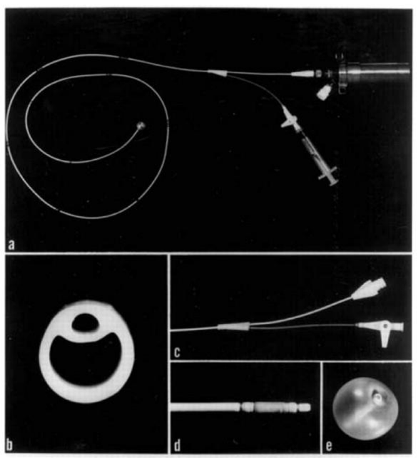


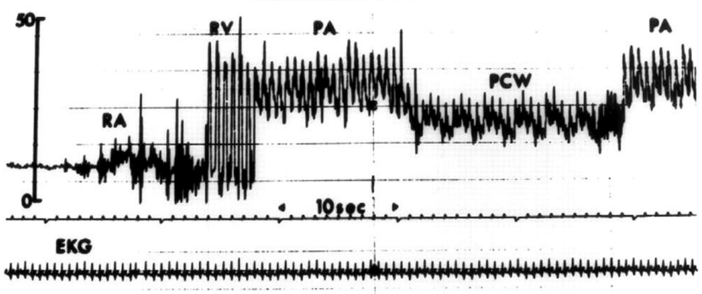
André Frédéric Cournand

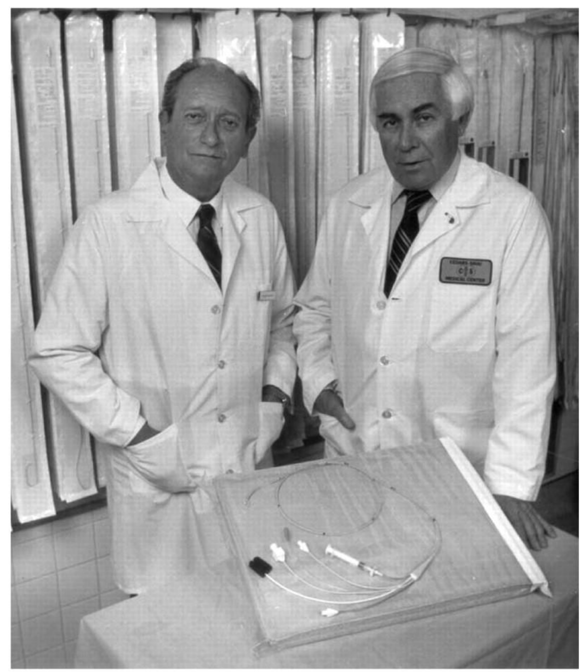
Werner Forssmann

Dickinson W. Richards

The Pulmonary Artery Catheter







William Ganz and H.J.C. Swan

Large V waves in CVP and Pwedge