Pravostranná srdeční katetrizace

(invazivní hemodynamika jako okno do fyziologie oběhu)

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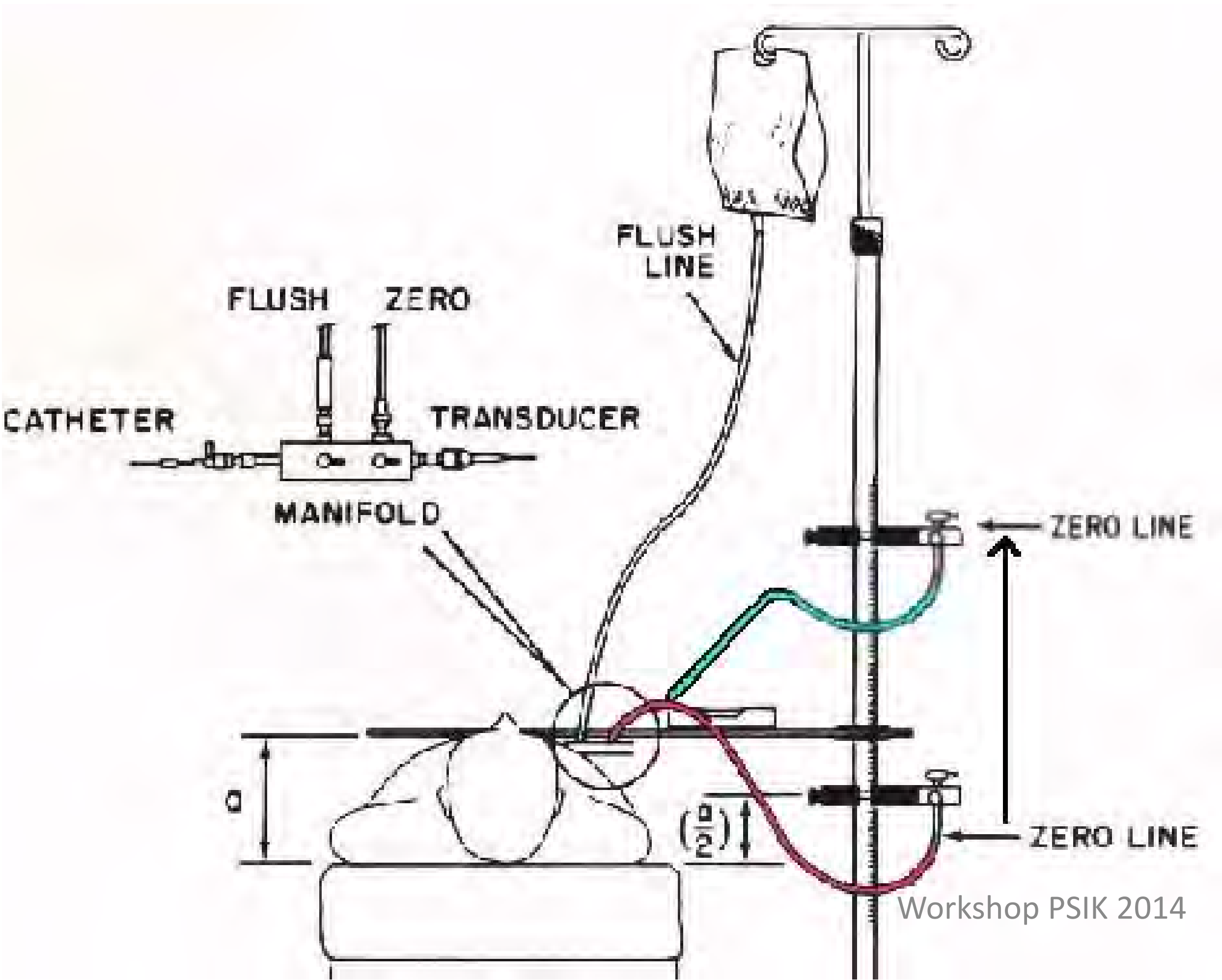
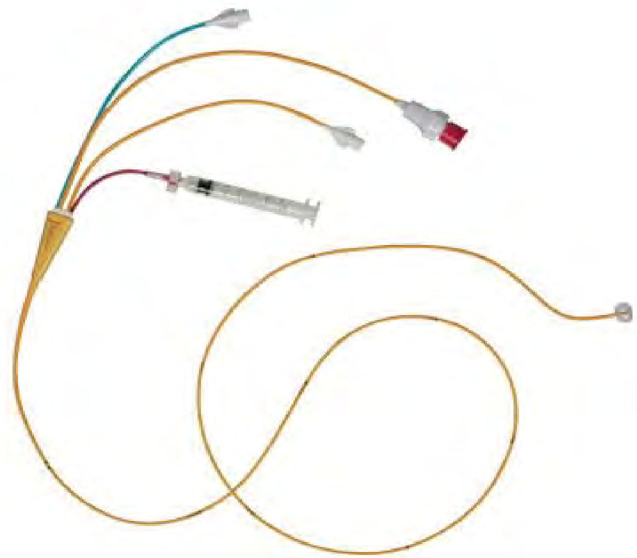
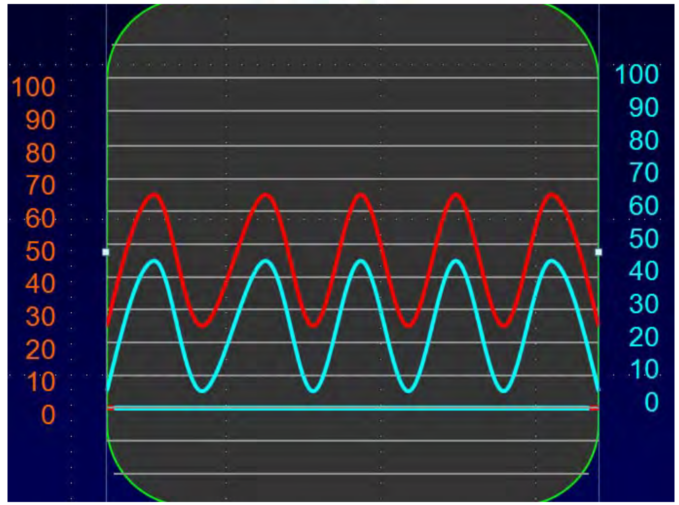
Měření tlaků - technika

- Přenos tlakového signálu tekutinou v katetru a senzor umístěn mimo tělo pacienta („kapsle“)
- Kalibrace !!



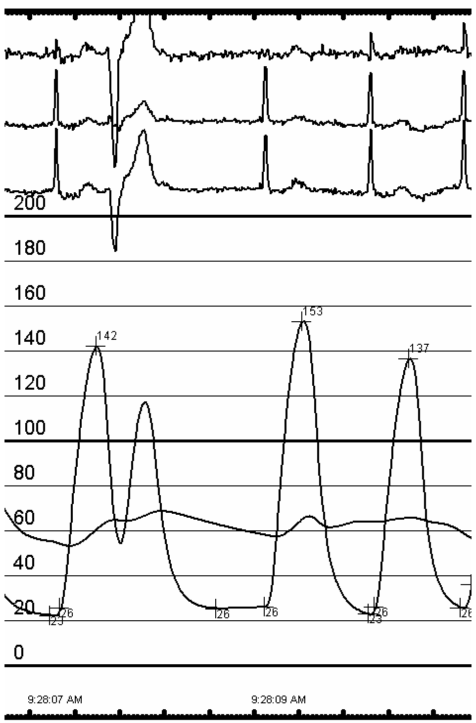




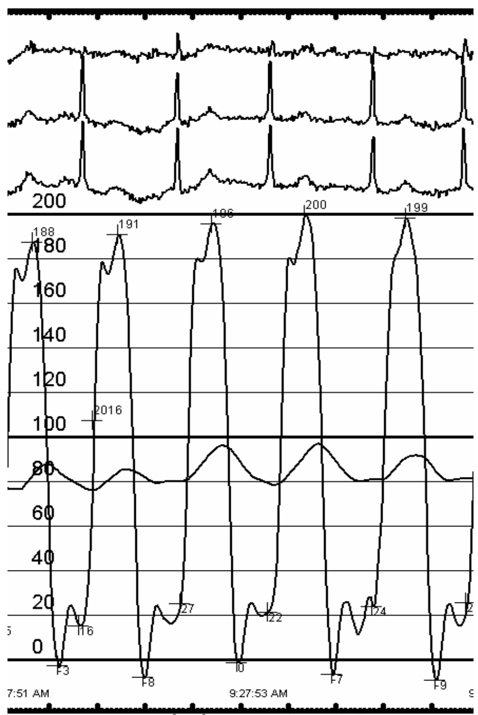
Měření tlaků - chyby

- Kvalitní signál – tlumení je závislé na délce a kalibru katetru, viskozitě tekutiny, absence vzduchových bublin !!

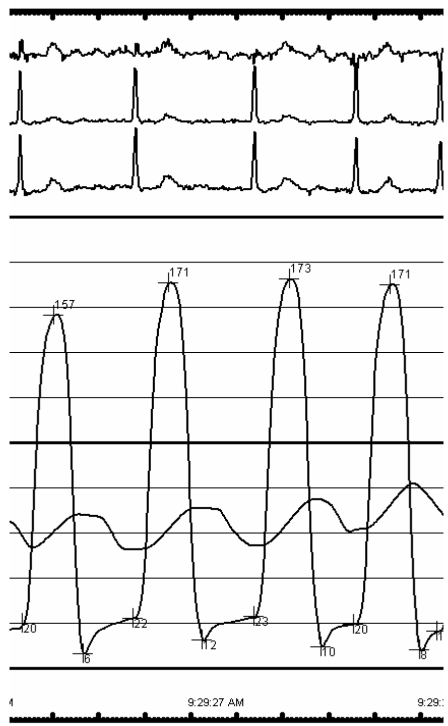
Viskózní kontrast



Dobrá kvalita



Vzduchová bublina



Indikace invazivní hemodynamiky

- **1) u lůžka – ARO, KJ** – kritické stavy (dif.dg. šoků a srdečního selhání)
  – Typicky cestou v.jugularis interna, často bez RTG navigace
- 2) **v katetrizační laboratoři** – dříve časté, dnes často nahrazeno echokardiografií. Nejčastěji cestou v.femoralis.
  – Závažná rozhodnutí – před Tx nebo jinou KCH operací
  – Potřeba určení typu, tíže a event. reverzibility plicní hypertenze
  – Nesouhlas mezi klinickým nálezem a echokardiografií
  – Kvantifikace zkratových vad
  – Diagnostika konstriktivní versus restriktivní fyziologie
- 3) **během invazivních strukturálních intervencí** – TAVI, ASA

Vždy je jasná otázka, „rutinní" postup již neexistuje

Rizika pravostranné katetrizace

- Krvácení z místa vpichu, vznik AV fistule
- Arytmie při manipulaci katetru v P oddílech. CAVE kompletní AV blok při manipulaci katetrem v RVOT u pacientů s LBBB
- Vyšší radiační zátěž

Měření srdečního výdeje (CO; L/min)

- **Indikace:**
  - Výpočet plochy ústí u stenotických vad
  - Výpočet cévních resistencí
  - Výpočet u zkratových vad
- **Metody stanovení CO:** Normální hodnota 4-8L/min.
  - Fickova metoda AV diference
  - Diluční metody (**termodiluce**, barvivová diluce)
  - Angiograficky při ventrikulografii
- **Srdeční index** (CI) *(L/min/m²)* = CO *(L/min)* / plocha těla *(m²)*
  - Normální hodnota 2,5-4 (L/min/m^2)
- **Tepový objem** (SV) (ml/stah) = CO *(L/min)* / srdeční frekvence *(stah/min)*

CO – Fickova metoda

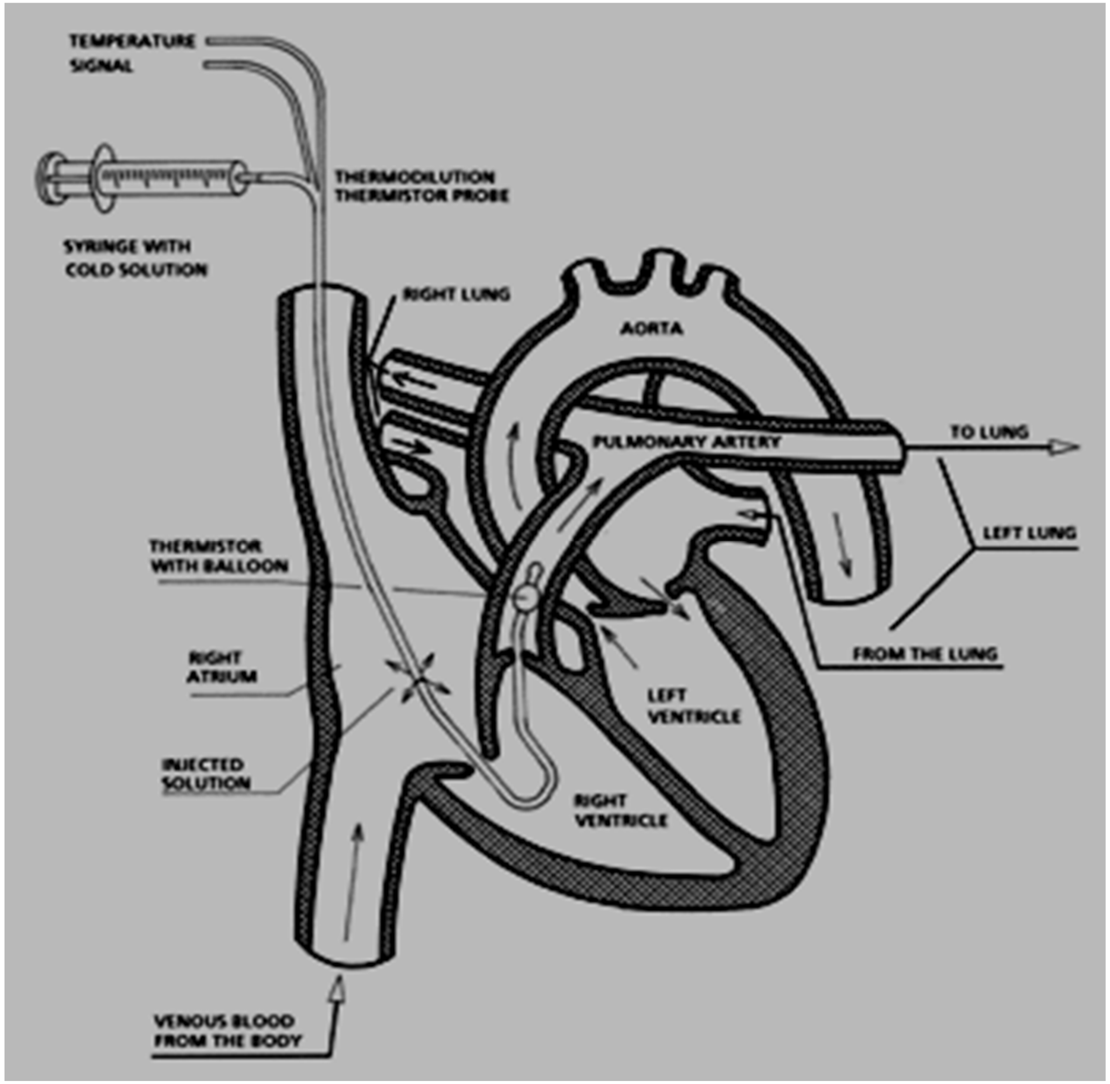
- CO *(L/min)* = spotřeba O_2 *(ml/min)* / AV diference O_2 *(ml/L)*

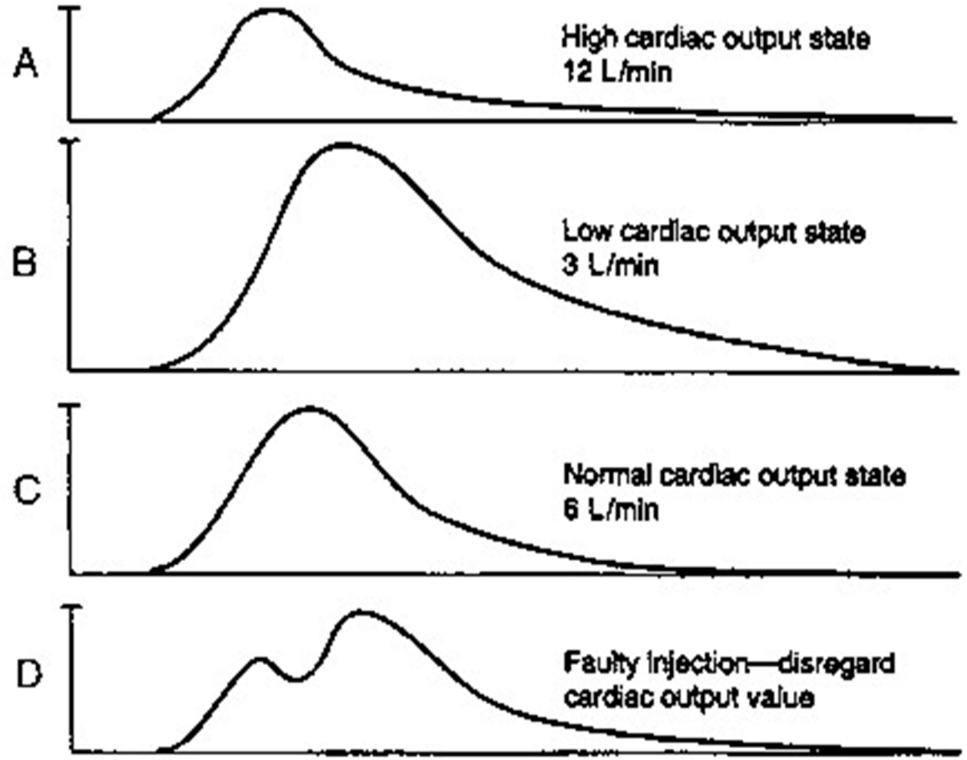
- Spotřeba O_2 *(ml/min):*
  - Přímo měřením dýcháním do vaku *(klaustrofobní)*
  - Odhadem dle tabulek (srdeční frekvence, pohlaví, váha) – chyba až 40% !!!
  - Odhadem 3ml/kg váhy – např. 70kg = 210ml/min
- AV diference O_2 *(ml/L)* = Hb (g/L) x konstanta 1,34 x rozdíl saturace krve O_2 arteriální – žilní

- Příklad: CO=210ml/min / 130 x 1,36 x (0,95-0,65) = 210 / 53 = 3,96 L/min

CO - termodiluce

- Rychlá injekce 10ml FS s pokojovou teplotou do PS a detekce změny teploty termistorem v plicnici. Nespolehlivá metoda u trikuspidální regurgitace, zkratů, nízkého výdeje a arytmií.





Cévní resistence

- Plicní cévní resistence = $(PA_{mean} – LA/PCW_{mean})$ / Qp
  - Normální hodnota je do 2 Wood Units = 160 $dyn \cdot s/cm^5$
- Systémová cévní resistence = $(Ao_{mean} – RA_{mean})$ / Qs
  - Normální hodnota je do 20 Wood Units = 1600 $dyn \cdot s/cm^5$

Oxymetrie – kvantifikace zkratů

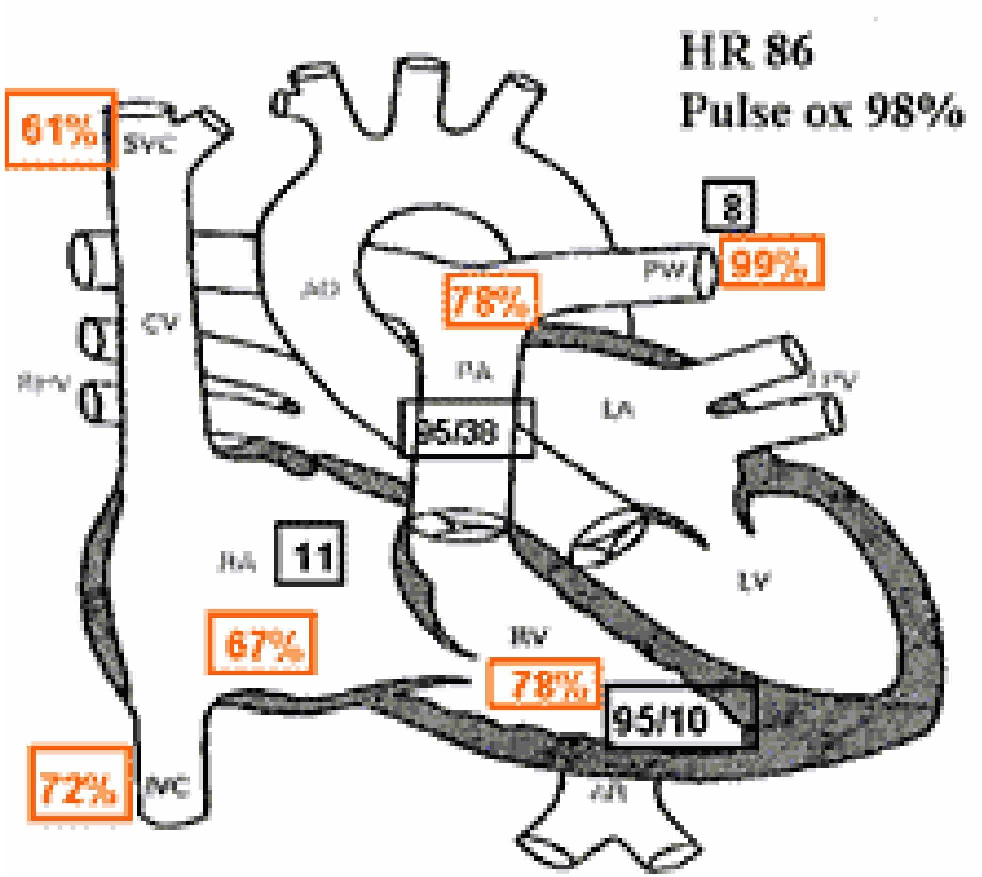
- Průtok plicním řečištěm není stejný jako systémovým řečištěm
- Typický odběr saturací: (PCW, PA, RV, RA, SVC, IVC, aorta) x2
- Technika
  - vždy odsát několik ml krve před odběrem, bez bublin, led
  - rychlé stanovení saturace, včetně iontů a Hb (identické hodnoty)
- Lze detekovat vzestup saturace krve O2, typicky vzestup o více než 7% budí podezření na zkrat
- Smíšená žilní krev MV = (3xSVC + 1xIVC) / 4
  - Saturace krve v IVC je ovlivněna malou desaturací krve v ledvinách

Oxymetrie – kvantifikace zkratů

- Defekt septa síní s L-P zkratem

- $$Qp/Qs = \frac{\dfrac{\cancel{\text{Spotřeba O2}}}{\text{Hb x 1.34 x sat(aorta-PA)}}}{\dfrac{\cancel{\text{Spotřeba O2}}}{\text{Hb x 1.34 x sat(aorta-MV)}}}$$

$$= \frac{\cancel{\text{Hb x 1.34 x}}\ \boxed{\text{sat(aorta-MV)}}}{\cancel{\text{Hb x 1.34 x}}\ \boxed{\text{sat(aorta-PA)}}}$$



Stenotické vady

- Při znalosti průtoku a gradientu lze vypočítat plochu ústí

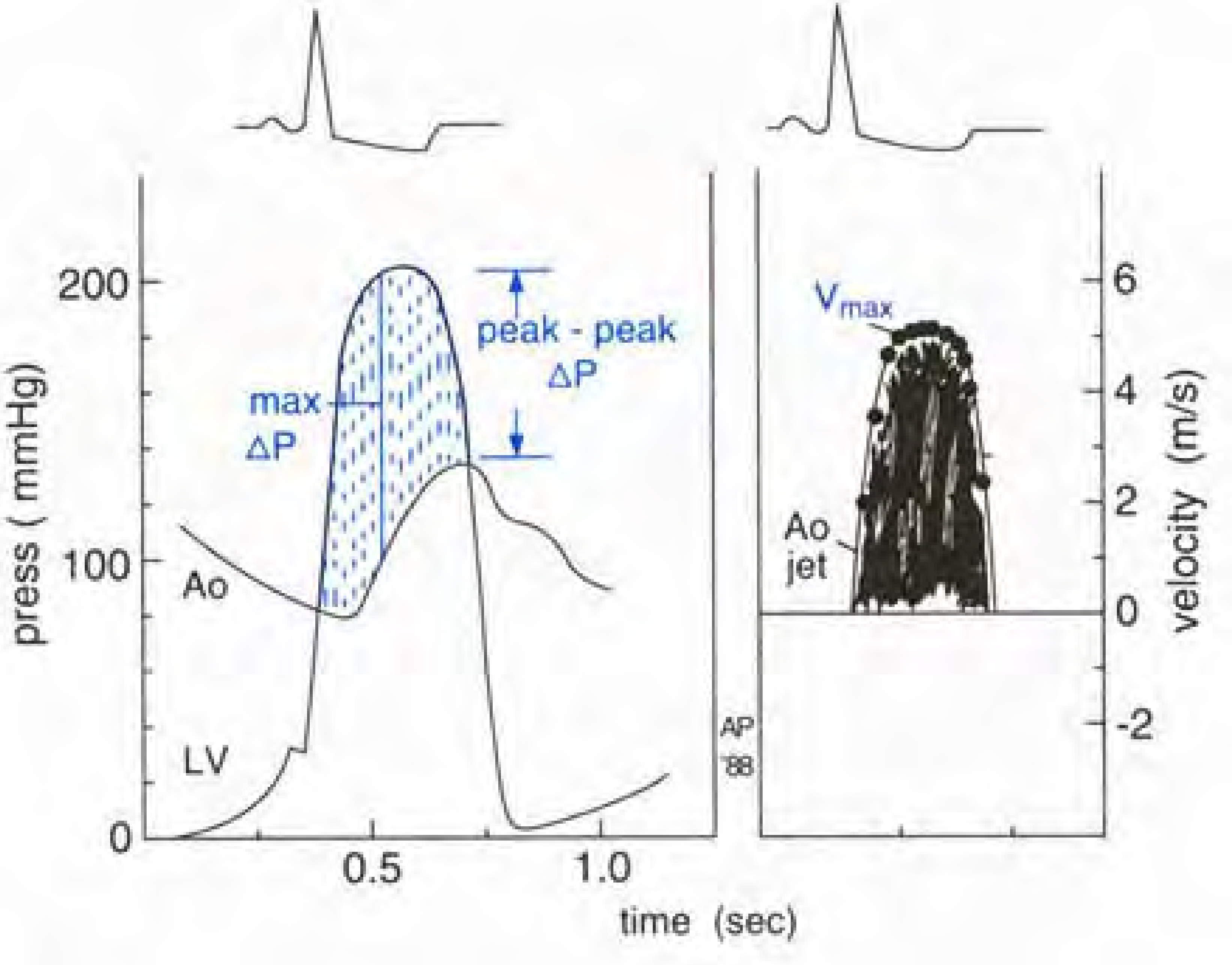
Am Heart J. 1951 Jan;41(1):1-29. GORLIN R, GORLIN SG.

Hydraulic formula for calculation of the area of the stenotic mitral valve, other cardiac valves, and central circulatory shunts.

- **AVA = CO / 44.3 x HR x ejekční perioda x $\sqrt{\text{střední gradient}}$**
- Jednoduchá kontrola – Hakki formule AVA=CO / $\sqrt{\text{peak grad.}}$

- **Chyba v CO má matematicky větší vliv než chyba v gradientu**
- **Pro Mitrální Stenosu se přidává do jmenovatele koeficient 0,85**
- **Pro trikuspidální a pulmonální chlopeň se používají pouze gradienty, nikoliv Gorlinova formule**

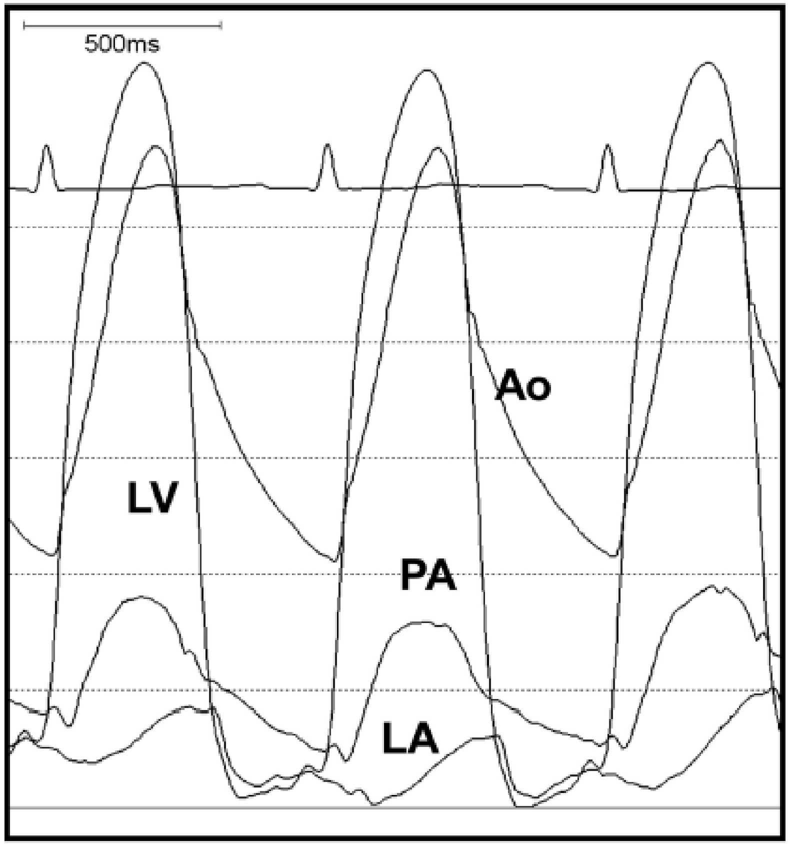
Aortální stenosa



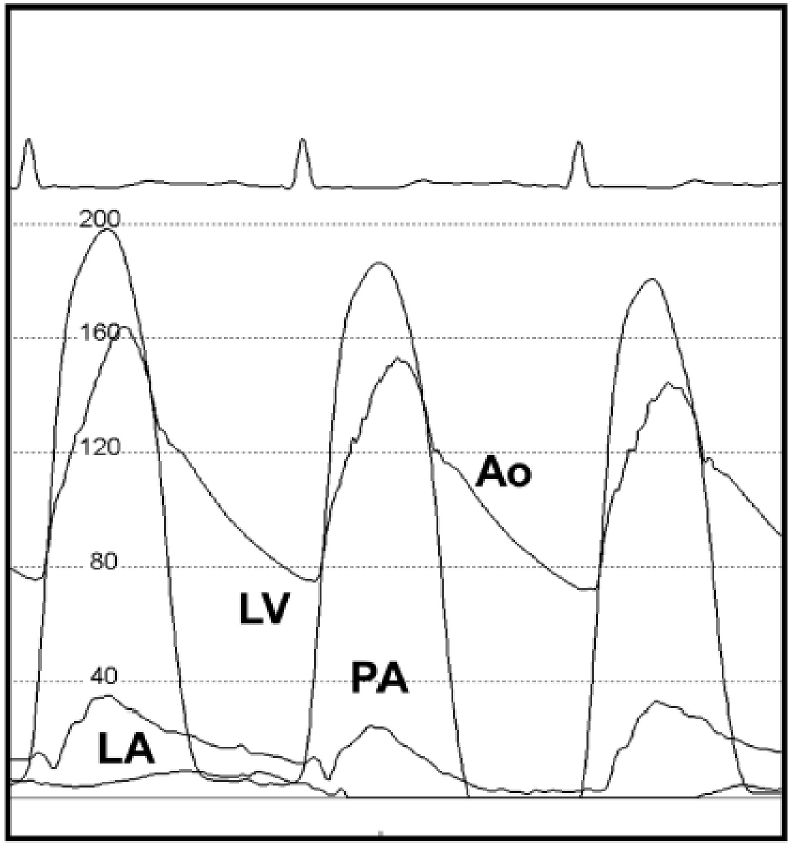
Aortální stenosa - chyby

Srdeční výdej a gradient musí být měřeny současně !!

CO = 4,1 L/min ← CHYBA → CO = 4,9 L/min



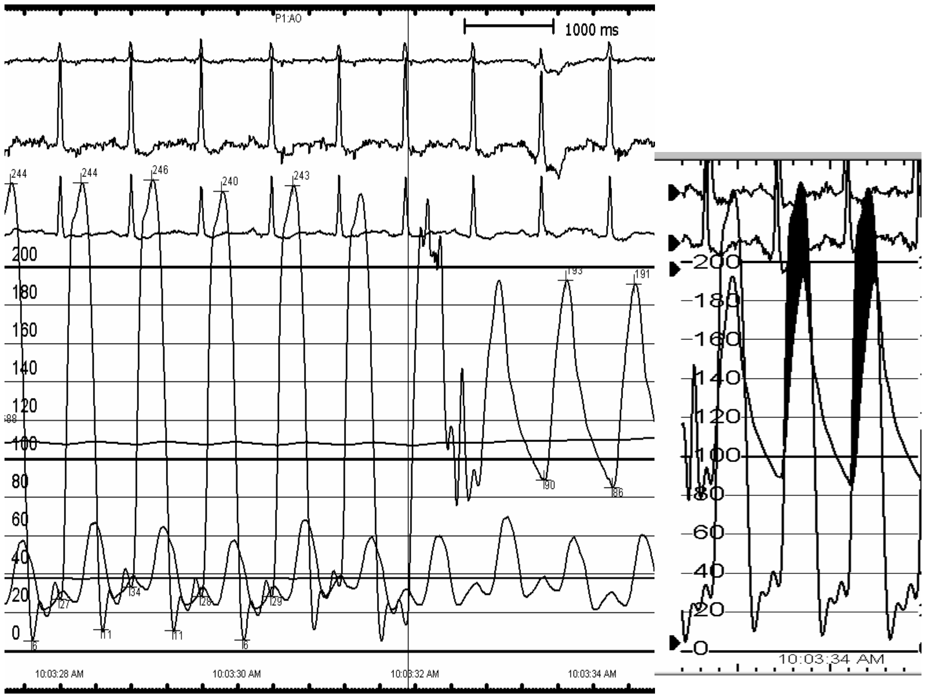
Gradient 32 mm Hg
AVA 0.9 cm²



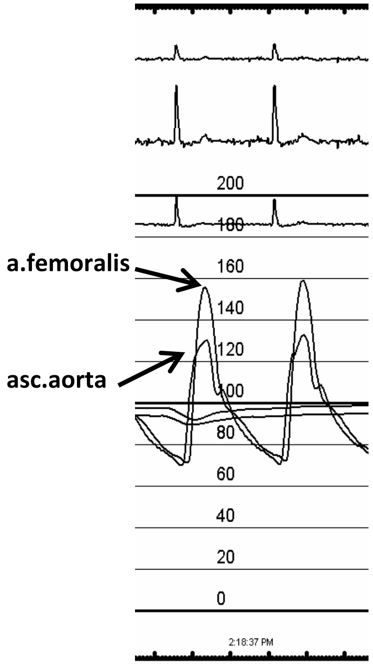
Gradient 45 mm Hg
AVA 0.9 cm²

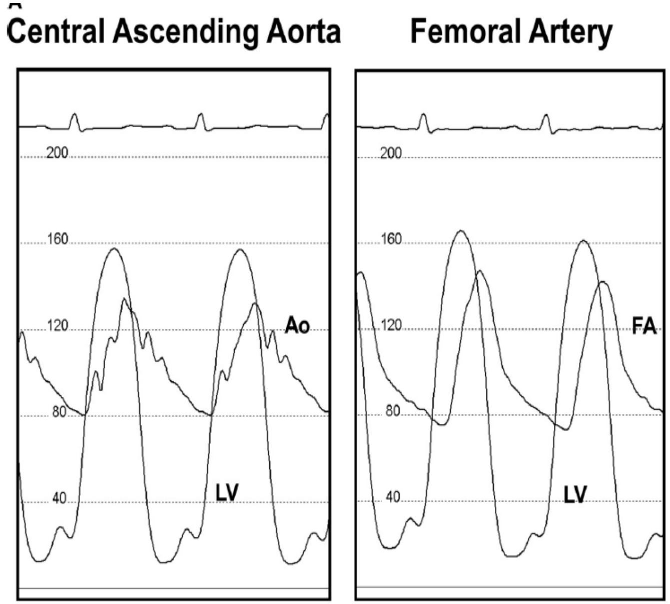
Aortální stenosa - chyby

Pravidelný SR, pull-back je OK

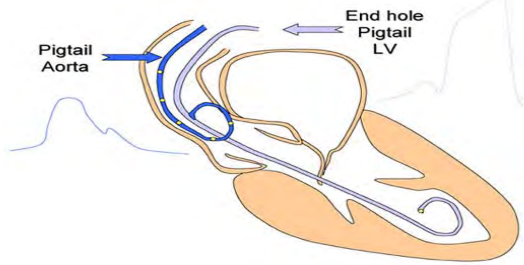


Arytmie, nebo četné KES (katetr v LK)



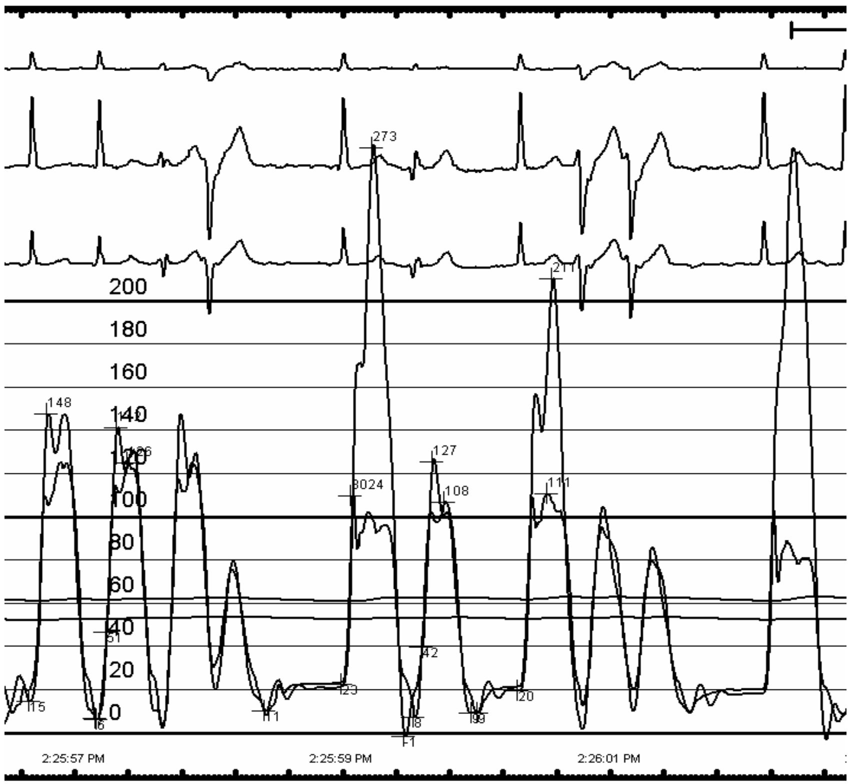


<u>Simultánní</u> měření tlaku v LK a <u>asc.aortě</u>

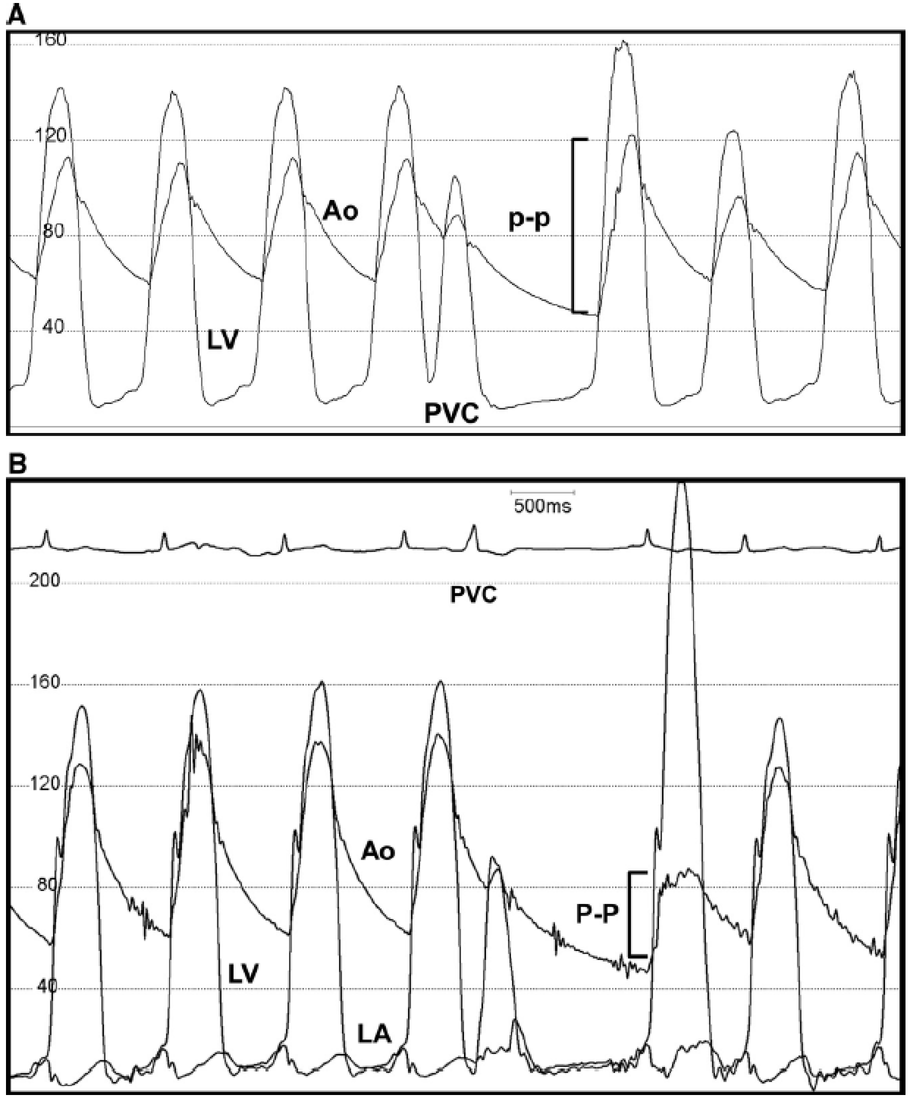


Ao Stenosa versus HOCM

- Rozlišení ECHO KG obtížné, jety se míchají



Průkaz gradientu mezi hrotem LK a LVOT



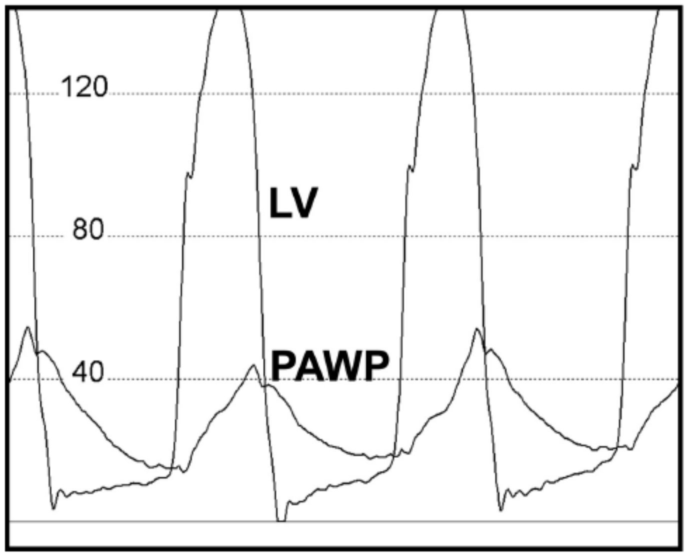
Ao Stenosa

HOCM

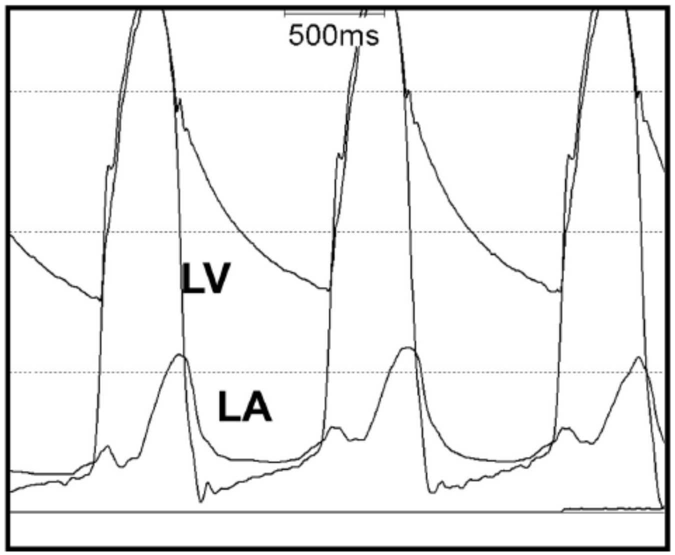
Mitrální stenosa

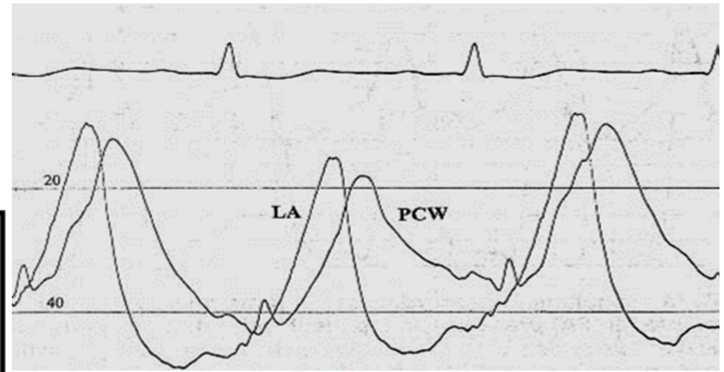
- **<u>Echokardiografie je velmi přesná a spolehlivá</u>**
- Potřeba hemodynamiky je spíše k **posouzení tíže a typu plicní hypertenze**, zvláště při nesouladu mezi ECHO KG a klinikou
- Měření **gradientu mezi tlakem v LK a PCW je zatíženo chybou** (posun a tlumení)

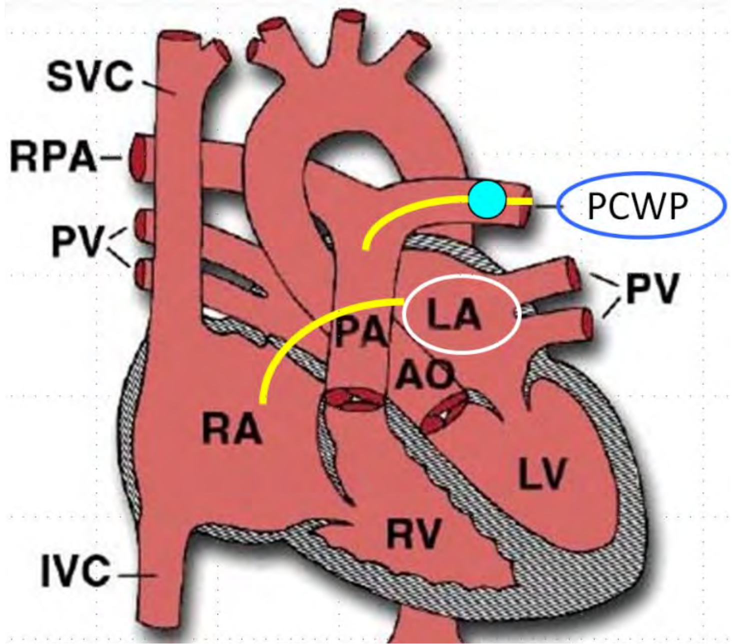
Mean Mitral Gradient 15 mm Hg



Mean Mitral Gradient 6 mm Hg

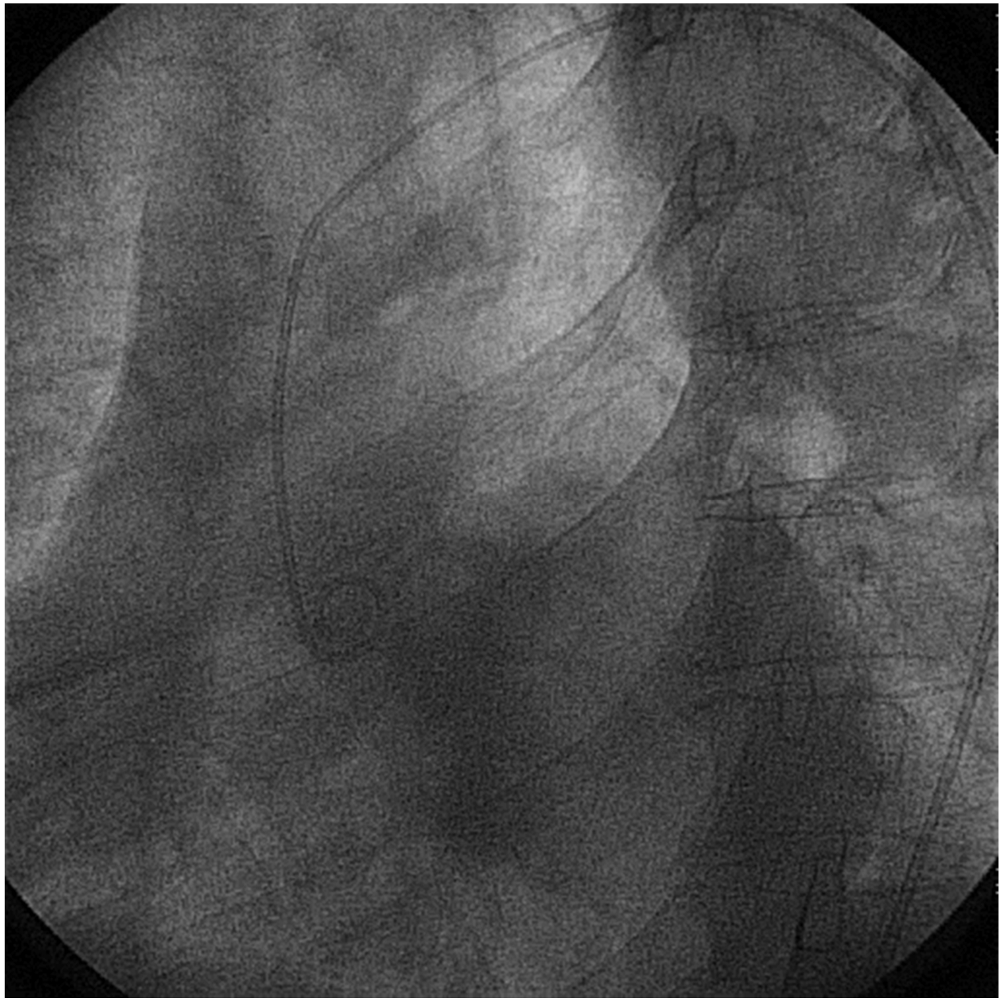






Regurgitační vady

- Angiograficky nehodnotíme „jety“, ale densitu KL
- Nutné podat dostatečné množství KL a zvolit vhodnou projekci

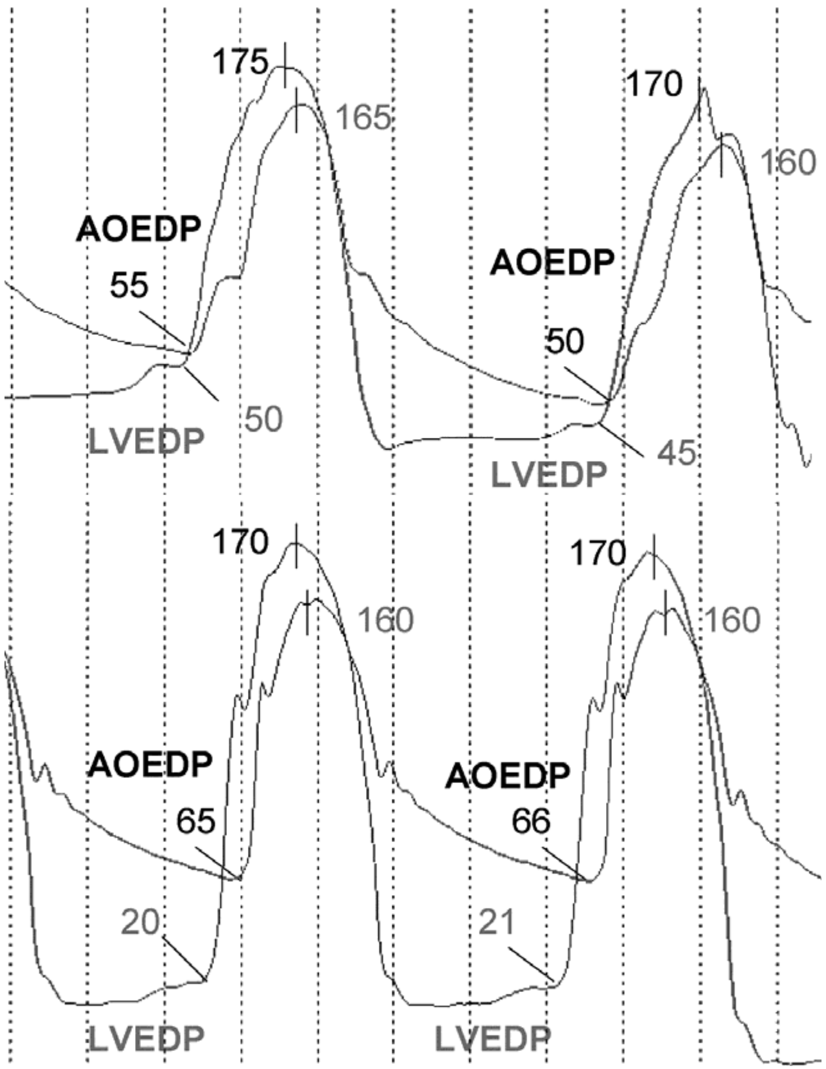


Aortální regurgitace

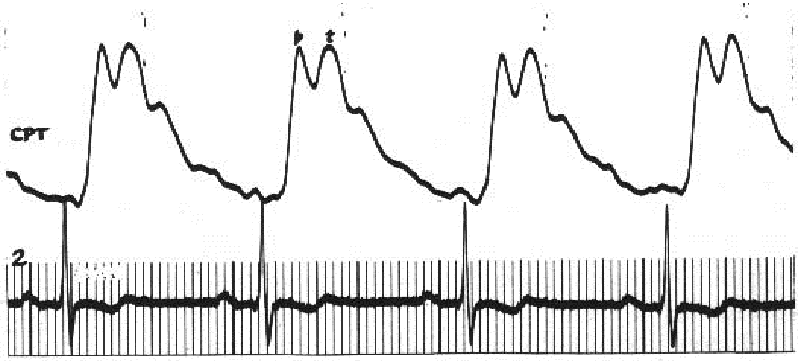
- Rozdíl systolického a end-diastolického tlaku v aortě nad 100mmHg
- Index Aortální Regurgitace

AoR Index = (AoEDP – LVEDP) / Ao systolic

Hodnota nad 25 značí méně významnou vadu

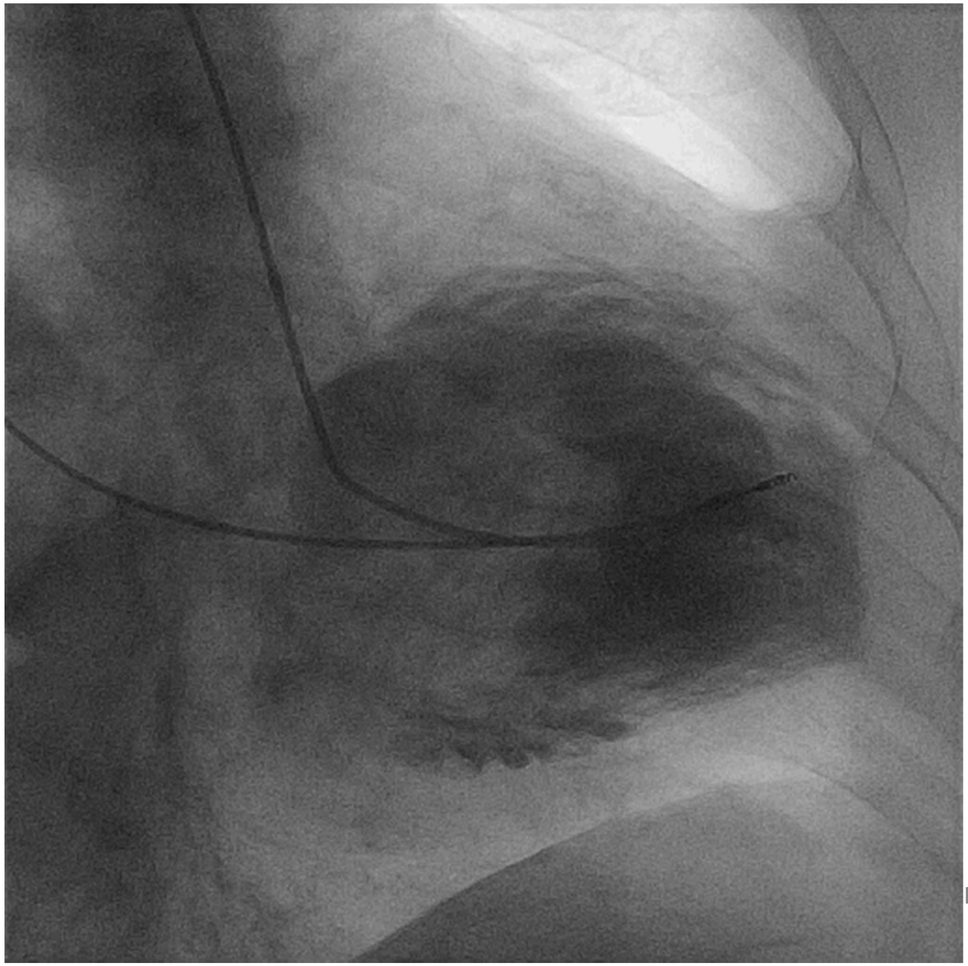


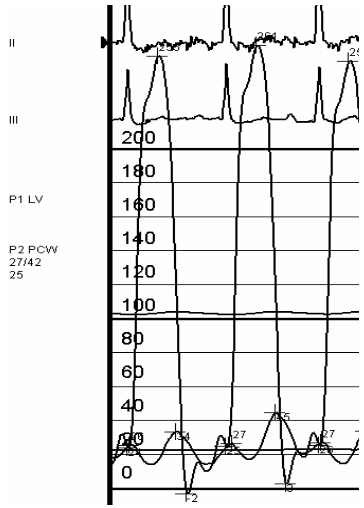
Pulsus bisferiens - HOCM nebo AoReg

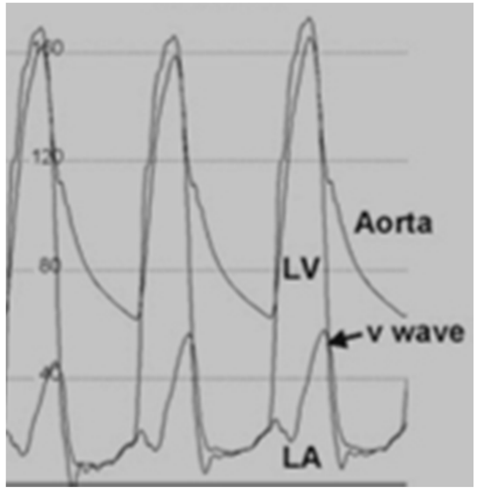


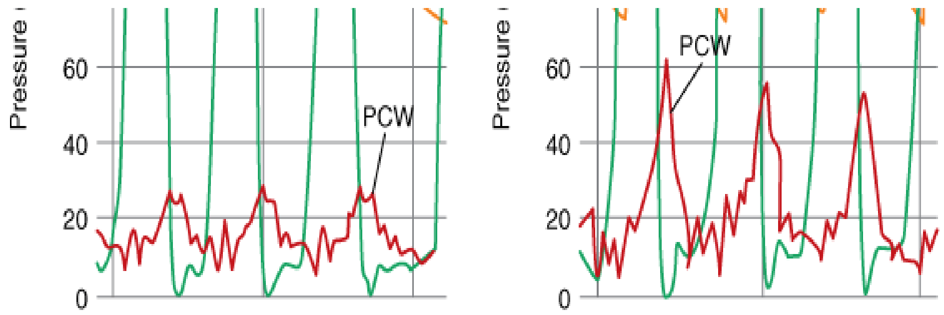
Mitrální regurgitace

- Vysoká vlna „v“ v zaklínění – definována jako ≥2 x vyšší než střední tlak v zaklínění (LS). Není příliš spolehlivý parametr.
- Postkapilární plicní hypertenze





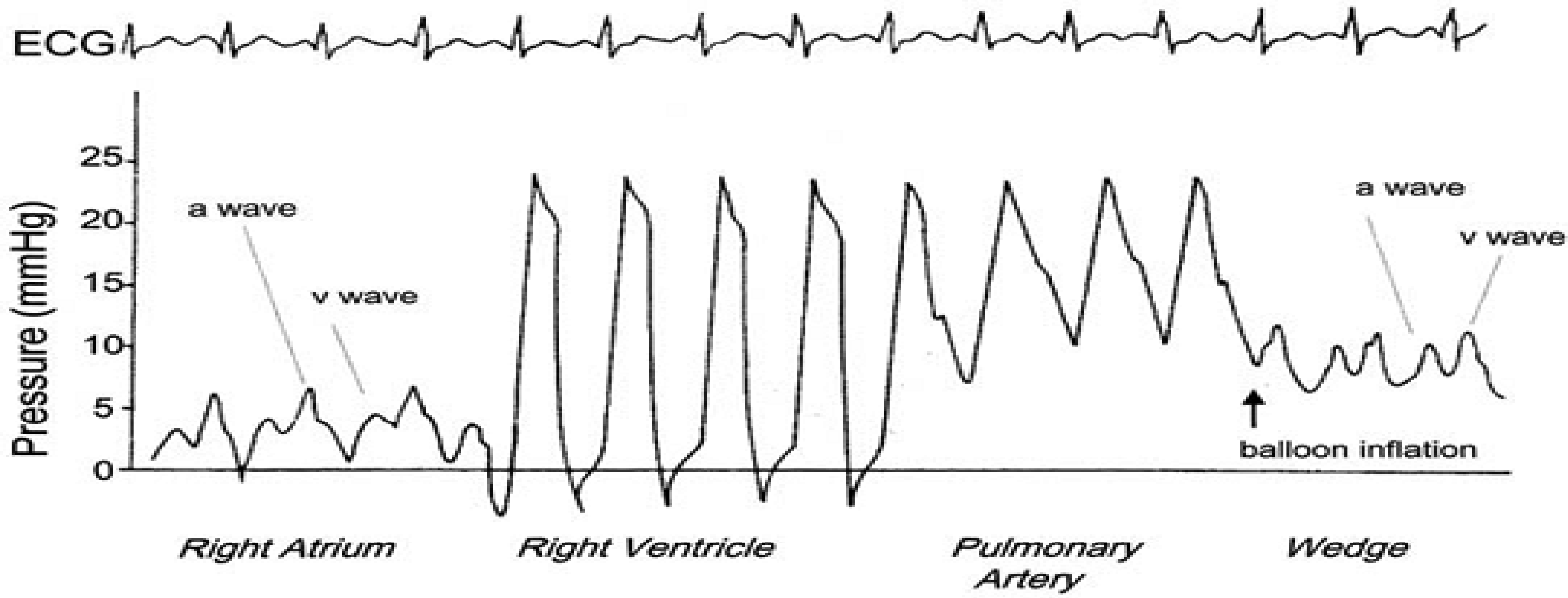




Source: Fauci AS, Kasper DL, Braunwald E, Hauser SL, Longo DL, Jameson JL, Loscalzo J: *Harrison's Principles of Internal Medicine*, 17th Edition: http://www.accessmedicine.com

Plicní hypertenze

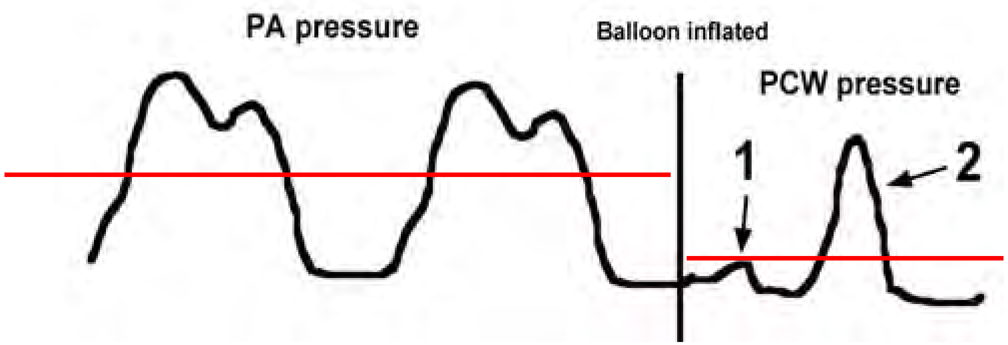
- Obecně – známka horší prognózy mnoha diagnóz



Tabulka 3 Stupně závažnosti plicní hypertenze

	Lehká	*Střední*	*Těžká*
Střední tlak v plicnici (mm Hg)	26-35	36-45	>45
Systolický tlak v plicnici (mm Hg)	36-45	46-60	>60

Plicní hypertenze



Transpulmonální gradient

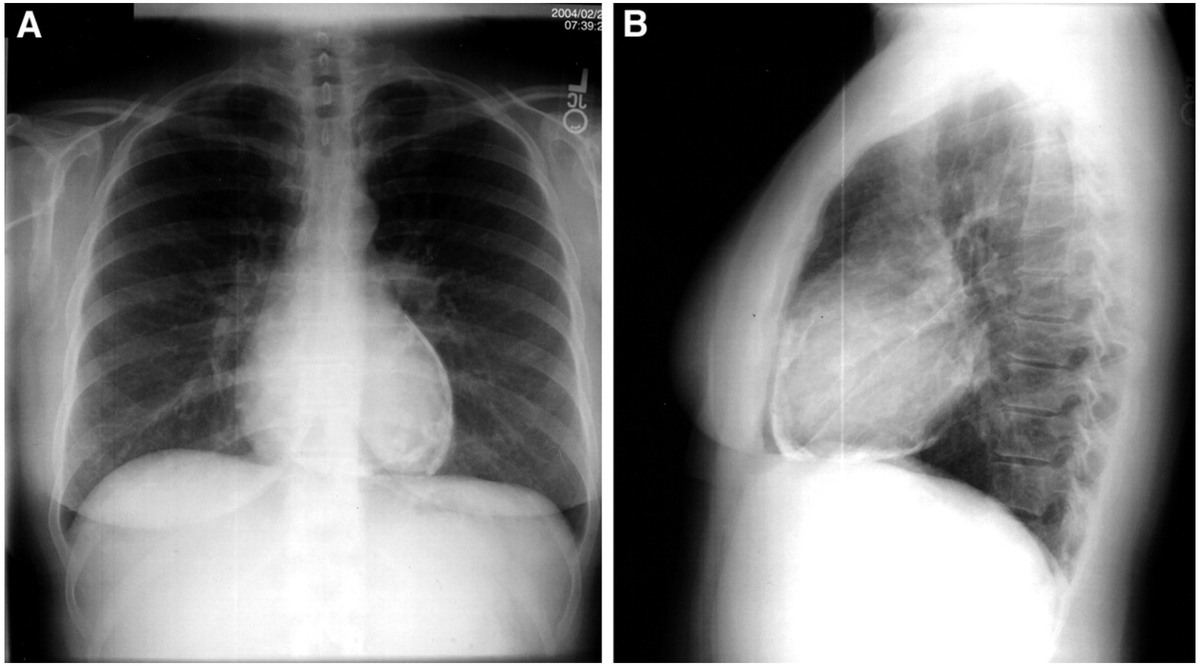
PA_{mean} - PCW_{mean}

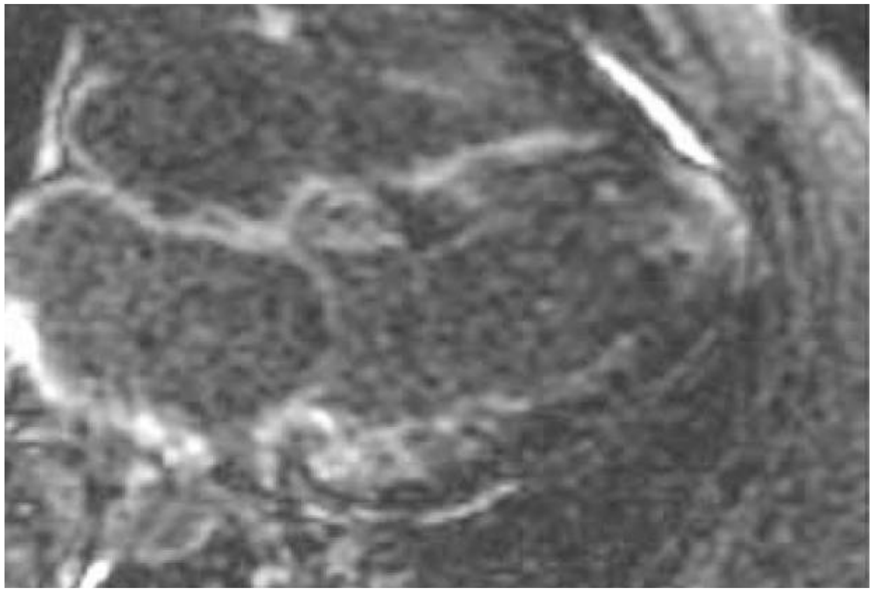
Tabulka 1. Hemodynamické rozdělení plicní hypertenze (PH)(střední tlak v plicnici 25mmHg a více)

		Tlak v zaklínění (mmHg)	Transpulmonální gradient	Srdeční výdej	Klinická skupina
Prekapilární PH		≤15		snížený či normální	1,3,4,5
Postkapilární PH		>15			
	pasivní		≤12	snížený či normální	2
	reaktivní, dříve smíšená PH		>12	snížený či normální	2
Hyperkinetická		≤15	>10	zvýšený (plicní průtok)	část 1.4

Konstrikce versus Restrikce

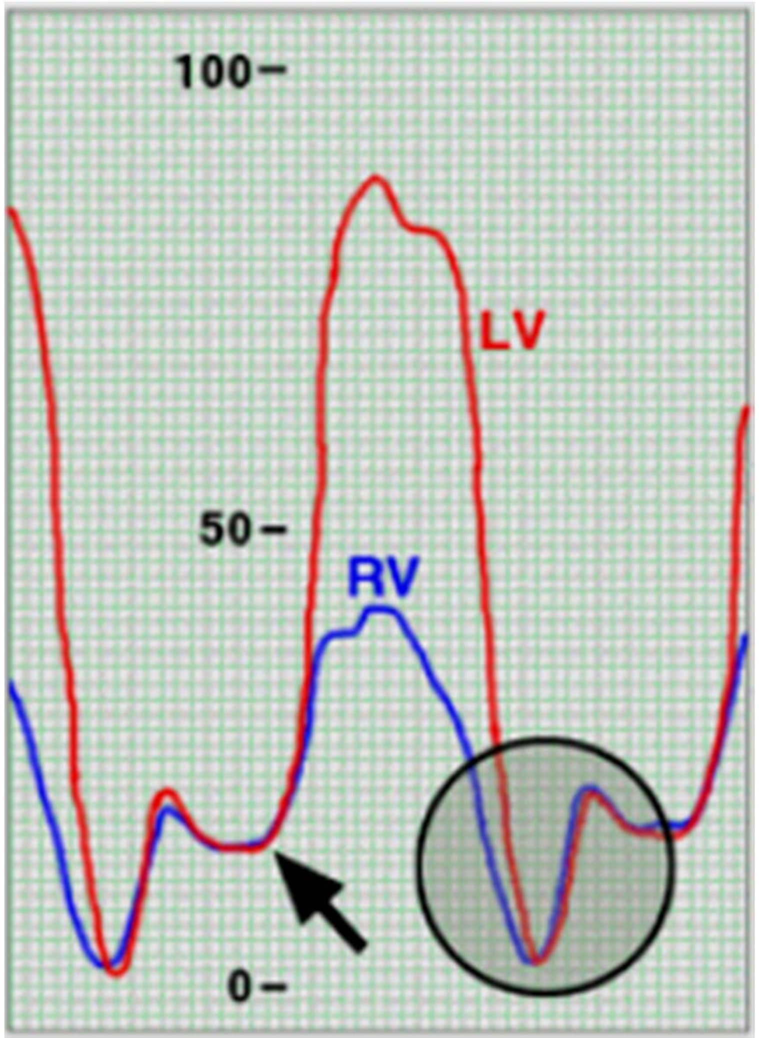
- Pravostranné srdeční selhání u pacienta s normální EF LK
- Přibývá pacientů po radiaci hrudníku a chemoterapii a pacientů po sternotomii
- Moderní zobrazovací metody mohou významně pomoci – např. kalcifikace perikardu na angiografii či CT, typický nález na MRI u amyloidosy



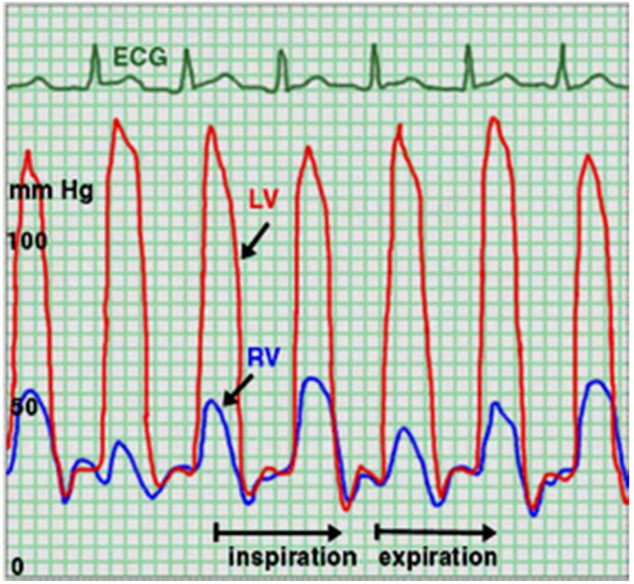


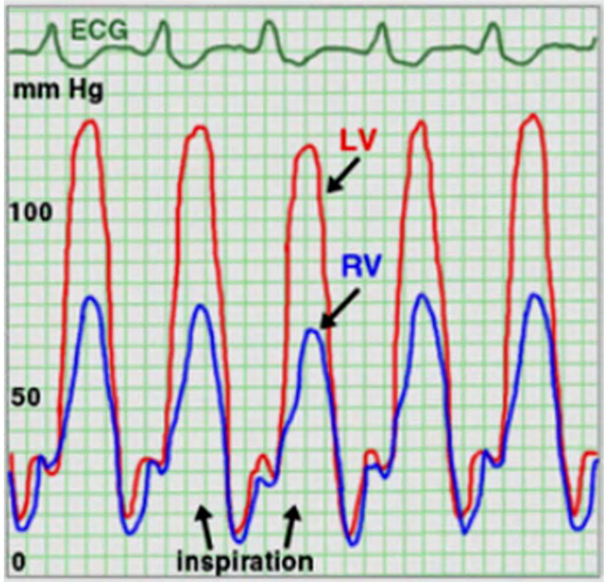
Konstrikce versus Restrikce

- Dip a plateau
- Ekvalizace tlaků v LK a PK v diastole
- U pacientů vyšetřovaných ve stabilním stavu s normálním tlakem v PS může být nutná objemová zátěž k detekci těchto znaků



Konstrikce versus Restrikce

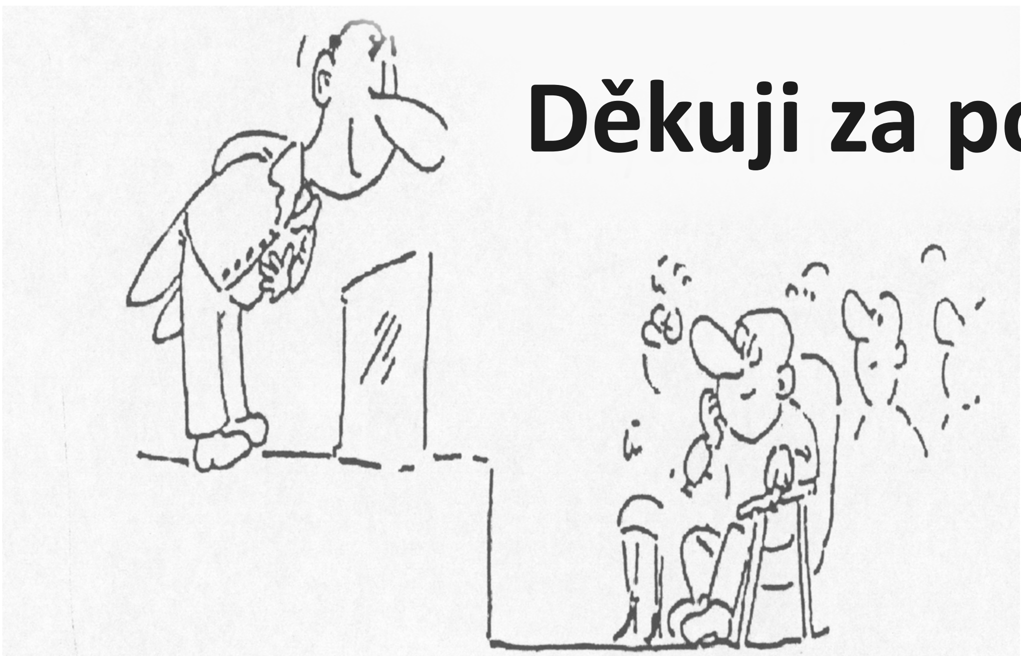




	Constrictive Pericarditis	Restrictive Cardiomyopathy
End diastolic pressure equalization (LVED-RVED)	$\leq$ 5 mm Hg	> 5 mm Hg
Pulmonary artery pressure	< 55 mm Hg	> 55 mm Hg
RVEDP / RVSP	> 1/3	$\leq$ 1/3
Dip-plateau morphology	LV rapid filling wave > 7 mm Hg	LV rapid filling wave $\leq$ 7 mm Hg

Závěr

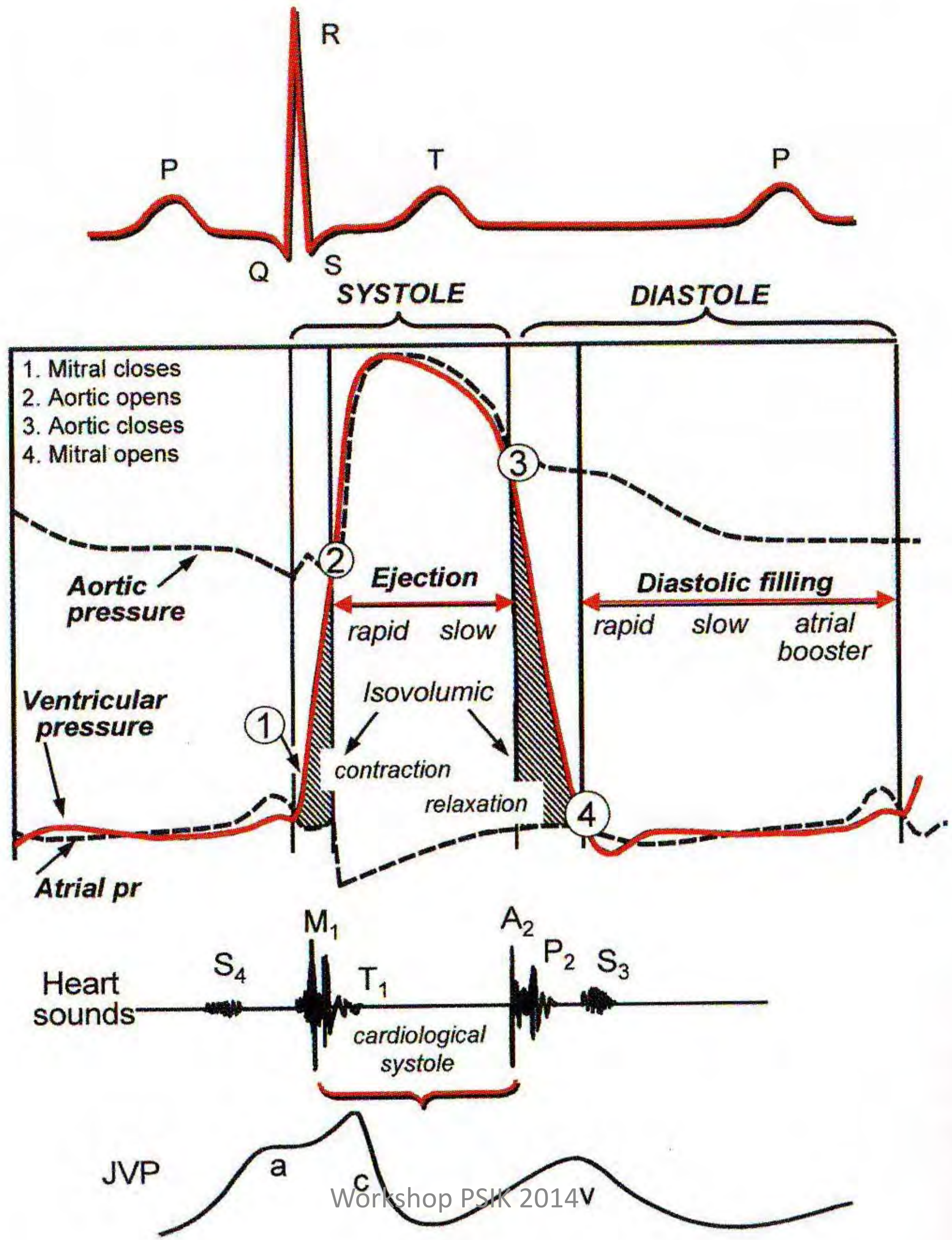
- Hemodynamické vyšetření v katetrizační laboratoři v 21. století není nikdy rutinní – diagnosa u typických a jednoduchých nálezů je stanovena pomocí neinvazivních metod a invazivní vyšetření je indikováno pouze u komplikovaných stavů
- Individuální přístup a precizní technika je zásadní



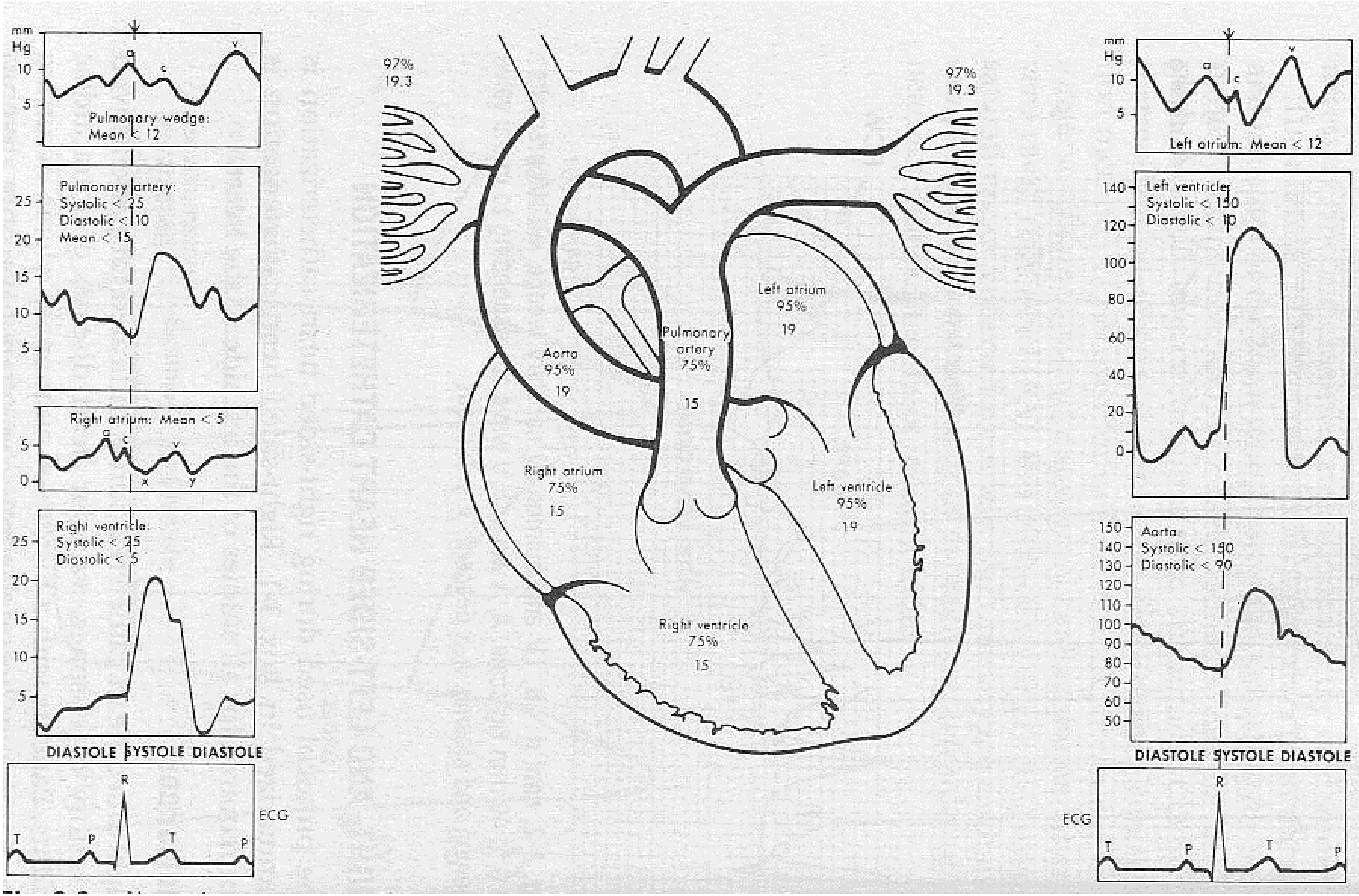
Děkuji za pozornost

Zdroje

- **Databáze hemodynamických vyšetření, Oddělení invazivní kardiologie, Fakultní nemocnice Královské Vinohrady**
- **Základy invazivní hemodynamiky, Jiří Widimský, Petr Widimský, Triton**
- **Morton J Kern, The Cardiac Catheterization Handbook, Mosby**
- **Hemodynamics in the Cardiac Catheterization Laboratory of the 21st Century, Nishimura and Carabello, *Circulation. 2012;125:2138-2150***
- **Hemodynamic Principles, Alan Keith *Berger*, MD. Divisions of Cardiology and Epidemiology. University of Minnesota. Minneapolis**
- http://www.google.cz/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CC0QFjAA&url=http%3A%2F%2Fwww.med.umn.edu%2Fintcardio%2Fcurriculum%2Fmodules%2FHemodynamic%2FHemodynamic_files%2FHemodynamic.ppt&ei=BzWVUt28J4KFhQfWqIHoAw&usg=AFQjCNHYBVT02dOen1wQrCc4egMVcoSQkg



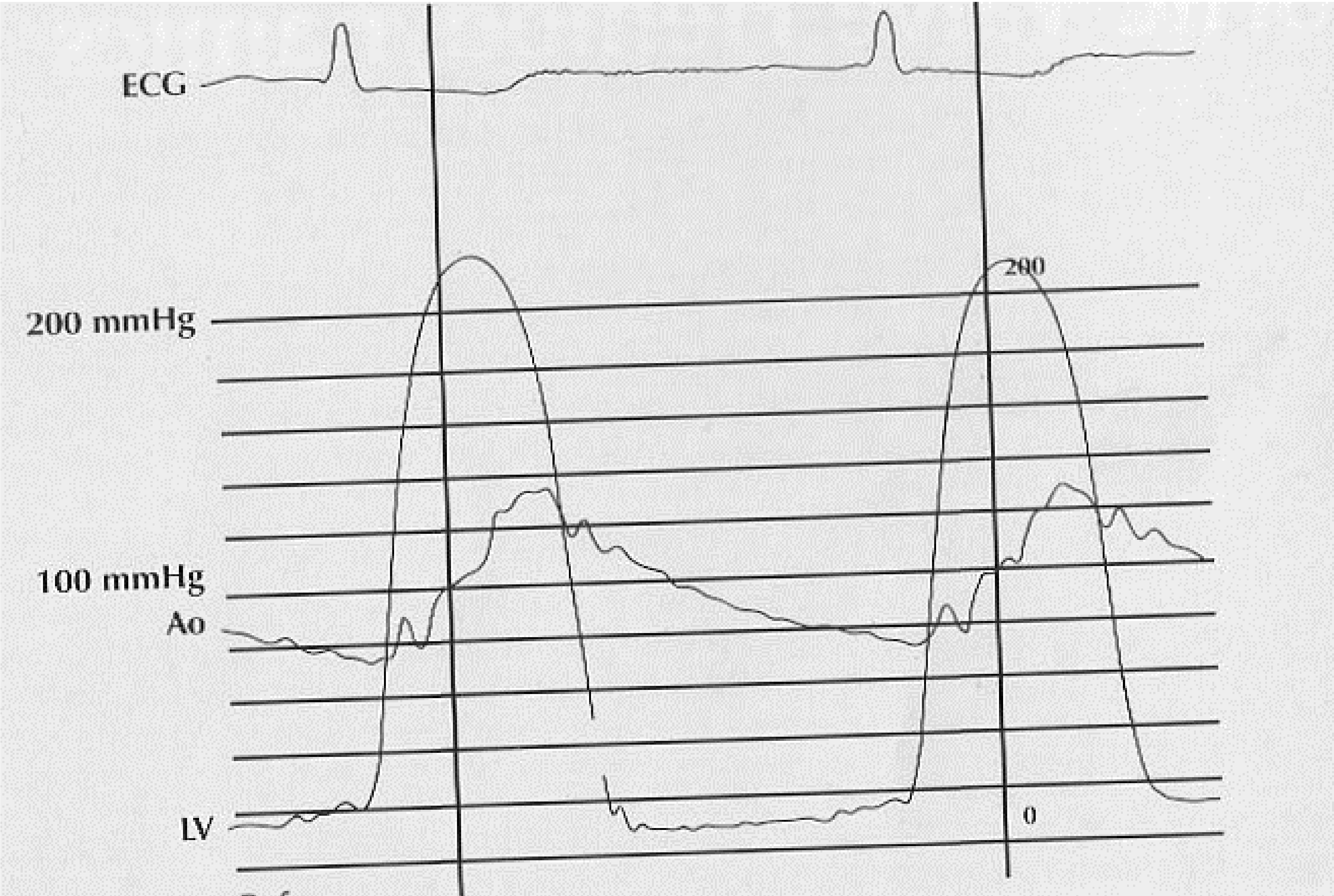
R
P
T
P
Q
S
SYSTOLE
DIASTOLE
1. Mitral closes
2. Aortic opens
3. Aortic closes
4. Mitral opens
Aortic pressure
Ejection
rapid slow
Diastolic filling
rapid slow atrial booster
Isovolumic
contraction
relaxation
Ventricular pressure
Atrial pr
Heart sounds
S_4
M_1
T_1
A_2
P_2
S_3
cardiological systole
JVP
a
c
v



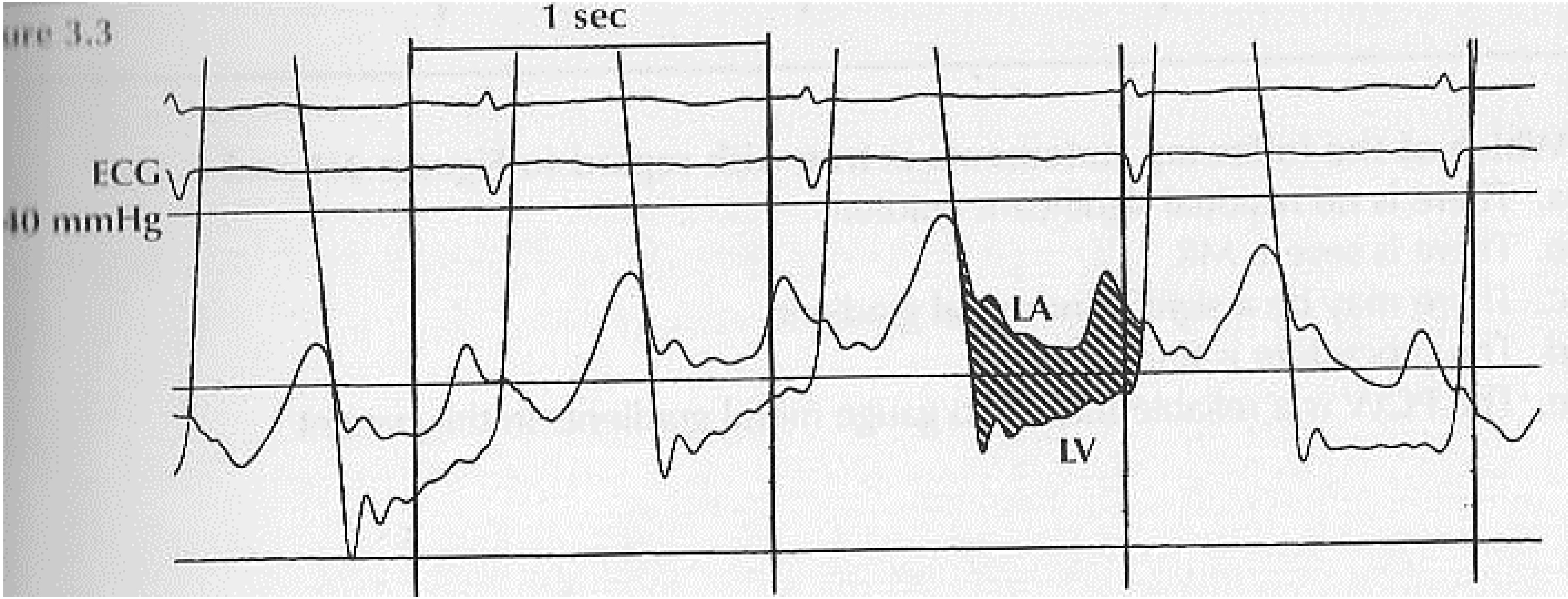
mm Hg
Pulmonary wedge: Mean < 12
Pulmonary artery: Systolic < 25 Diastolic < 10 Mean < 15
Right atrium: Mean < 5
Right ventricle: Systolic < 25 Diastolic < 5
DIASTOLE SYSTOLE DIASTOLE
ECG
97% 19.3
97% 19.3
Left atrium 95% 19
Pulmonary artery 75% 15
Aorta 95% 19
Right atrium 75% 15
Left ventricle 95% 19
Right ventricle 75% 15
mm Hg
Left atrium: Mean < 12
Left ventricle: Systolic < 150 Diastolic < 10
Aorta: Systolic < 150 Diastolic < 90
DIASTOLE SYSTOLE DIASTOLE
ECG

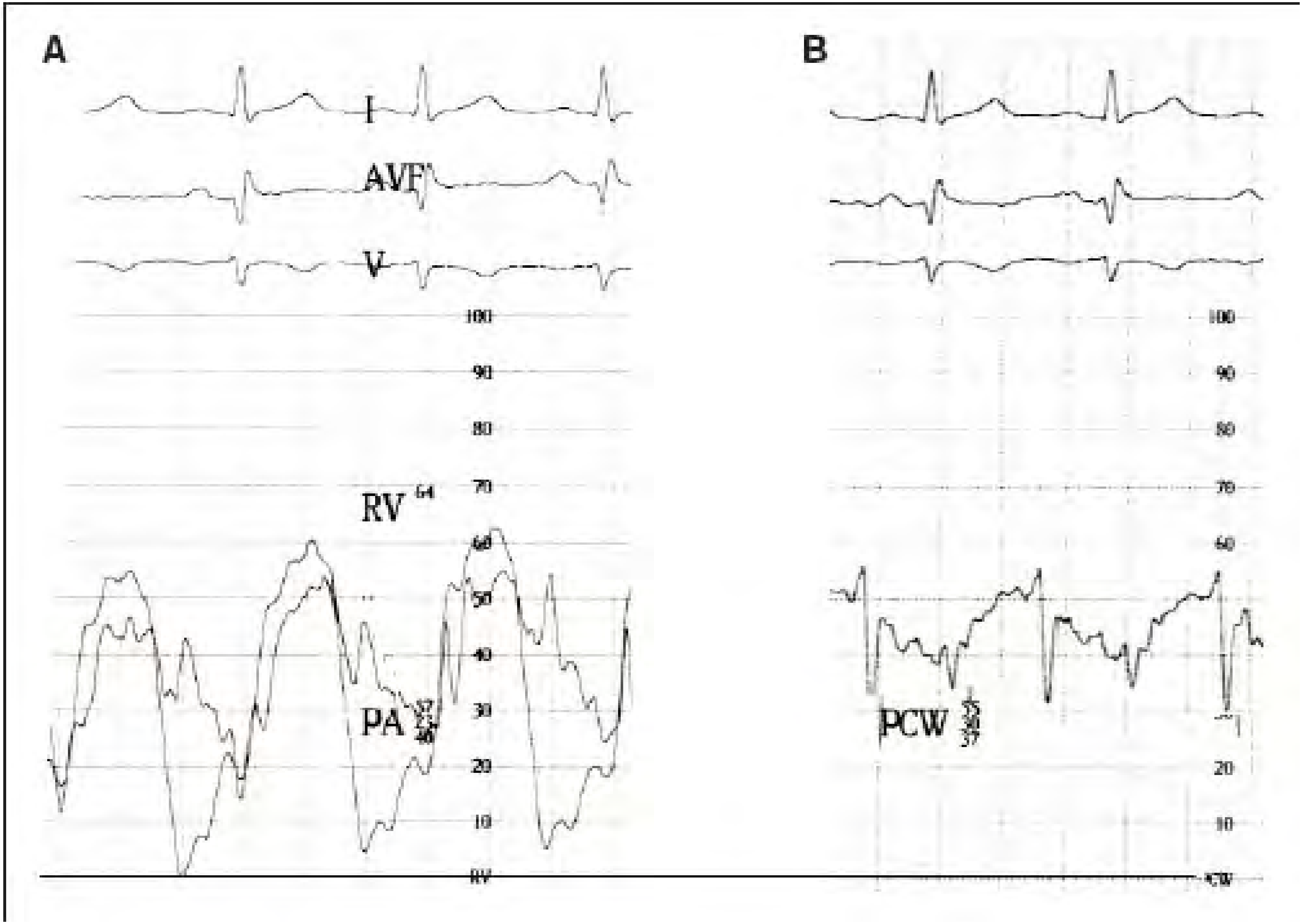
CASES

- Study range
- Synchronise with ECG
- Usually name of chamber is written


ECG
200 mmHg
100 mmHg
Ao
LV
200
0


ECG
200 mmHg
Ao
LV


ure 3.3
1 sec
ECG
40 mmHg
LA
LV



A
I
AVF
V
RV 64
PA 57 23 40
100
90
80
70
60
50
40
30
20
10
RV
B
PCW
100
90
80
70
60
20
10

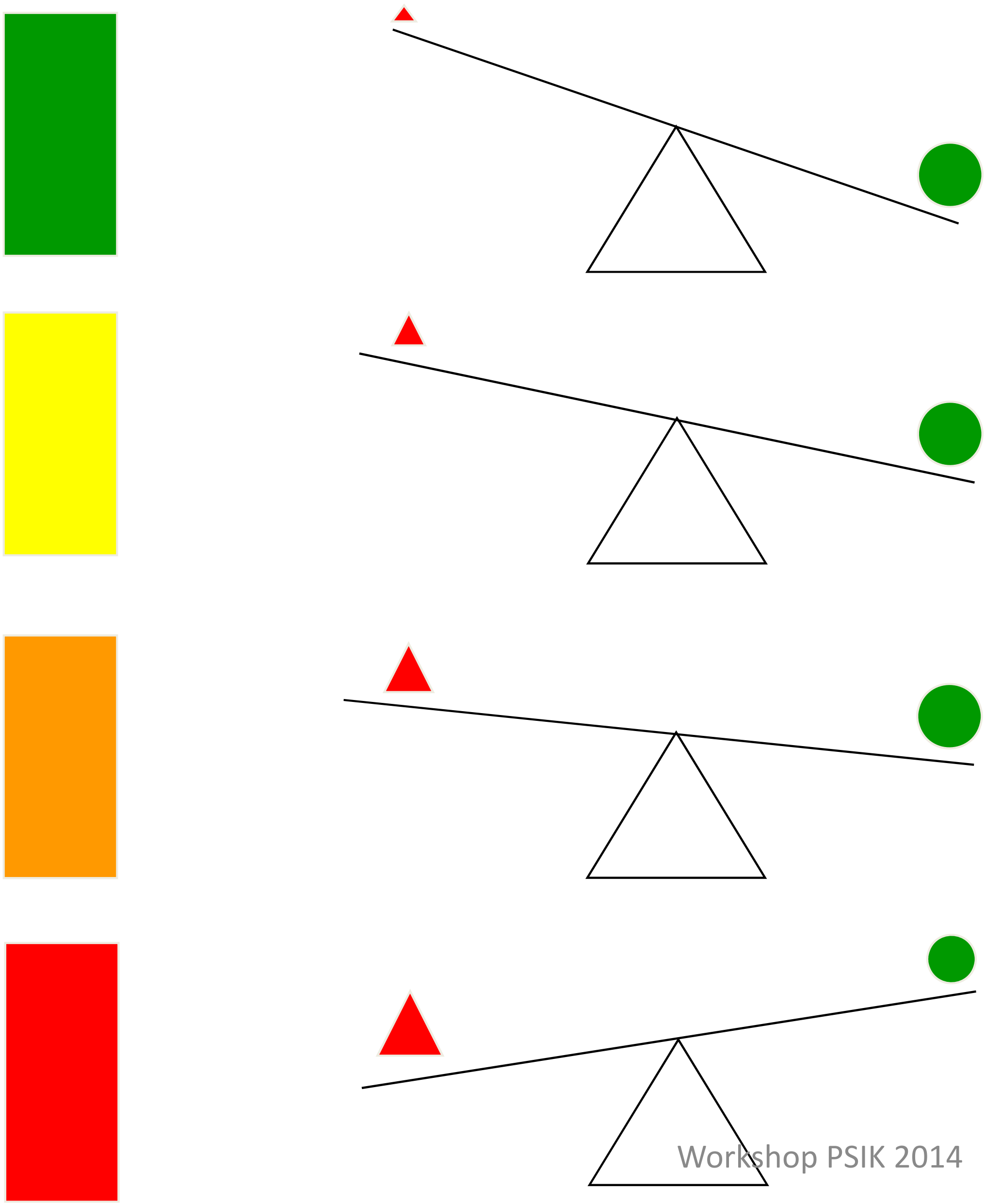
Cardiac Output

- 5L/min. and more
- Indexed to BSA – over 2.5L/min/m2
- Vascular resistence
- Systemic resistence – Ao-RA/CO
- Pulmonary vascular resistence–PA-LA/CO
- Shunt calculation

Complications of Coronary Angiography

- Death 0.1%
- Neurological event 0.1%
- Arrhythmias(DC or pacing) 0.3%
- Local vascular problems 1.6%
- Vasovagal reactions 2.1%
- Allergies 2.0%
- Air embolism
- Contrast nephropathy

Risk vs Benefit:
The code of appropriateness



B>>>R

I (appropriate indication)

B>>R

IIa (probably appropriate)

B≥R

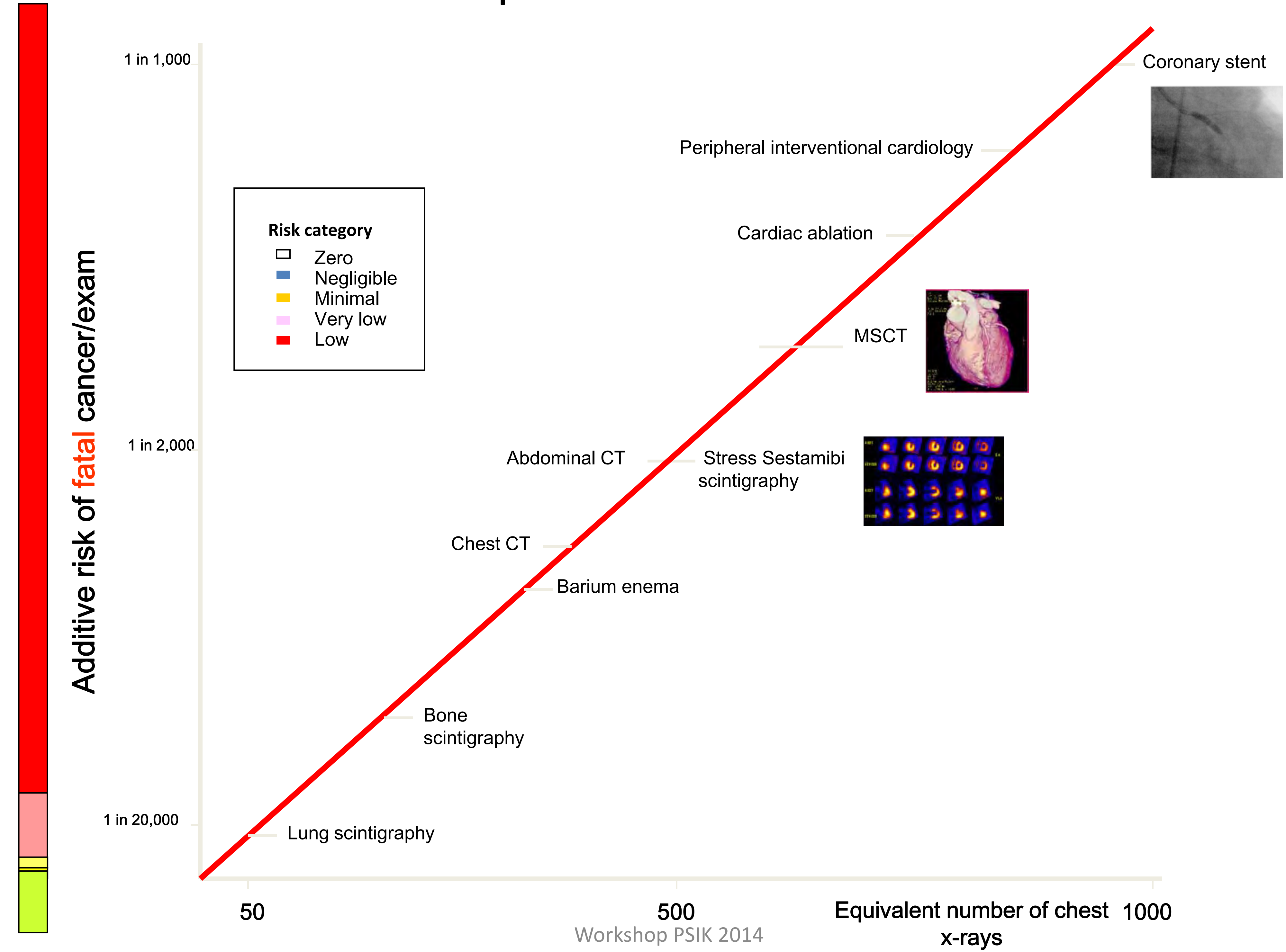
IIb (possibly appropriate)

R≥B

III (inappropriate)

AHA-ACC-ESC Guidelines 2007

Informed consent: How to escape from a communication Inferno

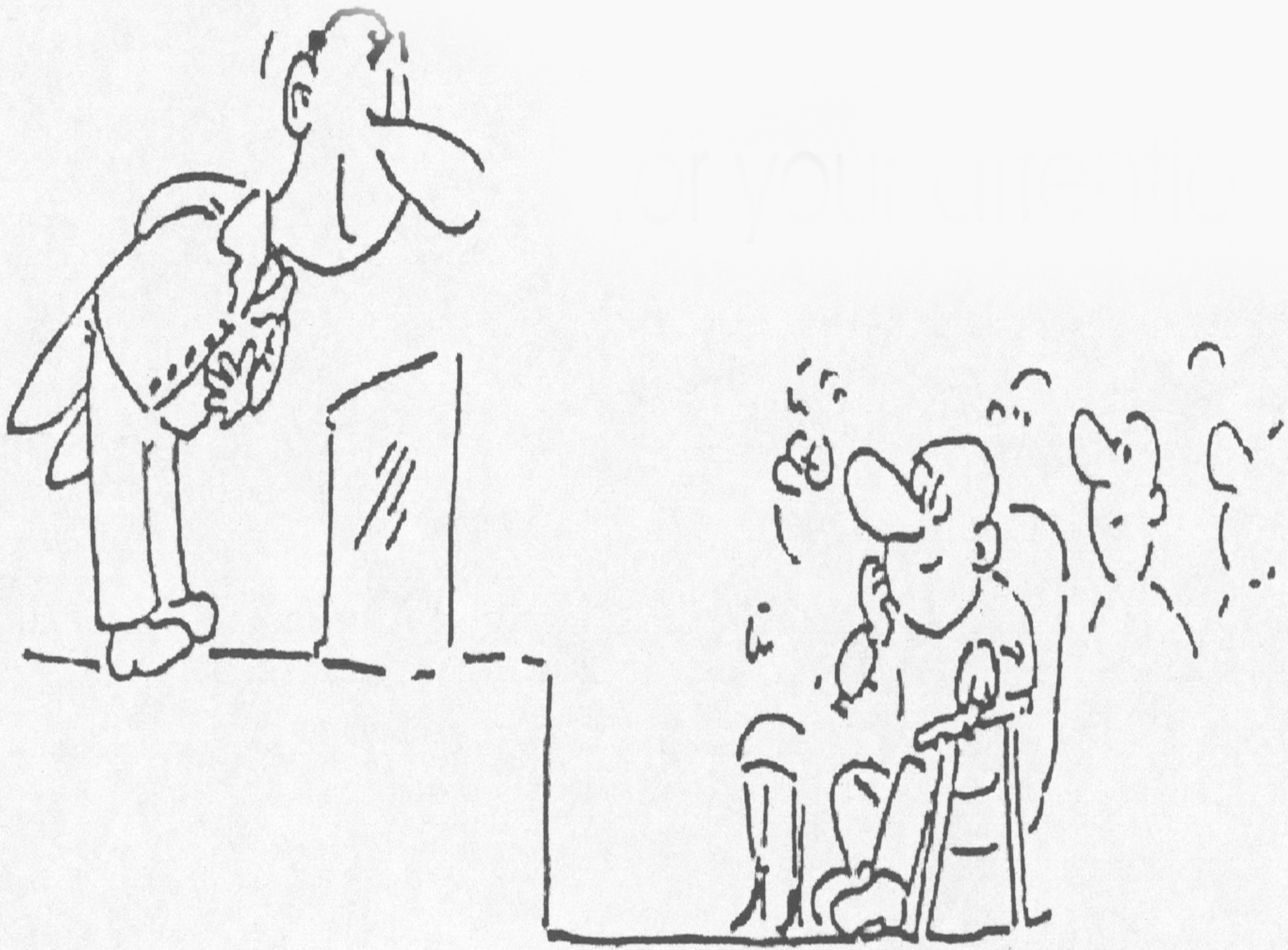


Picano E. BMJ, October 9, 2004

“Free of radiation”:
population perspective

- Stress perfusion imaging (Brindis RG, JACC 2005):
  - 10 million /year in US
- Average dose per exam (Thompson RC, J Nucl Med, 2006):
  - 1000 chest x-rays (500 to 1600)
- Risk per exam (BEIR VII, 2005):
  - 1 cancer in 500
- **Population risk: 20,000 cancer/year**

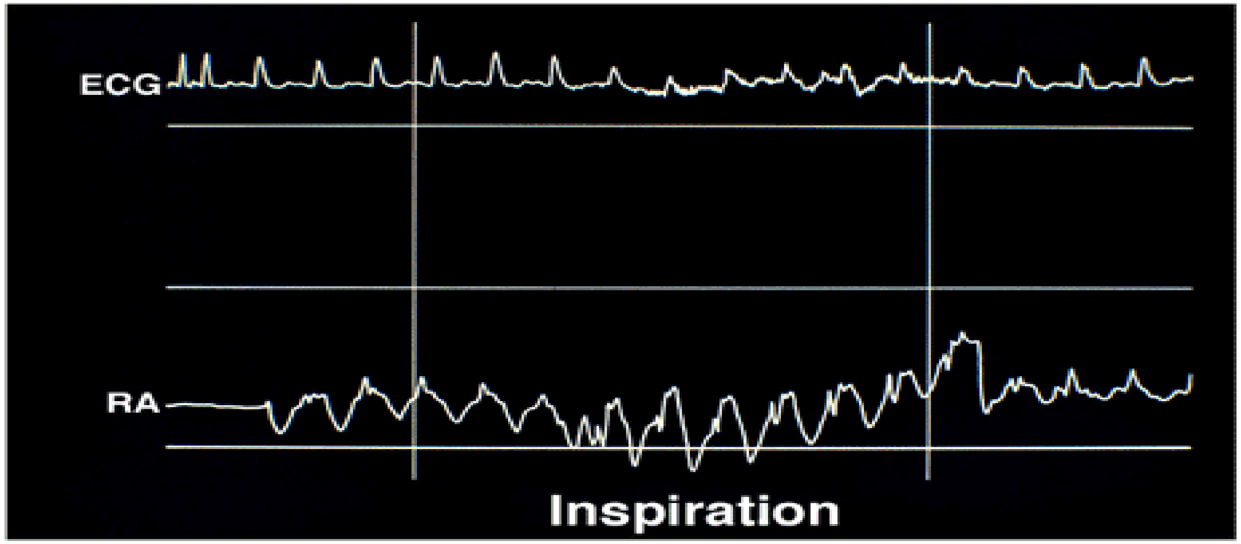
Small individual risks multiplied by billion examinations become significant population risks



Right Heart Catheterization

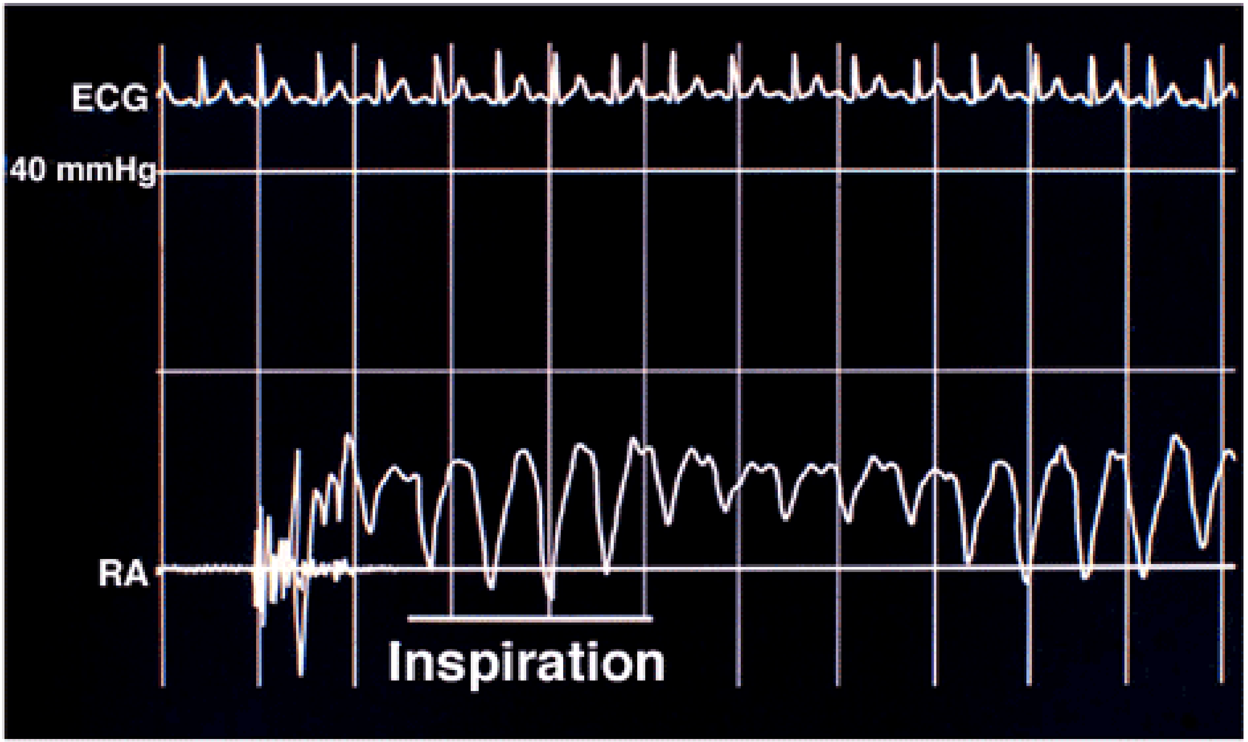
Inspiratory Effect on Right Atrial Pressure

- Normal physiology
  - Inhalation: Intrathoracic pressure falls → RA pressure falls
  - Exhalation: Intrathoracic pressure increases → RA pressure increases



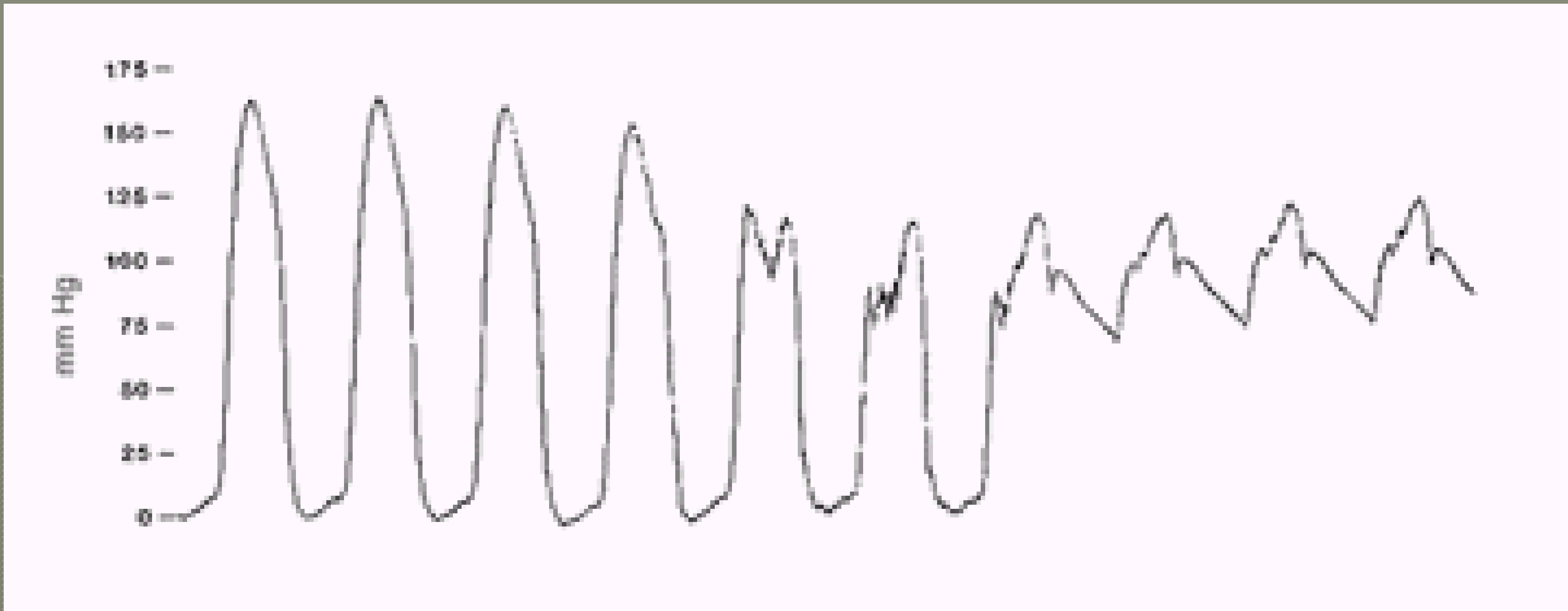
Right Heart Catheterization
Abnormalities in RA Tracing

- Elevated mean atrial pressure



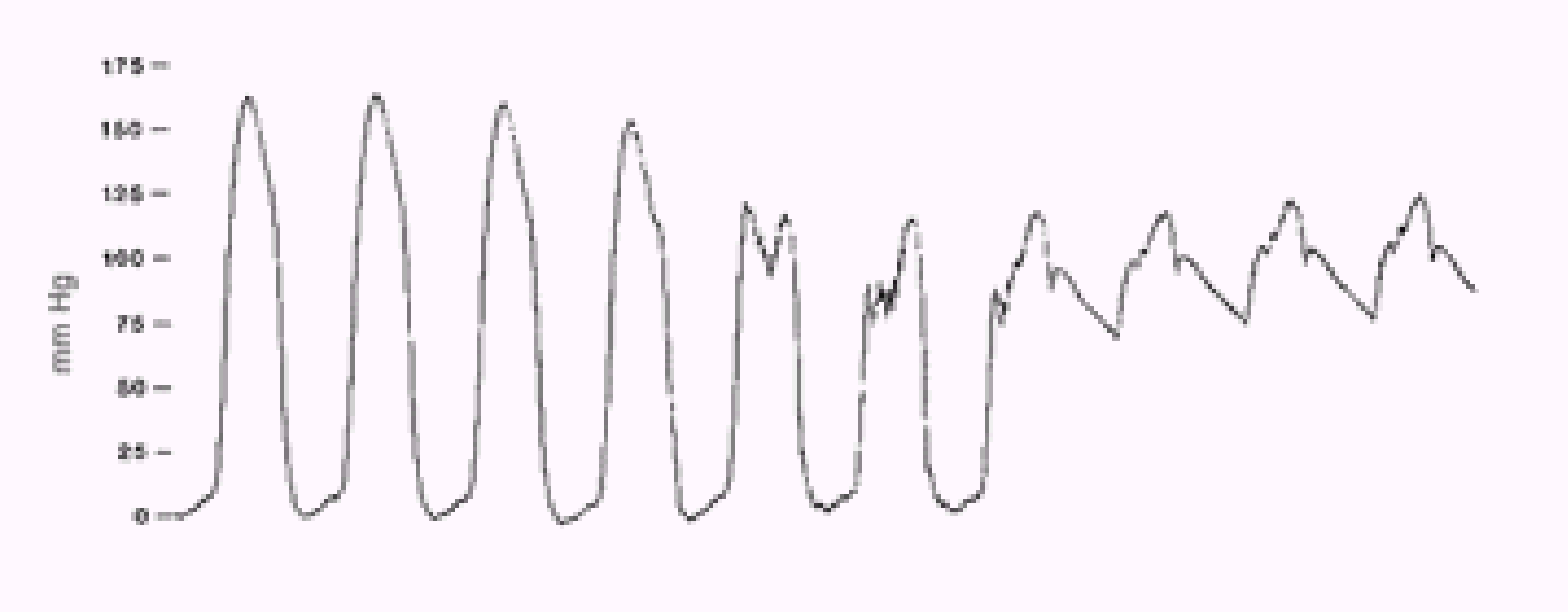
Davidson CJ, et al. Cardiac Catheterization. In: Heart Disease: A Textbook of Cardiovascular Medicine, Edited by E. Braunwald, 5th ed. Philadelphia: WB Saunders Company, 1997

Hemodynamic Principles



A. She has valvular aortic stenosis.
B. She has hypertrophic cardiomyopathy with obstruction.
C. She has an intraventricular pressure gradient.
D. She has a bicuspid aortic valve with mild stenosis.
E. She has a pressure gradient but it is likely an artifact.

Hemodynamic Principles



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C. She has an intraventricular pressure gradient.
D. She has a bicuspid aortic valve with mild stenosis.
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Hemodynamic Principles

12. In the diagnosis of restrictive physiology, what are the criteria with the highest sensitivity?

A. Parallel increase in left and right ventricular end-diastolic pressures.
B. Concordance of left and right ventricular systolic pressures during normal respiration.
C. Dyssynchronous increase in right ventricular systolic pressure with left ventricular pressure at end inspiration.
D. Simultaneous increase in left ventricular, pulmonary capillary wedge, and left ventricular systolic pressures.
E. Dip and plateau of LV diastolic pressure.

Hemodynamic Principles

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Hemodynamic Principles

13. A 65-year-old man presents with progressive dyspnea on exertion, edema, and ascites. A history of coronary artery disease was present and coronary artery bypass surgery had been performed several years earlier. Echocardiography revealed normal left ventricular function with small-to-moderate pericardial and pleural effusions. On examination, there was jugular venous distention with rapid 'Y' descent, bilateral lower extremity, and distant heart sounds. The electrocardiogram showed sinus tachycardia. In examination of the hemodynamics of this patient, which findings are most diagnostic of constrictive physiology?

A. Abrupt cessation of ventricular filling with simultaneous right and left ventricular diastolic pressures.
B. Respiratory disconcordance of simultaneous right and left ventricular systolic pressures.
C. Respiratory concordance of simultaneous right atrial and left ventricular pressures.
D. Respiratory disconcordance of simultaneous pulmonary capillary wedge and right atrial pressures.
E. Dip and plateau of left ventricular diastolic pressure.

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Cardiac Output Measurement
Fick Oxygen Method: AV O_2 Difference

Step 1: Theoretical oxygen carrying capacity

O_2 carrying capacity (mL O_2 / L blood) =
1.36 mL O_2 / gm Hgb x 10 mL/dL x Hgb (gm/dL)

Step 2: Determine arterial oxygen content

Arterial O_2 content = Arterial saturation x O_2 carrying capacity

Step 3: Determine mixed venous oxygen content

Mixed venous O_2 content = MV saturation x O_2 carrying capacity

Step 3: Determine A-V O_2 oxygen difference

AV O_2 difference = Arterial O2 content - Mixed venous O_2 content

Baim DS and Grossman W. Cardiac Catheterization, Angiography, and Intervention. 5th Edition. Baltimore: Williams and Wilkins, 1996.

Cardiac Output Measurement
Fick Oxygen Method

- Fick oxygen method total error ≈ 10%
  - Error in O2 consumption ≈ 6%
  - Error in AV O2 difference ≈ 5%. Narrow AV O2 differences more subject to error, and therefore Fick method is most accurate in low cardiac output states
- Sources of Error
  - Incomplete collection of expired air (Douglas bag)
    - Underestimate O2 consumption and CO
  - Respiratory quotient = 1
    - Volume of CO2 expired is not equal to O2 inspired
    - Leads to underestimation of O2 consumption and CO
  - Incorrect timing of expired air collection (Douglas bag)

Baim DS and Grossman W. Cardiac Catheterization, Angiography, and Intervention. 5th Edition. Baltimore: Williams and Wilkins, 1996.

Cardiac Output Measurement
Fick Oxygen Method

- Sources of Error
  - Spectophotometric determination of blood oxygen saturation
  - Changes in mean pulmonary volume
    - Douglas bag and MRM measure amount of O2 entering lungs, not actual oxygen consumption
    - Patient may progressively increase or decrease pulmonary volume during sample collection. If patient relaxes and breathes smaller volumes, CO is underestimated
  - Improper collection of mixed venous blood sample
    - Contamination with PCW blood
    - Sampling from more proximal site

Baim DS and Grossman W. Cardiac Catheterization, Angiography, and Intervention. 5th Edition. Baltimore: Williams and Wilkins, 1996.

Cardiac Output Measurement
Indicator Dilution Methods

- Requirements
  - Bolus of indicator substance which mixes completely with blood and whose concentration can be measured
  - Indicator is neither added nor subtracted from blood during passage between injection and sampling sites
  - Most of sample must pass the sampling site before recirculation occurs
  - Indicator must go through a portion of circulation where all the blood of the body becomes mixed

Baim DS and Grossman W. Cardiac Catheterization, Angiography, and Intervention. 5th Edition. Baltimore: Williams and Wilkins, 1996.

Cardiac Output Measurement
Indicator Dilution Methods

Stewart-Hamilton Equation

$$CO = \int_0^{\infty} \frac{\text{Indicator amount}}{C\,(t)\,dt}$$

C = concentration of indicator

$$CO = \frac{\text{Indicator amount (mg) x 60 sec/min}}{\text{mean indicator concentration (mg/mL) x curve duration}}$$

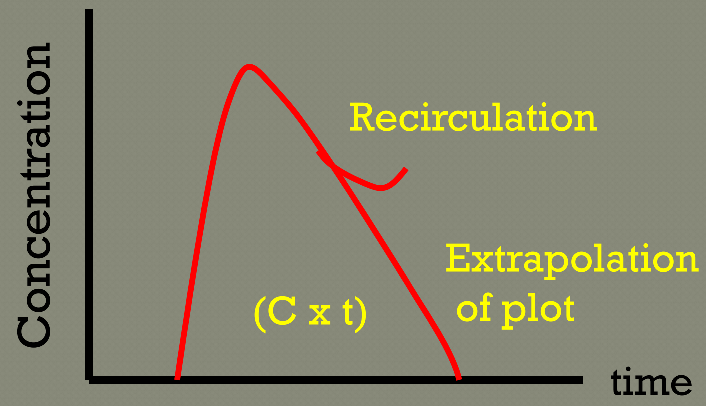
- Indicators
  - Indocyanine Green
  - Thermodilution (Indicator = Cold)

Baim DS and Grossman W. Cardiac Catheterization, Angiography, and Intervention. 5th Edition. Baltimore: Williams and Wilkins, 1996.

Cardiac Output Measurement
Indocyanine Green Method

- Indocyanine green (volume and concentration fixed) injected as a bolus into right side of circulation (pulmonary artery)
- Samples taken from peripheral artery, withdrawing continuously at a fixed rate
- Indocyanine green concentration measured by densitometry

$$CO = \frac{I}{(C \times t)}$$



CO inversely proportional to area under curve

Baim DS and Grossman W. Cardiac Catheterization, Angiography, and Intervention. 5th Edition. Baltimore: Williams and Wilkins, 1996.

Cardiac Output Measurement
Indocyanine Green Method

- Sources of Error
  - Indocyanine green unstable over time and with exposure to light
  - Sample must be introduced rapidly as single bolus
  - Bolus size must be exact
  - Indicator must mix thoroughly with blood, and should be injected just proximal or into cardiac chamber
  - Dilution curve must have exponential downslope of sufficient length to extrapolate curve. Invalid in Low cardiac output states and shunts that lead to early recirculation
  - Withdrawal rate of arterial sample must be constant

Baim DS and Grossman W. Cardiac Catheterization, Angiography, and Intervention. 5th Edition. Baltimore: Williams and Wilkins, 1996.

Cardiac Output Measurement
Thermodilution Method

$$CO = \frac{V_I\,(T_B - T_I)\,(S_I \times C_I / S_B \times C_B) \times 60}{\int_0^{\infty} \Delta T_B \, dt}$$

V_I = volume of injectate

S_I, S_B = specific gravity of injectate and blood

C_I, C_B = specific heat of injectate and blood

T_I = temperature of injectate

ΔT_B = change in temperature measured downstream

Baim DS and Grossman W. Cardiac Catheterization, Angiography, and Intervention. 5th Edition. Baltimore: Williams and Wilkins, 1996.

Cardiac Output Measurement
Thermodilution Method

- Advantages
  - Withdrawal of blood not necessary
  - Arterial puncture not required
  - Indicator (saline or D5W)
  - Virtually no recirculation, simplifying computer analysis of primary curve sample

Baim DS and Grossman W. Cardiac Catheterization, Angiography, and Intervention. 5th Edition. Baltimore: Williams and Wilkins, 1996.

Cardiac Output Measurement
Thermodilution Method

- Sources of Error (± 15%)
  - Unreliable in tricuspid regurgitation
  - Baseline temperature of blood in pulmonary artery may fluctuate with respiratory and cardiac cycles
  - Loss of injectate with low cardiac output states (CO < 3.5 L/min) due to warming of blood by walls of cardiac chambers and surrounding tissues. The reduction in ΔT_B at pulmonary arterial sampling site will result in overestimation of cardiac output
  - Empirical correction factor (0.825) corrects for catheter warming but will not account for warming of injectate in syringe by the hand

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Cardiac Output Measurement
Stroke Volume

- Stroke Volume
  - Volume of blood ejected in a single contraction
  - Volumetric analysis requires 3-dimensional analysis to calculate end-diastolic and end-systolic volume

Stroke volume = End-diastolic volume – End-systolic volume

  - Estimation based on cardiac output

$$\text{Stroke volume} = \frac{\text{Cardiac output}}{\text{Heart rate}}$$

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Hemodynamic Principles

1. In the cardiac catheterization laboratory, cardiac output is measured using the Fick principle or thermodilution technique. Which of the following statements is correct?

   A. Using an assumed O_2 consumption of 125 ml/m^2 is acceptable and results in minimal variability in cardiac output compared with direct measurements of O_2 consumption.
   B. The thermodilution method underestimates cardiac output in patients with low forward flows (cardiac outputs <3.5 L/min).
   C. The thermodilution method underestimates cardiac output in the presence of important tricuspid regurgitation.
   D. O_2 saturation measured in blood collected from a central line in the right atrium is an acceptable substitute for a pulmonary artery sample when calculating the AV O_2 difference.
   E. A high cardiac output will produce a large area under the temperature-time curve in thermodilution determinations.

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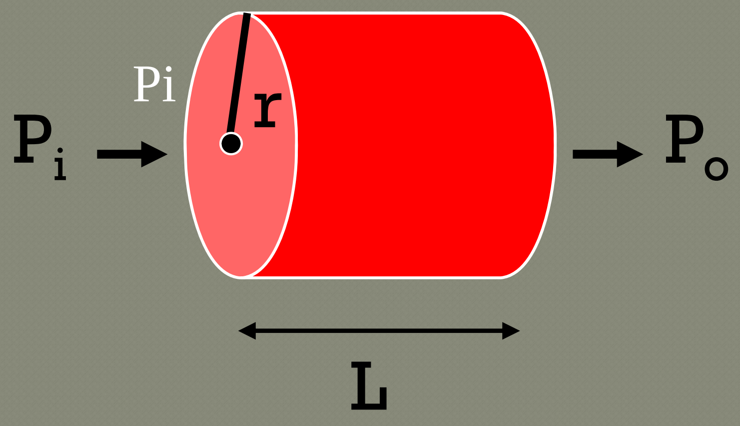
Hemodynamic Principles
An Overview

- Pressure measurement
- Right and left heart catheterization
- Cardiac output measurement
  - Fick-oxygen method
    - Arterial-venous oxygen difference
  - Indicator-dilution methods
    - Indocyanine green
    - Thermodilution
- Vascular resistance
- Shunt detection and measurement
- Gradients and valve stenoses

Vascular Resistance
Poiseuille's Law

$$Q = \frac{\pi (P_i - P_o) r^4}{8 \eta L}$$



Q = volume flow
Pi – Po = inflow – outflow pressure
r = radius of tube
L = length of tube
η = viscosity of the fluid

$$\text{Resistance} = \frac{\Delta P}{Q} = \frac{8 \eta L}{\pi r^4}$$

In vascular system, key factor is radius of vessel

Baim DS and Grossman W. Cardiac Catheterization, Angiography, and Intervention. 5th Edition. Baltimore: Williams and Wilkins, 1996.

Vascular Resistance
Definitions

Normal reference values

	Woods Units	x 80 =	Metric Units
Systemic vascular resistance $$SVR = \frac{\overline{Ao} - \overline{RA}}{Q_s}$$	10 – 20		770 – 1500
Pulmonary vascular resistance $$PVR = \frac{\overline{PA} - \overline{LA}}{Q_p}$$	0.25 – 1.5		20 – 120

Baim DS and Grossman W. Cardiac Catheterization, Angiography, and Intervention. 5th Edition. Baltimore: Williams and Wilkins, 1996.

Vascular Resistance
Systemic Vascular Resistance

- Increased
  - Systemic HTN
  - Cardiogenic shock with compensatory arteriolar constriction
- Decreased
  - Inappropriately high cardiac output
    - Arteriovenous fistula
    - Severe anemia
    - High fever
    - Sepsis
    - Thyrotoxicosis

Baim DS and Grossman W. Cardiac Catheterization, Angiography, and Intervention. 5th Edition. Baltimore: Williams and Wilkins, 1996.

Vascular Resistance
Pulmonary Vascular Resistance

- Increased
  - Primary lung disease
  - Eisenmenger syndrome
  - Elevated pulmonary venous pressure
    - Left-sided myocardial dysfunction
    - Mitral / Aortic valve disease
- Decreased

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Hemodynamic Principles

1. An obese patient with a dilated cardiomyopathy comes to the cardiac catheterization laboratory to determine whether or not he might be a candidate for cardiac transplantation. The pulmonary artery pressure is 40 mmHg, the pulmonary artery wedge pressure is 25 mmHg, and the cardiac output is 5 L/min. Which of the following statements is true?

A. He would be a candidate for cardiac transplantation based upon the calculated pulmonary arteriorlar resistance.
B. He should undergo further evaluation with infusion of nitrprusside.
C. He would not be a candidate for cardiac transplantation based upon pulmonary arteriorlar resistance.
D. He should be considered for combination heart-lung transplanation.
E. More information is required to determine the pulmonary arteriorlar resistance.

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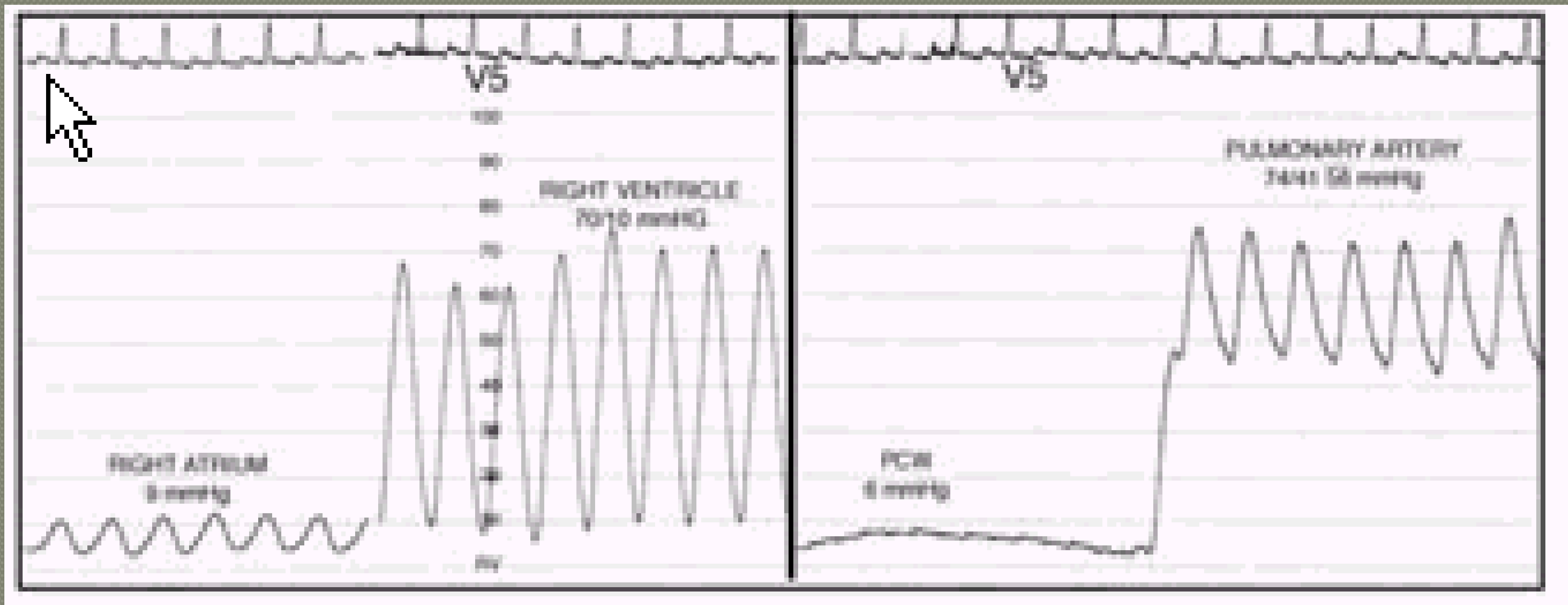
Hemodynamic Principles

2. The patient is a 55-yo woman who was diagnosed with severe pulmonary hypertension 2 months ago. She has had evidence of RVH by ECG dating back 6 years, but remained asymptomatic until recently. A daughter died at the age of 8 years from primary pulmonary hypertension. She was referred for right heart catheterization to exclude an intracardiac shunt and to perform an intravenous prostacyclin challenge to assess her pulmonary vasoreactivity. Her pulmonary artery hydrogen curve appearance time was 12 seconds.

The hydrogen curve technique is performed by having the patient inhale one breath of hydrogen and record the time to downward drift of the electrocardiographic baseline recorded from the tip of an electrode catheter placed in the main pulmonary artery. A short appearance time of the ECG drift (1-2 seconds) confirms the presence of a left-to-right intracardiac shunt. The 12 second recorded in this patient is normal and excludes a left-to-right shunt. The hydrogen curve technique is very sensitive compared to oximetry, but is not useful in quantifying the magnitude [illegible]he shunt nor in detecting a right to left shunt.

Hemodynamic Principles

A Flolan (IV prostacyclin) infusion was begun. At a dose of 8 ngm/kg/minute, she had moderate cutaneous flushing and her systemic arterial pressure was reduced from the baseline of 107/81 (mean 90 mmHg) with a heart rate of 136bpm to 86/61 (mean 67 mmHg) with a heart rate of 137 bpm. Thermodilution cardiac output was 2.50 L/min at baseline and 4.20 L/min during the maximum prostacyclin infusion. The pressure tracing below was recorded before prostacyclin was initiated.



Hemodynamic Principles

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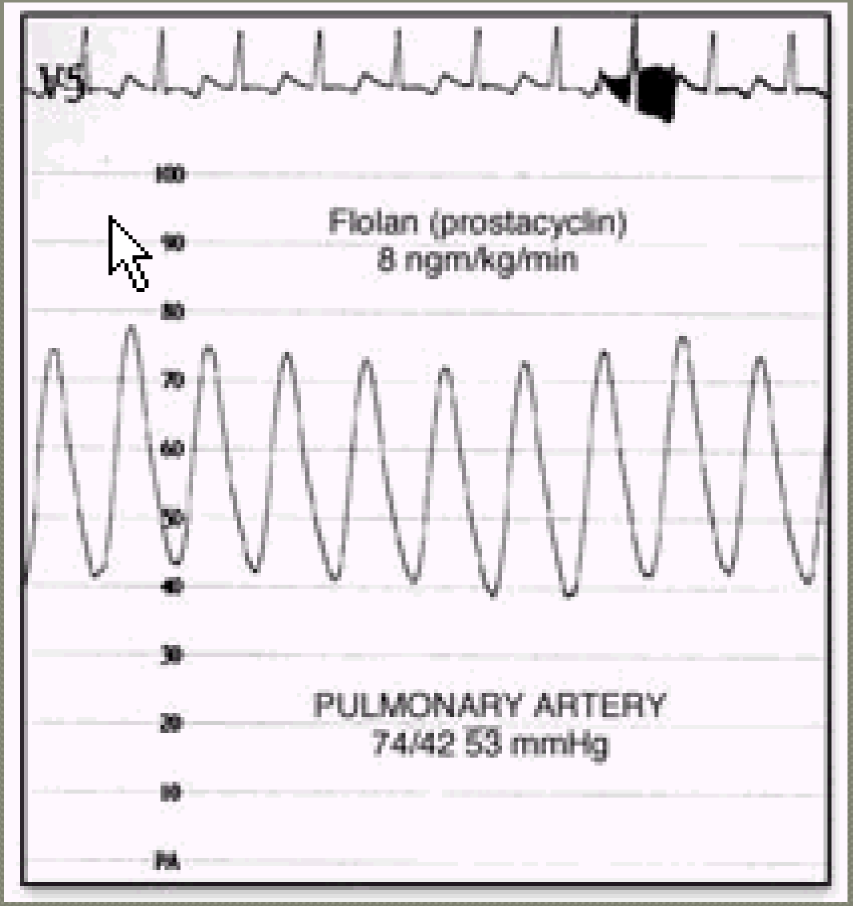

Hemodynamic Principles

Which of the following correctly describes these data or the management of this patient?

A. Further reductions in pulmonary artery pressure can likely be achieved at higher dose of this prostaglandin.
B. The hydrogen curve result suggests there is an intracardiac left-to-right shunt.
C. At baseline, the pulmonary resistance is elevated at 20 Wood units.
D. At baseline, the pulmonary resistance is elevated at 20 dyne/sec/cm-5.
E. Primary pulmonary hypertension has no genetic determinants.

Hemodynamic Principles

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Hemodynamic Principles

3. The patient is a 42-year-old woman who presents with mild dyspnea. She has gained considerable weight and feels that it is the primary reason for the new symptoms. Her initial exam suggests no CHF, but a pulmonic flow murmur is heard. The second heart sound is clearly widely split. She has a right bundle branch block on her ECG. An echocardiogram is obtained that reveals an enlarged RA and RV. By Doppler/echocardiogram, a left-to-right shunt is noted across the atrial septum. Using saline contrast a few microcavitations appear on the left side of the heart. A cardiac catheterization is performed to assess size of shunt and pulmonary pressures.

Hemodynamic Principles

3. The cardiac catheterization revealed:
   Pressures (mmHg): RA: mean 7, RV: 45/6, PA: 45/25, mean 33, PCW: mean 10, LV: 120/5, Aortic: 120/80, mean 95.
   Saturations (%): SVC: 60, IVC: 65, (Mixed Venous 62), RA: 80, RV: 75, PA: 75, PV: 95, Aortic: 95.
   Hemoglobin: 13 mg/dl, Oxygen consumption: 250 ml/min.
   LA angiogram: Consistent with secundum atrial septal defect.

   Using these data, the pulmonary blood flow was determined to be 7.1 liters/min and the systemic blood flow was found to be 4.3 liters/min. Select the correct answer based on the findings at cardiac catheterization.

A. The Q_P/Q_S suggests that no therapy is required at this time.
B. The PVR/SVR ratio suggests the elevated PA pressure is due to Eisenmenger's syndrome, and it is too late to consider ASD closure.
C. The PVR/SVR ratio is low enough that she would be a candidate for ASD closure at this time.
D. There are inadequate data to decide the patient's operability.
E. Endocarditis prophylaxis is highly recommended to prevent endocarditis given these hemodynamics.

Hemodynamic Principles

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Hemodynamic Principles

4. A 48-year-old patient with pulmonary hypertension is admitted with profound cyanosis and clubbing. Her workup reveals primary pulmonary hypertension with a patent foramen ovale and right-to-left shunt. Given the following information, calculate her pulmonary vascular resistance.

Hemodynamic Principles

4. At catheterization, the SVC oxygen saturation is 43%, the IVC oxygen saturation is 50%, the RA saturation is 45%, the PA oxygen saturation is 45%, the PV saturation is 90%, the aortic oxygen saturation is 80%. Oxygen consumption is 275 ml/min. The hemoglobin is 15gm%. The RA pressure mean is 15, the RV pressure is 90/15, the PA pressure is 90/60 with a mean of 75, the pulmonary wedge pressure is 10, the LV pressure is 110/10, the aortic pressure is 110/80 with a mean of 95 mmHg.

A. There is inadequate information to calculate the PVR.
B. The PVR is 21.7 Wood units.
C. The PVR is 16.2 Wood units.
D. The PVR is 10.3 Wood units.
E. The PVR is 8.8 Wood units.

Hemodynamic Principles

4. At catheterization, the SVC oxygen saturation is 43%, the IVC oxygen saturation is 50%, the RA saturation is 45%, the PA oxygen saturation is 45%, the PV saturation is 90%, the aortic oxygen saturation is 80%. Oxygen consumption is 275 ml/min. The hemoglobin is 15gm%. The RA pressure mean is 15, the RV pressure is 90/15, the PA pressure is 90/60 with a mean of 75, the pulmonary wedge pressure is 10, the LV pressure is 110/10, the aortic pressure is 110/80 with a mean of 95 mmHg.

A. There is inadequate information to calculate the PVR.
B. The PVR is 21.7 Wood units.
C. The PVR is 16.2 Wood units.
D. The PVR is 10.3 Wood units.
E. The PVR is 8.8 Wood units.

Hemodynamic Principles
An Overview

- Pressure measurement
- Right and left heart catheterization
- Cardiac output measurement
  - Fick-oxygen method
    - Arterial-venous oxygen difference
  - Indicator-dilution methods
    - Indocyanine green
    - Thermodilution
- Vascular resistance
- Shunt detection and measurement
- Gradients and valve stenoses

Shunt Detection & Measurement
Indications

- Arterial desaturation (<95%)
  - Alveolar hypoventilation (Physiologic Shunt) corrects with deep inspiration and/or O_2
    - Sedation from medication
    - COPD / Pulmonary parenchymal disease
    - Pulmonary congestion
  - Anatomic shunt (Rt→Lf) does not correct with O_2
- Unexpectedly high PA saturation (>80%) due to Lf→Rt shunt

Baim DS and Grossman W. Cardiac Catheterization, Angiography, and Intervention. 5th Edition. Baltimore: Williams and Wilkins, 1996.

Shunt Detection & Measurement
Methods

- Shunt Detection
  - Indocyanine green method
  - Oximetric method
- Shunt Measurement
  - Left-to-Right Shunt
  - Right-to-Left Shunt
  - Bidirectional Shunt

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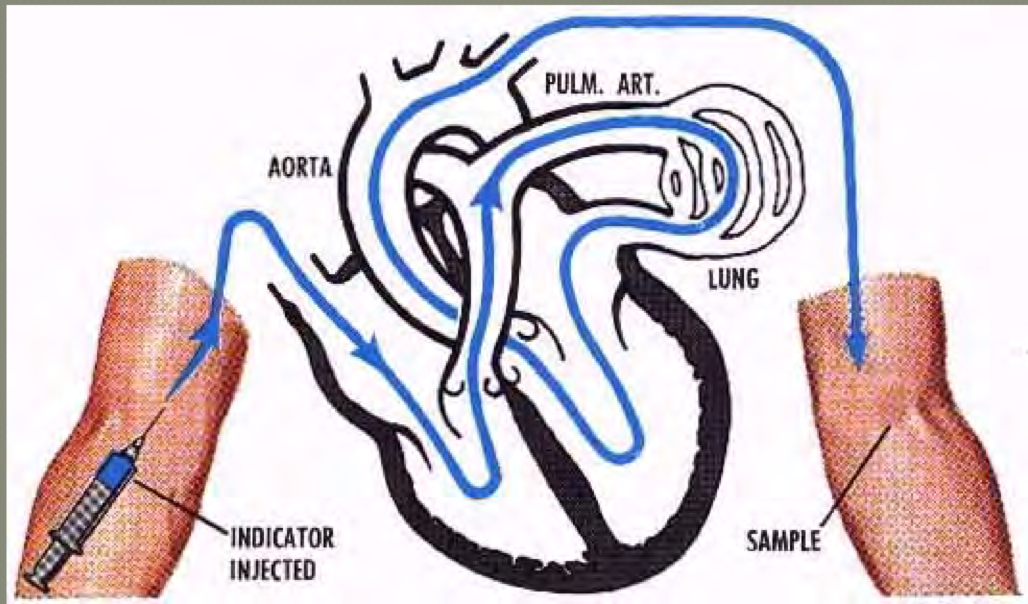
Shunt Detection & Measurement
Indocyanine Green Method

- Indocyanine green (1 cc) injected as a bolus into right side of circulation (pulmonary artery)
- Concentration measured from peripheral artery
- Appearance and washout of dye produces initial 1st pass curve followed by recirculation in normal adults



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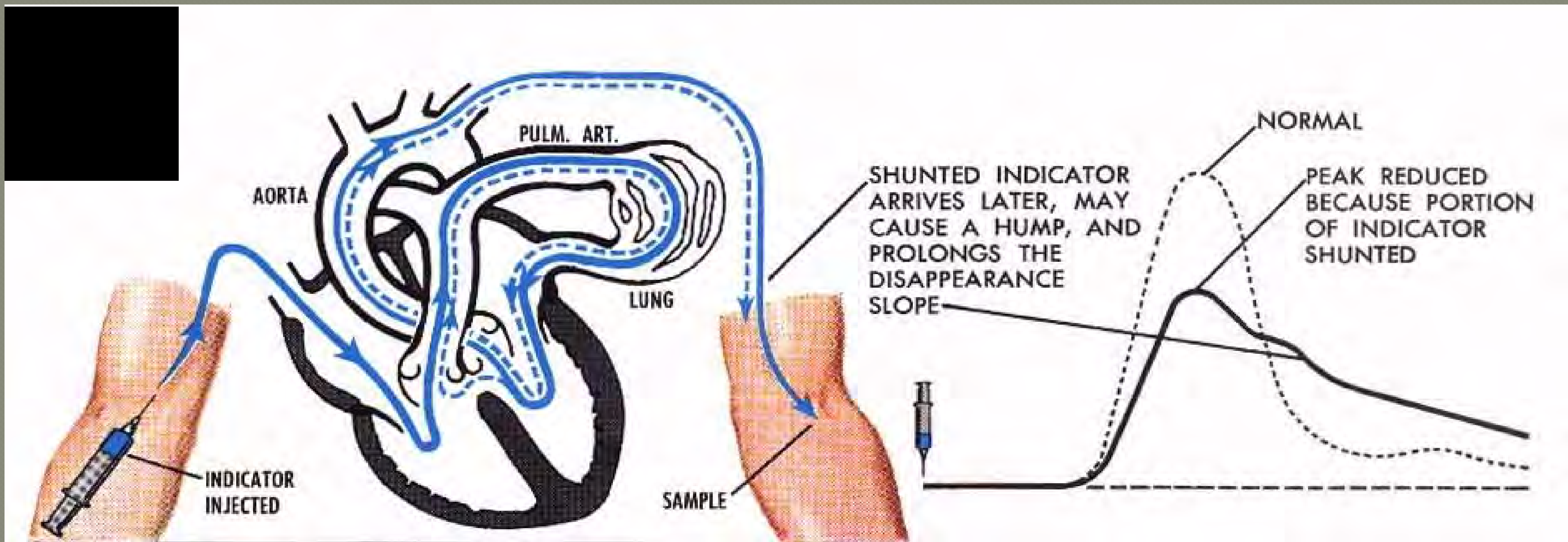
Shunt Detection & Measurement

Left-to-Right Shunt



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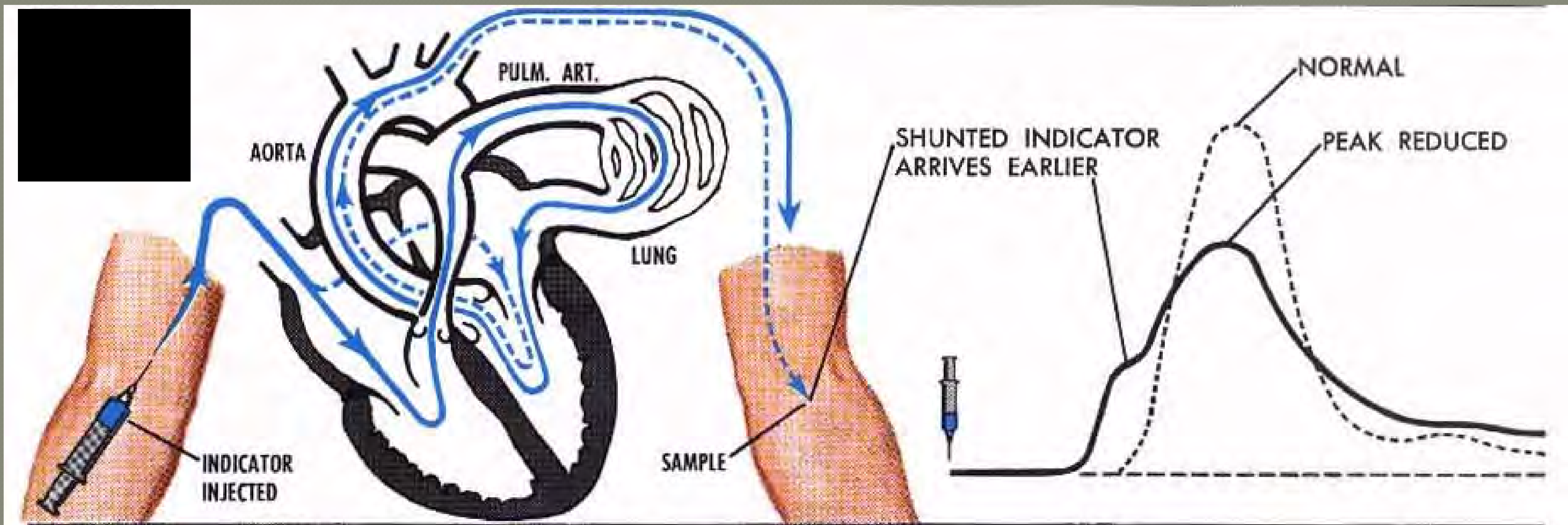
Shunt Detection & Measurement
Right-to-Left Shunt



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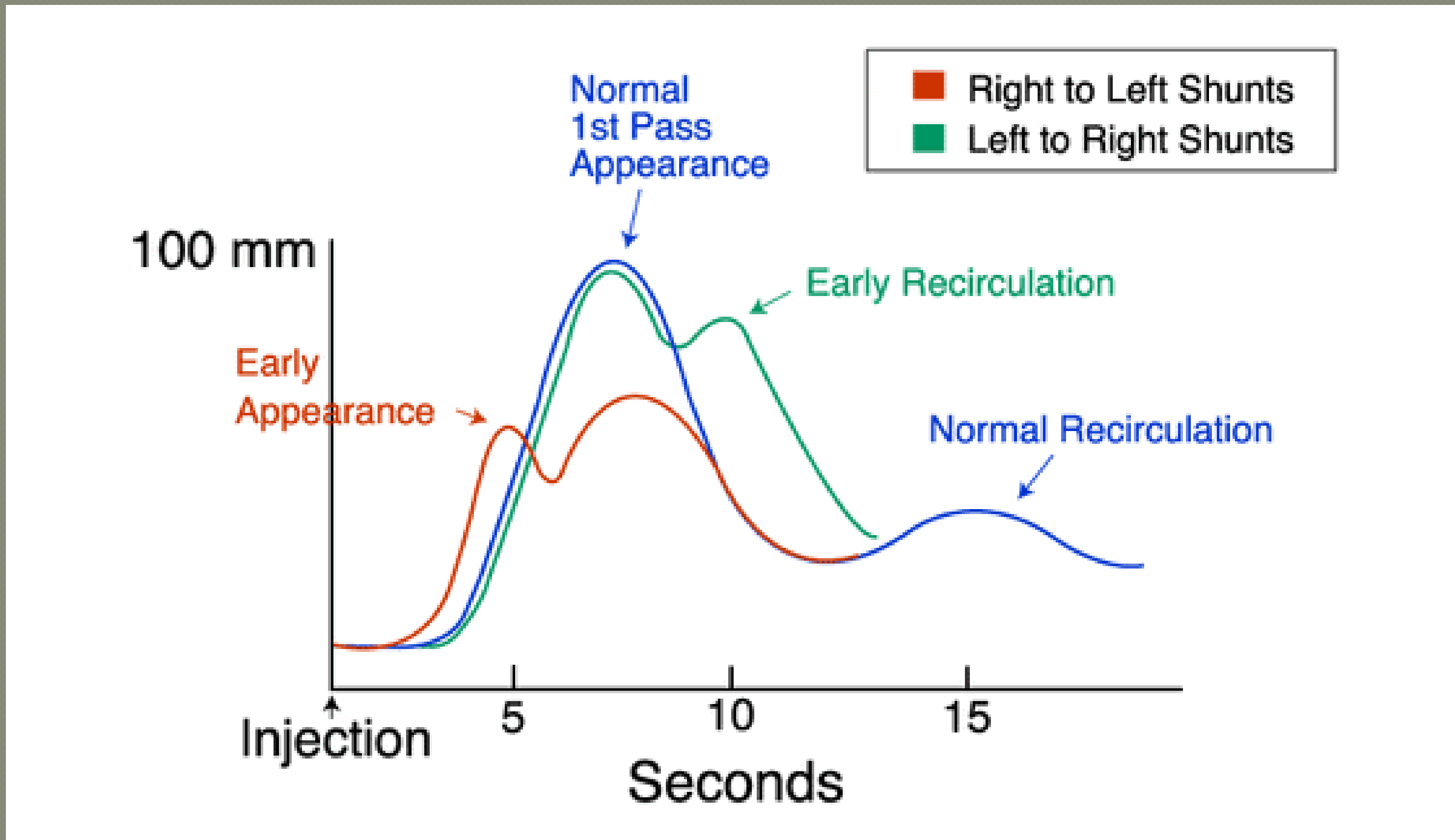
Shunt Detection & Measurement
Indocyanine Green Method



Bashore, TM. Congenital Heart Disease in Adults. The Measurement of Intracardiac Shunts. In: CATHSAP II. Bethesda: American College of Cardiology, 2001.

Shunt Detection & Measurement
Methods

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Shunt Detection & Measurement
Oximetric Methods

- Obtain O2 saturations in sequential chambers, identifying both step-up and drop-off in O2 sat
- Insensitive for small shunts (< 1.3:1)

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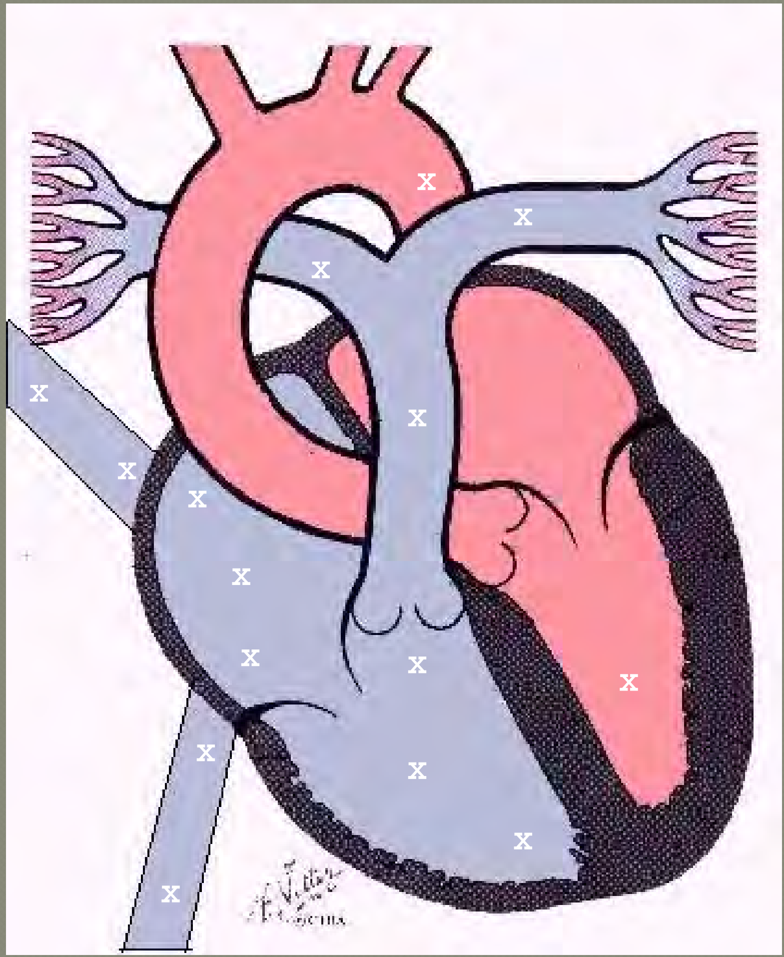
Shunt Detection & Measurement

Oximetry Run

- IVC, L4-5 level
- IVC, above diaphragm
- SVC, innominate
- SVC, at RA
- RA, high
- RA, mid
- RA, low
- RV, mid
- RV, apex
- RV, outflow tract
- PA, main
- PA, right or left
- Left ventricle
- Aorta, distal to ductus



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Shunt Detection & Measurement
Oximetric Methods

- RA receives blood from several sources
  - SVC: Saturation most closely approximates true systemic venous saturation
  - IVC: Highly saturated because kidneys receive 25% of CO and extract minimal oxygen
  - Coronary sinus: Markedly desaturated because heart maximes O2 extraction
- Phlamm Equation: Mixed venous saturation used to normalize for differences in blood saturations that enter RA

$$\text{Mixed venous saturation} = \frac{3\,(\text{SVC}) + \text{IVC}}{4}$$

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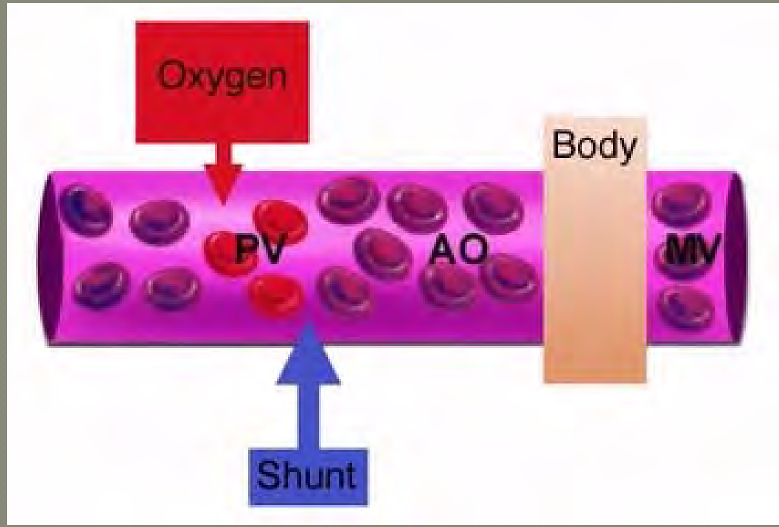
Shunt Detection & Measurement

Right-to-Left Shunt

- Left to right shunt results in step-down in O_2 between PV and Ao
- Shunt is the difference between systemic flow measured and what it would be in the absence of shunt (EPBF)
- Pulmonary Blood Flow = EPBF



Right-Left Shunt = Systemic Blood Flow – Effective Blood Flow

$$= \frac{O_2 \text{ consumption}}{(AoO_2 - MVO_2) \times 10} - \frac{O_2 \text{ consumption}}{(PvO_2 - MVO_2) \times 10}$$

$$Qp / Qs \text{ Ratio} = PBF / SBF = \frac{(AoO_2 - MVO_2)}{(PvO_2 - PaO_2)}$$

Bashore, TM. Congenital Heart Disease in Adults. The Measurement of Intracardiac Shunts. In: CATHSAP II. Bethesda: American College of Cardiology, 2001.

Shunt Detection & Measurement
Right-to-Left Shunt

- Tetralogy of Fallot
- Eisenmenger Syndrome
- Pulmonary arteriovenous malformation
- Total anomalous pulmonary venous return (mixed)

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Shunt Detection & Measurement
Methods

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  - Indocyanine green method
  - Oximetric method
- Shunt Measurement
  - Left-to-Right Shunt
  - Right-to-Left Shunt
  - Bidirectional Shunt

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Shunt Detection & Measurement

Bidirectional Shunts

- Left-to-Right Shunt

$$= \frac{Q_p \text{ (MV } O_2 \text{ content} - \text{PA } O_2 \text{ content)}}{\text{(MV } O_2 \text{ content} - \text{PV } O_2 \text{ content)}}$$

- Right-to-Left Shunt

$$= \frac{Q_p \text{ (PV } O_2 \text{ content} - \text{SA } O_2 \text{ content) (PA } O_2 \text{ content} - \text{PV } O_2 \text{ content)}}{\text{(SA } O_2 \text{ content} - \text{PV } O_2 \text{ content) (MV } O_2 \text{ content} - \text{PV } O_2 \text{ content)}}$$

* If pulmonary vein not entered, use 98% x O_2 capacity.

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Shunt Detection & Measurement
Bidrectional Shunt

- Transposition of Great Arteries
- Tricuspid atresia
- Total anomalous pulmonary venous return
- Truncus arteriosus
- Common atrium (AV canal)
- Single ventricle

Shunt Detection & Measurement
Limitations of Oximetric Method

- Requires steady state with rapid collection of O_2 samples
- Insensitive to small shunts
- Flow dependent
  - Normal variability of blood oxygen saturation in the right heart chambers is influenced by magnitude of SBF
  - High flow state may simulate a left-to-right shunt
- When O_2 content is utilized (as opposed to O_2 sat), the step-up is dependent on hemoglobin.

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Hemodynamic Principles

1. A patient undergoes right and left heart catheterization. The patient is breathing room air, hemoglobin is 13.6 gm/dl, and measured oxygen consumption is 250 ml/minute. The systemic arterial oxygen content is 195 ml/liter and the mixed venous oxygen content is 145 ml/liter. Which of the following is the correct cardiac output?

   A. 5.0 liters/minute.
   B. 5.3 liters/minute.
   C. 5.8 liters/minute.
   D. 6.2 liters/minute.
   E. 6.5 liters/minute.

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Hemodynamic Principles

2. The following oxygen saturations were obtained during cardiac catheterization from a patient with a suspected shunt. The saturations shown are the means of multiple values.

Superior vena cava	55%	High right atrium	70%
Mid-right atrium	79%	Low right atrium	83%
Inferior vena cava	75%	Right ventricle	78%
Pulmonary artery	80%	Left atrium	98%
Pulmonary vein	99%	Aorta	98%

Which of the following is the correct location and Q_P/Q_S ratio?

A. 3-to-1 shunt at the atrial level.
B. 2-to-1 shunt at the ventricular level.
C. Bidirectional shunting at the atrial level with a 1.8-to-1 left to right shunt and 1.2-to-1 right-to-left shunt.
D. 2-to-1 at the atrial level.
E. 3-to-1 at the ventricular level.

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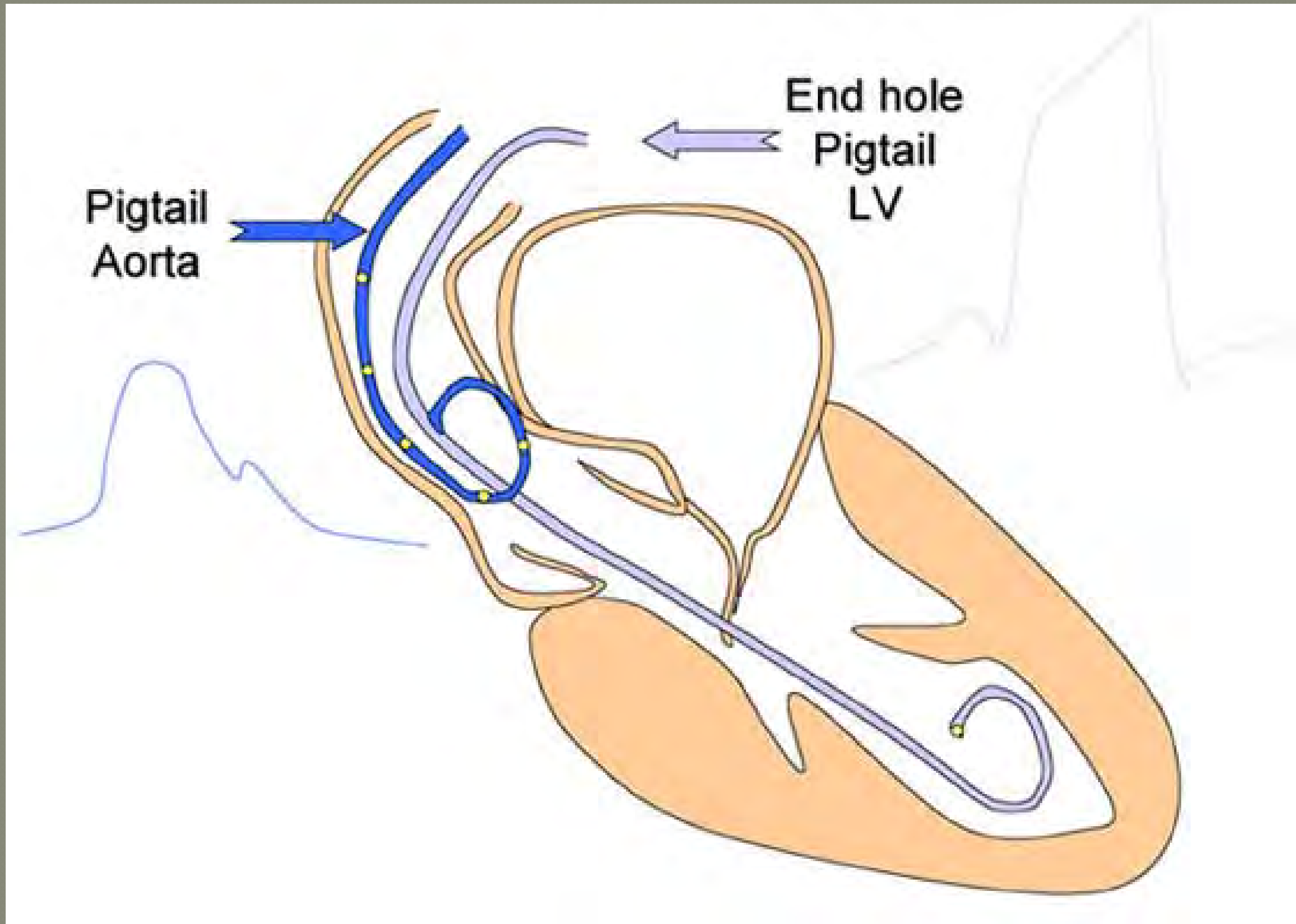
D. 2-to-1 at the atrial level.
E. 3-to-1 at the ventricular level.

Hemodynamic Principles

3. A 40-year-old obese woman is admitted to the hospital with shortness of breath and you are asked to consult. She has ruddy cheeks and perhaps mild cyanosis, but there is no clubbing. Her jugular venous pulse is not elevated and lungs are clear. A right ventricular heave is palpated, as is the second heart sound along the left sternal border. Her left ventricular apex is not displaced. Auscultation shows a soft systolic murmur along the left sternal border that radiates slightly toward the left with an S3 present, but you cannot distinguish whether it is a left or right-sided S3. The pulmonary component of her second heart sound is loud. There is no hepatomegaly or edema. Her echocardiogram is of marginal quality, but there is marked enlargement of the right atrium and right ventricle. Agitated saline injection results in filling of the left heart structures immediately through what appears to be a secundum atrial septal defect (ASD).

Valve Stenoses
Two Catheter Technique



Valve Stenoses

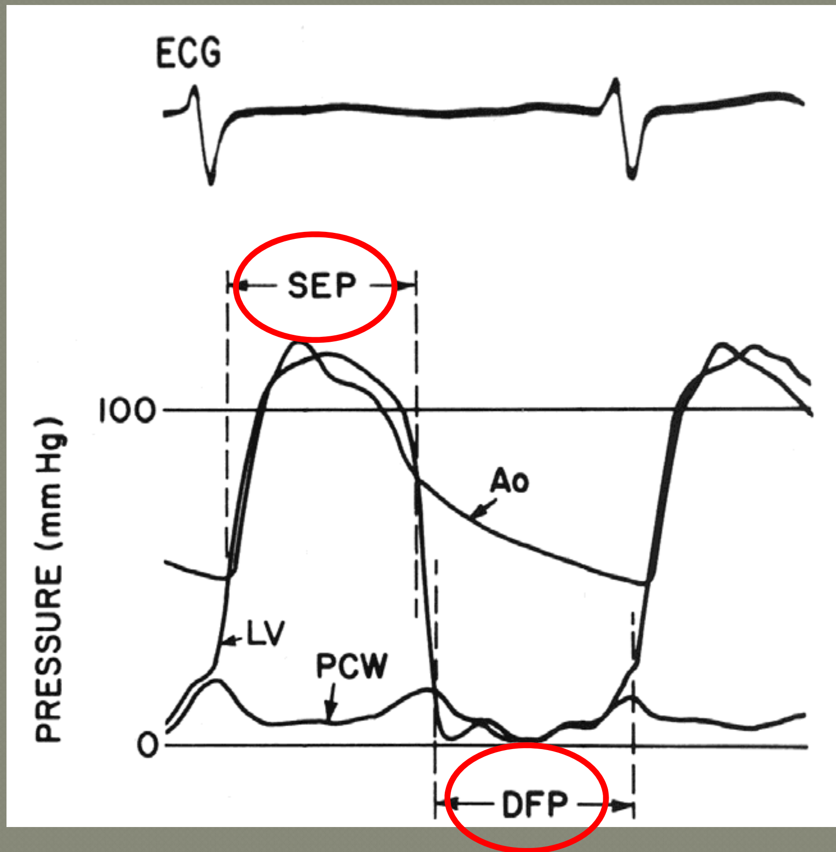
Gorlin Formula Derivation

$$A = \frac{Flow}{C \cdot 44.3 \sqrt{h}}$$

Flow has to be corrected for the time during which there is cardiac output across the valve.

Aortic, Pulmonic } Systolic Flow (SEP)

Tricuspid, Mitral } Diastolic Flow (DFP)



Gorlin Formula:

$$A = \frac{CO / (DFP \text{ or } SEP) \cdot HR}{C \cdot 44.3 \sqrt{\Delta P}}$$

Constant:

Aortic, Tricuspid, Pulmonic: C = 1.0

Mitral: C = 0.85

VSD, PDA: C = 1.0

Valve Stenoses

The "Quick Valve Area" Formula

Gorlin Formula:

$$A = \frac{CO / (DFP \text{ or } SEP) \cdot HR}{C \cdot 44.3 \sqrt{\Delta P}}$$

Quick Valve Area Formula (Hakki Formula):

Determine peak gradient across valve.

$$A = \frac{CO}{\sqrt{\text{Peak gradient}}}$$

Aortic Valve Stenosis
Calculating Valve Area

Step 1: Planimeter area and calculate SEP

	Area of gradient (mm^2)	Length of SEP (mm)	Gradient Deflection (mm)
#1	________	_____	______
#2	________	_____	______
#3	________	_____	______
#4	________	_____	______
#5	________	_____	______

Average deflection = ______ mm