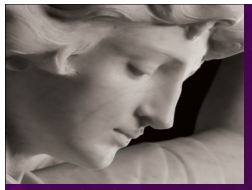


INTERPRETING FLOW IN THE PULMONARY SYSTEM

•A Primer on pressure and flow velocity wave interpretation.

•Claude Tousignant MD FRCPC

•St Michael's hospital

•University of Toronto

OBJECTIVES:

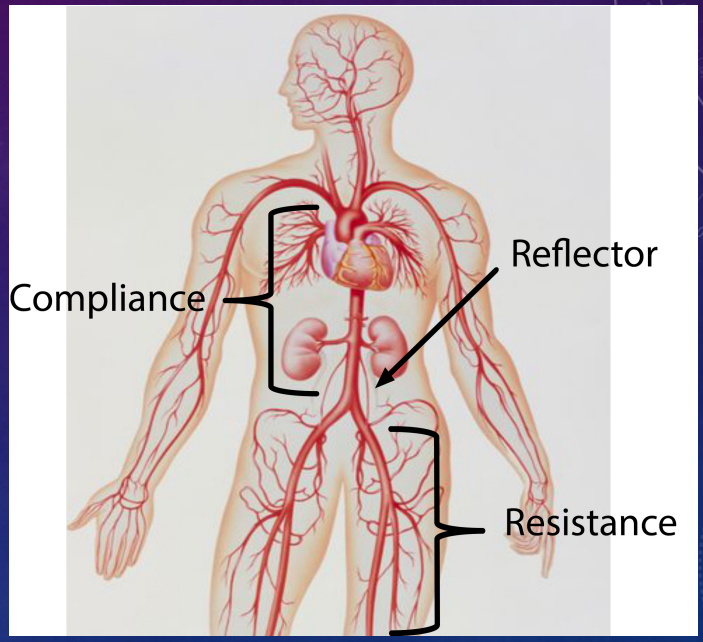
- 1) Understand the forces that shape the pulmonary pressure and flow traces.
- 2) Describe a normal pulmonary flow and pressure trace.
- 3) Recognize abnormal pulmonary Doppler flow traces.
- 4) Perioperative assessment of pulmonary vascular disease.

THE CARDIO-PULMONARY SYSTEM:

- Right Ventricular Function:
    - Low workload.
    - Low pressure.
  - Due to a vascular arrangement that is different from systemic.
  - Long “hangout” interval.
    - Flow despite equalization of pressures.
      - Thanks to low resistance, high capacity of system.
      - Inertia maintains flow.
- Well adapted to volume variability.
- Poorly adapted to increases in impedance.

VASCULAR ARRANGEMENTS: ARTERIAL CIRCULATION

- Systemic circulation arranged in series.
  - Compliance vessels proximal
  - Resistance vessels distal.
- Compliance mitigates systolic pressure.
- Compliance supports diastolic pressure.
- In disease: ↑ PP.
- Systolic pressure augmentation
  - Iliac bifurcation is a strong reflector.

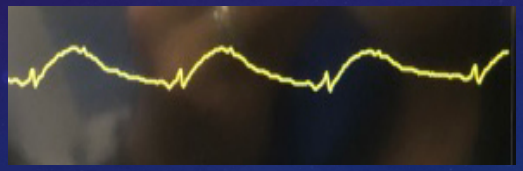


Normal

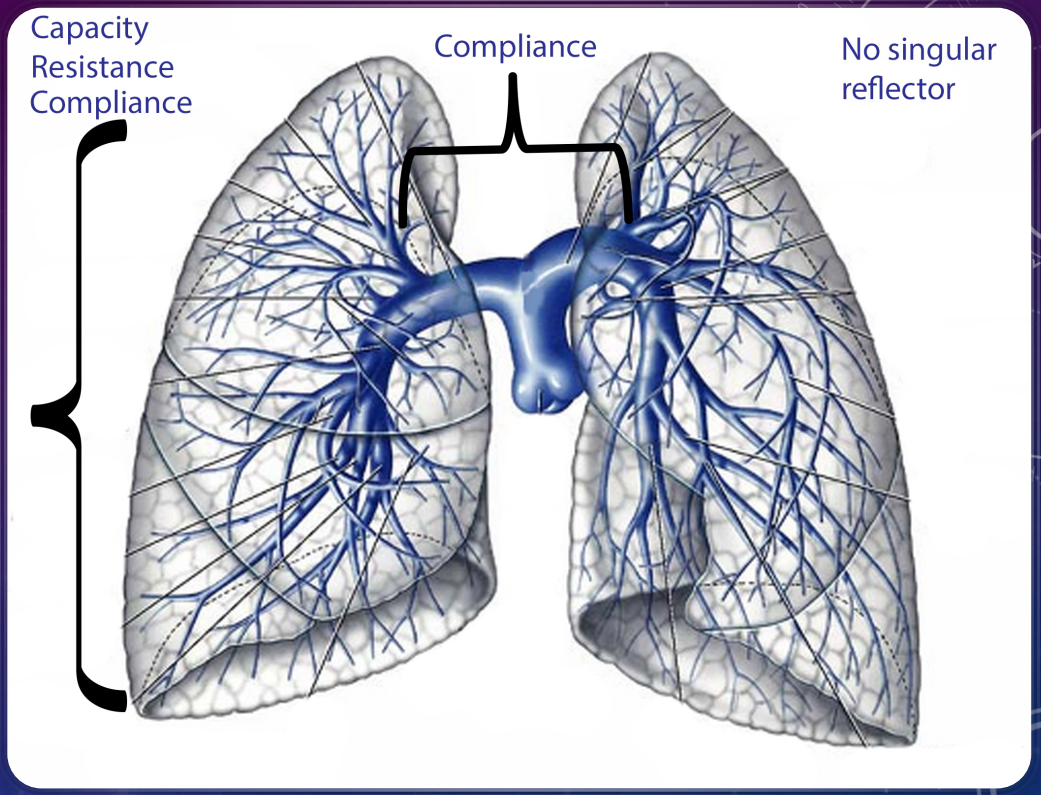
Abnormal with
Pressure augmentation

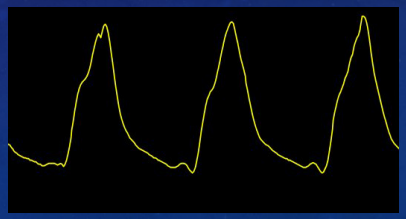
THE PULMONARY VASCULAR SYSTEM

- Large proximal but short compliance vessels.
- *Large Distributed Compliance.*
  - Extensive branching of vessels.
  - Each with its own compliance.
- Low resistance system.



Normal PAP trace





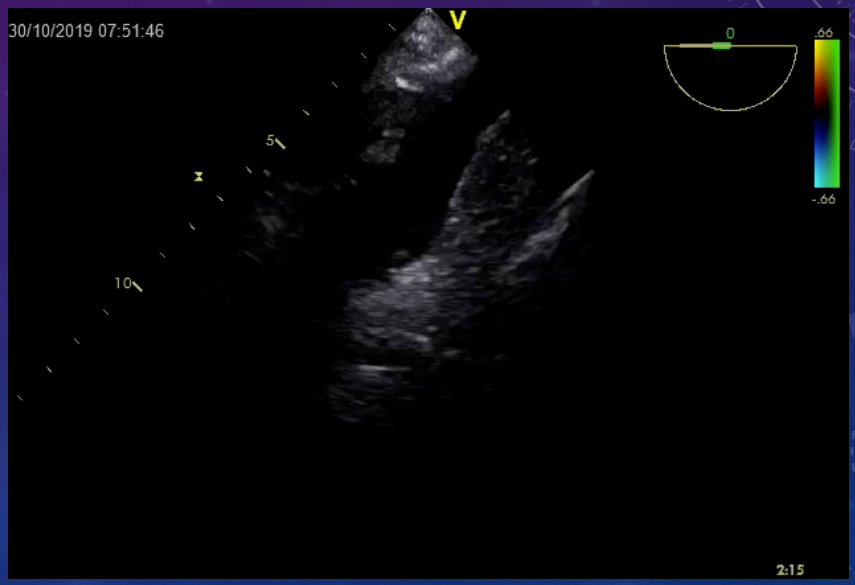
Severely diseased PAP trace

THE PULMONARY CIRCULATION IN CARDIAC DISEASE:

- Most common cause of PHTN in cardiac patients is an elevated LAP.
- “Congestive Vasculopathy”.
  - May become fixed and non modifiable.
  - When extensive, can generate significant reflections.

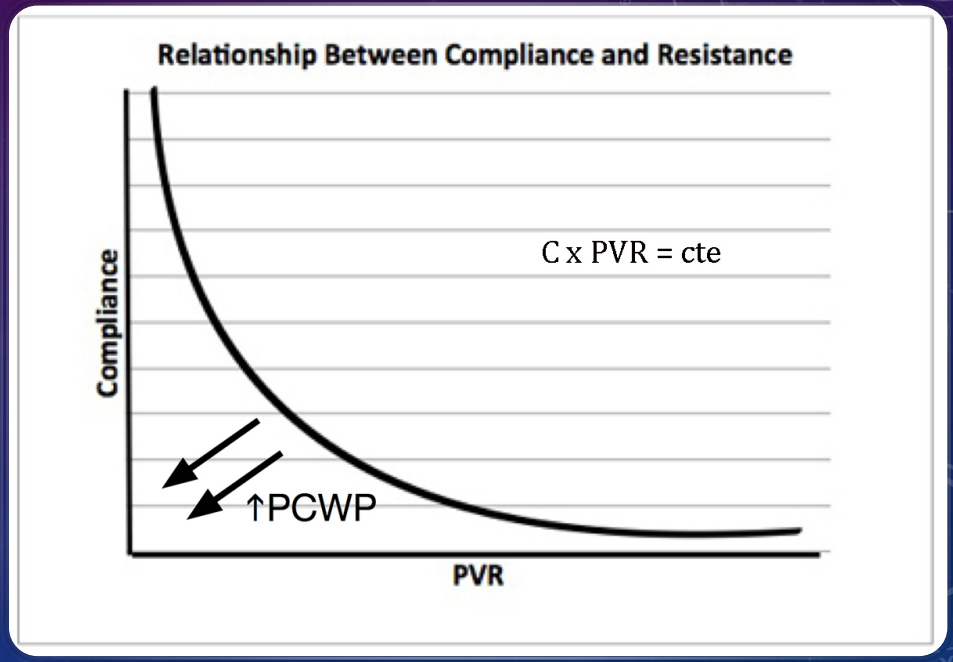
PULMONARY VASCULAR COMPLIANCE

- The pulmonary arteries are normally very compliant.
- Exquisitely sensitive to distal constraints.



PULMONARY COMPLIANCE:

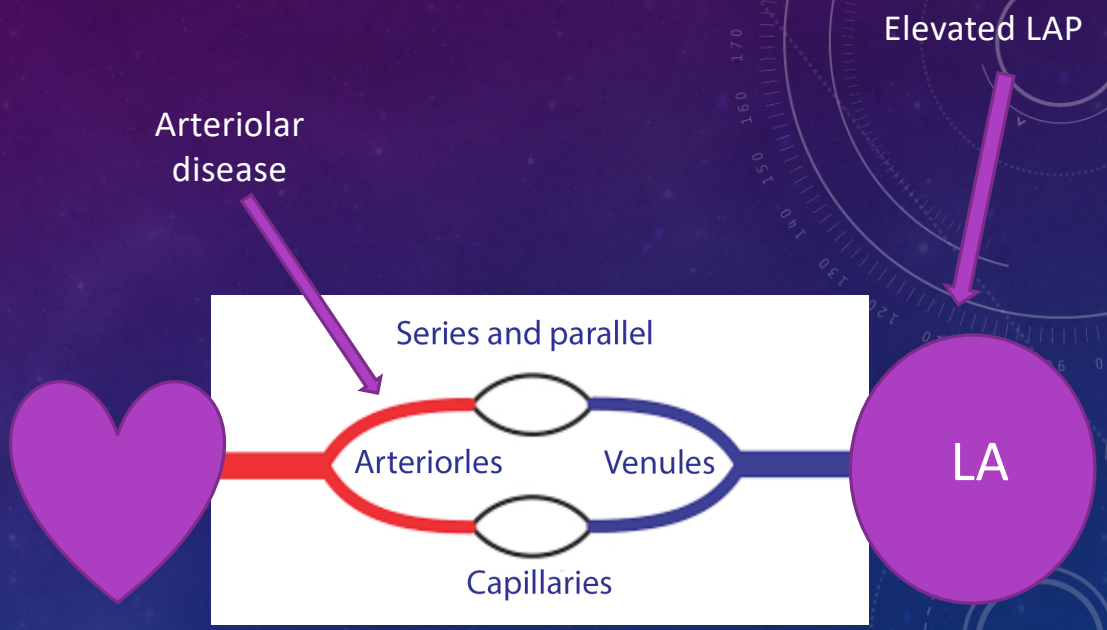
- Large drop in compliance very early in disease.
- LAP is a significant contributor to TOTAL resistance.
- ***Distended vessels have reduced compliance***.



Adapted from Lankhaar 2008

RESISTANCE:

- Steady state measurement:
  - (PAP-PCWP)/CO
- Modified by:
- LAP
- Arteriolar disease.
  - TPG: PAPm – PCWPm.
    - NL: < 12mmHg.
- Total resistance.
  - All the above.

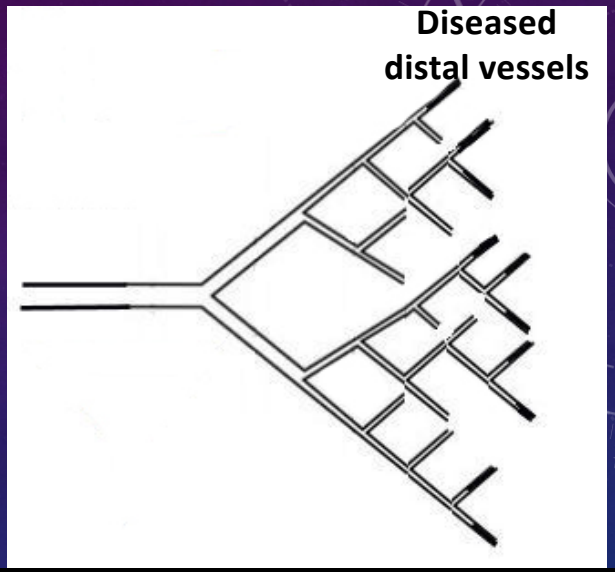


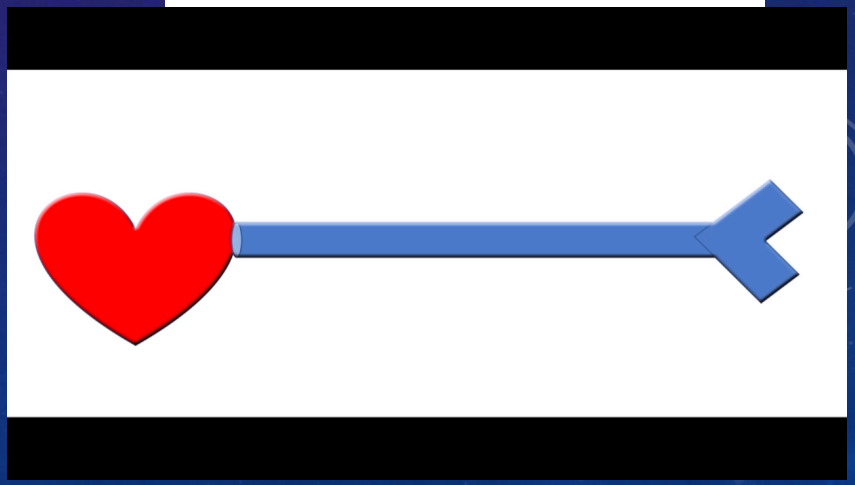
CAPACITANCE:

- Capacitance is a measure of ***pressure response to input volume***.
- CAP = SV/PP
- The larger the PP for a given SV, the worse the capacitance becomes.
- Influenced by:
  - Compliance.
  - Resistance.
  - Loss of *distribution capacity*.
  - Wave reflections.

WAVE REFLECTIONS

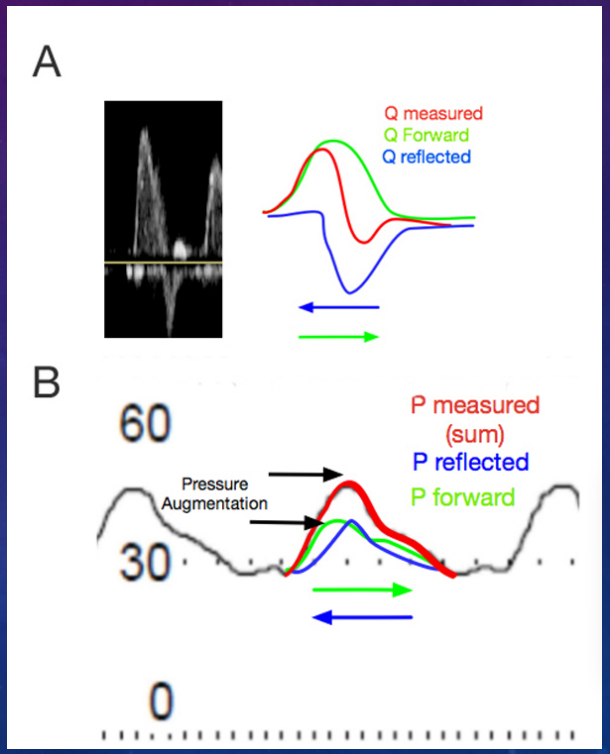
- *Distal arteriolar disease* can generate strong reflections.
- In noncompliant vessels:
  - Wave amplitude maintained.
  - Increased wave speeds:
    - From 1m/s to >2m/s
    - Compounded by short vessels.
- Reflected waves return to the heart.
- ***Depress flow during ejection.***

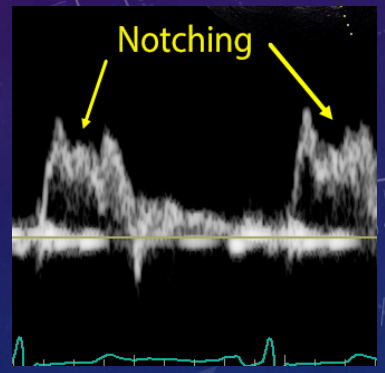


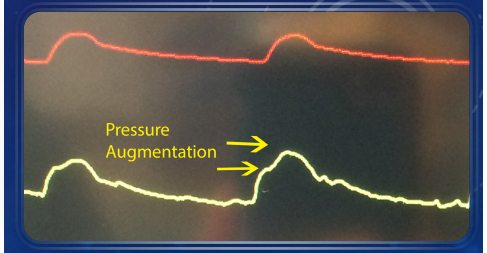


WAVE FLECTIONS: FLOW AND PRESSURE

- **Flow waves** are reflected inversely.
- Depress outgoing flow at PV.
- Flow recovery will produce notching on PWD of PA.
- **Pressure waves** are reflected positively.
- Reflected waves are ***additive***. They AUGMENT pressure.



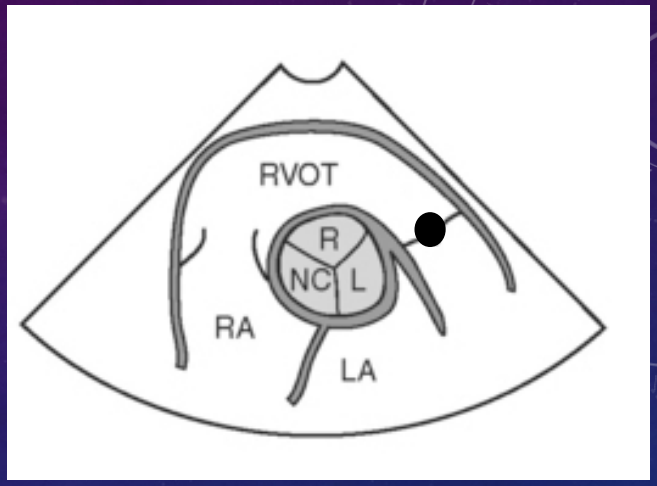




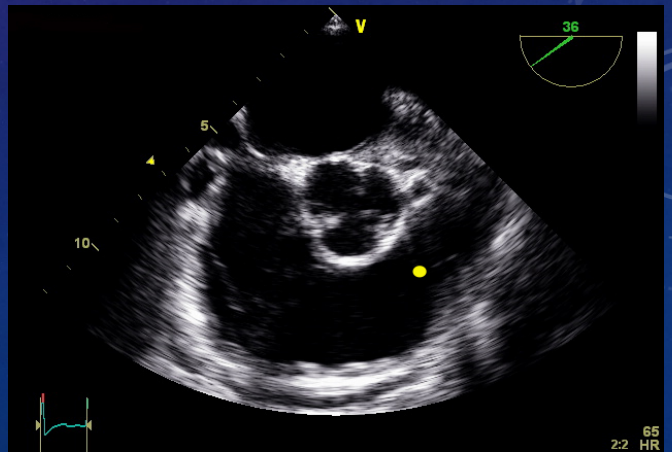
ASSESSING PULMONARY FLOW

- In TTE:
- Parasternal short axis.
- PWD at the level of the pulmonary valve.
- Equivalent TEE view not feasible.

PWD Sampling sites

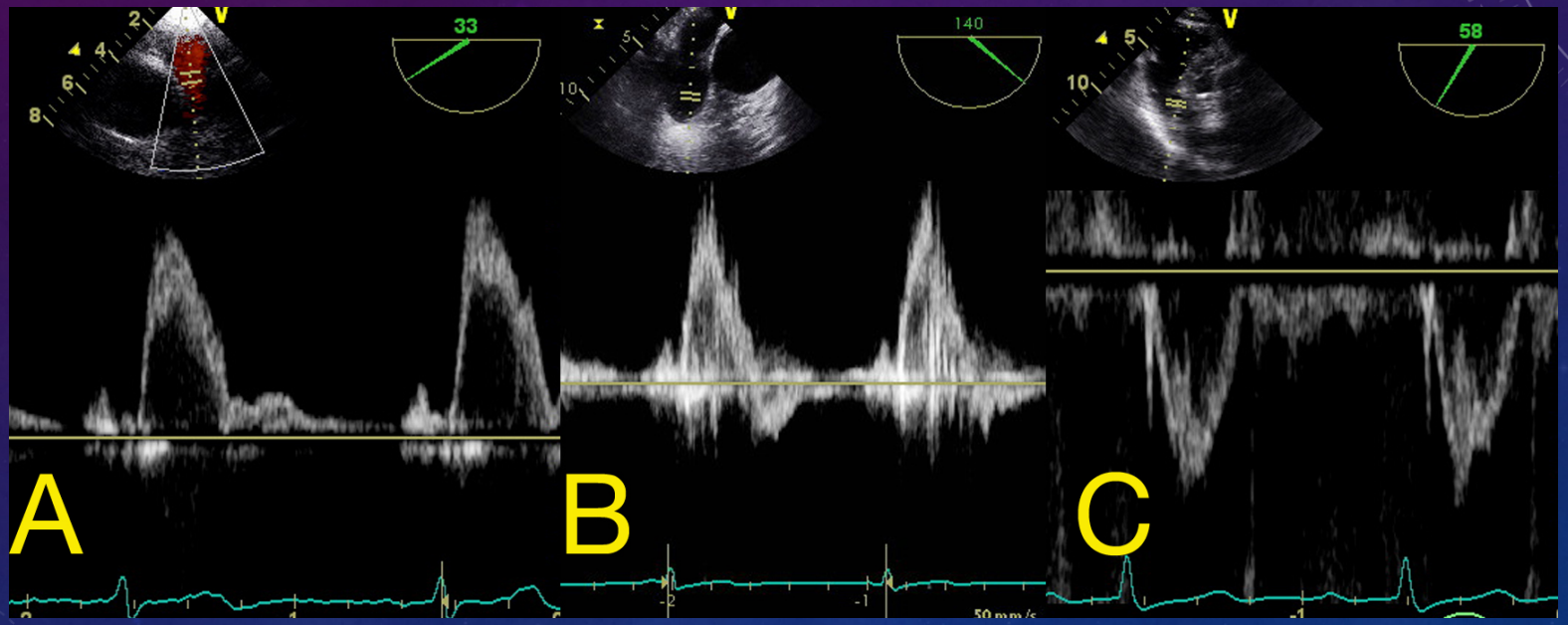


Echocardiography
Sidebotham



TEE OPTIONS

Getting close to PV a struggle in TEE



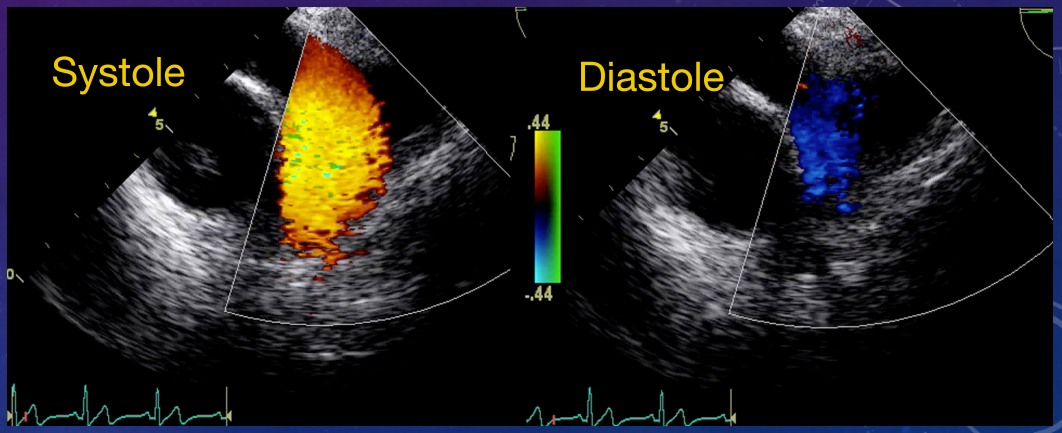
Aortic SAX

Aortic Long
With modification

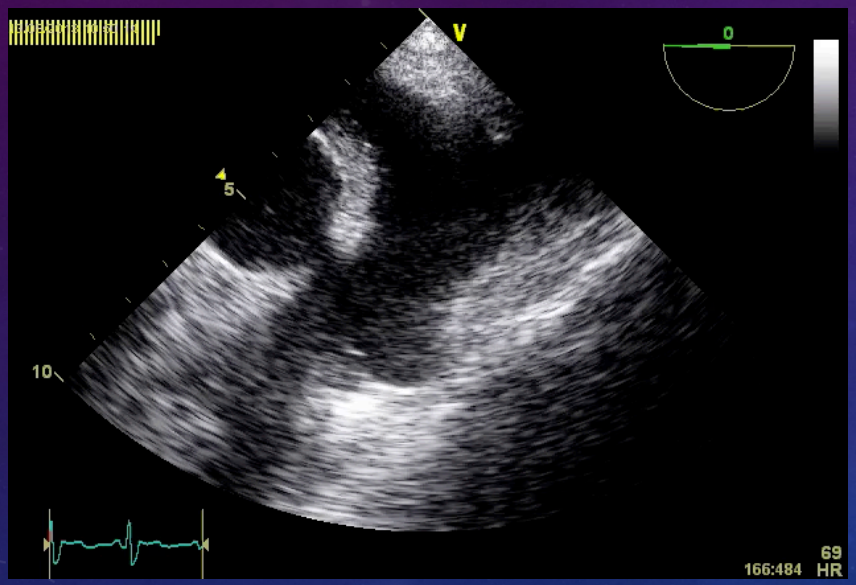
TG RV inflow outflow view

CFD PULMONARY ARTERY:

- Flow pattern uniformly even in systole.
- Some diastolic reversal common.

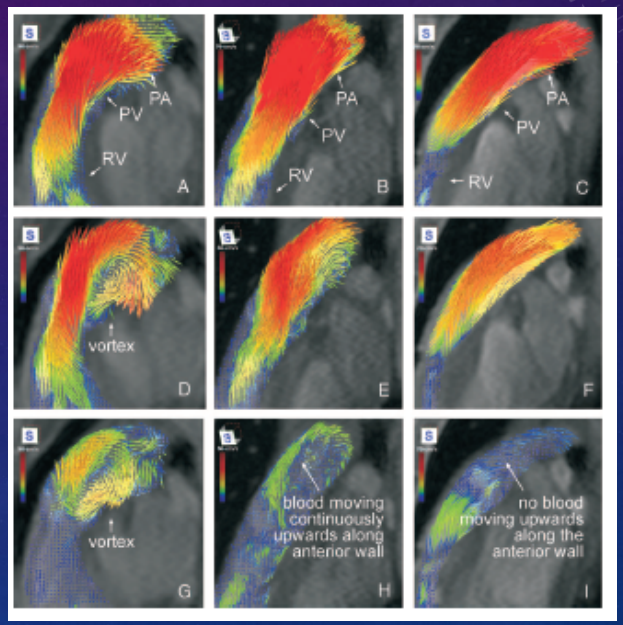


VORTEX FORMATION:



Saline contrast

Reiter *et al*: 2008



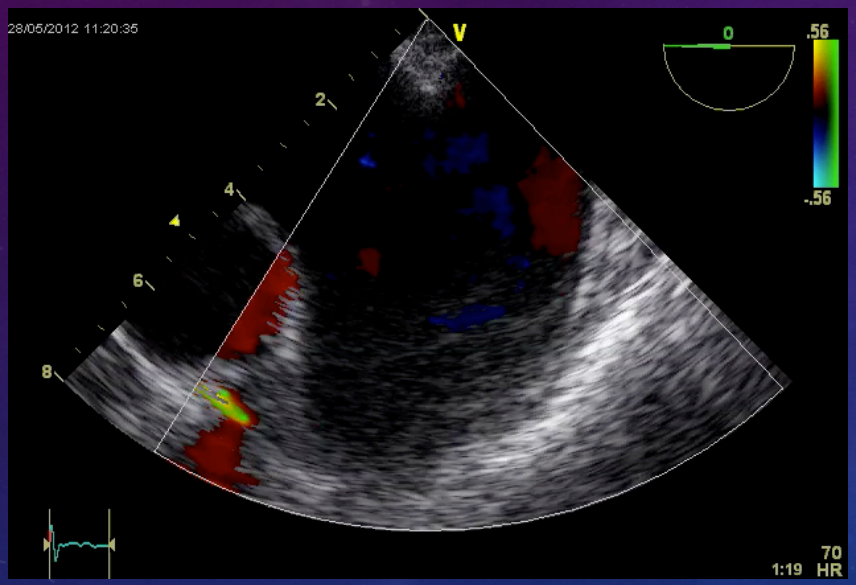
Early systole

Late Systole

Diastole

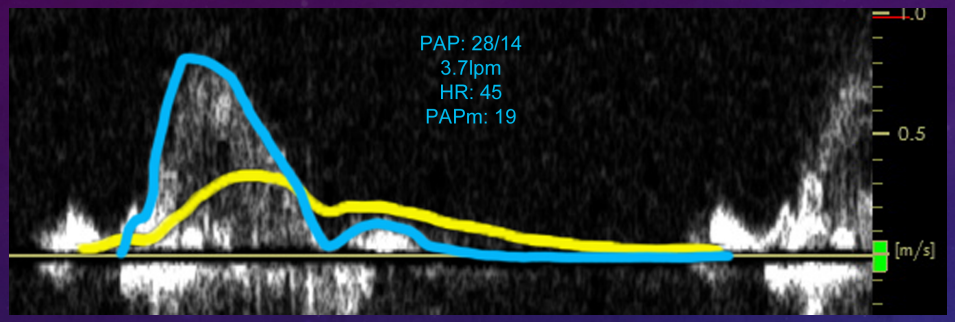
PHTN Latent PTHN Normal

SEVERE PHTN



- Dilated PA.
- Severely disorganized flow with large, expansive vortex.

NORMAL PULMONARY PRESSURE AND FLOW.

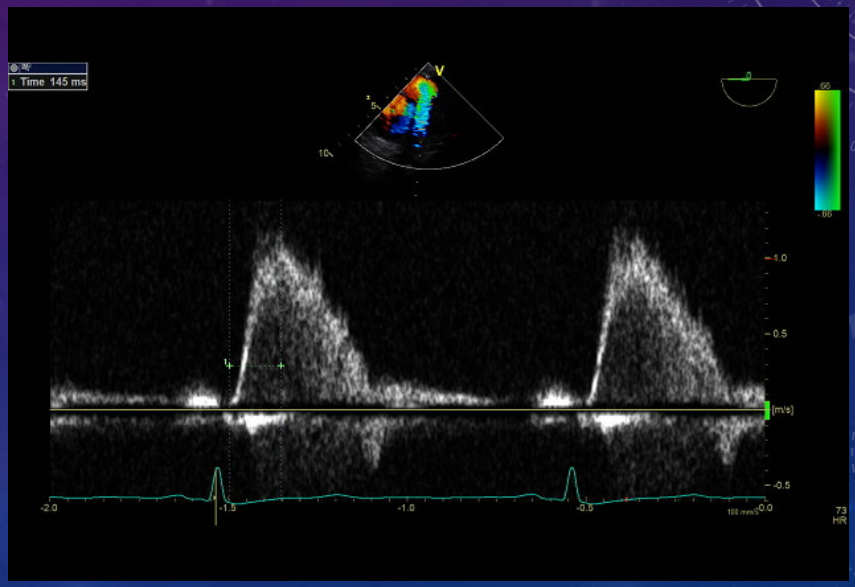


- Both traces *broad and rounded*.
- Flow precedes pressure in high compliance system.

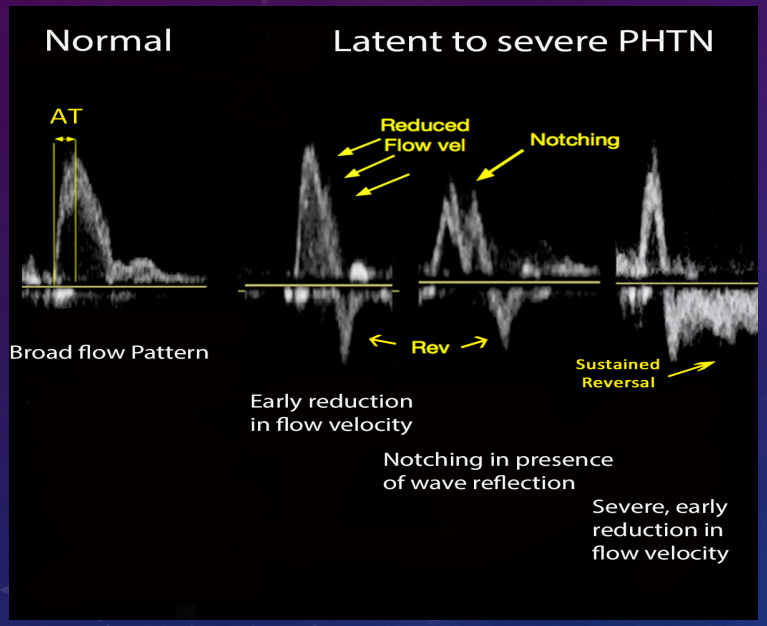
Grade 1 LV cardiac surgery
PAP: 28/14 (19)
Cap: 5.9ml/mmHg
(<0.8 = high mortality)

ACCELERATION TIME

- Time from onset to peak flow velocity at PV.
- Depends on:
  - SV (unreliable in high or low SV).
  - PVR.
  - Wave reflection.
  - Compliance/capacitance.
- *Indicator of severity of distal constraints*
- *Not a reliable estimate of PAP or PVR values.*

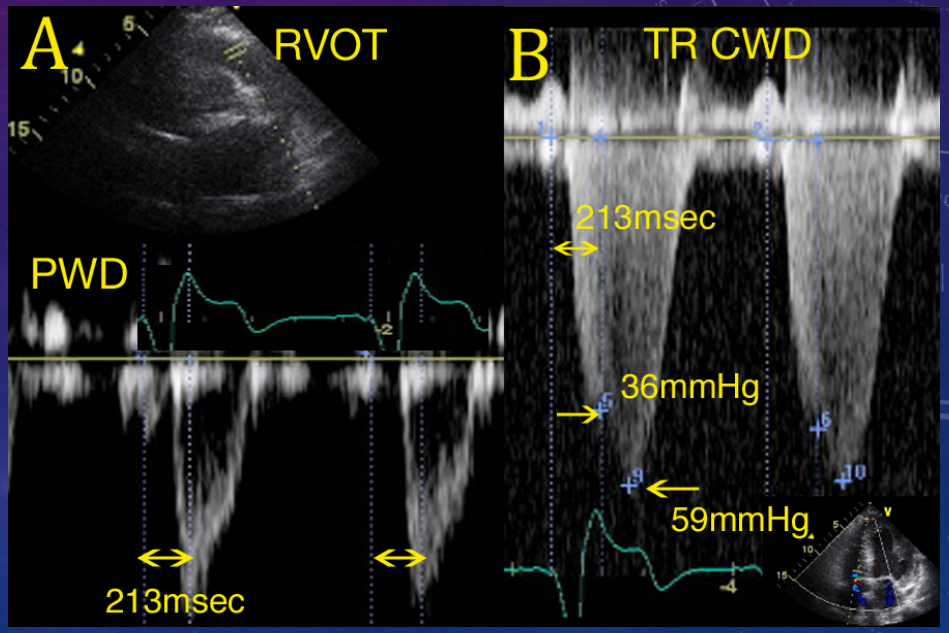


PULMONARY FLOW PATTERNS IN DISEASE



PRESSURE AUGMENTATION BY DOPPLER:

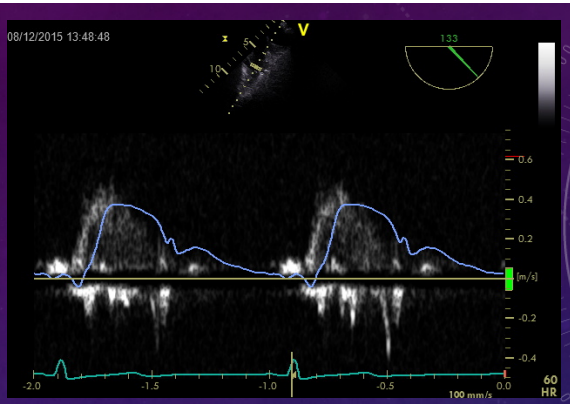
- Doppler Profile:
  - RVOT.
  - Tricuspid regurgitation.
- Time from QRS to peak RVOT flow.
- Time superimposed on TR profile.
  - Pressure difference between this time and peak velocity ($4V^2$) is the pressure augmentation.



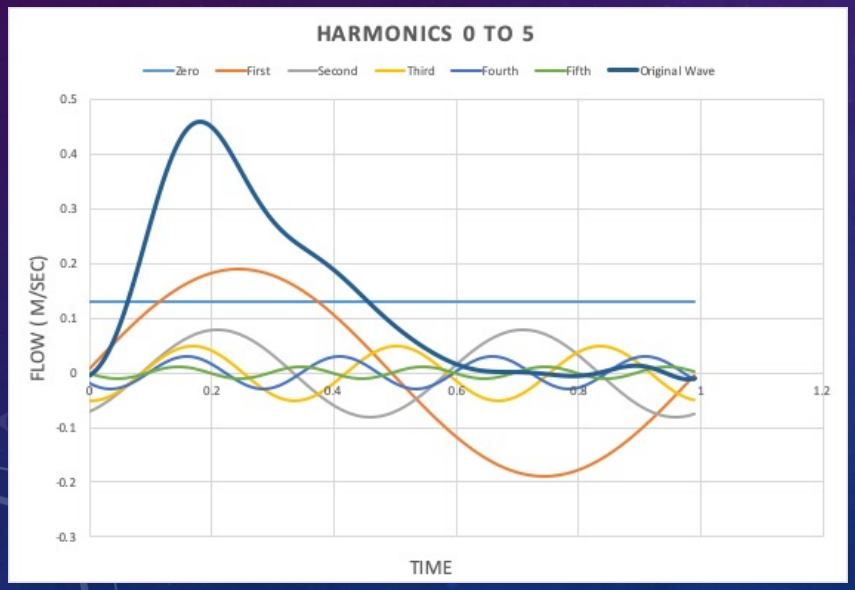
TTE

WAVE DECONSTRUCTION FOURIER TRANSFORMATION

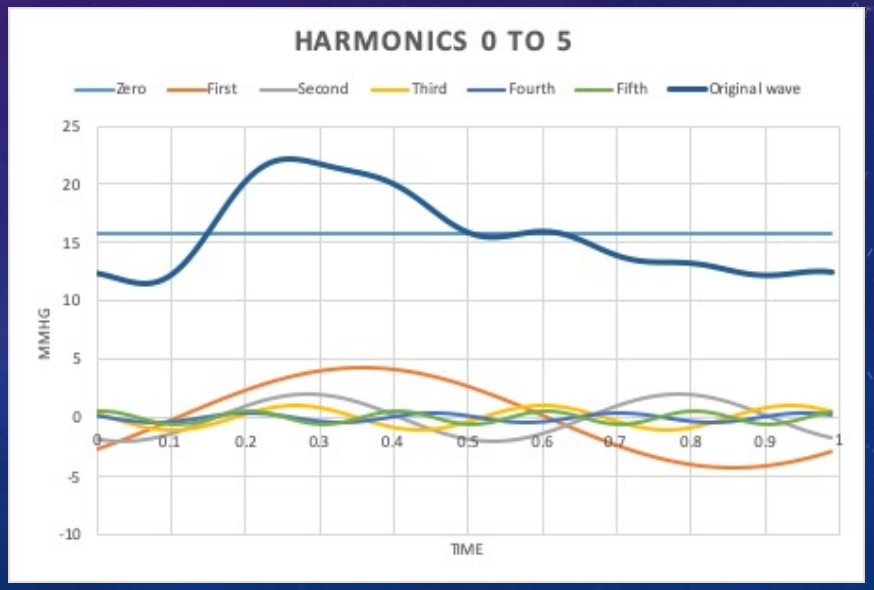
Fundamental frequency = HR
Harmonics of fundamental frequency



Flow

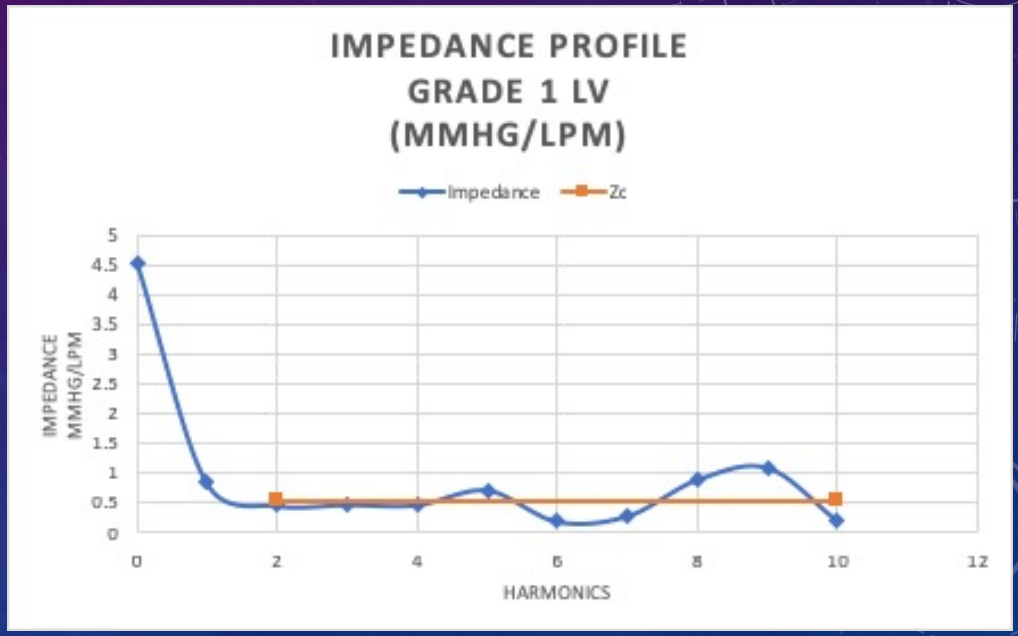


Pressure



IMPEDANCE ANALYSIS: FREQUENCY DOMAIN

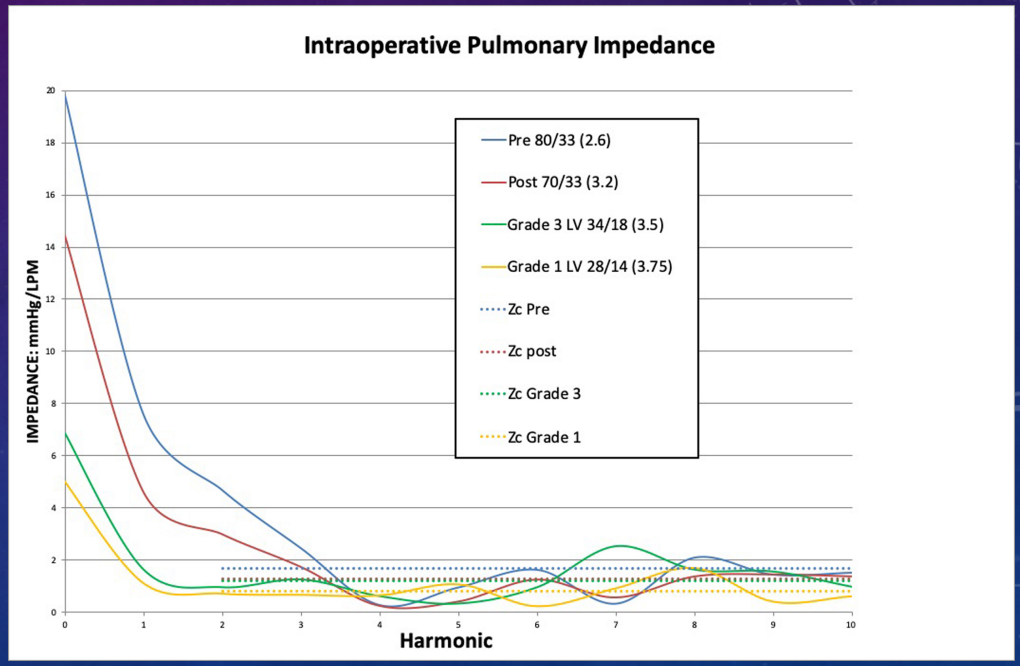
- Impedance: (Z = P/Q) for each harmonic.
- When using echo:
  - Flow velocity converted to Q:
    - (Mean CO = mean Velocity.)
- Harmonics 0 to 10
- Z_0 = ***Total*** resistance.
- Z_{1to3} = large reflections
- Z_c = characteristic impedance:
  - Inertance / compliance.



Low Z_0
Low Z_1 to Z_4
Low Z_c

EFFECT OF VARIOUS DISEASE STATES:

- Severe MR of long duration:
  - Pre inhaled milrinone: 80/33 (2.6lpm).
    - Large oscillations to 3rd harmonic.
  - Post inhaled milrinone: 70/33 (3.2lpm).
    - Reduced oscillations but remain until 3rd harmonic.
- Grade 3 LV:
  - PAP 34/18 (3.5lpm).
- Normal cardiac patient:
  - PAP 28/14 (3.75lpm).



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