Cardiac Physiology: From Infant to Adult

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Pediatric Echocardiography Symposium

Foundations of Congenital Echocardiography

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No disclosures

An Overview of Cardiac Physiology

- The physics of flow
- The path of least resistance
- Compliance
- How physiology changes over our lives

A Quick Jog Down Physics Lane

- Blood flow as it relates to physics

$V = IR$

Voltage across a circuit = Current through a circuit x Resistance

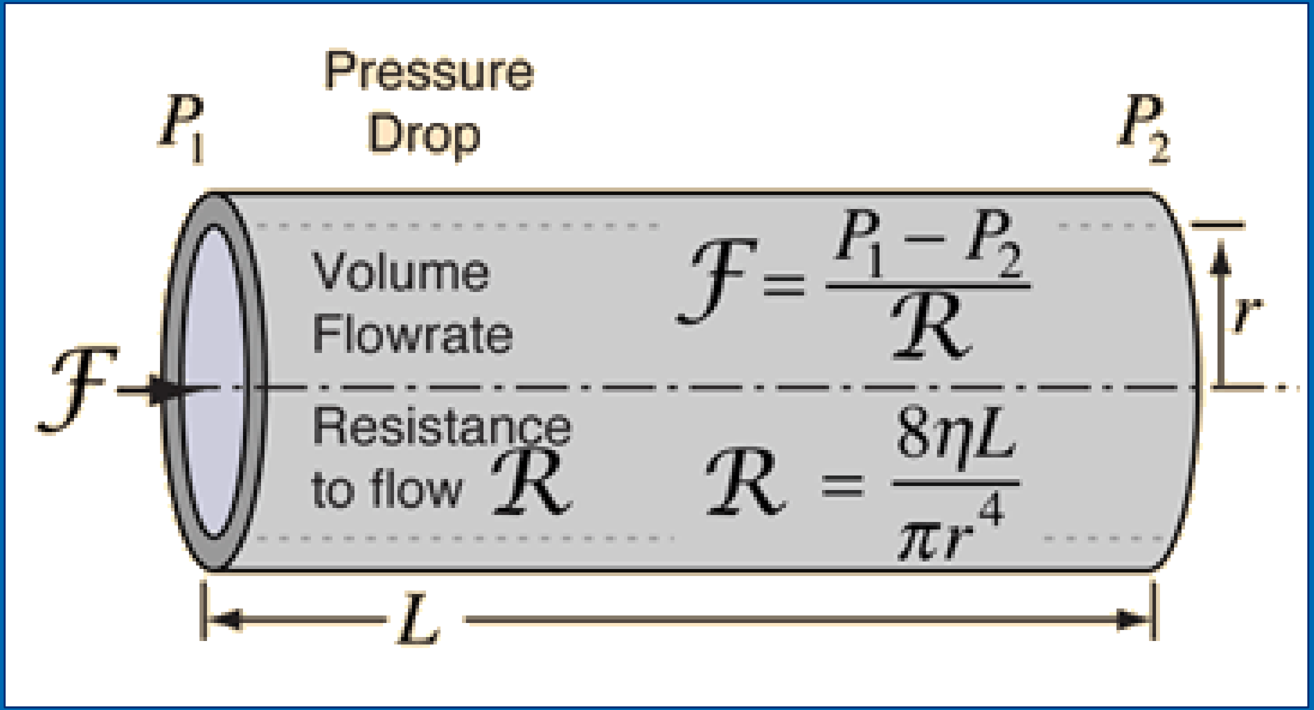
Pressure drop across a vascular bed = Flow through a vascular bed x Resistance to flow

A Quick Jog Down Physics Lane

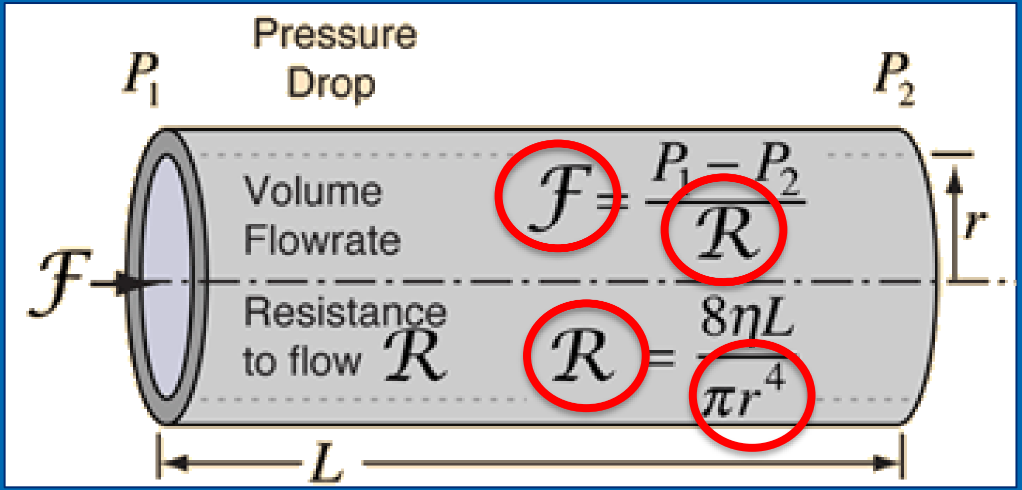
- Poiseuille's Law

Pressure drop across a vascular bed = Flow through a vascular bed x Resistance to flow

$\Delta P = QR \rightarrow \frac{\Delta P}{R} = Q$



Poiseuille's Law



- **Flow** <u>inversely</u> related to **resistance**
  - Lower resistance → increased flow
  - Increased resistance → reduced flow
- **Resistance** <u>inversely</u> related to **radius**
  - Smaller vessel → exponentially increased resistance
  - Larger vessel → exponential reduced resistance

The Path of Least Resistance

The Path of Least Resistance

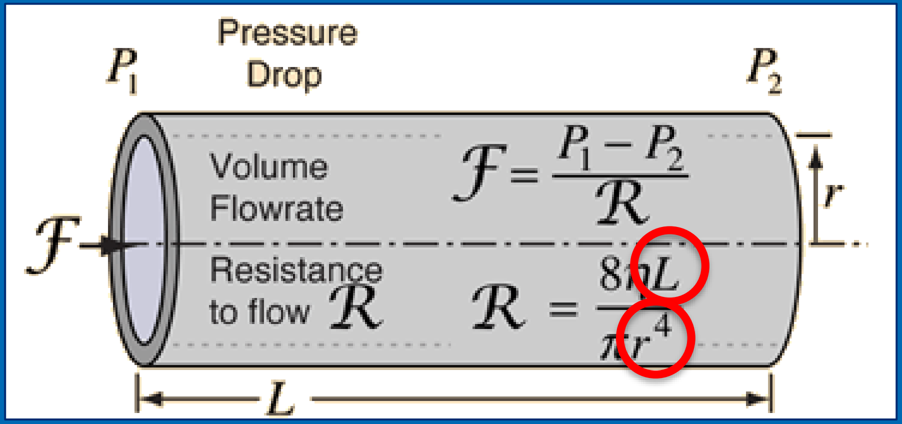
- ***"Blood flows down the path of least resistance"***
  - Flow through the heart and ANY shunt is determined by downstream resistance

The Path of Least Resistance

- What is downstream?
  - Depends on the location of interest & a patient's physiology
  - Atrial septal defect – atria, atrioventricular valves, ventricles
  - Ventricular septal defect – ventricles, outflow tracts, semilunar valves, arterial resistance

The Path of Least Resistance

- Factors that affect resistance to flow:
  - Size & length of a shunt or vessel
  - Compliance of a chamber



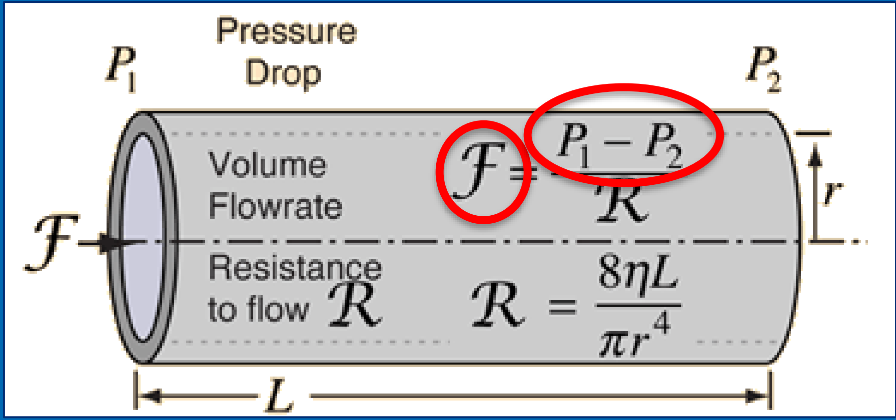
Compliance $= \frac{\Delta V}{\Delta P}$

- The relationship between volume & pressure
  - High compliance – large volume increase with minimal pressure
    - "soft," easy to expand

  - Low compliance – minimal volume increase despite high pressure
    - "stiff," difficult to expand

The Path of Least Resistance

- *Resistance determines* the *direction* of a shunt
- The *pressure gradient determines* the *velocity* of a shunt
  - Increased pressure gradient leads to higher velocity flow
  - **Modified Bernoulli** $\Delta P = 4V^2$



Newborn Physiology

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Fetal
~~Newborn~~ Physiology

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Fetal Physiology

- In a fetus, the RV does as much/more cardiac output as the LV
  - Functions as a systemic ventricle:
    - Pumping against lungs (pulmonary vascular resistance, PVR); minimal pulmonary blood flow
    - Also to the body via the PDA (systemic vascular resistance, SVR)
  - RV typically similar size and wall thickness as the LV
  - LV supplies ascending aorta
  - RV supplies much of the descending aorta
- IVC & oxygenated ductus venosus flow directed across the atrial septum
  - Right-to-left shunt, → LV → ascending aorta → brain & coronaries

Fetus → Newborn

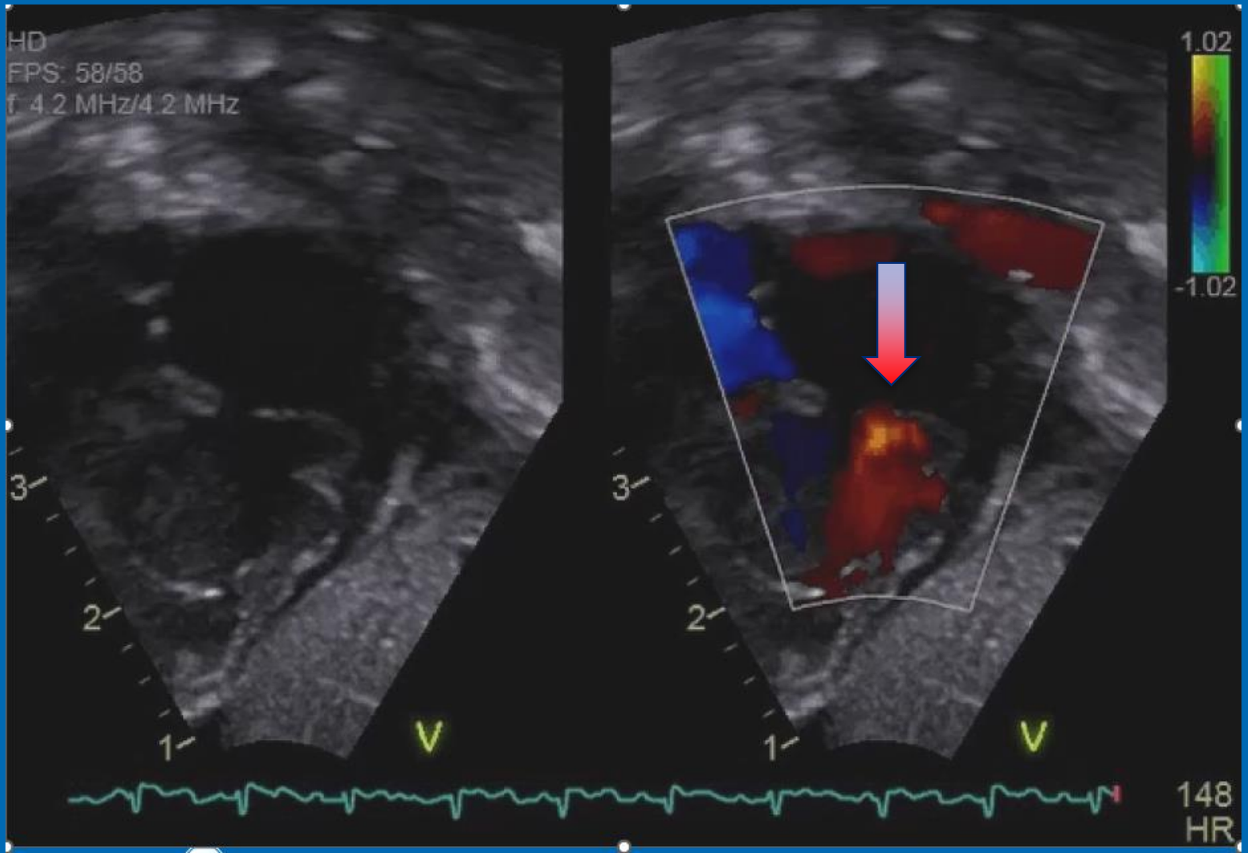
- A baby is born!
  - Stimulate crying to expand the lungs and clear fluid
    - Dramatic increase in pulmonary blood flow & return
  - Clamp the umbilical cord
    - Lose oxygenated ductus venosus flow
    - All oxygenation now from the lungs

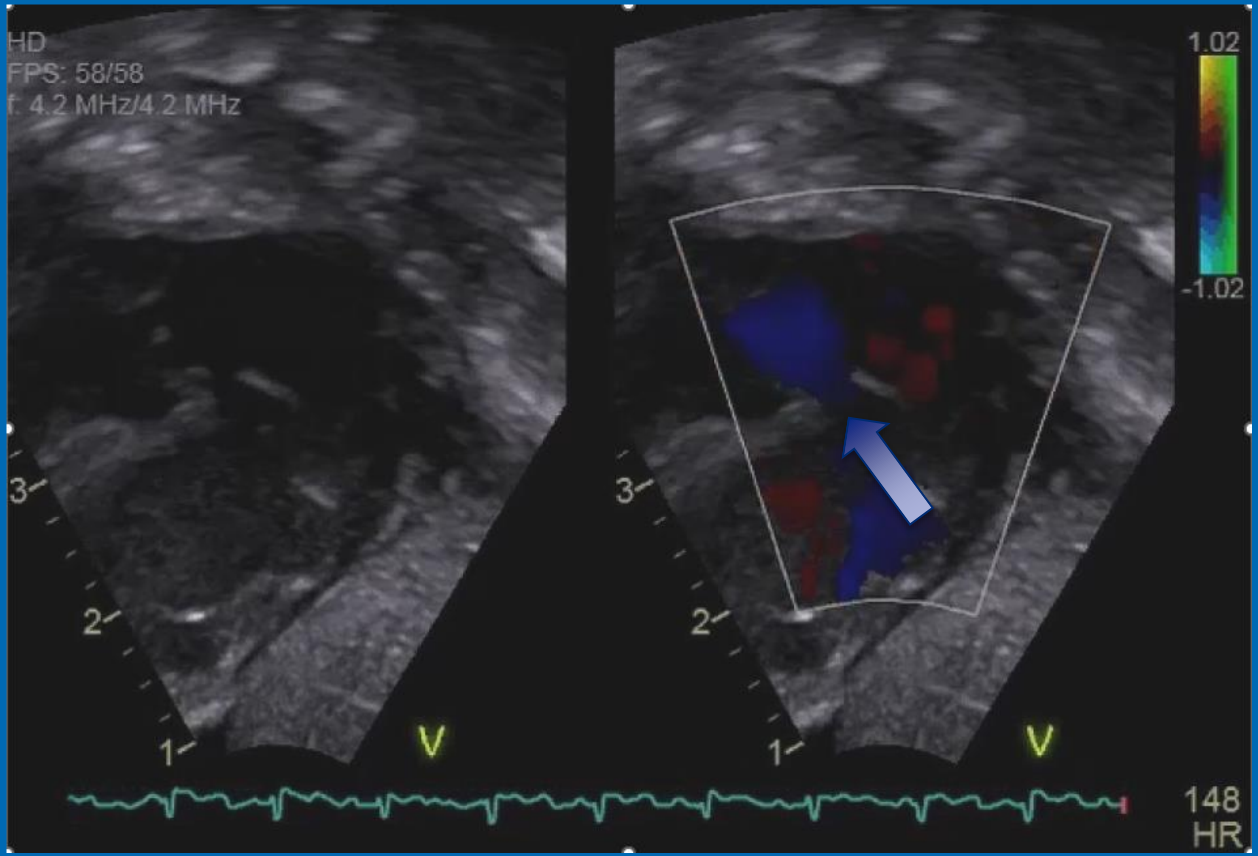
Newborn Physiology

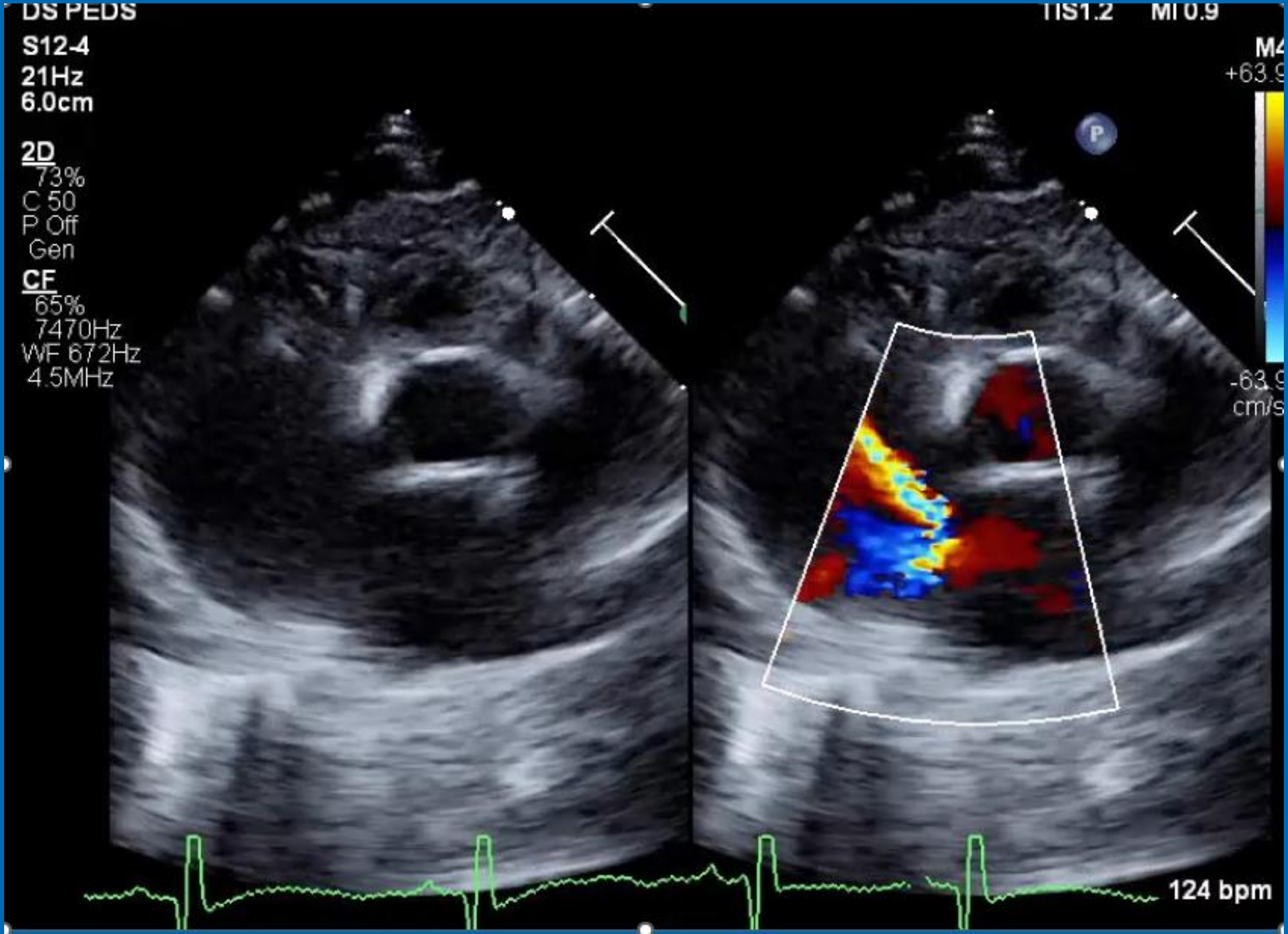
- The RV is as large & thick as the LV
  - Similar ventricular (and atrial) compliance
    - Atrial shunts are thus typically bidirectional
- The lungs are full of fluid at birth
  - PVR is high, close to SVR
  - VSD's and PDA's often bidirectional, low velocity
    - Often inaudible
  - Septal flattening is present


HD
FPS: 161/
f: 6.0 MHz/6.0 MHz
4
2
V
153
HR

PFO bidirectional



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S12-4
21Hz
6.0cm
2D
73%
C 50
P Off
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65%
7470Hz
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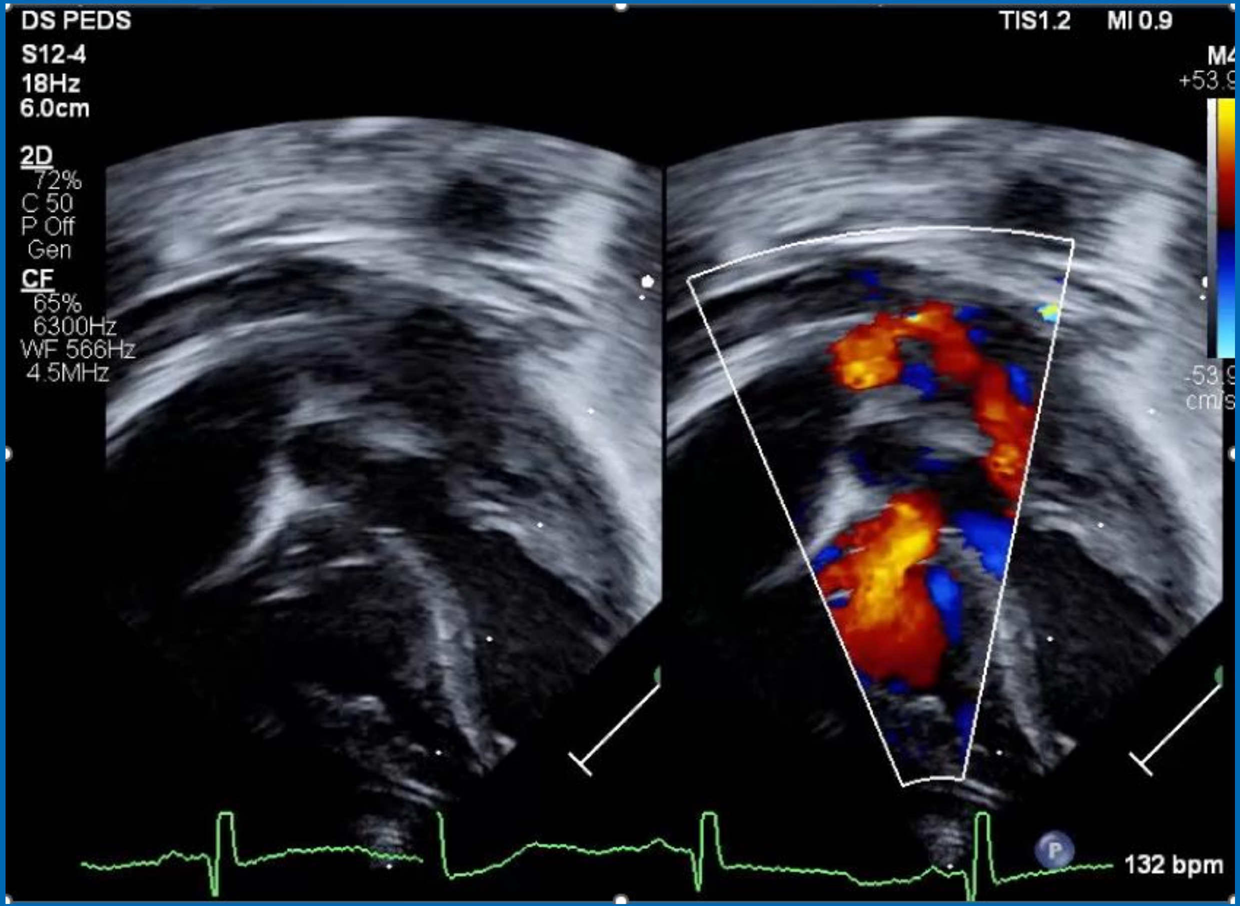
TIS1.2
MI 0.9
P
124 bpm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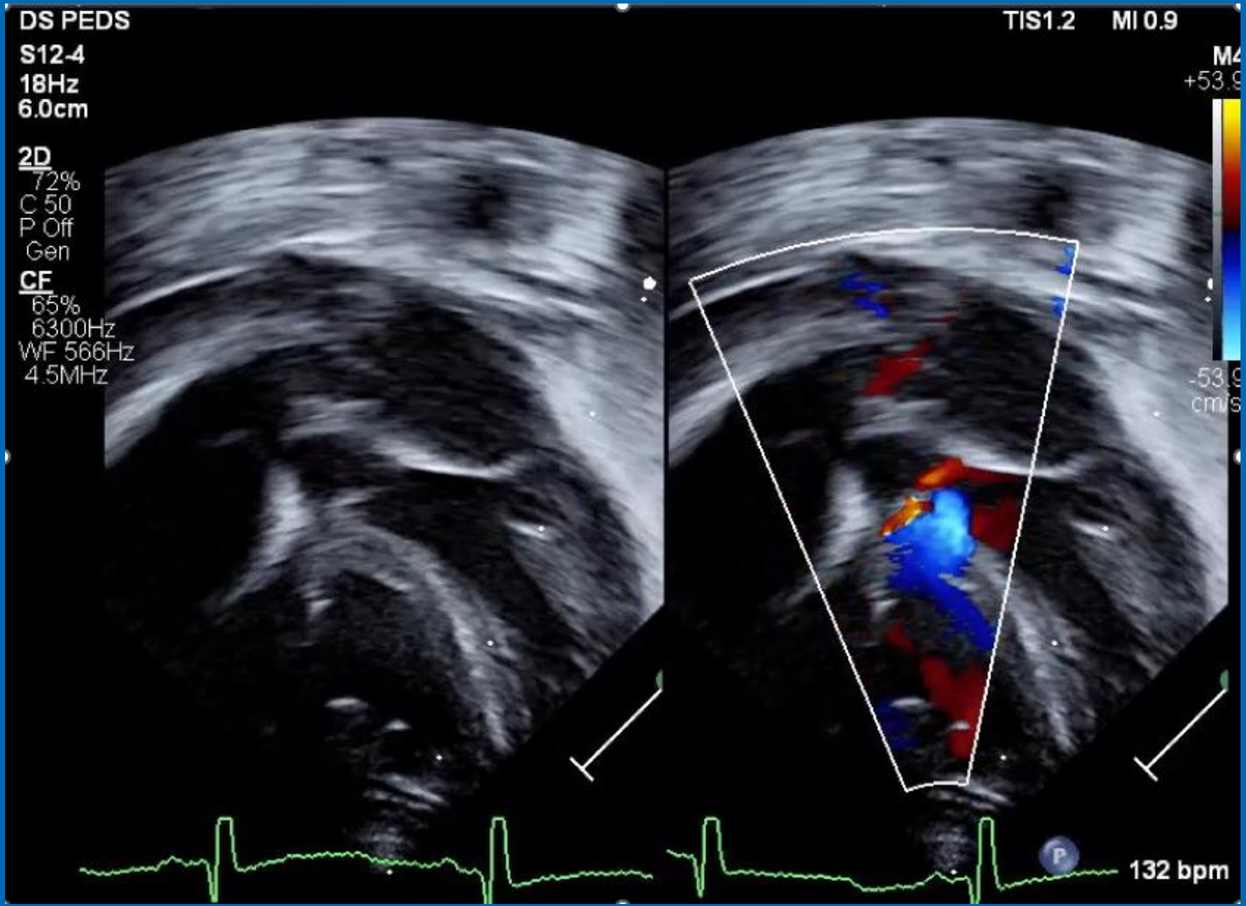
MI 0.9
132 bpm


DS PEDS
S12-4
18Hz
6.0cm
2D
72%
C 50
P Off
Gen
CF
65%
6300Hz
WF 566Hz
4.5MHz
TIS1.2
MI 0.9
132 bpm

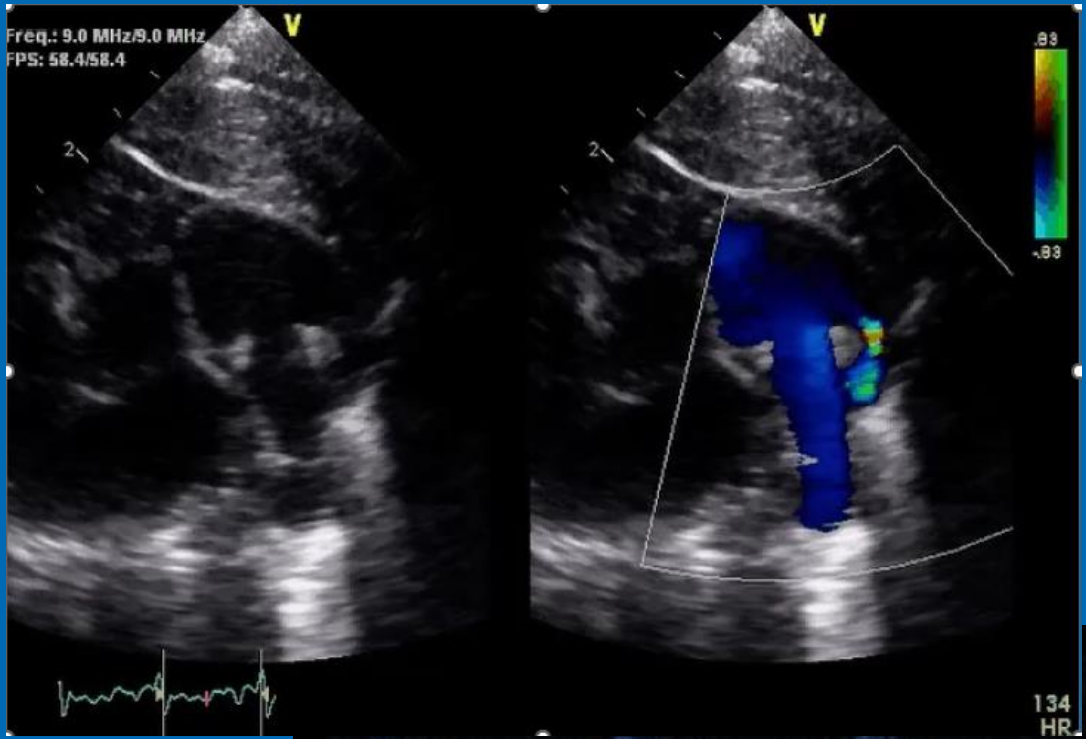
4 hours of life

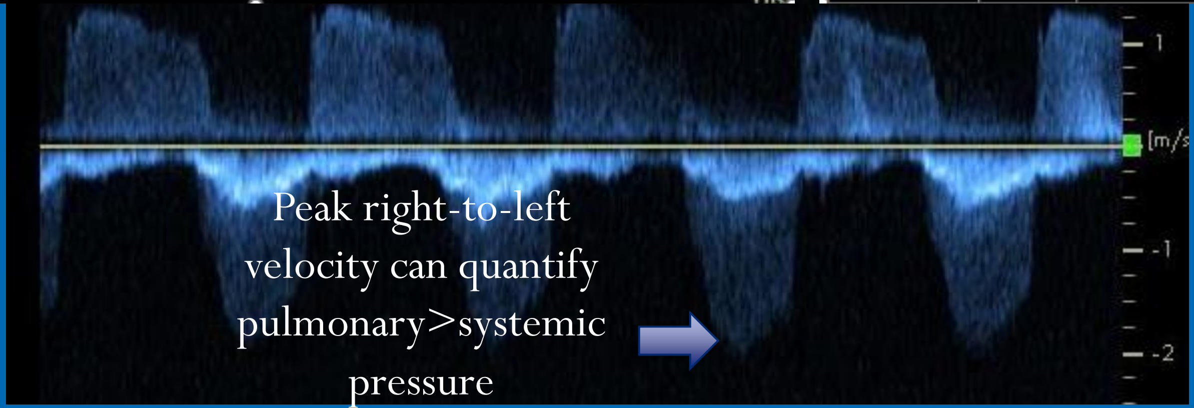
Small PDA

Bidirectional

High PVR

Suprasystemic pulmonary pressure





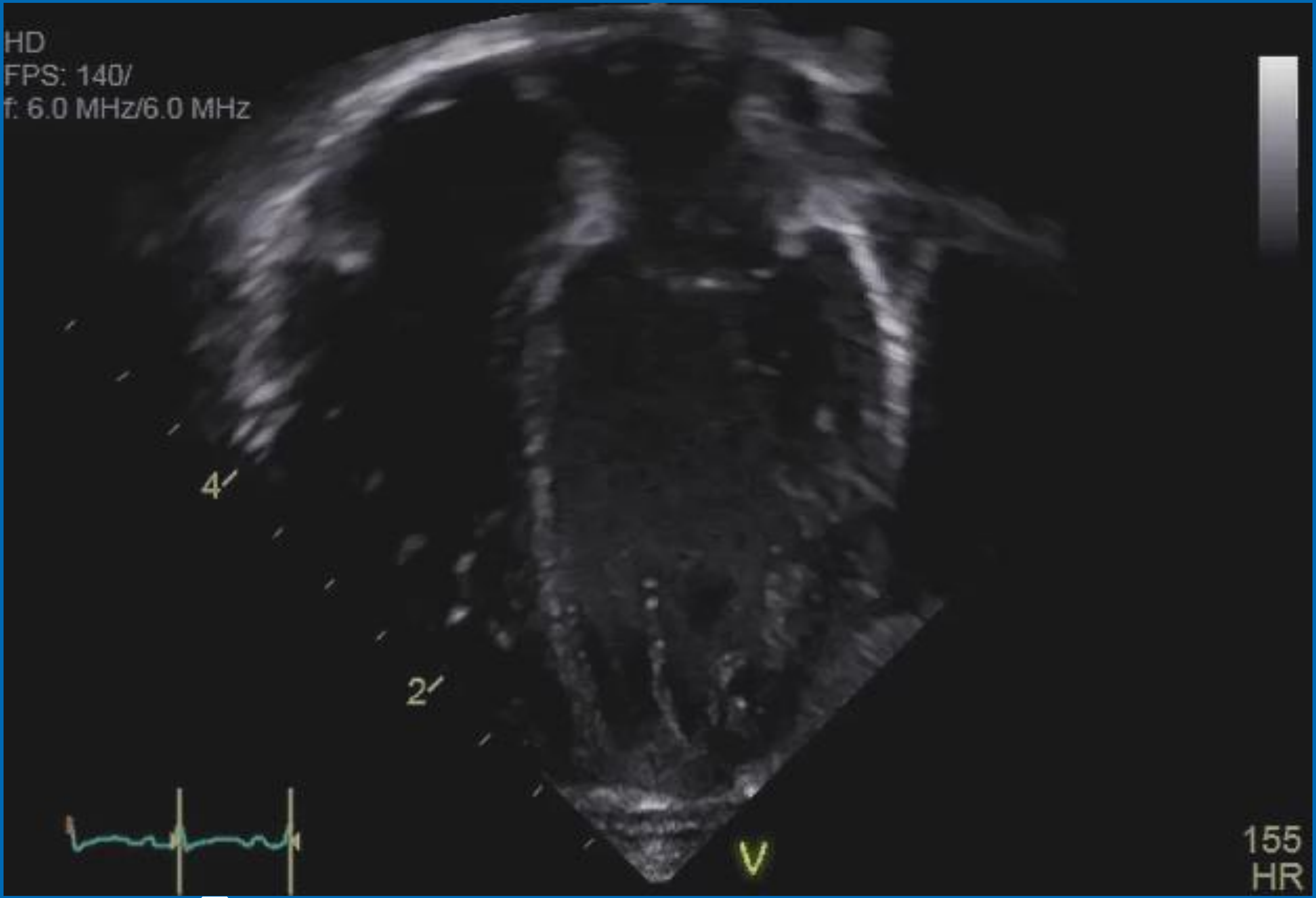
Peak right-to-left velocity can quantify pulmonary>systemic pressure

Newborn → Childhood Physiology

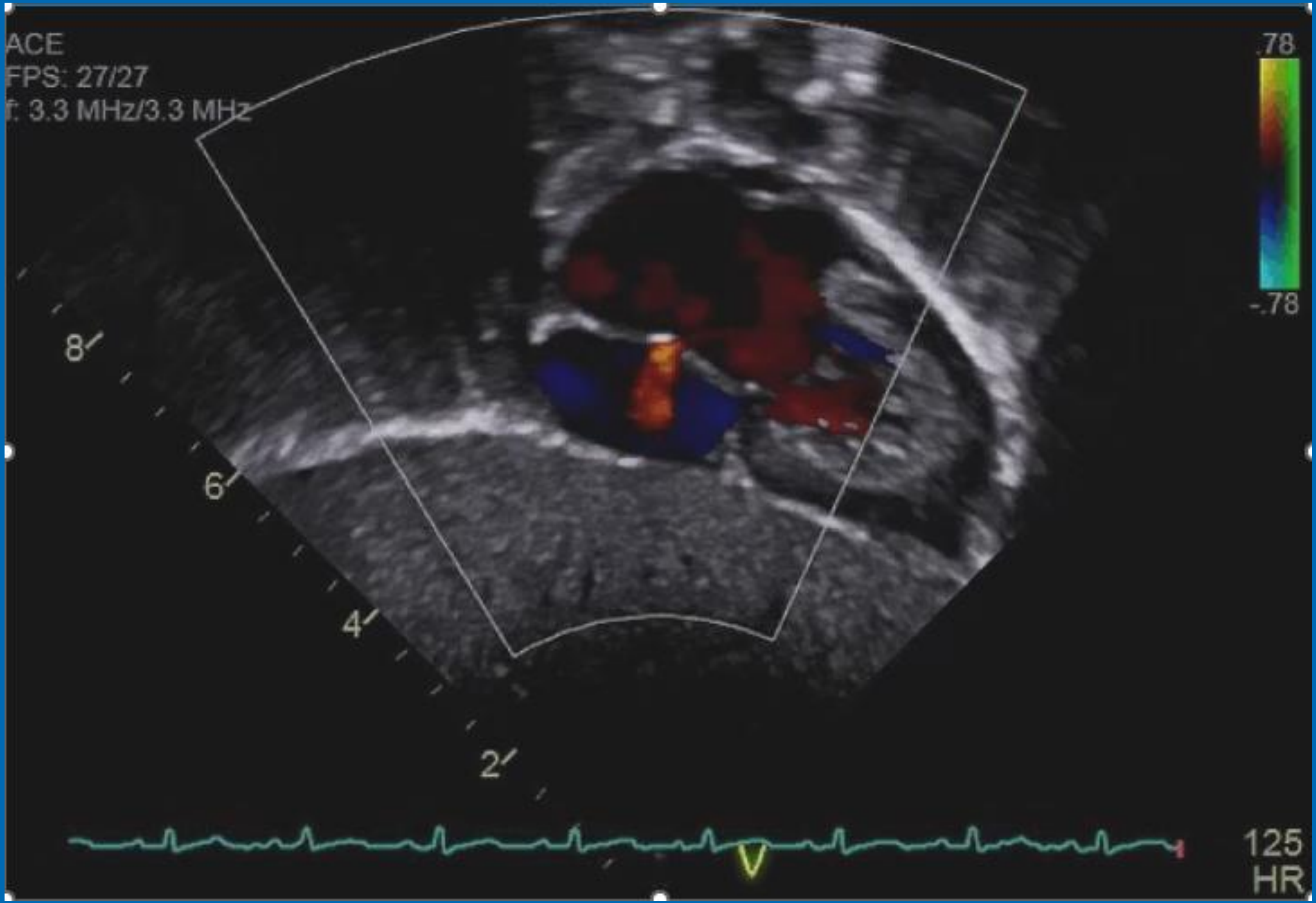
- PVR nadirs over next 6-8 weeks of life
  - RV thins
    - RV becomes more compliant than LV
      - Atrial shunts thus shift to left-to-right
  - RV gets smaller

Newborn → Childhood Physiology

- PVR nadirs over next 6-8 weeks of life
  - Shunts become to left-to-right
  - Pressure drops in right heart
    - ↑ interventricular or interarterial pressure gradient = ↑ velocity across shunts
    - $\Delta P = 4V^2$
    - Shunts are thus more audible
  - Septal curvature normalizes (circular, no flattening)


HD
FPS: 140/
f: 6.0 MHz/6.0 MHz
4
2
V
155
HR

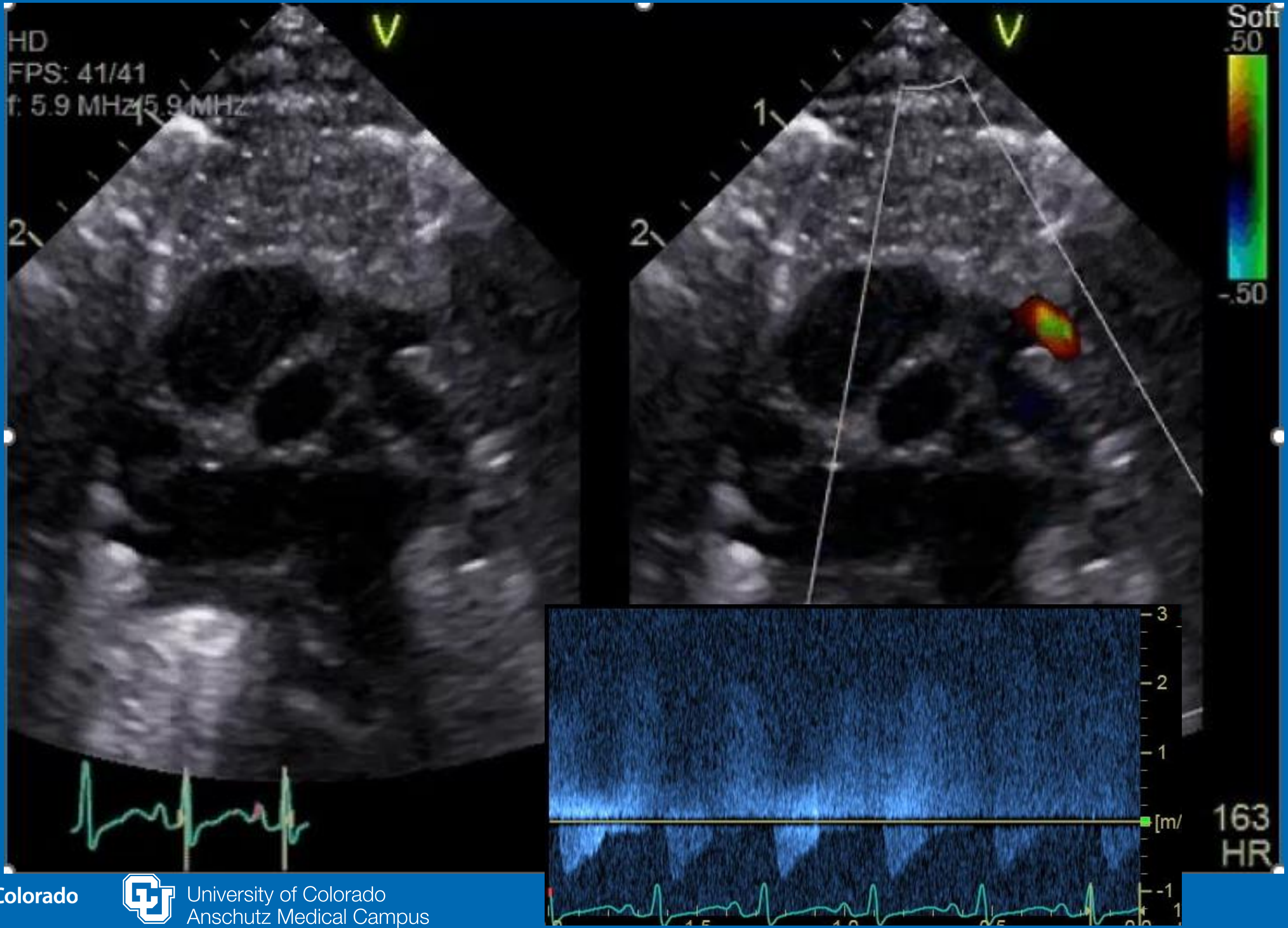
PFO
left-to-right



4 days of life

Small PDA

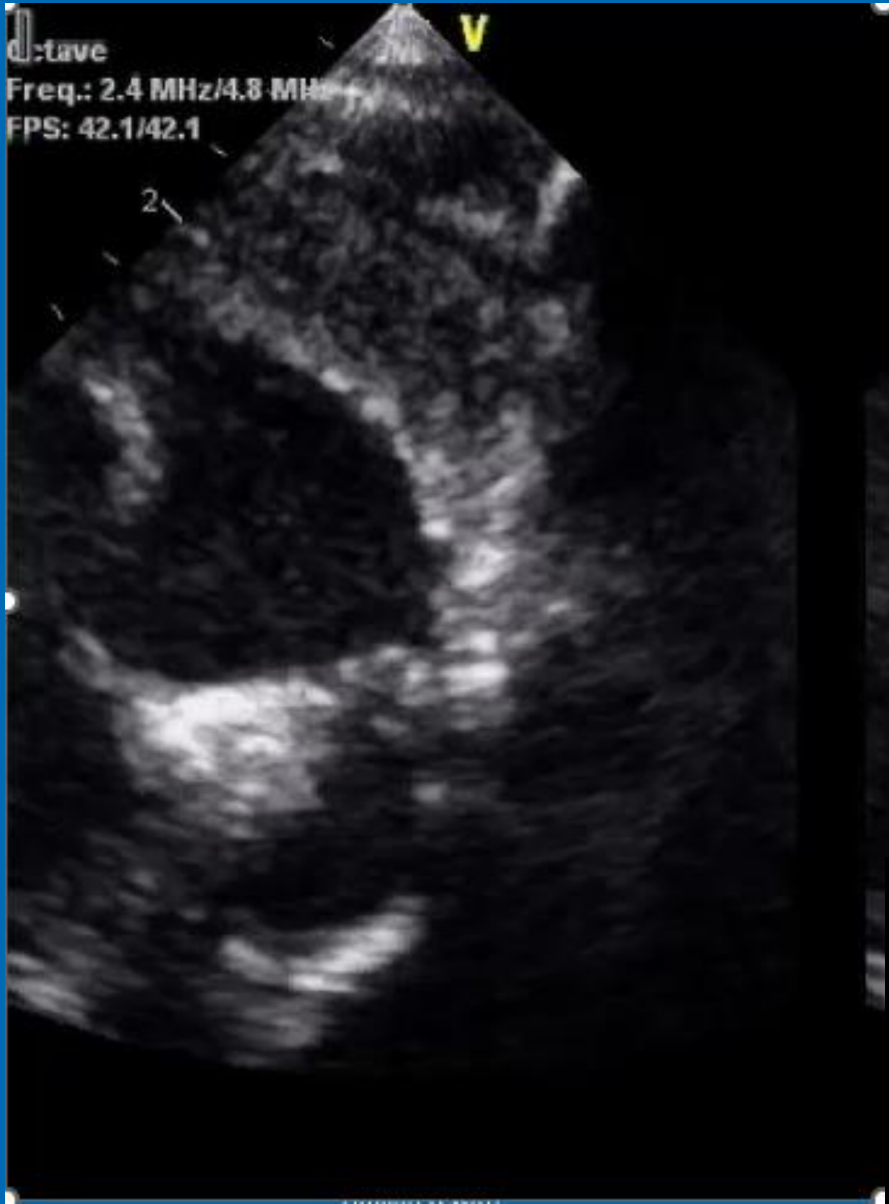
Continuous
left-to-right
Vm 2.2 m/s

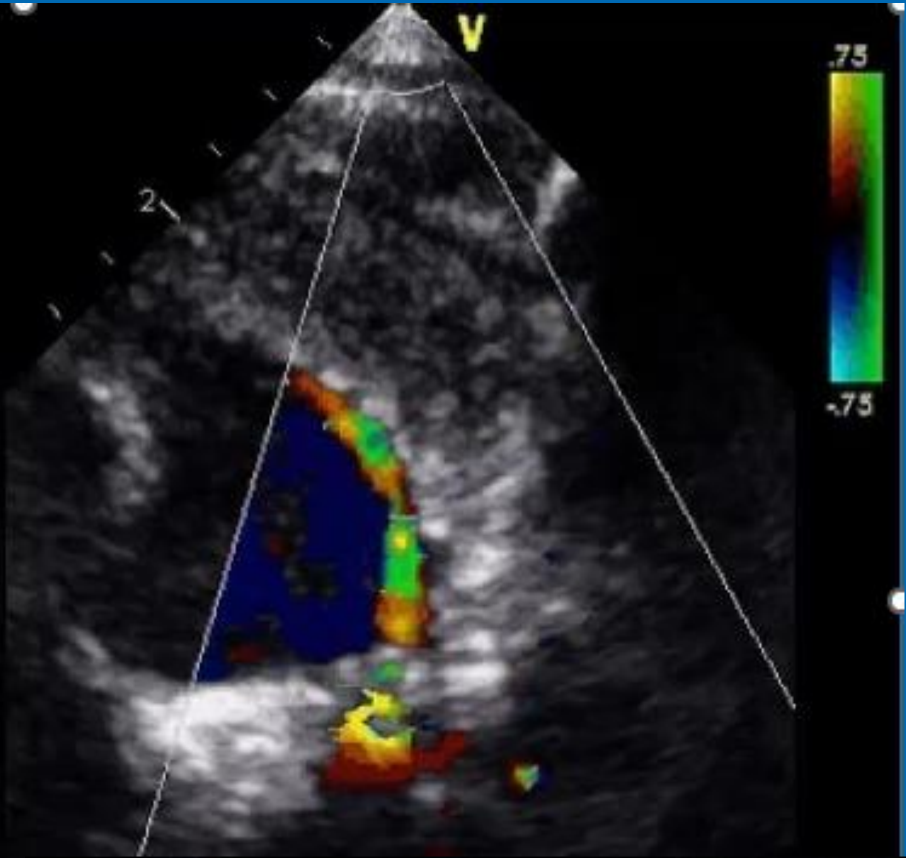


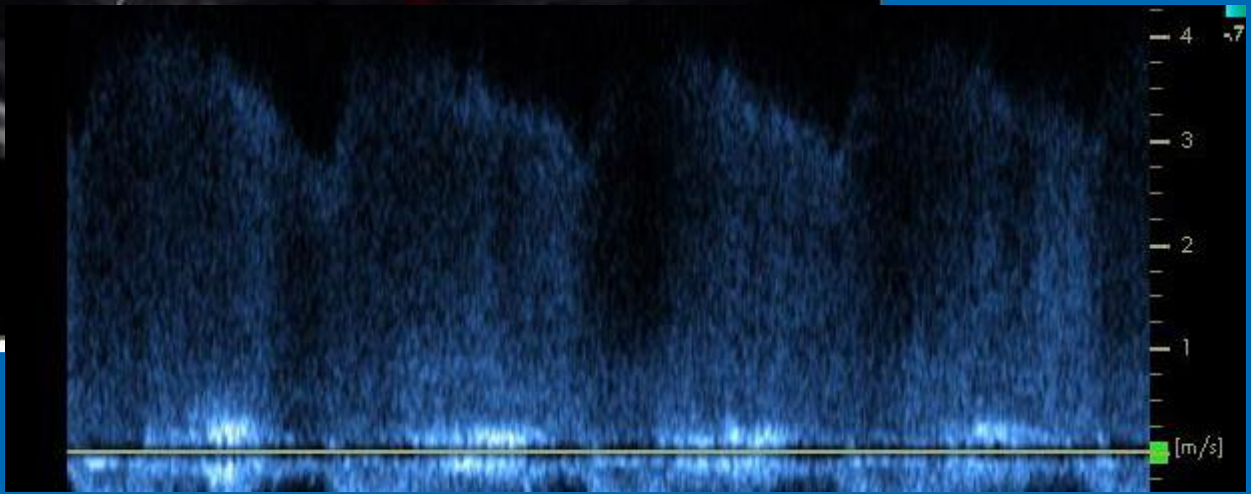
1 month old

Small PDA

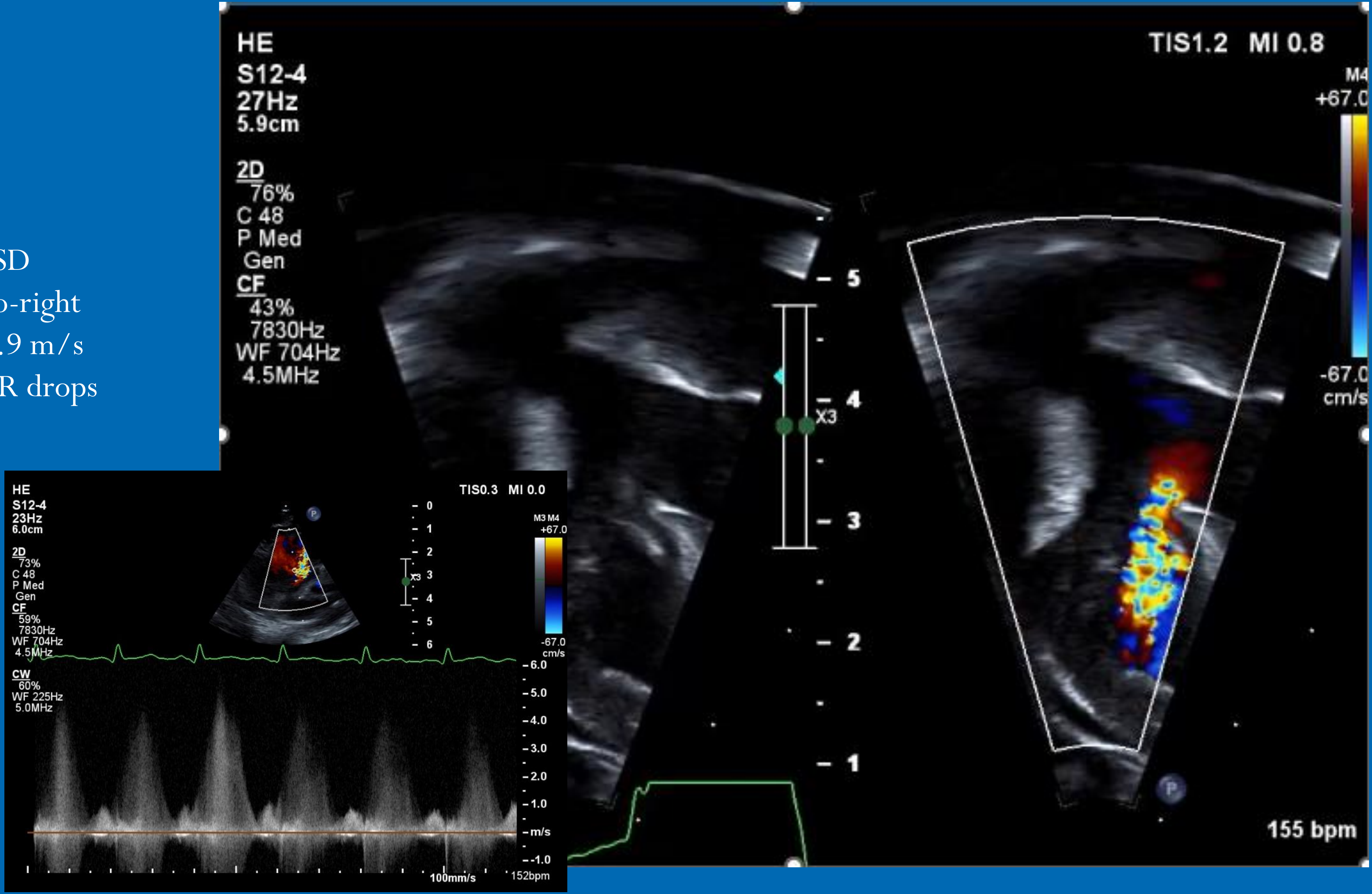
Continuous
left-to-right
Vm 4 m/s
As PVR drops







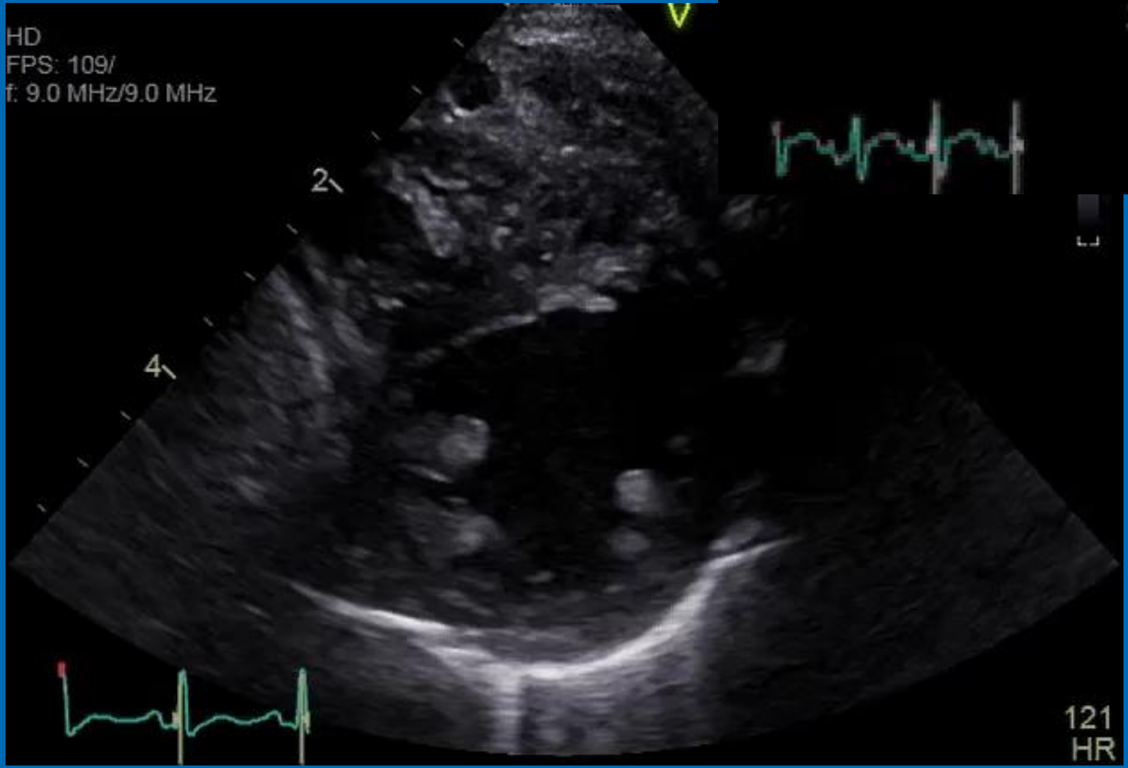
VSD
left-to-right
Vm 4.9 m/s
As PVR drops

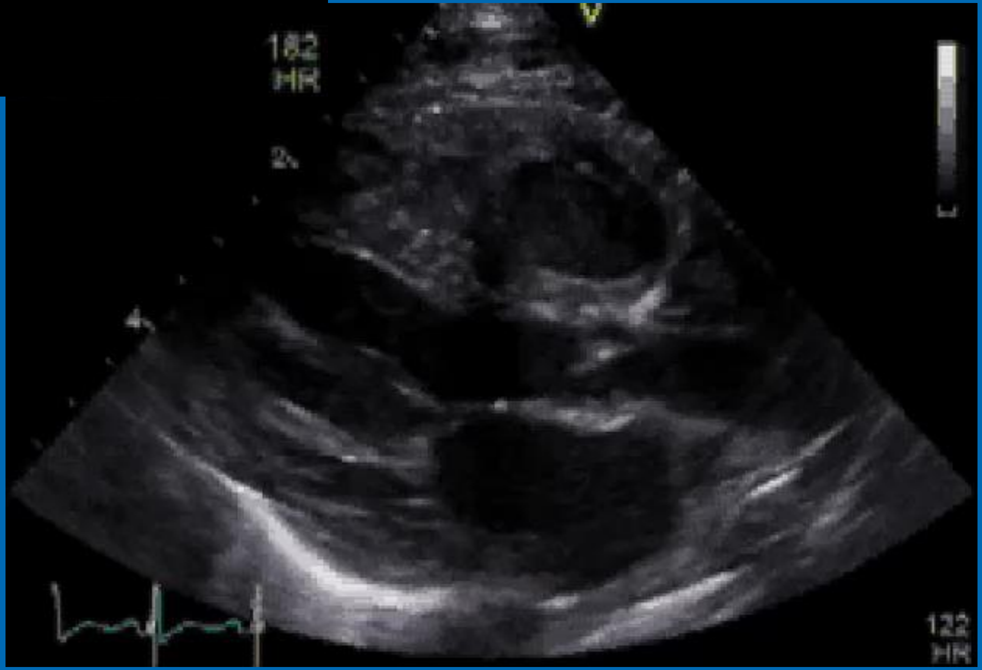


Abnormal Newborn Physiology

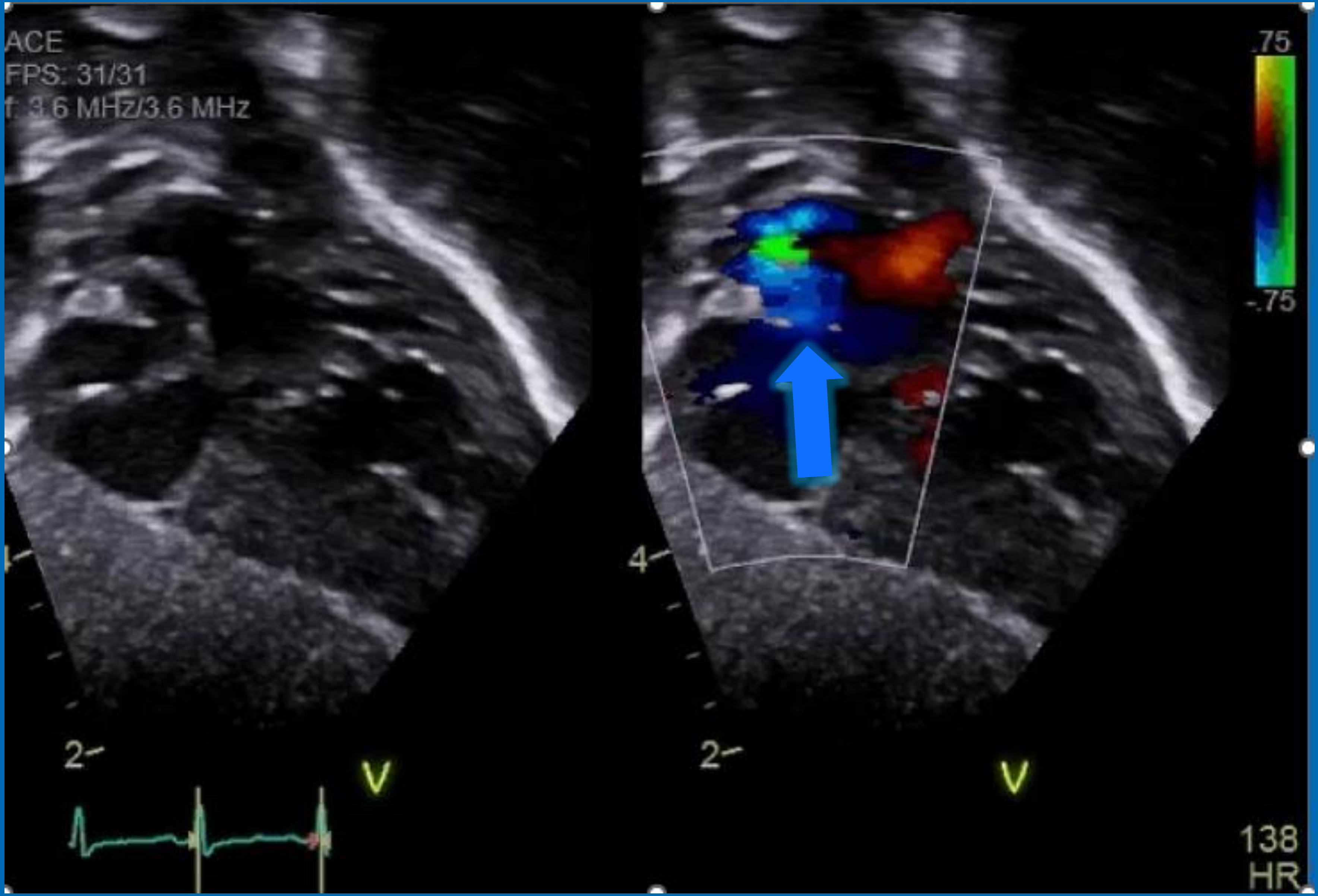
- PVR may remain elevated
  - RV compliance may worsen
    - Atrial shunts may flow more right-to-left
  - Pressure remains near or above systemic
    - Shunts will be low velocity, may flow right-to-left
  - Septal curvature flattens

So what about
atrial shunting
in a heart
with a thick RV?





Right-to-left atrial shunting



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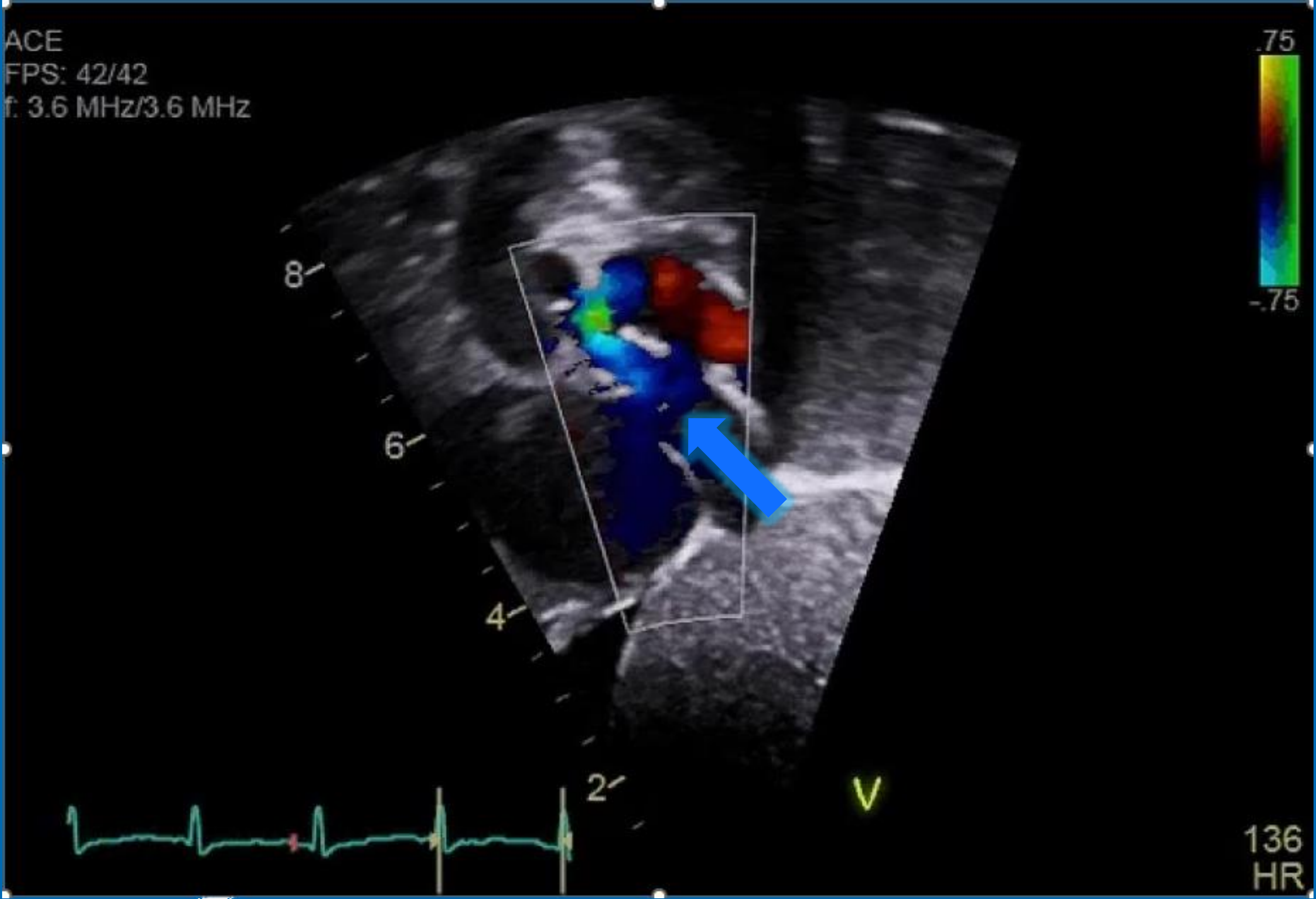
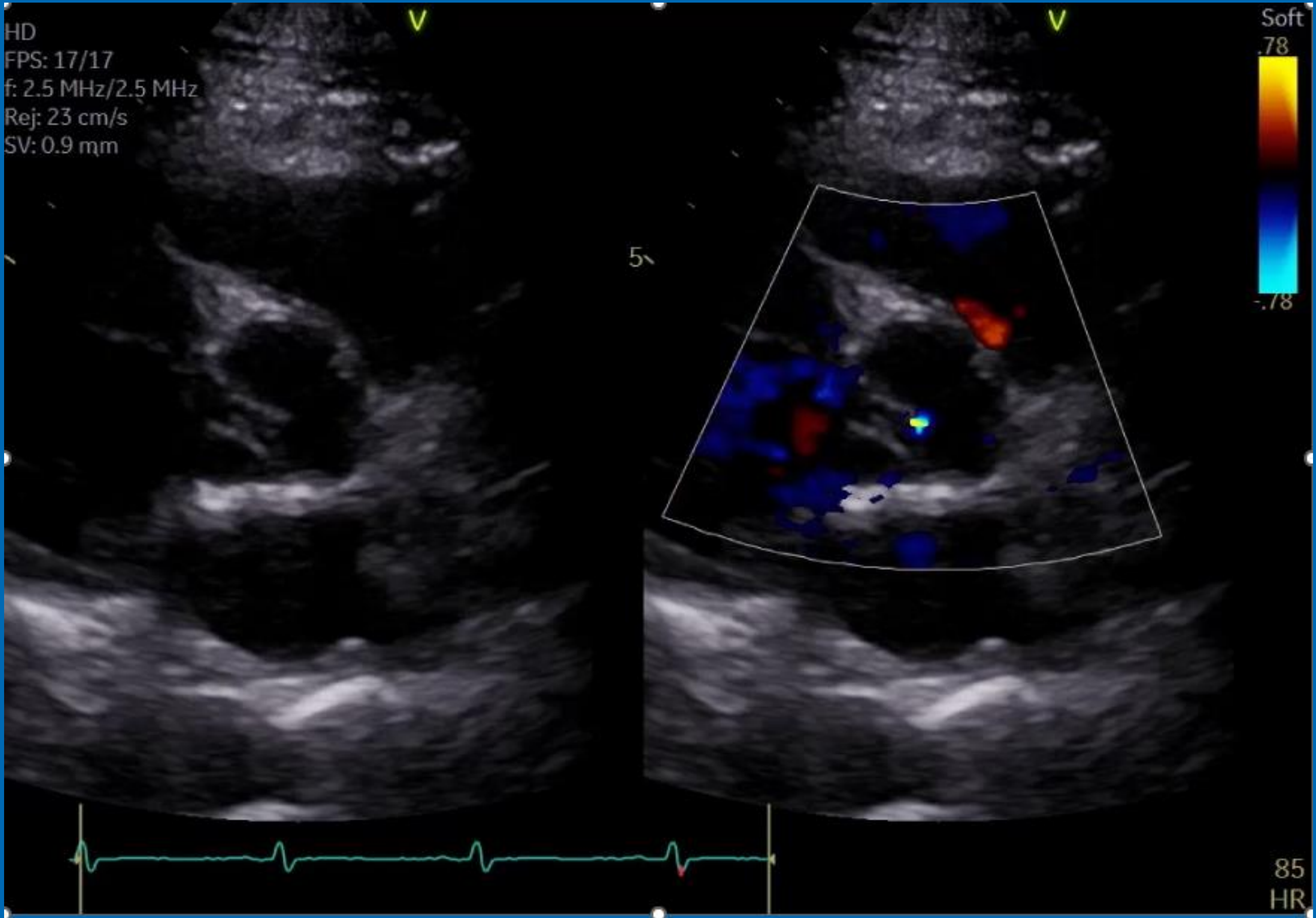

ACE
FPS: 42/42
f: 3.6 MHz/3.6 MHz
.75
-.75
8
6
4
2
V
136
HR

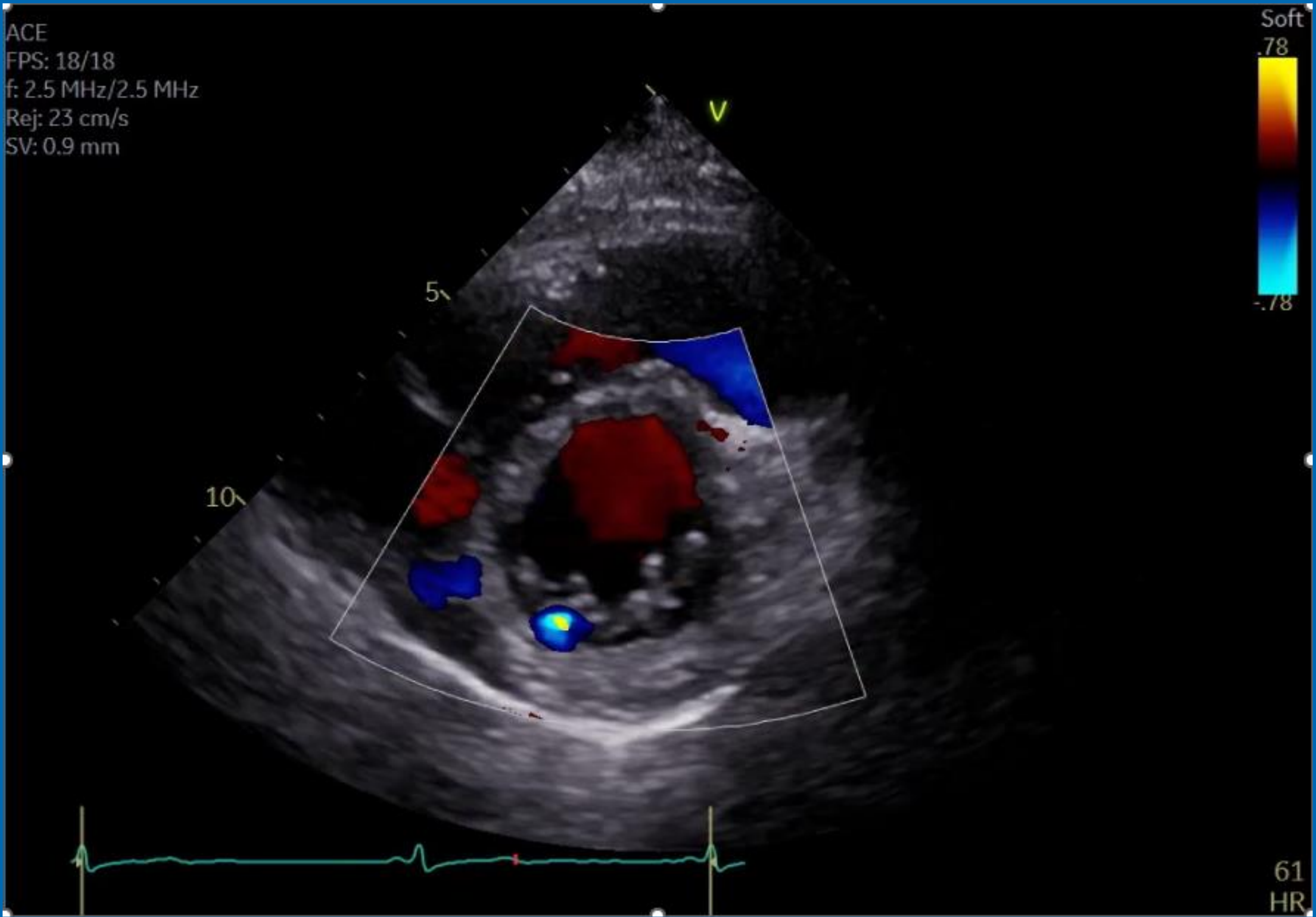
Childhood → Adult Physiology

- As SVR increases, so too does systemic pressure
  - Often 10:1 ratio of SVR:PVR
- LV myocardial wall stress drives hypertrophy
- The LV hypertrophies to meet pressure demands
  - Hypertrophy results in reduced compliance
  - Results in LV > RV diastolic pressure

Adult Physiology

- Minimal changes over time
- Left ventricular compliance reduces over time
  - Increasing diastolic pressure
- Common to have mitral regurgitation, aortic insufficiency


HD
FPS: 17/17
f: 2.5 MHz/2.5 MHz
Rej: 23 cm/s
SV: 0.9 mm
V
V
5
Soft
.78
-.78
85
HR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f: 2.5 MHz/2.5 MHz
Rej: 23 cm/s
SV: 0.9 mm
V
5
10
Soft
.78
-.78
61
HR

Take Home Points

- Blood flows down the path of least resistance
  - **Resistance** determines shunt **direction**
  - **Pressure gradient** determines **velocity** of flow
  - Compliance determines atrial shunting
- There are significant changes to resistance and compliance in a newborn heart over the first months

Thank You!