Basics Hemodynamic Assessment:
waveforms and cardiac output

V. Vivian Dimas, MD, FSCAI
Associate Professor Pediatrics, Cardiology
UT Southwestern Medical Center

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Disclosures

- None
Cardiovascular Hemodynamics

What we measure:
- Intracardiac pressures
- Oxygen saturations

What we calculate:
- Cardiac output/index
- Qp (pulmonary blood flow)
- Qs (systemic blood flow)
- PVR
  - Transpulmonary gradient
- SVR
- Valve gradients
Cardiovascular Hemodynamics

- Fluid filled catheter  → Transmits pressure wave from the heart
- Pressure transducer → Converts pressure to electrical impulse
- Amplifier          → Amplifies small electrical impulse
                        Converted to a pressure wave
Cardiovascular Hemodynamics

- Pressures are relative

- Middle of the heart assumed to be the midway point between the back of the thorax and the top of the sternum in a supine patient
  - Defined as 0 mm Hg
  - Transducer zeroed at this point

- Tubing should be non-compliant, fluid filled (NS)

- Any disruption of continuity of fluid from catheter tip to transducer affects the quality of tracing
  - Bubbles, blood or contrast, clot, compliant tubing
Cardiovascular Hemodynamics

- During spontaneous respirations, negative pleural/intrathoracic pressures cause pressures to fall
  - At end inspiration they increase again

- Opposite true for mechanically ventilated patients (pressures rise during inspiration and fall during expiration)
Changes in intrathoracic pressure affect pressures
Waveforms rise and fall during respiratory cycle
Spontaneous vs. mechanical respirations
Cardiovascular Hemodynamics

- **Atrial tracings:**
  - 3 positive deflections: $a$, $v$, and $c$ waves
  - 2 negative deflections: $x$ and $y$ descent

- **A and V waves correlate to an electrical event:**
  - $A$-wave is the first positive deflection after the surface ECG $p$-wave
  - $V$-wave is the first positive deflection after the surface ECG $t$-wave
Cardiovascular Hemodynamics

Atrial waveforms

- **A-wave:**
  - Atrial contraction

- **C-wave:**
  - Bulging of atroventricular valve into atrium during isovolumic ventricular contraction

- **X-descent:**
  - Combination of atrial relaxation, downward displacement of atroventricular valve during ventricular systole, ejection of blood from ventricle
    - Steeper than Y-descent

- **V-wave:**
  - Filling of atrium
  - Larger than ‘a’ wave in LA/smaller than ‘a’ wave in RA

- **Y-descent:**
  - Opening of atroventricular valve → ventricular filling
Cardiovascular Hemodynamics
Atrial waveforms
Cardiovascular Hemodynamics

1. Isovolumic contraction
2. Ejection
3. Isovolumic relaxation
4. Passive ventricular filling
5. Atrial contraction (active ventricular filling)

LA/LV tracing, EDP is point at which pressure tracings cross
Cardiovascular Hemodynamics

- Atrial pressures are a reflection of ventricular function, particularly diastolic function.

- Changes in ventricular compliance reflected in atrial pressures:
  - Hypertrophy
  - Myocardial diseases
  - Pericardial constriction
Cardiovascular Hemodynamics

Normal values

- RA mean (CVP) = 1-5 mm Hg

- RV:
  - Systolic ≤ 25-30 mm Hg
  - Diastolic = 0-1 mm Hg
  - End-diastole = < 5 mm Hg

- PA:
  - Systolic ≤ 25-30 mm Hg
  - Diastolic ≤ 10
  - Mean ≤ 15 mm Hg

- PCWP mean = 8-12 mm Hg
Cardiovascular Hemodynamics

Atrial pressure

\[ a = 3 \]
\[ v = 2 \]
\[ m = 1 \]
Cardiovascular Hemodynamics

Ventricular pressure

End-diastolic pressure at upstroke of QRS
Cardiovascular Hemodynamics

Pulmonary artery

Transpulmonary gradient
(Normal $\leq 12$)

18/10, 15

$m = 6$
Cardiovascular Hemodynamics

Pulmonary vein wedge

- Can be used as surrogate for pulmonary artery pressure

- Two ventricle patients‡:
  - Diastolic PA and diastolic PVW nearly identical
  - Systolic pressures correlated well at lower pressures
    - Discrepancy noted at higher pressures:
      - PA Systolic pressure > 35 mmHg
      - Mean PAp > 20 mmHg
    - By adding the difference between diastolic PVWp and mean LAp to systolic or mean PAp able to estimate fairly accurately

- Single ventricle patients:
  - Good correlation in palliated single ventricles*
    - Less accurate in patients with pulmonary artery band
  - Good correlation when mean PVWp < 18 mmHg€

€Mori Y et al. Am J Cardiol 2003; 91(6): 772-74
Cardiovascular Hemodynamics

Pulmonary capillary wedge

Should look like atrial tracing!
Cardiovascular Hemodynamics
Normal Values

- **LA mean** = 2-12 mm Hg

- **LV:**
  - Systolic = systemic (in absence of LVOTO)
  - Diastolic = 0-1 mm Hg
  - End-diastolic ≤ 12 mm Hg

- **FA:**
  - Systolic = central aortic + pulse wave amplification
Cardiovascular Hemodynamics

Arterial tracing

- Starts with steep systolic upslope during ejection (follows R wave by 120-180 msec), then starts to decline
  - End systole = closure of aortic valve (dicrotic notch)

- As pressure wave travels from aorta to peripheral arterioles, alterations in impedance and harmonic resonance lead to distal pulse amplification

- Distal arterial pressure has
  - Higher and steeper systolic peak
  - Dicrotic notch which appears later
  - Lower diastolic pressure
Cardiovascular Hemodynamics

• As move distally, systolic and pulse pressures increase, dicrotic notch more prominent

• Normal pulse pressure 25-50 mmHg or < 50% systolic value

• Increased pulse pressure: diastolic run-off lesions

• Narrow pulse pressure: low CO, tamponade

Cardiovascular Hemodynamics

Troubleshooting waveforms

1. Inaccurate calibration or baseline drift
2. Underdamped - catheter fling, air in system, turbulent jet
3. Overdamped - loose connection, air in system, dense fluid, clot, catheter kink, catheter entrapment
Cardiac Output

- In absence of intracardiac shunts!!

- FICK calculation:
  
  \[
  \text{CO} = \frac{\text{VO}_2 \text{ (ml/min)}}{\text{Systemic arterial O}_2 \text{ content} - \text{Pulmonary artery O}_2 \text{ content}}
  \]
  
  \[
  \text{CI} = \frac{\text{VO}_2 \text{ (ml/min/m2)}}{\text{Systemic arterial O}_2 \text{ content} - \text{Pulmonary artery O}_2 \text{ content}}
  \]

- Pay attention:
  - CO = L/min
  - CI = L/min/m2 (indexed for BSA)
    - Many use it interchangeably, adults tend to speak in terms of output
Cardiac Output

- Get baseline ABG

- Cardiac output calculations are based on indicator
  - Most common indicator is oxygen
  - Temperature
  - In past… green dye
  - Requires “steady state” for accurate measurement

- FICK uses difference in oxygen content across a vascular bed → AVO2 difference
  - Systemic venous (PV) or arterial and mixed venous (PA)
  - Normal 20-25%
Cardiac Output

- 1 gm Hb carries 1.36 ml of O2
- Coefficient of solubility for O2 in blood is 0.003 ml O2/100 ml plasma/mmHg
  - At PO2 of 100 mmHg, 100 ml of plasma contains 0.03 ml O2/L/mmHg

- Calculation of outputs dependent on accurate determination of oxygen saturations in the blood

\[
\text{Oxygen content (CaO2)} = (\text{SaO2} \times \text{Hb} \times 13.6) + (0.03 \times \text{PaO2})
\]

- Dissolved oxygen negligible at PaO2 < 100 mmHg
Cardiac Output

- VO2 = (concentration of O2 in room air - concentration of O2 in the expired air) \( \times \) (volume of gas flow in ml/min) typically indexed to BSA in pediatrics
  - VO2 in ml/min/m²
- In past was cumbersome to measure
- Usually assumed but up to 40 % error
- Newer devices allow VO2 to be measured even in intubated patients
- VO2 measurement inaccurate if supplemental O2 utilized
Troubleshooting Fick
Sources of error

- Oxygen consumption
  - Assuming it
  - Non-steady state condition
    - sedation
    - anxiety
    - disease state

- Large time interval between saturation samples
- Obtaining saturations in improper location
- Neglecting dissolved oxygen in calculations
Thermodilution

- Most accurate when mixing chamber between thermistor at catheter tip (PA) and infusion port (RA)

- Bolus volume:
  - < 15kg 5cc
  - > 15kg 10cc

- Designed for ice water, first bolus cools catheter shaft: do not count; average next 3
  - Variation should be 10% or less

- Accuracy ± 20%

- Inaccurate: TR, PR, shunts, Fontan, thermistor closely approximated to vessel wall (heat sink), very low cardiac output
Final Thoughts

- Obtaining accurate hemodynamics requires careful attention to detail

- Calculation of cardiac output has many potential sources of error
  - Limit assumptions as much as possible

- Valuable information about disease states can be obtained with basic diagnostic catheterization