MODULE F – HEMODYNAMIC MONITORING

Topics to be Covered

• Cardiac Output
• Determinants of Stroke Volume
• Hemodynamic Measurements
• Pulmonary Artery Catheterization
• Control of Blood Pressure
• Heart Failure

Cardiac Measurements

• Stroke Volume: Volume of blood ejected from the ventricle with each contraction.
  • 60-130 mL per beat
• Cardiac Output: Volume of blood pumped by the ventricles per minute
  • \[ CO = SV \times HR \]
  • Normal Value is 4-8 L/min
  • 5,040 mL/min = 70 mL \times 72/min
  • Cardiac Output directly influences blood pressure (both HR and SV).

Distribution of Blood Volume

• Blood Volume is normally 5 L (varies with age, sex, body size)
  • 75% is found in the systemic circulation
    • 60% in the systemic veins
    • 10% in systemic arteries
  • 15% is found in the heart
  • 10% is found in the pulmonary circulation
    • Usual volume is 75 mL with capacity of 200 mL.

Distribution of Pulmonary Ventilation & Blood Flow

• Blood flow is gravity dependent
  • Sitting/standing position → blood goes to the lung bases.
  • Lying flat, blood flow preferentially will go to posterior lung.
Distribution of Pulmonary Ventilation & Blood Flow

• Ventilation is also gravity dependent, BUT...
  • At FRC, the alveoli are larger at the apices.
  • Once the FRC is established, the majority of the tidal volume goes to the bases.

Net effect is that there is both perfusion and ventilation are greatest at the bases, but not in equal proportions.

West’s Lung Zones

• Zone 1
  • Least Gravity Dependent
  • \( P_a > P_a > P_v \)  NO BLOOD FLOW

• Zone 2
  • Some Gravity Dependency
  • \( P_a > P_a > P_v \)  SOME BLOOD FLOW –  AS YOU GO DOWN THE LUNG

• Zone 3
  • Most Gravity Dependent
  • \( P_a > P_v > P_a \)

Changing Body Position to Improve Oxygenation

• Unilateral Lung Disease
  • Examples: Pneumonia only in right lung; fractured ribs with pulmonary contusion only on left.
  • Bad lung up & Good lung down (GOOD TO GROUND)
    • Improved ventilation will match greater area of perfusion
  • Ventilate each lung separately (Independent Lung Ventilation)

Determinants of Cardiac Output

• The amount of blood pumped each minute is determined by the number of beats (Heart Rate) and the amount pumped each beat (Stroke Volume).
• The Stroke Volume is dependent on three factors:
  • Preload
  • Afterload
  • Contractility
    • http://www.manbit.com/PAC/chapters/PAC.cfm (look under physiology)
Pulmonary Artery Catheterization

- Initially devised by Swan and Ganz.
- Allows for view of Left Ventricular function by using extrapolation of right heart measurements.
- Catheter is floated into right side of the heart and into a small pulmonary arteriole.
- Catheter is then “wedged” and a pressure is measured.
  - Pulmonary Capillary Wedge Pressure (PCWP) or Pulmonary Occlusion Pressure (POP)
  - PCWP reflects Left Atrial Pressure (LAP) which reflects Left Ventricular End Diastolic Pressure (LVEDP) which reflects Left Ventricular End Diastolic Volume (LVEDV)

Preload

- Definition
  - The degree that the myocardial fiber is stretched prior to contraction at end diastole
  - The more the fiber is stretched, the more it will contract. However, if it is overstretched the amount of contraction goes down.
    - (Think rubber band)
- On right side of heart – Right Ventricular End Diastolic Volume which is reflected by Right Atrial Pressure or Central Venous Pressure (CVP)
- On left side, the LVEDV is reflected by the PCWP.

Pulmonary Artery Catheterization

- Catheter is inserted into the right side of the heart and advanced into the pulmonary artery.
- The physician knows the position of the catheter by watching the waveforms and noting the change in pressures.
CVP = 2-6 mm Hg

RVP = 25/0 mm Hg

PAP = 25/8 mm Hg

PCWP = 4-12 mm Hg

http://rmceus.com/hemo/pacath.htm
Afterload

- **Definition**
  - The force against which the ventricles must work to pump blood
  - The ventricular wall tension generated during systole
  - Determined by:
    - Volume and viscosity of blood
    - Vascular resistance
    - Heart valves

Vascular Resistance

- **Derivation of Ohm’s Law**
  - The resistance in a circuit is determined by the voltage difference across the circuit and the current flowing through the circuit.
  - Resistance = $\frac{\Delta \text{Pressure}}{\text{Flow}}$
  - Vascular Resistance = $\frac{\Delta \text{Blood Pressure (mmHg)}}{\text{Cardiac Output (L/min)}}$

Where $\Delta$ Blood Pressure is the highest pressure in the circuit minus the lowest pressure in the circuit.

Pulmonary Vascular Resistance (PVR)

- **Key Components**:
  - Highest Pressure – MPAP
  - Lowest Pressure – LAP or PCWP
  - Flow – Cardiac Output

- **Formula**
  - PVR = $(\text{MPAP-PCWP})/\text{CO} \times 80$

Systemic Vascular Resistance (SVR)

- **Key Components**
  - Highest Pressure – MAP
  - Lowest Pressure – RAP or CVP
  - Flow – Cardiac Output

- **Formula**
  - SVR = $(\text{MAP-CVP})/\text{CO} \times 80$

Contractility

- **Definition**
  - The force generated by the myocardium when the ventricular muscle fibers shorten.
  - Positive **Inotropic** effect ($\uparrow$ force of contraction)
  - Negative **Inotropic** effect ($\downarrow$ force of contraction)

- **Contractility is affected by**:
  - Drugs
  - Oxygen levels within the myocardium
  - Cardiac muscle damage
  - Electrolyte imbalances
Heart Failure
• Right Heart Failure vs. Cor Pulmonale
  • Right ventricular hypertrophy
  • Peripheral edema
  • Pitting edema, swollen ankles, palpable liver (hepatomegaly), ascites, engorged neck veins (JVD)
• Left Heart Failure
  • Left ventricular hypertrophy
  • Pulmonary edema and pleural effusions

Types of Invasive Catheters
• Arterial Line (A-line)
  • Inserted into an artery
• Central Venous Catheter (CVP)
  • Inserted into a vein
• Pulmonary Artery Catheter (PAP)
  • Inserted into a vein

Blood Pressure
• Low Blood Pressure is hypotension
  • Prevents the tissues from receiving the O₂ and nutrients it needs to survive
• High Blood Pressure is hypertension
  • This strains the heart and over time may lead to heart failure
Heart/Vascular Pressures
- Left Ventricle: 120/0 mm Hg
- Arterial Blood Pressure: 120/80 mm Hg
- Mean Arterial Pressure: 93 mm Hg (80 - 100)
- Arterioles: 30 mm Hg
- Capillaries: 20 mm Hg
- Veins: 10 mm Hg
- Right Atrium (CVP): 2-6 mm Hg (4-12 cm H2O)
- Right Ventricle 25/0 mm Hg
- Pulmonary Artery 25/8 mm Hg
- Mean Pulmonary Artery Pressure: 14-15 mm Hg (10-20 cm H2O)
- Pulmonary Capillary Wedge Pressure (PCWP): 4-12 mm Hg
- Pulmonary capillaries 12 mm Hg
- Pulmonary veins 8-10 mm Hg
- Left Atrium 5 mm Hg
- Left Ventricle - 120/0

Factors that Control Blood Pressure
- **Heart**
  - ↑HR and Stroke Volume, ↑ BP
  - ↓ HR and Stroke Volume, ↓ BP
- **Blood**
  - Hypervolemia: Increased BP
  - Hypovolemia: Reduced BP
- **Blood Vessels**
  - Vasoconstriction: Increased BP
  - Vasodilation: Reduced BP

Mean Blood Pressure
- Mean = \( \frac{2 \text{ (diastolic pressure)} + \text{systolic pressure}}{3} \)
- Mean arterial blood pressure is 90–100 mm Hg
- Mean pulmonary artery pressure is 9-18 mm Hg

Indexed Values
- Relates values to body size
  - Allows for better correlation between patients
- Calculated by using Dubois nomogram
  - Appendix IV, p 513
- Cardiac Index
  - \( \text{CO/BSA} \)
- Stroke Volume Index
  - \( \text{SV/BSA} \)
- Pulmonary & Systemic Vascular Resistance Index
  - Divide by CI instead of CO