Learning Objective:
- Explain hemodynamic monitoring techniques and the implications of values for hemodynamic parameters.

Rationale
- Hemodynamic data are crucial in diagnosis and management of many critically ill patients
- Gold standard for monitoring involves invasive techniques with complications
- Noninvasive monitoring would avoid complications, while providing necessary data

Noninvasive Monitoring

Methods:
- Impedance cardiography
- Echocardiography
- Partial CO2 rebreathing

Impedance Cardiography
- Description- translates electrical conductivity in the thorax into blood flow data
- Presently, not a viable alternative to invasive procedures
Impedance Cardiography

Lead placement

Click to see impedance cardiography (ICG) lead placement and overview
http://impedancecardiography.com/icgover10.html

Impedance Cardiography

Data obtained

- Cardiac Output (CO)
- Stroke Volume (SV)
- Systemic Vascular Resistance (SVR)
- Acceleration Index (ACI) initial acceleration of blood flow in aorta
- Thoracic Fluid Content (TFC)

FYI - Click to view or download a PowerPoint on impedance cardiography
http://www.powershow.com/view/15afd7-ZGUyO/Prospective_Evaluation_and_Identification_of_Cardiac_Decompensation_in_Patients_with_Heart_Failure_b_flash_ppt_presentation

Echocardiography - Types

- transesophageal echocardiography (TEE)
- stress echocardiography
- three-dimensional

FYI - Link to more information on echocardiography
http://www.echoincontext.com/basicEcho.asp

Echocardiography

Data obtained

- cardiac chamber size,
- wall thickness & motion,
- valve configuration & motion
- proximal great vessels
- pericardial effusions
- neoplasms
- congenital defects
- estimates cardiac output
- estimate pulmonary artery pressure

FYI - Link to more information on echocardiography
http://www.echoincontext.com/basicEcho.asp

Partial CO2 Rebreathing

Description

- uses ratio of change in PetCO2 and CO2 excretion, in response to 50 sec rebreathing, to calculate pulmonary capillary blood flow.
- CO is estimated by adding a correction factor for shunt flow, based on SpO2.
Partial CO2 Rebreathing

- Data obtained
  - cardiac output - good correlation with thermodilution technique
  - systemic vascular resistance
  - pulmonary capillary blood flow
  - EtCO2, VCO2
  - Alveolar VE

Partial CO2 Rebreathing

- Applications
  - hemodynamic monitoring
  - fluid management
  - ventilator management
  - ventilator weaning

Partial CO2 Rebreathing

- Novametrix NICO (TM) monitor

FYI - Link to NICO respironics
http://nico.respironics.com/

Invasive Monitoring

Overview

- Definition - invasive procedures to measure blood flow and pressures
- Indications
  - hypovolemia
  - septic shock
  - pulmonary edema
  - pulmonary hypertension
  - cardiac failure
  - cardiovascular surgery
  - multiple organ system failure

Measured Parameters

- systemic arterial pressures
- central venous pressure
- cardiac output
- pulmonary arterial pressure
- pulmonary arterial occlusion (wedge) pressure
- systemic vascular resistance
- pulmonary vascular resistance
Arterial Lines

Purposes
◆ obtain blood for gas analysis
◆ monitor arterial pressure
▶ titration of vasoactive drugs
▶ patients with extreme pressures

Click to see arterial pressure waveform
http://ericglenn.com/images/Project1.jpg

Normal Arterial Pressures
◆ systolic = 120 mm Hg
◆ diastolic = 80 mm Hg
◆ pulse pressure = 40 mm Hg
◆ mean pressure = 100 mm Hg

Abnormal Arterial Pressures
◆ decreased systolic
◆ hypovolemia
◆ cardiac failure
◆ vasodilation
◆ decreased diastolic- important, because coronary flow occurs on diastole

Abnormal Arterial Pressures
◆ decreased pulse pressure
◆ first sign of hypovolemia
◆ cardiac tamponade
◆ mean arterial pressure (MAP)
◆ decreased values precede multiple organ system failure
◆ used to titrate vasoactive agents
◆ used to reflect myocardial work

Error Sources For Arterial Pressures
◆ air in lines- decreased pressure
◆ loose connections- decreased pressure
◆ clotting- decrease or eliminate pressure

Complications of Arterial Lines
◆ hemorrhage
◆ infection
◆ ischemia- best to use artery with collateral flow
### Central Venous Line

**Description:** Insertion of line that goes to vena cava

**Purposes:**
- Measure central venous pressure (CVP)
- Venous access for infusion, when peripheral lines cannot be inserted

### Central Venous Line Purposes:
- Administration of vasoactive/inotropic drugs that cannot be given peripherally
- Administration of hypertonic solutions including total parenteral nutrition
- Hemodialysis/plasmapheresis

### Central Venous Line Sites

- Femoral vein
- Internal jugular vein
- Subclavian vein
- Peripherally-inserted central catheter (PICC)

### Central Venous Line Sites

- Subclavian vein

 FYI - Click for video of subclavian line placement (3) (requires sign-in for age verification)

http://www.youtube.com/watch?v=iIAhNsww9yc

### Central Venous Line Sites

- External jugular vein

 Click to see illustration of external jugular vein

http://cordial.perso.infonie.fr/jex06.jpg

 FYI - Click to see video of external jugular vein cannulation (13 min.)

http://clip.bing.com/_bl-7hpDU12/1 video/11/26/2016/AAAAXAAAASGAA/tF///y99%7Vj0b/clickvideo.gif

### Central Venous Line Sites

- Peripherally inserted central catheter (PICC)

 Click to see illustration of PICC line in place

http://clip.bing.com/_bl-7hpDU12/1 video/11/26/2016/AAAAXAAAASGAA/tF///y99%7Vj0b/clickvideo.gif
Central Venous Lines

Advantages (compared to peripheral sites):
- accommodate high flows
- easier to place with hypotension
- permit monitoring

Disadvantages
- more complications
- must interrupt CPR to insert (except PICC)

Complications
- damage to thoracic duct, nerves
- infusion of fluids into mediastinum
- pneumothorax- subclavian veins
- air embolus
- infection
- cannulation of artery

FYI - Click for article about central venous monitoring
http://www.bmj.sk/2008/10904-10.pdf

Central Venous Pressure

Normal <5 mm Hg

Decreased by:
- hypovolemia
- decreased intrathoracic pressure
- increased cardiac output

Increased by:
- right ventricular or bi-ventricular failure
- hypervolemia
- increased intrathoracic pressure; e.g., PEEP
- pulmonary hypertension
- pulmonary embolism
- tamponade

Pulmonary Artery Catheter

AKA, Swan-Ganz catheter- inserted through heart, into pulmonary artery

Purposes:
- measure PA pressures
- measure cardiac output
- obtain mixed venous blood
- monitor mixed venous saturation
- provide atrial-ventricular pacing
Pulmonary Artery Catheter

Insertion

- Peripheral veins - less complication
- Jugular veins - right jugular is most direct
- Subclavian veins - less chance of carotid puncture

Insertion

- Guidance for insertion
  - Fluoroscopy - in catheterization lab
  - Pressures/pressure waveforms
- Catheter advanced to right atrium, then balloon is inflated
- Balloon floats catheter through ventricle to pulmonary artery

If catheter advanced to 50 cm and pulmonary waveform is absent, assume it is curling in atrium or ventricle ==> deflate, withdraw to atrium & proceed again

Click to see different types of PACs
http://www.edwards.com/products/pacatheters/

Click for information and images of PAC components
http://www.mceus.com/hemo/pacath.htm

Click to see illustration of PA catheter in place
http://cvphysiology.com/Heart%20Failure/HF%20pulmonary%20wedge%20pressure.jpg
**Pulmonary Artery Catheter**

**Insertion- confirmed by:**
- pressure wave form
- arterialized blood from wedge sample
- chest radiograph

Click to see pressure waveforms for PA catheter
http://www.frca.co.uk/images/pac1.jpg

**Complications**
- infection
- pneumothorax
- dysrhythmias
- air embolism
- perforation of vessels, heart

Click for article with x-ray of knotted PA catheter
(Click on the thumbnails)

**Interpretation- PA pressures**
- Normal = 22/8 (mean = 13)
- Decreased by:
  - RV failure
  - pulmonary vasodilation
  - hypovolemia

**Increased by:**
- pulmonary embolism
- pulmonary vasoconstriction-
  (PADP - PAOP) >5 ==> increased PVR
- LV failure
- congenital heart disease with left-to-right shunt

Click to see x-ray of PA catheter placed correctly
http://webmm.ahrq.gov/media/cases/images/case51_fig3.jpg

Click to see x-ray of PA catheter placed distally
http://www.learningradiology.com/caseofweek/caseoftheweekpix2010%20387-/cow396-2arr.jpg
### Pulmonary Artery Catheter

**Interpretation - PAOP (wedge)**
- Intended to reflect LV preload
- Created by inflating balloon in small branch of PA
- Normal:
  - 4-12 mm Hg, or
  - 2 mm less than PADP

**Interpretation - PAOP**
- Increased by:
  - LV failure (>18 mm Hg)
  - PAOP > 25 mm => pulmonary edema, depending on colloid osmotic pressure (COP)

**Interpretation - PAOP**
- Increased in:
  - mitral valve stenosis, regurgitation
  - pulmonary venous constriction or obstruction
  - high levels of PEEP - do not remove from PEEP to measure PAOP

**Optimal PAOP**
- 12- without PEEP
- 18- with PEEP

### Invasive CO Measurement

**Methods**
- dye dilution
- Fick method
- intermittent thermodilution - solution injected for measurement
- continuous thermodilution - solution automatically injected by system
- continuous SvO2 monitoring - depends on constant SaO2

### Cardiac Output Parameters

**Normals**
- CO = 4-8 L/min
- CI (CO/BSA) = 2.5-5.0 L/min/m²
- SVR = 900-1400 dynes/sec/cm²
- PVR = 110-250 dynes/sec/cm²
- EF = 65-75%
Components of Monitoring System
- Catheter - patency maintained by heparanized solution under pressure
- Transducer - translates pressure to electronic signal
- Computer for CO
- Monitor - to display data

Technical Aspects Of Monitoring
- Transducers
  - calibrated with manometer
  - zeroed at level of atria
- Monitor sensitivity calibrated each shift

Technical Aspects Of Monitoring
- Transducers
  - calibrated with Hg manometer
  - zeroed at level of atria
- Monitor sensitivity calibrated
- Tubing tested for dampening
- Circuit must be air-free
- Patency confirmed by visibility of wave fluctuations with ventilation

Summary & Review
- Noninvasive monitoring
  - purposes
  - parameters
  - types:
    - impedance cardiography
    - echocardiography
    - partial rebreathing ETCO2

Summary & Review
- Invasive monitoring
  - purposes
  - parameters - values, significance
  - complications
  - types:
    - arterial pressure
    - central venous
    - pulmonary artery catheter
    - cardiac output

Reference