Hemodynamic Monitoring in Critical Care Transport

Mike Watkins
MPA, RN, FP-C
VCUHS

Overview

- Introduction to Hemodynamic Monitoring
  - How it applies to CCT
  - Patient population and clinical conditions
    - “Sickest of the sick”
- Types of Monitoring
- Systems and Equipment setup

Overview

- Hemodynamic Waveforms
  - Basic interpretation and differentiation
- Vasoactive agents and effects on Hemodynamics
  - Specific continuous infusions
- Conclusion

Hemodynamic Monitoring

- Vital signs
  - Non-Invasive and Invasive
- Patient condition determines appropriateness
  - Trending specific parameters
- Comparing Non-invasive and Invasive provides reference for quality of perfusion and circulation

Non-Invasive Measurements

- Standards:
  - Pulse
  - Pulse Oximeter
  - Blood Pressure
  - Respiration
- What do the alterations tell you?
  - Each a different facet of the big picture

Invasive Monitoring

- Variation off of the Non-invasive
  - “From within the body”
- Measurements
  - Fluid flow properties
  - Location of port
  - Blood content
**Application in CCT**

- Most Useful: Arterial Blood Pressure
  - Correlate to non-invasive BP, then cuff can cycle less
  - Work when cuff does not
- Helpful for titration of high potency vasoactive infusions
  - Nitroglycerin
  - Epinephrine
  - Norepinephrine
  - Esmolol

**Concerns in CCT**

- Placed by physicians often prior to transport
  - ED to ICU or ICU to ICU
- Potential:
  - Source of bleeding
  - Route of infection
  - Thrombus

**Concerns in CCT:**

- Apply to a limited patient population
  - Cardiac and surgical
  - Trends more important than a single measure
- Treat the patient, not the monitor
  - Avoid tunnel vision
  - Keep the patient safe
- "Normal" values are based on supine and healthy

**Safety**

- Account for everything attached to the patient
  - Transduce the lines even if the values do not make sense
  - Important to secure connections, prevent air embolus, bleeding, movement of catheter

**Transport Considerations**

- Location of lines and security of lines?
  - Central lines verified by chest X-ray?
    - Internal Jugular
    - Subclavian
    - Swan-Ganz
    - Balloon Pump
- Copies to travel: essential!

**Anatomy**

- Heart
  - Atria and Ventricles
  - Coronary Arteries
  - Valves
    - Aortic and Pulmonic
    - Tricuspid (Right) and Mitral (Left)
- Pulmonary Vasculature
  - Arteries
  - Capillaries
  - Veins
  - Blood
Physiology
- Tank: blood vessels
  - Size; what has happened?
- Pump: Heart
  - Is it working? How effective?
- Fluid status: blood and hydration
  - Is the tank full?

Cardiac Cycle
- Ventricular Diastole
  - Isovolumic Relaxation: filling from sources
    - Vena cava, passive filling from pulmonary vessels
    - Closure of pulmonic and aortic valves
- Atrial Systole
  - “Kick” signals from SA to AV
- Ventricular Systole
  - Isometric contraction
  - Greatest myocardial expenditure and oxygen consumption

Stroke Volume
- Volume of blood ejected by the heart with each: 60 to 130ml
- Preload
  - End-diastolic stretch on myocardial muscle fibers
- Afterload
  - Sum of all the forces against which the muscle fibers of both ventricles must work
- Contractility
  - Inotropic state of the myocardium
- Muscular Synchrony

Invasive Monitoring
- Arterial Pressure
- Central Venous Pressure
- Pulmonary Artery Pressure
  - Pulmonary Artery Wedge Pressures
  - SWAN GANZ catheters

Pressure Measurement Access Points
- Arterial lines
- Central Lines
  - Cordis: the line
  - Swan: inserted through the line
- Other pressures
  - ICP
  - Bladder
Additional Hemodynamic Parameters
- Mean Arterial Pressure
- Cardiac Output
- Cardiac Index
- Systemic Vascular Resistance
- Systemic Vascular Resistance Index

Arterial Pressure Lines
- Continuous Blood Pressure monitoring
  - “Instant” response to vasoactive agents
  - Correlate against the non-invasive blood pressure
    - Match to gauge accuracy
- Common sites:
  - Radial Artery
  - Brachial artery
  - Femoral artery
- Different sites may have a gradient difference

Indications: Intra-arterial Monitoring
- Critically ill or injured
- Major surgical procedures
- Major vasopressor or vasodilator support
- Intra-aortic Balloon Pump: IABP
  - Provides pressure trigger
- ICP Monitoring
- Serial Blood gas measurement
- Severe acid-base imbalance

Arterial Pressure Waveform

Waveform Qualities
- Crisp: sharp, clear lines, flowing
  - ideal
- Dampened: blunted, smooth
  - Low flow states, air in line
- Hyperdynamic: spikes
  - Pinched, compliant tubing

Patient Effects on Arterial Pressures
- Tachycardia
- Hypotension
- Atrial Fibrillation/Irregular Heart rate
Every IABP transport will use these skills
Arterial pressure wave is one of three triggers for balloon sensing
  - ECG, internal, and Pressure (Fiberoptic)
  - Ratios: 1:1, 1:2, 1:3 depending
Evaluation of waveform
  - Improved coronary perfusion (Augmentation)
  - Afterload Reduction
  - Assisted and Unassisted flows

Complications of Arterial Lines
  - Ischemia to extremity
    - Especially in IABP
  - Hemorrhage
    - Arterial
  - Degraded signal in low flow states
Transport Consideration

- Secure transducer to stretcher or tape to patient’s chest at phlebostatic axis
- Verify distal, collateral circulation
- Radial artery line
  - Skin color and cap refill, ulnar pulse palpable, place pulse oximeter on finger to monitor
- Femoral (IABP)
  - Dorsal pedis and posterior tibial pulses, foot warm to touch

Mean Arterial Pressure

- CO, SVR, and CVP factors
- Formula:
  - Systolic BP + (2 x Diastolic BP)
- Formula 2
  - \( (CO \times SVR) + CVP \)

Central Venous Pressure

- Catheter placed in large “central vein” or right atrium
- Works with large, central venous access point for fluid and medications
  - Benefits: central lines better for rapid infusions and less risk for highly concentrated medication
  - Risks: placement increases risk for infection, bleeding, and pneumothorax

Central Venous Pressure Monitoring

- Measures venous return to right atrium
  - Right atrial pressures
  - Right ventricular end-diastolic pressure
    - Correlates to the left end-diastole in healthy individuals
- Mean number; calculated from high and lows
  - “Normal” is 0 to 8mmHg
  - Critically ill often need to be higher
- Used to guide fluid resuscitation

Clinical Significance

- Elevated CVP
  - Fluid Overload
  - Poor right ventricular function (stiff, non-compliant)
- Decreased CVP
  - Dehydration
  - Poor peripheral vascular tone
- In CCT is least important of invasive monitors
  - Resource dependent
  - Other clinical signs will guide you

CVP Limitations

- Evaluate as a trend
- Systemic vasoconstriction can present a CVP elevated despite hypovolemia
- Mechanical ventilation:
  - Positive pressure ventilation increases thoracic and central venous pressures
  - Measure at end-expiration
CVP and Respirations

Complications of Central Lines
- Hemorrhage
- Vascular damage/erosion
- Arrhythmias
  - Catheter tickles the heart
- Infection: time in place
- Thrombo-embolic
  - Air embolus or thrombus of clot
- Pneumothorax

Pulmonary Artery Pressures
- Normal measures:
  - 15 to 25 systolic
  - 6 to 12 diastolic (CVP should never be lower)
- Indicator of left ventricular function and pulmonary vascular status
  - Increased in cases of COPD, ARDS, Sepsis, shock
  - Pulmonary hypertension occurring secondary to decreased left heart function
- CVP should never be lower than PAD
Note: “mitten” shape appearance, indicating PA placement

Pulmonary Artery Pressures

Swan Ganz Tip migration

Right Ventricle

Pulmonary Artery Wedge Pressures

Inadvertent Wedge

Inadverent Wedge Pressure

Swan Ganz Tip migration

Right Atrium: think CVP

Recognize: the previous wave has changed
Assess: are there any changes in patient condition?
- All ABCs with ECG, SaO2, and EtCO2 if available
- Noninvasive: turn or move patient
  - Lift up head slightly, turn neck
- Contact medical control of receiving hospital
  - May advise withdrawing catheter

Normal 4–12 mmHg
Balloon inflated with 1.25 ml air, for less than 15 seconds
PA Wedge Dangers

- Creates pulmonary embolism/ischemic injury
  - Mechanical occlusion
- Over-inflation of balloon puts pressure on vessels and damages tissue
- Balloon Rupture

Swan–Ganz waves on advancement

Tour of the SWAN Ganz

Tour of the Swan Ganz

Swan Balloon port

Syringe lock off: in line
Cardiac Output

- Amount of blood ejected from the ventricle in a minute: 4 to 8 L
- Heart Rate X Stroke Volume
- With Swan Ganz determined CO through **Thermo–dilution**
  - Known volume of solution at known temperature
  - Injected rapid bolus through CVP port of catheter
  - “Downstream” temperature measured and the time difference calculation performed provides the cardiac output
- Cardiac Index: adjusts CO for BSI

Cardiac Output

- Non–invasive methods
  - Vigileo Flo–trac system
  - Uses the arterial pressure waveform
- Echocardiograph
  - Creates visual image of flow
  - Bedside, in hospital

Cardiac Output

- USCOM (Ultrasound Cardiac Output Monitor)
- Continuous Doppler Wave
- Non–invasive
- Literature NOT fully supporting device, although some correlation exists
Systemic Vascular Resistance

- Cannot be measured directly
- Computed:
  - MAP minus CVP/Cardiac Output times 80
- Use of Swan or Vigileo monitor
- Normal: 770 to 1500 dynes/sec/cm²
- SVR Index: evaluates SVR as compared to BSI

Swan Ganz VIP catheter

- Thermodilution catheter
  - Inject temperature measured fluid and calculate CO, CI, SVR, and SVRI off of values
- Floated through a large bore (Cordis) central line
  - Subclavian or Internal Jugular (RIJ most common)
- Tip sits in pulmonary artery

Swan–Ganz VIP Catheter

- Yellow, 110cm in length, marked in 10cm increments
- Multiple-pressure measure points
  - CVP
  - Right atrial and ventricular pressures
  - Pulmonary Artery Pressures
  - Invasive body Temperature
- Four to Five Lumens
- Thermistor for measuring temperature

Transport the Swan Ganz

- Recognition
  - Note depth and secure so it does not move or migrate deeper
- Transduce: establish a have a waveform
  - Pull syringe to vacuum and lock off

Hazards of the Swan Ganz

- Irritates the heart
- Too deep or balloon inflated too long:
  - Pulmonary embolism
- Obstruction and/or irritation of smaller blood vessels

Venous Oxygen Saturation

- Obtain from PA catheter
- Assesses tissue oxygenation
  - Reflects how well tissue is “taking up” oxygen
- “Normal” is 75%
  - SaO₂ is 96 to 99%
  - Body uses about 25% of the O₂ available
- Increased O₂ consumption: pain, agitation, fever, vasopressor medications
- Decreased O₂ consumption: hypothermia, assisted ventilations, narcotics
Components of Pressure System

- Monitor
- Low Compliance Tubing
  - More rigid for reducing interference
- Transducer: interfaces the tubing with the monitor
- Fast flush
- Stopcock
- Pressure bag and fluid

Transducer

- “A substance or device, such as a piezoelectric crystal, microphone, or photoelectric cell, that converts input energy of one form into output energy of another.”
  - From Latin transducere, to transfer: trans-, trans- + ducere, to lead.
- From Answers.com
  - http://www.answers.com/topic/transducer
Setup

- Tubing
- Isotonic Fluid:
  - Normal Saline
- Pressure bag for fluid size
  - 500ml usual
  - Trauma infusers usually for 1000ml
- Site appropriate
  - Arterial, CVP, ICP, etc.

Set up

- Tubing flushed: observe flush out of each port
- Pressure bag inflated to 300mmHg
  - Applies continuous pressure 3 to 6 microdrops per minute
- Leveled Phlebostatic Axis
- Labeled in Monitor and Connected
- Zero monitor

Tubing

- Standard Tubing
  - Flexible
  - Ports may "Y" in or stopcock
  - Bore size differs with make, purpose
  - Blood tubing
  - Gravity flushes

- Monitor Tubing
  - Stiffer to touch
  - "In line" requirements
  - May use stopcocks
  - Small bore
  - Transducer has a pig tail for flushing
  - Setup requires diligent flushing of air

Pressure Bag and Flush

- Inflate to 300mmHg
- Most bags use a green marking or visible indicator
- Applies a constant pressure to infuse 3 to 6 minidrops per minute
- Essential to reduce risk for clot

Flush by pulling pigtail

Phlebostatic Axis

- Midchest position; approximate location of aorta and left ventricle
- Midway point from the anterior and posterior surfaces under the Angle of Louis
- Key is consistency in transfer of care
  - Zero monitors based on what was previously used
  - OR account for variation (high or low)
Phlebostatic Axis
Using a level, a little high

Phlebostatic Axis
A little better

Zero Referencing
- Eliminates the effect of atmospheric pressure on the system
  - Atmospheric pressure: 760mmHg
  - Open system to air
- Eliminate hydrostatic pressure on system
  - Level to phlebostatic axis
  - Transducer placed at approximate level of the catheter tip within the body

Zero Monitor
- Transducer stopcock
  - “OFF” to patient
  - “OPEN” to air
  - “ZERO” from monitor menu

Connections
Labels

Flushing

- Pulling red pigtail creates fast flush
  - Clear system of air prior to connection to patient
  - Creates the “dynamic response” test to clear line of blood once connected

Technique

- Consistency from shift to shift and in transfer
  - Reassess and zero at handoff of possible
- In transport, match as close as practical
  - Tape transducer to patient if possible
  - Stretcher
  - Account for this as potential variable

- Problems of leveling
  - Transducer below axis
    - Pressure increased over true pressure
  - Transducer above axis
    - Pressure decreased below true pressure
  - Factor: about 1 inch equals 2mmHg in pressure variant

Troubleshooting

- CHECK THE PATIENT FIRST
  - Change in clinical condition may manifest in waveform change prior to outward physical change
    - Tension pneumothorax:
    - Hypotension
    - Excessive PEEP
  - In transport patient may be sedated and not complain

- Troubleshooting Pressure Systems
  - No waveform
    - Check monitor, power, pressure range, connected to proper line (CVP versus ABP), kinked tubing, loose tubing, aspirate blood
  - Artifact:
    - Electrical interference, patient movement, tubing movement or vibration

  Problem | Solution
  --- | ---
  No waveform | Check monitor, power, pressure range, connected to proper line (CVP versus ABP), kinked tubing, loose tubing, aspirate blood
  Artifact | Electrical interference, patient movement, tubing movement or vibration
Troubleshooting

- Unable to flush line
  - Check for kinks, pressure bag inflated to 300mmHg, stopcocks turned off
  - Level, flush, check for occlusion
  - Level, flush, air bubbles, blood, or other

- Reading too high
  - Check for kinks, pressure bag inflated to 300mmHg, stopcocks turned off
  - Level, flush, check for occlusion
  - Level, flush, air bubbles, blood, or other

- Reading too low
  - Check for kinks, pressure bag inflated to 300mmHg, stopcocks turned off
  - Level, flush, check for occlusion
  - Level, flush, air bubbles, blood, or other

Problem | Solution
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Troubleshooting

- Overdampening
  - Waveform blunted
  - Sine like or slurred appearance
  - False low systolic
  - False high diastolic
  - Patient: clinical conditions that may cause this?
  - Equipment issues

- Underdampening
  - Waveform artifact
  - Sharp, spiked appearance
  - False high systolic
  - False low diastolic
  - Patient: clinical conditions that may cause this?
  - Equipment issues

Medications

- Potent vasoactive medications benefit from invasive monitoring
- Highly concentrated meds require central venous access for administration
- Multiple medications require compatibility checks

Vasoactive Continuous Infusions

- Nitroglycerin
- Nitroprusside
- Esmolol
- Labetelol
- Epinephrine
- Norepinephrine
- Milrinone
- Vasopressin
- Dopamine
- Dobutamine
- Phenylephrine

Dynamic Response/Square Wave Test

Decrease BP and HR | Increase BP and HR
Decrease BP: Nitrates

- Nitroglycerin: vasodilator, hits preload
  - Acute Coronary Syndrome
- Nitroprusside: vasodilator, balanced in reducing preload and afterload
  - Systemic hypertension/hypertensive crisis
  - Acute CVA
  - (not in ACS due to coronary steal: shunts coronary blood flow away myocardium)

Nitroglycerin

- ACS Standard for angina, chest pain from STEMI
- Vasodilator
  - Venous smooth muscle relaxer, decrease preload
  - Coronary vasodilation
- Glass bottle: 50mg/250ml D5W
- Dosing 5mcg/min to max of 200mcg/min
  - Hint: if at 100mcg/min, try another drug

Decrease BP: Beta blockers

- Esmolol: (Brevibloc)
  - Short acting Beta 1 selective blocker
  - Potent
  - Manage hypertensive crisis, reduced shear in dissection of aortic aneurysm
- Labetalol
  - Nonselective Beta with some Alpha 1
  - Reduce myocardial contractility
  - Vasodilation
  - Hypertensive crisis, dissection of aneurysm
  - Bolus or continuous
  - Slower onset, longer acting

Increase BP

- Epinephrine: Adrenalin
- Norepinephrine: Levophed
- Milrinone
  - Phosphodiesterase inhibitor
  - Positive Inotrope and vasodilator
  - Pulmonary Hypertension
- Vasopressin (100 units/100ml D5W)
  - Vasoconstrictor
  - 0.01 to 0.04 units/min IV

Dopamine:

- Low dose: increases renal blood flow
  - less than 3mcg/kg/min
- Medium dose: increase myocardial contractility and heart rate
  - 3 to 10mcg/kg/min
- Higher dosing: generalized vasoconstriction
  - Greater than 10mcg/kg/min

Increase BP

- Dobutamine
  - Specific Beta1 adrenergic, increase myocardial contractility
  - Used in Acute heart failure, does not cause vasoconstriction
  - Home dobutamine used as bridge to transplant or device
Increase BP

- Phenylephrine: Neo–synephrine
  - Alpha 1
  - Systemic arterial vasoconstriction
  - Often last ditch for vascular failure in shock
  - Drug induced hypotension: beta blocker overdose

- Epinephrine
  - ACLS standard
    - Alpha1 and Alpha2: Vasoconstriction
    - Beta1: Cardiac stimulant, coronary vasodilation
    - Beta2: Bronchodilation
  - Infusion:
    - 2mg or 4mg in 250ml D5W in central line
    - 1mg/250ml for 4mcg/ml concentration peripheral
    - Dosing: 1 to 2 mcg/min or 0.02 to 0.1mcg/kg/min

Norepinephrine

- Levophed
  - Systemic vasoconstriction
    - Alpha1 (more) and Beta1 effects
  - Used in shock states
    - Drug of choice for sepsis
  - Infusion: 2mg in 250ml D5W
    - 8 to 12 mcg/min or 0.02 to 0.1mcg/kg/min

Conclusions

- Recognize the types and presentations of hemodynamic monitoring
  - Basic waveforms
  - Patient Types
- Understand the key safety factors in the transport of these patients
- Review basic setup of monitor systems

Sources:

- www.icufaqs.org
- www.pacep.org