DM SEMINAR

Invasive and non-invasive hemodynamic monitoring in the ICU

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14.03.08
Not everything that counts can be counted;
And not everything that can be counted counts

ALBERT EINSTEIN
INTRODUCTION

• Hemodynamic monitoring - cornerstone in the management of the critically ill patient

• Identify impending cardiovascular insufficiency, its probable cause, and response to therapy

• Despite the many options available, utility of most hemodynamic monitoring is unproven.

Intensive Care Med. 2008 Jan 5 .e pub
Why hemodynamic monitoring?

- Physicians have developed a psychological dependence on feedback from continuous hemodynamic monitoring tools, independent of their utility.
- Effectiveness of hemodynamic monitoring to improve outcome limited to specific patient groups and disease processes for which proven effective treatments exist.

Chest. 2007;132(6):2020-9
Rationale for Hemodynamic Monitoring

• Monitoring device will improve patient-centered outcomes when coupled to a treatment which, itself, improves outcome.

• Time - crucial for early diagnosis of hemodynamic catastrophe - earlier therapy improves outcome in this situation.

Hemodynamic Monitoring

Non Invasive
- Clinical variables
- BP
- ECG
- Echocardiography
- Esophageal doppler
- Gastric tonometry

Invasive
- CVP
- PAOP
- Pulse waveform analysis
- Microcirculation
  - SvO2/ ScvO2
  - DO2/VO2
  - Lactate levels
CLINICAL PARAMETERS

- Blood pressure
- Heart rate and rhythm
- Rate of capillary refill of skin after blanching
- Urine output
- Mental status
- Effects of body position on blood pressure

Level 1 D

Intensive Care Med. 2007; 33:575–590
International Consensus Conference
BLOOD PRESSURE

• Arterial pressure is commonly measured non-invasively on an intermittent basis using a sphygmomanometer
• Normal blood pressure ≠ hemodynamic stability
• Hypotension (MAP < 65 mmHg) is always pathological
• No RCTs evaluating the impact of arterial pressure monitoring on outcomes when used in ICU or operating room

Critical Care 2005, 9:566-572

Intensive Care Med. 2008
Jan 5 .e pub
Measuring Blood Pressure

- Mercury sphygmomanometer
- Oscillatory method
  - Measures mean pressure - systolic and diastolic pressures are calculated, prone to error
- Infra sound / Ultrasonic technology
  - Very low frequency components of Krotokoff sounds below 50 Hz- very operator dependent
- Impedance plethysmography
  - Monitors change in electrical impedance with local pulsatile arterial distension occurring with each cardiac cycle
- Arterial tonometry
  - Applied pressure measured by sensors and arterial waveform constructed using an algorithm- not shown good correlation with directly measured pressure

INVASIVE BP

• Guidelines recommend invasive blood pressure measurement in refractory shock - Level 1D

  Intensive Care Med. 2007; 33:575–590
  International Consensus Conference

• Intra-arterial pressure measurement more precise

• Continuous monitoring of pressure

• Blood sampling for blood gas analysis

• Pulse waveform analysis - beat-to-beat waveform analysis - CO can be determined continuously
What is the target BP?

- No threshold BP that defines adequate organ perfusion among organs, between patients, or in same patient over time
- Based mainly on anecdotal experience, a systolic pressure of 100 mmHg usual target, with HR < 120 B/min - Controversial

\[ \text{MAP} \geq 65 \text{ mmHg} - \text{Initial target in septic shock,} > 40 \text{ mmHg in hemorrhagic shock and} > 90 \text{ mmHg in Traumatic brain injury} \]

- Level 1 B


Intensive Care Med. 2007; 33:575–590

International Consensus Conference Surviving sepsis Campaign 2008
Arterial waveform Analysis

• PiCCO (Pulsion Medical Systems) uses the aortic transpulmonary thermodilution curve to calculate CO

  Crit Care Med. 2003; 31:793–99

• LiDCO injection dilution method using Lithium as contrast: good correlation with thermodilution

• A large PP/SV variation (10% to 15%) is indicative of hypovolemia and predictive of volume responsiveness

ECG IN ICU

• Arrhythmia Monitoring
  – Up to 95% of AMI have arrhythmia within 1st 48 hrs
  – Up to 1/3 have VT. Early diagnosis and prompt treatment may improve survival
  – Heart rate variability may reflect prognosis

• Ischemia Monitoring
  – Significant uncertainty to reliably detect myocardial ischemia and diagnose MI in critically ill patients

Crit Care Med 2006; 34:1338–1343
Technical issues

• Patient safety requirements
  – Proper grounding of equipment
  – Insulation of exposed lead connectors

• Adequate signal size
  – Good site preparation
  – Electrodes
  – Conducting gel
  – Appropriate signal damping

• Personnel issues
  – Formal training of ICU staff
  – Physician / cardiology back up
Evidence

- Ischemia in ICU related to pain, fluid balance, fever, catecholamine levels, or other physical stresses
- Hurford et al. - worsening of ischemia (cont ECG) in patients rapidly weaned from positive pressure to spontaneous ventilation
- Continuous ECG monitoring in ICU detected a 6.4% incidence of ischemia during weaning
- Patients with ischemia fail to wean more commonly

Chest 1996;109;1421-1422
Echocardiography in ICU

• Sole imaging modality that provides real-time information on cardiac anatomy and function at bedside

• Ideally suited to early hemodynamic evaluation of patients with persistent shock despite aggressive goal-directed therapy


• European survey - only 20% of intensivists have certification in echocardiography

INDICATIONS – TTE IN ICU

- Hemodynamic instability
  – Ventricular failure
  – Hypovolemia
  – Pulmonary embolism
  – Acute valvular dysfunction
  – Cardiac tamponade
- Complications after cardiothoracic surgery
- Infective endocarditis
- Aortic dissection and rupture
- Unexplained hypoxemia
- Source of embolus
INDICATIONS – TEE IN ICU

• High image quality vital
  – Aortic dissection
  – Intracardiac thrombus
  – Assessment of endocarditis

• Inadequately seen by TTE
  – Thoracic aorta
  – Left atrial appendage
  – Prosthetic valves

• Inadequate image clarity with TTE
  – Severe obesity
  – Emphysema

• Mechanical ventilation with high-level PEEP
• Presence of surgical drains, surgical incisions, dressings
• Acute perioperative hemodynamic derangements
Ventricular Function

• **Left Ventricular Systolic Function**
  - Significant LV dysfunction is common in critically ill patients (26%)
  - Important for guiding resuscitation and informing decisions management with unexplained hemodynamic instability

• **Sepsis-Related Cardiomyopathy**
  - Cause of hemodynamic instability (hypovolemic, cardiogenic, or distributive origin)
  - Subsequent optimization of therapy (fluid administration, inotropic or vasoconstrictor agent)
  - Repeat bedside examination vital in assessing the adequacy and efficacy of therapy

*Am J Cardiol 2003; 91:510–513*
Right Ventricular Function and Ventricular Interaction

- In critical care setting, massive pulmonary embolism (PE) and ARDS - two main causes of acute cor pulmonale in adults

- Regional RV dysfunction had a sensitivity of 77% and a specificity of 94% for diagnosis of acute PE; PPV - 71% and NPV - 96%

- RV dysfunction may alter therapy (fluid loading, vasopressors, thrombolytics) and provide information about prognosis

*Crit Care Med 2001;29:1551–55*
Assessment of Filling Pressures and Volume Status

• A dilated IVC (diameter of 20 mm) without a normal inspiratory decrease in caliber (50% with gentle sniffing) usually indicates elevated RA pressure

• In MV pt. 12% cutoff value in IVC diameter variation - respond to a fluid challenge (CO > 15 %, with PPV and NPV of 93% and 92%, respectively

Cardiac Tamponade in the ICU

• Myocardial or coronary perforation secondary to catheter-based interventions (pacemaker lead insertion, central catheter placement, or percutaneous coronary interventions)

• Uremic or infectious pericarditis

• Compressive hematoma after cardiac surgery

• Proximal ascending aortic dissection

• Blunt or penetrating chest trauma

• Complication of myocardial infarction (e.g., ventricular rupture)

• Pericardial involvement by metastatic disease or other systemic processes
Bedside Echocardiography vs PAC in ICU

- TEE produced a change in therapy in at least one third of ICU patients, independent of the presence of a PAC
  
  *Chest 1995; 107:774–779*

- Study by Benjamin et al. TEE was performed in 12 ± 7 mins vs. ≥ 30 mins for PAC insertion
  

- Bedside echocardiography has a better safety profile

- PAC continuous monitoring technique to assess the response to a therapeutic intervention
Effect of ECHO in the diagnosis and management in ICU

- Changes in management after TEE in 30–60% of patients leading to surgical interventions in 7–30%
  
  *Crit Care Med 2007; 35[Suppl.]:S235-49*

- Critically ill patients with unexplained hypotension, new diagnoses were made in 28% - leading to surgical intervention in 20%
  
  *J Am Coll Cardiol 1995; 26:152–15*

- ECHO for diagnosis in patients with clinical evidence of ventricular failure and persistent shock despite adequate fluid resuscitation - Level 2 B
  
  *Intensive Care Med. 2007; 33:575–590*
ECHO – Final words

• All physicians in charge of critically ill patients should be trained in goal directed echocardiography
• Far from being competitive or conflicting, use of echocardiography by intensivists and cardiologists is complementary
• German Society of Anesthesiology and Intensive Care Medicine- already developed their own certification
• Brief (10 hrs) formal training in using a handheld ECHO system, intensivists able to successfully perform limited TTE in 94% of patients and interpreted correctly in 84% - changed management in 37% of patients.
• “ECHO-in-ICU group”- France 2004

EDM - Clinical Application

• EDM useful for detecting changes that otherwise have gone unnoticed - covert and overt compensated hypovolemia

• EDM shown to predict subsequent complications in the critically ill. \( N\text{ Engl J Med. 2001;345(19):1368-77.} \)

• EDM is as good or better than pulmonary artery pressures for indicating changes in preload \( \text{Crit Care Med. 1999;27(1):A111.} \)

• A reduction in postoperative complications was reported, with a significant reduction in-hospital length of stay in 4 studies \( \text{Intensive Care Med.2008 JAN 5 – E pub} \)
Limitations – EDM

Esophageal Doppler monitoring contraindicated
• pathology of the esophagus
• coarctation of aorta
• Intraaortic balloon pumps
• Coagulopathies

Further RCT are needed to evaluate EDM in ICU
Gastric Tonometry

- Gastric intramucosal pH and carbon dioxide tension - attractive option for diagnosis and monitoring of splanchnic hypoperfusion
- Prolonged acidosis in gastric mucosa - a sensitive, but not specific, predictor of outcome in critically ill patients

*Curr Opin Crit Care 2001, 7:122-127*
Current position

• Guidelines do not recommend routine use of gastric tonometry and capnography to assess regional or micro-circulation- Level 1B

  International Consensus Conference

• Gomersall et al. showed no clinically or statistically significant differences in ICU or hospital survival, organ function, or duration of stay

INVASIVE MONITORING

• Information received cannot be acquired from less invasive and less risky monitoring

• Information received improves the accuracy of diagnosis, prognosis, and/or treatment based on known physiological principles

• Changes in diagnosis and/or treatment result in improved patient outcome (morbidity and mortality)
Central venous pressure

- Central venous pressure very common clinical measurement, but frequently misunderstood and misused
- CVP can be obtained with transducers and electronic monitors, simple water manometer, by simply JVP on physical examination
- Assessment of volume status and preload of heart- Common indication
- Most readily obtainable target for fluid resuscitation

Surviving sepsis campaign.2008
Rationale for the use of central venous pressure

• CVP and CO determined by interaction of two function curves: cardiac function curve and return curve
Principles of measurement

Leveling

• Standard reference level for assessment sternal angle, 5 cm vertically above the mid-point of the right atrium - even when the person sits up at a 60° angle

• In supine patient, reference level - intersection of the fourth intercostal space with midaxillary line (3 mm Hg / 4.2 cm > sternal angle measurement)

Am J Respir Crit Care Med 2004; 169:A344
Principles of measurement

Transmural pressure

• CVP, should be made at end expiration - pleural pressure is closest to atmospheric pressure

• intrinsic or extrinsic PEEP, pericardial fluid, or increased abdominal pressure can increase CVP

• PEEP of 10 cmH2O, increases the measured CVP by less than 3 mmHg in normal lung and even less in deceased lung

Potential Uses of the CVP

• CVP only elevated ( > 10 mm Hg ) in disease, but clinical utility of CVP as a guide to diagnosis or therapy has not been demonstrated

• If CVP is ≤ 10 mmHg then CO decrease when 10 cm H2O PEEP applied whereas a CVP above 10 mmHg - no predictive value

Fluid resuscitation initially target a CVP of at least 8 mm Hg (12 mm Hg in mechanically ventilated patients)- Level 1 C

Critical Care 2005, 9:566-572

Surviving Sepsis Campaign.2008
Potential Uses of the CVP

• Using ECHO > 36% SVC collapse during positive-pressure inspiration or complete IVC collapse - CVP is below 10 mmHg.

• However no threshold value of CVP that identifies patients whose CO will increase in response to fluid resuscitation

*Intensive Care Med 2004;30:1734-1739*

*Crit Care Med 2004;32:691-699*
PULMONARY ARTERY CATHETER

• 1970 PAC introduced
• 1976 FDA charged with insuring device safety & effectiveness
• Designated as Class II requiring special controls
• 1.5 million in US/yr
  – 30% cardiac surgery
  – 30% cardiac cath
  – 25% high risk surgery
  – 15% MICU

PAC based hemodynamic measurements

• The use of an indwelling catheter to measure
  • – pulmonary artery pressure
  • – pulmonary capillary wedge pressure
  • – right atrial pressure
  • – pulmonary artery oxygen saturation
  • – thermodilution cardiac output

in the intensive care unit
ISSUES

• Do we have data to improve our definition of the type of patients or diseases for which PAC may improve quality of care and outcomes in the ICU?
• Can the data provided by the PAC improve outcomes in severely ill patients?
• Does PAC insertion carry a significant risk of complications?
Physician Knowledge of PAC

JAMA 264:2928,1990
PAC VS NO PAC

Connors, JAMA 276;889,1996
Why do we need PAC

• Hemodynamic profiles predicted in 56%
• PAC derived profiles changed therapy in 50%
• No change in overall mortality!
• Improvement in mortality of Pts. With shock not responding to usual measures

Mimoz et al. CCM 1994;22:573-9
Evidence for Effectiveness
Decompensated Heart Failure: ESCAPE trial

• Randomized trial of PAC vs. no PAC
  – 433 pts hospitalized with CHF and volume overload
  – In PAC group: goal PCW 15 and RA 8
  – PAC group had greater wt loss (4.0 vs 3.2 kg) but similar final BUN/creat
  – 9 serious adverse events in PAC group (infection, bleed, catheter knot, VT, pulmonary infarction)

ESCAPE Investigators. JAMA 2005; 294: 1625
Evidence for Effectiveness
Decompensated Heart Failure: ESCAPE trial

• For the primary endpoint, there was no difference between intervention and control groups:

ESCAPE Investigators. JAMA 2005; 294: 1625
Evidence for Effectiveness
Medical ICU: PAC-Man trial

• Randomized trial of PAC vs. no PAC
  – 1041 pts admitted to ICU who attending thought needed a PAC. 66% medical. 65% multi-organ dysfunction.
  – Therapy at the discretion of the clinician
  – Serious complications occurred in 10% of pts in the PAC group

Harvey et al. Lancet 2005; 366: 472
Evidence for Effectiveness
Medical ICU: PAC-Man trial

• For the primary endpoint, there was no difference between intervention and control groups:

Harvey et al. Lancet 2005; 366: 472
Evidence for Effectiveness
Meta-analysis

• Quantitative review of 13 RCTs of PAC vs. no PAC in
  – medical
  – surgical
  – cardiac patients
• Significantly higher rate of use of vasodilator and inotropic agents in PAC groups
• No difference in mortality between groups

Shah et al. JAMA 2005; 294: 1664
Critical Care 2006, 10(Suppl 3):S8
Evidence for Effectiveness
Meta-analysis

- Use of PAC did not improve survival or decrease the length of hospital stay
- None of the studies used PAC derived variables to drive therapies of proven benefit
- Merely noted the impact of having a PAC in place on outcome.

Shah et al. JAMA 2005; 294: 1664
Critical Care 2006, 10(Suppl 3):S8
NIH ARDS Net FACTT
(Fluids and Catheters Treatment Trial)

• Multicenter trial to evaluate safety and efficacy of PAC-guided versus CVC-guided management in reducing mortality and morbidity in patients with established ALI
• Only trial coupling a treatment protocol with use of PAC
• compared a ‘fluid conservative’ approach with a ‘fluid liberal’ strategy with specific hemodynamic goals and treatment strategies

Critical Care 2008, 12:301
FACTT Protocol

Fluid boluses or diuretics are used to move hemodynamically stable patients toward filling pressure targets:

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<th>PAOP</th>
<th>CVP</th>
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<tr>
<td>Liberal</td>
<td>14 – 18</td>
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<td>Conservative</td>
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NIH ARDS Net FACTT- RESULTS

- PAC-guided therapy did not improve survival or organ function
- Associated with more complications than CVC-guided therapy
- Use of a conservative fluid management strategy in patients with ALI
- PAC should not be routinely used for the management of acute lung injury.

Critical Care 2008, 12:301
Practical guidelines for use of the pulmonary artery catheter

• Cardiac failure
  • Myocardial infarction complicated by cardiogenic shock or progressive hypotension - class I indication ACC/AHA

• PAC insertion in AHF unnecessary, could be used to distinguish between a cardiogenic and a noncardiogenic mechanism in complex patients with concurrent cardiac and pulmonary disease- class llb recommendation (level C evidence)

*Critical Care 2006, 10(Suppl 3):S7

Practical guidelines for use of the pulmonary artery catheter

Severe sepsis or septic shock

• Guidelines do not recommend the routine use of the PAC in shock Level 1(A)

Intensive Care Med. 2007; 33:575–590 International Consensus Conference

• Monitoring combined with fluid infusion titrated to a goal-directed level of filling pressure associated with greatest increase in cardiac output and stroke volume

• PA occlusion pressure in the 12-15 mmHg range

Crit Care Med 2004, 32:1928-1948
Limitation of PAC monitoring

• Cost
• Incorrect measurement of data
  – calibration, damping, zeroing
  – transient respiratory muscle activity
  – reliance on digital readout
  – failure to wedge
  – non zone-III region
Limitation of PAC monitoring

• Incorrect interpretation of data
  – ventricular compliance
  – valve disease

• Improper therapeutic strategies - poor application of data on over zealous goals/targets
Mixed venous oxygen saturation (SvO2)

- SvO2 promoted as an indicator of changes in CO
  - Normal values for SvO2 - 70 to 75%
- Exercise, anemia, hypoxemia, and decreased cardiac output all decrease SvO2
- Hyperdynamic sepsis, hypothermia and muscle relaxation increase SvO2
- SvO2 above 70% does not reflect adequate tissue oxygenation; persistently low SvO2 (< 50 %) is associated with tissue ischemia

Central Venous Oxygen Saturation (ScvO2)

- Simple method to assess adequacy of global oxygen supply in various clinical setting
- Rivers et al - severe sepsis and septic shock- ScvO2 >70% / SVO2 > 65% absolute reduction of mortality by 15%(30.5 vs. 46.5%; \(p < 0.009\)) and major improvements in organ function - **Level 1B**

  Intensive Care Med. 2007;33:575–590 International Consensus Conference

- ScvO2 tracks SvO2 except GA, severe head injury, redistribution of blood flow in shock, microcirculatory shunting or cell death
Oxygen delivery (DO2) and consumption (VO2)

- Among various haemodynamic variables, VO2 below required level most strongly related to death
  
  Critical Care 2006, 10(Suppl 3):S4

- Oxygen consumption (VO2) = CO x Hb x (SaO2-SvO2) x 13.4 = 110-160 ml/min/m2

- Oxygen delivery (DO2) = CO x Hb x SaO2 x 13.4 = 520-600 ml/min/m2

- Oxygen extraction (O2ER) = VO2/DO2 = (SaO2-SvO2) / SaO2 = 0.2 - 0.3
VO2 – DO2 interrelation

VO2 = DO2 x OER

- VO2 becomes supply dependent
- Critical DO2
- Maximal OER
- NORMAL
- SHOCK
Clinical implications

• The Supranormal DO2 Approach
  • Shoemaker: DO2 maintained supranormal values (at least 600 ml/min.M²) in all patients at risk of complications, to ensure sufficient oxygen availability  
    Chest. 1988; 94:1176–1186
  • Guidelines do not recommend targeting supranormal oxygen delivery in patients with shock
    Level 1A

• The Titrated Approach
  • individualized according to careful clinical evaluation, cardiac index, SvO2, blood lactate concentrations  
    Intensive Care Med. 2007;33:575–590
    International Consensus Conference
Blood Lactate Levels

- Sepsis is accompanied by hypermetabolic state, with enhanced glycolysis and hyperlactataemia - not due to hypoxia.
- Marker of tissue perfusion and adequacy of resuscitation.
- Blood lactate concentration in excess of 4 mmol/L is associated with a high risk of mortality.

Clinical Implications

• Appropriate to use elevated lactate trigger to initiate aggressive care- Level 1C

• In the event of hypotension and/or lactate > 4 mmol/l (36 mg/dl):
  – initial minimum of 20 ml/kg of crystalloid (or colloid equivalent)
  – Apply vasopressors for hypotension not responding to initial fluid resuscitation to maintain MAP >65 mmHg

• In the event of persistent hypotension despite fluid resuscitation (septic shock) and/or lactate > 4 mmol/l (36 mg/dl):
  – Achieve central venous pressure > 8 mmHg
  – Achieve central venous oxygen saturation >70%

Surviving Sepsis Campaign.2008
Conclusions

- A knowledge deficit disorder continues to exist in ICU regarding ideal hemodynamic monitoring.
- Major problem is the user not the device of monitoring.
- RCTs in homogenous populations are necessary.
- Tx must be rigorously protocolized as per monitoring in order to have a positive outcome.