DM SEMINAR

Invasive and non-invasive hemodynamic monitoring in the ICU

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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

. N Engl J Med 2001; 345:1368–1377

Hemodynamic Monitoring

Non Invasive

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

Invasive

- CVP
- PAOP
- Pulse waveform analysis
- Microcirculation
  - SvO_2/ $ScvO_2$
  - DO_2/VO_2
  - 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

Critical Care 2005, **9:**566-572

- No RCTs evaluating the impact of arterial pressure monitoring on outcomes when used in ICU or operating room

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

Crit Care Clin.2007; 23 :383–400

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 100mmHg usual target, with HR < 120 B/min- Controversial

Curr Opin Crit Care.2001; 7:422–430

- MAP ≥ 65 mmHg - Initial target in septic shock,>40 mmHg in hemorrhagic shock and > 90 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 Crit Care Clin.2007; 23 :383–400

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

Ann Emerg Med.2006 48:28–54

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

Intensive Care Med 2002 (Suppl) 28(1):S18 - 13.

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

Crit Care Med 2007; 35[Suppl.]:S235–S249

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

Am J Cardiol 2003; 91:510–513

- *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

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

Crit Care Med 2001;29:1551–55

- 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

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

Intensive Care Med (2008) 34:243–249

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

J Cardiothorac Vasc Anesth 1998; 12:10–15

- 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
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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

Intensive Care Med .2008.34:243–249

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 Engl J Med.* 2001;345(19):1368-77.
- EDM is as good or better than pulmonary artery pressures for indicating changes in preload

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

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

Intensive Care Med (2007) 33:575–590
International Consensus Conference

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

Crit Care Med.2000;28:607–614

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

Curr Opin Crit Care.2006;12:219–227.

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

Critical Care 2005, **9:**566-572

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

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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**

JAMA 2001, **286:**348-350.

PAC based hemodynamic measurements

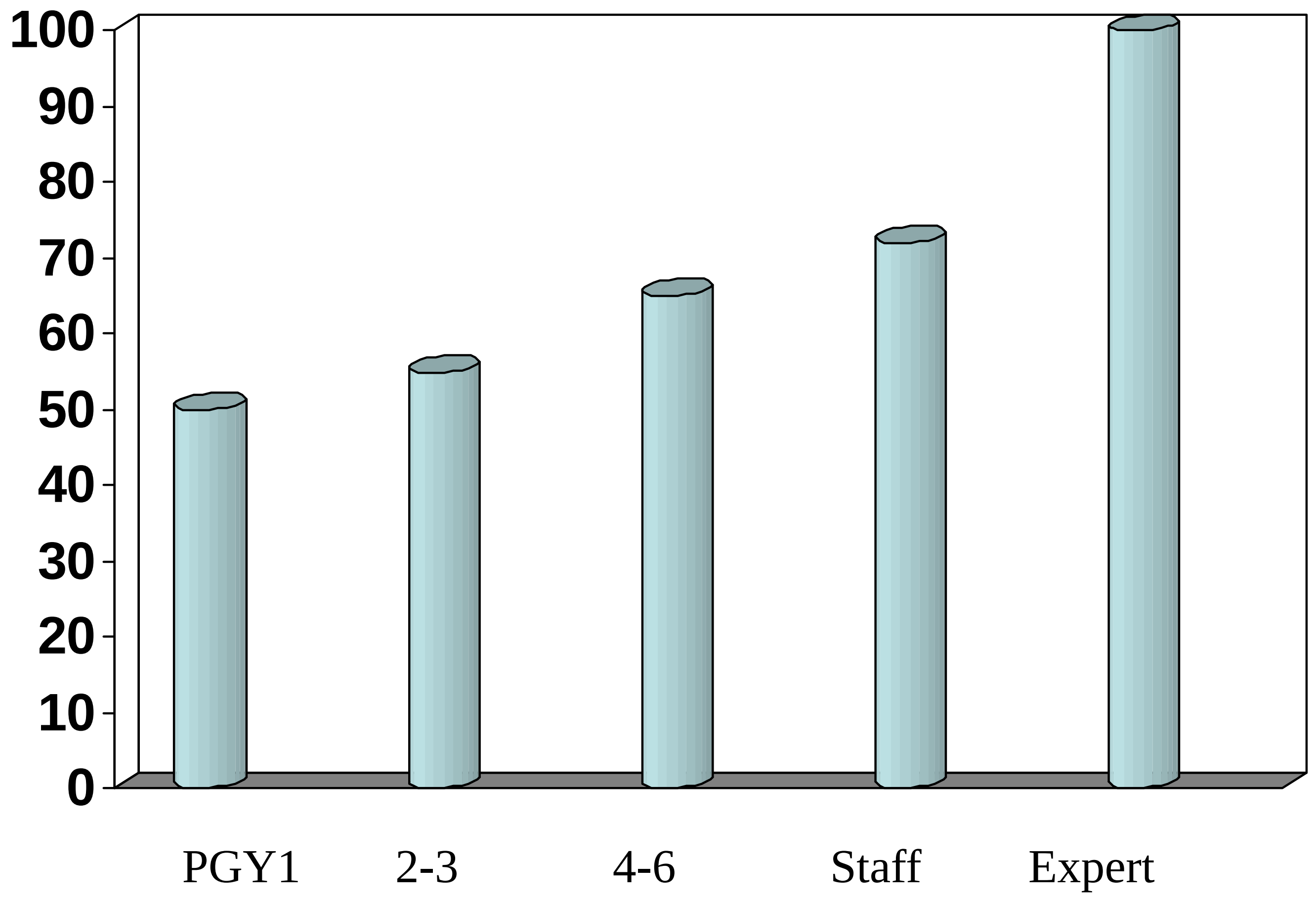
- The use of an indwelling catheter to measure
- – *pulmonary artery pressure*
- – *pulmonary capillary wedge pressure*
- – *right atrial pressure*
- – *pulmonary artery oxygen saturation*
- – *thermodilution cardiac output*

  in the intensive care unit

ISSUES

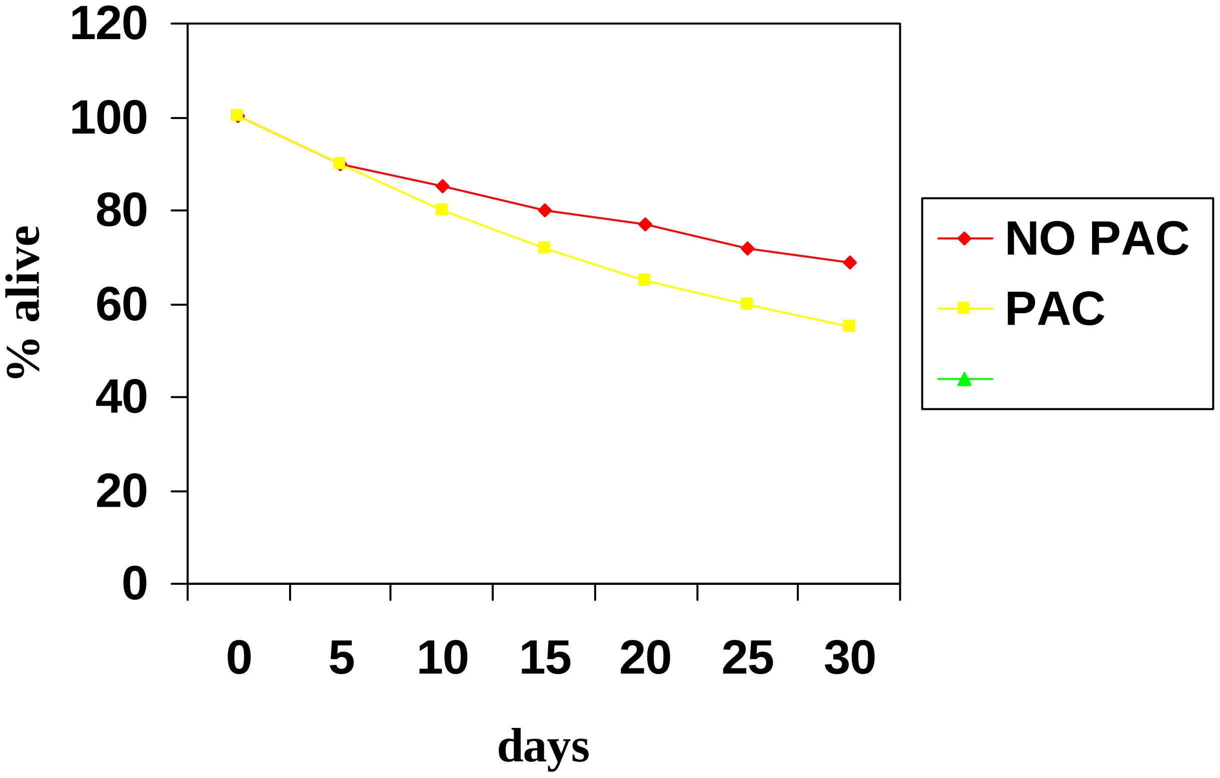
- Do we have data to improve our definition of the type of patients or diseases for which PAC may improve quality of care and outcomes in the ICU?
- Can the data provided by the PAC improve outcomes in severely ill patients?
- Does PAC insertion carry a significant risk of complications?

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 over all mortality!
- <u>Improvement</u> in mortality of Pts. With <u>shock</u> 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

N Engl J Med 2006;354:2213-24.
Critical Care 2008, 12:301

FACTT Protocol

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

	PAOP	CVP
Liberal	14 – 18	10 – 14
Conservative	< 8	< 4

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.

N Engl J Med 2006;354:2213-24.
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

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

  - 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 IIb recommendation (level C evidence)

Eur Heart J 2005, **26:**384-416.

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 (SvO_2)

- SvO_2 promoted as an indicator of changes in CO
  - Normal values for SvO_2 - 70 to 75%
- Exercise, anemia, hypoxemia, and decreased cardiac output all decrease SvO_2
- Hyperdynamic sepsis, hypothermia and muscle relaxation increase SvO_2

- SvO_2 above 70% does not reflect adequate tissue oxygenation ; persistently low SvO_2 (< 50 %) is associated with tissue ischemia

Curr Opin Crit Care.2007; 13:318–323.

Central Venous Oxygen Saturation ($ScvO_2$)

- Simple method to assess adequacy of global oxygen supply in various clinical setting
- Rivers et al - severe sepsis and septic shock- $ScvO_2$ >70% / SVO_2 > 65% absolute reduction of mortality by 15%(30.5 vs. 46.5%; $p < 0.009$) and major improvements in organ function - **Level 1B**

N Engl J Med.2001. 345:1368–1377
Intensive Care Med. 2007;33:575–590 International Consensus Conference

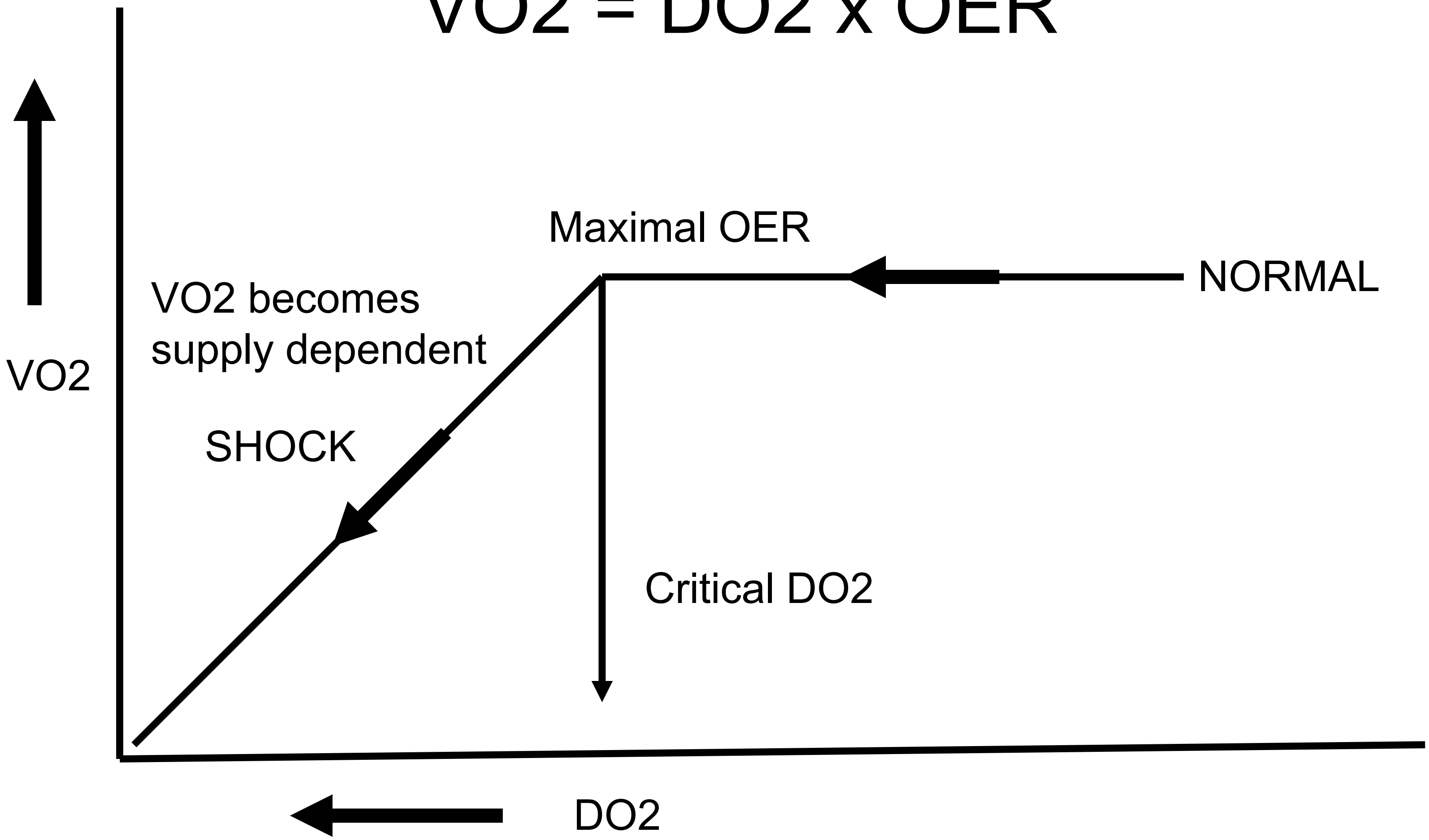
- $ScvO_2$ tracks SvO_2 except GA, severe head injury, redistribution of blood flow in shock,microcirculatory shunting or cell death

Oxygen delivery (DO_2) and consumption (VO_2)

- Among various haemodynamic variables VO_2 below required level most strongly related to death *Critical Care* 2006, **10(Suppl 3):**S4
- Oxygen consumption (VO_2) = CO x Hb x (SaO_2-SvO_2) x 13.4 = 110-160 ml/min/m2
- Oxygen delivery (DO_2) = CO x Hb x SaO_2 x 13.4 = 520- 600 ml/min/m2
- Oxygen extraction (O_2ER) = VO_2/DO_2 = (SaO_2-SvO_2) / SaO_2 = 0.2 - 0.3

VO2 – DO2 interrelation

$$VO2 = DO2 \times OER$$



Clinical implications

- The Supranormal DO_2 Approach
  - Shoemaker : DO_2 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, SvO_2, blood lactate concentrations

Intensive Care Med. 2007;33:575–590
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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

Curr Opin Crit Care.2006 12:315–321

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