In the name of Allah, the Beneficient, the Merciful.
Volume status in critically ill patient

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• Accurate assessment if intravascular volume is one of the most important and also challenging task for physicians.
• **Hypovolemia** leading to inappropriate using vasopressors which may increase organ hypoperfusion and ischemia.
• **Liberal fluid** resuscitation has been associated with increase complications, increase length of ICU and hospital stay and increase mortality.
• Each 1 lit. positive fluid balance during 1st 72 hrs of ICU stay is associated with a 10% increase in mortality.
• In ARDS and Sepsis it is prefered to keep the pts on dry side of the road.
Assessment of volume status and fluid responsiveness

Optimum fluid balance

Volume depletion
- Hypotension
- Shock
- Organ hypoperfusion
- Acute kidney injury

Inadequate fluid therapy

Volume overload
- Impaired oxygenation
- Edema
- Hypertension
- Organ congestion

Overaggressive fluid therapy
Adequate organ perfusion and oxygenation

- SBP<90 mmHg
- MAP(<70mmHg)
- Urine output
- Mentation
- Capillary refill
- Skin perfusion/mottling
- Cold Knee’s (Marik’s sign; T gradient between thigh and knee)
- Blood lactate level
- Arterial PH, and HCO3
- Lactate level(>1.5mmol/lit, Nl=1mmol/lit)
- Mixed venous oxygen saturation(SmvO2) or central venous oxygen saturation(ScvO2)
- Tissue pCO2(sublingual capnography)
- Gastric impedance spectroscopy
- Skeletal muscle tissue oxygenation
Adequate organ perfusion and oxygenation contd.

- Generalized edema
- Pulmonary edema (chest X-ray and vascular pedicle width)
- Increase extravascular lung water (PiCCO technology)
- Increase intra abdominal pressure
- Pulse Pressure Variation (PPV)
- Stroke Volume Variation (SVV)
- Echocardiography
Hypovolemia

- PCWP < 5mmHg, CVP < 5mmHg, Tachycardia, Urine output < 0.5ml/kg/hr.
• Accuracy of clinical data and some tests such as Na, spot urine Na, CXR, in assessment of volume status is less than 50%.

• CVP and also PAOP has been shown to fail to volume status of this pts.
Preinfusion CVP (○, individual values; •, mean values) of responders (R) and nonresponders (NR).
More than 100 studies have been published that have demonstrated no relationship between the CVP (or change in CVP) and fluid responsiveness in various clinical setting.

Preinfusion PaOP (○, individual values; •, mean values) of responders (R) and nonresponders (NR).
PA Catheter

Markings on catheter.
1. Each **thin** line = 10 cm.
2. Each **thick** line = 50 cm.

Static pressures

- **CVP**: is dependent to VR,RV compliance, peripheral vascular tone and posture.
- **CVP** is unreliable in pulmonary vascular diseases, RV dis. Tense ascites, isolated LV failure and valvular heart dis. (a pt with CVP of 2mmHg is as fluid responsive as a pt with CVP of 20 mmHg).
- **PAOP(PCWP)**: is proportional to LVEDV/P, but has a poor correlation with volume state and responsiveness to fluid administration.
Echocardiography

- TTE or TEE can provide cardiac chamber volume assessment.
- LVEDA may be a predictor of volume responsiveness.
- Esophageal Doppler monitoring of aorta and measuring blood velocity to descending aorta, diameter of aorta and monitoring changes of them with respiratory cycle correlate with fluid responsiveness in pt on Positive pressure ventilation.
Dynamic variables: heart-lung interaction during mechanical ventilation

- Systolic Pressure Variation
- Stroke volume variation (SVV)
- Pulse pressure variation (PVV)
- Aortic flow velocity change
- SVC or IVC diameter change
- End Expiratory Occlusion test
- Passive Leg Raising
Mechanically ventilated patient inspiration

1. Reduction in venous return
2. Reduction in right ventricular preload
3. Increase in right ventricular afterload

Biventricular dependence

Decrease in left ventricular output occurs during expiration

Inspiration | Expiration | Inspiration

Arterial pressure
Dynamic markers.
FloTrac/Vigileo

No calibration needed, derives measurements based on compliance and patient characteristics (gender, age, height and weight – derived from experimental cadaver data)

Measures the pulsatility of the arterial waveform by calculating the standard deviation of the arterial pressure wave over a 20s period – multiplied by the compliance

The initial software autocalibrated every 20 minutes, leading to bad ROC when compared to PACs – however it now autocalibrates every minute.
LiDCO

Made by the LiDCO group in London
Measures Cardiac output using a small dose of lithium injected in the periphery and then generating a arterial lithium concentration-time curve by withdrawing blood past a lithium sensor attached to the patient's a-line
It then uses proprietary software to calculate continuous beat-to-beat cardiac output, by analysis of the arterial blood pressure tracing.
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• PPV and SVV has high accuracy for in pts with volume responsive hemodynamic instability with a threshold of 12-13%.
• The predictive value was maintained in pts with poor LV function.
• Arhythmia and spontaneous breathing activity will lead to misinterpretation of resoriratory variation in PP/SV.
• The tidal volume mus be at least 8ml/kg.
• Less invasive technique is pulse pressure analysis using dynamic changes in both the peak and amplitude of the pulse oximeter plethysmograph wave form.
• Dynamic changes in pulse oximeter wave form have shown significant correlation with PPV and accurately predicted fluid responsiveness.
Pleth variability index

- Pleth V.I > 14% predict that a pt will respond to fluid with sensitivity of 81%.
Attention

- Pt must be in nl sinus rhythm, have no spontaneous respiration, have a closed chest and tidal volume of at least 8ml/kg.
- **Systolic Pressure Variation > 10 mmHg** demonstrated hypovolemia.
- PPV 13% or more has sensitivity of 94% and specificity of 96% to differentiates between fluid responders vs non responders.
- PPV has a gray zone 9-13% which may affect up to 25% of pts.
- PPV is superior to SPV in discriminate fluid responders.
- Stroke Volume Variation is computed by pulse contour analysis and computation of area under the systolic portion of the arterial pressure curve.
Less variability
SVV is low < 13%

More variability
SVV is high >13%

Source: Transfusion Alt Transfusion Med © 2011 Blackwell Publishing Ltd.
Intrathoracic pressure induced by mechanical ventilation.
IVC diameter and collapsibility (NI IVC 8-11mm/m2)

Volume Responsive: IVC diameter <1 cm
Not Responsive: IVC diameter >3 cm
Assessment of Fluid Status and Measures of Volume Responsiveness

IVC Diameter Variation

• Measure proximal IVC AP diameter 3 cm from the RA

• Spontaneous breathing
  - > 50% decrease in the IVC diameter with inspiration predicts responsiveness to volume expansion

• Positive pressure ventilation
  - > 12% increase in the IVC diameter with inspiration predicts responsiveness to volume expansion
    - Max D – min D / average D > 12%
    - Max D - min D / min D > 18%
Passive Leg Raising

• A recent meta-analysis determined that the area under curve of PLR for determining fluid responsiveness is 95% and was not affected by spontaneous breathing or dysrhythmias.

• 10% or more increase in cardiac output predict volume responsiveness of the pt.
Assessment of Fluid Status and Measures of Volume Responsiveness

Passive Leg Raising and Stroke Volume Variation

• Straight leg raising test: Can be done on any patient
  – Sinus or irregular rhythm
  – Spontaneous breathing or on ventilator
  – On pressors or off pressors

• Use apical 5 chamber view and measure the aortic blood flow (stroke volume)
• Raise legs to 45 degree (you have just given a “blood bolus” 500 ml blood in legs returned to the heart)
• Wait 30-60-90 sec (highest values within 90 sec)
• Recheck the stroke volume
  – SVV > 12%
Passive Leg Raising
on spontaneously breathing pt

transfer of blood from the legs and abdominal compartments
= test for fluid responsiveness

passive leg raising
End Expiratory Occlusion test

- Airway pressure (cm H₂O)
- 15-sec EEO
- In cardiac preload
- Cyclic ↓ in cardiac preload
- = Test for fluid responsiveness
Volume overload

Radiographic signs of pulmonary edema and anasarca are late signs of volume overload.
VPW of 70 mm + C/T ratio >55%  
(it is better measure serially in single pt)
Extravascular lung water

- Is calculated by thermodilution.
- Detect small (10-20%) increase in lung water.
- Nl value is 5-7 ml/kg(IBW).
- Mortality is about 65% in pts with EVLW>15 ml/kg and 33% in pts with EVLW<10ml/kg.
Intra abdominal pressure

• Intra abdominal HTN defined by WSACS is intra abdominal pressure $\geq 12$mmHg and abdominal compartment syn. Is IAP above 20 mmHg.

• Abdominal perfusion pressure (MAP-IAP) more than 60 mmHg correlating with improve survival.

• It is best measured by intravesicular method. In end expiration and complete supine position.
Bioimpedance

- High frequency current applied to chest cavity and measure impedance.
- Resistance is inversely proportional to amount of water.
- It’s data is indicative of total body water and not simply intravascular volume.
<table>
<thead>
<tr>
<th>Method</th>
<th>Invasive or noninvasive</th>
<th>Static or dynamic</th>
<th>Assess fluid responsiveness</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Historical findings</td>
<td>Noninvasive</td>
<td>Static</td>
<td>No</td>
<td>Of limited value with poor correlation with invasive pressure measurements</td>
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<tr>
<td>Physical exam</td>
<td>Noninvasive</td>
<td>Static and dynamic</td>
<td>Yes</td>
<td>Of limited value but serial examinations may detect changes in organ perfusion</td>
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<tr>
<td></td>
<td></td>
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<td></td>
<td>Requires use of standardized measures of vascular pedicle width and cardiothoracic ratio.</td>
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<td></td>
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<td>Serial chest X-ray may be helpful in determining effects of fluid therapy</td>
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<tr>
<td>Chest radiograph</td>
<td>Noninvasive</td>
<td>Static</td>
<td>No</td>
<td>Requires use of standardized measures of vascular pedicle width and cardiothoracic ratio.</td>
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<tr>
<td>Central venous pressure</td>
<td>Invasive</td>
<td>Static</td>
<td>No</td>
<td>Poor correlation with fluid responsiveness</td>
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<tr>
<td>Pulmonary capillary wedge</td>
<td>Invasive</td>
<td>Static</td>
<td>No</td>
<td>Poor correlation with fluid responsiveness</td>
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<tr>
<td>pressure</td>
<td></td>
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<tr>
<td>Echocardiogram</td>
<td>Noninvasive</td>
<td>Static</td>
<td>No</td>
<td>Single measures of cardiac chamber volume hard to assess. Serial measures may be helpful</td>
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<td>Stroke volume or pulse</td>
<td>Invasive (pulse oximeter</td>
<td>Dynamic</td>
<td>Yes</td>
<td>Requires sedated, mechanically ventilated patient</td>
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<td>pressure variation</td>
<td>method in noninvasive)</td>
<td></td>
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<tr>
<td>Esophageal doppler</td>
<td>Invasive</td>
<td>Dynamic</td>
<td>Yes</td>
<td>Not useful for continuous measurements</td>
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<td>Vena cava diameter</td>
<td>Noninvasive</td>
<td>Dynamic</td>
<td>Yes</td>
<td>Body habitus dependent</td>
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<tr>
<td>Passive leg raising</td>
<td>Noninvasive (bioreactance, end-tidal CO₂)</td>
<td>Dynamic</td>
<td>Yes</td>
<td>Unreliable with intra-abdominal hypertension</td>
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<tr>
<td>End-expiratory occlusion</td>
<td>Passive leg raising</td>
<td>Dynamic</td>
<td>Yes</td>
<td>Requires 15-s end-expiratory occlusion</td>
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<tr>
<td>Bioimpedance</td>
<td>Noninvasive</td>
<td>Static</td>
<td>No</td>
<td>Not able to assess intravascular volume</td>
</tr>
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</table>
Mini fluid challenge test

- 100 ml of colloid infuse in 1 min.
- >10% increase in aortic velocity time index by transthoracic echo. Predicted fluid responsiveness with a sensitivity of 95% and specificity of 78%.

References

• Marik, Paul Ellis Handbook of Evidence-Based Critical Care, chapter 8, fluid Resuscitation and volume assessment, Springer, 2010.
• Pual E Marik, Xavier Monner, Jean-Louis Teboul: Hemodynamic parameter to guide fluid therapy. Annals of Intensive Care; 2011,1:1
• Takehiko lijima et al: The maintenance and monitoring of perioperative blood volume. Perioperative Medicine, 2013, 2:9