Update on Hemodynamic Monitoring

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Disclosure

- I have no affiliations to disclose.
- There will be display of new technologies and monitors during this presentation. All the opinions that will be displayed here reflects scientific data that is supported by literature.
Outline:

“What have we been doing and Why?”

Invasive vs. Noninvasive Methods

Arterial Wave Form Analysis

Why does it matter?
How can we monitor it?
Monitoring critically ill patients:

What are we really worried about?
- “Tissue Hypoperfusion”

What do we really want to monitor?
- “Adequate Oxygen Delivery”

Definition of Shock:
- “Inadequate tissue perfusion affecting multiple organ systems.”
Hemodynamic Monitoring:
Review of Basics

**Oxygen Demand > Oxygen Supply**

**Oxygen Delivery (DaO2)**

\[
\text{Oxygen Delivery (DaO2)} = \text{CaO2} \times \text{CO} \times 10 = 1000 \text{ ml/min}
\]

**Arterial Oxygen Content (CaO2)**

\[
\text{Arterial Oxygen Content (CaO2)} = (0.0138 \times \text{Hgb} \times \text{SaO2}) + (0.0031 \times \text{PaO2}) = 20.1 \text{ ml/dl}
\]

**Cardiac Output (CO)**

\[
\text{Cardiac Output (CO)} = \text{SV} \times \text{HR} = 4-8 \text{ L/min}
\]
Oxygen Delivery
[Cardiac Output (CO) x Arterial Oxygen Content (CaO₂)]

Cardiac Output (CO)
- Stroke Volume
- Heart Rate

Arterial Oxygen Content (CaO₂)
- Hemoglobin
- SaO₂ (Arterial Oxygen Saturation)
- PaO₂ (Arterial Oxygen Tension)

Preload

Afterload

Contractility
Assessment of Adequate Oxygen Delivery

- Tachycardia  
- Diaphoresis  
- Tachypnea  
- Cool Peripheries  
- Prolonged Capillary Refill  
- Increased Temperature Difference  
- Reduced Level of Consciousness  
- Decreased Urine Output

Clinical Estimation

- Lactate
- Base Excess

Lab Values

- Lactate
- Base Excess

Measurement of CO and/or SvO2%

- Invasive & Noninvasive
- New vs. Old
Basics of Hemodynamic Monitoring

- Heart Rate
- Blood Pressure (Noninvasive vs. Invasive)
- Central Venous Pressure
Basics of Hemodynamic Monitoring

Patient is hypotensive, now what?

Aline, CVP, ECG, Sato2% in place…

**WHY IS HE HYPOTENSIVE?**

**WHAT IS THE FIRST STEP?**
Why is he hypotensive?

1. Hypotension → Decreased venous return → Hypovolemia  
   (Preload)

2. Hypotension → Myocardial dysfunction → Mechanical obstruction  
   (Contractility)

3. Hypotension → Arterial vasodilatation → Afterload
IS PATIENT VOLUME RESPONSIVE?

- Primary resuscitation question is whether the patient will increase their cardiac output in response to intravascular volume infusion.

- That is why almost always the first step is to give fluids and see patient’s response, in case of a hypotension.

- It is important to determine “volume responsiveness” !!!
Volume Responsiveness:

**FRANK STARLING CURVE...**
How to assess volume responsiveness?

- Volume Responsiveness was defined as increase in CO by 15% or more, by 500 ml fluid bolus.
- Passive Leg Raising*
- CVP-MAP Relationship
- CVP vs. EDV/EDVI?
- Stroke Volume Variations
- Pulse Pressure Variations
- Systolic Pressure Variations

New Generation Monitors
Central venous pressure (CVP) =.

CVP can reflect a volume increase in RA pressures or decrease in RV contractility can be both.

Need to be monitored in conjunction with other monitors (CVP & MAP).

The main limitations of CVP monitoring:
(a) it does not allow to measure cardiac output
(b) it does not provide reliable information on the status of the pulmonary circulation in the presence of left ventricular dysfunction.
WHY IS HE HYPOPOTENSIVE?

Hypotension → Decreased venous return

CVP↑ (preload)

Hypovolemia

Mechanical obstruction

Myocardial dysfunction (contractility)

Arterial vasodilatation (afterload)
Measurement of Cardiac Output:

- Thermo Dilution
- Dye/Indicator Dilution
- Arterial Pulse Pressure Analysis**
Measurement of Cardiac Output:

Thermodilution (TD):
- Dilution of Temperature (Cold NS)
- Area Under the Curve (AUC)
- Pulmonary Artery Catheter (PACs) or Newer Generation CVL w sensors
- Intermittent vs. Continuous TD

Dye/Indicator Dilution:
- Same Technique (Dilution of dye or indicator instead of NS)
- Dye(indocyanine green) vs. Indicator(Lithium)
- A line vs. CVL, no need for PACs.
**Thermodilution (TD) - Measurement of Cardiac Output**

**Intermittent Bolus** Pulmonary Artery Thermodilution Technique:

1. 1870 - oldest defined CO measurement system
2. Cold solution – proximal port/RA – distal port - thermistor
3. Measures RV outflow, not systemic CO.
4. Not perfect because
   - Volume & temp of cold solution may vary.
   - Baseline blood temperature changes
   - Intracardiac shunts (R_L ; L_R)
   - Mechanical and Spontaneous Resp. Cycle effects.
Thermodilution (TD) - Measurement of Cardiac Output

Figure taken from reference #2.
Thermodilution (TD)- Measurement of Cardiac Output

Continuous Pulmonary Artery Thermocilution Technique:

- Same principle, New technology.
- Electric filament (vigilance) vs. thermal coil (optiQ)
  - Intermittently heating R heart
  - Temp change is being detected at tip of PAC.
- Every 30 – 60 second data collection but...
- Displayed value is average of 5-15 minutes of data collection.

Advantage:
1. Continuous trend of CO
2. Decrease operator workload
3. Reduce infection risk (no more boluses into system)
Pulmonary Artery Catheters (PACs):

- Both TD techniques to calculate CO requires PACs.
- Standard of reference for cardiac filling pressures.

**KEY advantage:**
Simultaneous measurements of other hemodynamic parameters:
- CO
- Pulmonary Artery Pressures (PAD, PAOP)
- Right Sided Filling
- Left Sided Filling
- SvO2%
PACs3-6:

Studies overall the years had conflicting results:

- Increased Mortality?
- Multiple RCTs were conducted in several RCTs.
- Conclusion:

  **No difference in LOS in the ICU**
  **No difference in Mortality**
  **No benefit, no harm**

- “There is no guided therapy tailored towards PAC use.”
- “PAC is a diagnostic tool, not a therapeutic one.”
Other ways of measuring CO by dilution technique?

Transpulmonary Thermodilution Methods:
- PiCCO & PiCCO2  (Pulsion Medical Systems)
- VolumeView  (Edwards Life Sciences)

Lithium Dilution Technique:
- LiDCO /LiDCOplus/LiDCOrapid  (LiDCO limited)

Ultrasound Indicator Dilution
- COstatus  (Transonic Systems, Inc.)
COstatus® AV Tubing Loop
with connections to a patient’s existing arterial and central venous catheters.

COstatus Monitor
HCM101

AV Tubing Loop

Pump

Injection Syringe for Normal Saline Indicator

Venous Sensor

Arterial Sensor

Central Venous Catheter

Arterial Pressure

Arterial Catheter

Ultrasound flow/dilution sensors connect to existing catheters in patient.

**COstatus® Advantages**

1. Uses a harmless indicator – body temperature normal saline
2. Uses existing standard arterial and central venous catheters lines
3. Operator independent
4. Involves no blood loss
5. Patient set-up times are less than 6 minutes
6. Uses well established ultrasound dilution technology
7. Applicable for patients of all size: neonates, pediatrics and adults

Taken from http://www.transonic.com/ICU/COstatusSetup
LiDCO and PiCCO ***
Less Invasive Methods for CO Calculation

Arterial Waveform Analysis - Waveform Derived CO Measurements.
Arterial Pressure Waveform-Derived CO Measurements

“BP is a product of SV (CO) and Vascular Resistance.”

**Advantages:**

- Non invasiveness
- Works through an already existing a line catheter
- Continuous CO monitoring

May require **calibration** for arterial compliance and resistance:

1. Lithium Dilution (LiDCO)
2. Thermodilution (VolumeView, PiCCO)
Arterial Pressure Waveform-Derived CO Measurements

Arterial Pressure Waveform Analysis

- Pressure Recording Analytical Method (PRAM)
- Pulse Power Analysis
- Pulse Contour Analysis

- FloTrac Vigileo
- LiDCOplus
- LiDCORapid
- PiCCO$_2$
PiCCO$_2$

- Pulse Contour Analysis — **Aline Wave Form matters**!
- Area under systolic area (until dicrotic notch) on arterial waveform is detected. **

- External manual calibration for CO is necessary.
- This is done via transpulmonary TD every 8 hours or
- Hourly calibration is required, if patient is hemodynamically unstable.

Taken from [http://www3.pulsion.de/fileadmin/pulsion_share/Products_Flyer/PiCCO_Broschure_E_MPI810205_R02_270208.pdf](http://www3.pulsion.de/fileadmin/pulsion_share/Products_Flyer/PiCCO_Broschure_E_MPI810205_R02_270208.pdf)
PiCCO₂

System Requires:
Thermistor Tipped Aline Catheter – Femoral Aline (longer cath, better signal)
   Radial, Axillary, Brachial ok as well
Central Venous Catheter (thermo indicator solution injection)

Provides:
Dynamic parameters of Preload: SVV, PPV, SPV.
Other Volumetric parameters: GEDV, EVLW, ITBV.
Global end diastolic volume
Extravascular lung water
Intrathoracic Blood Volume

Taken from http://www3.pulsion.de/fileadmin/pulsion_share/Products_Flyer/PiCCO_Broschure_E_MPI810205_R02_270208.pdf
Height 178 cm  Weight 83 kg
HR 86
AP 132/71
MAP 101
CVP 9

Overview
Circulation  Volume Status  Organ Function  Oxygenation

PCCI 4.52 l/min/m²
SVI 47 mL/m²
CI 3.41 l/min/m²

GEDI 863 ml/m²
SVV 9%

Afterload
SVRI 1735 dyn·s·cm⁻²·m⁻²
GEF 36%
dPmx 847 mmHg/s

Temp Blood 36.7°C

ELWI 14 ml/kg
PVPI 2.7
CPI 0.5 W/m²

ScvO₂ 77%
DO₂I 553 ml/min/m²
VO₂I 159 ml/min/m²

Values at time of TD, 0 h 52 min ago
LiDCOplus

- Combination of two monitors
  - LiDCO (Indicator dilution CO calculation & monitor)
  - PulseCO (Software, CO from aline waveform.)

- Unlike PiCCO2, aline waveform is not important in pulse power analysis.
  (This is why damping effect is also minimized in LiDCO system.)
  (No need to detect dicrotic notch.)

- Requires:
  - Aline
  - Peripheral or Central Access (to insert a lithium sensitive sensor)

- **External CO calibration with lithium every 8 hours is necessary.**
  - Neuromuscular blockers within 30 min. (due to interactivity with lithium on sensor level)
  - Lithium therapy receiving patients*
LiDCOrapid

- **No need for CO calibration with lithium.**
- Replaced by nomogram which is derived from in vivo data to estimate CO.
Patients’ optimal MAP target, set by the clinician

Patients’ ideal status line

Patient’s optimal CO/CI target, set by clinician

Indexed value enables this easy to interpret format

Pressure = Flow x Resistance
FloTrac Vigileo

- FloTrac Algorithm integrates multiple characteristics of arterial pressure waveform with patient specific demographic data.
- **No external CO calibration is required.** (Unlike LiDCO, PiCCO)
- **An arterial aline** is adequate to use the monitor.
- **No CVL is required.**
The FloTrac System Algorithm

Formula for Cardiac Output = Heart Rate x Stroke Volume
FloTrac System Cardiac Output = Pulse Rate x [std(BP) * χ]

Pulse Rate [PR]
- Measured as beats per minute
- Beats identified by upslope of waveforms
- Advanced beat detection differentiates fully perfused beats
- Computed from 20-second time period of beats

Standard deviation of arterial blood pressure [std(BP)]
- Pulse pressure ∝ SV ∝ std(BP)
- Measured as mm Hg
- Computed on a beat-by-beat basis

The χ factor compensates for differences in vascular compliance and resistance
- Patient-to-patient differences estimated from biometric data
- Dynamic changes estimated by waveform analysis (skewness, kurtosis, of the waveform)
- Measured as mL per beat/mm Hg
- 1-minute average updates
FloTrac Vigileo: Advantages

- Requires No Manual Calibration for CO Calculation.
- User enters Patient (Pt) Specific Data.
  
  (age, gender, height, weight to initiate the monitoring.)
- Advanced Arterial Waveform Analysis (PRAM) by FloTrac Sensor.
  
  Pt to pt differences in vasculature.
  
  Real time changes in vascular tone.
  
  Different arterial sites are acceptable.
- **Central Venous Oximetry** (Scvo2) is available.
  
  (if used in conjunction with appropriate oximetry CVL.)*
FloTrac Vigileo Monitor - Disadvantages

- Aline Wave form is important!
- **Good Arterial Signal Quality is critical for accurate CO calculation.**
- Still Not Reliable
  - During Arrhythmias
  - For Hemodynamically Unstable Patients
  - Intra Aortic Balloon Pump in use.
  - Ventricular Assist Devices in use.
Vigileo Monitor:

Can display:
- CCO
- CCI
- SV
- SVI
- SVV

Every 20 seconds
When used with FloTrac Sensor.
NEW CONCEPTS IN HEMODYNAMIC MONITORING

How to assess volume responsiveness?

Stroke Volume Variations (SVV)
Pulse Pressure Variations (PPV)
Systolic Pressure Variations (SPV)
How to assess volume responsiveness?

- Volume Responsiveness was defined as increase in CO by 15% or more, by 500 ml fluid bolus.
- Passive Leg Raising*

New Generation Monitors

- CVP-MAP Relationship
- CVP vs. EDV/EDVI?
- Stroke Volume Variations
- Pulse Pressure Variations
- Systolic Pressure Variations
**FloTrac Vigileo – Stroke Volume Variation**

\[
SVV = \frac{SV_{\text{max}} - SV_{\text{min}}}{SV_{\text{mean}}}
\]
Can be used as a tool for volume responsiveness in low CO states.

**SVV > 13% = Volume Responsive**

“SVV and PPV are more effective indicators for Volume Responsiveness than static indicators of preload (CVP, PAOP).”

Limitations:

*Pt needs to be on 100% Controlled Mechanical Ventilation.*

*Spontaneous Ventilation & SVV? Arrhythmias can affect SVV.*
FloTrac System

Volume Responsive Algorithm

Volume Responsive SVV > 13%

- YES
- NO

Volume Challenge
SVI Normal (40-50)
SVI Low (<40)
SVI High (>50)

Pressor
Inotrope
Diuretic

Stroke Volume Variation
A sensitive indicator of preload responsiveness (on control ventilated patients)

\[
\%SVV = \frac{SV_{max} - SV_{min}}{SV_{mean}}
\]

SQUARE WAVE TEST (for assessing dynamic performance):
1. Pull and release snap-tab, 2. Observe square wave on monitor, 3. Count oscillations

Optimally Damped: 1.5-2 oscillations before returning to baseline.

Underdamped: >2 oscillations: SBP overestimated & DBP may be low or normal. Results - false widening of pulse pressure and overestimation of CO. See product insert for potential causes.

Overdamped: <1 oscillation: SBP falsely low & DBP may be high or normal. Results - false narrowing of pulse pressure and underestimation of CO. See product insert for potential causes.

FloTrac Pocket Guide

1. Cardiac Output
   Blood pumped from heart in liters/min.

2. Central Venous Oxygen Saturation*
   Assessment of balance between DO₂ and VO₂. Lower values indicate increased oxygen extraction or decreased delivery. Higher levels are seen with impaired oxygen utilization and extraction.

3. Stroke Volume
   Blood ejected from left ventricle per beat. Low value indicates poor ventricular performance.

4. Stroke Volume Variation
   (For use on control ventilated patients). Variation in arterial pulsations caused by volume changes during positive pressure inspiration. >15% may indicate hypovolemia.

5. Systemic Vascular Resistance*
   Clinical indicator of afterload.

Vigileo Monitor Hemodynamic Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normal Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO (Cardiac Output)</td>
<td>4.0 - 8.0 L/min</td>
</tr>
<tr>
<td>CI (Cardiac Index)</td>
<td>2.5 - 4.0 L/min/m²</td>
</tr>
<tr>
<td>SV (Stroke Volume)</td>
<td>60 - 100 mL/beat</td>
</tr>
<tr>
<td>SVI (Stroke Volume Index)</td>
<td>33 - 47 ml/m²</td>
</tr>
<tr>
<td>SVRI (Systemic Vascular Resistance)</td>
<td>800 - 1200 dynes/ sec/cm²</td>
</tr>
<tr>
<td>SVV (Stroke Volume Variation)</td>
<td>1970-2390 dynes/sec/cm²</td>
</tr>
<tr>
<td>ScvO₂</td>
<td>&lt;15%</td>
</tr>
<tr>
<td></td>
<td>≥70%</td>
</tr>
</tbody>
</table>

*Available when used with the PreSep catheter
†Available when interfaced with CVP from appropriate bedside monitor

Rx only. See instructions for use for full prescribing information.

Edwards and Vigileo are trademarks of Edwards Lifesciences Corporation. Edwards Lifesciences, the stylized E logo, and FloTrac are trademarks of Edwards Lifesciences Corporation and are registered in the United States Patent and Trademark Office.

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Venous Oximetry
FICK PRINCIPLE

\[ \text{SvO}_2 = \left[ \text{SaO}_2 - \text{VO}_2 / \text{CO} \right] \left[ 1 / \text{Hb} \times 1.34 \right] \]

- Oxygen Delivery (DaO2): 1000 ml/min
- Oxygen Consumption (VO2): 200-250 ml/min
- Oxygen Extraction Ratio: 25%
- Normal SvO2%: 65-75%

**SvO2 < 60%**  
**MORE O2 EXTRACTION**

**SvO2 > 75%**  
**INADEQUATE O2 UTILIZATION**
Increased VO2 will be compensated by increased CO.

If this is not adequate, elevated oxygen extraction occurs in the peripheral tissues.

SvO2 will drop.

SvO2 thus reflects the balance between oxygen delivery and oxygen demand.
Supranormal SvO2 (or ScvO2) values do not guarantee adequate tissue oxygenation. (SvO2% > 80%)

If tissue is not capable of extracting oxygen, venous return may have a high oxygen content despite persistent cellular hypoxia.

E.g.: Sepsis, Burn Patients, Shunts etc.
Venous Oximetry
Continuous SvO2/ScvO2 Monitoring

Critical illness
Injury
Perioperative period

↓ Venous oxygen saturations
- ↓ O₂ delivery
  - Anaemia
  - Haemorrhage
  - Hypoxia
  - Hypovolemia
  - Heart failure
- ↑ O₂ consumption
  - Agitation
  - Pain
  - Fever
  - Shivering
  - Respiratory failure
  - Metabolic demand

↑ Venous oxygen saturations
- ↑ O₂ delivery
  - Oxygen therapy
  - Blood transfusion
  - Intravenous fluid
  - Inotropics
  - ↑ Cardiac output
- ↓ O₂ consumption
  - Sedation
  - Analgesia
  - Hypothermia
  - Mechanical ventilation
  - ↓ O₂ extraction
  - Shunting (sepsis)
  - Cell death
How do we measure SvO2% & ScvO2%?:

- **Swan Ganz Pulmonary Artery Catheter:**
  “Old Method, New Technology”

**Advanced Technology Catheters:**

- **SWAN-GANZ CCOMBO** Pulmonary Artery Catheter:
  (Combo = Continuous CO + **Venous Oximetry**)

- **SWAN-GANZ CCOMBO VIP** Catheters:
  
  CCO & **Venous Oximetry**

  Provide additional lumen.
### Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Derived Information</th>
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<tbody>
<tr>
<td>SvO₂ (Mixed Venous Oxygen Saturation)</td>
<td>Tissue oxygenation</td>
</tr>
<tr>
<td>CEDV (Continuous End Diastolic Volume)</td>
<td>Preload</td>
</tr>
<tr>
<td>SVR (Systemic Vascular Resistance)</td>
<td>Afterload</td>
</tr>
<tr>
<td>CCO (Continuous Cardiac Output)</td>
<td>Contractility</td>
</tr>
<tr>
<td>SV (Stroke Volume)</td>
<td>Contractility</td>
</tr>
<tr>
<td>RVEF (RV Ejection Fraction)</td>
<td>Contractility</td>
</tr>
</tbody>
</table>

### Advanced Technology Catheters

- CCO
- CCOombo
- CCOombo/MIP
- CCOombo/EDV
- SvO₂
- CCO/CEDV
- CCOombo/CEDV
- CCOombo/CEDV/MIP
Balloon Inflation Volume
- Appropriate inflation volume is 1.25 – 1.5 cc

VIP Port
777F8, 777HF8
- 30 cm from tip

Proximal Injectate Port
- 26 cm from tip
- Located in RA or SVC
- If incorrectly positioned in introducer sheath, Bolus CO measurement will be erroneously high due to reflux of injectate within introducer
- Transduce Proximal Injectate Lumen – proper waveform is RA or SVC

PA Distal Port
- Transduce distal lumen – proper waveform is PA

Thermistor
- 4 cm from tip
- In main body of PA

Thermal Filament
- 14 – 25 cm from tip
- Rests between RA and RV
- Should be free floating and avoid endocardial surface
- Erroneous CCO measurements may result if beyond pulmonic valve

Note: Assess patient physiology. Atypical physiology and heart size may require special handling.
Swan Ganz Catheters are capable of providing every cardiac filling pressure and hemodynamic parameter to solve the puzzle.
Continuous ScvO2 Monitoring – PreSep Catheters & Vigileo Monitors

Taken from http://www.edwards.com/presentationvideos/2007annualreport/prodPreSepOxi.html
Continuous SvO2/ScvO2 Monitoring

ScvO2

Oxygen Delivery

Cardiac Output
- Heart Rate
- Stroke Volume

Hemoglobin
- Bleeding
- Hemodilution
- Anemia

Oxygenation
- SaO2
- FiO2
- Ventilation

Oxygen Consumption

Metabolic Demand
- Fever
- Anxiety
- Pain
- Shivering
- Muscle Activity
Early Goal-Directed Therapy Treatment Protocol

1. Supplemental oxygen ± endotracheal intubation and mechanical ventilation
2. Central venous oximetry catheter and continuous arterial pressure monitoring
3. Sedation, paralysis (if intubated), or both

- CVP:
  - CVP < 8 mm Hg
  - CVP 8-12 mm Hg
  - CVP ≥ 12 mm Hg

- MAP:
  - MAP < 65 mm Hg
  - MAP > 90 mm Hg

- ScvO₂:
  - ScvO₂ < 70%
  - ScvO₂ ≥ 70%

- Goals Achieved:
  - Transfusion of red cells until hematocrit ≥ 30%
  - Inotropic agents

- Hospital Admission:
  - Ref#2

Taken from http://ht.edwards.com/sci/edwards/sitecollectionimages/edwards/products/presp/presepbrochure2.pdf
### Other Hemodynamic Monitors for ICU²:

- Echocardiography (TTE, TEE.)
- Tissue Oxygen Saturation Measurements
- Thoracic Bioimpedance
- Thoracic Bioreactance
- Endotracheal CO Monitor
- The NICO System (Fick’s Principle for CO₂)
- Esophageal Doppler
<table>
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<tr>
<th>Monitor Type</th>
<th>Hemodynamic Measure</th>
<th>Limitations</th>
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<td>NICO</td>
<td>Ease of use</td>
<td>Shunt</td>
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<tr>
<td></td>
<td></td>
<td>Ventilatory variables</td>
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<tr>
<td>Bioimpedance</td>
<td>Noninvasive</td>
<td>Cutaneous electrodes</td>
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<tr>
<td></td>
<td>Continuous CO</td>
<td>Electrode contact affected by temperature and humidity</td>
</tr>
<tr>
<td></td>
<td>measurement</td>
<td>Requires hemodynamic stability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Not useful in dysrhythmias</td>
</tr>
<tr>
<td>ECOM</td>
<td>SV</td>
<td>Endotracheal intubation</td>
</tr>
<tr>
<td>Ultrasound</td>
<td>CI</td>
<td>Electrocautery produces interference</td>
</tr>
<tr>
<td>dilution</td>
<td>SVR</td>
<td>No fully validated human studies</td>
</tr>
<tr>
<td>Ultrasound</td>
<td>HR, ECG</td>
<td>Arterial line</td>
</tr>
<tr>
<td>Ultrasound</td>
<td>Measures flow in ECMO and hemodialysis circuits</td>
<td>Central venous catheterization</td>
</tr>
<tr>
<td>TEE</td>
<td>SV</td>
<td>Esophageal probe</td>
</tr>
<tr>
<td>Esophageal Doppler</td>
<td>SV</td>
<td>Esophageal probe</td>
</tr>
<tr>
<td></td>
<td>Use of goal-directed therapy</td>
<td>Assumptions about aortic size may be erroneous</td>
</tr>
</tbody>
</table>
References:


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Thank you!