Cardiac output monitoring
What the Fact !!

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Introduction

• Hemodynamic instability in patients who admitted in ICU causing a mismatch between oxygen delivery and demand that leading to multiple organ failure

• If basic vital parameters were failed there is an increased need for hemodynamic monitoring
Benefit of cardiac output monitoring

**Diagnostic**
- Differential diagnosis of shock
- Evaluation of pulmonary edema
- Evaluation of cardiac failure
- Evaluation of cardiac structure

**Therapeutic**
- Guide therapy in shock
- Guide therapy peri-operatively
- Guide therapy in cardiac failure
- Ventilator management
- Multi-organ failure
History

• The first technique for measuring CO was described by Adolph Fick in 1870
  • Fick’s technique calculation of CO from measurements of the oxygen content of arterial and mixed venous blood as well as oxygen consumption
  • The Fick technique became the accepted standard for the measurement of CO

Cardiac Output Monitoring; Seminars in Cardiothoracic and Vascular Anesthesia 2010
• Fick principle

\[ CO = \frac{VO_2}{C_a - C_v} \]

• CO = Cardiac Output
• \( VO_2 \) = Oxygen consumption \( \text{(ml/min)} \)
• \( C_a \) = Oxygen concentration of arterial blood
• \( C_v \) = Oxygen concentration of mixed venous blood
History

• The dye dilution technique for CO determination is based on the work of Stewart in the late 19th century and later modified by Hamilton in the 1930s
  • Calculate CO by dividing the quantity of an injected indicator dye by the area under the dilution curve measured downstream
  • Dye dilution became an “accepted method of reference” in the measurement of CO
History

- In the 1970’s by Swan, Ganz, and Forrester introduced pulmonary artery catheterization into clinical practice
  - Pulmonary artery catheters generate the thermodilution curves and analyze them to determine CO
  - Reliable, clinically relevant, and clinically useful
  - “Gold” standard to which all new CO monitors are compared

- Several invasive and less-invasive methods have been developed during the last few decades to measure CO
Cardiac output monitoring

• Invasive method
• Less-invasive method
• Non-invasive method
<table>
<thead>
<tr>
<th>Monitor</th>
<th>Method</th>
<th>Real time</th>
<th>Calibrated</th>
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<tr>
<td>Invasive</td>
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<td>Pulmonary artery catheter</td>
<td>Thermodilution</td>
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<tr>
<td>PiCCO® LiDCO® VolumeView®/EV1000®</td>
<td>Transpulmonary Thermodilution</td>
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<td>FloTrac®/Vigileo®</td>
<td>Pulse contour and pulse pressure variation</td>
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<td>NiCO®</td>
<td>Partial CO2 rebreathing</td>
<td>+</td>
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<td>Transesophageal echocardiography</td>
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<tr>
<td>Non-invasive</td>
<td>Transthoracic echocardiography</td>
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<td>T-line®/Nexfin®/CNAP®</td>
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<td>esCCO®</td>
<td>Estimated continuous cardiac output</td>
<td>+</td>
<td>-</td>
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<td>USCOM®</td>
<td>Ultrasonic cardiac output monitoring</td>
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</tbody>
</table>
Cardiac output monitoring

- Invasive method
  - Pulmonary artery catheter
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Pulmonary artery catheter

- Gold standard
- CO is measured with thermodilution

Hemodynamic monitoring in the critically ill: an overview of current cardiac output monitoring methods; F1000Research2016
The standard catheter is 7.5 FR and 110 cm long. Maximal balloon volume 1.5cc.
Factor Influencing Accuracy of Thermodilution cardiac output measurement

• Intracardiac shunts
• Tricuspid or pulmonic valve regurgitation
• Inadequate delivery of thermal indicator
• Thermistor malfunction from fibrin or clot
• Pulmonary artery blood temperature fluctuations
• Respiratory cycle influences
Cardiac output monitoring

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Transpulmonary thermodilution PiCCO® system

• Use central venous catheter and arterial line with thermistor
• Injection of cold saline through a central line
• The arterial line measures the drop in blood temperature and from this obtain a Thermodilution Curve
• Use the area under thermodilution curve to calculate the CO
Transpulmonary thermodilution
Volume view® /EV1000®

• EV 1000 consist of PiCCO and FloTrac
• Volume view is an extra program that can measure Global end diastolic volume (GEDV)
The FloTrac sensor

EV1000 clinical platform
VolumeView System

1. Sensor provides continuous and intermittent hemodynamic information.
2. Femoral arterial catheter provides volumetric parameters through intermittent TPTD.
3. The thermistor manifold enables bolus injection (closed system) to record injectate temperature and to record start of injection.
Transpulmonary dye dilution
LiDCO® system

- LiDCO® system uses lithium as an intravascular indicator
- LiDCOrapid ® / PulseCO® The data are rapidly available and provide real-time beat-to-beat variations in CO by using pulse contour analysis system
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Pulse contour and pulse pressure analysis

- FloTrac, Vigileo, ProAQT, Pulsioflex, LiDCOrapid, PulseCO
- Estimate CO from pulse pressure analysis, impedance, arterial compliance, SVR
- Lack accuracy in unstable patients
FloTrac®/Vigileo®

• Use PPV and vascular tone to calculate stroke volume and CO
Stroke volume is derived from the area under the pulse pressure curve.

CO = (calibration factor) x (Heart rate) x (stroke Volume)

Calibration factor is derived from thermodilution.
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Partial CO2-rebreathing

NiCO®

• Using CO2 instead of O2 as an indicator
• Measure the CO2 production by exhaled CO2 content by the respiratory minute volume
• Every three minutes, a partial rebreathing cycle should be started using a rebreathing loop, resulting in reduced CO2 elimination
• Difference between normal and rebreathing ratios are used to calculate CO
• Significant pulmonary disease can interfere with the measurements
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Esophageal Doppler

• Flexible ultrasound probe
• The blood flow in the descending aorta is measured to determine stroke volume and CO
• Can provide real-time CO
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Nexfin  
CNAP  
T-line

Pulse contour analysis
Cardiac output monitoring

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Estimated continuous cardiac output esCCO®

- Estimate the CO with an algorithm based on patient characteristics and measurement of HR, SpO2, NIBP
Pulse wave transit time

Usual sensors:
ECG synchronised with the pulse oximeter

https://www.esahq.org
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Ultrasonic cardiac output monitoring USCOM®

- Measuring the flow velocity in the aortic and pulmonary outflow tracts
- Combines this with pre-calculated valve areas to estimate a CO

Hemodynamic monitoring in the critically ill: an overview of current cardiac output monitoring methods; F1000Research2016
Design: Prospective, observational study
Participants: Patients scheduled for elective CABG
Result: Agreement between the CCO method and both less-invasive measurements was clinically acceptable. There were no adverse events associated with the use of either device.
Fig 1. Bland-Altman plot between CCO and PCCO. The solid line represents the mean difference (bias); the dotted line represents the 2SD limits of agreement.
Fig 2. Bland-Altman plot between CCO and UCCO. The solid line represents the mean difference (bias); the dotted represents the 2SD limits of agreement.
Fig 3. Bland-Altman plot between UCCO and PCCO. The solid line represents the mean difference (bias); the dotted line represents the 2SD limits of agreement.
Calibrated versus uncalibrated arterial pressure waveform analysis in monitoring cardiac output with transpulmonary thermodilution in patients with severe sepsis and septic shock

An observational study

Cornelis Slagt, Mochamat Helmi, Ignacio Malagon and A.B. Johan Groeneveld

Design: Prospective, observational single-center study. Participants: Patients with severe sepsis or septic shock requiring hemodynamic monitoring by VolumeView/EV1000 and receiving mechanical ventilation. Result: Calibrated arterial pressure waveform analysis was more accurate and less dependent on vascular tone than uncalibrated method.
Take Home Message

• The thermodilution method is the clinical gold-standard for the measurement of CO
• Nowadays there are several less invasive method that had been developed for clinical use.
• Calibrated method is more accuracy than uncalibrated method.