The Importance of Cardiac Output Monitoring in Paediatric Management

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Cardiac function

- Systolic AND diastolic function
  
  - Systolic function
  
  - Diastolic function
    - rate and degree of ventricular relaxation
    - both active and passive components
Cardiac Function-Systolic

- **Systolic cardiac function**
  - interaction of four *interdependent* factors:
    - **Heart rate**
    - **Preload**
    - **Contractility**
    - **Afterload**

- Heart rate measurable
- Preload - invasive pressure - CVP/PA wedge
- Contractility and afterload - difficult (FS/conductance/SVR)
- ICU cardiac function - bedside cardiac output
# Cardiac function

## Adequacy of cardiac output and oxygen delivery

### Global assessment
- MVO2
- lactate

### Regional assessment
- capillary refill
- core-peripheral temperature gap
- splanchnic oxygen delivery-gastric tonometry
- secondary organ effects
  - renal/hepatic/neurological failure
Assessing circulatory disturbances

- Clinical estimate of cardiac output poor (1)

- ‘Clinicians substitute BP for flow’
  - no correlation between flow + pressure

- Plethora of methods to estimate CO
  - each potential for measurement errors
  - requirement for technical expertise may limit utility
  - degree of invasiveness required ⇒ incremental risk to pt

Caveat

n Flow without Hb + art’ sats - ?misleading

n Cellular viability depends
  • O2 delivery (CO X arterial oxygen content)
  • O2 extraction
    n As well as CO
Cardiac output

- Volume of blood ejected by heart per minute

- NB Interplay - HR preload contractility + afterload

- Manifestation of cardiac function measurable at bedside

- In children indexed to BSA-cardiac index
  - same “normal” value
    - 3.5–5.5 l/min/m² regardless age/size
**Why Measure CO in ICU**

- CVS one of commonest organ failures in PICU *Wilkinson*
- Other organ failure/support effects myocardial function
  - eg ventilation/CVVH
- Low flow state
  - high mortality in certain diseases *Mercier JC et al*
- Flow poorly estimated clinically *Tibby et al*
  - Hence titrate treatment against BP!
- Adequate organ perfusion pressure vital
  - BUT BP affected by CO and SVR

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*Wilkinson et al. Outcome of pediatric patients with MOSF. Crit Care Med 1986;14:271–4*
*Tibby et al Clinicians’ abilities to estimate CI in ventilated children and infants. Arch Dis Child 1997;77:516–18*
When to measure CO

- Not all children in ICU vs children outside ICU
- Risk vs benefit
  - **Risk**: Patient selection
  - **Benefit**: Understand haemodynamics

Method used


- Shock states
- Congenital and acquired heart disease
- Multiple organ failure
- **Cardiopulmonary interactions** during mechanical ventilation

Also

- Research
- Monitoring effects of drugs eg anaesthetic agents
- ? Role in early goal therapy prior to ICU

Accuracy vital as ultimate aim to change therapy
When to measure CO in ICU

- Evidenced based medicine
  - CO not (yet) convincingly shown to improve outcome

- But same for many monitoring procedures
  - invasive arterial pressure
  - CVP measurement
  - blood gas analysis
  - pulse oximetry

- NB CVO2
 Anyone like to NOT know her cardiac output?
Flow more important than pressure!
**Goal Therapy**

**Adjustments in:**

<table>
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<th>Gold standard</th>
<th>ICU manipulation</th>
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<td>LVEDP</td>
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<td>Ventriculo-arterial coupling -Ees/Ea</td>
<td>SVR</td>
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**Aim to balance O2 delivery with O2 demand**

- **End points**
  - Normalized MVO2
  - Arterial lactate
  - Base deficit
  - pH
MVO₂

- Good surrogate for cardiac index
  (assuming constant -O₂ consumption, Hb concentration, arterial O₂ saturation)

CVO₂

- Reasonable surrogate for MVO₂
  - Reinhart et al. Comparison of CV to MV O₂ sats during changes in O₂ supply/demand. Chest 1989;95:1216-21
Paediatric Sepsis

Manipulation other variables equally successful

Eg Cardiac output

Any of this valid in children


40 mL/kg in the first hour following ED presentation associated with: improved survival

Early Reversal of Pediatric-Neonatal Septic Shock by Community Physicians Is Associated With Improved Outcome

Each extra hour of shock: 2.3x risk of death
Ideal characteristics
-CO device

- Non-invasive
- Applicable to many patients
- Applicable over a wide range of flow
- Accurate (cf other techniques)
- Reproducible
- Easy to use
- Rapid data acquisition
- Cost effective
# How to measure cardiac output

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<td>Direct Fick</td>
<td><strong>Supra-sternal/USCOM</strong></td>
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- Fick
- Bioimpedance
- Echocardiography
- Trans-oesophageal doppler
- Pulse contour analysis
- Supra-sternal/USCOM
PA catheter


- Traditional ICU estimation CO
  - cold dextrose $\Rightarrow$ Rt atrium $\Rightarrow$ PA temp’ change (thermistor)
  - CO calculated - temperature time curve

- Disadvantages
  - technical limitations
  - catheter-related problems
  - Usually on ICU
  - skilled operator (1,2)

Measuring Cardiac Output

Invasive

Fick equation - ‘gold standard’

CO calculated →

- Art-Venous-O$_2$ content difference & O$_2$ consumption
  - O$_2$ consumption (spirometry) and O$_2$ content (ABG)
  - MVO$_2$ needs PA catheter

- technical skill -unfeasible as routine
- several devices use variants

Adolph Fick 1870
Measuring Cardiac Output - Invasive Fick principle with CO$_2$

- Total Re-breathing Cardiac Output

CO$_2$ not eliminated - exhaled CO$_2$ approaches MVCO$_2$
Et CO$_2$ - non-invasive estimate of PaCO2
"Upon the amount of blood that is thrown out by the heart during systole then, does the magnitude of the pulse-pressure in the aorta depend"

1904 Erlanger and Hooker

- Relation CO and arterial pulse contour
Pulse contour analysis
PiCCO

- Area under systolic portion of pulse pressure waveform
- Calibration - transpulmonary thermodilution
- 4-Fr arterial probe - so older children
- Now 1.3 Fr probe
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<th>Continuous Pulse Contour Analysis</th>
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<td>Continuous Pulse Contour CO</td>
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<td>Intrathoracic blood volume</td>
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<td>Global end-diastolic volume</td>
<td>Heart Rate</td>
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<td>Extravascular lung water</td>
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<td>Cardiac Function Index</td>
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<td>Global Ejection Fraction</td>
<td>Index of left ventricular contractility</td>
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<td>Pulse pressure variation</td>
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Pulse contour analysis
PulseCO [LiDCO, UK]

Frequency analysis
- aortic impedance
- aorta-radial transfer function
- aortic flow
- radial pressure

- Need radial arterial line
  + calibration - lithium dilution

- infants and children
Partial Rebreathing Cardiac Output
Indirect Fick (Non Invasive - NICO)

\[ VCO_2 = CO \times (CvCO_2 - CaCO_2) \quad \text{But } CvCO_2 \text{ 'invasive'} \]

Assuming \( CvCO_2 + CO \) constant 3 mins

- \( VCO_2N - VCO_2R = CO \times (CaCO_2R - CaCO_2N) \)
- \( \rightarrow CO = (VCO_2N - VCO_2R)/(CaCO_2R - CaCO_2N) \)

*Pulmonary shunt correction computed*
Cardiac Output
Non-invasively - Doppler

- Suprasternal and pulmonary
- Transgastric
- Trans-oesophageal

Oesophageal Doppler CO
- described 1971, refined 1989
- validated in children

Technical basis for technique

Concept

flow in cylinder = CSA of cylinder X velocity of fluid in cylinder

For aortic blood flow

- movement of blood pulsatile and velocity changes with time

⇒ Velocity characterized by area under velocity-time curve between two points in time
Oesophageal Doppler

In ICU
Ideal characteristics - *continuous CO device*

- Non-invasive
- Automatic and non-operator dependent
- Accurate (compared to other techniques)
- Continuous, real time data display
- Easy to use
- No calibration required
- Cost effective
USCOM-suprasternal aortic + pulmonary

Vpk Trend 0.73
12 retrievals
Range of ages 6 months-12 years
Differing diagnosis

Results:
36 cardiac outputs performed
4 successful readings per case
Median time to obtain data 7 minutes
Cardiac index-low variability - across range of ages and mean cardiac index
When to measure CO with USCOM

- EARLY goal therapy AND RETRIEVAL
  - (-NB CvCO2 invasive in coagulopathic septic infant)

- ICU
  - USCOM
    - PORTABLE
    - ROBUST
    - Accurate in adults, paed study being done
The Future
Benefits of cardiac output

- Early warning monitoring
- Rational fluid and drug administration
- Decreased procedural complications
e.g. bolus injections/vascular access
- Use for CVS physiology in well children
- Smart resuscitation
  - ie Early Goal directed therapy
- Prospect of outcome modification
Questions