Affordable Cardiac Output Monitoring for the Anaesthetist

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BLOOD PRESSURE (BP) AND HEART RATE (HR) MONITORING

Key role played in managing anaesthesia
Anaesthesia scenario:

- After induction BP drop to 60/30mmHg

- Treatment:
  - Fluids or Vasopressor
  - But which & how much?

- Knowing stroke volume would help
  - But how do you measure SV or CO?

\[
BP = CO \times SVR
\]
\[
CO = SV \times HR
\]
Perioperative fluid administration: Recent outcome data from the USA

84,722 Colon surgery patients from 499 USA Centers

Delta Cost (%)

Low Vol (Q1)  Ref Vol (Q2+3)  High Vol (Q4)

< 1.7L  Median 3.1L  > 5.0L

Complications associated with suboptimal fluid therapy

Hypovolemic
- Low blood pressure
- Low cardiac output
- Arrhythmia
- Hypoperfusion
- Infection
- Organ dysfunction
- Organ failure
- Adverse outcome

OPTIMAL

Hypervolemic
- Pulmonary edema
- Organ dysfunction
- Prolonged mechanical ventilation
- Hemodilution and Coagulopathy
- Adverse outcome

Poor intra-operative perfusion on gut mucosa causing ileus and leaks

M Mythen’s Lecture
Hong Kong April 2016
Pulmonary Artery Catheter:

- Was the Gold Standard
  - But use has declined worldwide
  - to 1% of the 1990s level

- Not a suitable Point-of-Care monitor for routine anaesthesia
  - Invasive
  - Costly in time & money
  - Reliable?
  - Did not improve outcomes
Emerging Technologies: Since 2000 - Continuous CO

• Intensive Care:
  Trans-Oesophageal Echo.
  Too bulky & expensive for regular theatre use

• Anaesthesia:
  *Minimally invasive CO monitors*
  - Arterial pulse contour analysis
  - BioImpedance
  - Continuous wave Doppler
WHAT IS AVAILABLE AND HOW DO THEY WORK?
Currently available systems: Pulse contour analysis

Direct / arterial-line
- FloTrac-Vigileo – (Edwards, US)
- PiCCO – (Pulsion, Germany)
- LiDCO-rapid – (England)
- Most-Care – (Italy)

Finger cuff technology
- ClearSight System – (Edwards)
  – [previously Finapres]
- CNAP – (CNSystems, Austria)
How does the system work: Pulse contour analysis

- Detects the arterial pressure waveform
- Wrist (radial), finger or major artery (femoral)
- Algorithm used to derive stroke volume (SV) and cardiac output (CO) from the area under the pressure curve
- But many different formulae!
Currently available systems: BioImpedance / Reactance

• BoMed (1980s)

• 20 years of improvement:
  – Signal detection
    • Electrode design & position
  – Waveform analysis

• Available systems today:
  – NICOM Cheetah
  – PhysioFlow
NICOM
Cheetah Medical, (Israel)

An electric current of known frequency is applied across the thorax between the outer pair of sensors.

A signal is recorded between the inner pair of sensors.

As the heart expands and contracts, a time delay, or phase shift, is created in the current by blood flow.

The monitor then uses this phase shift as a baseline for stroke volume measurement.
PhysioFlow (France)
BioImpedance method

Waveform morphology analysis
How does it work:
Continuous wave Doppler

• Not an imaging technique

• Requires a probe

• Uses ultrasound to detect flow in the aorta

• Analyses the flow profiles
UltraSound Cardiac Output Monitor USCOM, (Sydney). External Doppler
Deltex Medical – CardioQ – ODM+
Oesophageal Doppler

New Deltex Oesophageal Doppler Monitor which includes arterial pressure monitoring.

Direct flow & pressure
The CardioQ-ODM+ is the world’s first fluid management and cardiac output monitoring system to measure left flow and pressure directly.

Receive Crystal
Transmit Crystal

TIME
Marketing strategies and affordability:

• Research and developments costs money
  – In addition to manufacturing costs

• Why medical devices expensive
  – Return of initial capital outlay

• Cost of buying the equipment
  – Single payment

• Cost of Disposables
  – Where companies make their money

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Examples of consumables:

- PhysioFlow Electrodes
- Only system with minimal Expenditure on disposables
Validation studies and reliability: 
Single centre Random Controlled Clinical Trials

• Data from validation studies is poor
• Mainly comparisons with single bolus thermodilution (PAC)
• Issue of showing accuracy (precision) rather than trending (ability to detect changes)
• Good information on reliability and repeatability hard to find

![Bland-Altman plot]

N = 14 male patients

Percentage error = 34%
Benchmark <30% for good agreement
“No information regarding how well device measures changes in SV & CO!”
Validation studies showing trending:

- Need to compare serial changes in SV & CO
  - Statistics only recently established
- Times plots comparing changes in changes
- Multiple patient data studies
  - Serial change in CO - \( \Delta CO \)
  - Show data on four quadrant plots
  - Concordance analysis
- Polar plots
Validation studies: Pulse Contour

- PCA is not accurate.
- Readings vary by >20%
  - [i.e. range form 4-6L/min for a mean CO of 5L/min]

- CO reading effected by in peripheral resistance

- Unreliable in sepsis and liver cirrhosis, and when vasopressors used

- Should avoid these situations

Evidence from trending studies: Swings in Peripheral resistance


Meng et al. Anesth Analg 2011:113;751
FloTrac-Vigileo: Dynamic parameters May be more reliable

- Pulse pressure variation [PPV]
- IV fluid challenge
- Passive leg raise test
Validation studies: BiolImpedance systems:

- Not accurate in studies (c.f. pulse contour)
  - Calibrated using patient demographic
  - Assumptions about “volume of electrically participating tissue”
Pathway of electrical flux:
Volume of electrically participating tissue
Not a homogenously perfused thorax!!!

PA chest X-ray

Electrical flux pathways
Liver resection open surgery case: Effect of inserting large retractor

Partial hepatectomy case
Time and regression plots

Cardiac index (Litres.min\(^{-1}\).m\(^{-2}\))

- CardioQ
- USCOM
- NICOM

- Induction of anaesthesia
- Start of surgery
- Wound closure

Decrease in NICOM calibration relative to USCOM & CardioQ.

Retractor in use

Time from induction of anaesthesia (minutes)

\[
y = 0.9x - 0.1 \\
R^2 = 0.65
\]

\[
y = 1.1x - 0.2 \\
R^2 = 0.93
\]
Case 15: Sigmoid colectomy (from laparoscopic group)  
(involving insufflation of abdominal cavity with CO₂ gas)

Case 25: Total mesorectal excision (from robotic group)  
(Involving abdominal insufflation and head-down tilt)
Validation studies: BiolImpedance systems:

- Does trend changes in CO reliably *most of the time* intra-operatively
  - NICOM Cheetah (Hung et al. Anesth Analg 2015:121;936)
  - PhysioFlow (Zhang and Critchley [unpublished])

- Can be effected by factors that alter geometry of the upper abdomen.
  - Laparoscopy
  - Surgical retractors

- The Anaesthetist should be aware of these ill effects when using bioImpedance monitoring.
Validation studies: Doppler systems (Accuracy)

- In systematic reviews of Bland-Altman studies shown to lack accuracy.

- Due to calibration from population studies data that estimate aortic valve and descending thoracic aorta diameter.

For Oesophageal Doppler Percentage of Clinical Agreement (PCA) used which approximate in comparative studies with TDco to a percentage error of 40-50%
Validation studies: Doppler systems (Trending)

- Measures blood flow directly
  - Calibration unlikely to change
  - Unlikely to be effected by Peripheral vascular changes

- Shown to have good trending

- Very user dependent
  - Signal detection needs to be correct and consistent

- Effected by:
  - Aging process and
  - aortic changes

Summary:

- Clinical need for MICOM in anaesthesia
  - Especially the management IV fluids in major surgery
- Since 2000 several different cardiac output measurement technologies have become available
- Most require disposables that adds to running costs
- Much controversy surrounding validation studies
  - Accuracy and Trending need to be assessed
- Currently, there is no ideal MICOM system for operating theatre use and one needs to know the pros and cons of each
Thank you