Outcome-Driven Minimally Invasive Cardiac Output Monitoring

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Disclosure

- Consultant & Research Support
  - Edwards Lifesciences
- Previous Unrestricted Study Grants
  - BioTime, Inc
  - Abbott, Inc
  - Fresenius-Kabi, GmbH
Outline

Options of Hemodynamic Monitoring Tools

• Pressure based or Flow based?
• What Parameters?
• Which Patients?
• What environment?

Postoperative Complications

Predictors of Post-op Morbidity

- Age
- ASA
- Duration of surgery
- Blood loss
- Surrogates of HYPOVOLEMIA and tissue hypoperfusion e.g. metabolic acidosis, gastric tonometry


Reduced Circulating Volume
\[ \downarrow \]
Inadequate Tissue Perfusion
\[ \downarrow \]
Gut Mucosal Barrier Disruption
\[ \downarrow \]
Translocation of Bacteria/Endotoxin
\[ \downarrow \]
Activation of Inflammatory Pathways
\[ \downarrow \]
MODS

I Hate Being Dry!!

With Permission: Dr T.J. Gan
25-30% Hemorrhage in Healthy Subjects

Controlled

Hamilton-Davies, Intens Care Med 1997;23(3):276-81.
Hypovolemia and Pressure Measurement

Blalock 1943 – Shock:

“... blood volume and cardiac output are usually diminished in traumatic shock before the arterial blood pressure declines significantly.”

Blalock A. (1943) Surgery 14: 487-508
So, how can we measure it all???

The Fluid Challenge

Grocott, Mythen and Gan. Anesth Analg 2005;100:
High Risk Orthopedic Surgery

- 90 patients
- ≥ 65 years old
- Fracture neck of femur
- Randomized:
  - Standard of Care
  - Esophageal Doppler
  - ?-CVP

\[\text{Venn et al, BJA 2002:88:65-71}\]

?-CVP Fluid Challenges

<table>
<thead>
<tr>
<th>Time</th>
<th>CVP (mm Hg)</th>
<th>Gelofusine fluid challenge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial reading</td>
<td>&lt;14</td>
<td>200 ml</td>
</tr>
<tr>
<td></td>
<td>≥14</td>
<td>100 ml</td>
</tr>
<tr>
<td>During fluid challenge</td>
<td>Increase &gt;5</td>
<td>Stop fluid challenge and WAIT</td>
</tr>
<tr>
<td>Following fluid challenge</td>
<td>Increase &gt;3</td>
<td>WAIT</td>
</tr>
<tr>
<td></td>
<td>≤3</td>
<td>Repeat fluid challenge as per initial reading</td>
</tr>
</tbody>
</table>
The Pulmonary Artery Catheter


Minimally Invasive Cardiac Output

- Esophageal Doppler
- Arterial pulse waveform (APCO)
- Lithium indicator dilution
- Pulse contour analysis
- Transesophageal echo
- Impedance plethysmography

Esophageal Doppler Monitoring

Doppler probe in mid esophagus

- SV
- CO
- FTc
- PV
- SD
http://www.aic.cuhk.edu.hk/web8/Oesophageal%20Doppler.htm
Hypovolemia  After Volume Resuscitation

http://www.aic.cuhk.edu.hk/web8/Oesophageal%20Doppler.htm

Trace changes

http://www.frca.co.uk/article.aspx?articleid=10056
Does oesophageal Doppler guided goal directed therapy reduce surgical mortality and length of stay?

Hamilton MA¹, Grocott MPW¹, Mythen M¹, Bennett D²

European Society of Intensive Care Medicine 2006

¹ Centre for Anaesthesia, University College London, UK
² Intensive Care Department, St George's Hospital, London, UK

With Permission - Drs MA Hamilton & MG Mythen
Results

- 7 studies were identified for inclusion
- 7150 titles from search strategy
- All used technology from 1 manufacturer
- Deltex medical group plc, Chichester, UK
- 6 intra-operative and 1 post-operative
- 2 studies used the same goal directed algorithm
- 1 study used vasoactive agents in addition to fluid loading

Crystalloid

<table>
<thead>
<tr>
<th>Study</th>
<th>Treatment</th>
<th>Control</th>
<th>WMD (w/CI)</th>
<th>WMD (w/CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mythen</td>
<td>30</td>
<td>857.73 (71.76)</td>
<td>30</td>
<td>1993.00 (74.43)</td>
</tr>
<tr>
<td>Senior</td>
<td>28</td>
<td>787.50 (144.50)</td>
<td>28</td>
<td>987.50 (130.40)</td>
</tr>
<tr>
<td>Gab</td>
<td>36</td>
<td>4426.20 (480.30)</td>
<td>36</td>
<td>4870.00 (462.00)</td>
</tr>
<tr>
<td>Venet</td>
<td>26</td>
<td>1220.39 (98.59)</td>
<td>26</td>
<td>1350.00 (95.21)</td>
</tr>
<tr>
<td>McIndoe</td>
<td>89</td>
<td>266.10 (96.20)</td>
<td>89</td>
<td>328.00 (89.51)</td>
</tr>
<tr>
<td>Whitley</td>
<td>64</td>
<td>2567.15 (1397.31)</td>
<td>64</td>
<td>3983.83 (1367.53)</td>
</tr>
</tbody>
</table>

Total (95% CI): 243 | 279
WMD = -166.84 (-306.25, -27.43)
P = 0.02

With Permission - Drs MA Hamilton & MG Mythen
Colloid

WMD -661.22 (-588.22 , -734.22)
P = 0.02

With Permission - Drs MA Hamilton & MG Mythen

Length of Stay

WMD -2.94 (-4.22 , -1.66)
P = <0.00001

With Permission - Drs MA Hamilton & MG Mythen
Meta-Analysis Conclusions

• Goal directed therapy using the Esophageal Doppler results in significantly:
  • Shorter length of Hospital stay by 2.94 days
  • Less crystalloid administered by 167 mls
  • More colloid administered by 661 mls

EDM Benefits

• Greatest body of evidence
  – 7 RCT’s
  – Average reduction in LOS = 2-3 days
• No a-line required
• True flow measurement
Limitations

• Only measure blood flow to the descending aorta
• Output is not always constant
  – Refocusing of probe required
• Occasional difficult probe positioning
  – User dependent

Pulse Waveform Contour Analysis
Pulse Waveform Contour Analysis

PiCCO®, Pulsion Medical

Thermodilution - CVP Required for Calibration

Thermodilution Usually Femoral a-line
Pulse Waveform Contour Analysis

LiDCO Plus®

Calibration - Lithium Dilution
No CVP Required

Lithium Dilution
Any a-line
Edwards FloTrac / Vigileo®

Proprietary sensor (arterial catheter)

Cardiac Output

- 1899 - Otto Frank described the circulation in terms of a Windkessel model.
- 1904 Erlanger and Hooker theorized that the CO was proportional to the arterial pulse pressure.
- 1983 Wesseling developed an algorithm that define area under the systemic arterial pulse waveform that establish central venous pressure.
Benefits

- Continuous output
- User independent
- Dilution calibration (PiCCO/LiDCO)
- No calibration required (Vigileo)
- Variables e.g.
  - CO
  - SVV
  - DO
  - PPV

Table 2—Pearson Correlation Between Changes of Baseline Hemodynamic Indices and Changes of SVI*

<table>
<thead>
<tr>
<th>Variables</th>
<th>ΔSVI</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔCVP</td>
<td>0.206</td>
<td>0.235</td>
</tr>
<tr>
<td>ΔPCWP</td>
<td>0.019</td>
<td>0.912</td>
</tr>
<tr>
<td>ΔLVEDAI</td>
<td>0.462</td>
<td>0.005</td>
</tr>
<tr>
<td>ΔGEDVI</td>
<td>0.526</td>
<td>0.001</td>
</tr>
<tr>
<td>ΔPPV</td>
<td>−0.586</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>ΔSVV</td>
<td>−0.657</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>


SVV and Mechanical Ventilation

Arterial Pressure

Airway Pressure

Inspiration

Expiration
Stroke Volume Variation

Parry-Jones and Pittmann. Int J of Intens Care. 2003

Positive Pressure Ventilation & Stroke Volume Variation

Parry-Jones. Int J of Intens Care. 2003
CONCLUSION:
Continuous and real-time monitoring of stroke volume variation by pulse contour analysis can predict volume responsiveness and allows real-time assessment of the hemodynamic effect of volume expansion in patients after cardiac surgery.

Table 3. Results of receiver operating characteristics (ROC) curve analysis

<table>
<thead>
<tr>
<th></th>
<th>Study Group (LVEF &lt;35%)</th>
<th>Control Group (LVEF &gt;55%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SVV</td>
<td>Area (95% CI)</td>
<td>Threshold (Sensitivity/Specificity, %)</td>
</tr>
<tr>
<td></td>
<td>0.76 (0.50-0.96)</td>
<td>0.55 (71-98)</td>
</tr>
<tr>
<td>LVEDVI</td>
<td>0.78 (0.54-0.97)</td>
<td>24.5 cmH2O (61-99)</td>
</tr>
<tr>
<td>MAP</td>
<td>0.77 (0.58-0.96)</td>
<td>7 mmHg (74-70)</td>
</tr>
<tr>
<td>CVP</td>
<td>0.71 (0.50-0.92)</td>
<td>6 mmHg (59-60)</td>
</tr>
</tbody>
</table>

Reuter et al. CCM 2003;31:1399-1404
The influence of positive end-expiratory pressure on stroke volume
variation and central blood volume during open and
closed chest conditions

Jens C. Kubitz,*, Thorsten Annecie, Gregor L. Kemming, Stefanie Forl, Nils Kronsás, Alwin E. Goetz, Daniel A. Reuter

*Department of Anaesthesiology, University of Munich, Ludwig-Maximilians University Hospital, Munich, Germany

Institute for Cardiothoracic and Intensive Care, University Hospital, Munich, Germany

Department of Anaesthesiology, Center for Anaesthesiology and Intensive Care, University Hospital, Munich, Germany

Cardiac Output Determination From the Arterial Pressure Wave: Clinical Testing of a Novel Algorithm That Does Not Require Calibration

Gerard R. Manecke Jr, MD,* and William R. Auger, MD†

Objective: The purpose of this study was to evaluate the accuracy and precision of a novel algorithm that evaluates cardiac output by using arterial pressure waveform characteristics.

Design: Prospective, observational study comparing the cardiac output values of intermittent thermodilution, continuous thermodilution, and continuous arterial pressure wave assessment.

Setting: The intensive care unit in a tertiary care university hospital.

Participants: Fifty postoperative cardiac surgical patients, within the first 12 hours after surgery.

Interventions: All patients received a pulmonary artery catheter (PAC) and at least 1 systemic arterial pressure catheter. The data from the arterial catheter were processed by using a new arterial pressure cardiac output (APCO) algorithm. The data from the PAC (continuous and intermittent assessments) were collected for comparison with the APCO.

Measurements: Two hundred ninety-five cardiac output measurements using intermittent thermodilution (ICO), continuous thermodilution (CCO), and arterial pressure-based output (APCO) were obtained during various times during the first 12 postoperative hours. The measurements of each method at each time point were compared by using Bland-Altman analysis.

Results: The mean cardiac output ranged from 2.77 to 9.60 L/min. APCO, compared with ICO, revealed a bias of 0.56 L/min and precision of 0.96 L/min. APCO, compared with CCO, revealed a bias of 0.66 L/min and precision of 1.00 L/min. The APCO agreement between femoral and radial arterial catheters was close; the bias was −0.15 L/min, and the precision was 0.59 L/min.

Conclusions: This novel arterial pressure cardiac output algorithm provides cardiac output assessments that agree satisfactorily for clinical purposes with intermittent and continuous thermodilution techniques in postoperative cardiac surgical patients. Further study is required for other patient populations and clinical situations.

KEY WORDS: cardiac output measurement, arterial pressure-based cardiac output, thermodilution cardiac output, lithium dilution cardiac output

Manecke and Auger. JCVTA 2006 In press
Findings

- The mean cardiac output ranged from 2.77 to 9.60 L/min. APCO, compared with ICO, revealed a bias of 0.55 L/min and precision of 0.98 L/min.

- APCO, compared with CCO, revealed a bias of 0.06 L/min and precision of 1.06 L/min.

- The APCO agreement between femoral and radial arterial catheters was close: the bias was 0.15 L/min, and the precision was 0.56 L/min.

Partial CO₂ Rebreathing
25-30% Hemorrhage in Healthy Subjects

Controlled

Perioperative Fluid Administration Strategy?
Perioperative Plasma Volume Expansion Reduces the Incidence of Gut mucosal Hypoperfusion During cardiac Surgery
Mythen, MG and Webb AR. Arch Surg. 1995;130:423-9

- 60 ASA III patients
- Protocol and Control groups
- Fluid optimization with EDM in protocol group
- Standard practice in control group

200 ml 6% hetastarch to maintain maximum SV

Wakeling 2005, BJA, 95(5), 634-642

Measure CVP and stroke volume

200 ml of colloid over 10 minutes

Wait 5 minutes

CVP rise < 3 mmHg and increase in stroke volume
YES

Measure CVP and stroke volume

Fall in stroke volume
NO

CVP rise < 3 mmHg and increase in stroke volume
NO

Measure CVP and stroke volume every 15 minutes

Wakeling 2005, BJA, 95(5), 634-642
Perioperative Plasma Volume Expansion Guided by EDM

Goal-directed Intraoperative Fluid Administration Reduces Length of Hospital Stay after Major Surgery

Tong J. Gan, M.B., B.S., F.R.C.A.,* Andrew Sappitt, B.Sc., M.B., B.S., F.R.C.A.,† Mohamed Marof, M.D.,‡ Habib El-Moalem, Ph.D.,§ Kent M. Robertson, M.D.,* Eugene Moretti, M.D.,† Peter Durance, M.D.,‡ Peter A. Glass, M.B., F.F.A. (S.A.)

- 100 ASA II and III patients
- Surgery with expected blood loss > 500 ml
- Intraoperative goal directed fluid management vs. control
- Background crystalloid infusion & colloid bolus

- Primary outcome: LOS

Gan 2002, Anesthesiology, 97(4), 820-826
Doppler Derived Variables

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Therapy</th>
<th>* p&lt;0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stroke Volume</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>60</td>
<td>68</td>
<td></td>
</tr>
<tr>
<td>End of Surgery</td>
<td>72</td>
<td>70</td>
<td></td>
</tr>
</tbody>
</table>

Corrected Flow Time

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Therapy</th>
<th>* p&lt;0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>0.40</td>
<td>0.38</td>
<td></td>
</tr>
<tr>
<td>End of Surgery</td>
<td>0.34</td>
<td>0.36</td>
<td></td>
</tr>
</tbody>
</table>

Traditional Hemodynamic Variables

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Therapy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart Rate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>70</td>
<td>75</td>
</tr>
<tr>
<td>End of Surgery</td>
<td>80</td>
<td>85</td>
</tr>
</tbody>
</table>

Mean Arterial Pressure

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Therapy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>75</td>
<td>78</td>
</tr>
<tr>
<td>End of Surgery</td>
<td>80</td>
<td>82</td>
</tr>
</tbody>
</table>
Goal Directed Fluid Therapy

Gan et al., Anesthesiology 2002;97:820-6

Case Study

• 55 year old diabetic lady with a four day history of pain and swelling in her right foot
• On examination, temp = 38.4°C
• Pulse = 120/min; BP = 100/55; RR = 22/min
• Foot was edematous, indurated and tender with ascending inflammation involving her calf that was extending to her knee.
Case Study Cont.

- Emergency exploration and debridement of her right lower extremity
- 500 mL LR before induction of anesthesia
- Arterial catheter and 2 peripheral I.V.s
- 30 min later, BP = 85/40 mmHg; HR = 130/min

Case Study Cont.

- Bolus with Hextend 300 mL
- No change in hemodynamics
- Flo-Trac introduced
- PreSep SVO₂ central venous oximetry catheter
- CO < 3L; SV = 50 mL; SVV = 17%; SVO₂ = 65%
- 4 x 250 mL Hextend fluid challenges
Case Study Cont.

- SVR = 550 dyne s/cm² (SVRI, of 256 dyne s/cm²/m²).
- Norepinephrine 0.04 mcg/kg/min
- HR = 100/min; BP = 110/80 mmHg
- CO = >6 L/min, SVV < 13%
- Surgery uneventful, antibiotics adm;

CO with Fluid Challenges

0 mL Hextend Fluid Challenge
So, what’s the bottom line for all these toys?

- Depends on clinical environment
  - e.g. OR, ICU, ED…

- Depends on clinical disease severity of patient, e.g.
  - Fit, healthy
  - Septic
Useful Variables for Tony Roche

- CO, CI
- SV
- ?SV after fluid challenges
- SVV, PPV, SPV (PCWA devices)
- FTc (EDM devices)
- SVR, SVRi

EGDT Timeline

- Perioperative
- Trauma
- Early Sepsis

Established Sepsis

EGDT Works

EGDT Works

Unknown Efficacy???

Too Late

Time

Adapted from: MPW Grocott
Summary

- Hypovolemia is common and potentially avoidable.
- Flow based hemodynamic monitoring may be more sensitive in detecting hypovolemia than pressure based monitoring.
- Managing patient’s hemodynamics without CO or SV monitoring is akin to flying without an altimeter.
Questions?