esCCO, estimated Continuous Cardiac Output device

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SAUVEGARDE CLINIC, LYON, FRANCE
No conflict of interest
- **Technology**, based on Pulse Wave Transit Time
- **Limits of the technology**
- **Precision** and **Accuracy** of esCCO
- esCCO in **daily practice**: Can esCCO follow **changes in cardiac output**? during dynamic maneuvers (fluid challenge, change of PEEP, change of vasoconstrictors, Passive Leg Raising)
- Potential causes of inaccuracy
Technology

- THE PULSE WAVE TRANSIT TIME
- NON INVASIVE CALIBRATION
The Pulse Wave Transit Time (PWTT)

Usual sensors: ECG synchronised with the pulse oximeter

Figure 1. Components of PWTT
- PEP (pre-ejection period)
- $T_1$ (PWTT through elastic artery)
- $T_2$ (PWTT through peripheral arteries)
- PWTT (Pulse Wave Transit Time)
Relationship between Stroke Volume and PWTT
Relationship between Stroke Volume and PWTT

Technology

- \( es\text{CCO} = K \times (\alpha \times PWTT + \beta) \times HR; \)
- \( \alpha = -0.3, \) experimental constant according to unpublished preliminary data.

**Non invasive calibration:**

The **constants** \( K \) and \( \beta \) are individualized for each patient according to the physical profile (age, weight, height) and the initial measurement of the **Pulse Pressure**, the **Heart Rate** and the **PWTT**

Limits of the technology

ECG:
- Confusion between R wave and S wave
- Arrhythmias, pace maker (mixture of spontaneous and paced beat), OPCAB

Pulse oximetry (SpO2):
- Low perfusion index (vasoconstriction induced by drugs, hypothermia, ..., body movement) Index of Quality Signal available
- Aortic cross clamping: vein pulsation affects the pulse wave and therefore the PWTT
- Intra Aortic Balloon Pumping: no detection of the pulse wave

PWTT:
- Severe diastolic dysfunction: flawing of the relationship between PWTT and SV
- Aortic stenosis or insufficiency
Indications of esCCO

- General monitoring
- Hemodynamics monitoring after pulmonary artery catheter removal

Alhashemi et al. Critical Care 2011, 15:214
Indications of esCCO

- **Intraoperative Hemodynamic optimization:**
- Major component of **Enhanced Recovery After Surgery** and the Perioperative Surgical Home model of care:
  - In **Major surgery for low and intermediate risky patients**

Fluid management and goal-directed therapy as an adjunct to Enhanced Recovery After Surgery (ERAS)


**Enhanced recovery after surgery versus perioperative surgical home: is it all in the name?**

Cannesson M¹, Kein Z².

JL Vincent, Crit Care 2015
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<tr>
<th>Source</th>
<th>No. of Events</th>
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<td>0.94 (0.70-1.28)</td>
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**Total** 488 1548 614 1476 0.77 (0.71-0.83) 100.0

Heterogeneity: $\chi^2_{21} = 30.44; P = .08; I^2 = 31\%$

Test for overall effect: $z = 6.22; P < .001$
Indications of esCCO

- **Intraoperative Hemodynamic optimization:**
- **Major component of Enhanced Recovery After Surgery** and the **Perioperative Surgical Home** model of care:
  - In **Major surgery** for low and medium risk patients

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**Fluid management and goal-directed therapy as an adjunct to Enhanced Recovery After Surgery (ERAS)**

Timothy E. Miller, Anthony M. Roche, Michael Mythen

**Enhanced recovery after surgery versus perioperative surgical home: is it all in the name?**

Cannesson M°, Kein Z.

Benefits of esCCO

- non-invasive calibration
- No special skills required
- Real time and continuous
- Low cost (alongside the familiar vital sign parameters of ECG and SpO2).

Table 2. The key properties of an ‘ideal’ hemodynamic monitoring system

- Provides measurement of relevant variables
- Provides accurate and reproducible measurements
- Provides interpretable data
- Is easy to use
- Is readily available
- Is operator-independent
- Has a rapid response-time
- Causes no harm
- Is cost-effective
- Should provide information that is able to guide therapy

No additional sensors
Reliability: Reproducibility/Repeatability/Precision error of esCCO

- acceptable:
- reproducibility coefficient is 0.87 (P<0.05) during exercise (Stalter 2015)

A CO variation value display of 3.1% can be due to the device and not to a true variation of CO
Reliability: Reproducibility/Repeatability of esCCO

- acceptable:
- Repeatability along the time

Ishihara JCMC 2004
Reliability: Reproducibility/Repeatability of esCCO

- New Algorithm of esCCO (since 2012) with non-invasive calibration

- PWWT is averaged during 64 consecutive data of heart beats.

- Exclusion of PWTT if Delta PWTT > 20 millisec or Pulse amplitude > 30%

- If more than 16 PWTT are excluded: the calculation process is cancelled

1. Either ECG or pulse-oximetry pulse wave signal is not obtained.
2. Either R wave on ECG or the start point of the ascending portion of pulse-oximetry wave is not clearly identified.

Tsuitsui A&A 2013
Precision and Accuracy

echocardiography

thermodilution

Percentage of error
LOA/meanCO

<table>
<thead>
<tr>
<th>Authors</th>
<th>Bias and Limits of Agreement</th>
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<tbody>
<tr>
<td>Manseca</td>
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<td>Ishihara</td>
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Percentage of error

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<tr>
<td>54</td>
<td>35</td>
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</table>
Precision and Accuracy

Meta-analysis on totally non invasive CO monitoring
esCCO, nIPCA, CO2r, Bioimpedance
Versus bolus thermodilution
esCCO: bias -0.2 L/min, LOA 2.76 L/min

Mean PE 42%
<table>
<thead>
<tr>
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<th>mean radial bias</th>
<th>Radial LOA of the radial bias</th>
<th>Concordance rate (%)</th>
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<td>acceptable</td>
<td>&lt;5°</td>
<td>&lt;30°</td>
<td>&gt;85-90%</td>
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Mean radial bias

Exclusion zone if ΔCO < 0,5 L/min

<table>
<thead>
<tr>
<th>Year</th>
<th>Author</th>
<th>dynamic maneuver</th>
<th>angular bias</th>
<th>angular LOA</th>
<th>concordance rate (%)</th>
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<td>PLR and FL</td>
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<td>2015</td>
<td>Thonnereux</td>
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<td>-29</td>
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<tr>
<td>2012</td>
<td>Ishihara</td>
<td>successive measurements</td>
<td>-1.6</td>
<td>53.3</td>
<td>75</td>
<td>polar</td>
</tr>
</tbody>
</table>

esCCO underestimates changes of CO
Mean angular bias

Thonnerieux A&A 2015
The constant alpha to calculate the PWTT has not been published and is based on 14 subjects only.

Averaging CO on 64 heart beats with exclusion of numerous PWTTs could impact the capacity of esCCO to detect acute changes of CO.

Non invasive calibration algorithm based on Japanese cohort different for other complexions?
Limits of esCCO: Relationship between PWTT and SV

- Weak correlation between PWTT and SV

Ishihara JCMC 2004
Limits of esCCO: Influence of Systemic Vascular Resistance

Bataille 2012

Bias = -2.14 ln(SVR) + 13.65
R = -0.45, P < 0.0001

Fig 4 Relationship between bias (difference between cardiac output obtained using transthoracic echocardiography and esCCO) and systemic vascular resistance (SVR).

Biais BJA 2015
Limits of esCCO: Influence of Systemic Vascular Resistance

Figure 1.
Components of PWTT
PEP (pre-ejection period)
T₁ (PWTT through elastic artery)
T₂ (PWTT through peripheral arteries)
PWTT (Pulse Wave Transit Time)

ECG electrodes
Aortic root pressure
Radial arterial pressure
Differentiated

ECG

SVR (dyn s cm⁻⁵) \(\log_{10}\) scale

Bias = \(-2.14 \ln(SVR) + 13.65\)

Bataille 2012

Bias BJ A 2015
Could esCCO be a promising tool?

Repeatability is acceptable

**Most studies** have been conducted in ICU and cardiac surgery (ECG and pulse wave can be affected), what about medium to high risk patients in OR?

Editorial Views | November 2012

*Noninvasive Hemodynamic Monitoring: No High Heels on the Farm; No Clogs to the Opera*

Maxime Cannesson, M.D., Ph.D.; Yannick Le Manach, M.D., Ph.D.
Could esCCO be a promising tool?

Feissel Study:
Agreement: bias -0.47 with LOA 1.42 L/min PE of 24%  
Concordance rate of 100% before and after FL

Threshold 11%  
Se = 83%  
Sp = 77%
esC CO is a real time continuous non invasive CO monitoring

Most of studies show a wide LOA and an inability to follow CO changes

esC CO should be compare to a gold standard in animals (transonic flow probes)

Repeatability of the comparator (reference method) should also be assessed

esC CO should be tested in an outcome study