The answer is blowing in the wind; cardiac output and lung volume monitoring in intubated patients

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This work has been supported by;

The regional agreement on medical training and research (ALF) between Stockholm County Council and the Karolinska Institutet

The HMT project (Health, Medicine and Technology) a collaboration project between the Stockholm County Council and the Royal Institute of Technology

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Clinical review: What are the best hemodynamic targets for noncardiac surgical patients?

Suzana Margareth Lobo* and Neymar Elias de Oliveira

Perioperative increase in global blood flow to explicit defined goals and outcomes after surgery: a Cochrane Systematic Review

M. P. W. Grocott1, A. Dushianthan1*, M. A. Hamilton2, M. G. Mythen3, D. Harrison4, K. Rowan4 and Optimisation Systematic Review Steering Group5

Clinical review: Goal-directed therapy - what is the evidence in surgical patients? The effect on different risk groups

Maurizio Cecconi*, Carlos Corredor, Nishkantha Arulkumaran, Gihan Abuela, Jonathan Ball, RJ Michael Grounds, Mark Hamilton and Andrew Rhodes
Perioperative monitoring during high-risk surgery?

Poor Adoption of Hemodynamic Optimization During Major Surgery: Are We Practicing Substandard Care?

Timothy E. Miller, MB ChB, FRCA, Anthony M. Roche, MB ChB, FRCA, MMed (Anaes), and Tong J. Gan, MD, MHS, FRCA

DOI 10.1007/s10876-014-9646-7

A web-based Italian survey of current trends, habits and beliefs in hemodynamic monitoring and management

Gianni Biancofiore · Maurizio Cecconi · Giorgio Della Rocca

Hemodynamic monitoring and management in patients undergoing high risk surgery: a survey among North American and European anesthesiologists

Maxime Cannesson1, Gunther Pestel2, Cameron Ricks1, Andreas Hoesf3 and Aziel Perel4
A modified Fick's principle

\[ CO = \frac{VCO_2}{CvCO_2 - CaCO_2} \]

Partial rebreathing

A capnodynamic method


The capnodynamic equation

\[
\text{ELV} \cdot \left( F_{A}CO_{2}^{n} - F_{A}CO_{2}^{n-1} \right) = \text{EPBF} \cdot \Delta t^{n} \cdot \left( C_{v}CO_{2} - C_{c}CO_{2}^{n} \right) - \text{VTCO}_{2}^{n}
\]

ELV

Effective lung volume [L]

EPBF

Effective pulmonary blood flow [L/min]

n

current breath

n-1

previous breath

\( F_{A}CO_{2} \)

mean alveolar carbon dioxide fraction

\( C_{v}CO_{2} \)

mixed venous carbon dioxide content \([L_{\text{gas}}/L_{\text{blood}}]\)

\( C_{c}CO_{2}^{n} \)

end-pulmonary capillary carbon dioxide content \([L_{\text{gas}}/L_{\text{blood}}]\)

\( \text{VTCO}_{2}^{n} \)

volume [L] of carbon dioxide eliminated by the current breath

\( \Delta t^{n} \)

current breath cycle time [min]
Ventilatory pattern

Inspiratory holds

Expiratory holds

Pressure (cm H₂O)

Time

Pressure (cm H₂O)

Time
List of errata
Reference method for cardiac output ($CO_{TS}$)

An ultrasonic flow probe placed around truncus pulmonalis
Hämodynamic challenges in a porcine model (N=6-10)

Hällsjö Sander C, Hallbäck M, Wallin M, Emtell P, Oldner A, Björne H
Novel continuous capnodynamic method for cardiac output assessment during mechanical ventilation.
Hemodynamic and ventilatory challenges before and after lung lavage in a porcine model (N=9)

Hällsjö Sander C, Hallbäck M, Suarez Sipmann F, Wallin M, Oldner A, Björne H
The capnodynamic method $\text{CO}_{\text{EPBF}}$ with a modified ventilatory pattern compared to the reference method for cardiac output $\text{CO}_{\text{TS}}$ in a porcine model ($N=8$).
141 paired cardiac output values obtained from the reference method for CO ($CO_{TS}$) and the capnodynamic method ($CO_{EPBF}$) (L/min)
Conclusion

The capnodynamic method ($\text{CO}_{\text{EPBF}}$) with a ventilatory pattern based on expiratory holds did not display the paradoxical trending shown in our previous animal studies with a ventilatory pattern based on inspiratory holds.

Trending ability was preserved during all hemodynamic and respiratory interventions.
The capnodynamic equation

\[ ELV \cdot \left( F_A CO_2^n - F_A CO_2^{n-1} \right) = EPBF \cdot \Delta t^n \cdot \left( C_v CO_2 - C_c CO_2^n \right) - VT CO_2^n \]

**ELV**  Effective lung volume [L]

**EPBF**  Effective pulmonary blood flow [L/min]

**n**  current breath

**n-1**  previous breath

**F_A CO_2**  mean alveolar carbon dioxide fraction

**C_v CO_2**  mixed venous carbon dioxide content [L_{gas}/L_{blood}]

**C_c CO_2^n**  end-pulmonary capillary carbon dioxide content [L_{gas}/L_{blood}]

**VT CO_2^n**  volume [L] of carbon dioxide eliminated by the current breath

**\Delta t^n**  current breath cycle time [min]
ELV effective lung volume

The stability of ELV during significant hemodynamic alterations.

The correlation of ELV and a reference method for FRC (FRC_{PEEP}) at different PEEP levels.
The sulfur hexa fluoride method reference for FRC (FRC$_{PEEP}$)
Hemodynamic alterations in a porcine model (N=9)

ELV

CO_Ts
ELV compared the FRC\textsubscript{PEEP} during PEEP alterations (N=9)
Conclusions

ELV remained stable during hemodynamic alterations and was closely related to $FRC_{PEEP}$. 
Clinical and future perspectives

Evaluation of the modified ventilatory pattern after lung lavage

Correction for shunt flow

Human study; 30 patients high risk surgery $\text{CO}_{\text{EPBF}}$

Could ELV and EPBF be used in combination for optimisation of CO and PEEP?
Thank you for your attention!

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Materials and Methods

A 10 Fr Reliant catheter was placed below the diaphragm and inflated. Hemodynamic measurements were obtained:
- Before inflation of the balloon
- 27 minutes after inflation
- 1, 3 and 5 minutes after deflation

Reference method for cardiac output; The ultrasonic flow probe placed around truncus pulmonalis $\text{CO}_{\text{TS}}$
The capnodynamic method $\text{CO}_{\text{EPBF}}$
The pulmonary artery catheter $\text{CO}_{\text{PAC}}$
Pigs (N=8)
Conclusion

The ischemic model resulted in significant changes in lactate levels and severe hemodynamic changes.

$\text{CO}_{\text{EPBF}}$ showed good agreement at BL but markedly overestimated CO at minute one and three after deflation. Five minutes after deflation $\text{CO}_{\text{EPBF}}$ had re-established agreement with the reference method.