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

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Maquet Critical Care AB

A Systematic Review and Meta-Analysis on the Use of Preemptive Hemodynamic Intervention to Improve Postoperative Outcomes in Moderate and High-Risk Surgical Patients

Mark A. Hamilton, MRCP, FRCA, Maurizio Cecconi, MD, and Andrew Rhodes, FRCP, FRCA

(Anesth Analg 2011;112:1392–402)

Lobo and de Oliveira *Critical Care* 2013, 17:210
http://ccforum.com/content/17/2/210

CRITICAL CARE

REVIEW

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

Suzana Margareth Lobo* and Neymar Elias de Oliveira

Maintaining Tissue Perfusion in High-Risk Surgical Patients: A Systematic Review of Randomized Clinical Trials

Sanderland T. Gurgel, MD, and Paulo do Nascimento, Jr., MD, PhD

Anesth Analg. 2011 Jun;112(6):1384-91

British Journal of Anaesthesia **111** (4): 535–48 (2013)
Advance Access publication 9 May 2013 · doi:10.1093/bja/aet155

BJA

REVIEW ARTICLES

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

M. P. W. Grocott[1], A. Dushianthan[1*], M. A. Hamilton[2], M. G. Mythen[3], D. Harrison[4], K. Rowan[4] and Optimisation Systematic Review Steering Group[5]

Cecconi *et al. Critical Care* 2013, 17:209
http://ccforum.com/content/17/2/209

CRITICAL CARE

REVIEW

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 Abuella, Jonathan Ball, R Michael Grounds, Mark Hamilton and Andrew Rhodes

Perioperative monitoring during high-risk surgery?

EDITORIAL

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

Cannesson *et al. Critical Care* 2011, **15**:R197
http://ccforum.com/content/15/4/R197

CRITICAL CARE

RESEARCH Open Access

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

Maxime Cannesson[1*], Gunther Pestel[2], Cameron Ricks[1], Andreas Hoeft[3] and Azriel Perel[4]

J Clin Monit Comput (2015) 29:635–642
DOI 10.1007/s10877-014-9646-7

CrossMark

ORIGINAL RESEARCH

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

Gianni Biancofiore · Maurizio Cecconi · Giorgio Della Rocca

~ GOLD STANDARD SINCE 1870 ~

Adolf Eugen Fick

1829-1901

Invasive

$$CO = \frac{VCO_2}{CvCO_2 - CaCO_2}$$

Partial rebreathing

A modified Fick's principle

Non-invasive

A capnodynamic method

Gedeon A, et al; **Pulmonary blood flow (cardiac output) and the effective lung volume determined from a short breath hold using the differential Fick method.** J Clin Monit 2002; 17: 313-321

Peyton P, **Pulmonary carbon dioxide elimination for cardiac output monitoring in peri-operative and critical care patients; history and current status**. J of Healthcare engineering 2013; 4:2 :203-222

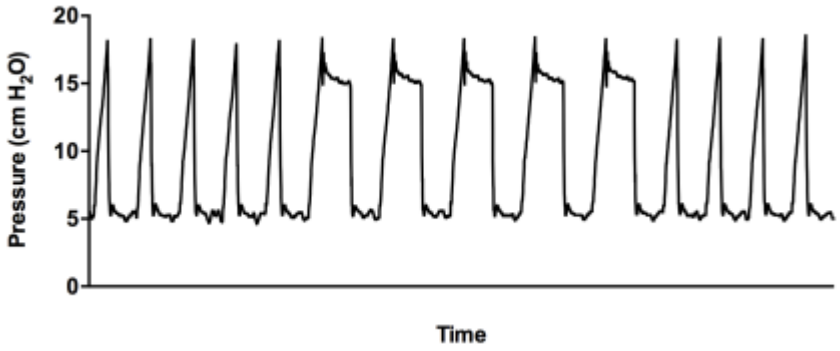
The capnodynamic equation

$$ELV \cdot \left(F_A CO_2^n - F_A CO_2^{n-1} \right) = EPBF \cdot \Delta t^n \cdot \left(C_v CO_2 - C_c CO_2^n \right) - VTCO_2^n$$

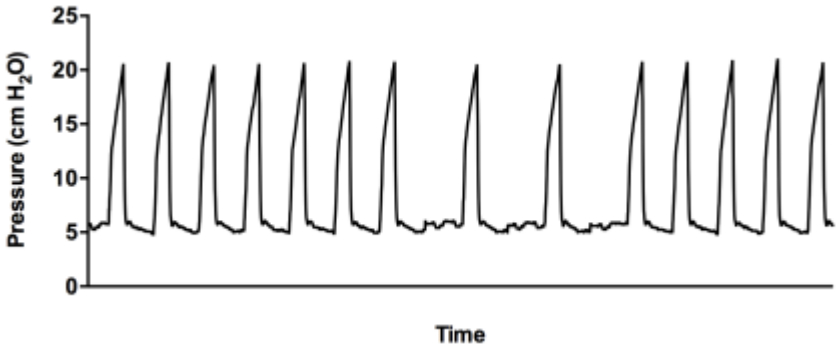
ELV	Effective lung volume [L]
EPBF	Effective pulmonary blood flow [L/min]
n	current breath
n-1	previous breath
F_ACO_2	mean alveolar carbon dioxide fraction
C_vCO_2	mixed venous carbon dioxide content [L_{gas}/L_{blood}]
$C_cCO_2^n$	end-pulmonary capillary carbon dioxide content [L_{gas}/L_{blood}]
$VTCO_2^n$	volume [L] of carbon dioxide eliminated by the current breath
Δt^n	current breath cycle time [min]

Ventilatory pattern

Inspiratory holds

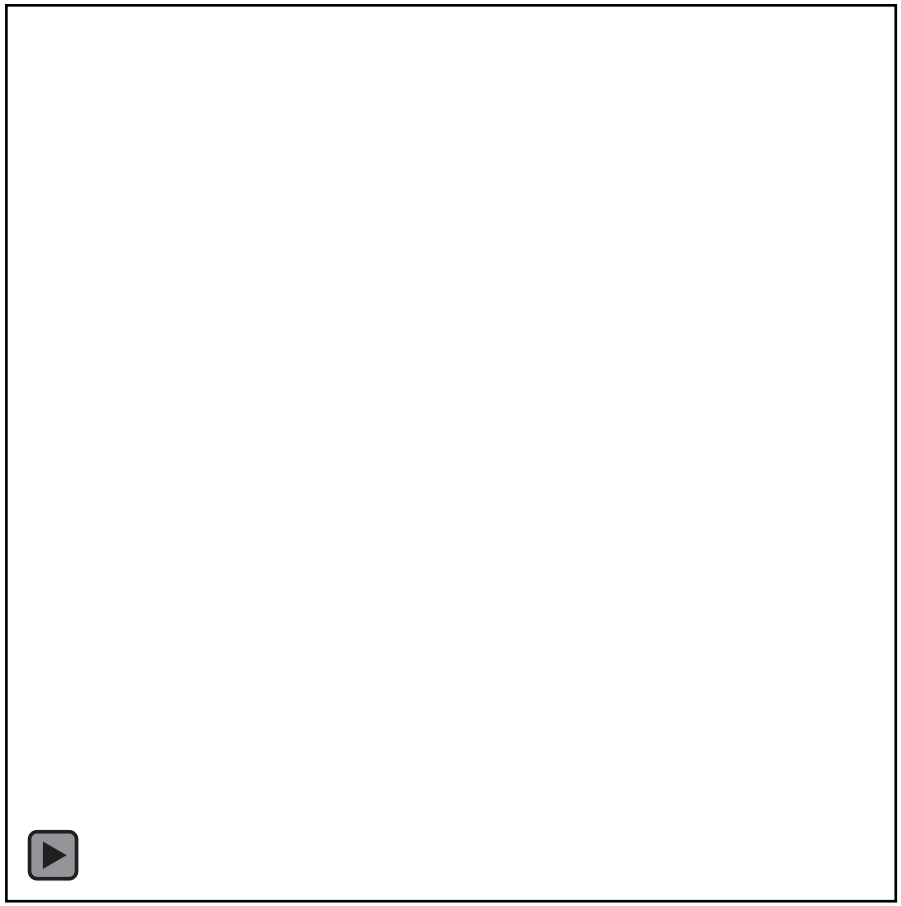


Expiratory holds



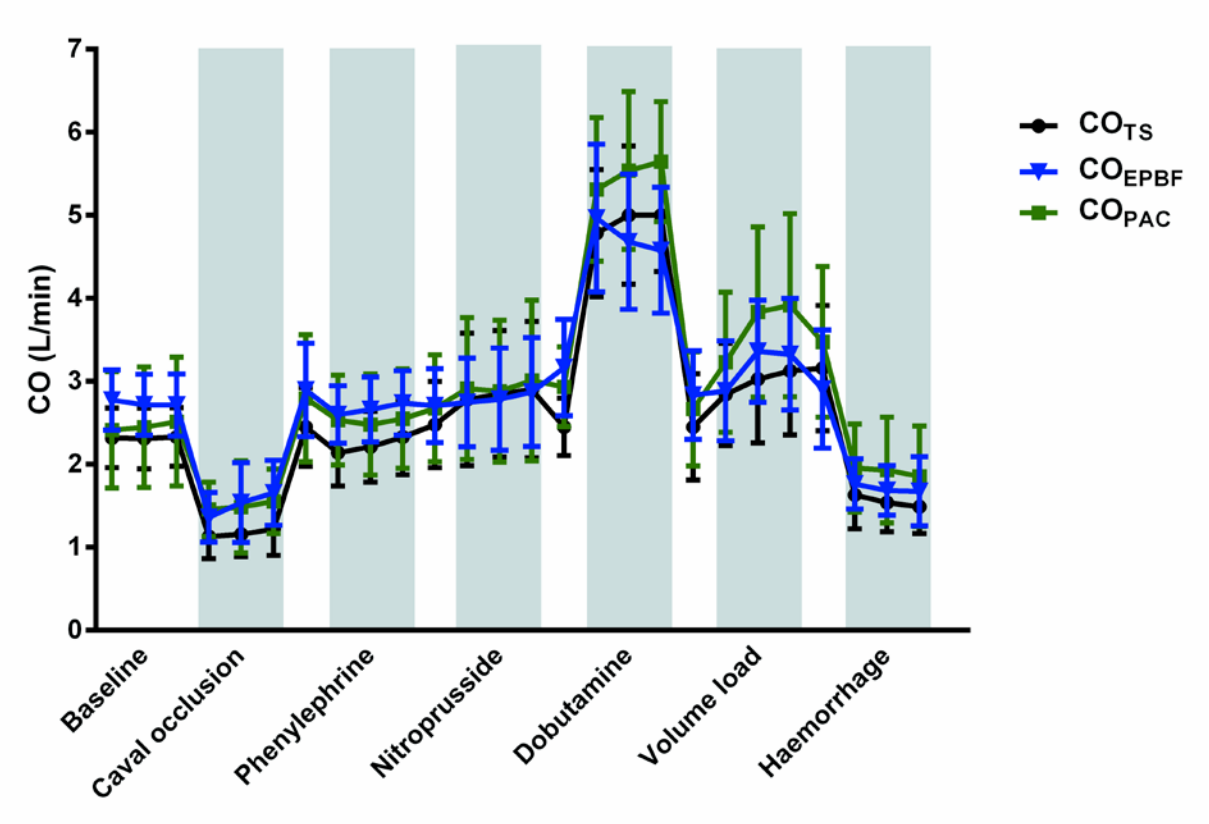
List of errata

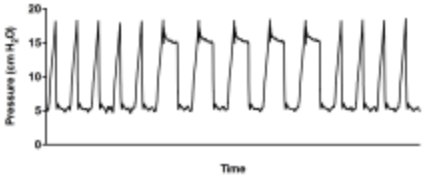
Reference method for cardiac output (CO_{TS})



An ultrasonic flow probe placed around truncus pulmonalis

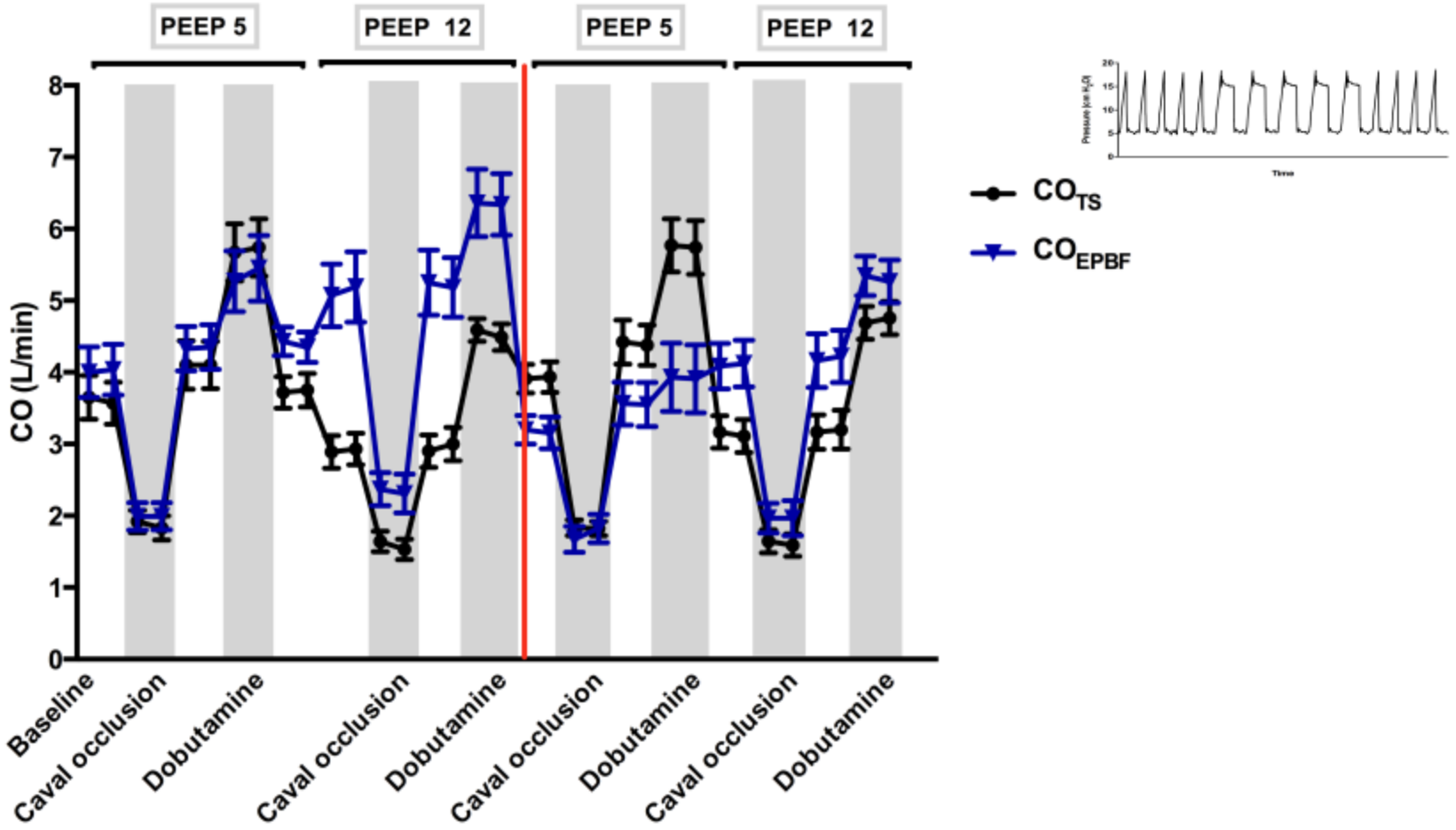
Hemodynamic challenges in a porcine model (N=6-10)



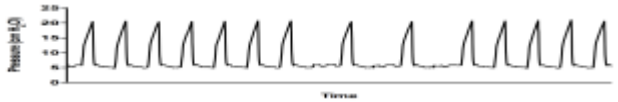


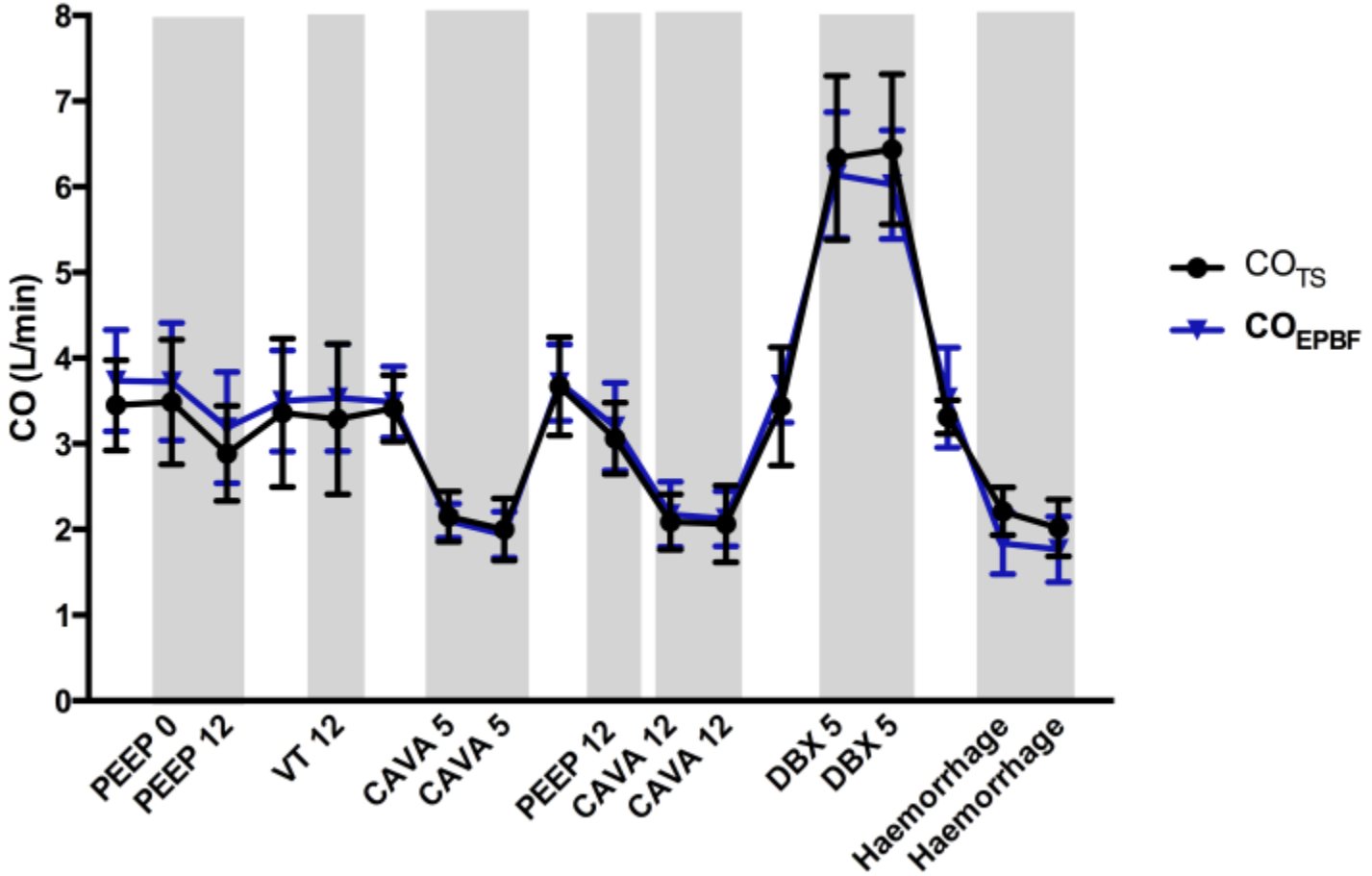
Hällsjö Sander C, Hallbäck M, Wallin M, Emtell P, Oldner A, Björne H
Novel continuous capnodynamic method for cardiac output assessment during mechanical ventilation.
Br J Anaesth. 2014 May;112(5):824-31. doi: 10.1093/bja/aet486.

Hemodynamic and ventilatory challenges before and after lung lavage in a porcine model (N=9)

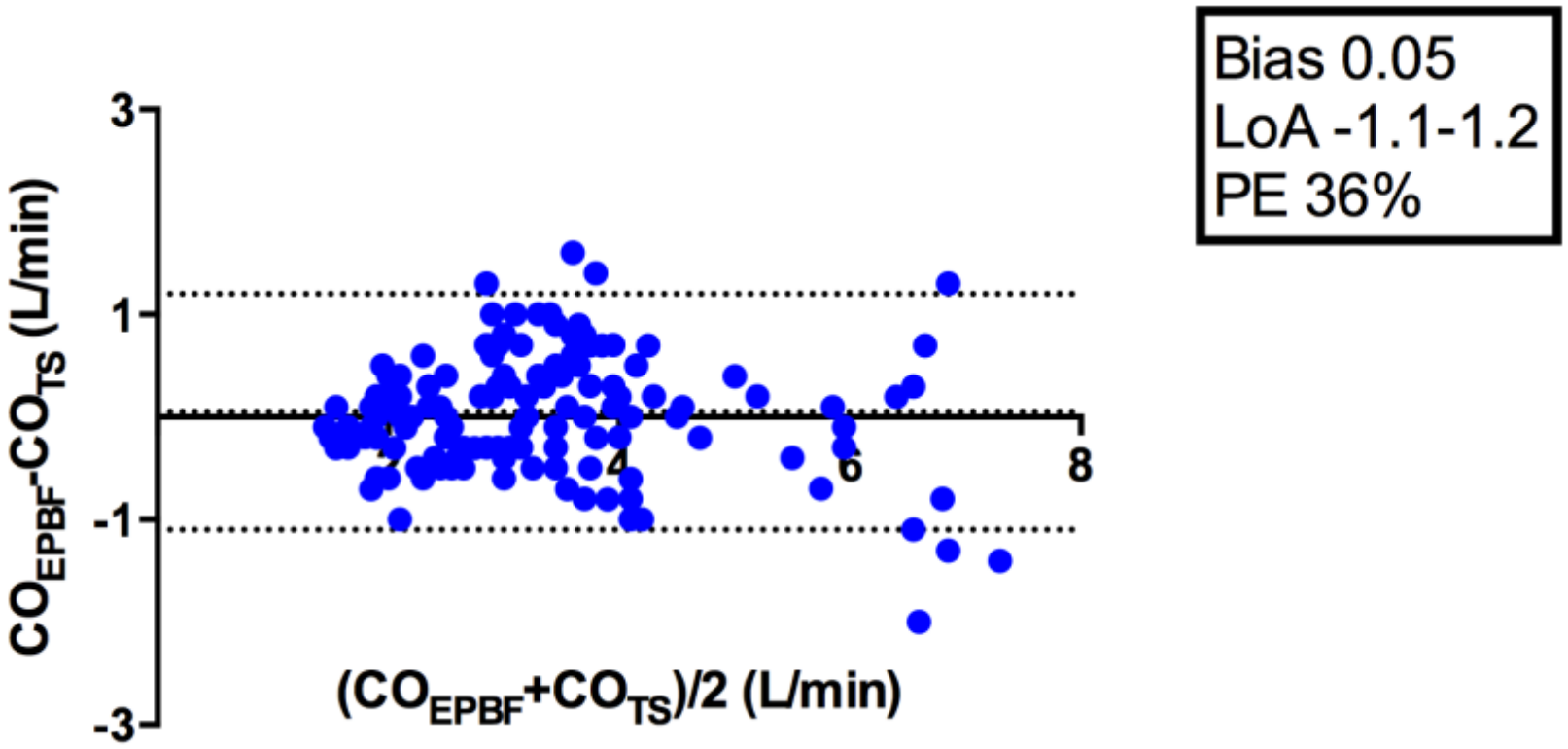


Hällsjö Sander C Hallbäck M, Suarez Sipmann F, Wallin M, Oldner A, Björne H
A novel continuous capnodynamic method for cardiac output assessment in a porcine model of lung lavage. Acta Anaesthesiologica Scandinavica 2015 Sep; 59(8):1022-31





The capnodynamic method CO_{EPBF} with a modified ventilatory pattern compared to the reference method for cardiac output CO_{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 (CO_{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

$$ELV \cdot \left(F_A CO_2^n - F_A CO_2^{n-1} \right) = EPBF \cdot \Delta t^n \cdot \left(C_v CO_2 - C_c CO_2^n \right) - VTCO_2^n$$

ELV	Effective lung volume [L]
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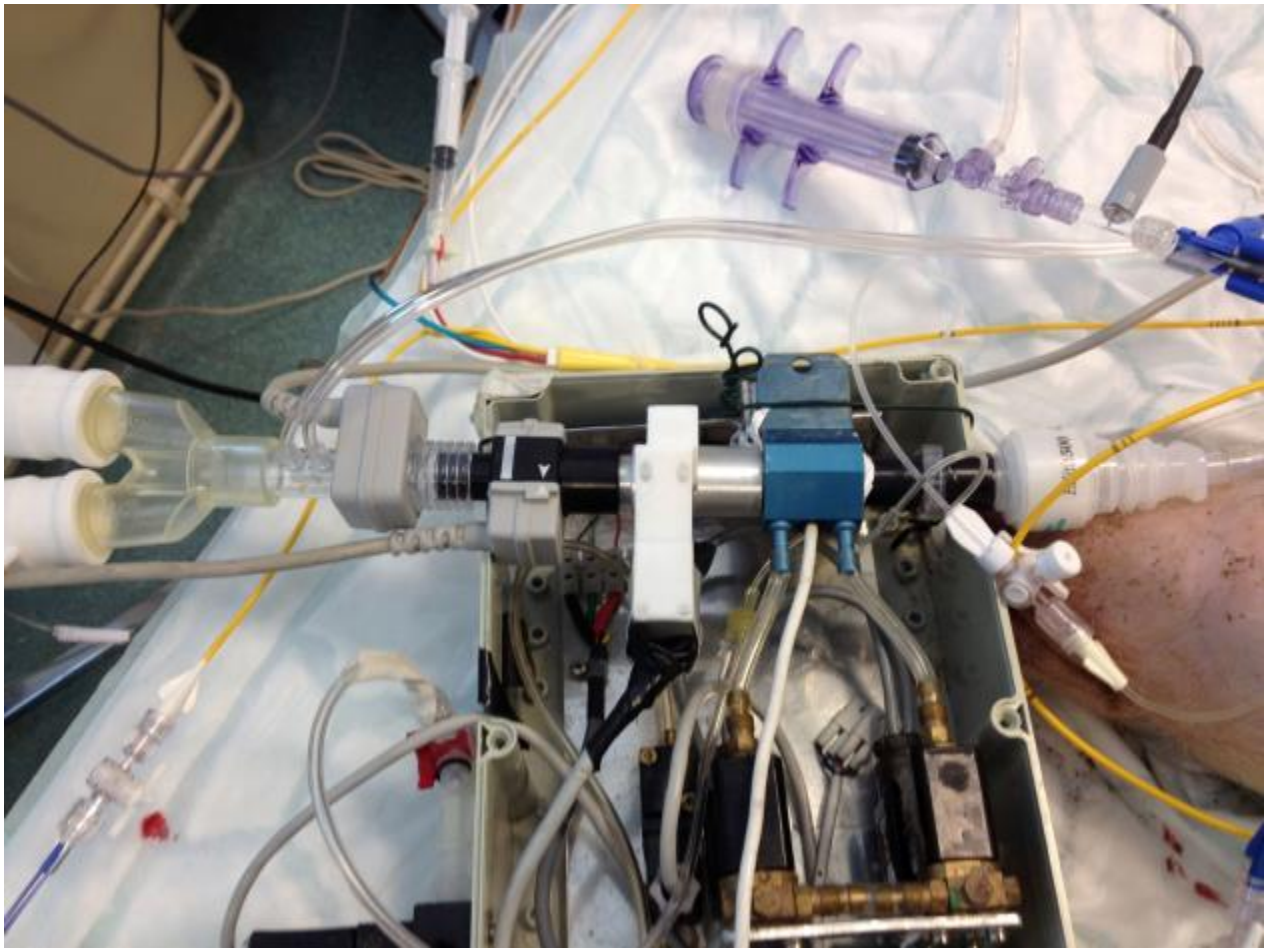
$VTCO_2^n$	volume [L] of carbon dioxide eliminated by the current breath
Δt^n	current breath cycle time [min]

ELV effective lung volume

The stability of ELV during significant hemodynamic alterations.

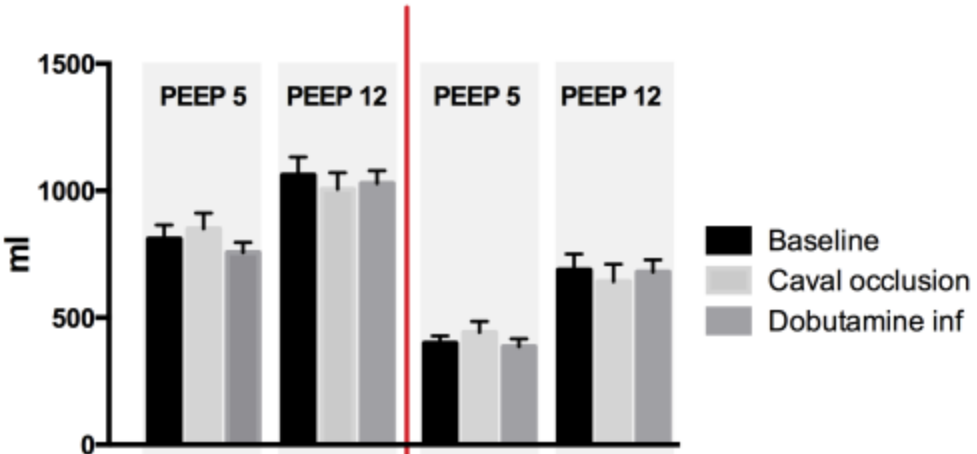
The correlation of ELV and a reference method for FRC (FRC_{PEEP}) at different PEEP levels.

The sulfur hexa fluoride method reference for FRC (FRC_{PEEP})

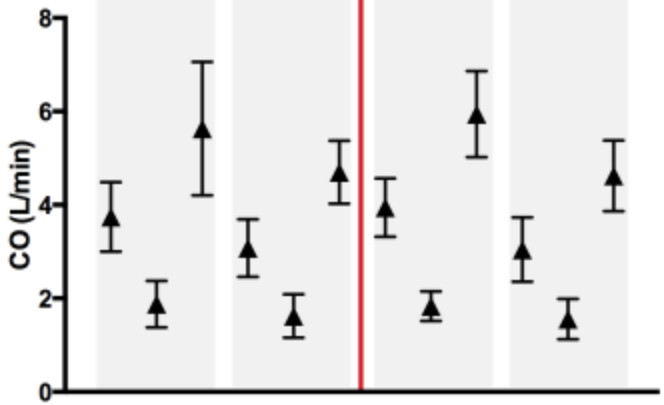


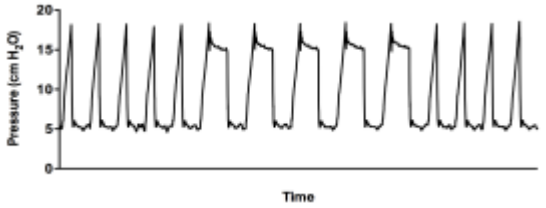
Hemodynamic alterations in a porcine model (N=9)

ELV

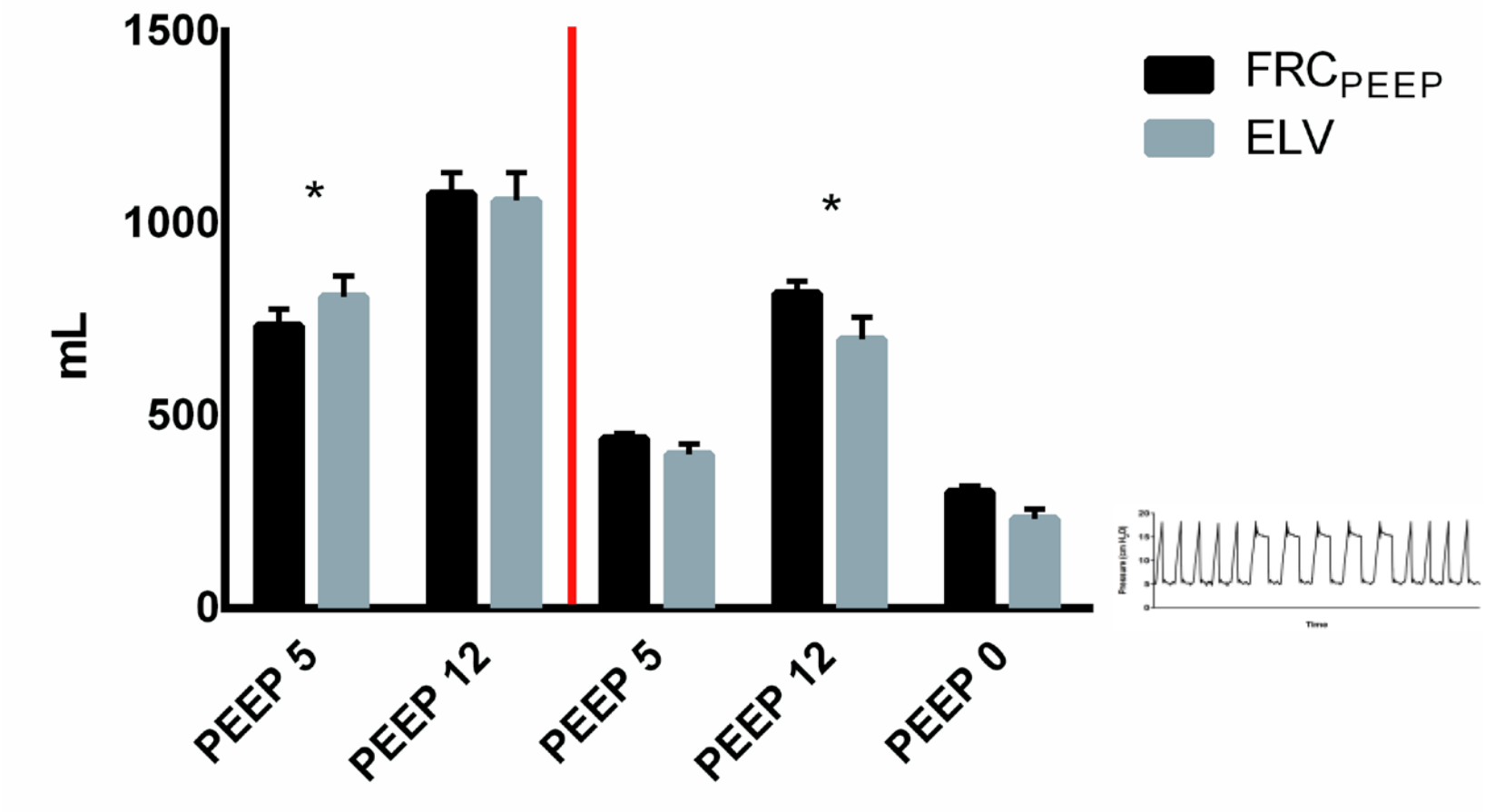


CO_{TS}





ELV compared the FRC_{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 CO_{EPBF}

Could ELV and EPBF be used in combination for optimisation of CO and 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

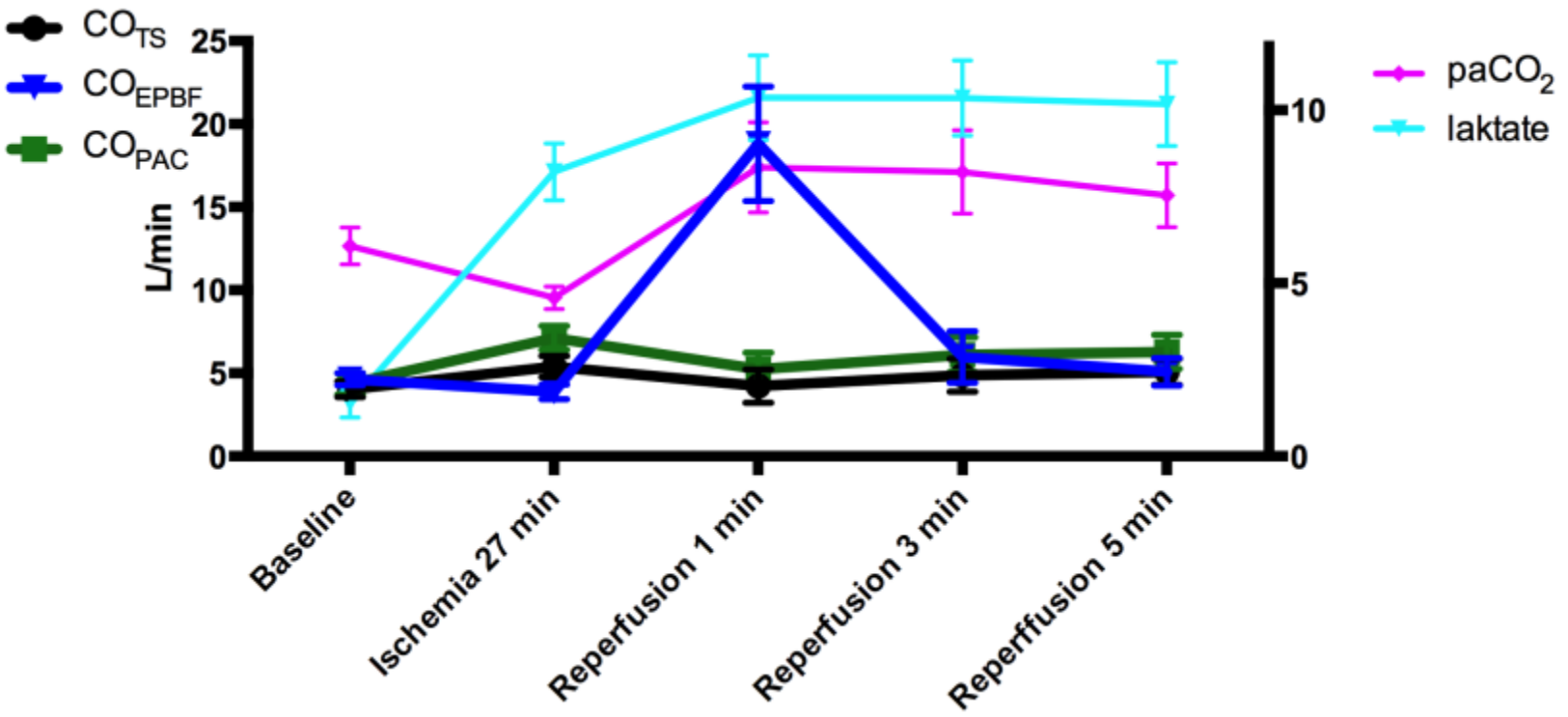
-1,3 and 5 minutes after deflation

Reference method for cardiac output; The ultrasonic flow probe placed around truncus pulmonalis CO_{TS}

The capnodynamic method CO_{EPBF}

The pulmonary artery catheter CO_{PAC}

Pigs (N=8)


CO_{TS}
CO_{EPBF}
CO_{PAC}
L/min
25
20
15
10
5
0
10
5
0
$paCO_2$
laktate
Baseline
Ischemia 27 min
Reperfusion 1 min
Reperfusion 3 min
Reperffusion 5 min

Conclusion

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

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