PCO_2 gap

- The advantages -

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UNIVERSITÉ PARIS SUD
Comprendre le monde, construire l'avenir®

Intensive Care Med (2014) 40:1795–1815

CONFERENCE REPORTS AND EXPERT PANEL

Maurizio Cecconi
Daniel De Backer
Massimo Antonelli
Richard Beale
Jan Bakker
Christoph Hofer
Roman Jaeschke
Alexandre Mebazaa
Michael R. Pinsky
Jean Louis Teboul
Jean Louis Vincent
Andrew Rhodes

Consensus on circulatory shock and hemodynamic monitoring. Task force of the European Society of Intensive Care Medicine

- In patients with a **central venous catheter**, we suggest measurements of **$ScvO_2$** and **v-aPCO_2** to help assess the underlying pattern and the **adequacy** of **cardiac output** as well as to **guide therapy**

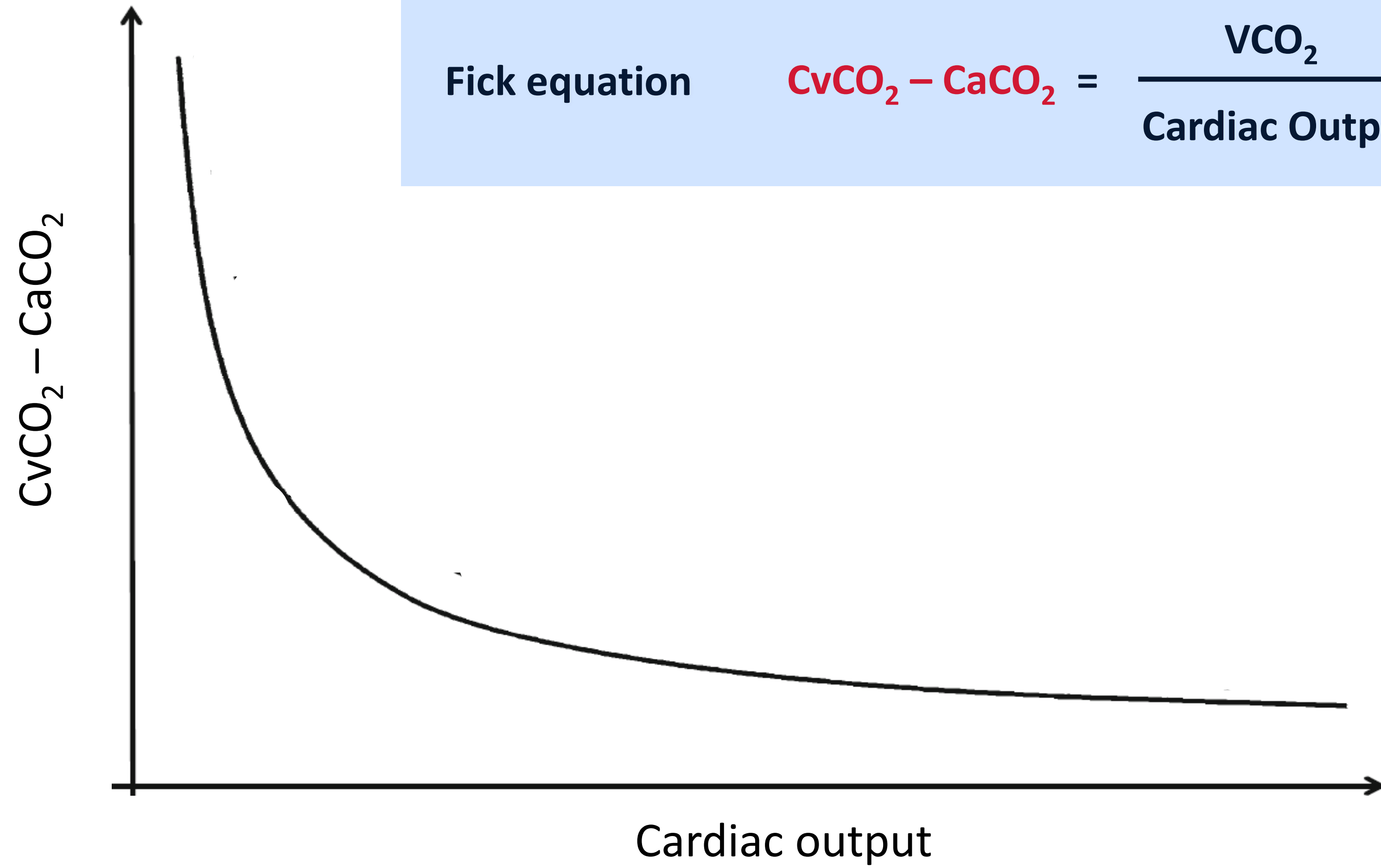
Level 2; QoE moderate (B)

Hemodynamic management of cardiovascular failure by using PCO_2 venous-arterial difference

Martin Dres · Xavier Monnet · Jean-Louis Teboul

J Clin Monit Comput (2012) 26:367–374

Fick equation $$CvCO_2 - CaCO_2 = \frac{VCO_2}{\text{Cardiac Output}}$$



Fick equation

$$CvCO_2 - CaCO_2 = \Delta CCO_2 = \frac{VCO_2}{\text{Cardiac Output}}$$

$$\Delta PCO_2 = k \cdot \Delta CCO_2$$

Fick equation

$$CvCO_2 - CaCO_2 = \Delta CCO_2 = \frac{VCO_2}{\text{Cardiac Output}}$$

$$\Delta PCO_2 = k \cdot \Delta CCO_2$$

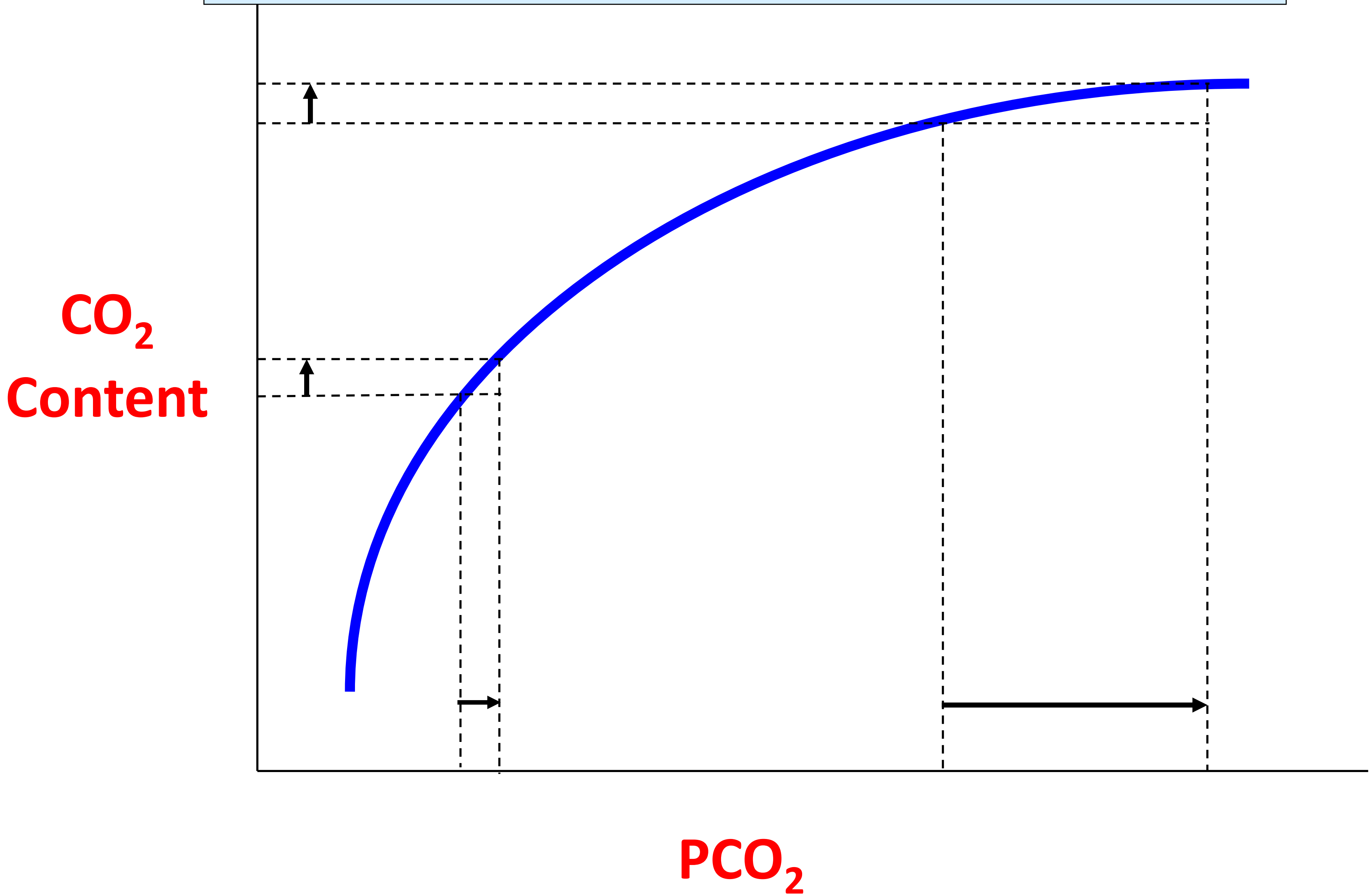
simplified Fick equation

$$\Delta PCO_2 = k \cdot \frac{VCO_2}{\text{Cardiac Output}}$$

ΔPCO_2 depends on:

- **k**, a factor defining the **relation** between **PCO_2** and **CO_2 content**
- **VCO_2** : global **CO_2 production**
- **Cardiac Output**

« **k** » is **not constant** and **increases** with **venous hypercapnia**



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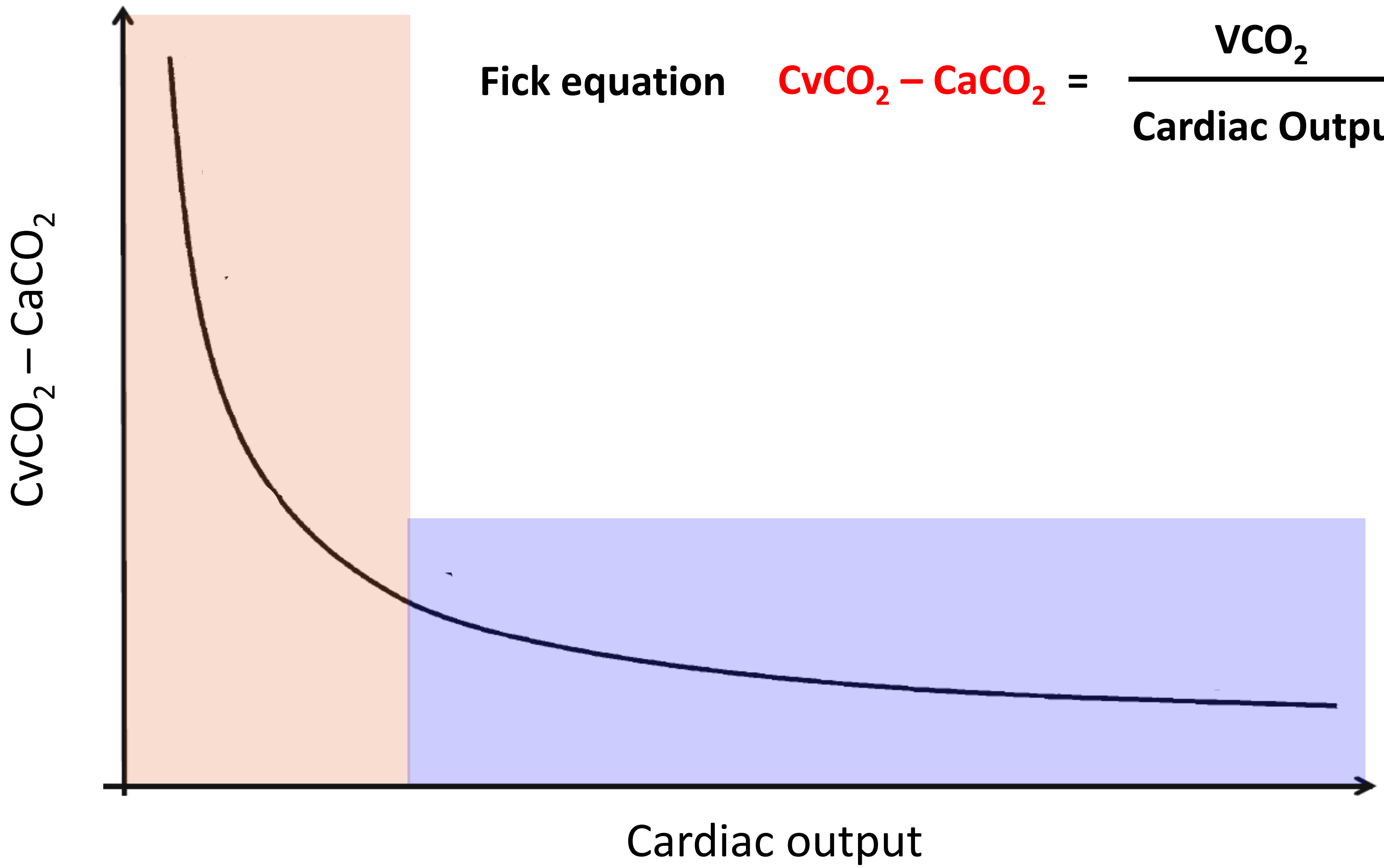


Δ PCO_2 and cardiac output

In case of **low cardiac output**, the **high Δ PCO_2** is related to **CO_2 stagnation**, a phenomenon that results from a **low clearance** of the **CO_2 produced** at the periphery (due to the **slow efferent venous blood flow**).

Δ PCO_2: clinical use

- Δ PCO_2: marker of tissue hypoxia?

$$\Delta PCO_2 = k \cdot \frac{VCO_2}{CO}$$

hypoxia

- ↓↓ **aerobic CO_2 production**
- ↑ **anaerobic CO_2 production**

anaerobic CO_2 production

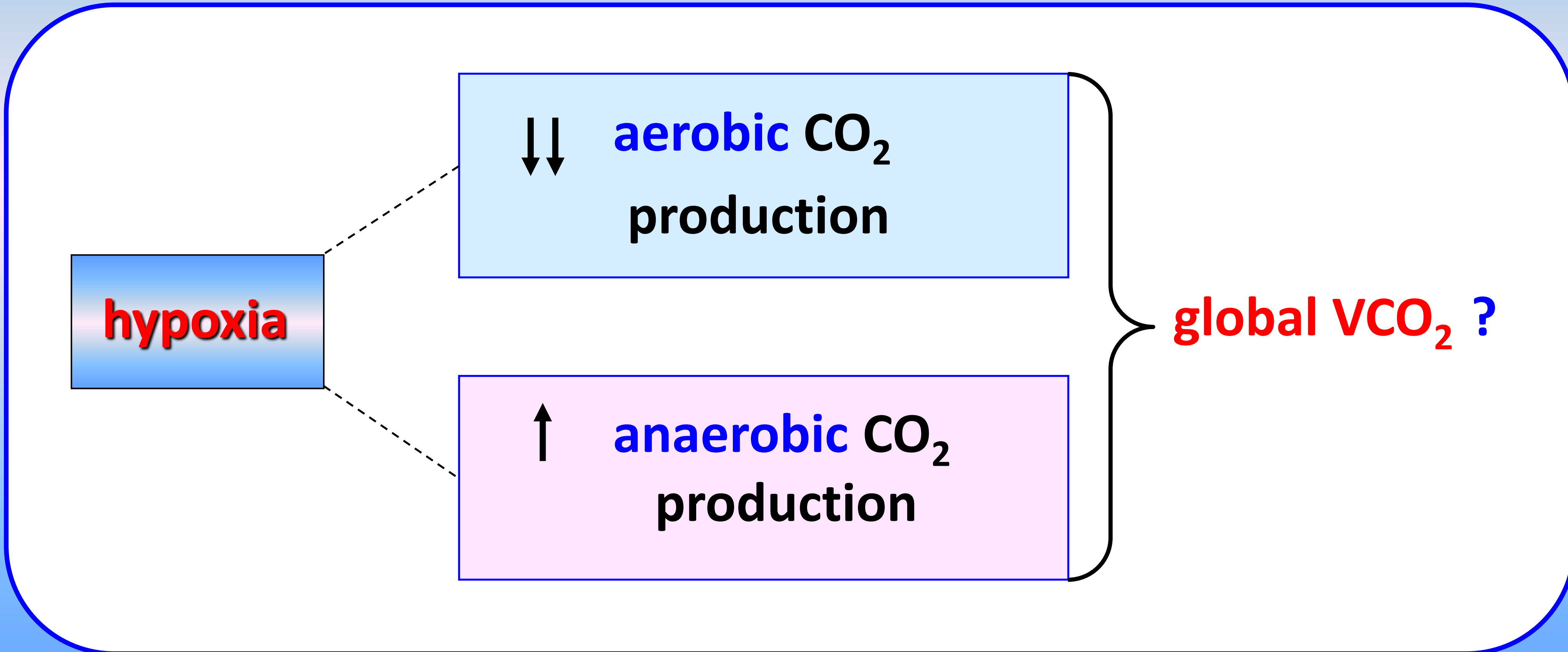
. **buffering** of H^+ ions generated under **hypoxic** conditions due to **hydrolysis** of **ATP** and **ADP**

→ **generation of CO_2**

. **anaerobic decarboxylation of** α cetoglutarate and oxaloacetate

→ **generation of CO_2**

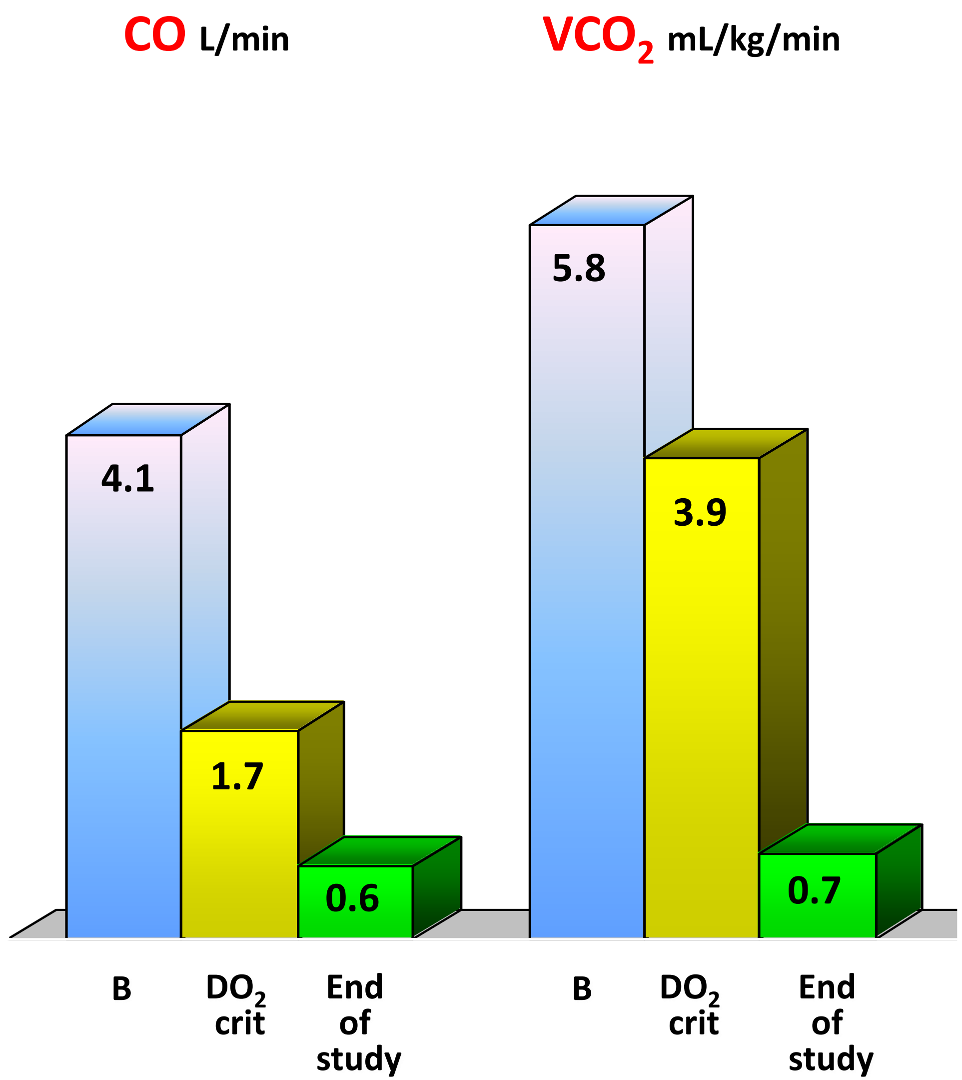
$$\Delta PCO_2 = k \cdot \frac{VCO_2}{CO}$$



Arteriovenous differences in PCO_2 and pH are good indicators of critical hypoperfusion

Zhang H and Vincent JL

Am Rev Respir Dis 1993 ; 148 : 867-871



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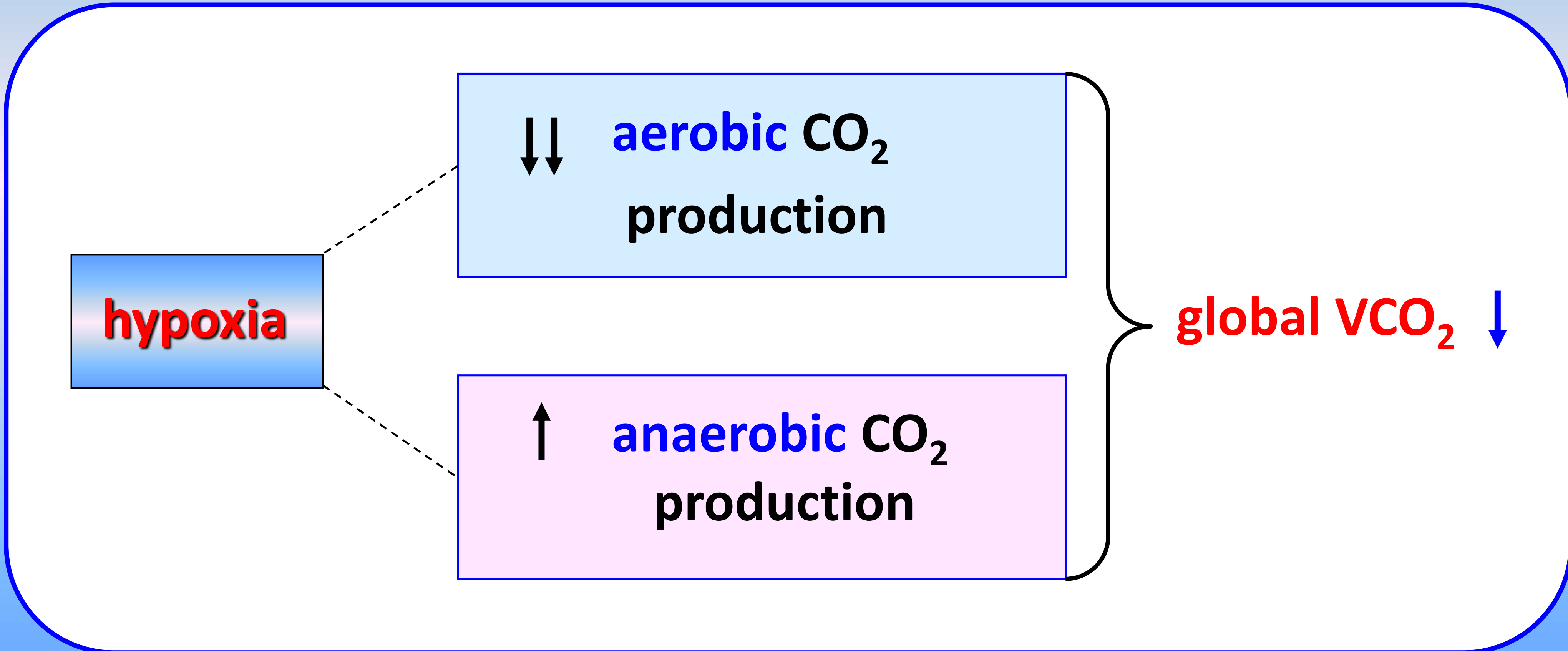


$$\Delta PCO_2 = k \cdot \frac{\downarrow VCO_2}{CO}$$

hypoxia ⟶ k ?

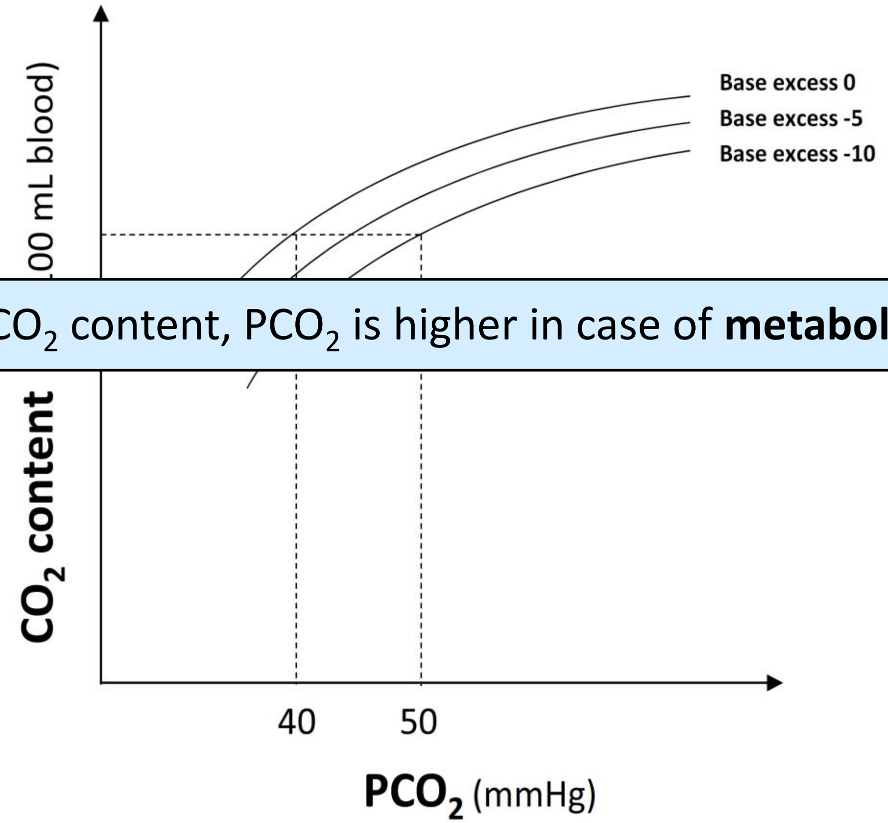
Intensive Care Med (2017) 43:91–93

UNDERSTANDING THE DISEASE

Understanding the Haldane effect

Jean-Louis Teboul[1,2*] and Thomas Scheeren[3,4]

« **k** » **increases** with **metabolic acidosis**



For a given CO_2 content, PCO_2 is higher in case of **metabolic acidosis**

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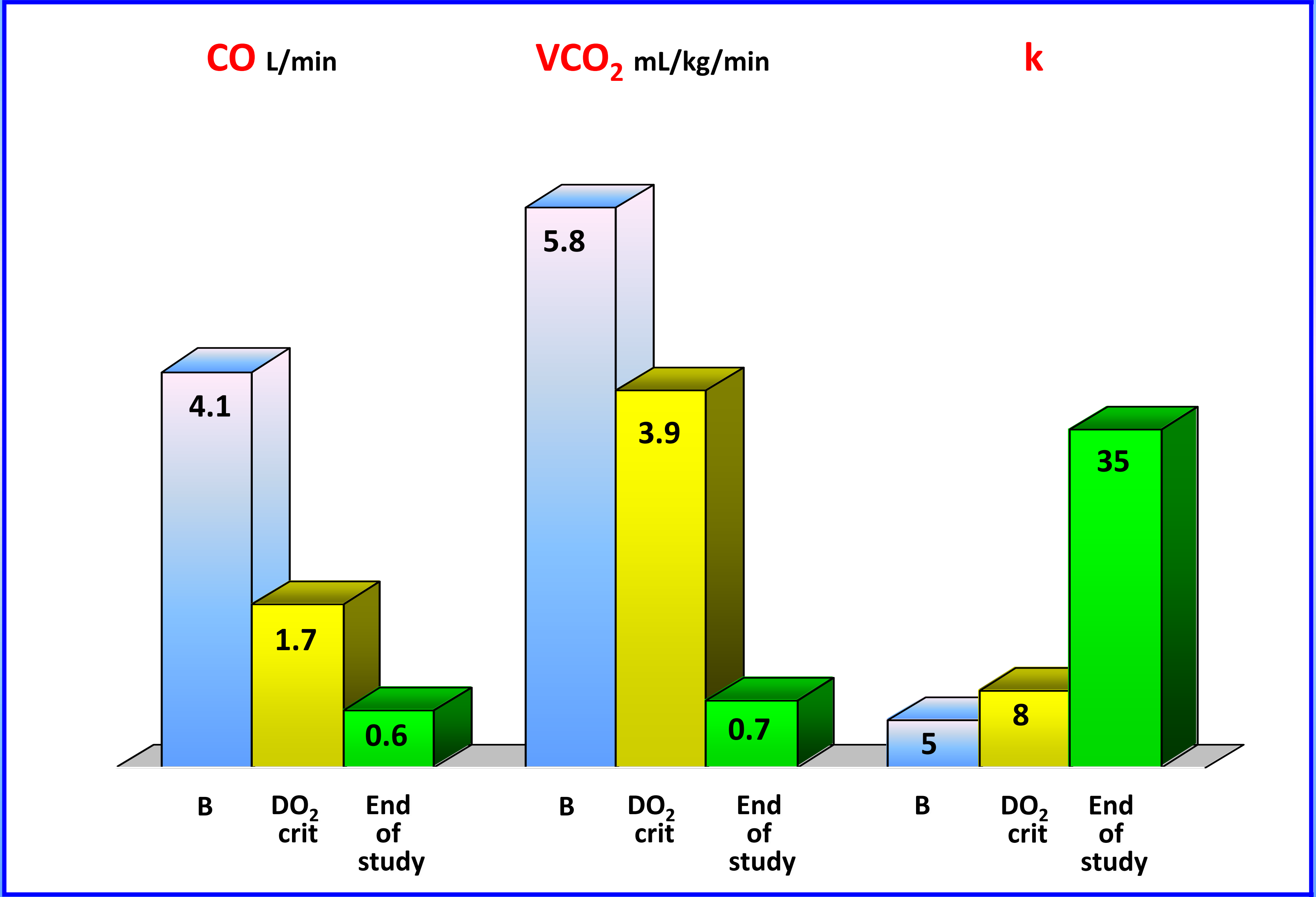
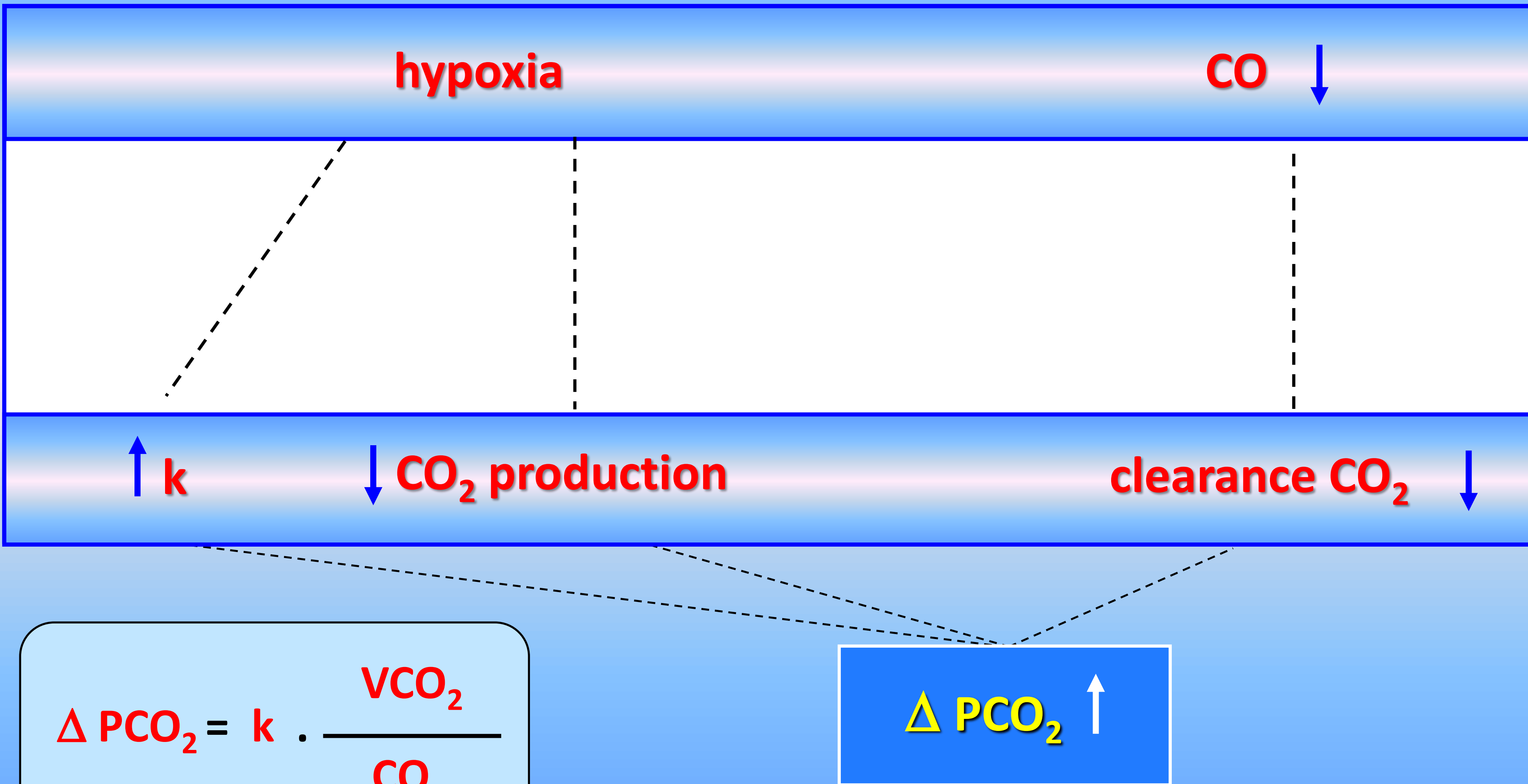


$$\Delta PCO_2 = \uparrow k \cdot \frac{\downarrow VCO_2}{CO}$$

hypoxia ⇢ **k** $\uparrow$

Tissue hypoxia with low CO



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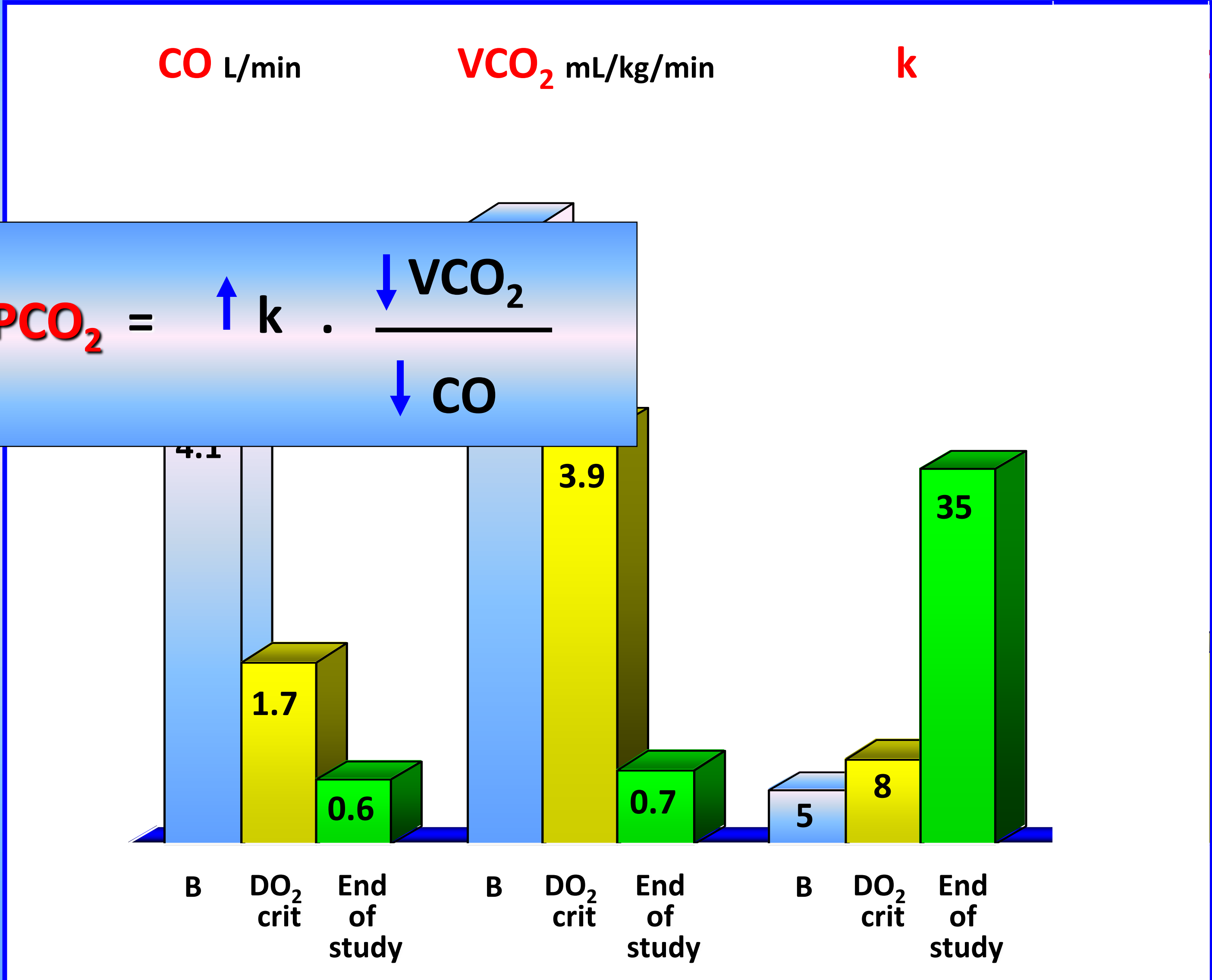


$$\uparrow \Delta PCO_2 = \uparrow k \cdot \frac{\downarrow VCO_2}{\downarrow CO}$$

Tissue hypoxia with normal or high CO

hypoxia

CO = or ↑

↑ k

↓ CO_2 production

clearance CO_2 ↑

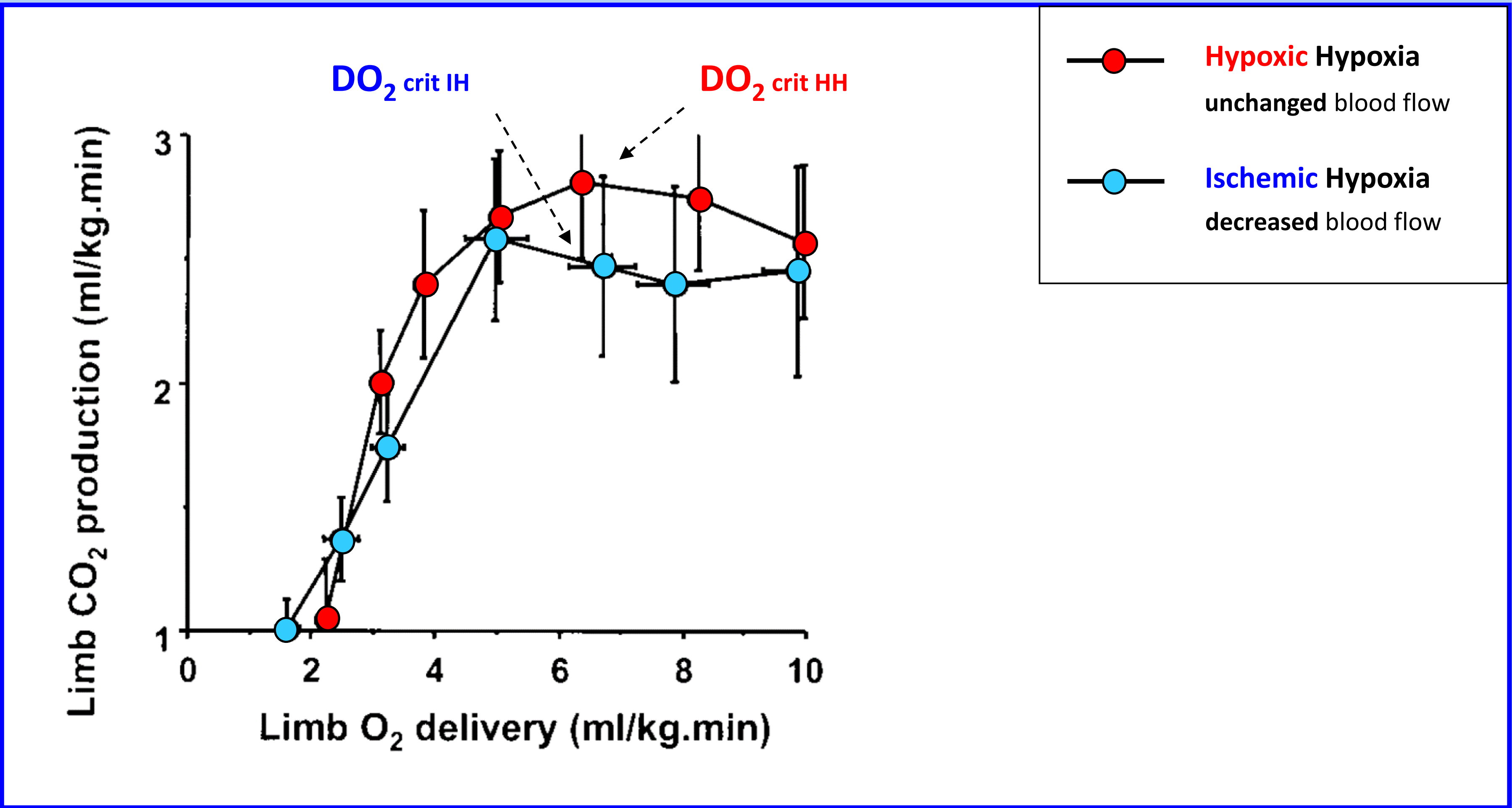
$$\Delta PCO_2 = k \cdot \frac{VCO_2}{CO}$$

ΔPCO_2 ↓ or =

Venoarterial CO_2 difference during regional ischemic or hypoxic hypoxia

BENOIT VALLET,[1] JEAN-LOUIS TEBOUL,[2] STEPHEN CAIN,[3] AND SCOTT CURTIS[4]

J Appl Physiol 89: 1317–1321, 2000



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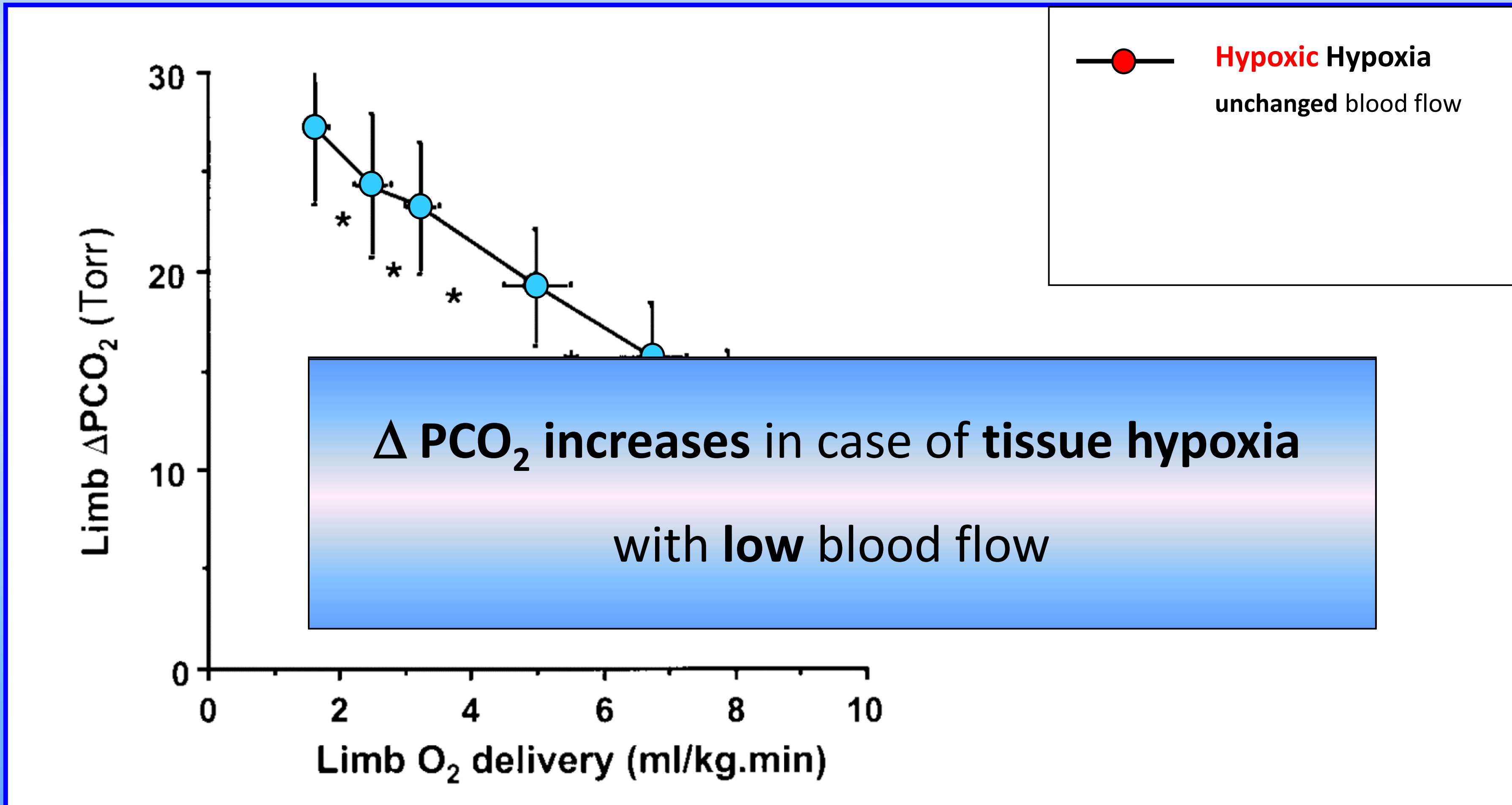


Δ PCO_2 increases in case of **tissue hypoxia**

with **low** blood flow

Veno-arterial Carbon Dioxide Gradient in Human Septic Shock*

Jan Bakker, M.D.; Jean-Louis Vincent, M.D., Ph.D, F.C.C.P.; Philippe Gris, M.D.; Marc Leon, M.D.; Michel Coffernils, M.D.; and Robert J. Kahn, M.D.

Chest 1992; 101:509-15

	Δ PCO_2	
	< 6 mmHg	> 6 mmHg
nb patients	49	15
lactate mmol/L	5.6 ± 3.9	6.2 ± 5.0
CI L/min/m²	4.3 ± 1.5	2.9 ± 1.3 *

Intensive Care Med (2008) 34:2218–2225
ORIGINAL

Fabrice Vallée
Benoit Vallet
Olivier Mathe
Jacqueline Parraguette
Arnaud Mari
Stein Silva
Kamran Samii
Olivier Fourcade
Michèle Genestal

Central venous-to-arterial carbon dioxide difference: an additional target for goal-directed therapy in septic shock?

50 pts with septic shock
all with $ScvO_2$ > 70%
following initial resuscitation

	Low gap group (n = 26)	High gap group (n = 24)	P value
Haemody			
MAP (			
Cardia			01
Heart r			
Biologi			
Lactate			
$ScvO_2$			
ERO_2			
P(cv-a			01
Hb (g/d			
SaO_2 (%)	95 ± 7	96 ± 5	0.43
PaO_2/FiO_2 (mmHg)	174 ± 58	202 ± 60	0.12
$PaCO_2$ (mmHg)	38 ± 9	36 ± 6	0.37
Arterial (pH)	7.29 ± 0.07	7.28 ± 0.1	0.41

A **high** value of **$P(cv\text{-}a)CO_2$**
could **encourage** to **increase CO**,
even if **$ScvO_2$ > 70%**

Take-home messages

Regardless of the presence of **tissue hypoxia**

- **normal ΔPCO_2 (≤ 6 mmHg) expected if normal or high CO**
- **high ΔPCO_2 (> 6 mmHg) expected if low CO**

- A **normal ΔPCO_2** suggests that **elevation** of **CO** **cannot** be a priority in the therapeutic strategy
- A **high ΔPCO_2** suggests that **elevation** of **CO** **may** be a **good** therapeutic option

Δ PCO_2: clinical use

- Δ PCO_2: marker of tissue hypoxia ?
- **Combined analysis of Δ PCO_2 and $C_{a\text{-}v}\ O_2$**

Intensive Care Med (2002) 28:272–277

ORIGINAL

Armand Mekontso-Dessap
Vincent Castelain
Nadia Anguel
Mabrouk Bahloul
Franck Schauvliege
Christian Richard
Jean-Louis Teboul

Combination of venoarterial PCO_2 difference with arteriovenous O_2 content difference to detect anaerobic metabolism in patients

a Δ **PCO_2 relatively greater than $C_{a\text{-}v}O_2$**

can suggest the presence of

anaerobic CO_2 production

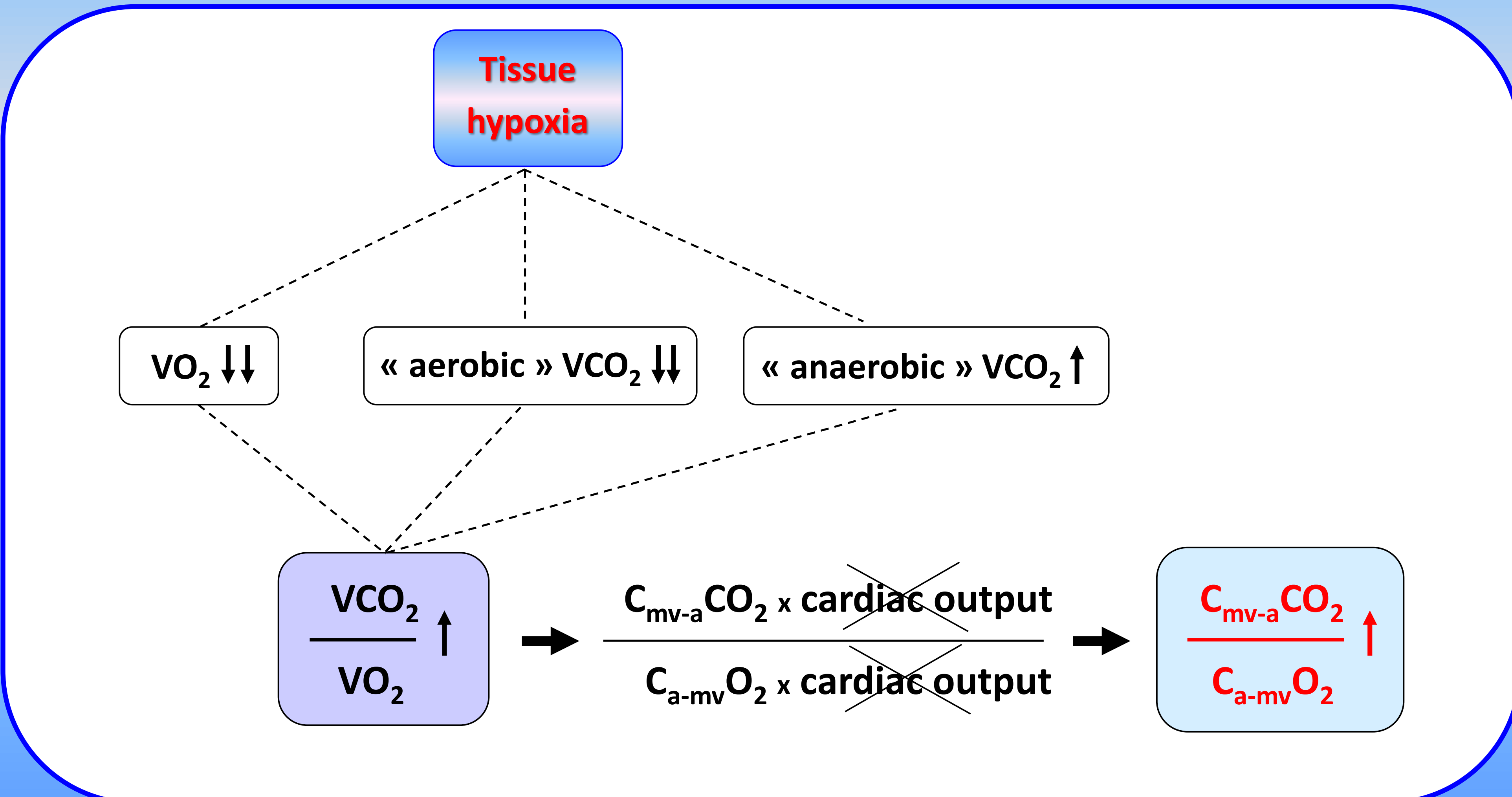
and thus can detect **tissue hypoxia**

Intensive Care Med (2015) 41:936–938

EDITORIAL

Stephan M. Jakob
A. B. Johan Groeneveld
Jean-Louis Teboul

Venous–arterial CO_2 to arterial–venous O_2 difference ratio as a resuscitation target in shock states?



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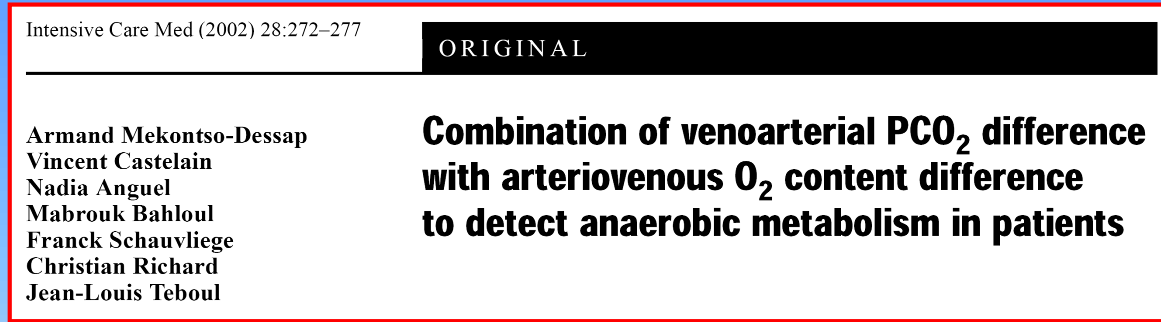
Combination of venoarterial PCO_2 difference with arteriovenous O_2 content difference to detect anaerobic metabolism in patients

	Lac < 2 mmol/L n=66	Lac ≥ 2 mmol/L n=68	p
SvO_2	69 ± 9	67 ± 15	0.47
$C_{a-v}O_2$	3.6 ± 1.0	3.3 ± 1.5	0.15
ΔPCO_2	4 ± 2	6 ± 2	<0.001
$\Delta PCO_2 / C_{a-v}O_2$	**1.1 ± 0.6**	**2.1 ± 1.0**	<0.001



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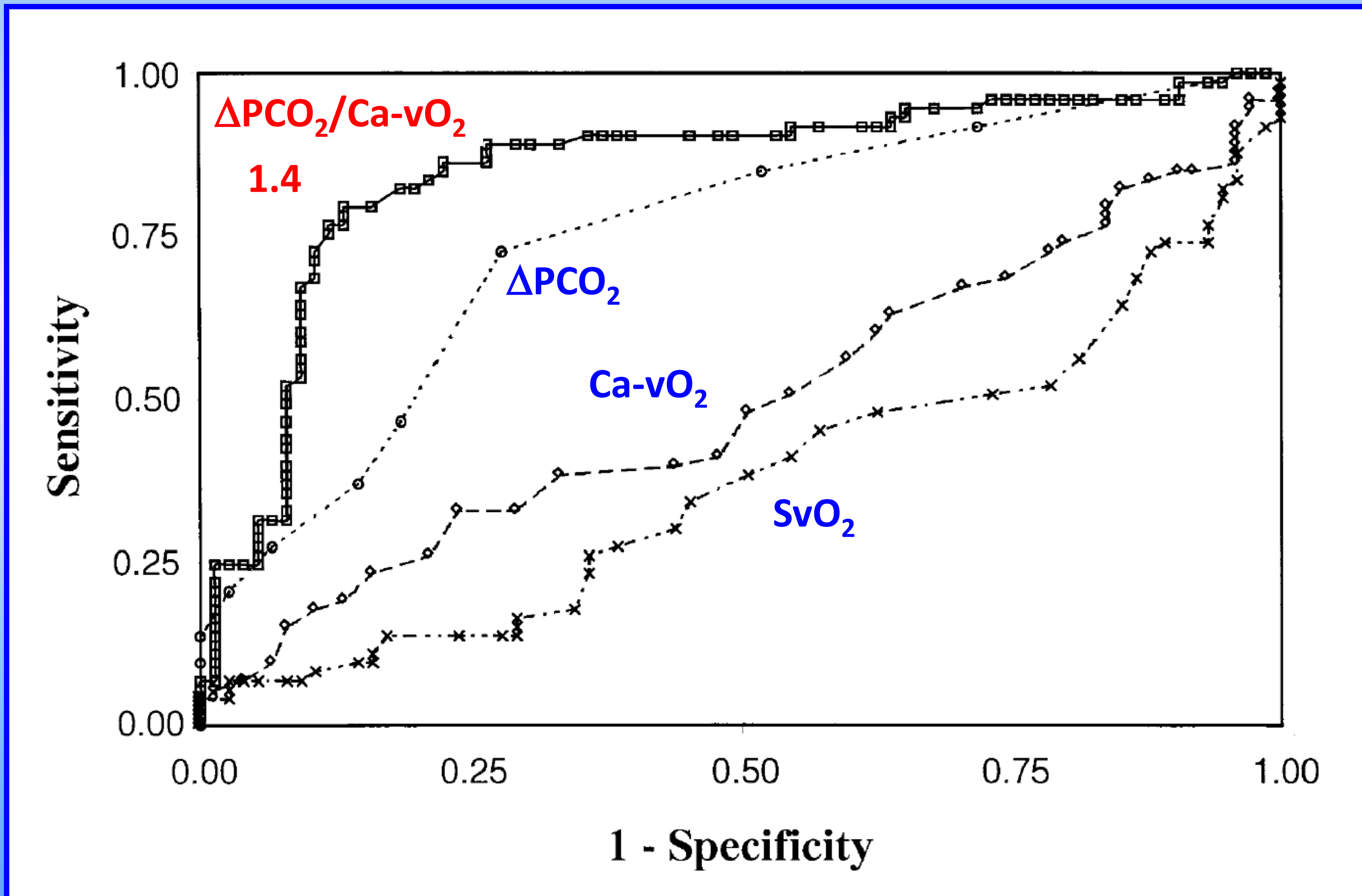

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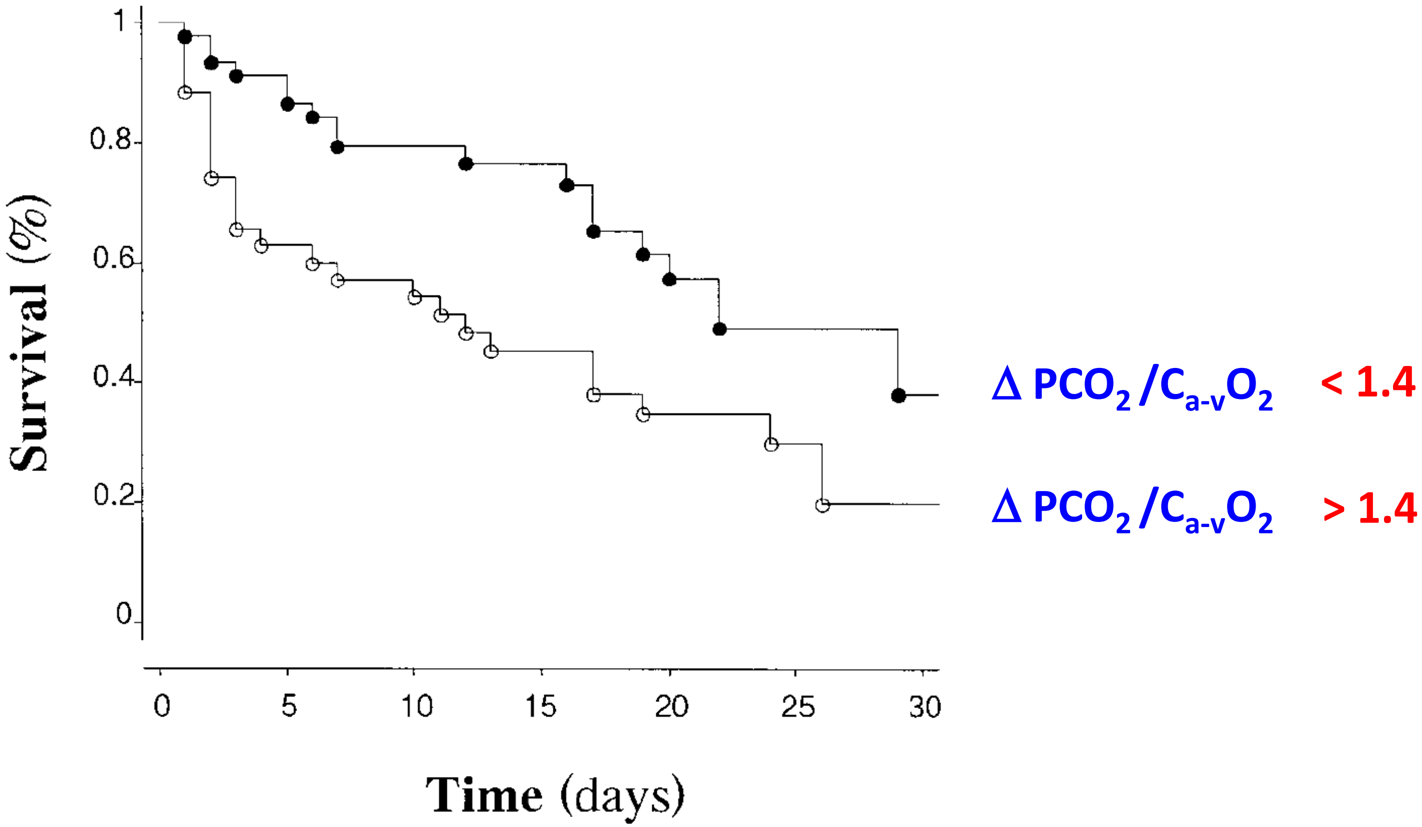
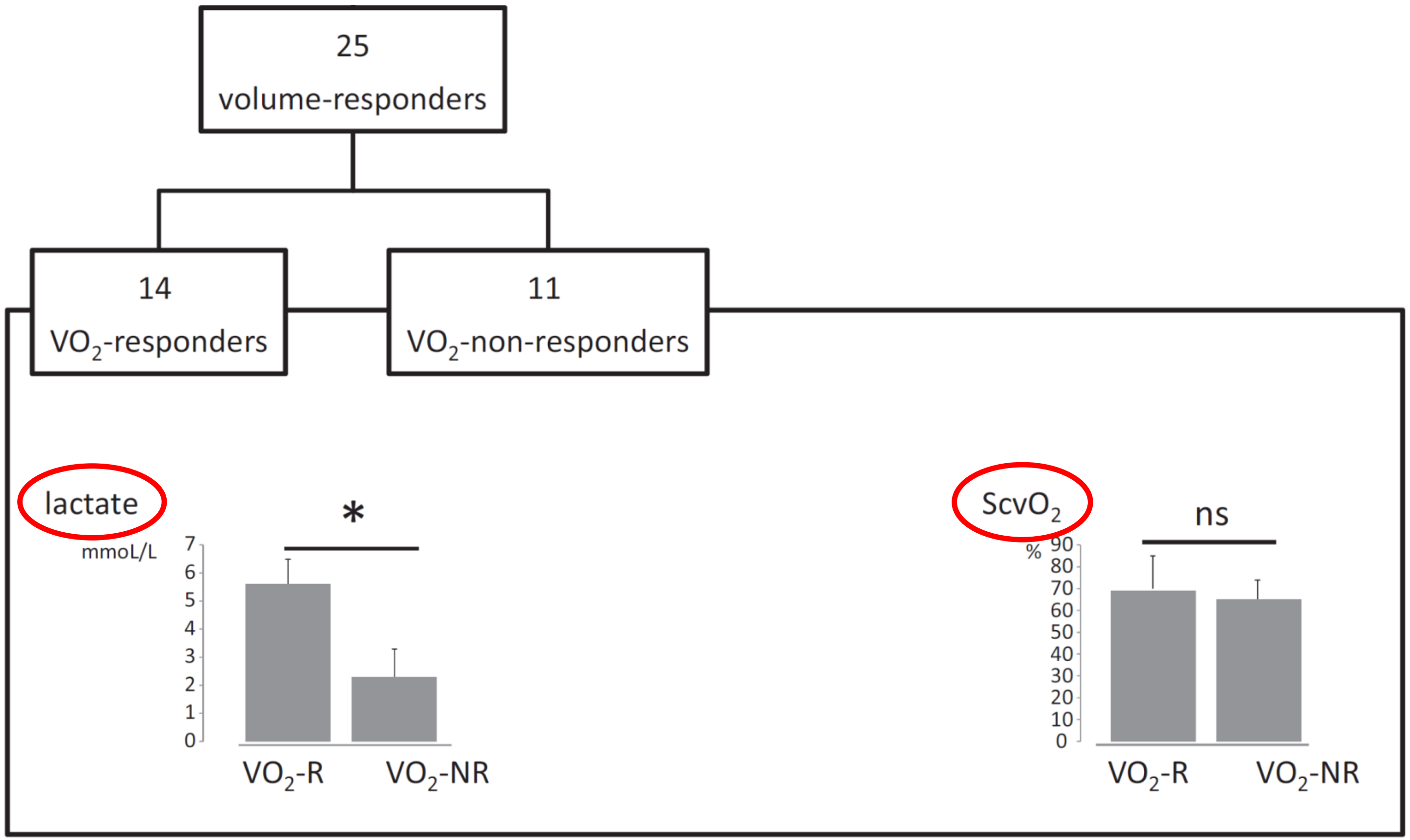


Lactate and Veno-Arterial Carbon Dioxide Difference/Arterial-Venous Oxygen Difference Ratio, but Not Central Venous Oxygen Saturation, Predict Increase in Oxygen Consumption in Fluid Responders

Xavier Monnet, MD, PhD[1,2]; Florence Julien, MD[1,2]; Nora Ait-Hamou, MD[1]; Marie Lequoy, MD[1,2]; Clément Gosset, MD[1,2]; Mathieu Jozwiak, MD[1,2]; Romain Persichini, MD[1,2]; Nadia Anguel, MD[1,2]; Christian Richard, MD[1,2]; Jean-Louis Teboul, MD, PhD[1,2]

Crit Care Med 2013; 41:1412–1420



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Crit Care Med 2013; 41:1412–1420

lactate

Δ PCO$_2$ / C$_{a\text{-}v}$O$_2$

predicts **better** than **ScvO$_2$**

the **benefits** for the **tissues**

of **fluid** administration

100-Specificity

Intensive Care Med (2015) 41:796–805

ORIGINAL

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Combination of arterial lactate levels and venous-arterial CO_2 to arterial-venous O_2 content difference ratio as markers of resuscitation in patients with septic shock

Table 3 Multivariate logistic regression for predictors of mortality at day 28

	T0			T6			T6 (for $SvO_2 \geq 65$ %)[a]		
	RR	95 % CI	*p*	RR	95 % CI	*p*	RR	95 % CI	*p*
$Cv\text{-}aCO_2/Da\text{-}vO_2$	3.85	1.60–9.27	0.003	3.97	1.54–10.24	0.004	5.71	1.20–27.19	0.03
Lactate, mmol/L	1.19	0.98–1.44	0.09	1.58	1.13–2.22	0.008	2.41	1.22–4.76	0.01
VO_2, mL/min/m^2	1.00	0.98–1.01	0.59	0.99	0.98–1.00	0.24	1.01	0.99–1.02	0.30
DO_2, mL/min/m^2	1.00	0.99–1.00	0.69	1.00	0.99–1.01	0.43	1.00	0.99–1.01	0.67
SvO_2, %	0.97	0.90–1.04	0.35	0.93	0.86–1.01	0.06			
CI, L/min/m^2	0.82	0.44–1.53	0.54	0.94	0.39–2.26	0.89	1.28	0.33–4.96	0.72
APACHE II	1.08	0.98–1.19	0.09	1.03	0.94–1.14	0.54	0.94	0.80–1.10	0.45
Age, years	1.03	0.99–1.06	0.14	1.02	0.98–1.06	0.38	1.10	0.99–1.21	0.06
Time before T0, h	0.62	0.36–1.04	0.07	0.72	0.41–1.27	0.26	0.63	0.29–1.40	0.25
Gender	0.45	0.16–1.27	0.13	0.77	0.24–2.45	0.66	0.15	0.03–0.99	0.05
Fluids, mL	1.00	0.99–1.01	0.84	1.00	1.00–1.01	0.93	1.00	0.99–1.00	0.81
Norepinephrine, µg/kg/min	1.78	0.23–13.94	0.58	0.41	0.06–2.89	0.37	0.25	0.01–7.56	0.42
MAP, mmHg	0.96	0.92–1.01	0.09	0.98	0.92–1.05	0.58	0.98	0.89–1.09	0.71

Intensive Care Med (2015) 41:796–805

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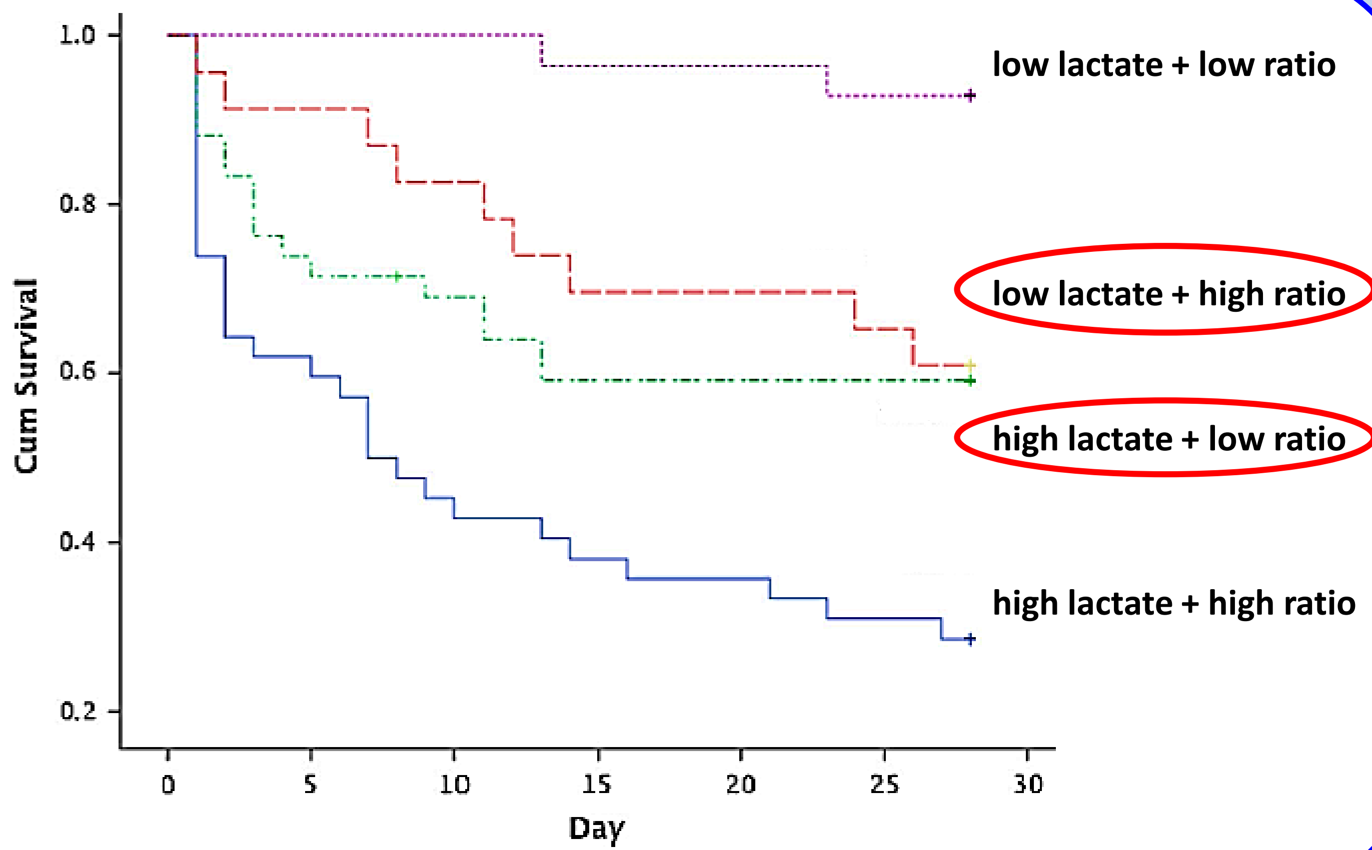
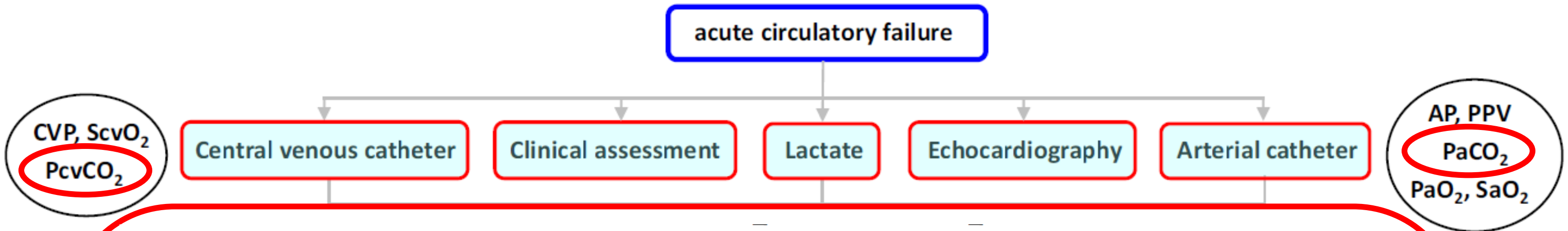


Intensive Care Med (2016) 42:1350–1359

CONFERENCE REPORTS AND EXPERT PANEL

Less invasive hemodynamic monitoring in critically ill patients

Jean-Louis Teboul[1*], Bernd Saugel[2], Maurizio Cecconi[3], Daniel De Backer[4], Christoph K. Hofer[5], Xavier Monnet[1], Azriel Perel[6], Michael R. Pinsky[7], Daniel A. Reuter[2], Andrew Rhodes[3], Pierre Squara[8], Jean-Louis Vincent[9] and Thomas W. Scheeren[10]



coupling arterial and central venous blood sampling allows calculation of the venous-to-arterial carbon dioxide pressure difference (PCO_2 gap), which could be a good indicator of the adequacy of CO relative to the actual global metabolic conditions and could be helpful in conditions where oxygen extraction is altered while $ScvO_2$ is within the normal range. In this particular case, an abnormally high PCO_2 gap (>6 mmHg) could suggest that CO should be elevated to improve tissue oxygenation.

Conclusion -1-

If shock (hyperlactatemia, etc…) persists while $ScvO_2$ > 70%

Consider ΔPCO_2

ΔPCO_2 > 6 mmHg

Consider further increase in CO

ΔPCO_2 < 6 mmHg

No benefits expected from CO increase

Just pray and **hope** some **benefits** from **treatment** of **infection**

Conclusion -2-

ΔPCO_2 / $C_{a-v}O_2$

- Can help to detect **anaerobiosis**
- When **combined** with **lactate**, can help to better define the patient's **prognosis**

Thank you