Savoir analyser et utiliser l'interaction cœur-poumon

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Medical ICU

Bicetre hospital

University Paris South

France

Hôpitaux universitaires Paris-Sud
Antoine-Béclère Bicêtre Paul-Brousse
ASSISTANCE PUBLIQUE HÔPITAUX DE PARIS

FACULTE DE MEDECINE PARIS-SUD

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

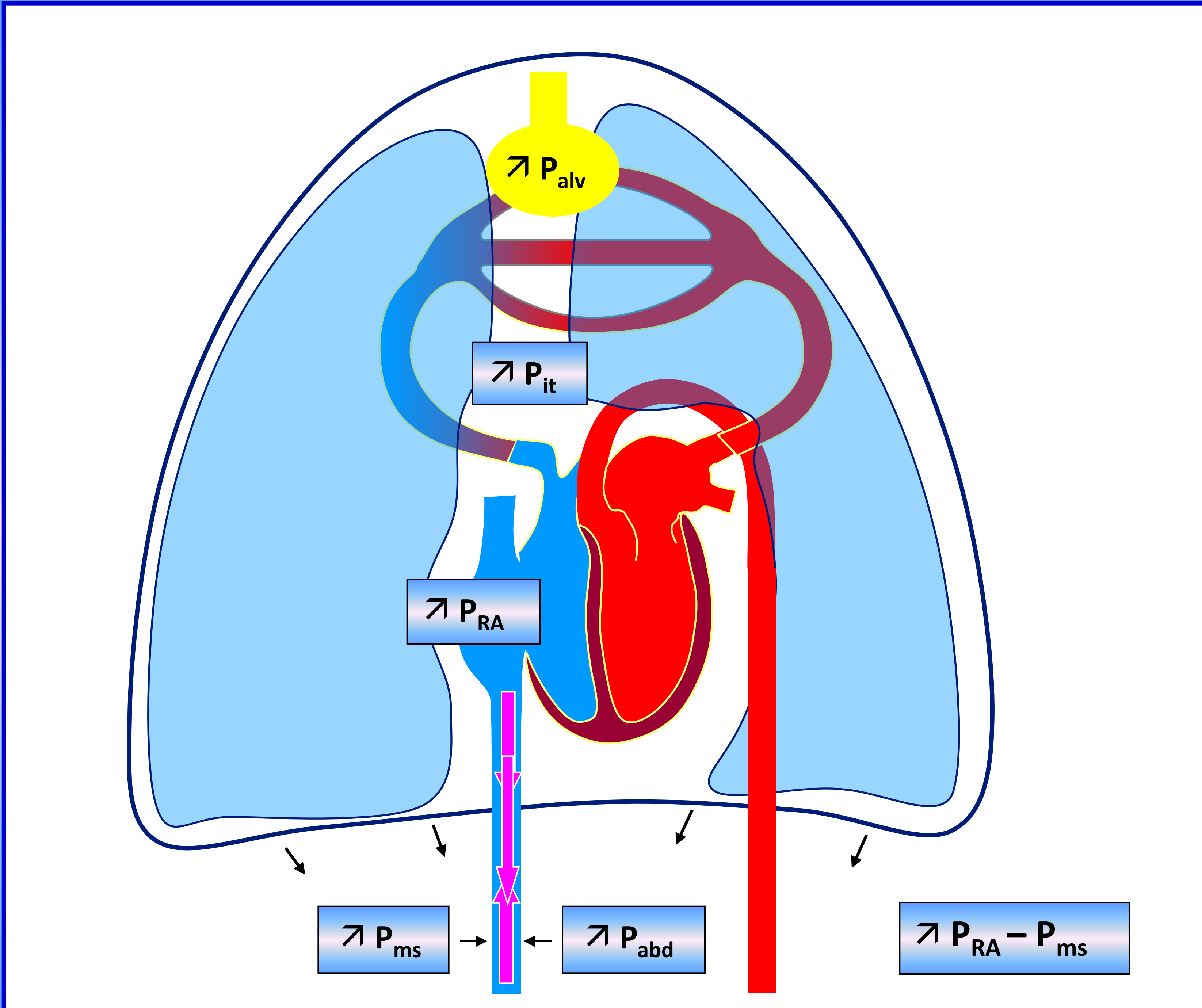
Hemodynamic effects

of **Mechanical Insufflation**

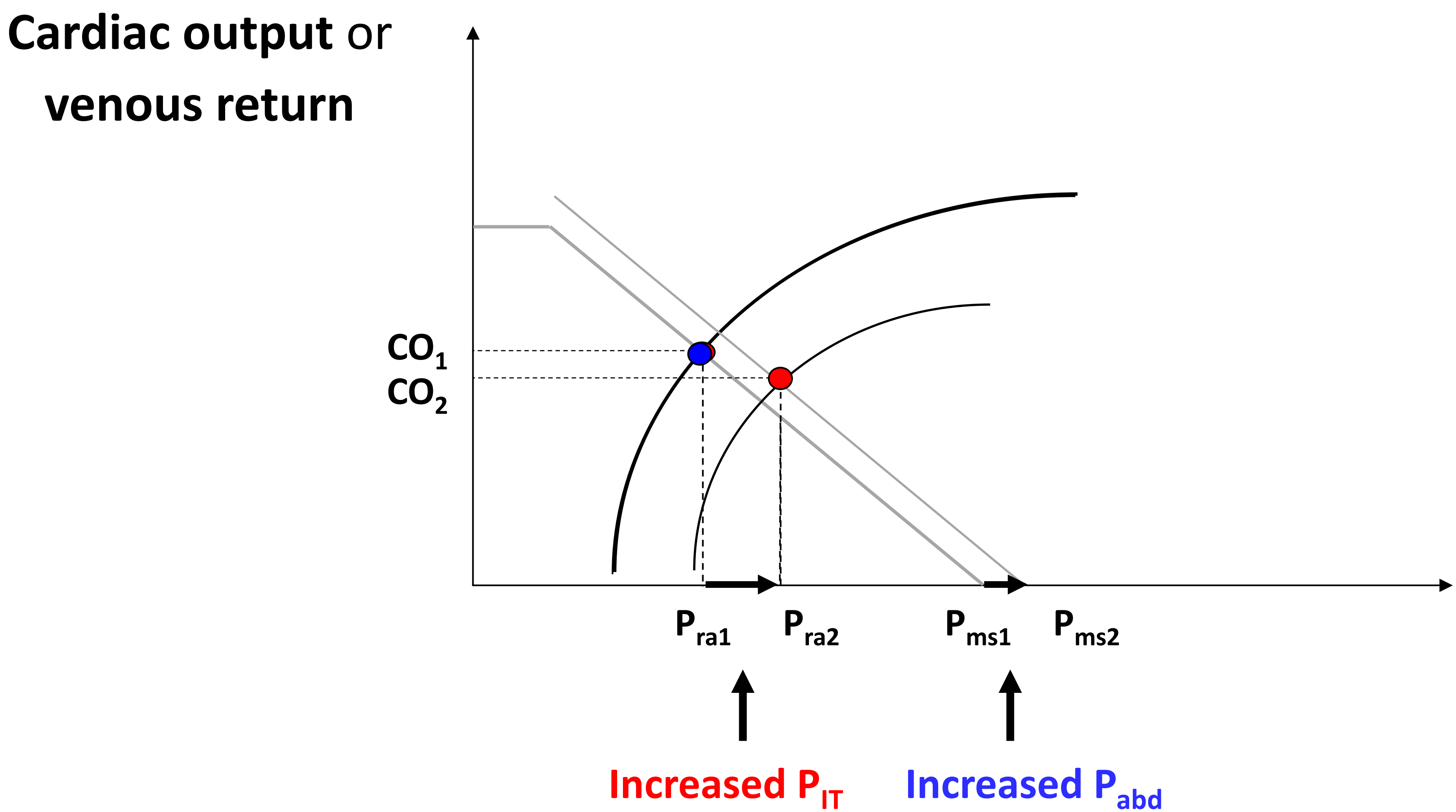
Use of heart-lung interaction

to assess fluid responsiveness

Mechanical insufflation and venous return


↗ P_{alv}
↗ P_{it}
↗ P_{RA}
↗ P_{ms}
↗ P_{abd}
↗ $P_{RA} - P_{ms}$

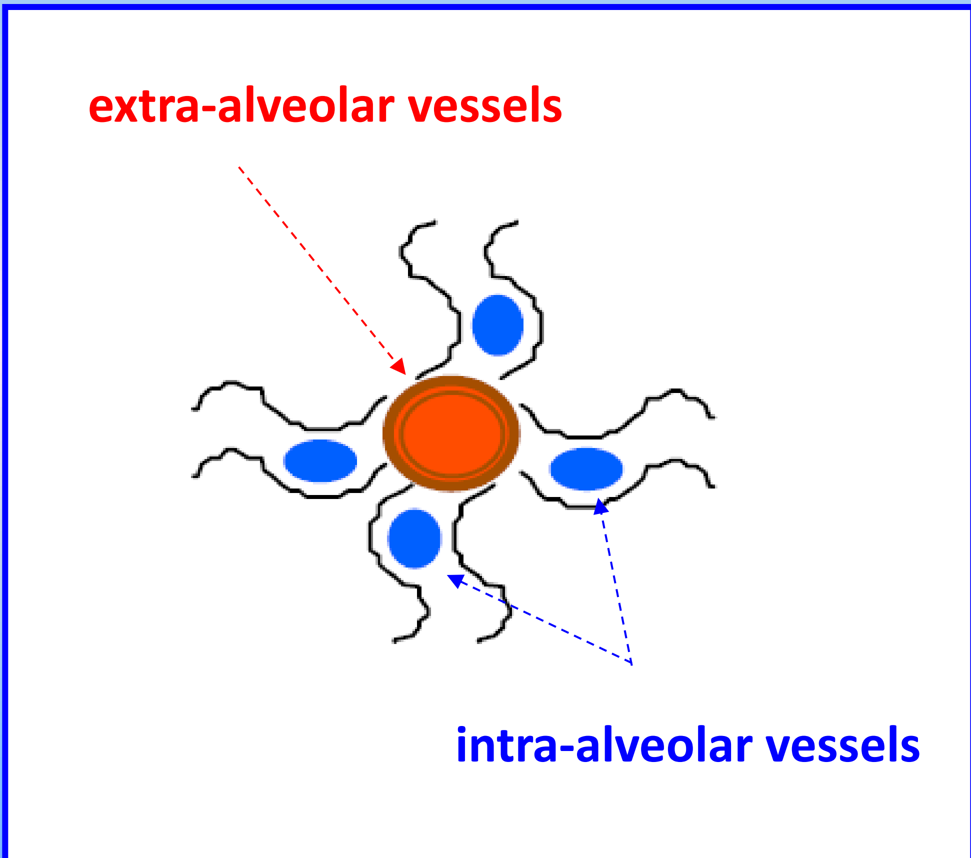
Effects of cyclic increase in intrathoracic pressure

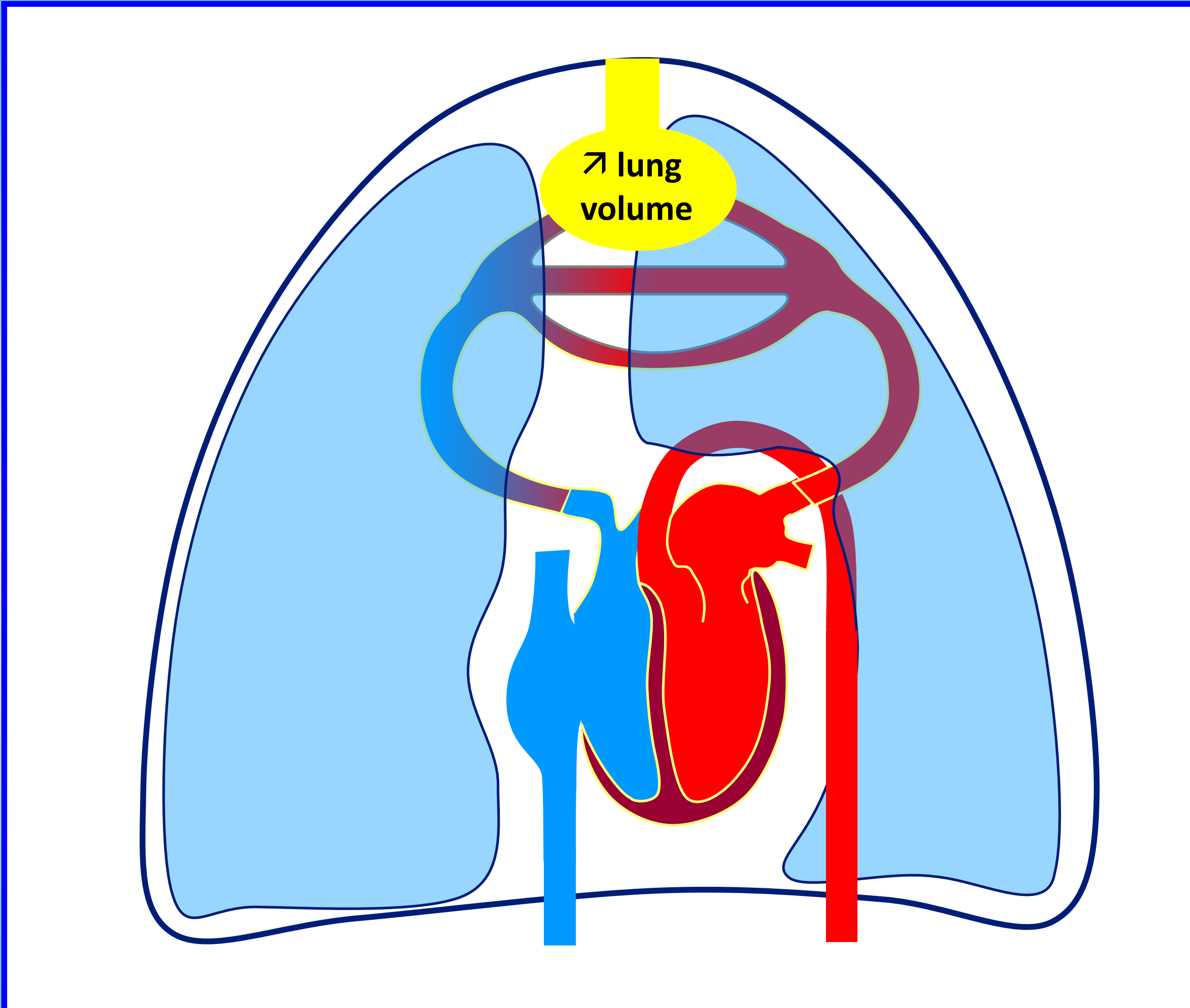


Mechanical insufflation and venous return

Mechanical insufflation and RV ejection

- Physiological aspects
  - **Pulmonary vascular resistance** and **lung volume**
- Clinical applications


extra-alveolar vessels
intra-alveolar vessels

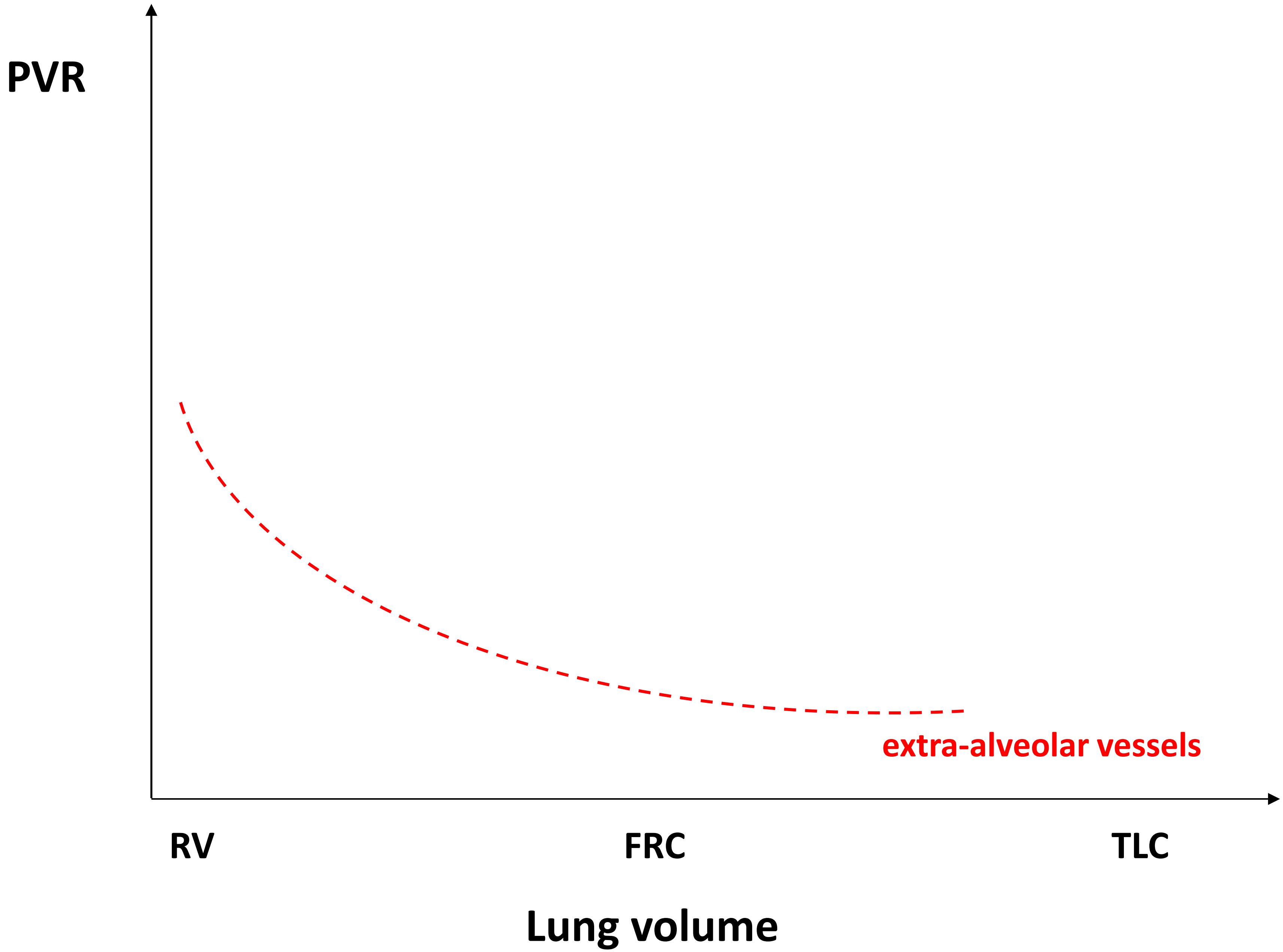


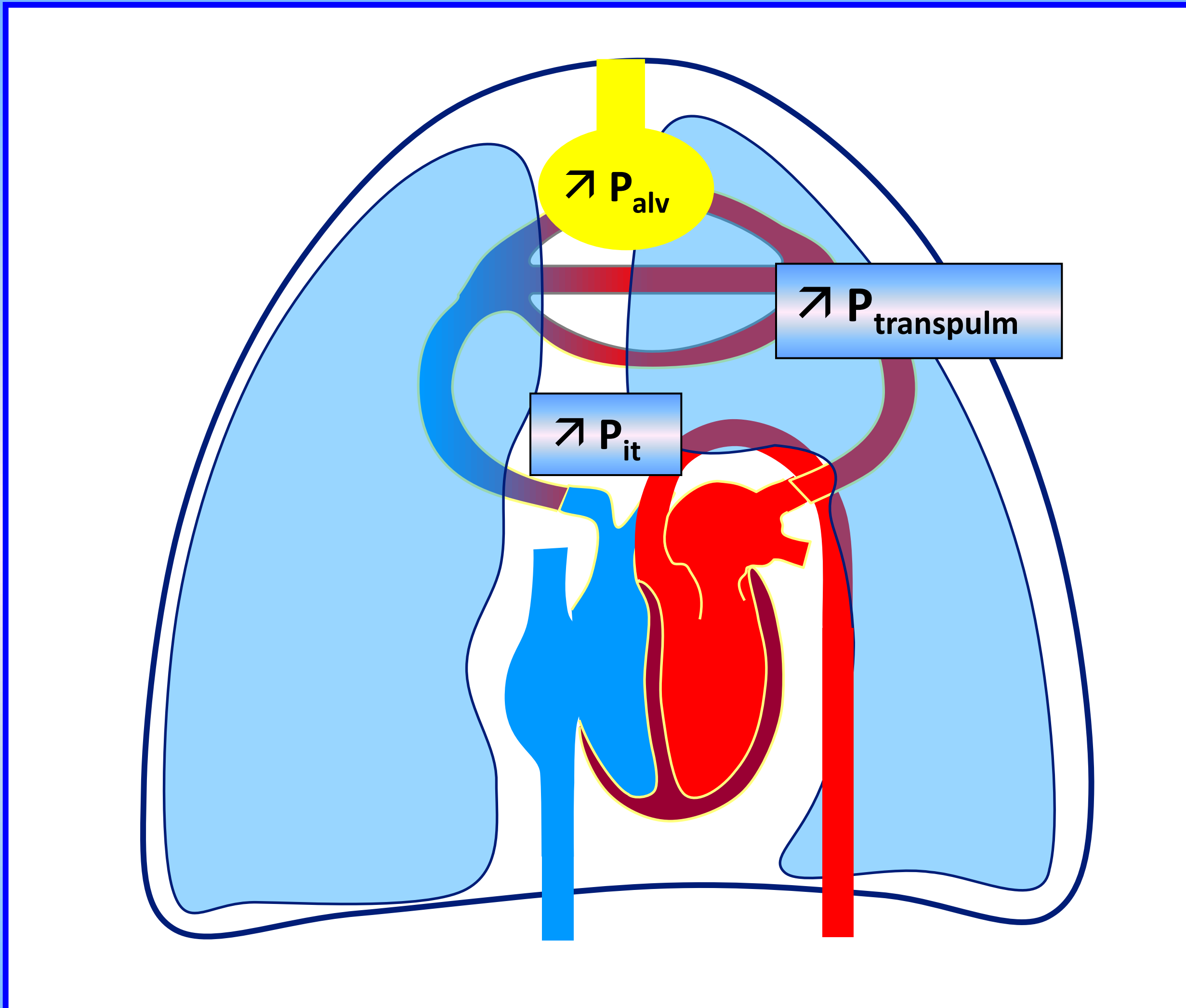
↗ **Lung volume**

improves the RV ejection

by **decreasing resistance**

of **extra-alveolar vessels**


PVR
extra-alveolar vessels
RV
FRC
TLC
Lung volume



↗ **Lung volume**

improves the RV ejection

by **decreasing resistance**

of **extra-alveolar vessels**

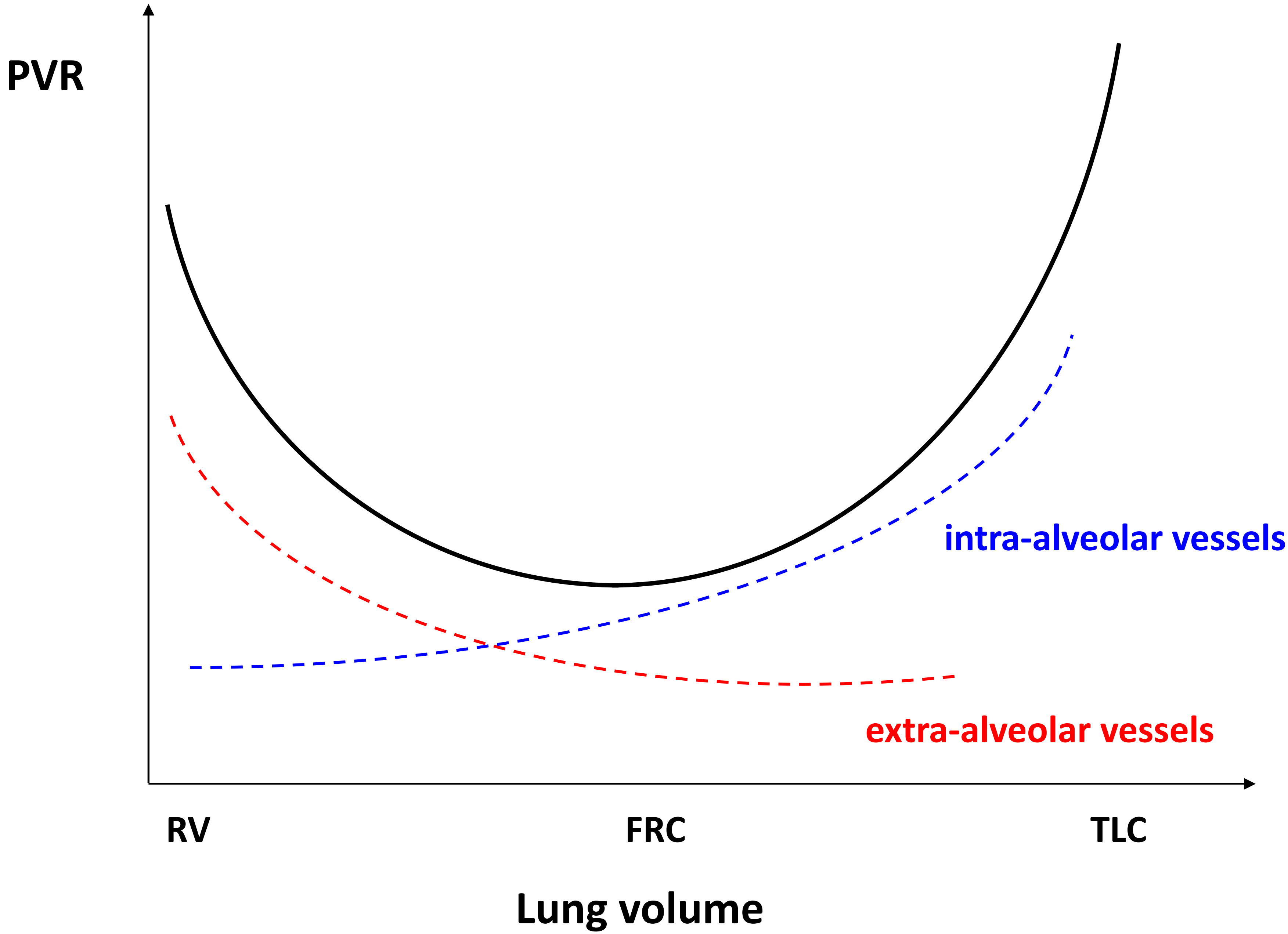
↗ Transpulmonary pressure

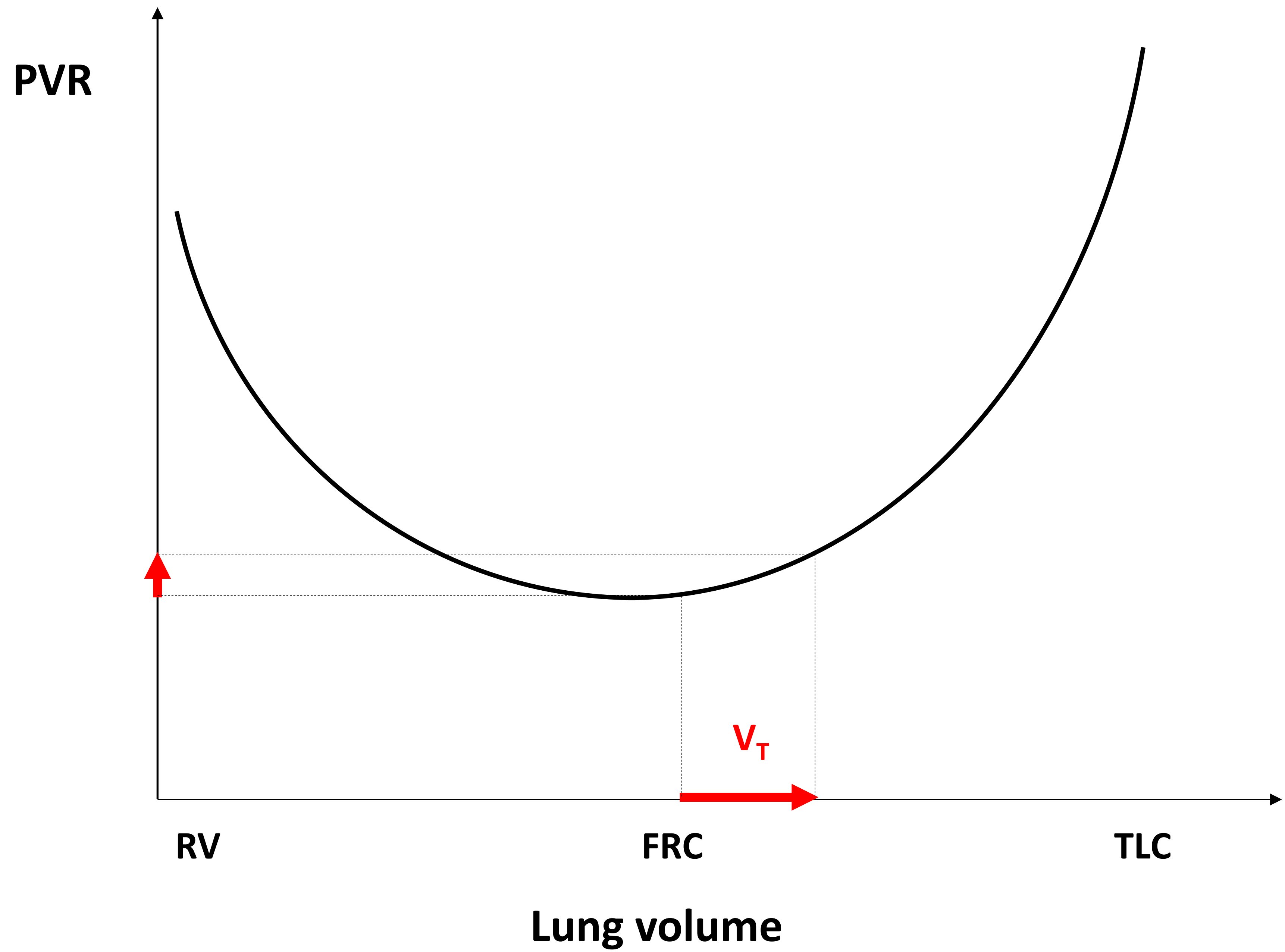
$$= P_{alv} - P_{it}$$

impedes the RV ejection

by **compressing** the

intra-alveolar vessels


PVR
intra-alveolar vessels
extra-alveolar vessels
RV
FRC
TLC
Lung volume

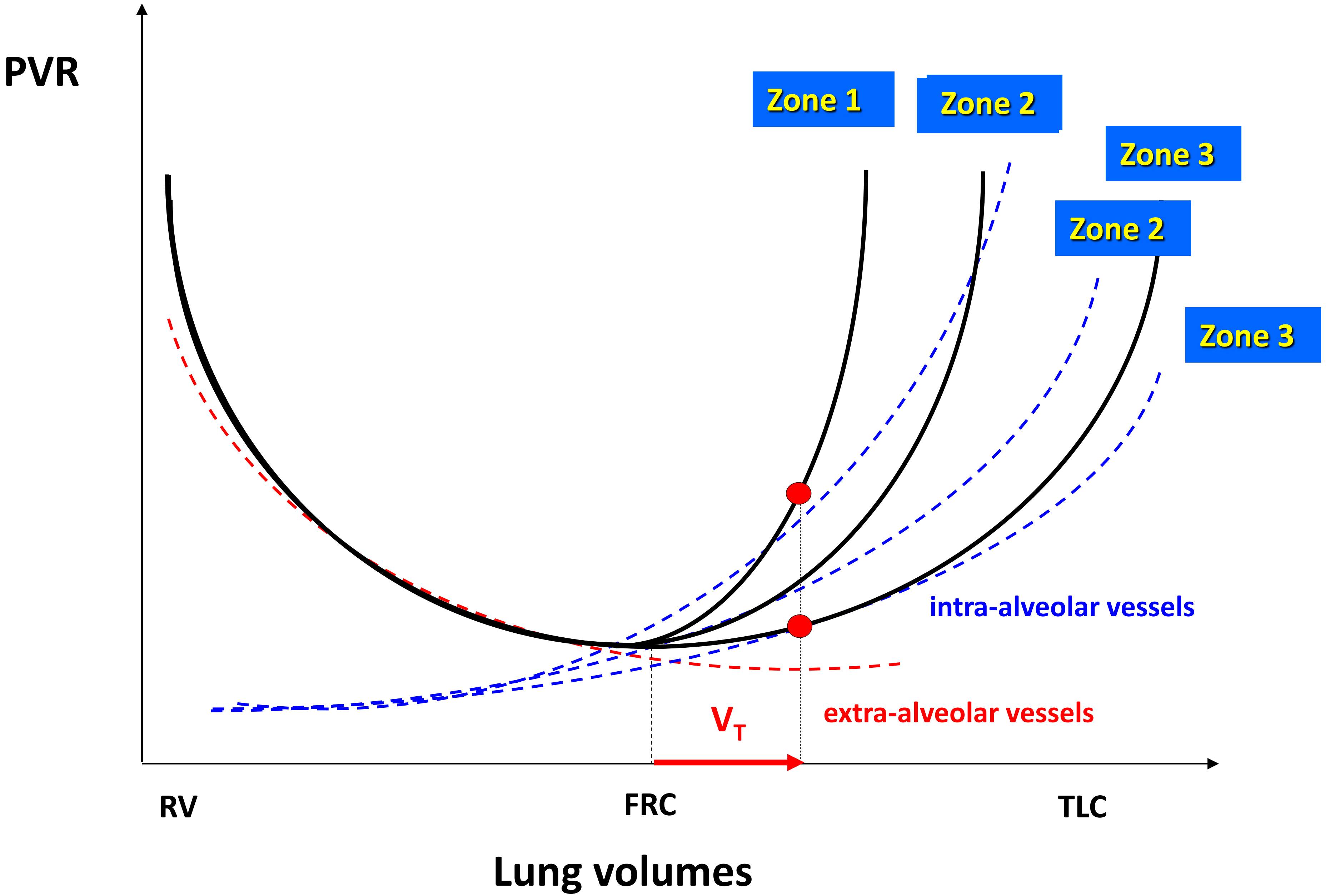

PVR
V
T
RV
FRC
TLC
Lung volume

Mechanical insufflation and venous return

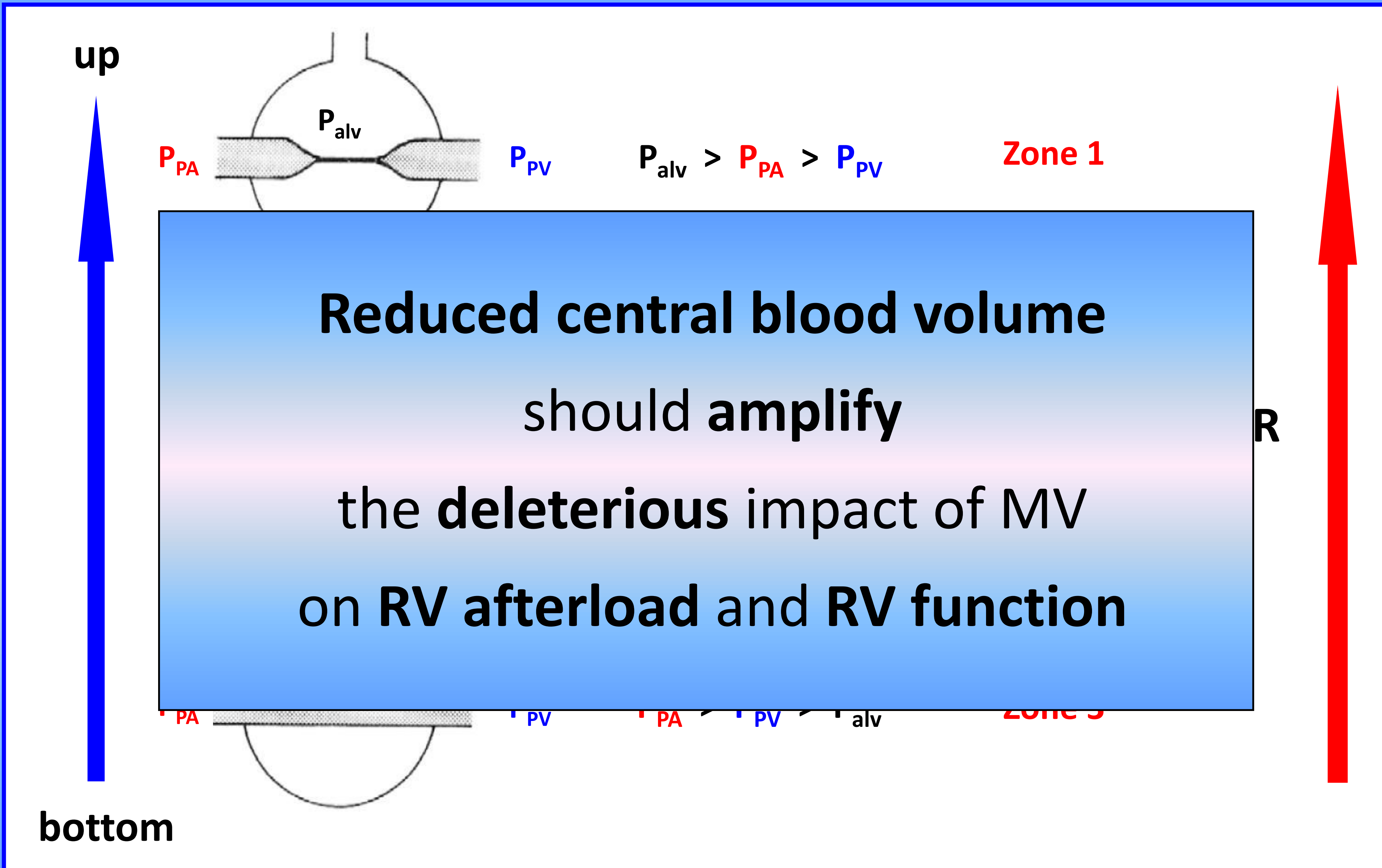
Mechanical insufflation and RV ejection

- **Physiological aspects**
  - **Pulmonary vascular resistance** and **lung volume**
  - **Pulmonary vascular resistance** and **West's zones**


up
PVR
bottom


PVR
Zone 1
Zone 2
Zone 3
Zone 2
Zone 3
intra-alveolar vessels
extra-alveolar vessels
V_T
RV
FRC
TLC
Lung volumes

Hypovolemia favors zones 1 and 2 by reducing intravascular pressures



Reduced central blood volume

should **amplify**

the **deleterious** impact of MV

on **RV afterload** and **RV function**

Mechanical insufflation and venous return

Mechanical insufflation and RV ejection

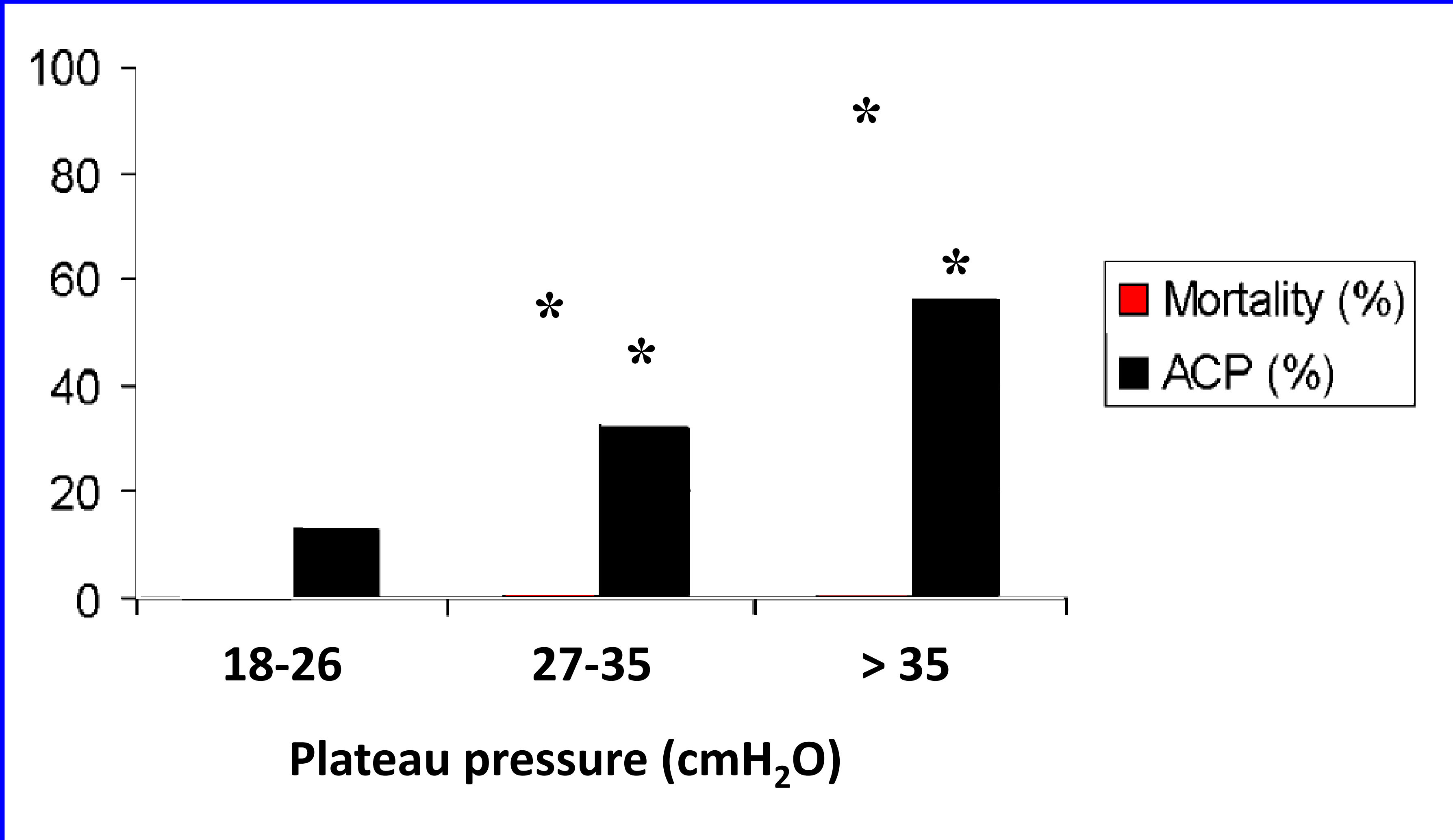
- Physiological aspects
- **Clinical applications**
  - **Transpulmonary pressure and ACP**

Intensive Care Med (2007) 33:444–447

ORIGINAL

François Jardin
Antoine Vieillard-Baron

Is there a safe plateau pressure in ARDS? The right heart only knows



Acute cor pulmonale in acute respiratory distress syndrome submitted to protective ventilation: Incidence, clinical implications, and prognosis

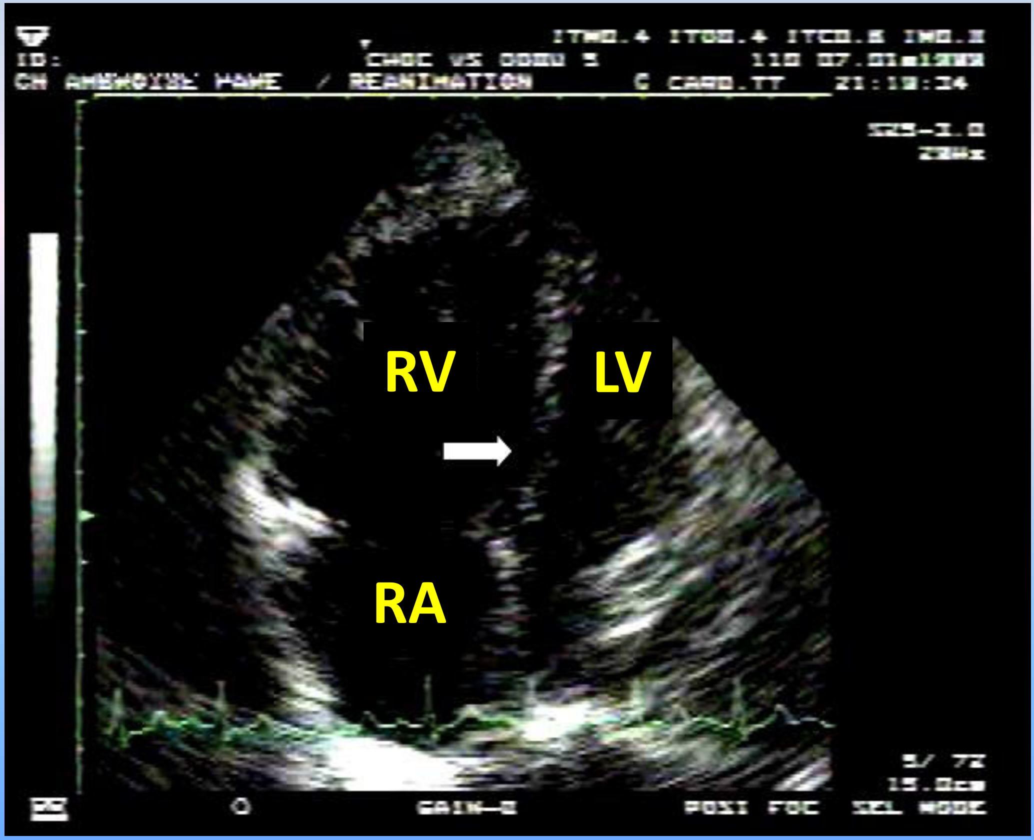
Antoine Vieillard-Baron, MD; Jean-Marie Schmitt, MD; Roch Augarde, MD; J. L. Fellahi, MD; Sebastien Prin, MD
Bernard Page, MD; Alain Beauchet, MD; François Jardin, MD

Crit Care Med 2001, 29:1551-1555

ARDS with **protective ventilation**
(Pplat < 30 cm H_2O)

ACP defined
as **RVEDA/LVEDA > 0.6**
and septal dyskinesia

Incidence of ACP: 25%



Intensive Care Med (2009) 35:69–76

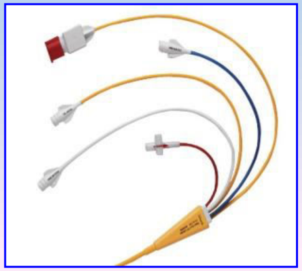
ORIGINAL

David Osman
Xavier Monnet
Vincent Castelain
Nadia Anguel
Josiane Warszawski
Jean-Louis Teboul
Christian Richard

Incidence and prognostic value of right ventricular failure in acute respiratory distress syndrome

145 ARDS pts with PAC

with **lung protective ventilation**



Definition of acute cor pulmonale

- **mean PAP > 25 mmHg**
- **RAP > PAOP**
- **Stroke Index < 30 mL/m^2**

Intensive Care Med (2009) 35:69–76

ORIGINAL

David Osman
Xavier Monnet
Vincent Castelain
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Incidence and prognostic value of right ventricular failure in acute respiratory distress syndrome

145 ARDS patients

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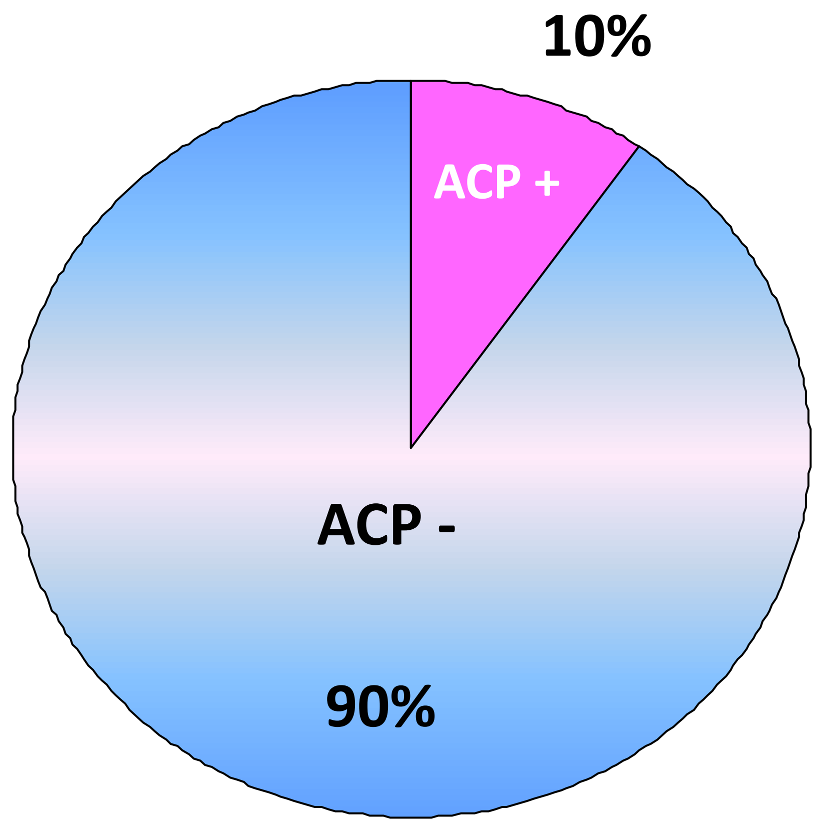


Reduction of transpulmonary pressure

using ventilatory strategies

aimed at limiting plateau pressure,

is associated with

high reduction of incidence and severity

of acute cor pulmonale during ARDS

Surviving Sepsis Campaign: International Guidelines for Management of Severe Sepsis and Septic Shock: 2012

R. Phillip Dellinger, MD[1]; Mitchell M. Levy, MD[2]; Andrew Rhodes, MB BS[3]; Djillali Annane, MD[4]; Herwig Gerlach, MD, PhD[5]; Steven M. Opal, MD[6]; Jonathan E. Sevransky, MD[7]; Charles L. Sprung, MD[8]; Ivor S. Douglas, MD[9]; Roman Jaeschke, MD[10]; Tiffany M. Osborn, MD, MPH[11]; Mark E. Nunnally, MD[12]; Sean R. Townsend, MD[13]; Konrad Reinhart, MD[14]; Ruth M. Kleinpell, PhD, RN-CS[15]; Derek C. Angus, MD, MPH[16]; Clifford S. Deutschman, MD, MS[17]; Flavia R. Machado, MD, PhD[18]; Gordon D. Rubenfeld, MD[19]; Steven A. Webb, MB BS, PhD[20]; Richard J. Beale, MB BS[21]; Jean-Louis Vincent, MD, PhD[22]; Rui Moreno, MD, PhD[23]; and the Surviving Sepsis Campaign Guidelines Committee including the Pediatric Subgroup*

O. Mechanical Ventilation of Sepsis-Induced Acute Respiratory Distress Syndrome (ARDS)

1. Target a tidal volume of 6 mL/kg predicted body weight in patients with sepsis-induced ARDS (grade 1A vs. 12 mL/kg).
2. Plateau pressures be measured in patients with ARDS and initial upper limit goal for plateau pressures in a passively inflated lung be ≤30 cm H_2O (grade 1B).

Mechanical insufflation and venous return

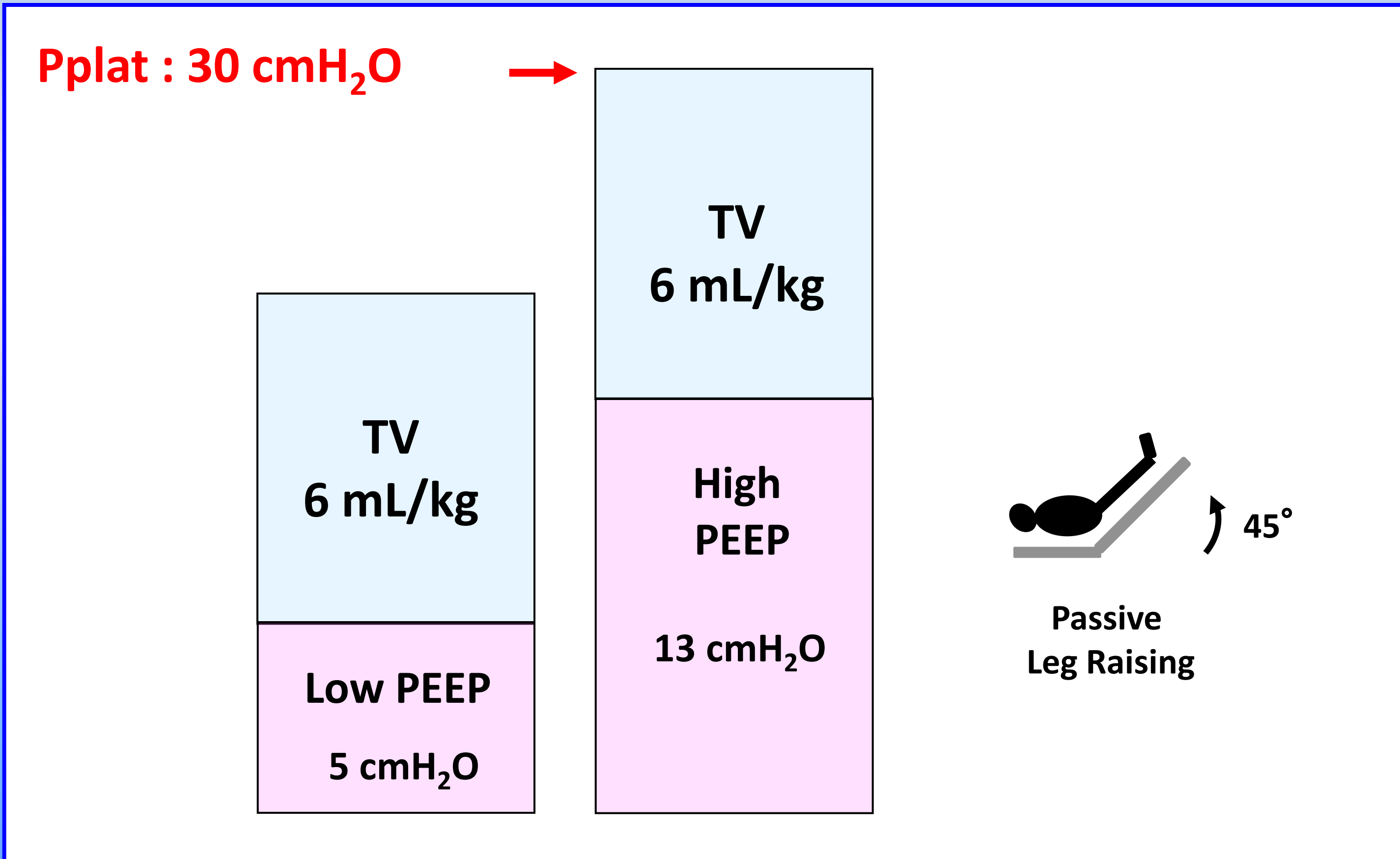
Mechanical insufflation and RV ejection

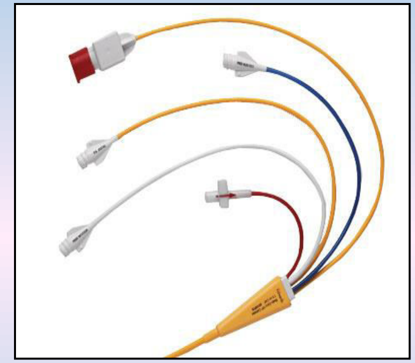
- Physiological aspects
- **Clinical applications**
  - Transpulmonary pressure and ACP
  - **Influence of volume status**

Hemodynamic impact of a positive end-expiratory pressure setting in acute respiratory distress syndrome: Importance of the volume status*

Emilie Fougères, MD; Jean-Louis Teboul, MD, PhD; Christian Richard, MD; David Osman, MD; Denis Chemla, MD, PhD; Xavier Monnet, MD, PhD

Crit Care Med 2010; 38:802–807





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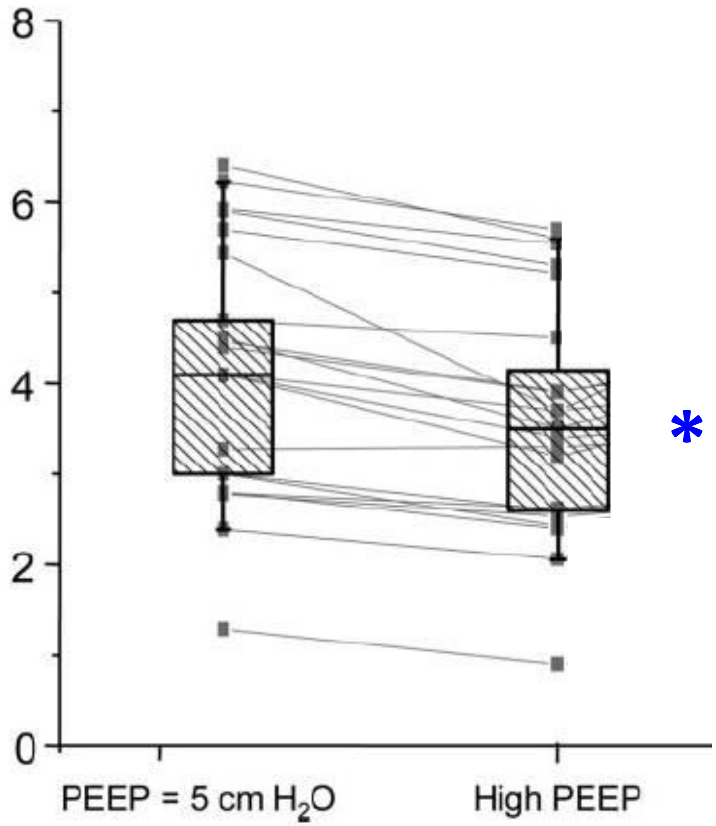
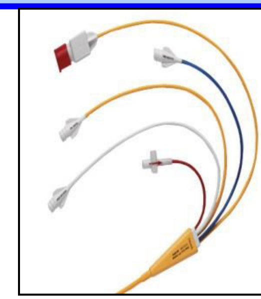
CI

L/min/m²





- **Decrease in RV preload?**
- **Increase in RV afterload?**

Hemodynamic impact of a positive end-expiratory pressure setting in acute respiratory distress syndrome: Importance of the volume status*

Emilie Fougères, MD; Jean-Louis Teboul, MD, PhD; Christian Richard, MD; David Osman, MD; Denis Chemla, MD, PhD; Xavier Monnet, MD, PhD

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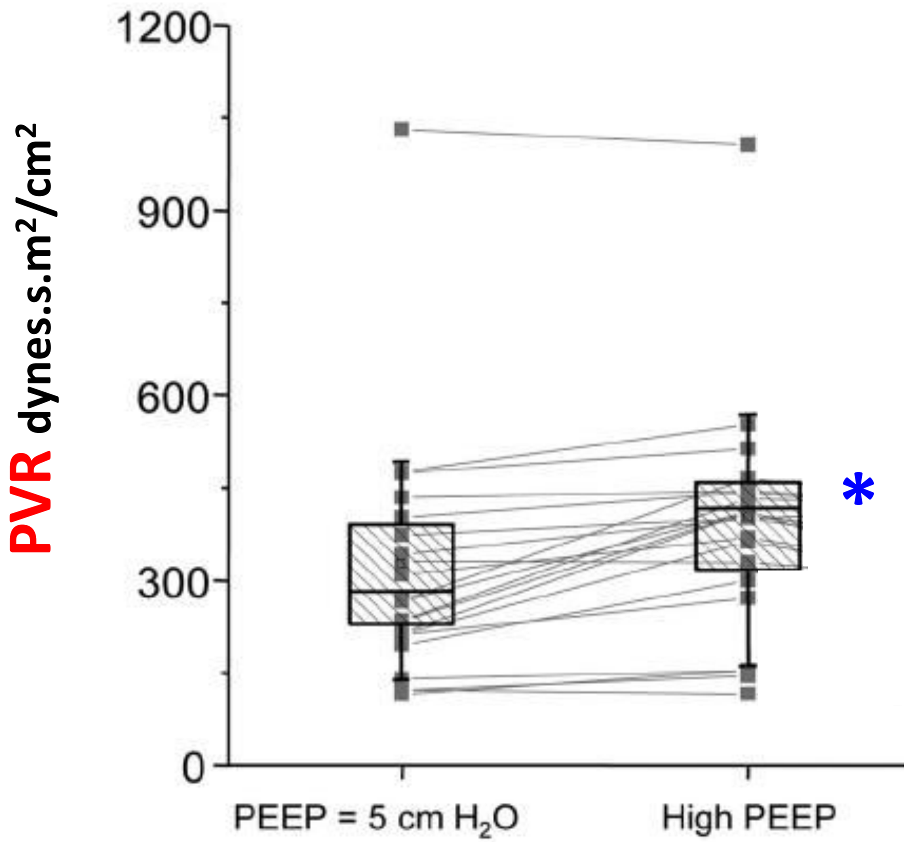

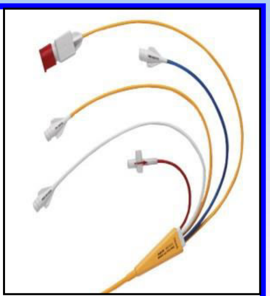

- Decrease in RV preload
- Increase in RV afterload

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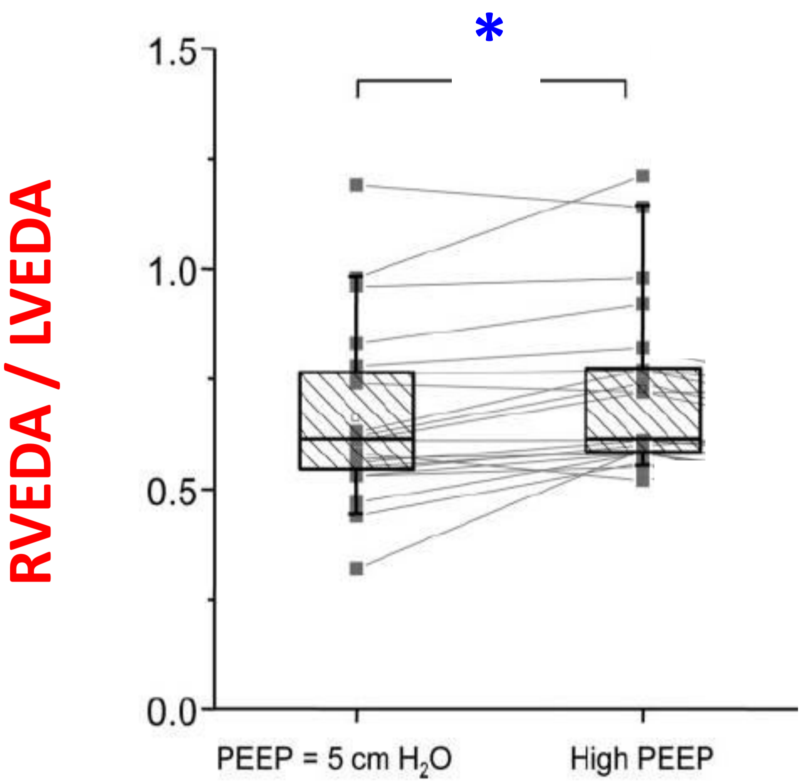

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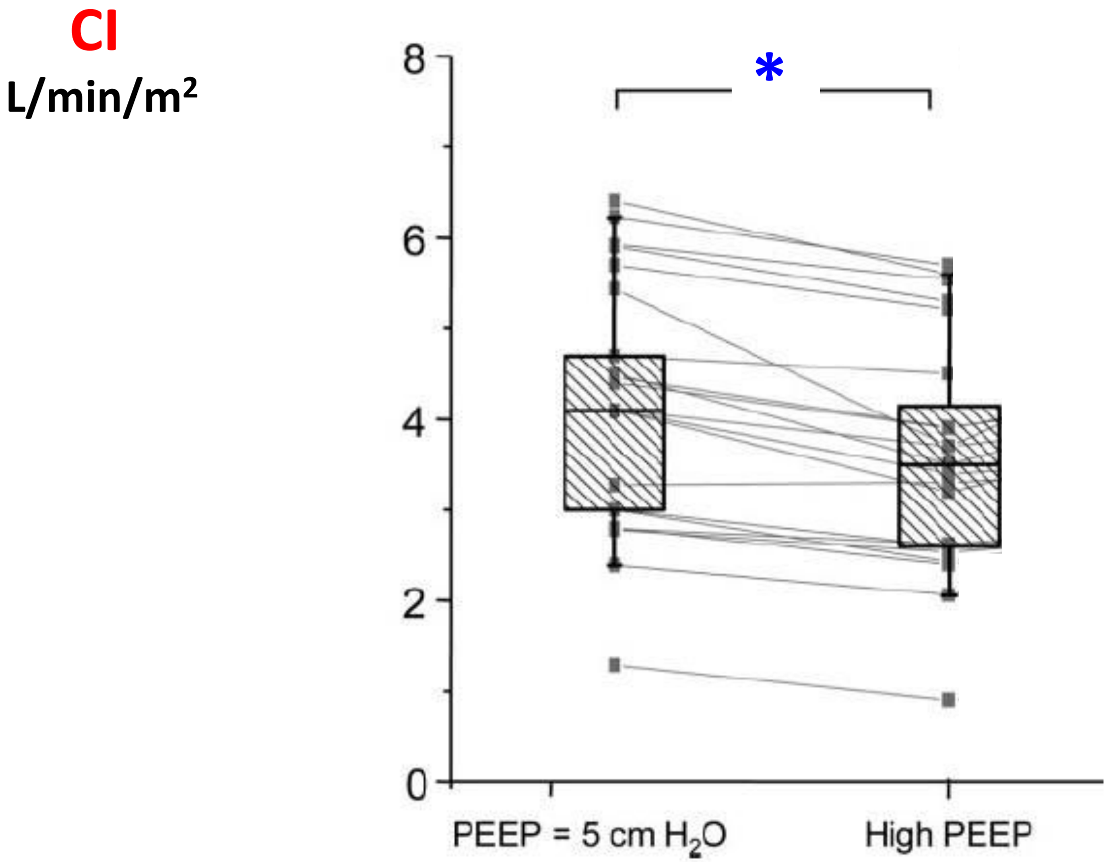

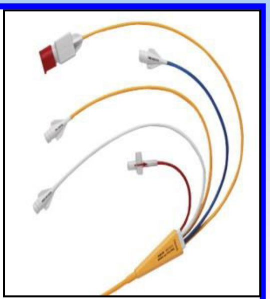

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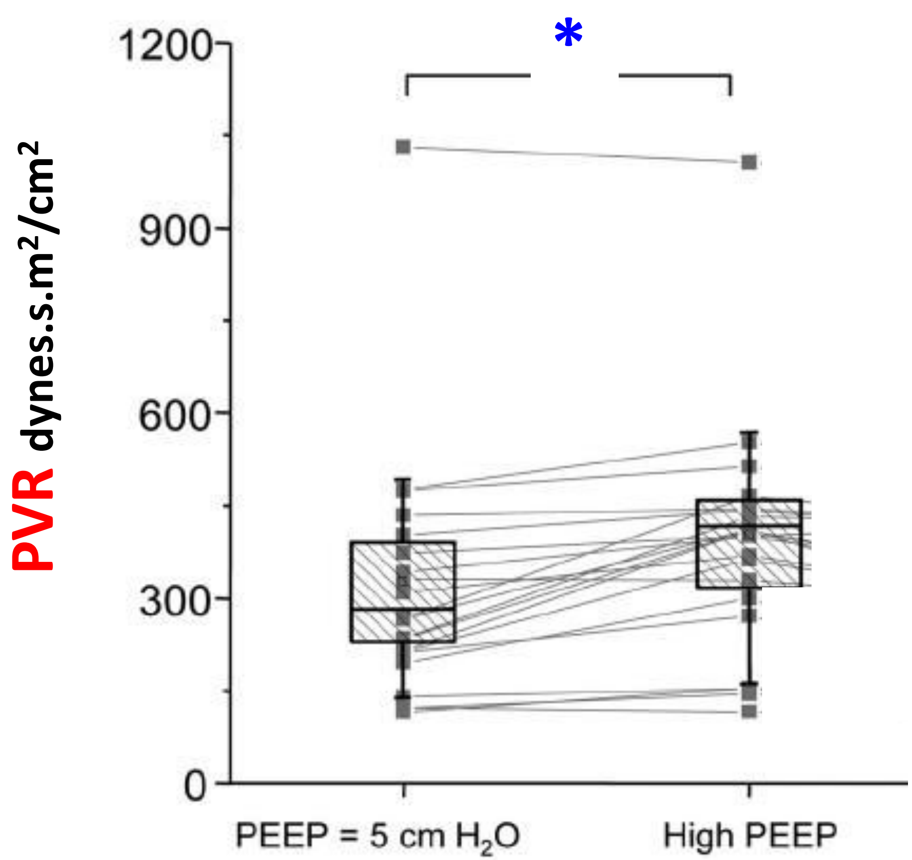

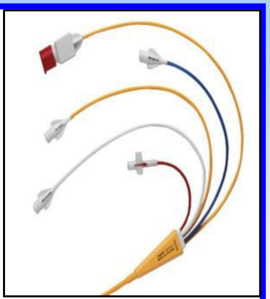

Decrease in RV afterload

with volume challenge

Hemodynamic impact of a positive end-expiratory pressure setting in acute respiratory distress syndrome: Importance of the volume status*

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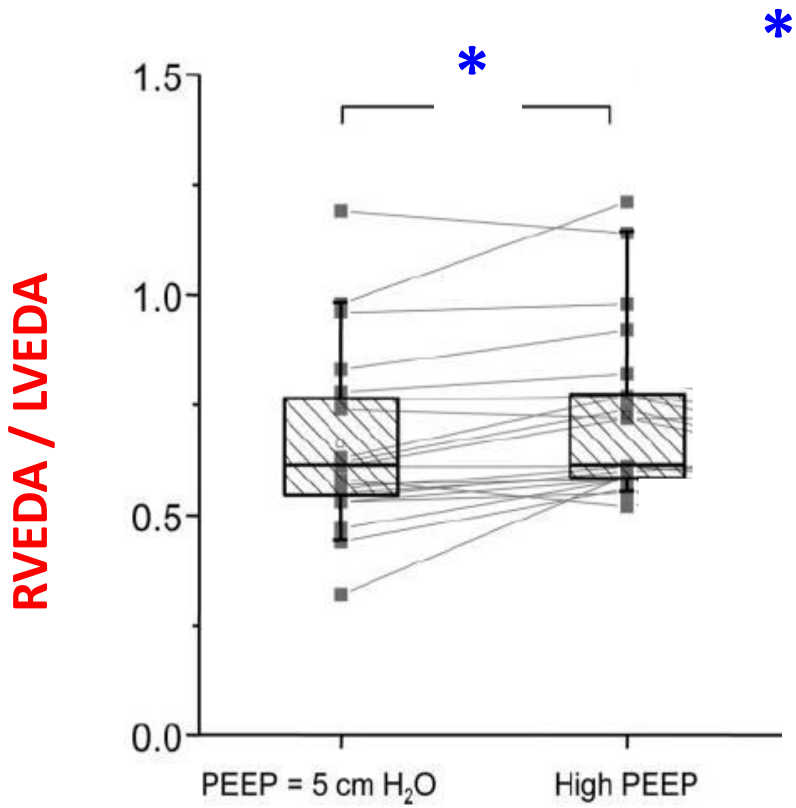
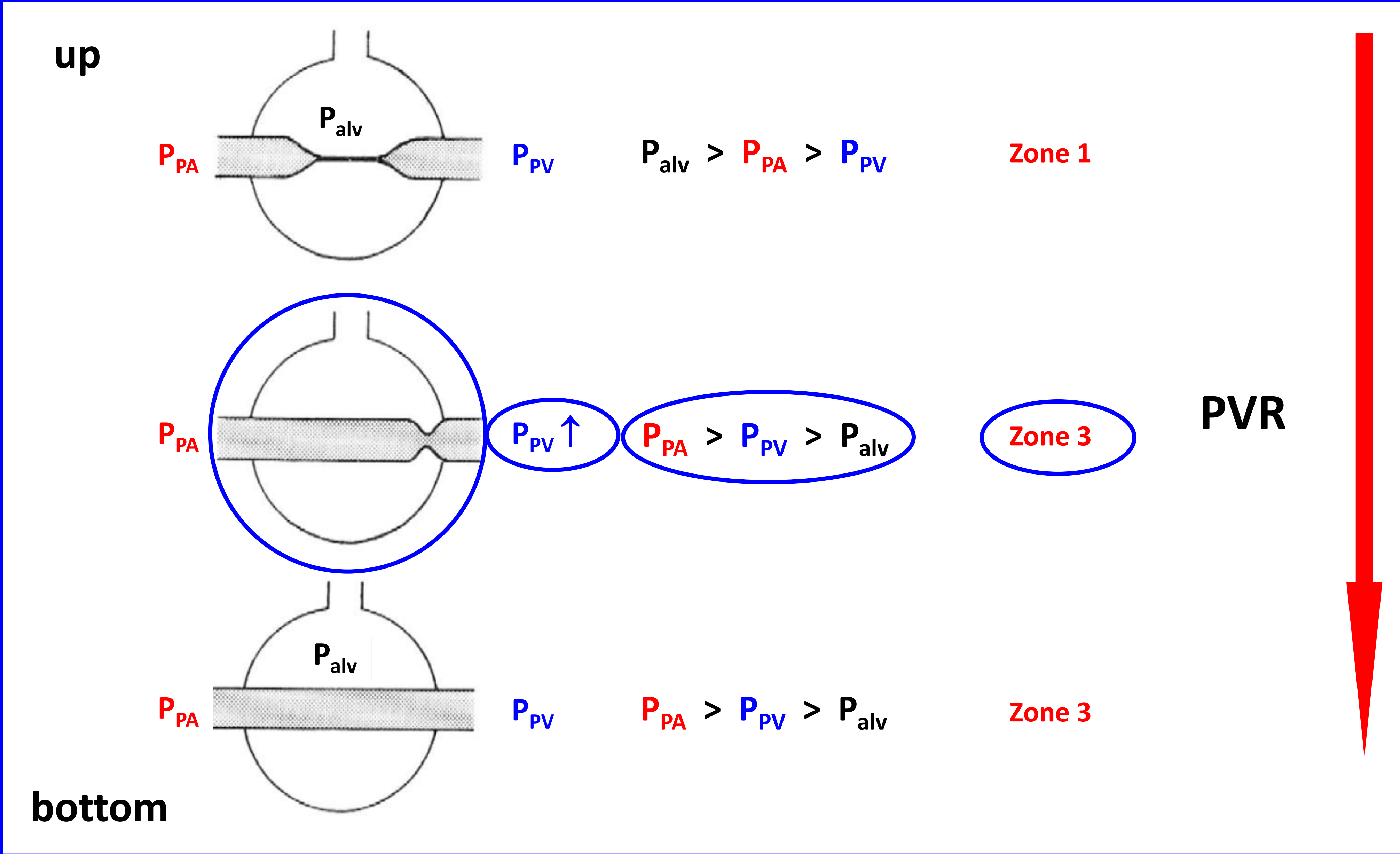
Crit Care Med 2010; 38:802–807



Decrease in RV afterload

with volume challenge

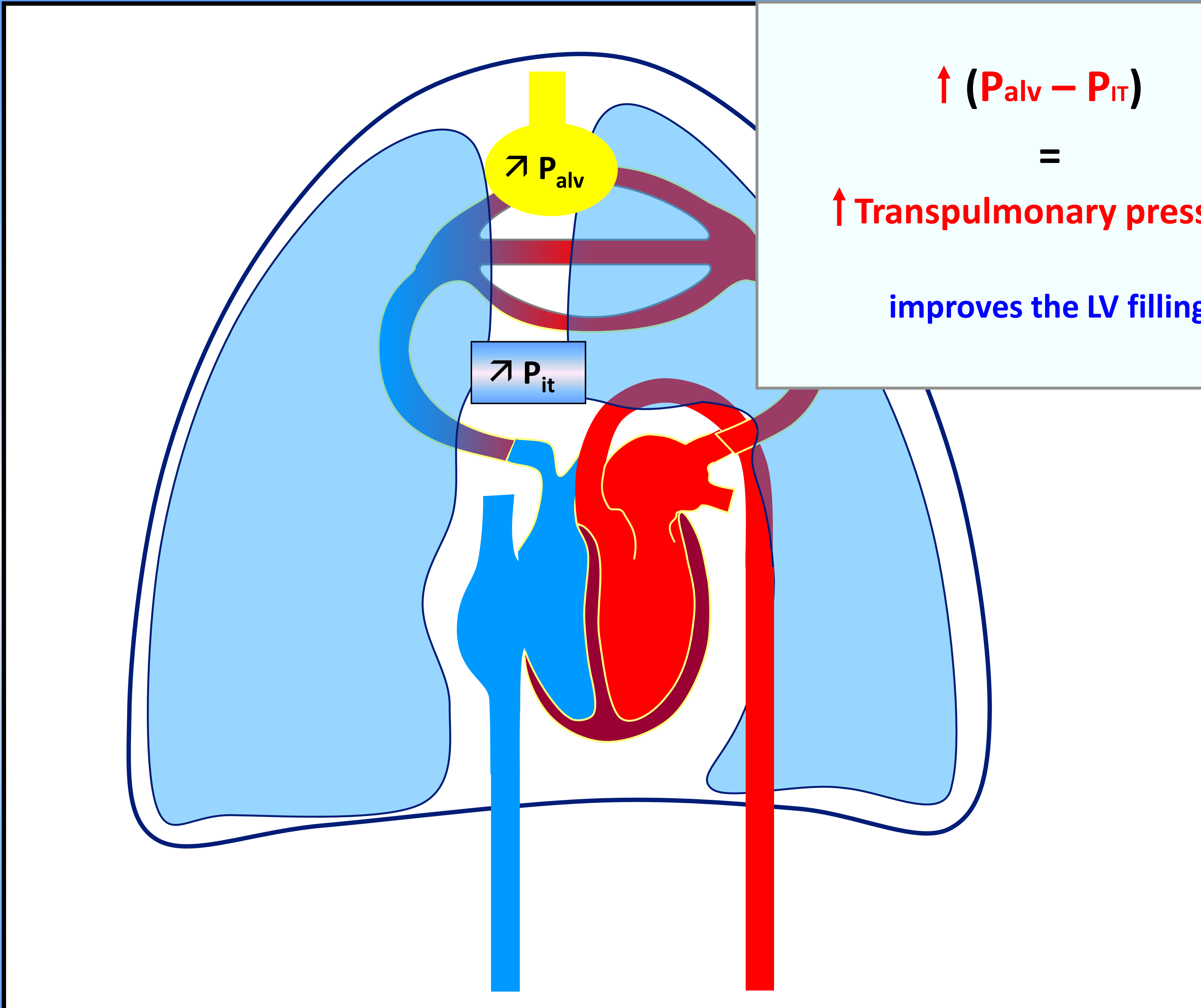
Volume loading may favor zones 3



Mechanical insufflation and venous return

Mechanical insufflation and RV ejection

Mechanical insufflation and LV filling



↑ $(P_{alv} - P_{IT})$

=

↑ Transpulmonary pressure

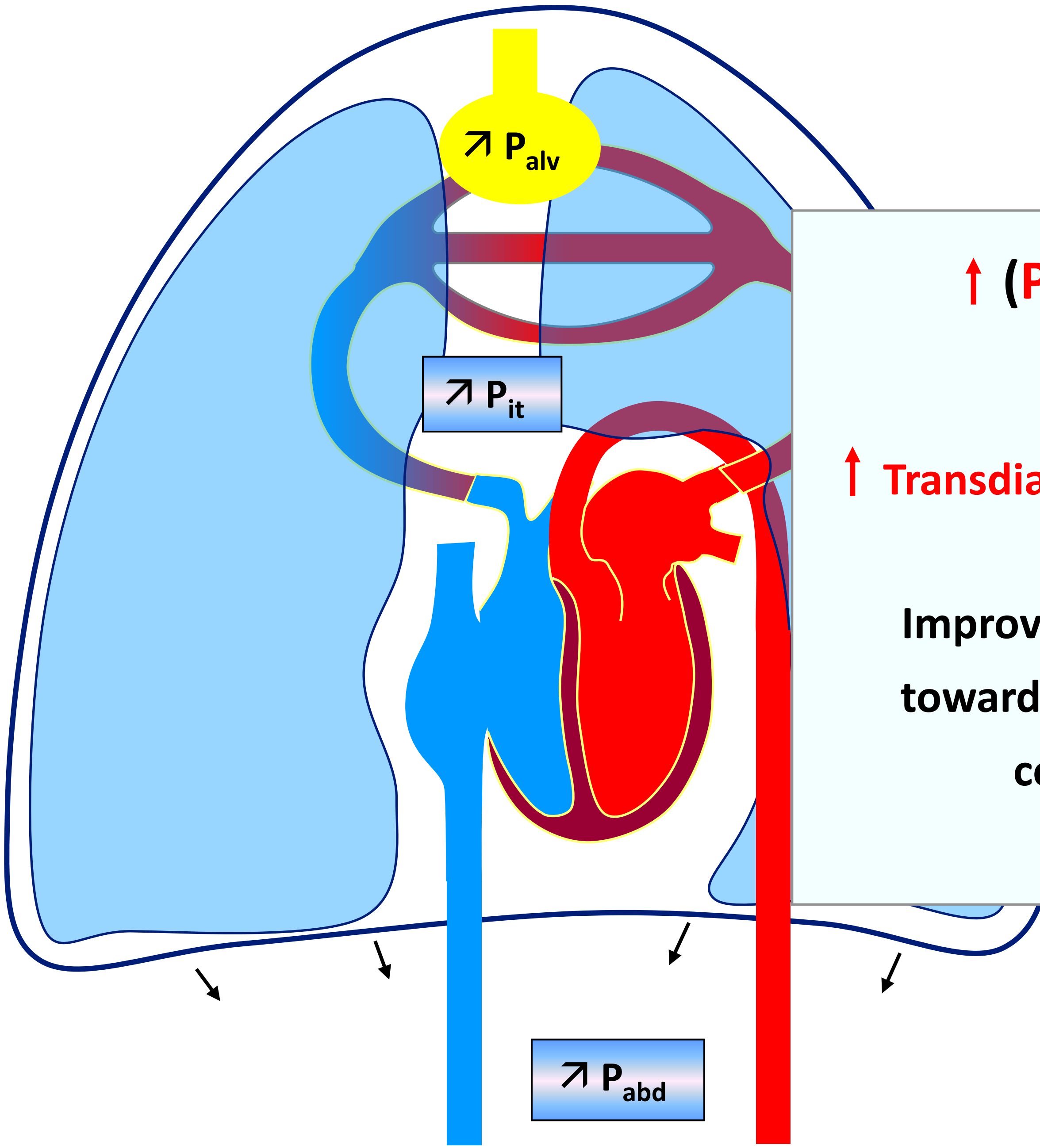
improves the LV filling

Mechanical insufflation and venous return

Mechanical insufflation and RV ejection

Mechanical insufflation and LV filling

Mechanical insufflation and LV ejection



$\uparrow (P_{IT} - P_{abd})$

=

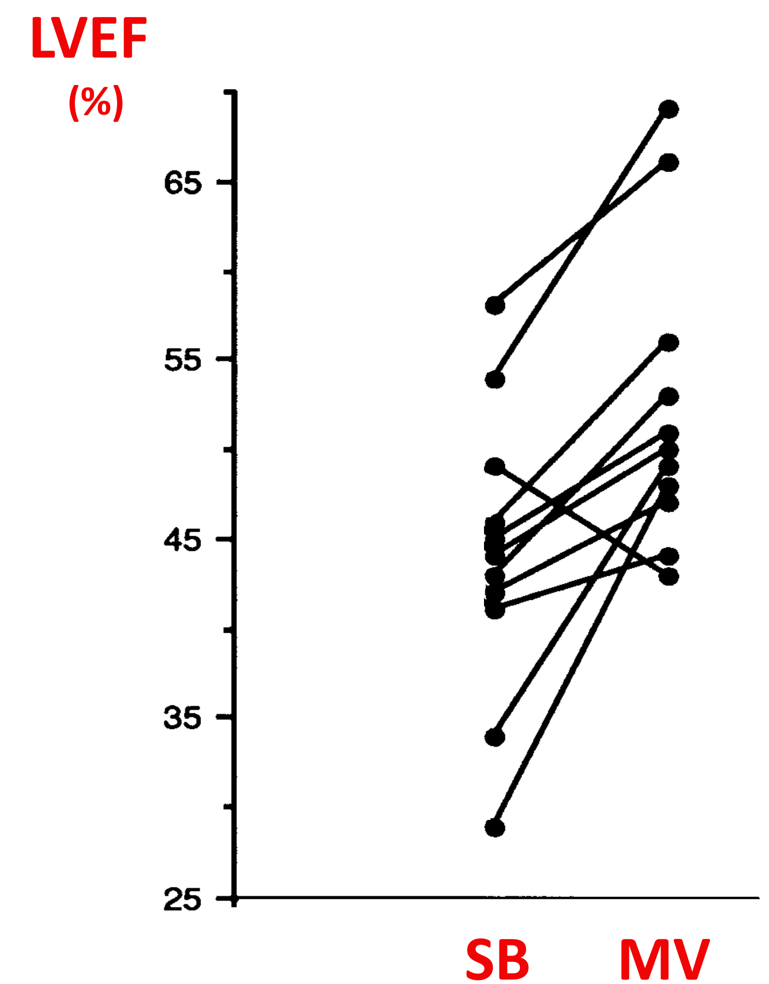
$\uparrow$ Transdiaphragmatic pressure

Improves the LV ejection toward the extrathoracic compartment

Left ventricular function during weaning of patients with chronic obstructive pulmonary disease

Ch. Richard[1], J.-L. Teboul[1], F. Archambaud[2], J.-L. Hebert[3], P. Michaut[1], P. Auzepy[1]

Intensive Care Med (1994) 20:181 – 186



Hemodynamic effects

of **Mechanical Insufflation**

Use of heart-lung interaction

to assess fluid responsiveness

critical care review

Predicting Fluid Responsiveness in ICU Patients*

A Critical Analysis of the Evidence

Frédéric Michard, MD, PhD; and Jean-Louis Teboul, MD, PhD

CHEST 2002, 121:2000-8

Source						Definition of	Rate of Response, %
Calvin et al[2]							71
Schneider et al[3]							72
Reuse et al[4]							63
Magder et al[5]							52
Diebel et al[6]							59
Diebel et al[7]							40
Wagner and Leatherman[8]							56
Tavernier et al[9]							60
Magder and Lag							45
Tousignant et al[11]							40
Michard et al[12]						15%	40
Feissel et al[13]	19	19	HES	8 mL/kg	30	ΔCO > 15%	53
Total	334	406					52

Only **52%** of patients **responded**

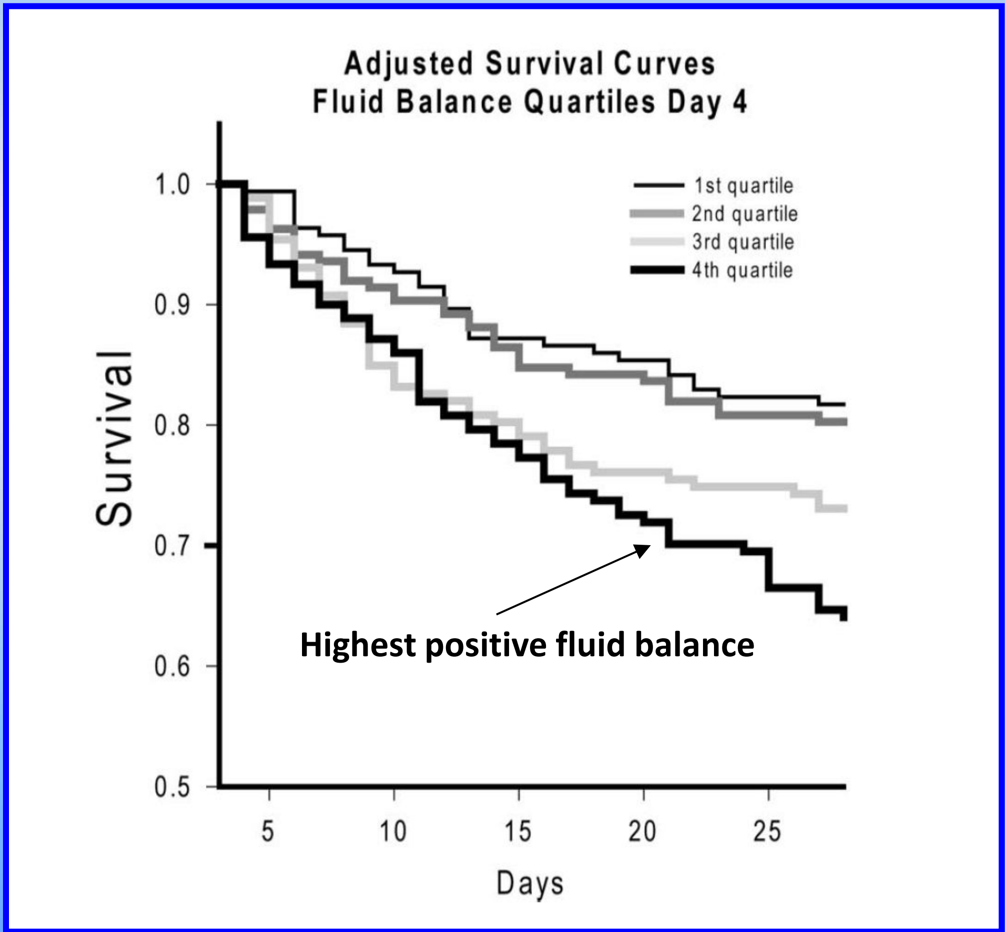
to **fluid** administration

in terms of **CO increase**

Fluid resuscitation in septic shock: A positive fluid balance and elevated central venous pressure are associated with increased mortality*

John H. Boyd, MD, FRCP(C); Jason Forbes, MD; Taka-aki Nakada, MD, PhD; Keith R. Walley, MD, FRCP(C); James A. Russell, MD, FRCP(C)

Crit Care Med 2011; 39:259–265



Decision of **starting** fluid administration

- presence of **hemodynamic instability/peripheral hypoperfusion** (mottled skin, hypotension, oliguria, hyperlactatemia…)
- and presence of **preload responsiveness**
- and **limited risks** of **fluid overload**

Predictors of preload responsiveness/unresponsiveness

Can help to choose the **best** fluid **strategy**

by **avoiding** to fluid **overload**

patients who would be fluid **unresponsive**

Fluid infusion will increase LV stroke volume only if both ventricles are preload responsive

Fluid responsiveness

equivalent to

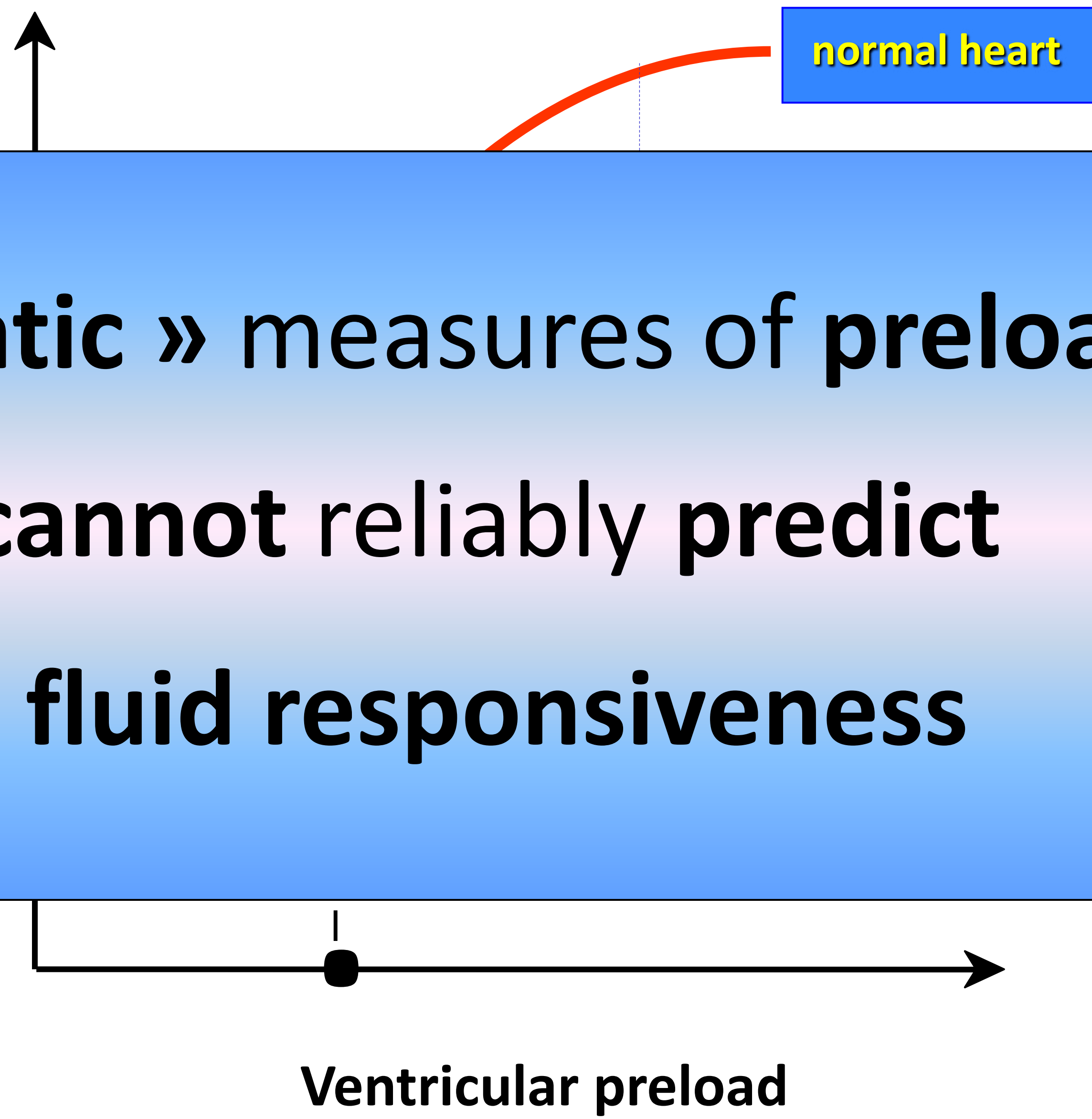
biventricular preload responsiveness

Ventricular preload

« static » measures of **preload**

cannot reliably **predict**

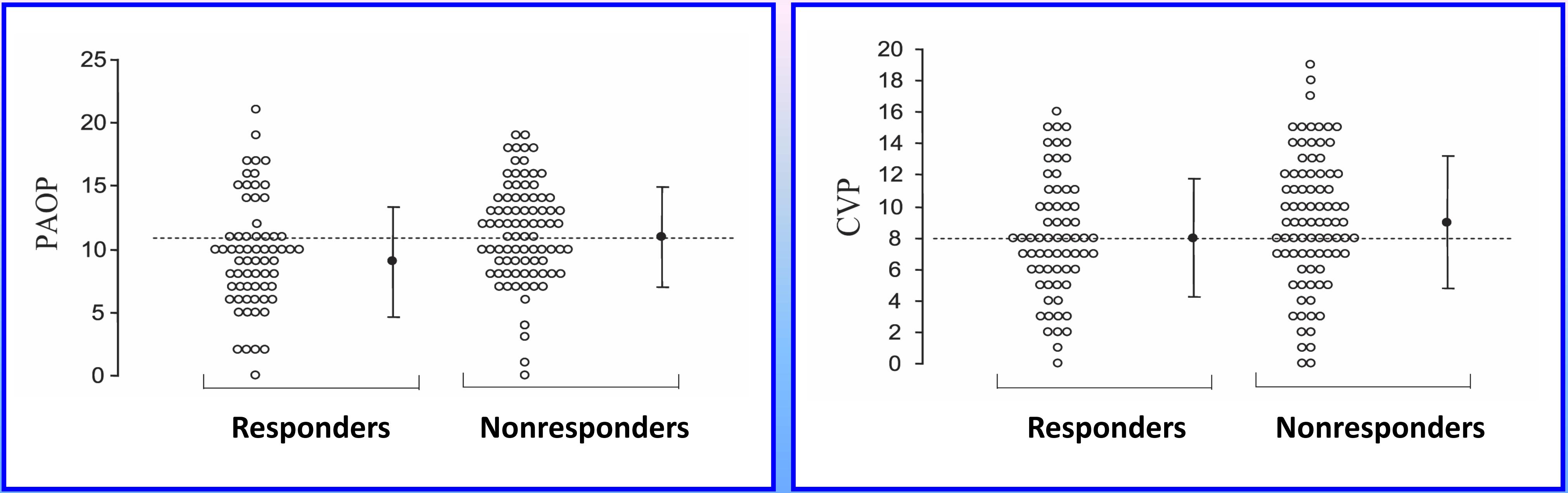
fluid responsiveness



Cardiac filling pressures are not appropriate to predict hemodynamic response to volume challenge*

David Osman, MD; Christophe Ridel, MD; Patrick Ray, MD; Xavier Monnet, MD, PhD; Nadia Anguel, MD; Christian Richard, MD; Jean-Louis Teboul, MD, PhD

Crit Care Med 2007; 35:64–68



Does the Central Venous Pressure Predict Fluid Responsiveness? An Updated Meta-Analysis and a Plea for Some Common Sense*

Paul E. Marik, MD, FCCM[1]; Rodrigo Cavallazzi, MD[2]

Crit Care Med 2013; 41:1774-81

1802 pts

43 Citations

22 ICU studies

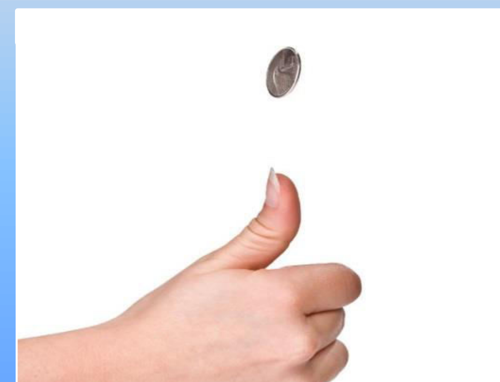
20 operating room studies

1 human volunteer study

Summary AUC

0.56

Predicting fluid responsiveness with **CVP** is like



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

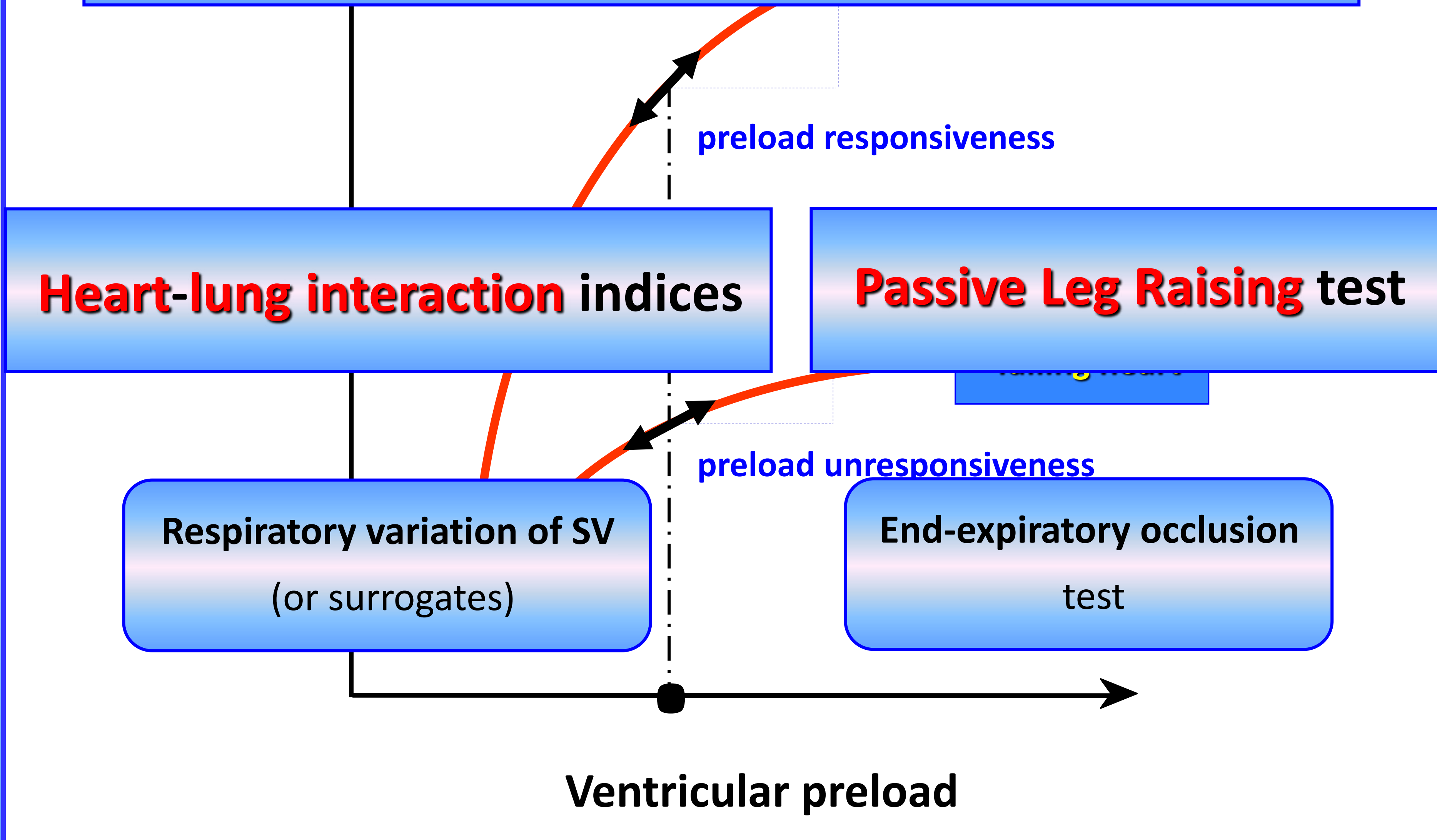
30. **We recommend not to target any absolute value of ventricular filling pressure or volume**

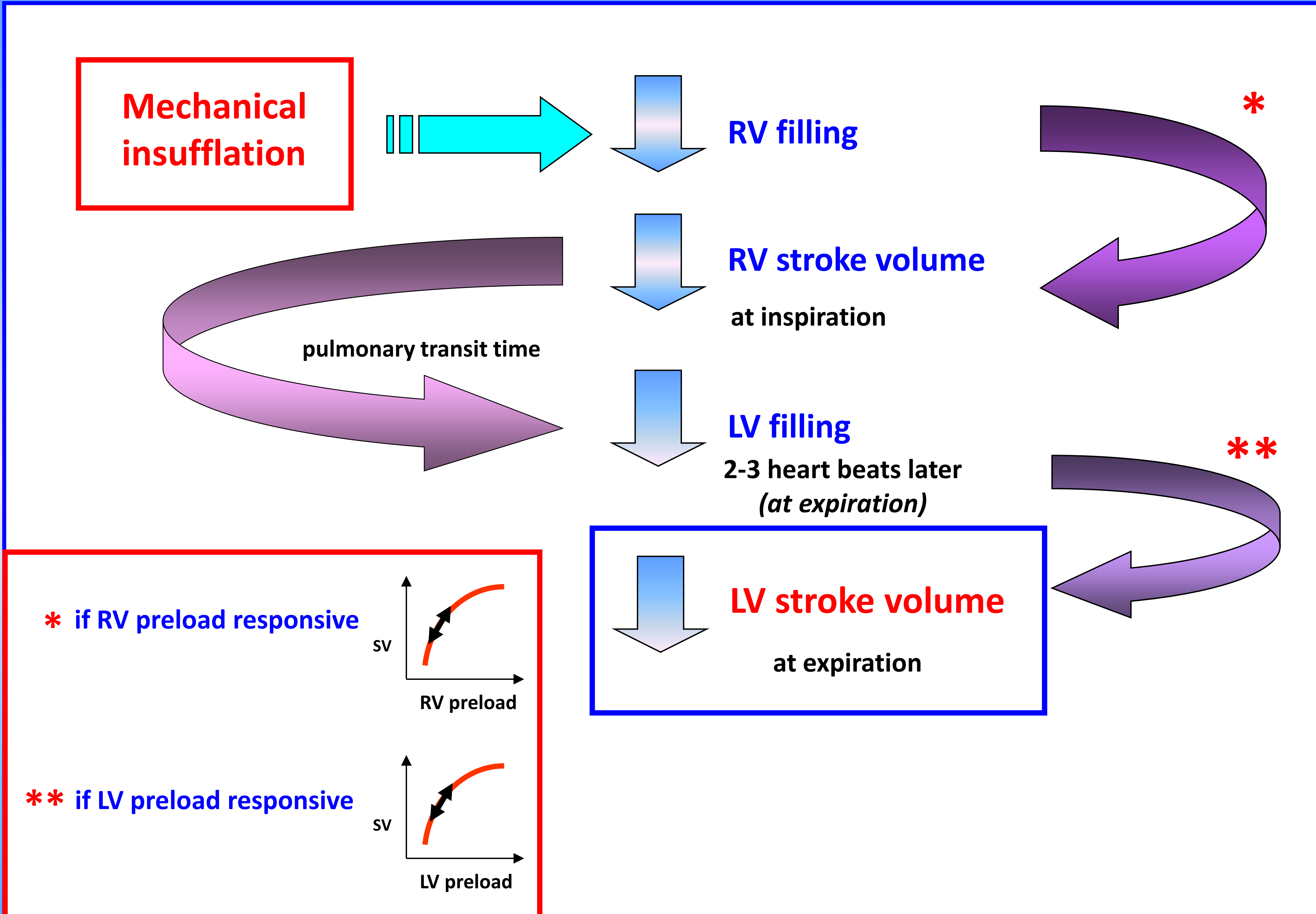
Level 1; QoE moderate (B)

31. **We recommend using dynamic over static variables to predict fluid responsiveness, when applicable**

Level 1; QoE moderate (B)

Dynamic indices of preload responsiveness





Mechanical insufflation
RV filling
*
RV stroke volume
at inspiration
pulmonary transit time
LV filling
2-3 heart beats later
(at expiration)
**
LV stroke volume
at expiration
* if RV preload responsive
SV
RV preload
** if LV preload responsive
SV
LV preload

MV induces **cyclic changes** in **SV**
only in pts with
biventricular
preload responsiveness

fluid responsiveness
occurs only in pts with
biventricular
preload responsiveness

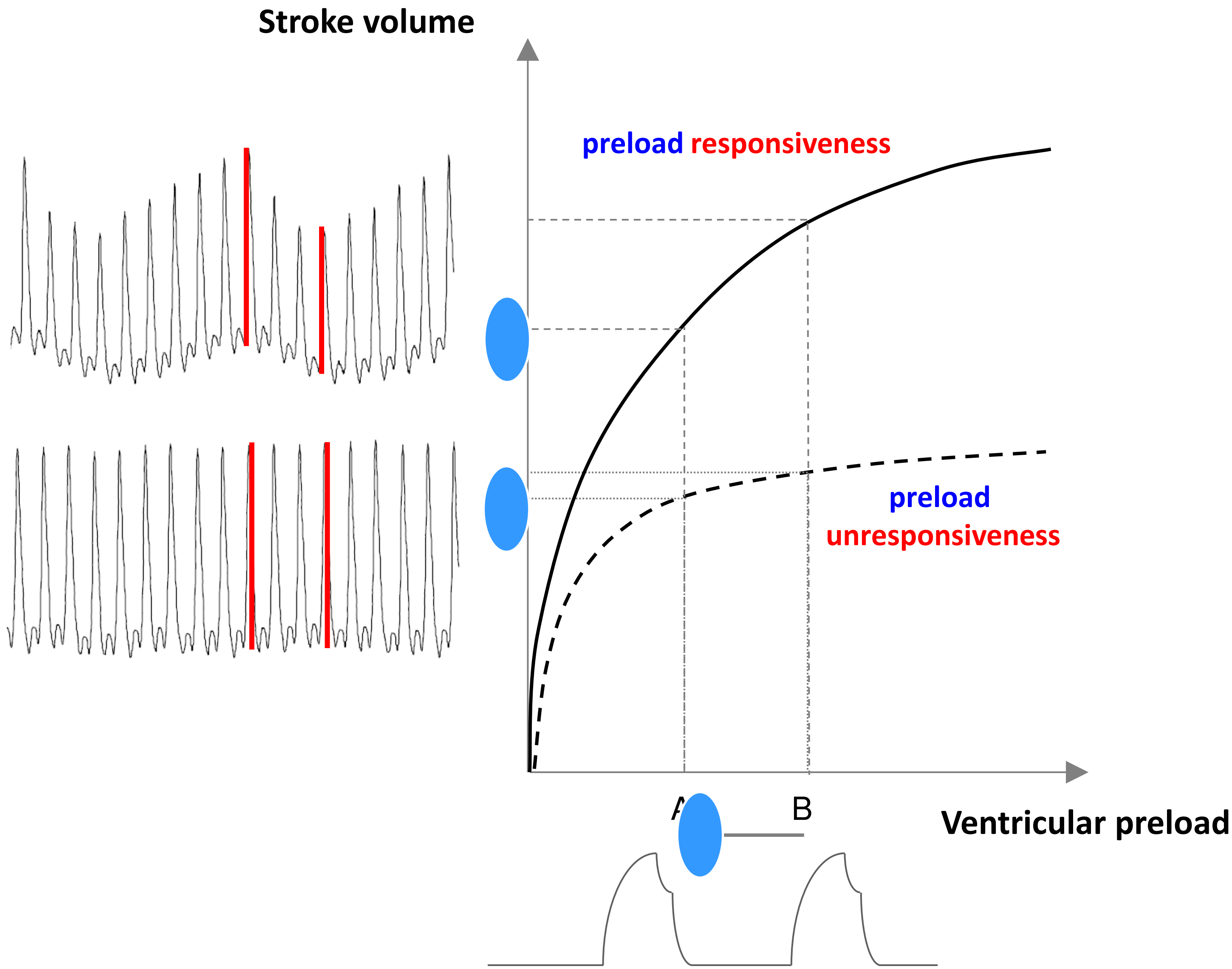
correlates with the magnitude
of the
induced by

Pulse Pressure Variation

$$\text{Pulse Pressure} = k \cdot \frac{\text{Stroke Volume}}{\text{arterial compliance}}$$

the respiratory changes in **arterial pulse pressure**
should **reflect** the respiratory changes in **LV stroke volume**

Pulse pressure variation should predict fluid responsiveness



Stroke volume
preload responsiveness
preload
unresponsiveness
A
B
Ventricular preload

Clinical Use of Respiratory Changes in Arterial Pulse Pressure to Monitor the Hemodynamic Effects of PEEP

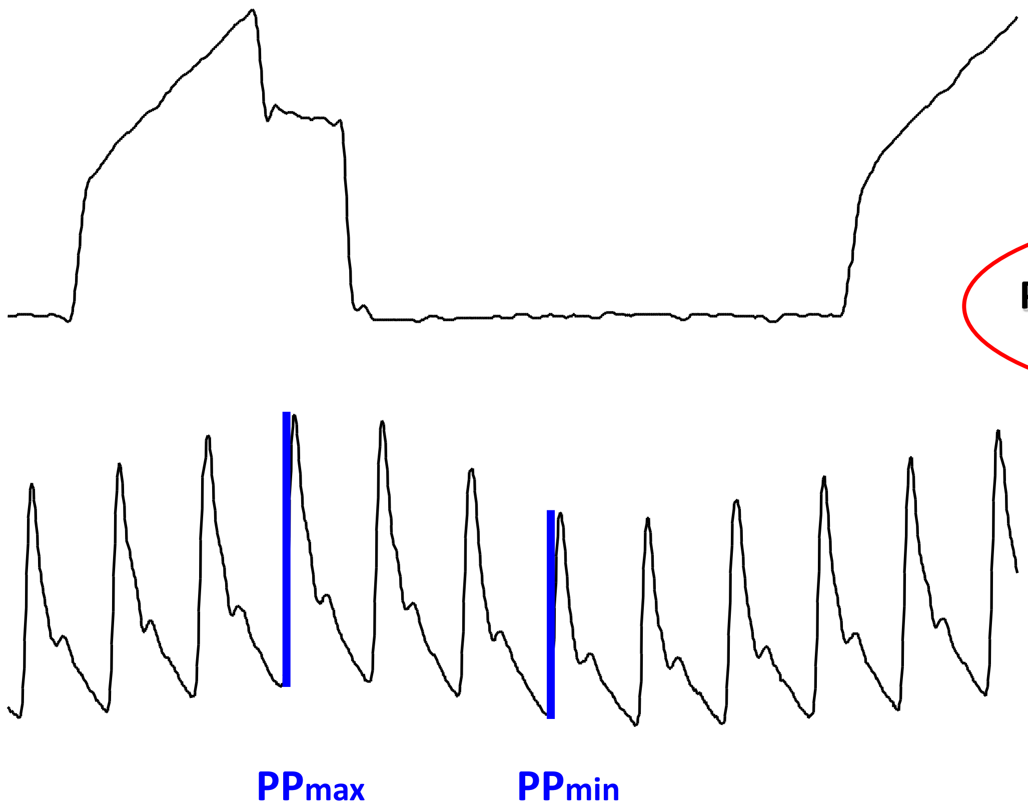
FRÉDÉRIC MICHARD, DENIS CHEMLA, CHRISTIAN RICHARD, MARC WYSOCKI, MICHAEL R. PINSKY, YVES LECARPENTIER, and JEAN-LOUIS TEBOUL

AM J RESPIR CRIT CARE MED 1999;159:935–939

Relation between Respiratory Changes in Arterial Pulse Pressure and Fluid Responsiveness in Septic Patients with Acute Circulatory Failure

FRÉDÉRIC MICHARD, SANDRINE BOUSSAT, DENIS CHEMLA, NADIA ANGUEL, ALAIN MERCAT, YVES LECARPENTIER, CHRISTIAN RICHARD, MICHAEL R. PINSKY, and JEAN-LOUIS TEBOUL

Am J Respir Crit Care Med 2000; 162:134-8



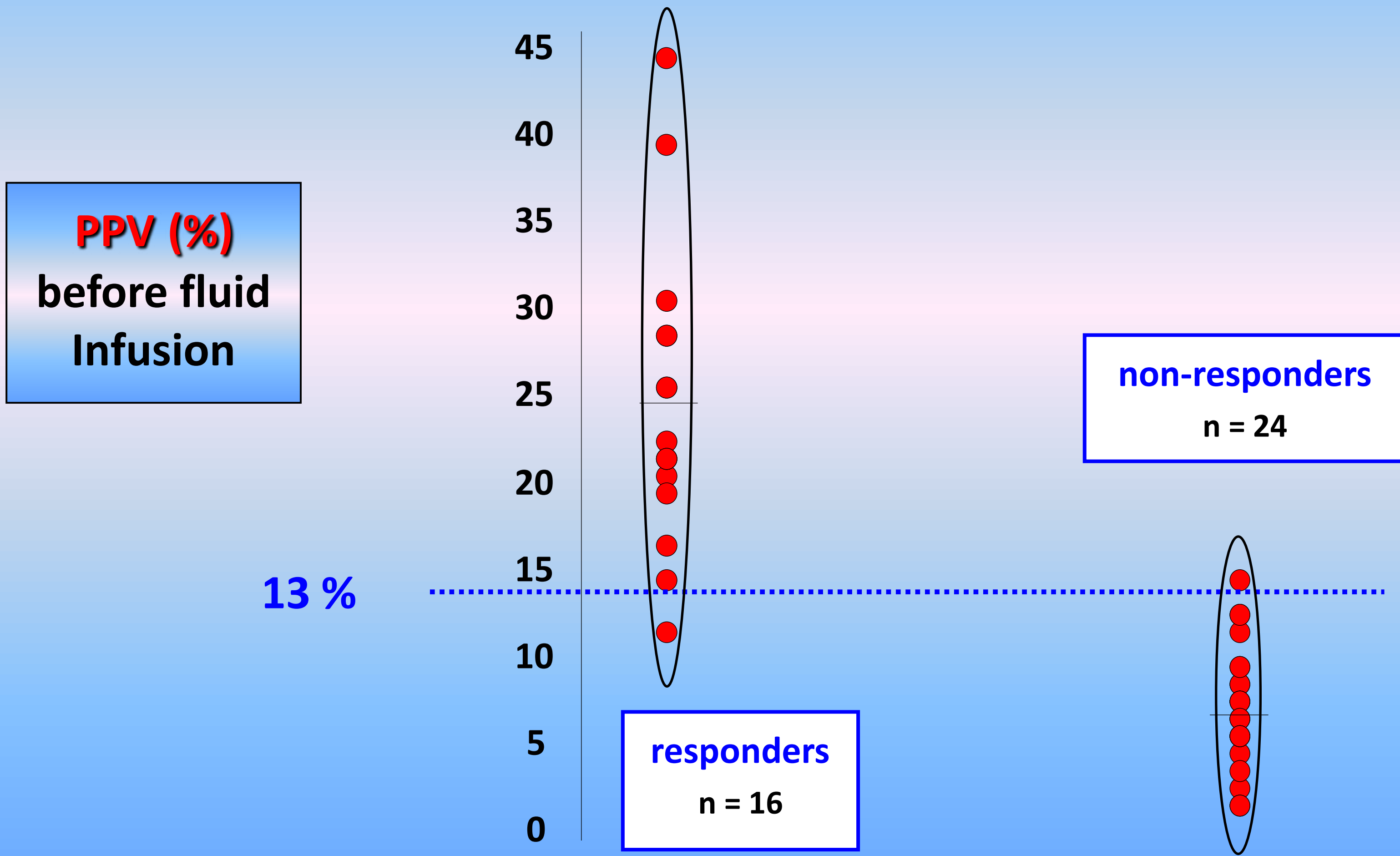
$$PPV = \frac{PP_{max} - PP_{min}}{(PP_{max} + PP_{min})/2}$$

Arterial catheter

Relation between Respiratory Changes in Arterial Pulse Pressure and Fluid Responsiveness in Septic Patients with Acute Circulatory Failure

FRÉDÉRIC MICHARD, SANDRINE BOUSSAT, DENIS CHEMLA, NADIA ANGUEL, ALAIN MERCAT, YVES LECARPENTIER, CHRISTIAN RICHARD, MICHAEL R. PINSKY, and JEAN-LOUIS TEBOUL

Am J Respir Crit Care Med 2000,162:134–138



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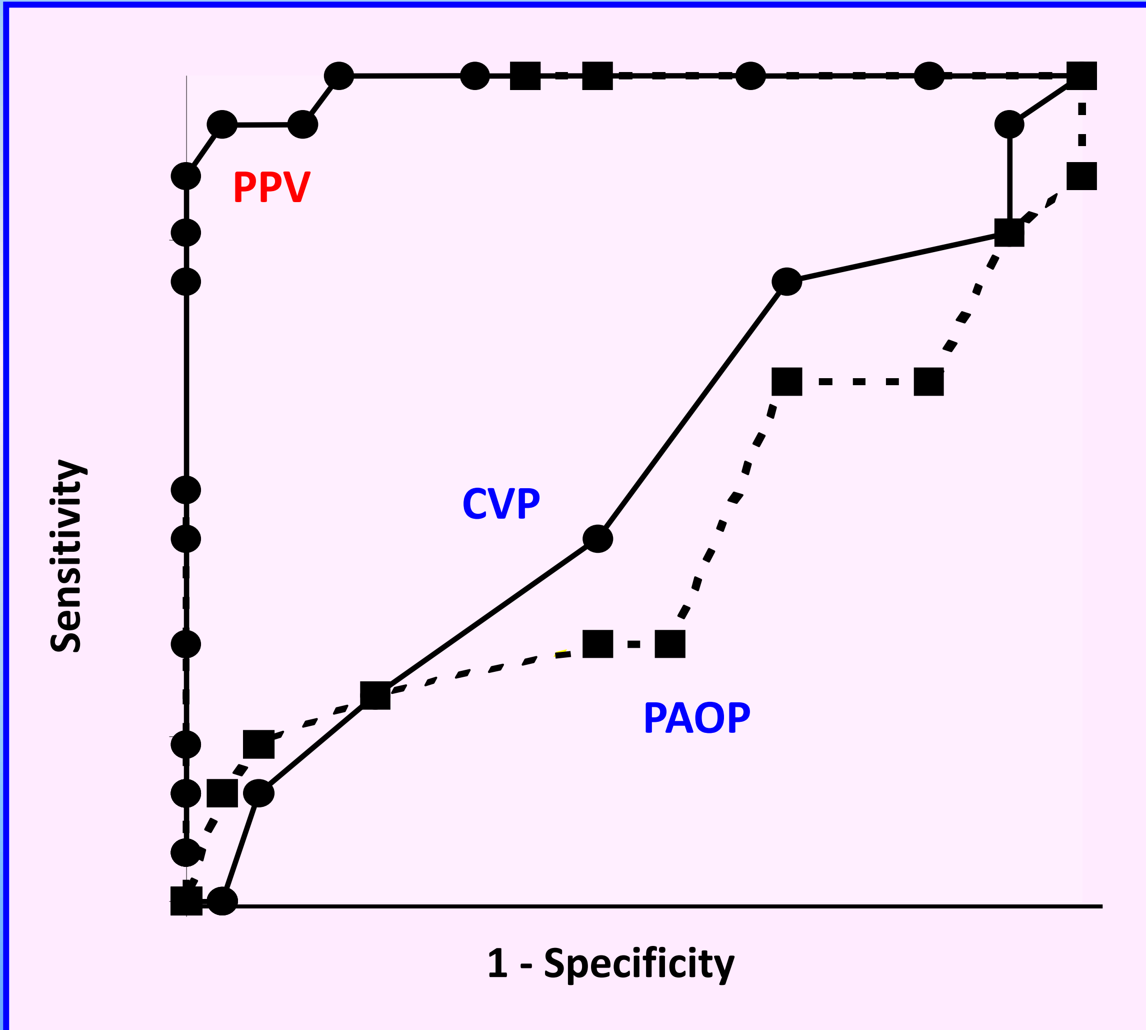


22 studies

Does pulse pressure variation predict fluid responsiveness in critically ill patients? A systematic review and meta-analysis

Xiaobo Yang and Bin Du*

Critical Care 2014, **18**:650

807 pts

Table 1 Selected spectrum characteristics of included studies

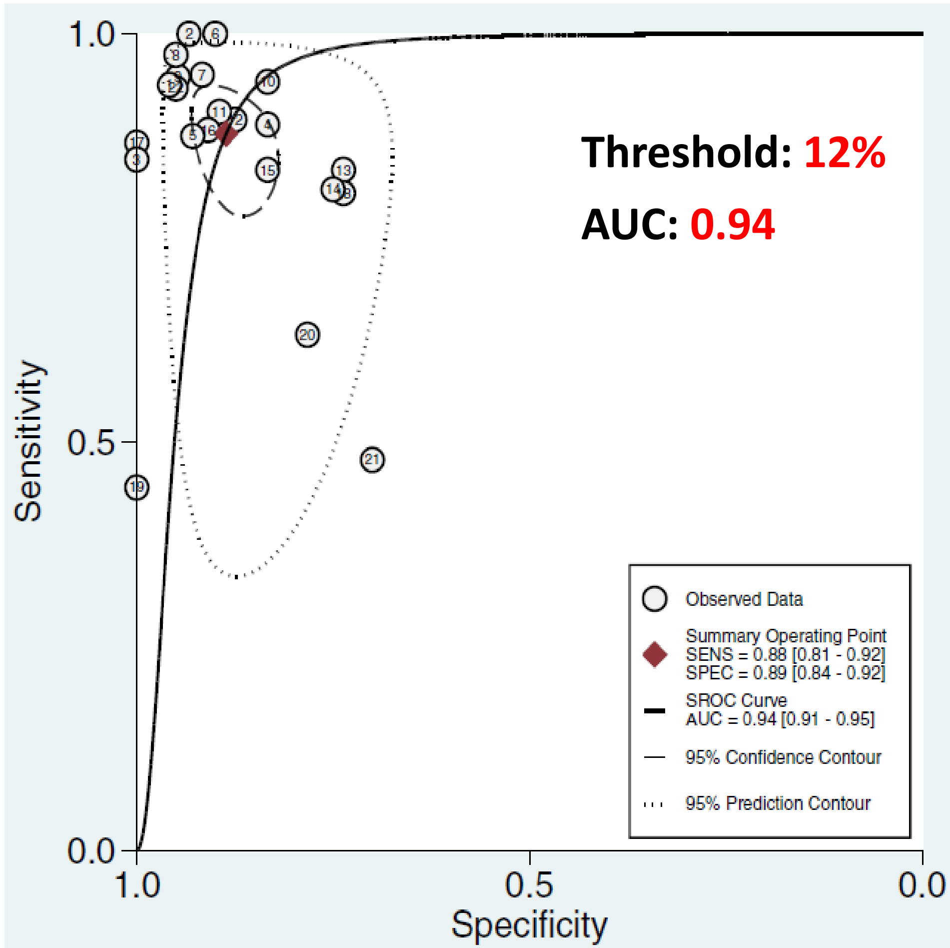
Order	Authors	Year	Sample size	Setting	Admission	Diagnosis
1	Michard and colleagues [23]	2000	40	ICU	Medical	Sepsis/septic shock
2	Kramer and colleagues [24]	2004	21	SICU	Surgical	Cardiac surgery
3	Feissel and colleagues [25]	2005	20[a]	ICU	Medical	Sepsis/septic shock
4	Charron and colleagues [26]	2006	21	ICU	NA	NA
5	Monnet and colleagues [27]	2006	30	MICU	Medical	Shock
6	Feissel and colleagues [28]	2007	23[b]	MICU	Medical	Sepsis/septic shock
7	Wyffels and colleagues [29]	2007	32	ICU	Surgical	Cardiac surgery
8	Auler and colleagues [30]	2008	59	SICU	Surgical	Cardiac surgery
9	Monge Garcia and colleagues [31]	2009	38	ICU	NA	Shock
10	Vistisen and colleagues [32]	2009	23	SICU	Surgical	Cardiac surgery
11	Loupec and colleagues [33]	2011	40	SICU	Surgical and medical	Surgery and septic shock
12	Biais and colleagues [34]	2012	35	SICU	Surgical and medical	Vascular surgery, trauma, septic shock
13	Cecconi and colleagues [35]	2012	31	ICU	Surgical	High-risk surgery
14	Fellahi and colleagues [36]	2012	25	SICU	Surgical	Cardiac surgery
15	Khwannimit and colleagues [37]	2012	42	MICU	Medical	Sepsis/septic shock
16	Monnet and colleagues [38]	2012	26	MICU	Medical	Shock
17	Monnet and colleagues [39]	2012	39	MICU	Medical	Shock
18	Yazigi and colleagues [40]	2012	60	SICU	Surgical	Cardiac surgery
19	Fischer and colleagues [41]	2013	37	SICU	Surgical	Cardiac surgery
20	Fischer and colleagues [42]	2013	80	SICU	Surgical	Cardiac surgery
21	Ishihara and colleagues [43]	2013	43	ICU	Surgical	Noncardiac surgery
22	Monnet and colleagues [44]	2013	35	MICU	Medical	Shock

MICU, medical intensive care unit; NA, not available; SICU, surgical intensive care unit. [a]Twenty-two fluid challenges included. [b]Twenty-eight fluid challenges included.

Does pulse pressure variation predict fluid responsiveness in critically ill patients? A systematic review and meta-analysis

Xiaobo Yang and Bin Du*

Critical Care 2014, **18**:650

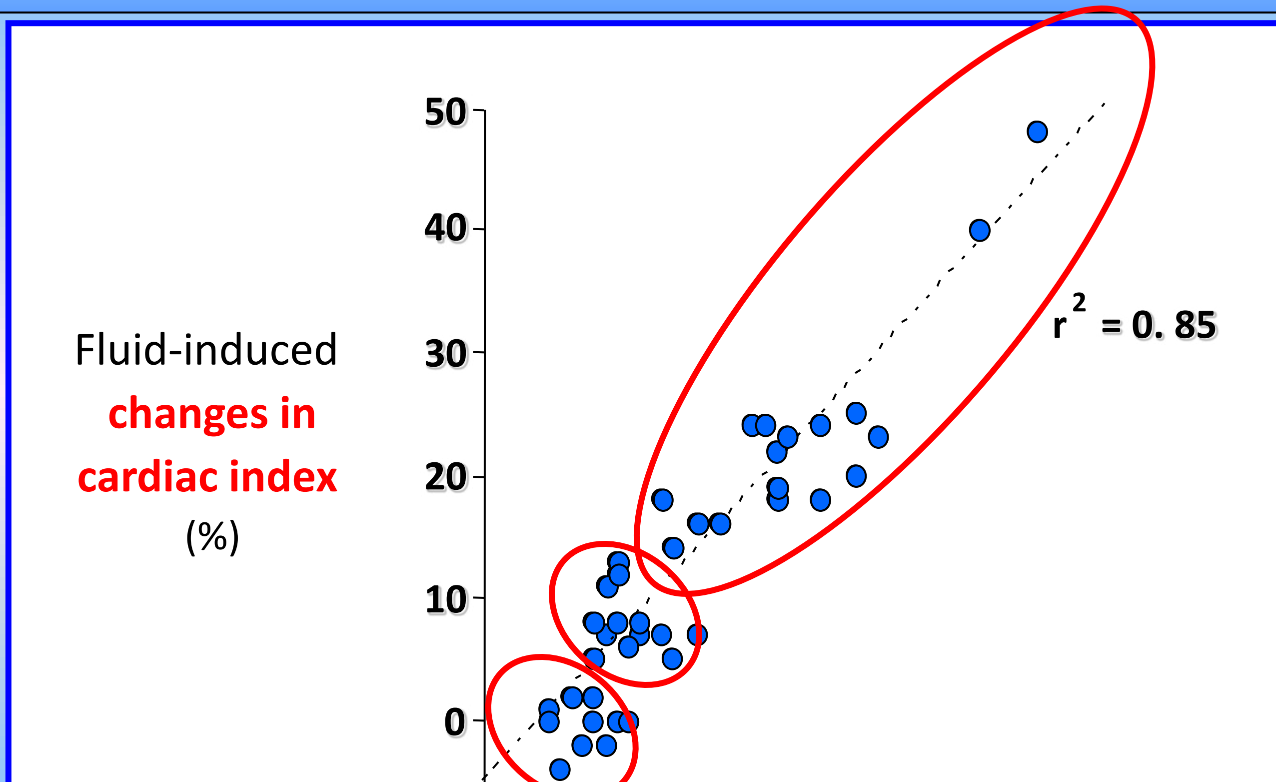


Threshold: 12%

AUC: 0.94

The **larger** the **PPV** ***before*** fluid infusion,

the **larger** the **increase** in **CO** ***after*** fluid infusion

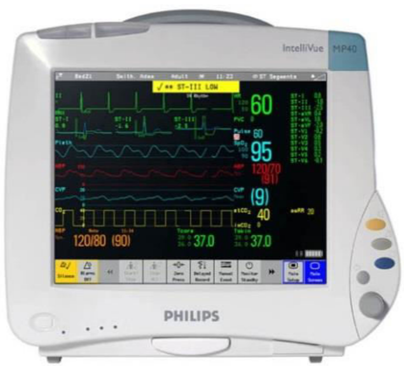


The **smaller** the **PPV** ***before*** fluid infusion,

the **smaller** the **increase** in **CO** ***after*** fluid infusion

Pulse Pressure Variation

Calculated automatically and displayed in real-time by functional hemodynamic monitors



Arterial pressure waveform analysis → Stroke volume

Stroke Volume Variation

Calculated automatically and **displayed** in **real-time**

by functional hemodynamic monitors

Dynamic changes in arterial waveform derived variables and fluid responsiveness in mechanically ventilated patients: A systematic review of the literature*

Paul E. Marik, MD, FCCM; Rodrigo Cavallazzi, MD; Tajender Vasu, MD; Amyn Hirani, MD

Crit Care Med 2009; 37:2642–2647

685 pts

	AUC
PPV	0.94 (0.93–0.95)
SPV	0.86 (0.82–0.90)
SVV	0.84 (0.78–0.88)
LVEDAI	0.64 (0.53–0.74)
GEDVI	0.56 (0.37–0.67)
CVP	0.55 (0.48–0.62)

Prediction of fluid responsiveness by a continuous non-invasive assessment of arterial pressure in critically ill patients: comparison with four other dynamic indices

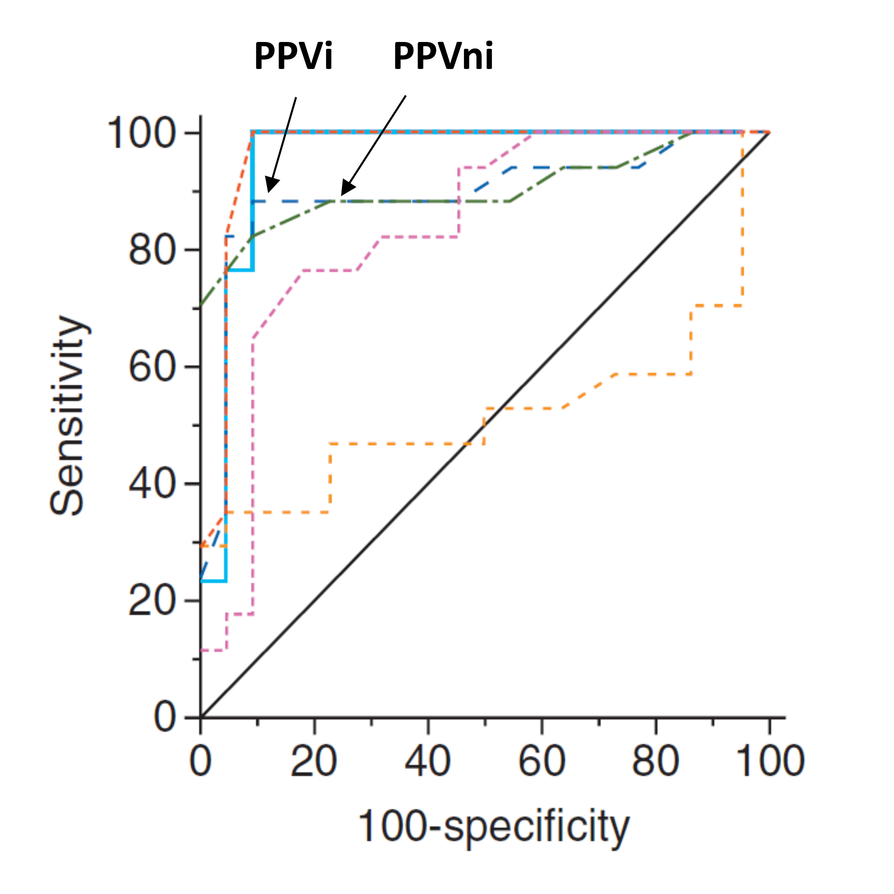
X. Monnet[1,2*], M. Dres[1,2], A. Ferré[1,2], G. Le Teuff[4], M. Jozwiak[1,2], A. Bleibtreu[1,2], M.-C. Le Deley[4], D. Chemla[1,3], C. Richard[1,2] and J.-L. Teboul[1,2]

British Journal of Anaesthesia **109** (3): 330–8 (2012)

Non-invasive

finger blood pressure

monitoring **device**



Intensive Care Med (2012) 38:1429–1437

REVIEW

Claudio Sandroni
Fabio Cavallaro
Cristina Marano
Chiara Falcone
Paolo De Santis
Massimo Antonelli

Accuracy of plethysmographic indices as predictors of fluid responsiveness in mechanically ventilated adults: a systematic review and meta-analysis

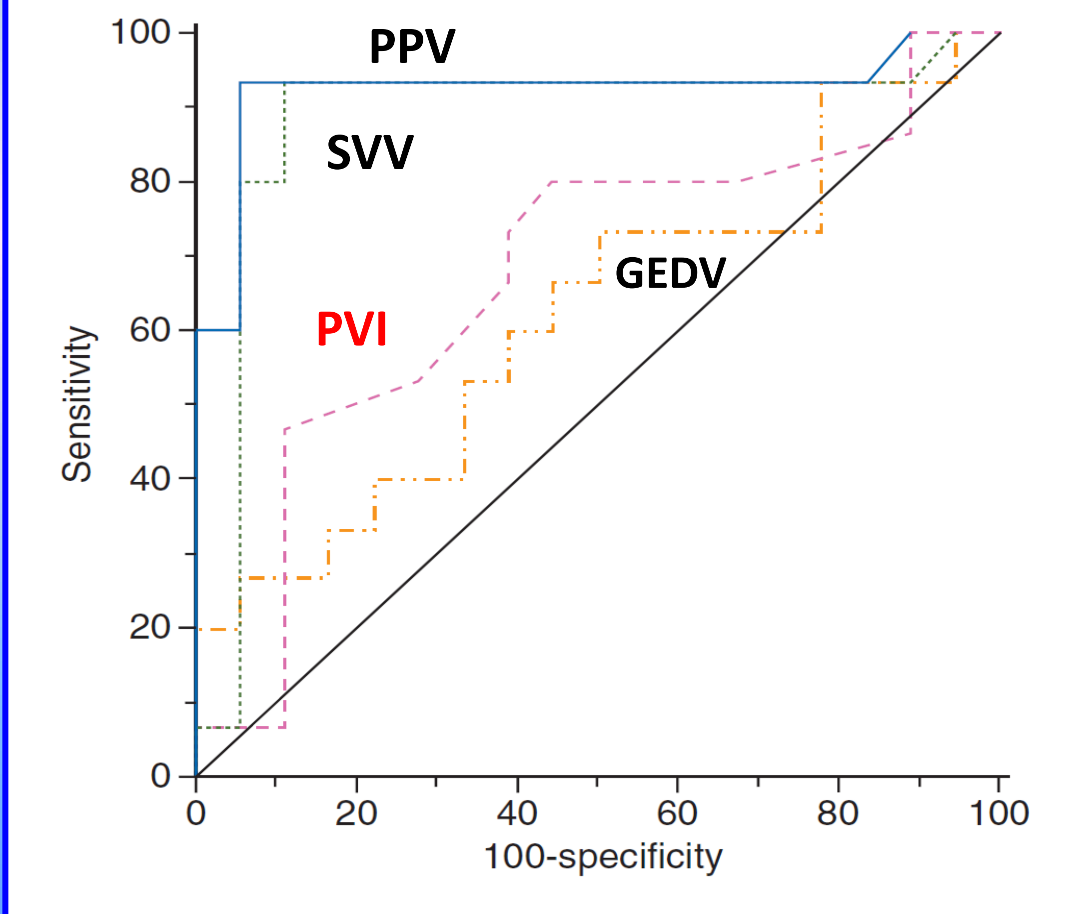
References (first author)	Index	Number of patients/boluses	% Responders	Best threshold	AUC (SE)	Sensitivity	Specificity
Natalini	ΔPOP	22/31	61.0	15.0	0.70 (0.094)	0.63	0.83
Solus-Biguenet	ΔPOP	8/54	42.0	9.5	0.68 (0.071)	0.64	0.68
Cannesson	ΔPOP	25/25	60.0	13.0	0.85 (0.081)	0.93	0.90
Feissel	ΔPOP	23/28	64.0	14.0	0.94 (0.050)	0.94	0.80
Wyffels	ΔPOP	32/32	62.5	11.8	0.89 (0.061)	0.90	0.83
Hoiseth	ΔPOP	25/34	64.7	11.4	0.72 (0.082)	0.86	0.67
Cannesson	ΔPOP[b]	25/25	64.0	12.0	0.94 (0.043)	0.87	0.89
	PVI	25/25	64.0	14.0	0.93 (0.051)	0.81	1.00
Zimmermann	PVI	20/20	75.0	9.5	0.97 (0.033)	0.93	1.00
Desgranges	PVI	28/28	68.0	12.0	0.84 (0.077)	0.74	0.67
Hood (large bolus)	PVI	25/25	88.0	10.0	0.96 (0.031)	0.86	1.00
Hood (small bolus)	PVI	25/63	36.5	10.0	0.71 (0.071)	0.65	0.67
Overall[a]		233/365	62.3 ± 14.0	9.5–15.0	0.85 [0.79–0.92]	0.80 [0.74–0.85]	0.76 [0.68–0.82]

British Journal of Anaesthesia **110** (2): 207–13 (2013)

BJA

Pleth variability index is a weak predictor of fluid responsiveness in patients receiving norepinephrine

X. Monnet[1,2*], L. Guérin[1,2], M. Jozwiak[1,2], A. Bataille[1,2], F. Julien[1,2], C. Richard[1,2] and J.-L. Teboul[1,2]



The effects of goal-directed fluid therapy based on dynamic parameters on post-surgical outcome: a meta-analysis of randomized controlled trials

Jan Benes[1*], Mariateresa Giglio[2], Nicola Brienza[2] and Frederic Michard[3]

Critical Care 2014, **18**:584

Study	Type of surgery	Risk	Number of participants*	Timing	GDFTdyn end point	Other optimization goals	Type of intervention	Mortality reported	Morbidity reported
Benes, 2010 [38] Europe	Major abdominal	High	120 (60/60)	Intra	SVV <10%	CI >2.5 l/min/m^2, MAP >65 mmHg, CVP <15 mmHg,	Fluids, inotropes	Y	CV, GI, infectious, renal, respiratory
Buettner, 2008 [11] Europe	Major abdominal	Moderate	80 (40/40)	Intra	SPV <10%	N/A	Fluids	Y	-
Forget, 2010 [37] Europe	Abdominal	Moderate	82 (41/41)	Intra	PVI <10%	MAP >65 mmHg	Fluids	Y	CV, GI, infectious, renal
Goepfert, 2013 [36] Europe	Elective cardiac	High	100 (50/50)	Intra, post	SVV <10%	CI >2.0 l/min/m^2, MAP >65 mmHg, HR 50-100 bpm, EVLWI ≤12 ml/kg	Fluids, inotropes	N	CV, infectious, respiratory, renal
Harten, 2008 [35] Europe	Emergency abdominal	High	29 (15/14)	Intra	PPV <10%	N/A	Fluids	Y	CV, GI, infectious, renal, respiratory
Kapoor, 2008 [39] India	Cardiac	High	27 (14/13)	Intra, post	SVV <10%	CI >2.5 mL/min/m^2, CVP >6 mmHg, $ScvO_2$ > 70%, SVI >30 ml/m^2, SVRI >1,500 dynes.s/cm^5/m^2, DO_2I >450 ml/min/m^2	Fluids, inotropes	Y	GI, CV, renal, respiratory
Lopes, 2007 [10] Brazil	Major abdominal	High	33 (16/17)	Intra	PPV <10%	N/A	Fluids	Y	CV, GI, infectious, renal, respiratory
Mayer, 2010 [40] Europe	Major abdominal	High	60 (30/30)	Intra	SVV <12%	CI >2.5 mL/min/m^2, MAP >65 mmHg, SVI >35 ml/m^2	Fluids, inotropes	Y	Renal, respiratory
Ramsingh, 2013 [34] USA	Major abdominal	High	38 (20/18)	Intra	SVV <13%	N/A	Fluids	N	-
Salzwedel, 2013 [30] Europe	Elective abdominal	Moderate	160 (81/79)	Intra	PPV <10%	CI >2.5 mL/min/m^2, MAP >65 mmHg	Fluids, inotropes	N	CV, GI, infectious, renal, respiratory
Sheeren, 2013 [33] Europe	Major abdominal	High	52 (26/26)	Intra	SVV <10%	SV increase >10%	Fluids	Y	CV, GI, infectious, renal, respiratory
Zhang Ju, 2012 [32] China	Major abdominal	Low	60 (20/40)	Intra	PPV <11%	N/A	Fluids	N	CV, GI, infectious, renal, respiratory
Zhang Ji, 2013 [31] China	Thoracic	Moderate	60 (30/30)	Intra	SVV <9%	CI >2.5 mL/min/m^2, MAP >65 mmHg	Fluids, inotropes	N	GI, infectious, renal, Respiratory
Zheng, 2013 [29] China	Elective abdominal	Moderate	60 (30/30)	Intra, post	SVV <12%	CI >2.5 mL/min/m^2, MAP >65 mmHg, SVI >35 ml/m^2	Fluids, inotropes	N	CV, GI

The effects of goal-directed fluid therapy based on dynamic parameters on post-surgical outcome: a meta-analysis of randomized controlled trials

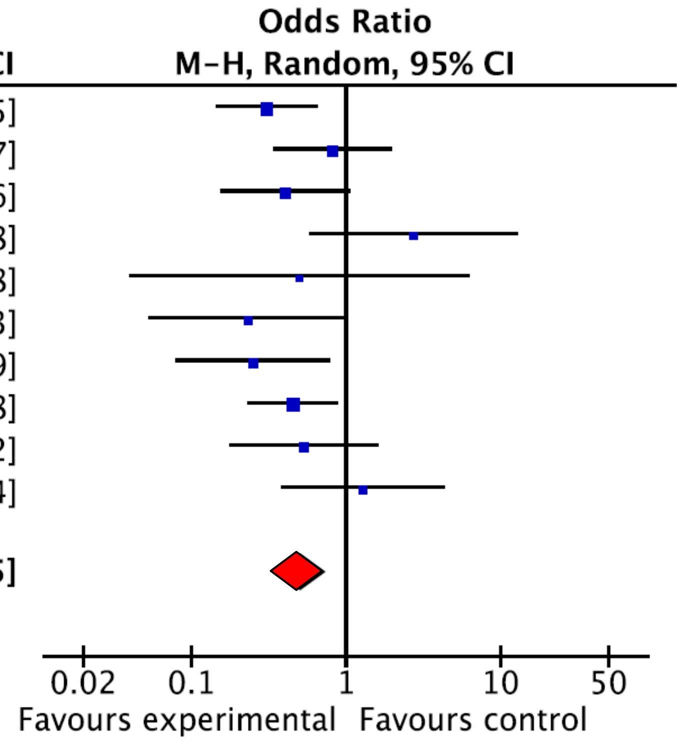
Jan Benes[1*], Mariateresa Giglio[2], Nicola Brienza[2] and Frederic Michard[3]

Critical Care 2014, **18**:584

post-surgical morbidity

Study or Subgroup	Experimental Events	Experimental Total	Control Events	Control Total	Weight	Odds Ratio M-H, Random, 95% CI
Benes 2010 (30)	18	60	35	60	16.0%	0.31 [0.14, 0.65]
Forget 2010 (29)	23	41	25	41	13.2%	0.82 [0.34, 1.97]
Goepfert 2013 (28)	34	50	42	50	11.7%	0.40 [0.15, 1.06]
Harten 2008 (27)	7	14	4	15	5.6%	2.75 [0.58, 12.98]
Kapoor 2008 (31)	1	13	2	14	2.3%	0.50 [0.04, 6.28]
Lopes 2007 (10)	7	17	12	16	6.0%	0.23 [0.05, 1.03]
Mayer 2010 (32)	6	30	15	30	9.1%	0.25 [0.08, 0.79]
Salzwedel 2013 (22)	21	79	36	81	18.3%	0.45 [0.23, 0.88]
Scheeren 2013 (25)	12	26	16	26	9.6%	0.54 [0.18, 1.62]
Zhang Ju 2012 (24)	12	40	5	20	8.3%	1.29 [0.38, 4.34]
Total (95% CI)		**370**		**353**	**100.0%**	**0.51 [0.34, 0.75]**
Total events	141		192			

Heterogeneity: $Tau^2 = 0.11$; $Chi^2 = 12.47$, df = 9 (P = 0.19); $I^2 = 28\%$
Test for overall effect: Z = 3.35 (P = 0.0008)



The effects of goal-directed fluid therapy based on dynamic parameters on post-surgical outcome: a meta-analysis of randomized controlled trials

Jan Benes[1*], Mariateresa Giglio[2], Nicola Brienza[2] and Frederic Michard[3]

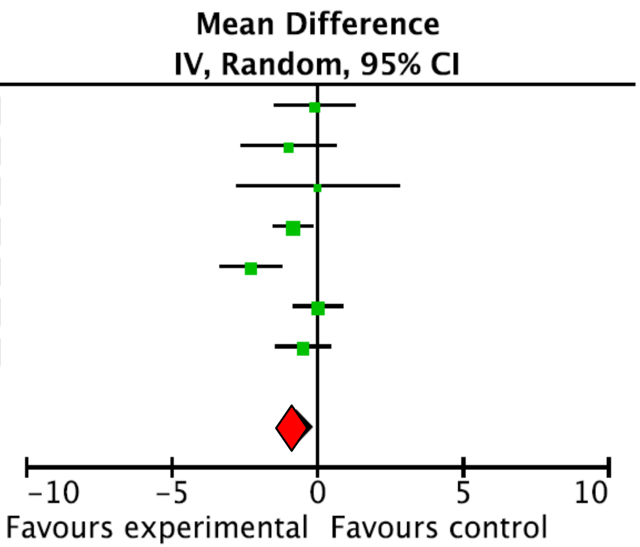
Critical Care 2014, **18**:584

ICU length of stay

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Benes 2010 (30)	3.7	3.3	60	3.8	4.4	60	12.0%	−0.10 [−1.49, 1.29]
Buettner 2008 (11)	1.8	1.5	40	2.8	5.1	40	9.7%	−1.00 [−2.65, 0.65]
Forget 2010 (29)	1.8	5.7	41	1.8	7.2	41	4.2%	0.00 [−2.81, 2.81]
Goepfert 2013 (28)	1.75	0.8	50	2.6	2.4	50	21.6%	−0.85 [−1.55, −0.15]
Kapoor 2008 (31)	2.6	0.9	13	4.9	1.8	14	16.0%	−2.30 [−3.36, −1.24]
Mayer 2010 (32)	1.7	1.6	30	1.7	1.8	30	19.0%	0.00 [−0.86, 0.86]
Scheeren 2013 (25)	1.3	1.2	26	1.8	2.2	26	17.4%	−0.50 [−1.46, 0.46]
Total (95% CI)			**260**			**261**	**100.0%**	**−0.75 [−1.37, −0.12]**

Heterogeneity: $Tau^2 = 0.34$; $Chi^2 = 12.62$, df = 6 (P = 0.05); $I^2 = 52\%$

Test for overall effect: Z = 2.35 (P = 0.02)



Applicability of pulse pressure variation: how many shades of grey?

Frederic Michard[1*], Denis Chemla[2] and Jean-Louis Teboul[3]

Critical Care (2015) 19:144

		False positive	False negative
L	**Low** HR/RR ratio (Extreme bradycardia or high frequency ventilation)		✓
I	**Irregular** heart beats	✓	
M	**Mechanical** ventilation with low tidal volume		✓
I	**Increased** abdominal Pressure (Pneumoperitoneum)	✓	
T	**Thorax** open		✓
S	**Spontaneous** breathing	✓	✓

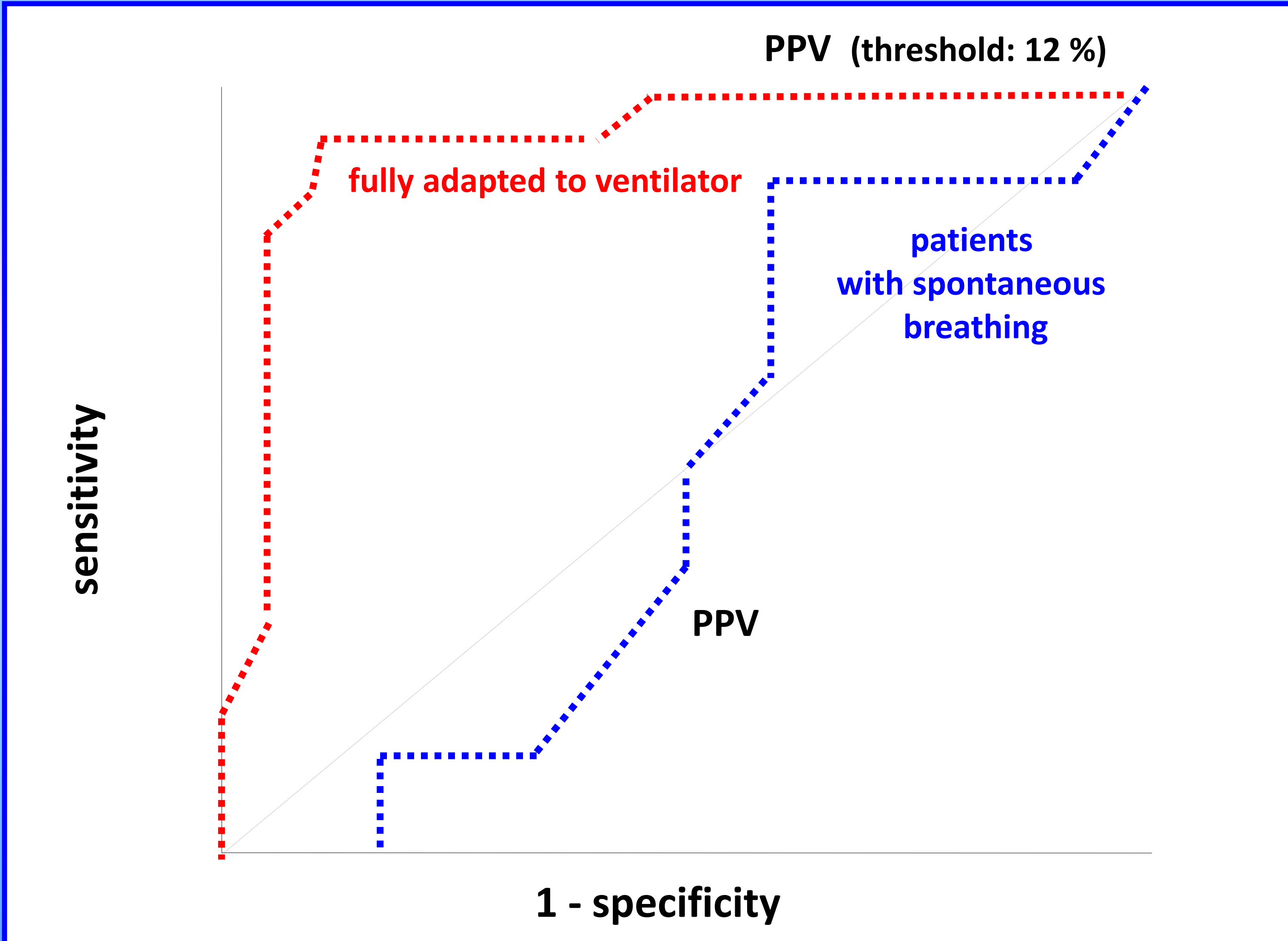
Limitations of respiratory variability indices

- impossible to interpret in pts with **spontaneous breathing activity**

Passive leg raising predicts fluid responsiveness in the critically ill*

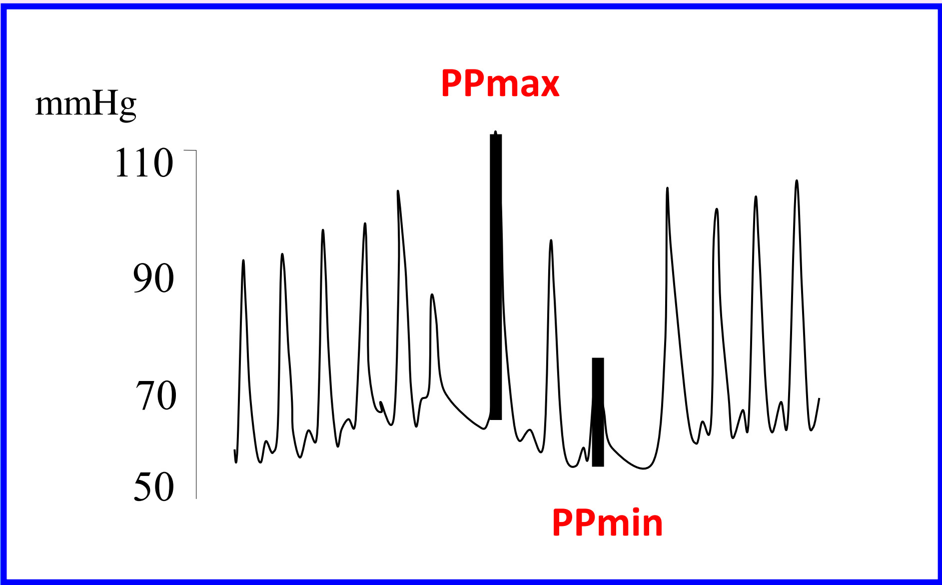
Xavier Monnet, MD, PhD; Mario Rienzo, MD; David Osman, MD; Nadia Anguel, MD; Christian Richard, MD; Michael R. Pinsky, MD, Dr hc; Jean-Louis Teboul, MD, PhD

Crit Care Med 2006; 34:1402–1407



Limitations of respiratory variability indices

- impossible to interpret in pts with **spontaneous breathing activity**
- impossible to interpret in patients with **arrhythmias**



Limitations of respiratory variability indices

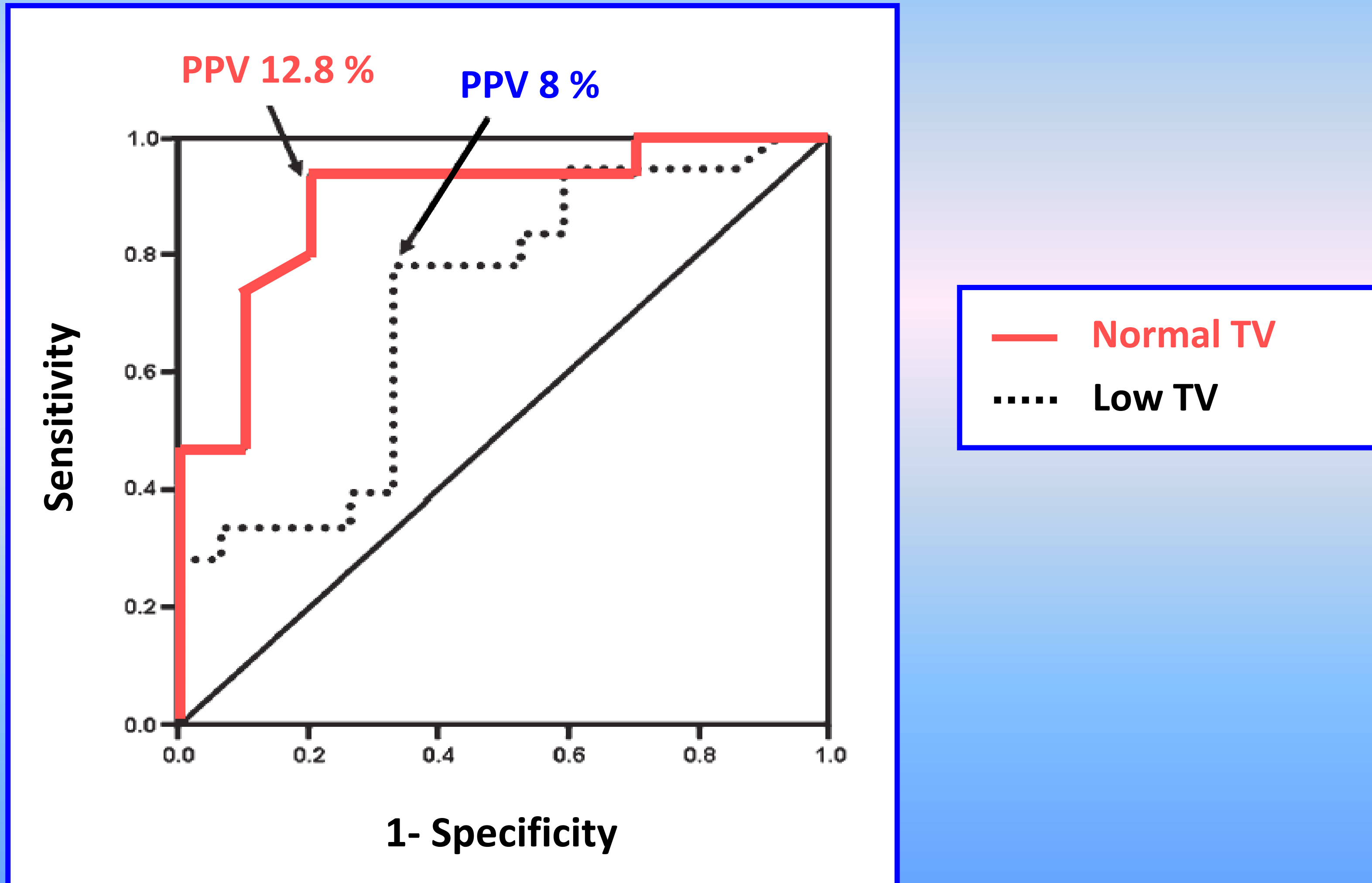
- impossible to interpret in pts with **spontaneous breathing activity**
- impossible to interpret in patients with **arrhythmias**
- difficult to interpret if **tidal volume** is **too low**

Intensive Care Med (2005) 31:517–523
DOI 10.1007/s00134-005-2586-4

ORIGINAL

Daniel De Backer
Sarah Heenen
Michael Piagnerelli
Marc Koch
Jean-Louis Vincent

Pulse pressure variations to predict fluid responsiveness: influence of tidal volume



Limitations of respiratory variability indices

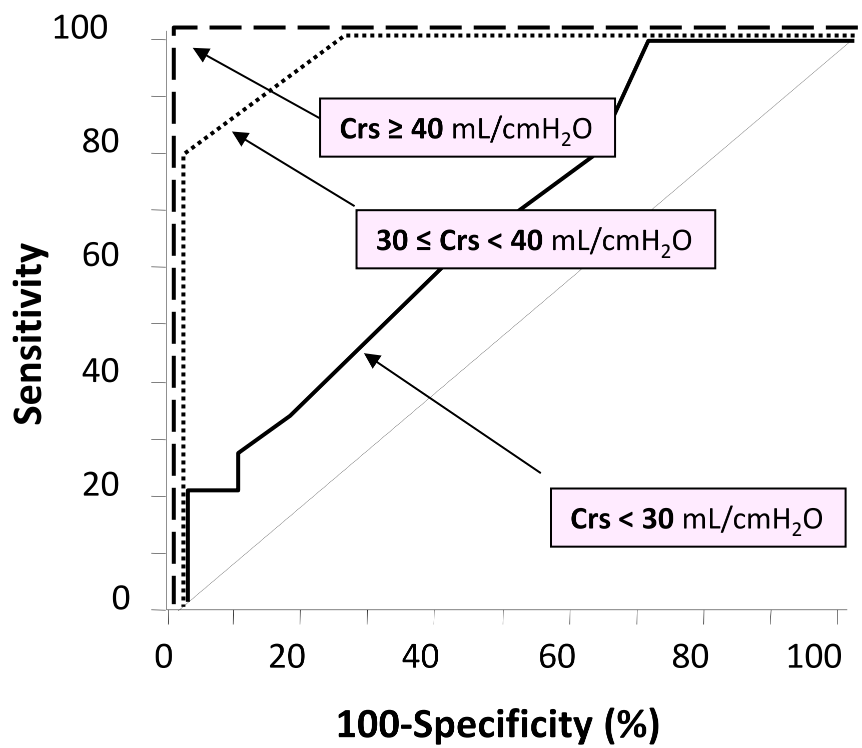
- impossible to interpret in pts with **spontaneous breathing activity**
- impossible to interpret in patients with **arrhythmias**
- difficult to interpret if **tidal volume** is **too low**
- difficult to interpret if **lung compliance** is **too low**

Passive leg-raising and end-expiratory occlusion tests perform better than pulse pressure variation in patients with low respiratory system compliance

Xavier Monnet, MD, PhD; Alexandre Bleibtreu, MD; Alexis Ferre, MD; Martin Dres, MD; Rim Gharbi, MD; Christian Richard, MD; Jean-Louis Teboul, MD, PhD

Crit Care Med 2012; 40:152–157

Ability of **PPV** to predict **fluid responsiveness** in function of **lung compliance**



Limitations of respiratory variability indices

- impossible to interpret in pts with **spontaneous breathing activity**
- impossible to interpret in patients with **arrhythmias**
- difficult to interpret if **tidal volume** is **too low**
- difficult to interpret if **lung compliance** is **too low**
- difficult to interpret in case of **high frequency ventilation**

PPV can be not reliable when the **heart rate/respiratory rate** is **> 3.6**

De Backer et al Anesthesiology 2009

Limitations of respiratory variability indices

- impossible to interpret in pts with **spontaneous breathing activity**
- impossible to interpret in patients with **arrhythmias**
- difficult to interpret if **tidal volume** is **too low**
- difficult to interpret if **lung compliance** is **too low**
- difficult to interpret in case of **high frequency ventilation**
- difficult to interpret under **open-chest conditions**
- difficult to interpret in case of **severe RV failure**

Mahjoub et al Crit Care Med 2009, Wyler von Ballmoos et al Crit Care 2010

Limitations of respiratory variability indices

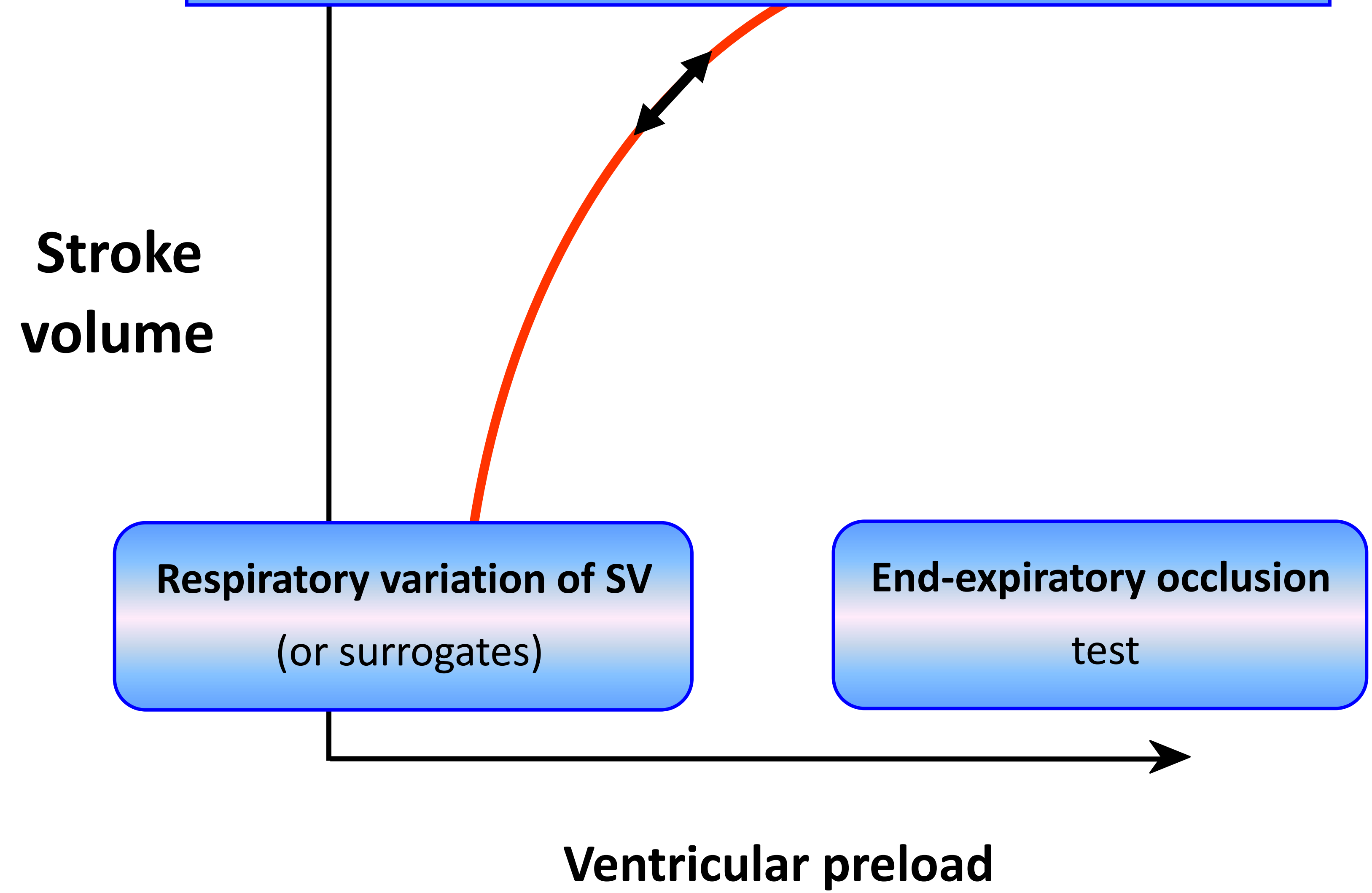
- impossible to interpret in pts with **spontaneous breathing activity**
- impossible to interpret in patients with **arrhythmias**
- difficult to interpret if **tidal volume** is **too low**
- difficult to interpret if **lung compliance** is **too low**
- difficult to interpret in case of **high frequency ventilation**

In all these situations and in case of any doubt about interpretation

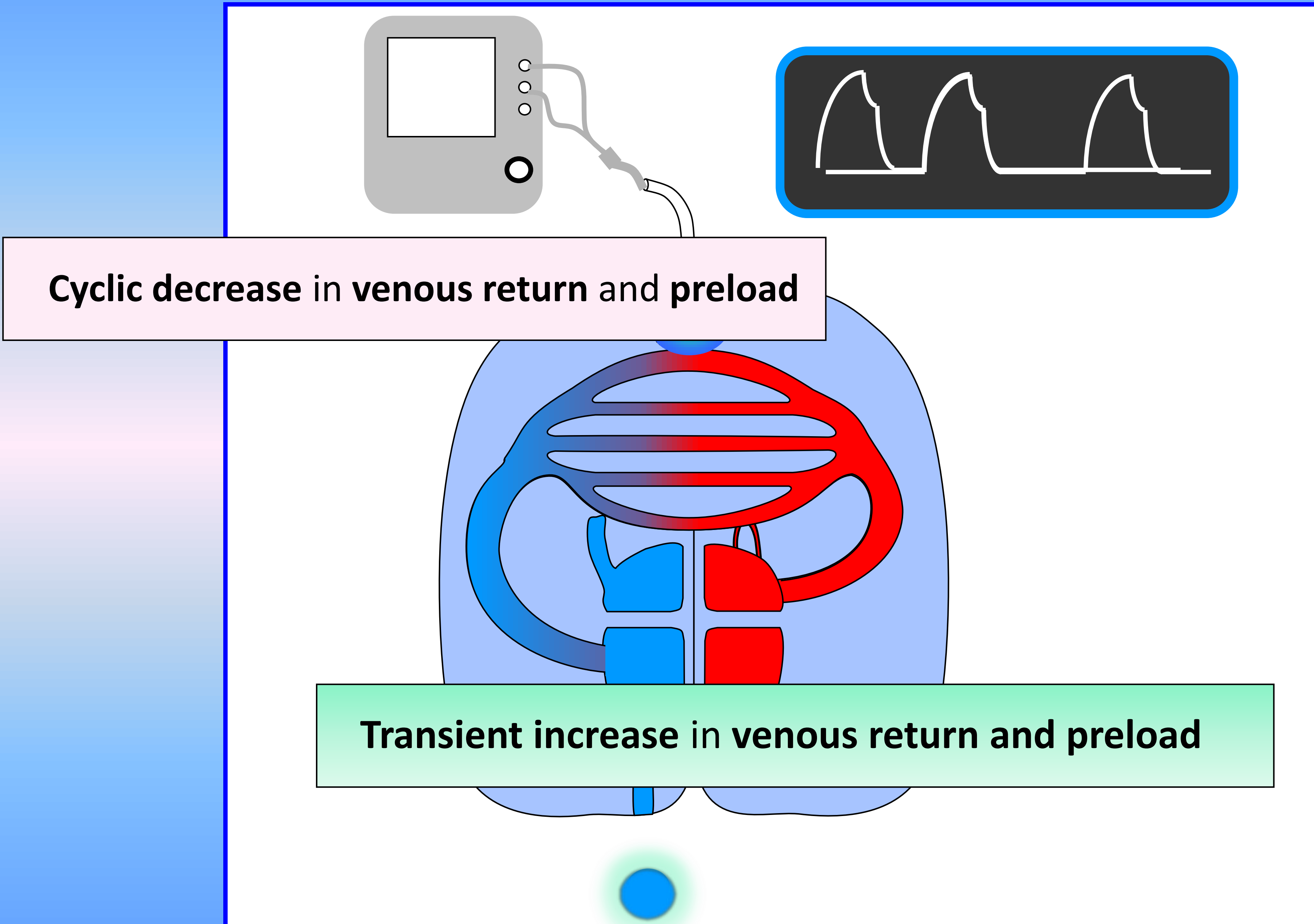
other reliable dynamic tests are required

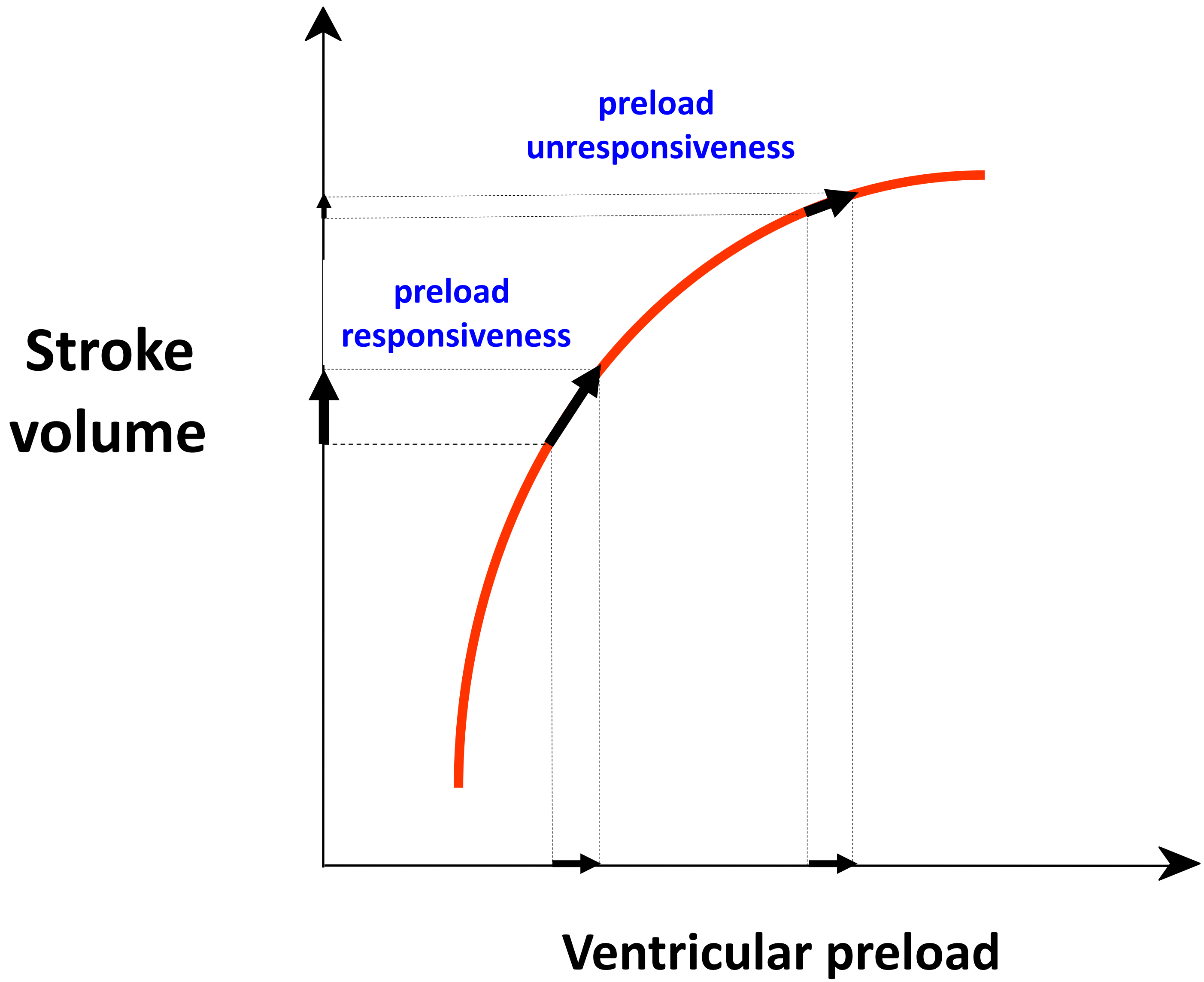
… and are now available

Heart-lung interaction indices

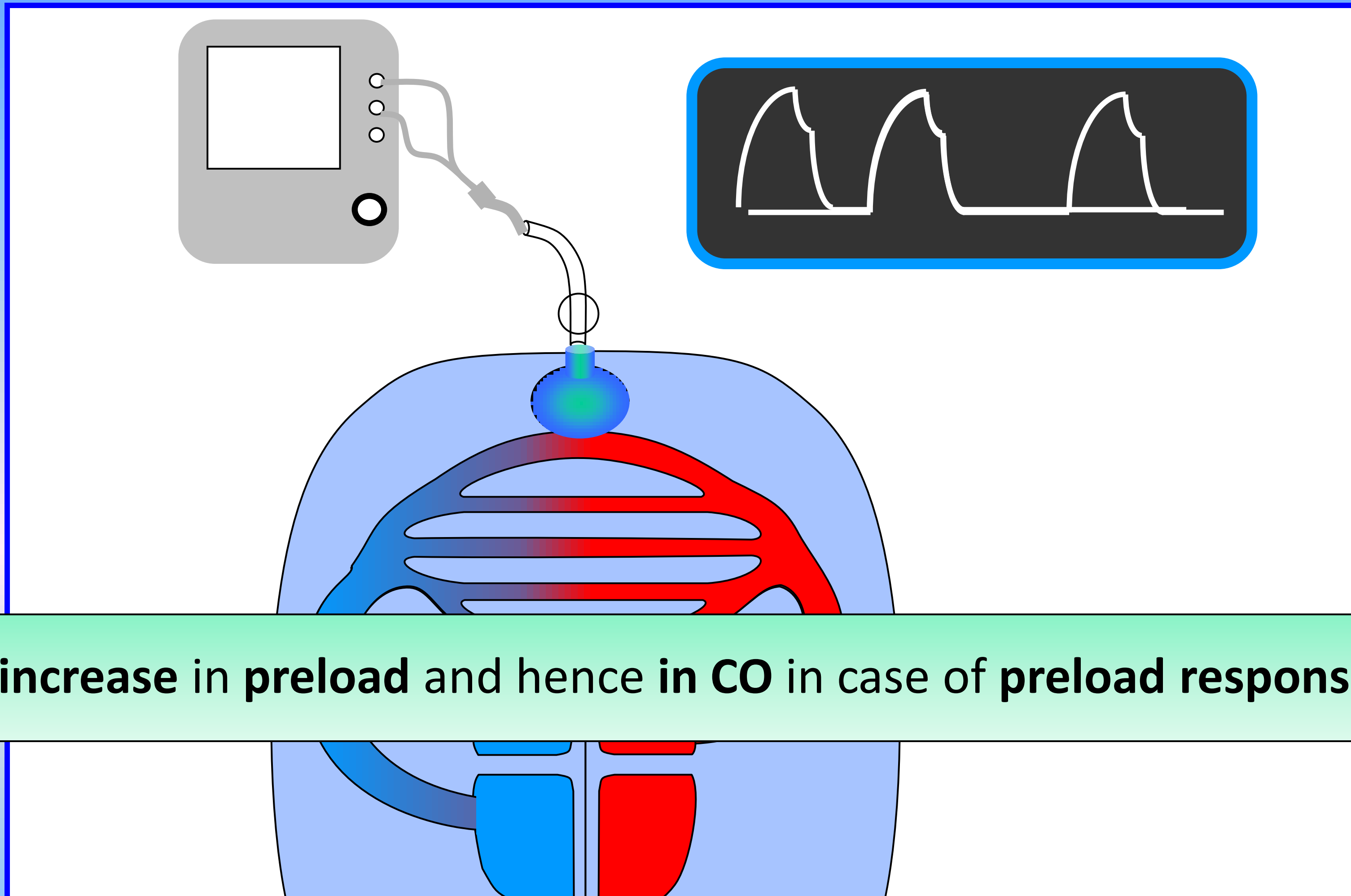


End-expiratory occlusion test




preload
unresponsiveness
preload
responsiveness
Stroke
volume
Ventricular preload

End-expiratory occlusion test



Transient increase in **preload** and hence **in CO** in case of **preload responsiveness**

Fluid responders should be identified

by an **increase** of their **CO** during the **end-expiration occlusion test**

Predicting volume responsiveness by using the end-expiratory occlusion in mechanically ventilated intensive care unit patients

Xavier Monnet, MD, PhD; David Osman, MD; Christophe Ridel, MD; Bouchra Lamia, MD; Christian Richard, MD; Jean-Louis Teboul, MD, PhD

Crit Care Med 2009; 37:951–956

	Responders (n = 23)	Nonresponders (n = 11)
Sepsis (n)	22	10
ARDS (n)	18	5
Tidal volume (mL/kg)	6.8 ± 1.1	6.8 ± 1.1
Total PEEP (cm H_2O)	8 ± 3	7 ± 2
LV ejection fraction (%)	53 ± 9	53 ± 5
Pa_{O}/F_{IO_2} (mm Hg)	123 ± 57	195 ± 122
I/E ratio	0.4 ± 0.1	0.3 ± 0.1
Patients receiving norepinephrine (n)	18	5
Rate of norepinephrine infusion (µg/kg/min)	1.0 ± 0.3	1.1 ± 0.4

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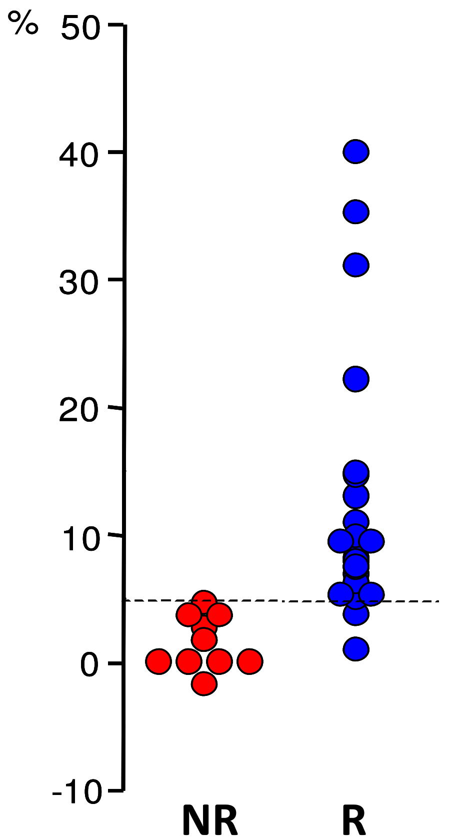
Crit Care Med 2009; 37:951–956

effect of eeO

on **Pulse contour CO**



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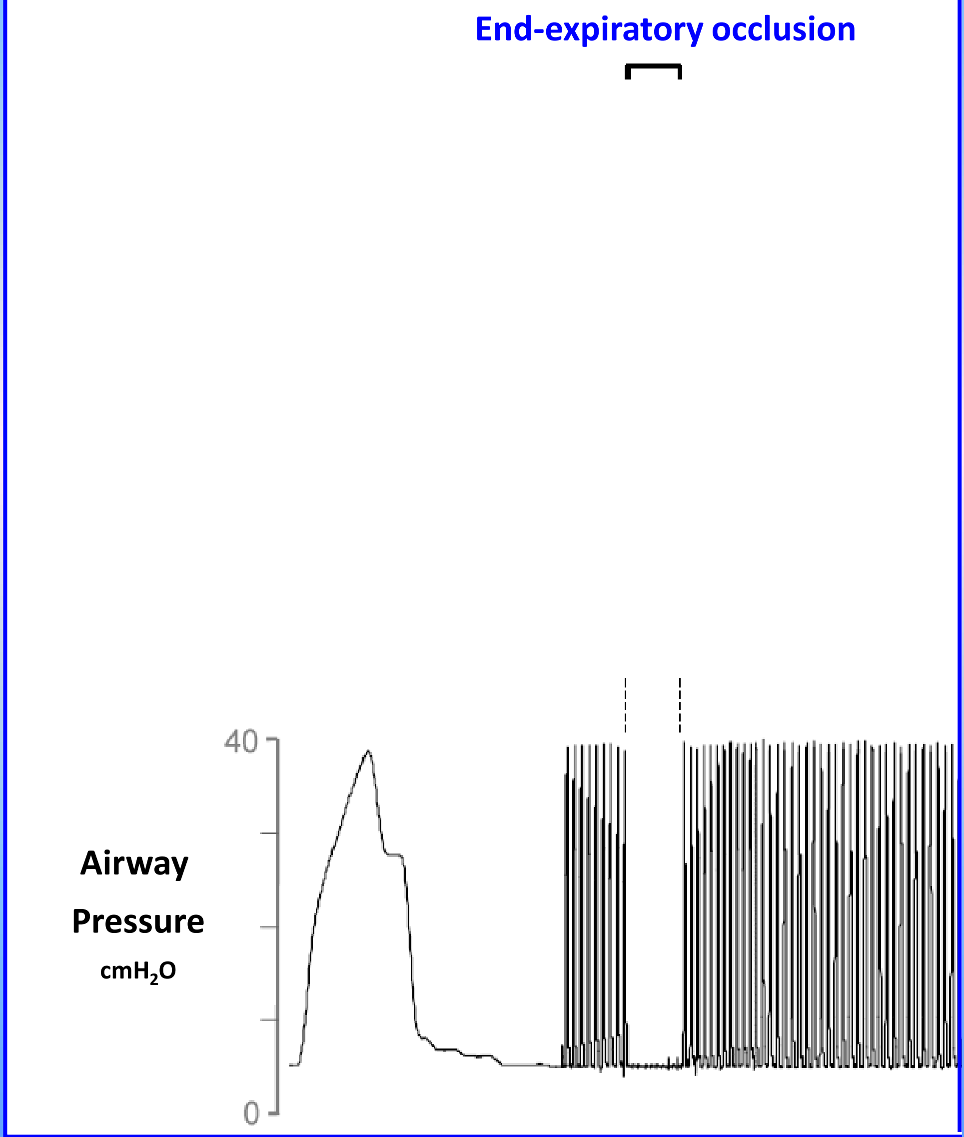

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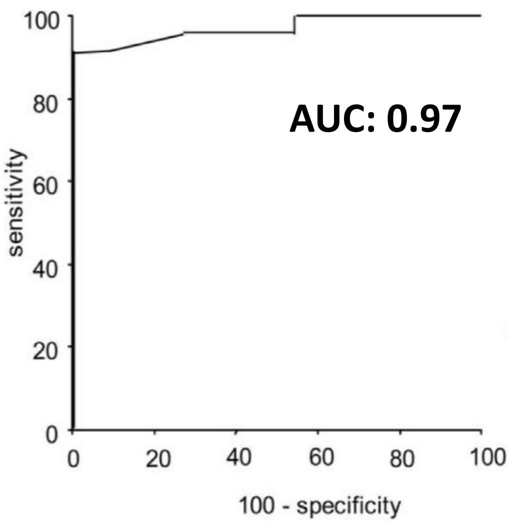
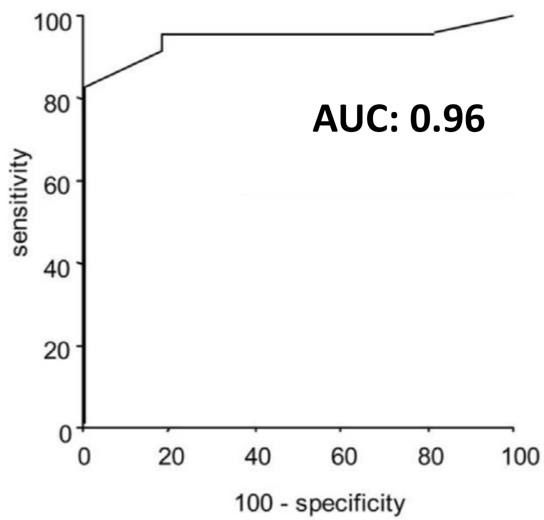
Crit Care Med 2009; 37:951–956

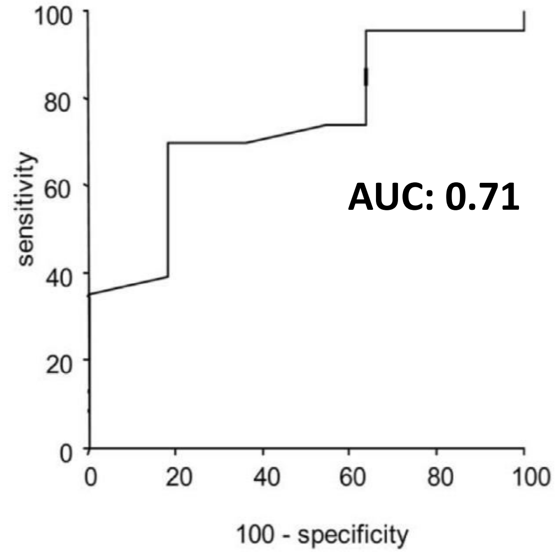
effect of **eeO**
on **CO**



effect of **eeO**
on **PP**



effect of **eeO**
on **SAP**



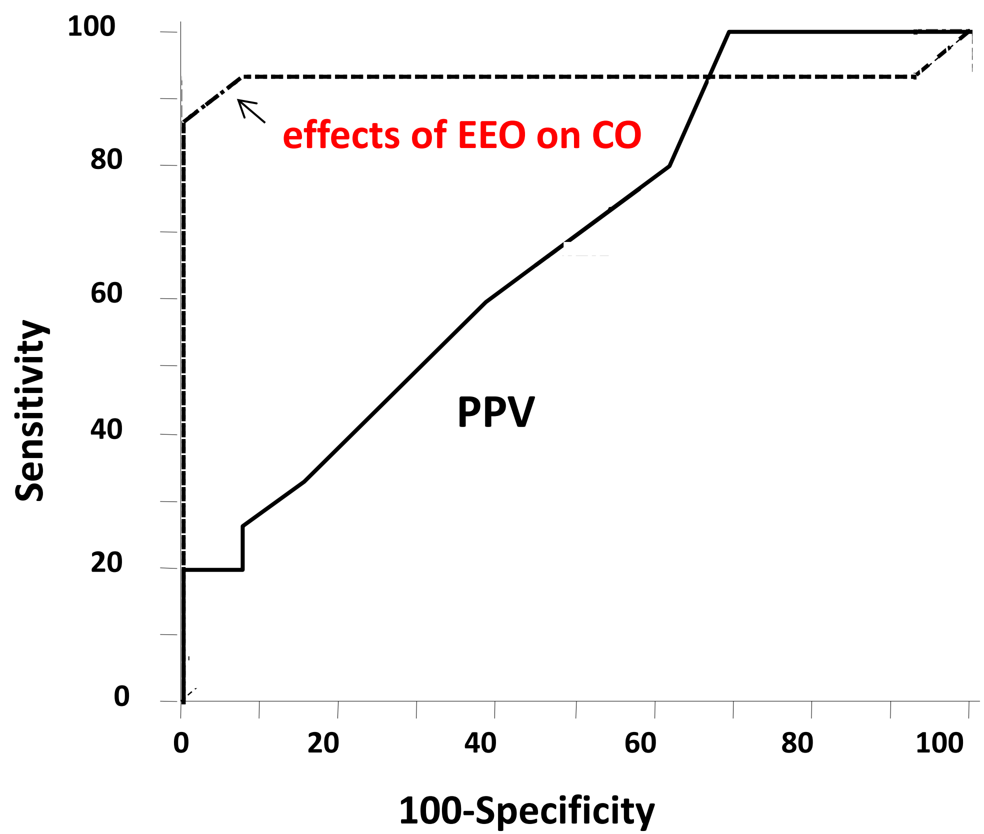
Passive leg-raising and end-expiratory occlusion tests perform better than pulse pressure variation in patients with low respiratory system compliance

Xavier Monnet, MD, PhD; Alexandre Bleibtreu, MD; Alexis Ferre, MD; Martin Dres, MD; Rim Gharbi, MD; Christian Richard, MD; Jean-Louis Teboul, MD, PhD

Crit Care Med 2012; 40:152–157

Lung compliance

< 30 mL/cmH_2O

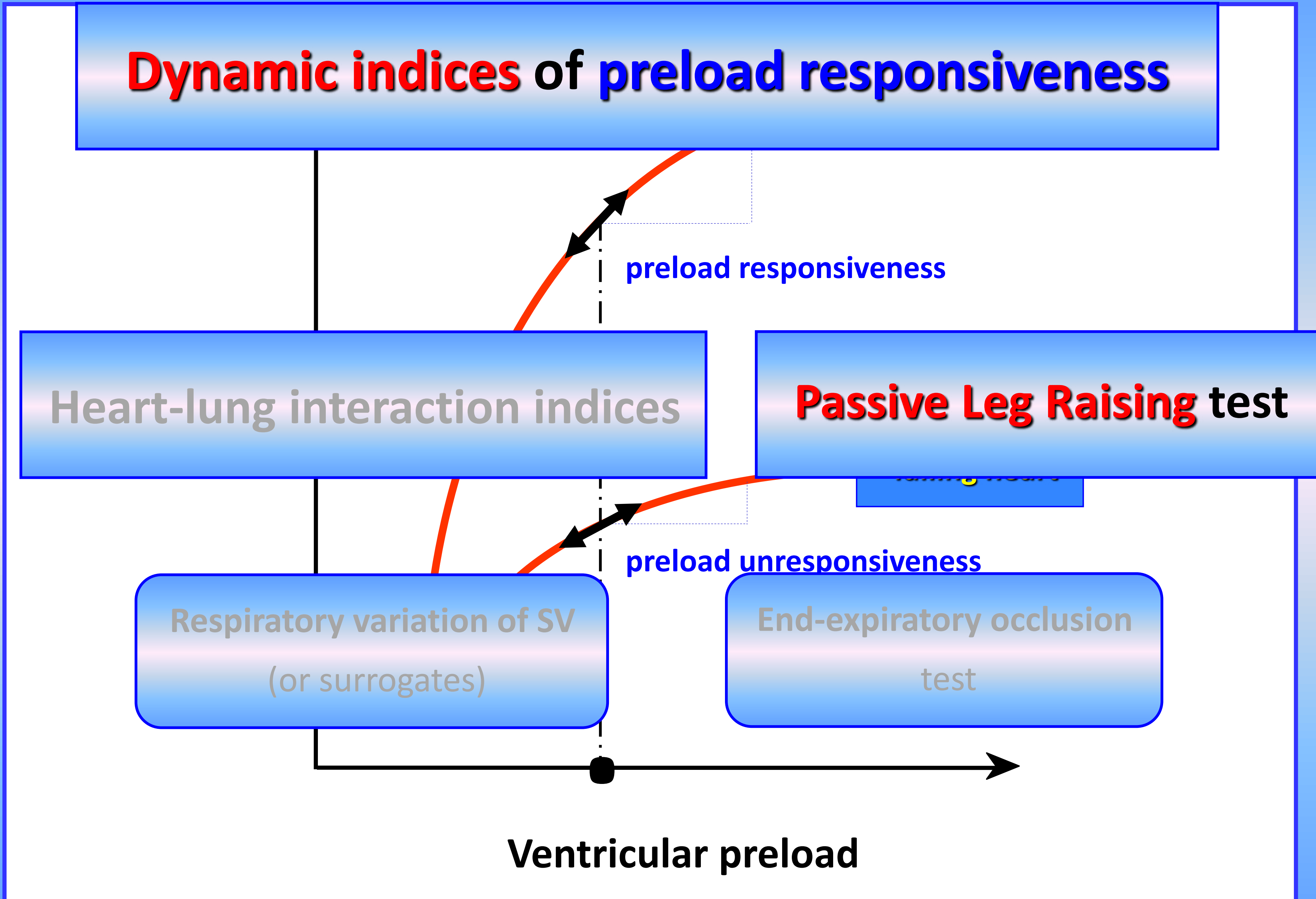


End-Expiratory Occlusion Test Predicts Preload Responsiveness Independently of Positive End-Expiratory Pressure During Acute Respiratory Distress Syndrome

Serena Silva, MD[1,2]; Mathieu Jozwiak, MD[1,2]; Jean-Louis Teboul, MD, PhD[1,2]; Romain Persichini, MD[1,2]; Christian Richard, MD[1,2]; Xavier Monnet, MD, PhD[1,2]

Crit Care Med 2013; 41:1692–1701

	Area Under the Receiver Operating Characteristics Curve	Cutoff (% Increase in Cardiac Index)	Sensitivity (%)	Specificity (%)
Effects of the end-expiratory occlusion on cardiac index at PEEP = 5 cm H_2O	0.90 (0.75–0.98)	5	90 (56–100)	88 (68–97)
Effects of the end-expiratory occlusion on cardiac index at high PEEP	0.96 (0.82–0.99)	6	100 (75–100)	90 (70–99)

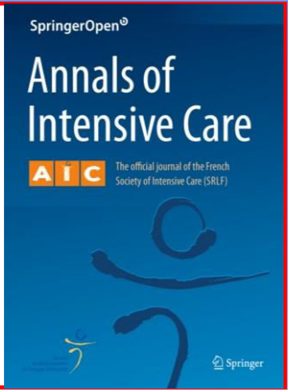


Dynamic indices of preload responsiveness
preload responsiveness
Heart-lung interaction indices
Passive Leg Raising test
preload unresponsiveness
Respiratory variation of SV
(or surrogates)
End-expiratory occlusion
test
Ventricular preload

Annals of Intensive Care 2011, **1**:1

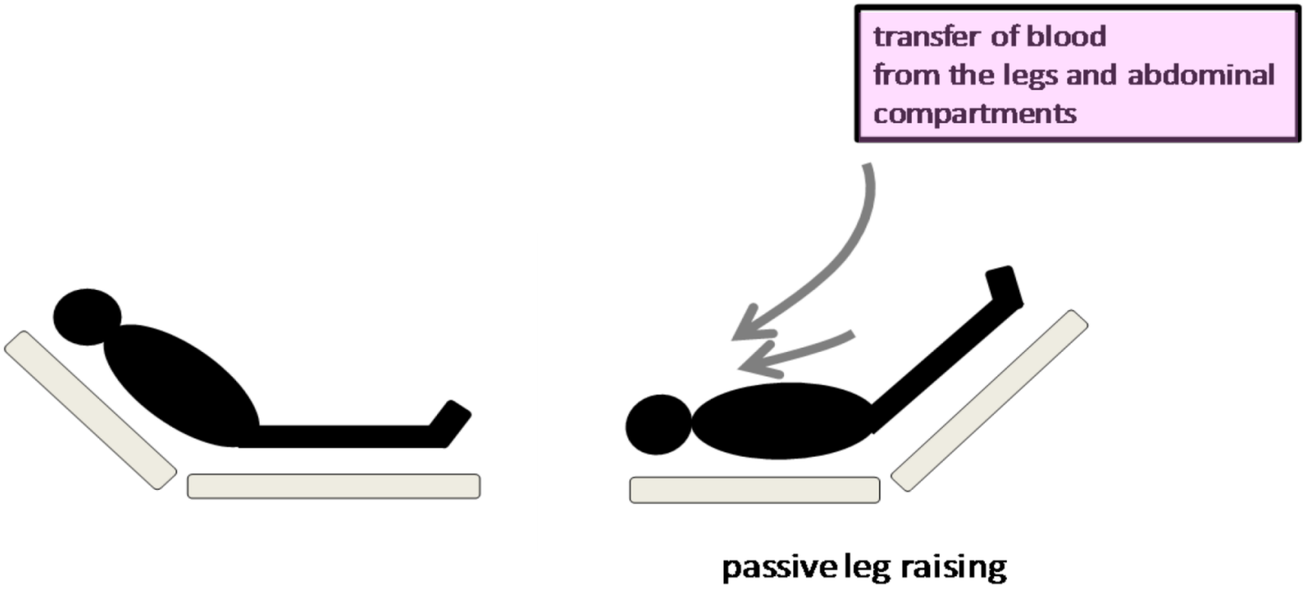
Annals of Intensive Care
a SpringerOpen Journal

REVIEW **Open Access**



Hemodynamic parameters to guide fluid therapy

Paul E Marik[1*], Xavier Monnet[2], Jean-Louis Teboul[2]

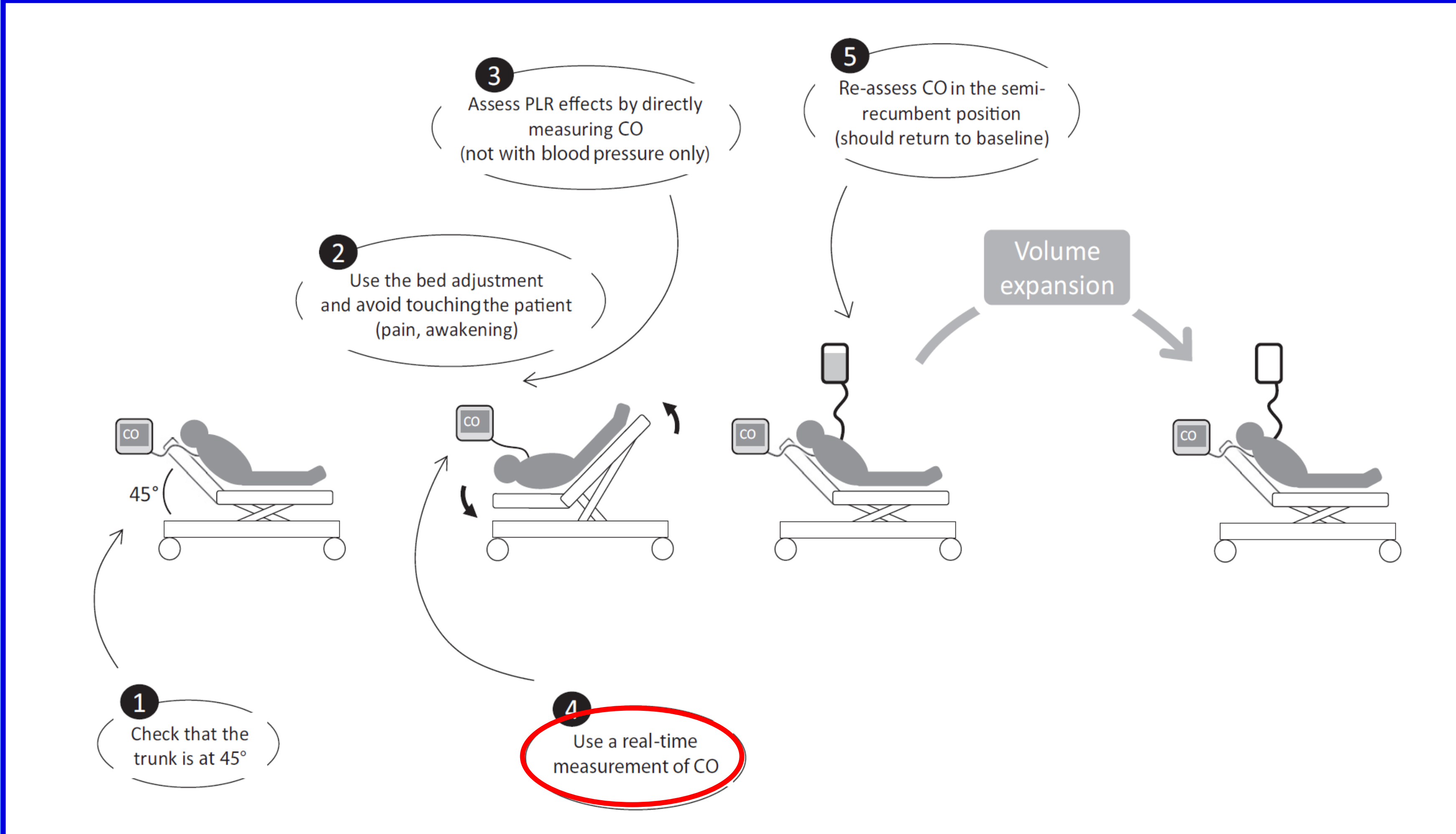


EDITORIAL

Passive leg raising: five rules, not a drop of fluid!

Xavier Monnet[1,2*] and Jean-Louis Teboul[1,2]

Crit Care 2015, 19:18

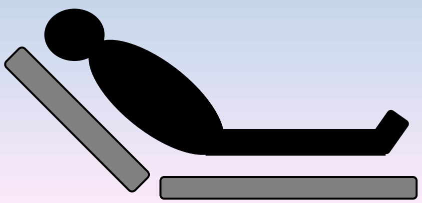


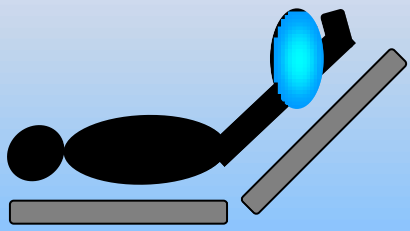
Intensive Care Med (2008) 34:659–663

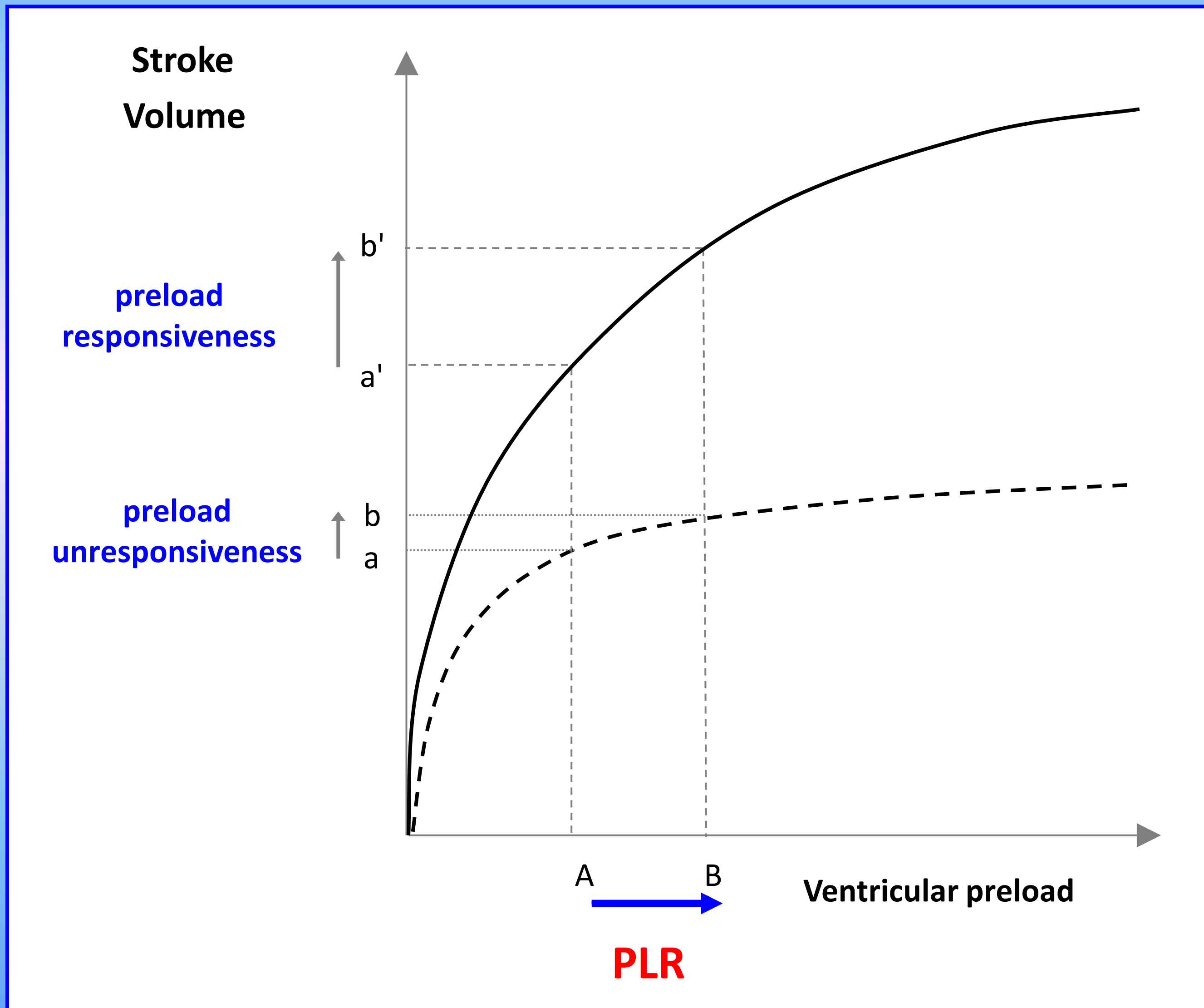
CLINICAL COMMENTARY

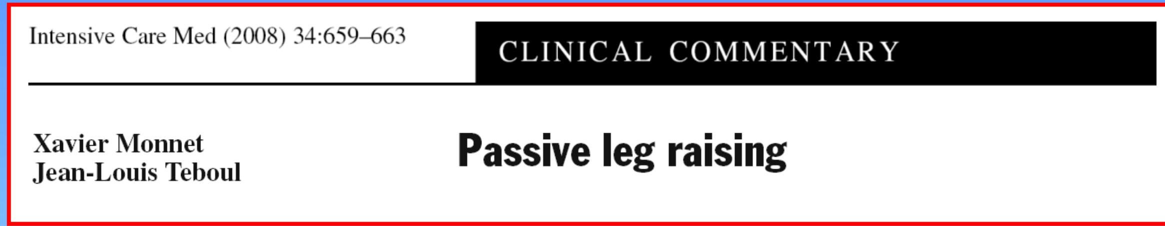
Xavier Monnet
Jean-Louis Teboul

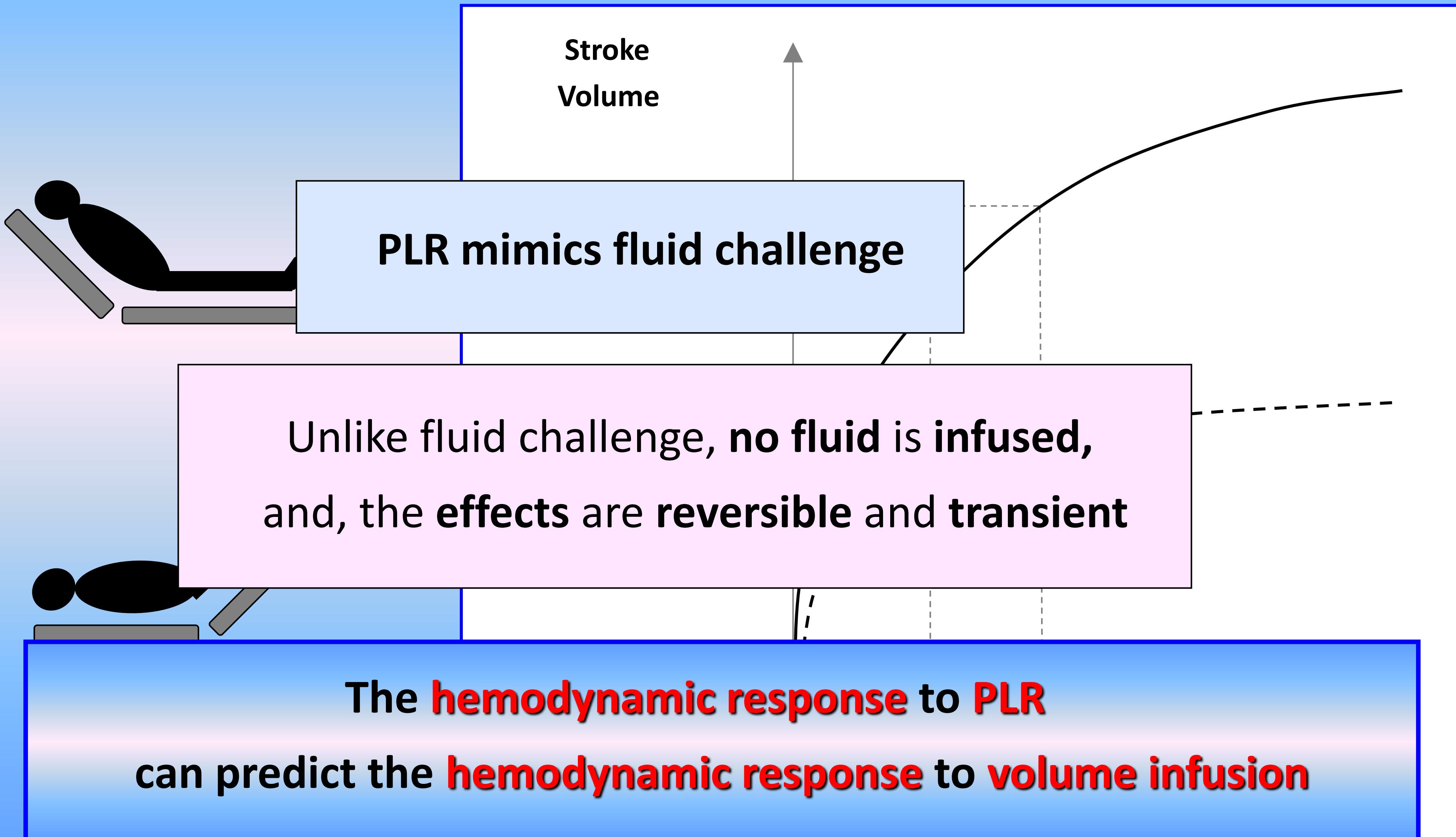
Passive leg raising











PLR mimics fluid challenge

Unlike fluid challenge, **no fluid** is **infused,**

and, the **effects** are **reversible** and **transient**

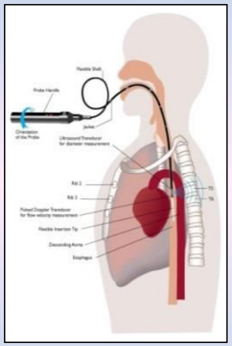
The hemodynamic response to PLR

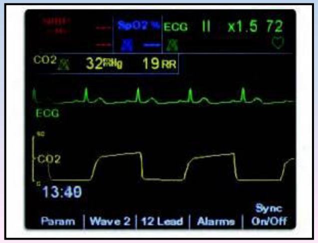
can predict the hemodynamic response to volume infusion

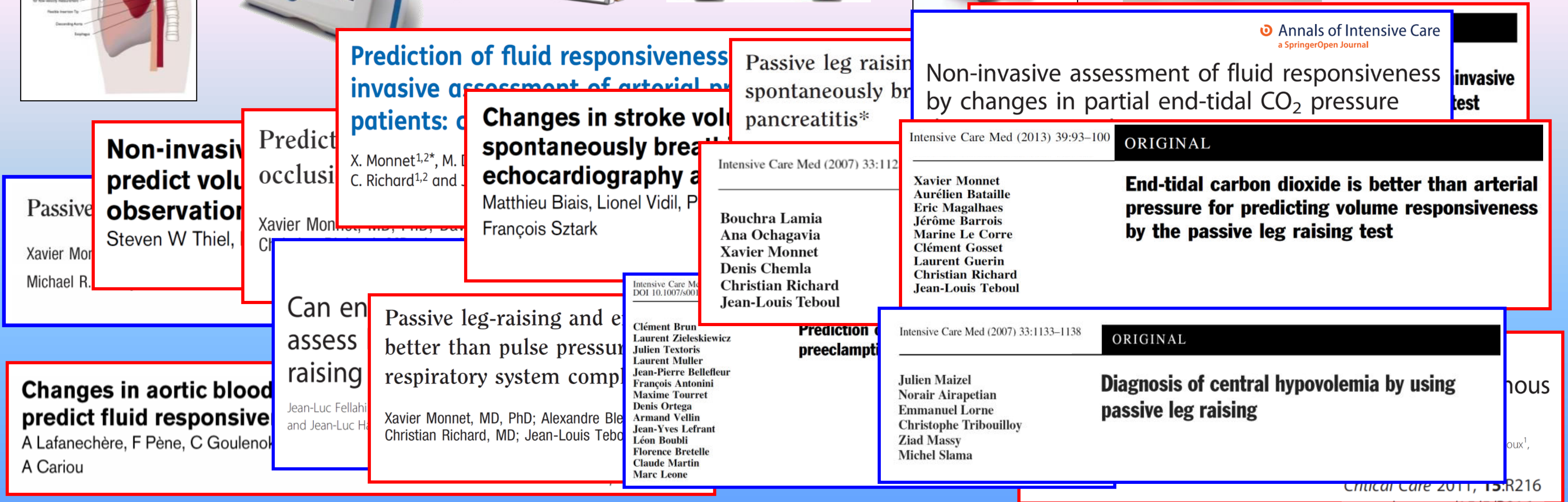
The **hemodynamic response** to **PLR**

can predict the **hemodynamic response** to **fluid infusion**

Real-time CO response to PLR







Intensive Care Med 2016

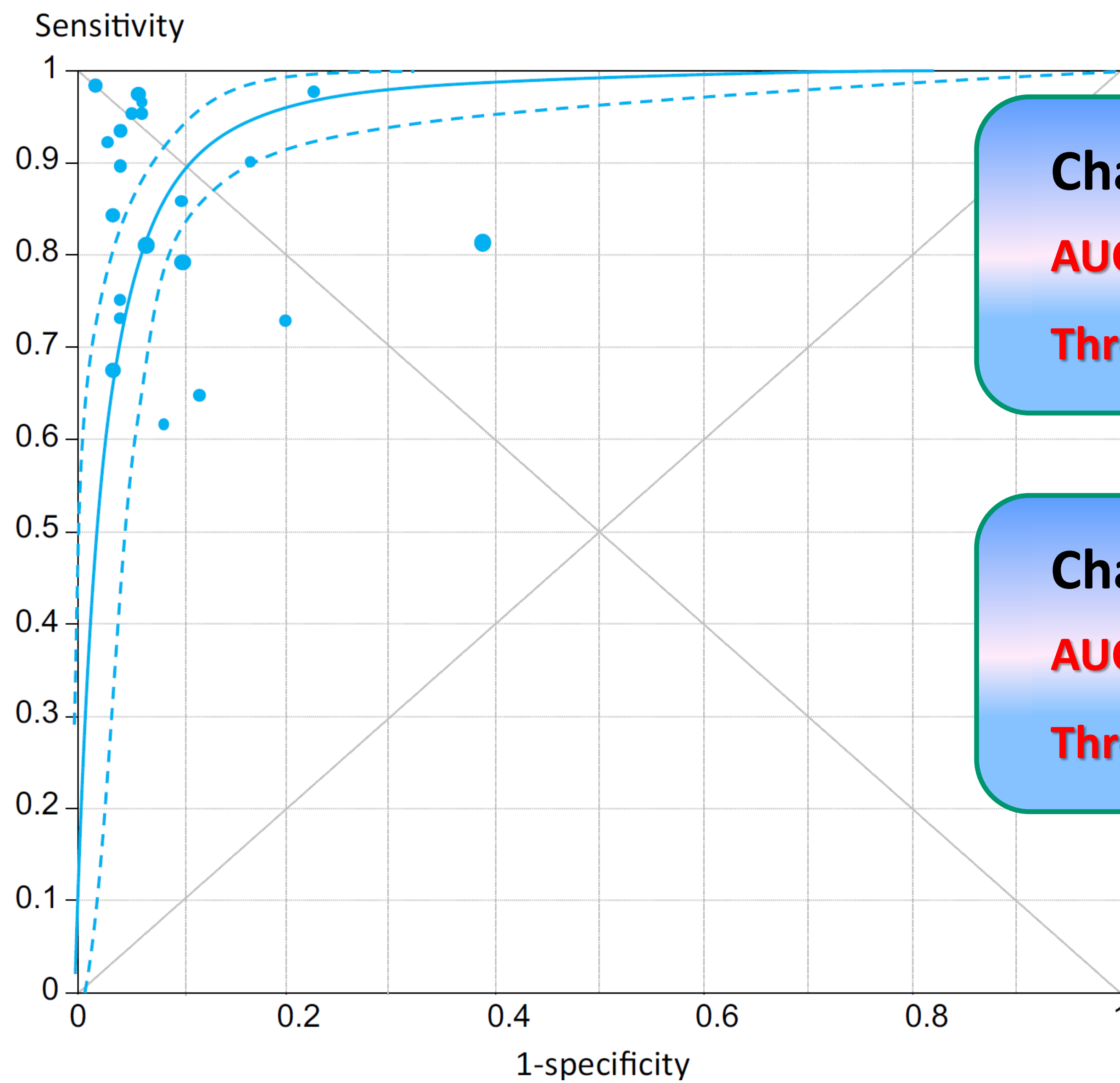
ORIGINAL

Xavier Monnet
Paul Marik
Jean-Louis Teboul

Passive leg raising for predicting fluid responsiveness: a systematic review and meta-analysis

21 clinical studies

995 patients



Changes in CO

AUC: 0.95 ± 0.01

Threshold: 10%

Changes in PP

AUC: 0.77 ± 0.05

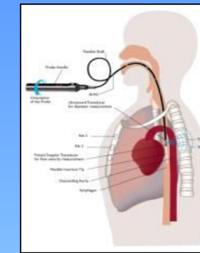
Threshold: 12%

Monnet X, Marik PM, Teboul JL ICM *in press*

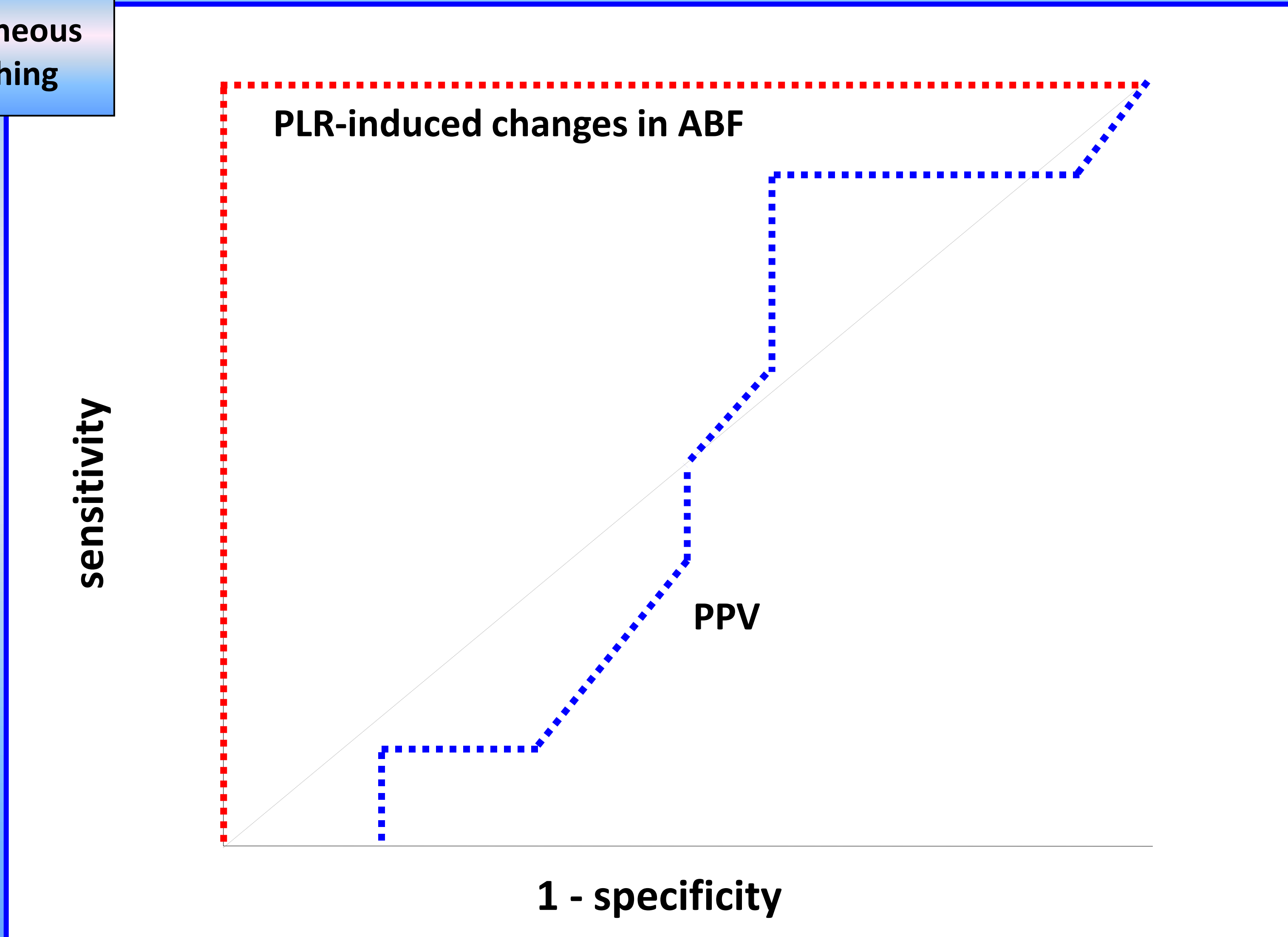
Passive leg raising predicts fluid responsiveness in the critically ill*

Xavier Monnet, MD, PhD; Mario Rienzo, MD; David Osman, MD; Nadia Anguel, MD; Christian Richard, MD; Michael R. Pinsky, MD, Dr hc; Jean-Louis Teboul, MD, PhD

Crit Care Med 2006; 34:1402–1407



Pts with **spontaneous breathing**



Passive leg-raising and end-expiratory occlusion tests perform better than pulse pressure variation in patients with low respiratory system compliance

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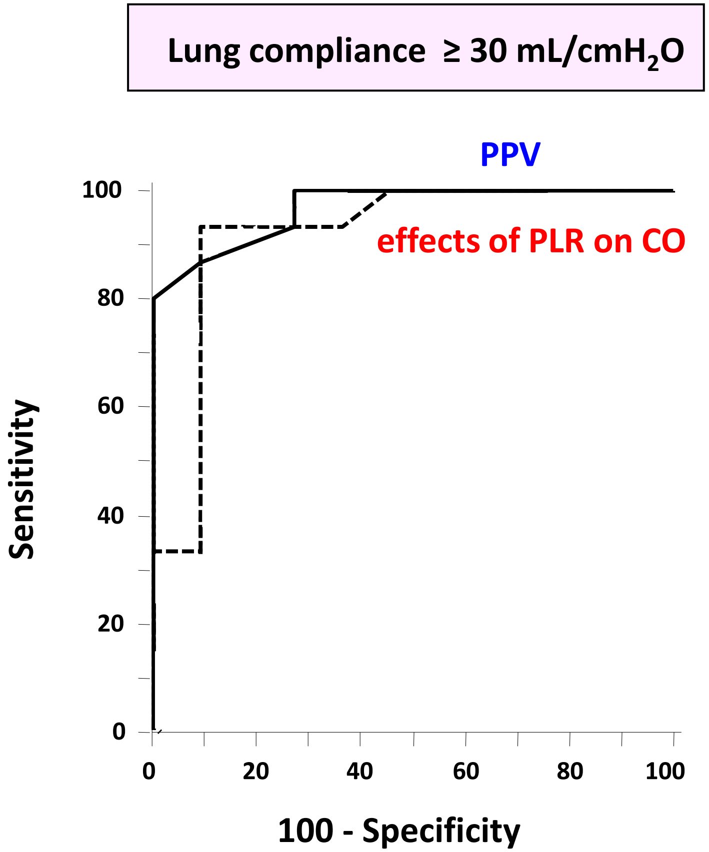
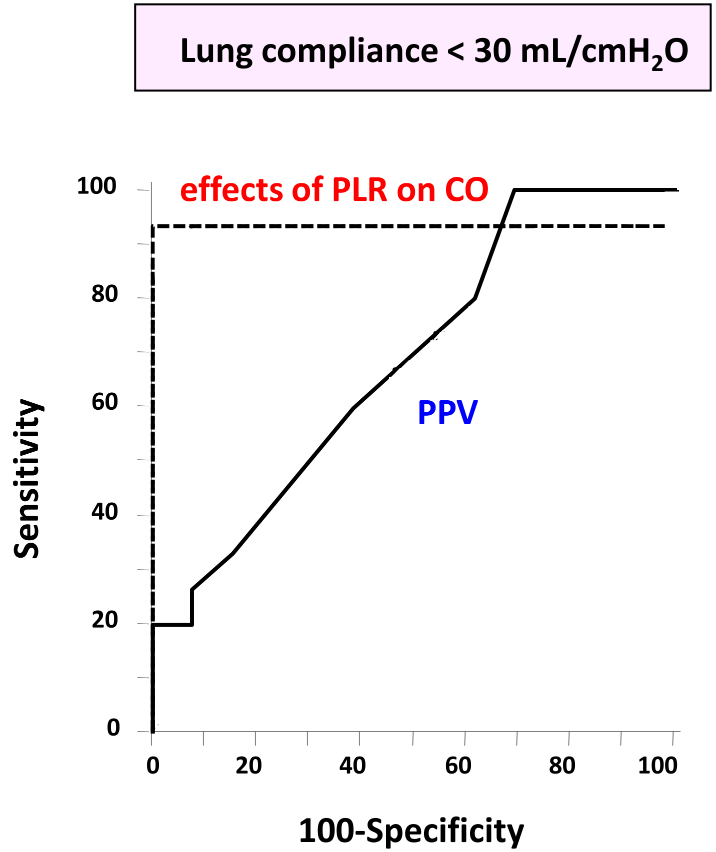
Crit Care Med 2012; 40:152–157





Preload dependence indices to titrate volume expansion during septic shock: a randomized controlled trial

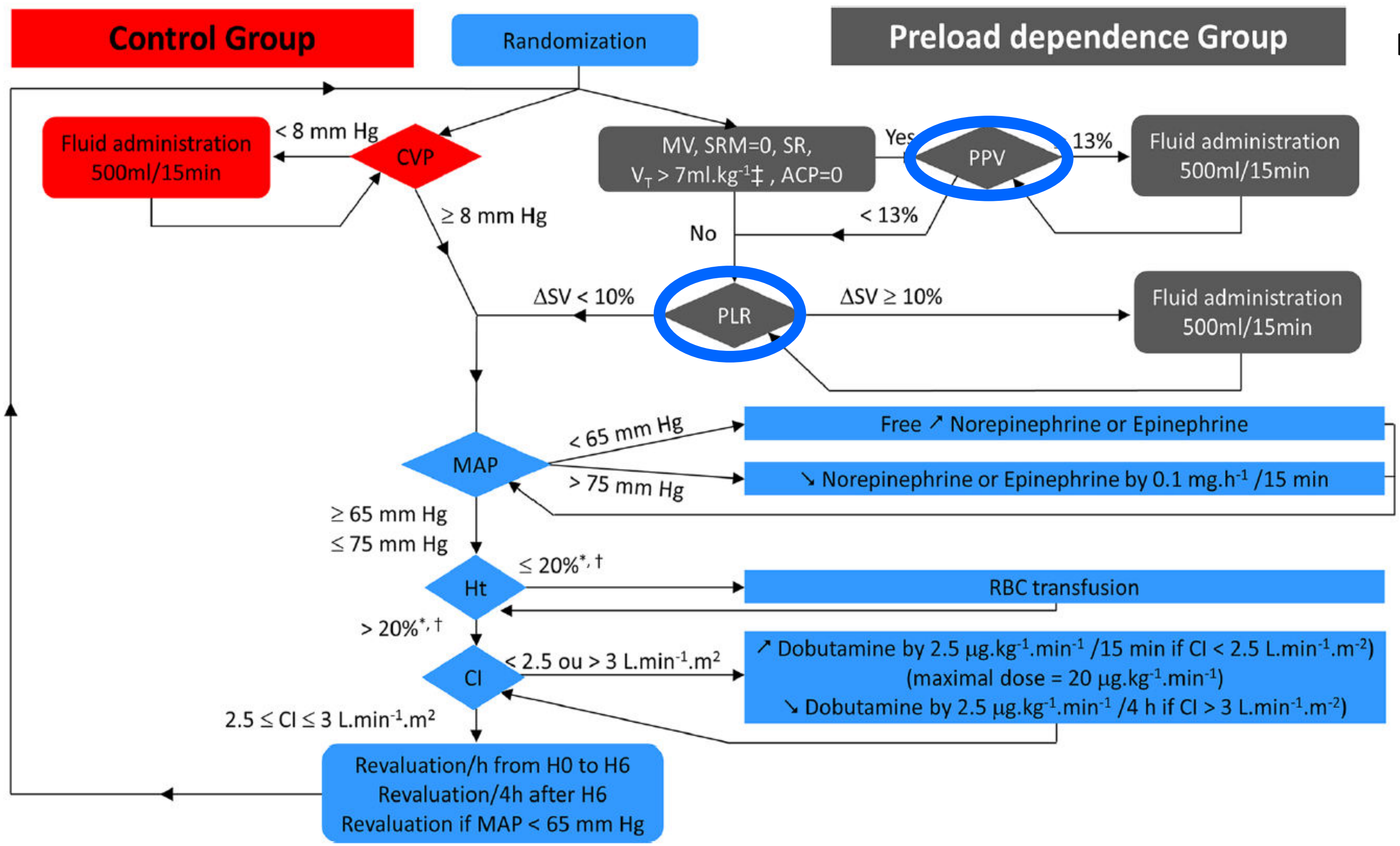
Jean-Christophe Richard[1,2,3*], Frédérique Bayle[1], Gael Bourdin[1], Véronique Leray[1], Sophie Debord[1], Bertrand Delannoy[1], Alina Cividjian Stoian[1,2], Florent Wallet[1], Hodane Yonis[1,2] and Claude Guerin[1,2,3]

Critical Care (2015) 19:5

Septic shock pts

n = 30 pts

n = 30 pts



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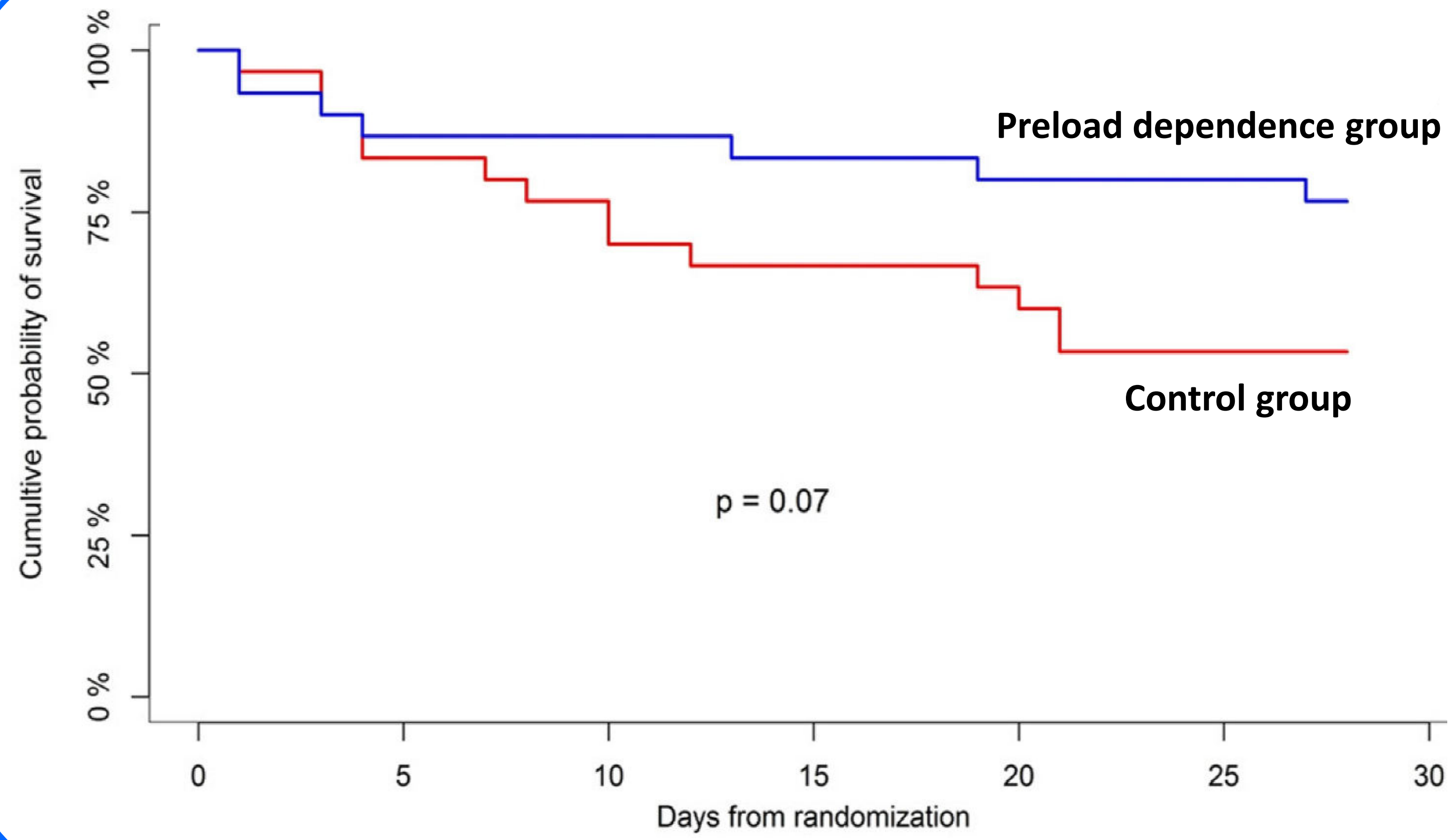
Critical Care (2015) 19:5



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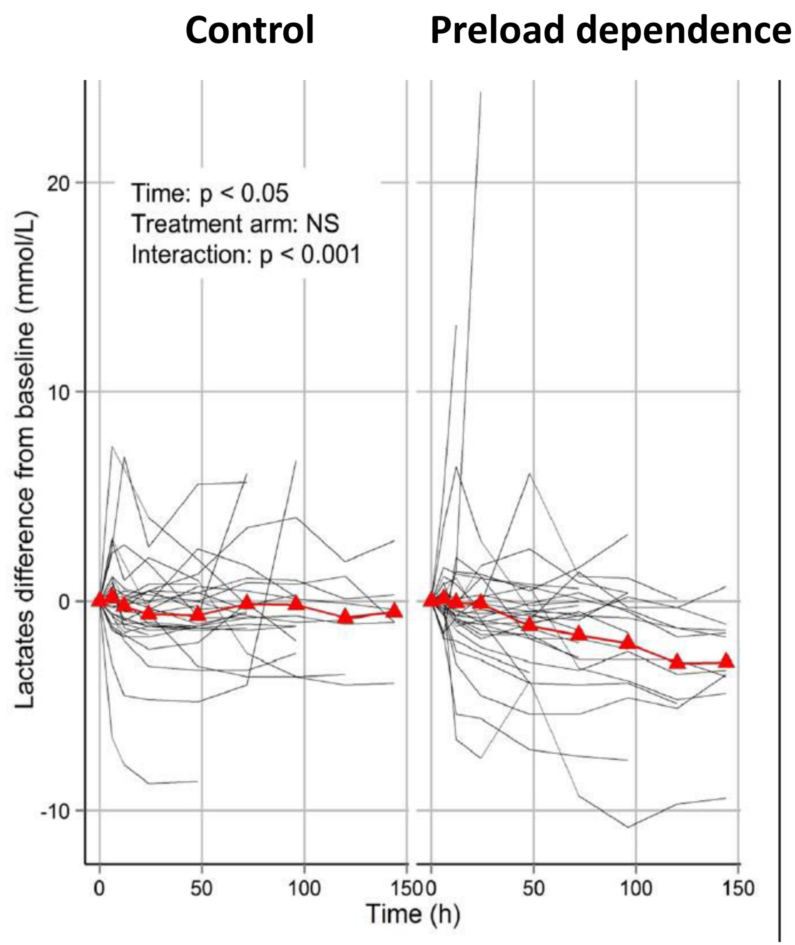
Critical Care (2015) 19:5



Preload dependence indices to titrate volume expansion during septic shock: a randomized controlled trial

Jean-Christophe Richard[1,2,3*], Frédérique Bayle[1], Gael Bourdin[1], Véronique Leray[1], Sophie Debord[1], Bertrand Delannoy[1], Alina Cividjian Stoian[1,2], Florent Wallet[1], Hodane Yonis[1,2] and Claude Guerin[1,2,3]

Critical Care (2015) 19:5

	Control (n = 30)	Preload dependence (n = 30)
Intravascular volume expansion ITT ($mL.day^{-1}$)	986 [654-1,624]	446 [295-1,105] *
Intravascular volume expansion PP ($mL.day^{-1}$)	917 [639-1,511]	383 [211-604] *
RBC transfusion ($mL.day^{-1}$)	178 [82-304]	103 (0-183] *

Decision of **starting** fluid administration

- presence of **hemodynamic instability/peripheral hypoperfusion** (mottled skin, hypotension, oliguria, hyperlactatemia…)
- <u>and</u> presence of **preload responsiveness**
- <u>and</u> **limited risks** of **fluid overload**

Decision of **stopping** fluid administration

- either disappearance of **hemodynamic instability**
- or presence of preload **unresponsiveness**
- or **high risks** of **fluid overload** or severe **hypoxemic** lung injury

Intensive Care Med (2007) 33:575–590

INTERNATIONAL CONSENSUS CONFERENCE

Massimo Antonelli
Mitchell Levy
Peter J. D. Andrews
Jean Chastre
Leonard D. Hudson
Constantine Manthous
G. Umberto Meduri
Rui P. Moreno
Christian Putensen
Thomas Stewart
Antoni Torres

Hemodynamic monitoring in shock and implications for management

International Consensus Conference, Paris, France, 27–28 April 2006

Intensive Care Med (2014) 40:1795–1815

CONFERENCE REPORTS AND EXPERT PANEL

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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

Topic	ICM Antonelli 2007

- We **do not recommend** the routine use of **dynamic measures** of fluid responsiveness (including but not limited to pulse pressure variation, aortic flow changes, systolic pressure variation, respiratory systolic variation test, collapse of vena cava).

  Level 1; QoE high (A)

- There may be some advantage to these me

  Level 1; QoE high (A)

We recommend using **dynamic** over static **variables** to predict fluid responsiveness, when applicable.

Level 1; QoE moderate (B)

Conclusion

Hemodynamic consequences

of Mechanical Insufflation

- **Venous return**
- **RV ejection**
- **LV filling**
- **LV ejection**

More marked

in cases of **hypovolemia**

Tool to assess **fluid responsiveness**

Thank you