Preload optimisation in severe sepsis and septic shock

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ASSISTANCE PUBLIQUE HÔPITAUX DE PARIS

FACULTE DE MEDECINE PARIS-SUD

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

Conflicts of interest

Member of the **Medical Advisory Board** of **Pulsion**

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**

- **Fluid Challenge**
- **Predictors of fluid responsiveness/unresponsiveness**

Fluid challenge revisited

Jean-Louis Vincent, MD, PhD, FCCM; Max Harry Weil, MD, PhD, ScD (Hon), FCCM

Crit Care Med 2006; 34:1333-1337

- Rate of infusion: **500-1000 mL crystalloids** or **300-500 mL colloids** over 30 mins
- Goal: **reversal** of the **marker of perfusion failure** that prompted the fluid challenge (ex: hypotension, tachycardia, oliguria, etc)
- Safety limits: **CVP** of **15 mmHg** measured every 10 mins

Fluid challenge revisited

Jean-Louis Vincent, MD, PhD, FCCM; Max Harry Weil, MD, PhD, ScD (Hon), FCCM

Crit Care Med 2006; 34:1333-1337

Limitations

- **Fluid challenge cannot** serve as a **test** to **predict** fluid responsiveness
  - First, it is **not a test** but a **real therapy**

    500-1000 mL crystalloids or **300-500 mL** colloids/30 mins **Not negligible amounts!**
  - Second, by definition, it **cannot predict fluid responsiveness**
- **Fluid challenge** is **successful** in **only 50% cases**

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	Patients, No.	FC, No.	Fluid Infused	Volume Infused, mL	Speed of FC, min	Definition of Response	Rate of Response, %
Calvin et al[2]	28	28	5% Alb	250	20–30	ΔSV > 0%	71
Schneider et al[3]	18	18	FFP	500	30	ΔSV > 0%	72
Reuse et al[4]	41	41	4.5% Alb	300	30	ΔCO > 0%	63
Magder et al[5]	33	33	9% NaCl	100–950		ΔCO > 250 mL/min	52
Diebel et al[6]	15	22	R. lactate Colloids	300–500 500		ΔCO > 10%	59
Diebel et al[7]	32	65	R. lactate	300–500		ΔCO > 20%	40
Wagner and Leatherman[8]	25	36	9% NaCl 5% Alb, FFP	938 ± 480 574 ± 187	7–120	ΔSV > 10%	56
Tavernier et al[9]	15	35	HES	500	30	ΔSV > 15%	60
Magder and Lagonidis[10]	29	29	25% Alb 9% NaCl	100 150–400	15	ΔCO > 250 mL/min	45
Tousignant et al[11]	40	40	HES	500	15	ΔSV > 20%	40
Michard et al[12]	40	40	HES	500	30	ΔCO > 15%	40
Feissel et al[13]	19	19	HES	8 mL/kg	30	ΔCO > 15%	53
Total	334	406					52

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  - First, it is **not a test** but a **real therapy**

    500-1000 mL crystalloids or **300-500 mL** colloids/30 mins **Not negligible amounts!**
  - Second, by definition, it **cannot predict fluid responsiveness**
- **Fluid challenge** is **successful** in **only 50% cases**
- **Fluid challenge** is potentially **risky**
  - **Assessing** fluid responsiveness is a « **every day** » issue

→ **Repetition** of fluid challenges could be **harmful**

Sepsis in European intensive care units: Results of the SOAP study*

Jean-Louis Vincent, MD, PhD, FCCM; Yasser Sakr, MB, BCh, MSc; Charles L. Sprung, MD; V. Marco Ranieri, MD; Konrad Reinhart, MD, PhD; Herwig Gerlach, MD, PhD; Rui Moreno, MD, PhD; Jean Carlet, MD, PhD; Jean-Roger Le Gall, MD; Didier Payen, MD; on behalf of the Sepsis Occurrence in Acutely Ill Patients Investigators

Crit Care Med 2006; 34:344–353

Table 7. Multivariate, forward stepwise logistic regression analysis in sepsis patients (n = 1177), with intensive care unit mortality as the dependent factor

	OR (95% CI)	*p* Value
SAPS II score[a] (per point increase)	1.0 (1.0–1.1)	<.001
Cumulative fluid balance[b] (per liter increase)	1.1 (1.0–1.1)	.001
Age (per year increase)	1.0 (1.0–1.0)	.001
Initial SOFA score (per point increase)	1.1 (1.0–1.1)	.002
Blood stream infection	1.7 (1.2–2.4)	.004
Cirrhosis	2.4 (1.3–4.5)	.008
Pseudomonas infection	1.6 (1.1–2.4)	.017
Medical admission	1.4 (1.0–1.8)	.049
Female gender	1.4 (1.0–1.8)	.044

N Engl J Med 2006;354:2564-75.

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*

11. We recommend a conservative fluid strategy for patients with established sepsis-induced ARDS who do not have evidence of tissue hypoperfusion (grade 1C).

➢Fluid Challenge

➢**Predictors of fluid responsiveness/unresponsiveness**

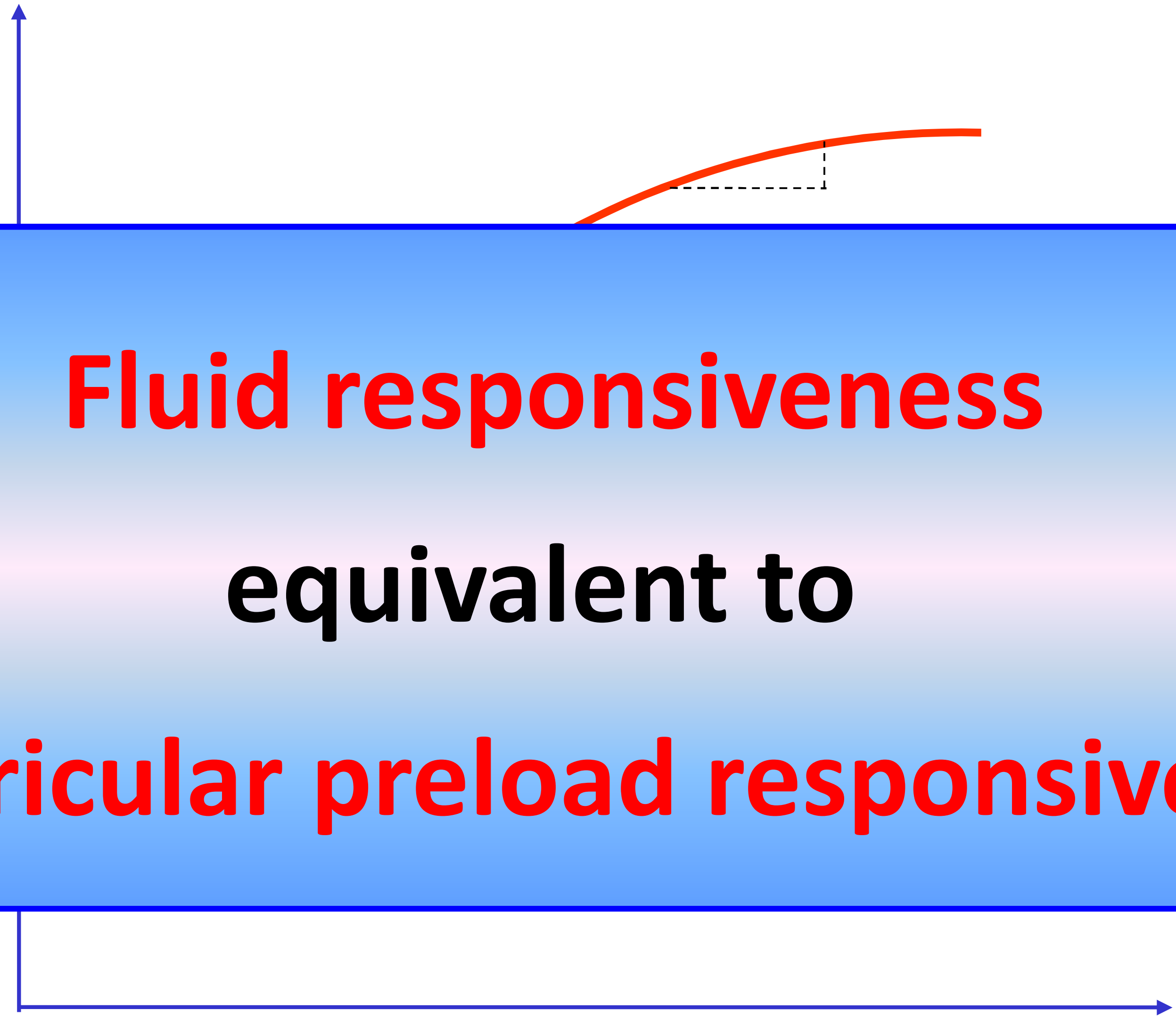
Can help to choose the **best** fluid **strategy**

Detecting volume responsiveness and unresponsiveness in intensive care unit patients: two different problems, only one solution

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

Critical Care 2009, **13:**175 (doi:10.1186/cc7979)

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



Fluid responsiveness

equivalent to

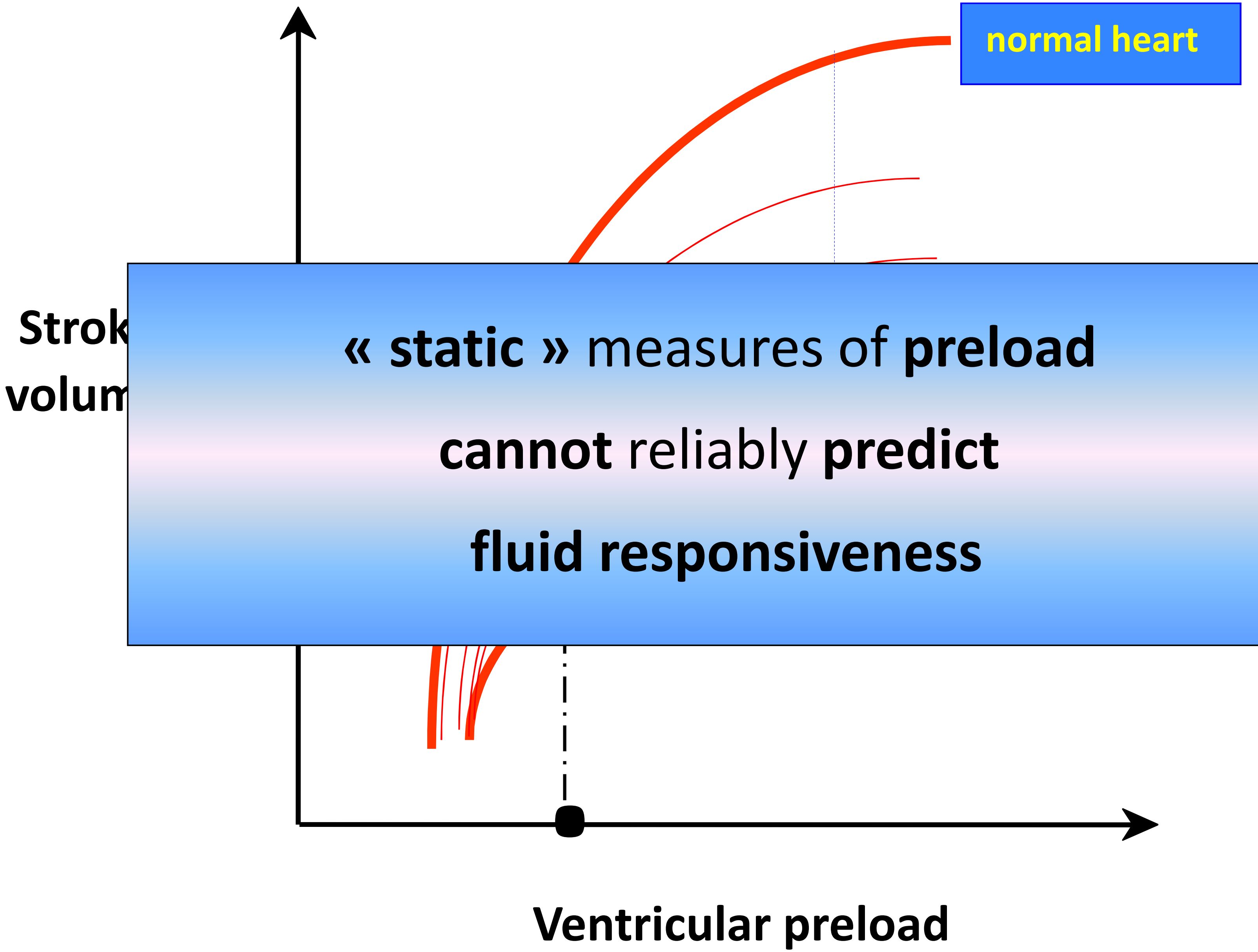
biventricular preload responsiveness

Ventricular preload

➢Fluid Challenge

➢**Predictors of fluid responsiveness/unresponsiveness**

- **Static** markers of **preload**



« static » measures of **preload**

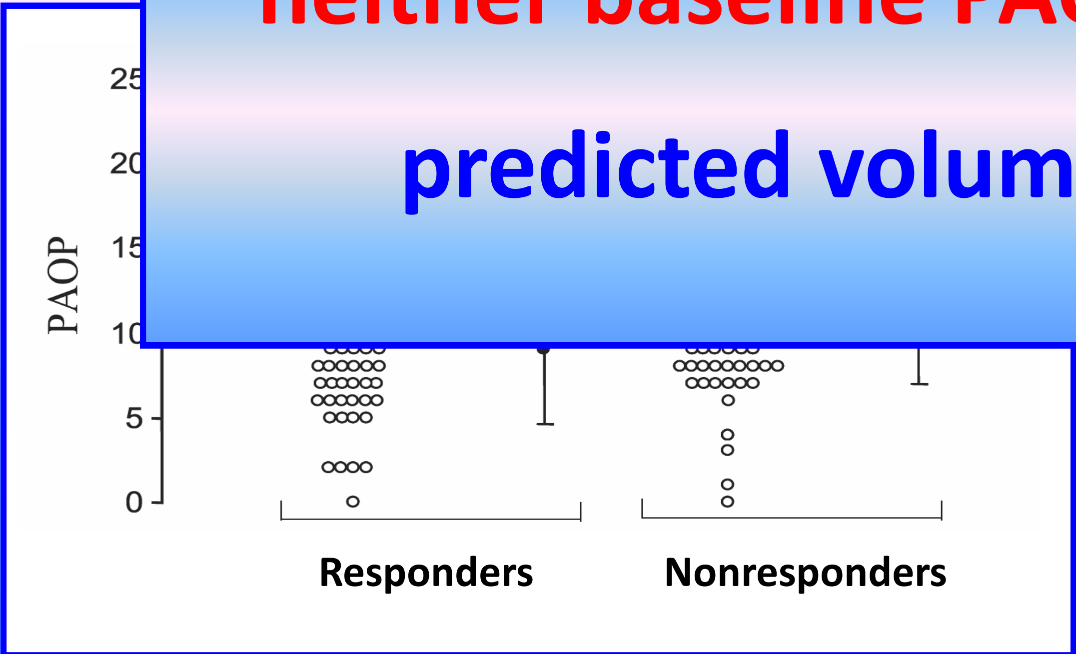
cannot reliably **predict**

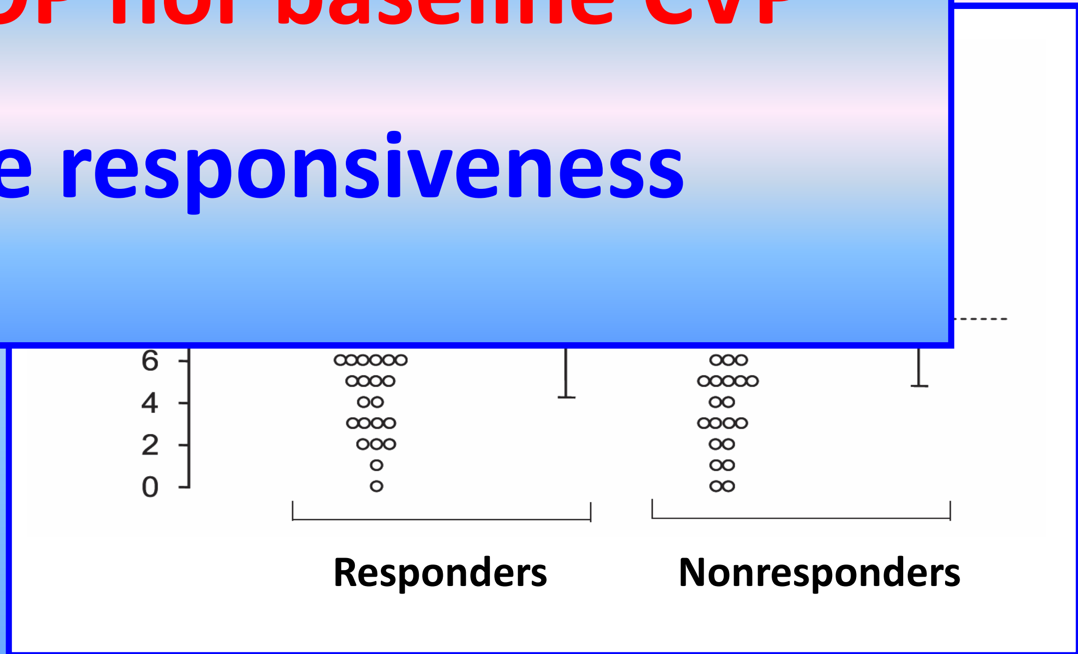
fluid responsiveness

Crit Care Med 2007; 35:64–68

neither baseline PAOP nor baseline CVP

predicted volume responsiveness





Crit Care Med 2013; 41: 1474-81

1802 pts

Summary AUC

0.56

In conclusion, there are no data to support the widespread practice of using CVP to guide fluid therapy. This approach to fluid resuscitation is without a scientific basis and should be abandoned.

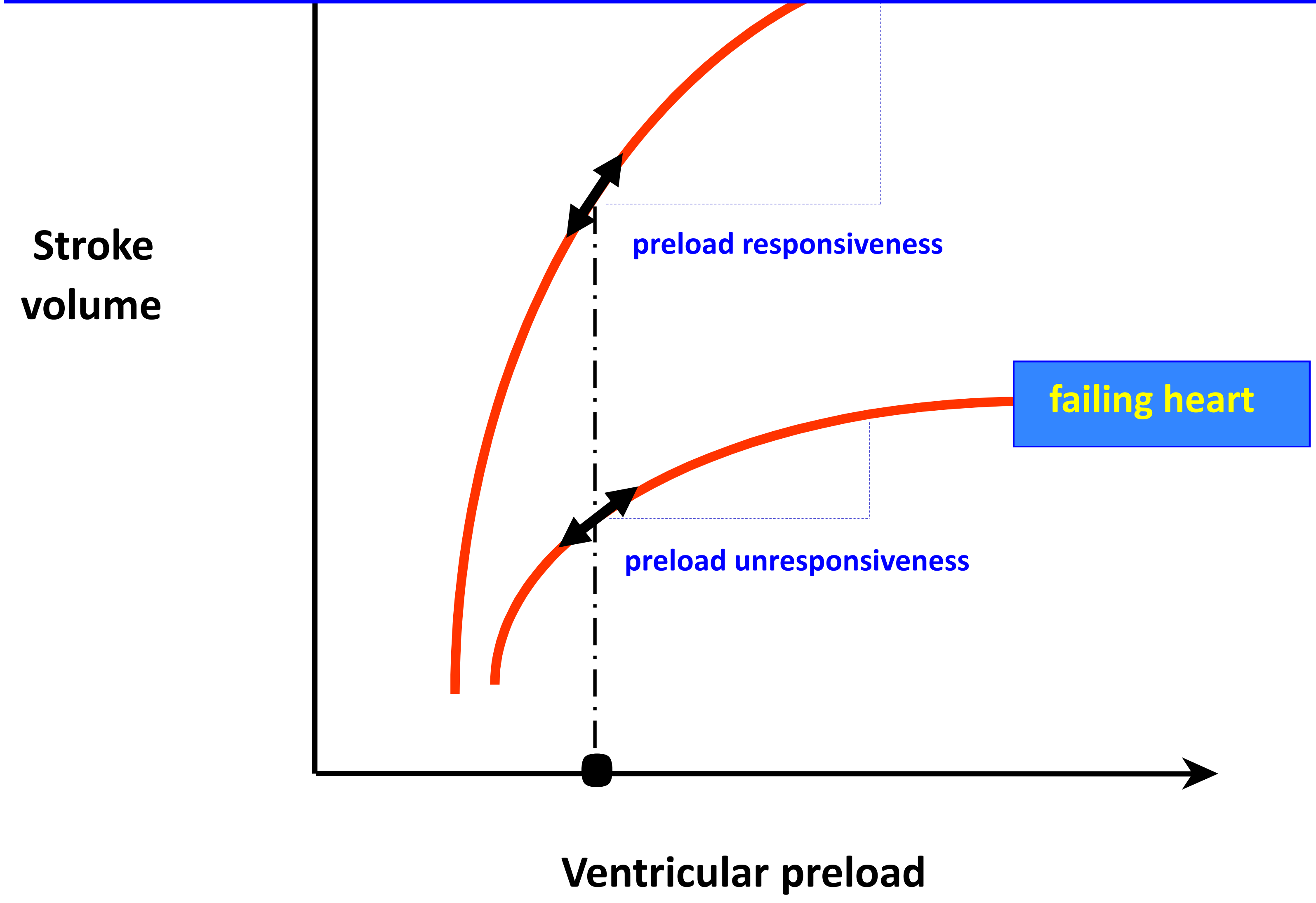
Surviving Sepsis Campaign: International Guidelines for Management of Severe Sepsis and Septic Shock: 2012

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*

Central venous pressure 8–12 mm Hg

???

Dynamic indices of preload responsiveness



➢ **Fluid Challenge**

➢ **Predictors of fluid responsiveness/unresponsiveness**

- **Static** markers of **preload**
- **Dynamic** markers of **preload responsiveness**
  - o **heart-lung interaction** tests
    - o **variability of stroke volume and of its surrogates**

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

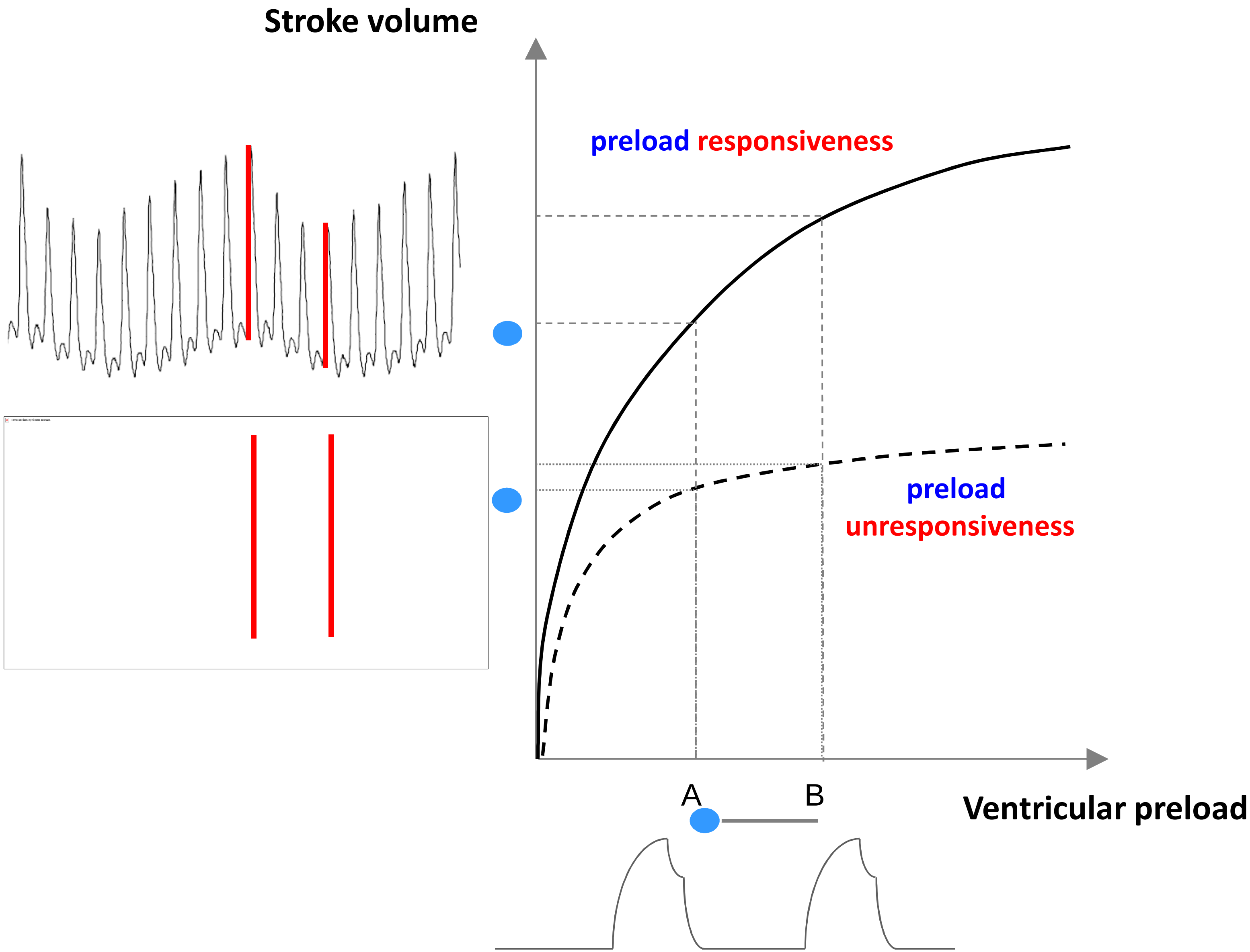
fluid responsiveness
occurs only in pts with
biventricular
preload responsiveness

correlates with the magnitude
of the
induced by

➢Fluid Challenge

➢**Predictors of fluid responsiveness/unresponsiveness**

- **Static** markers of **preload**
- **Dynamic** markers of **preload responsiveness**
  - o **heart-lung interaction** tests
    - o **variability of stroke volume and of its surrogates**
      - ✓ **Invasive** indices

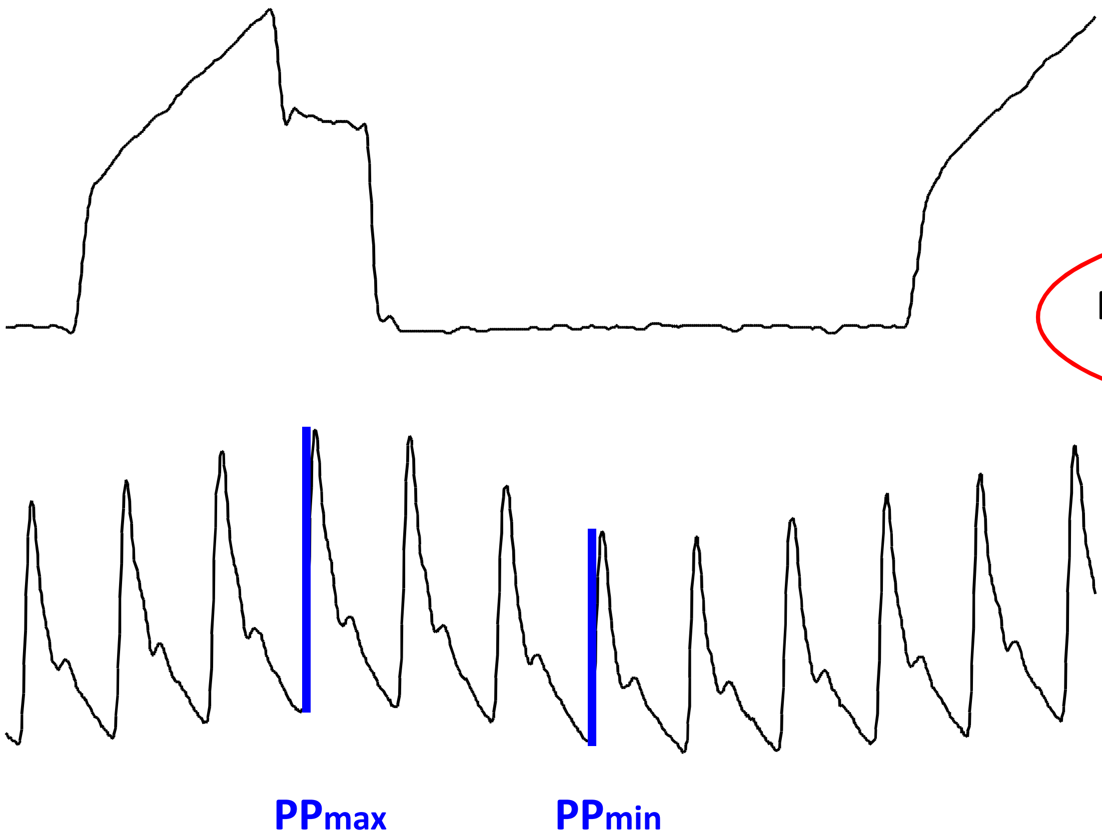

Stroke volume
preload responsiveness
preload
unresponsiveness
A
B
Ventricular preload

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



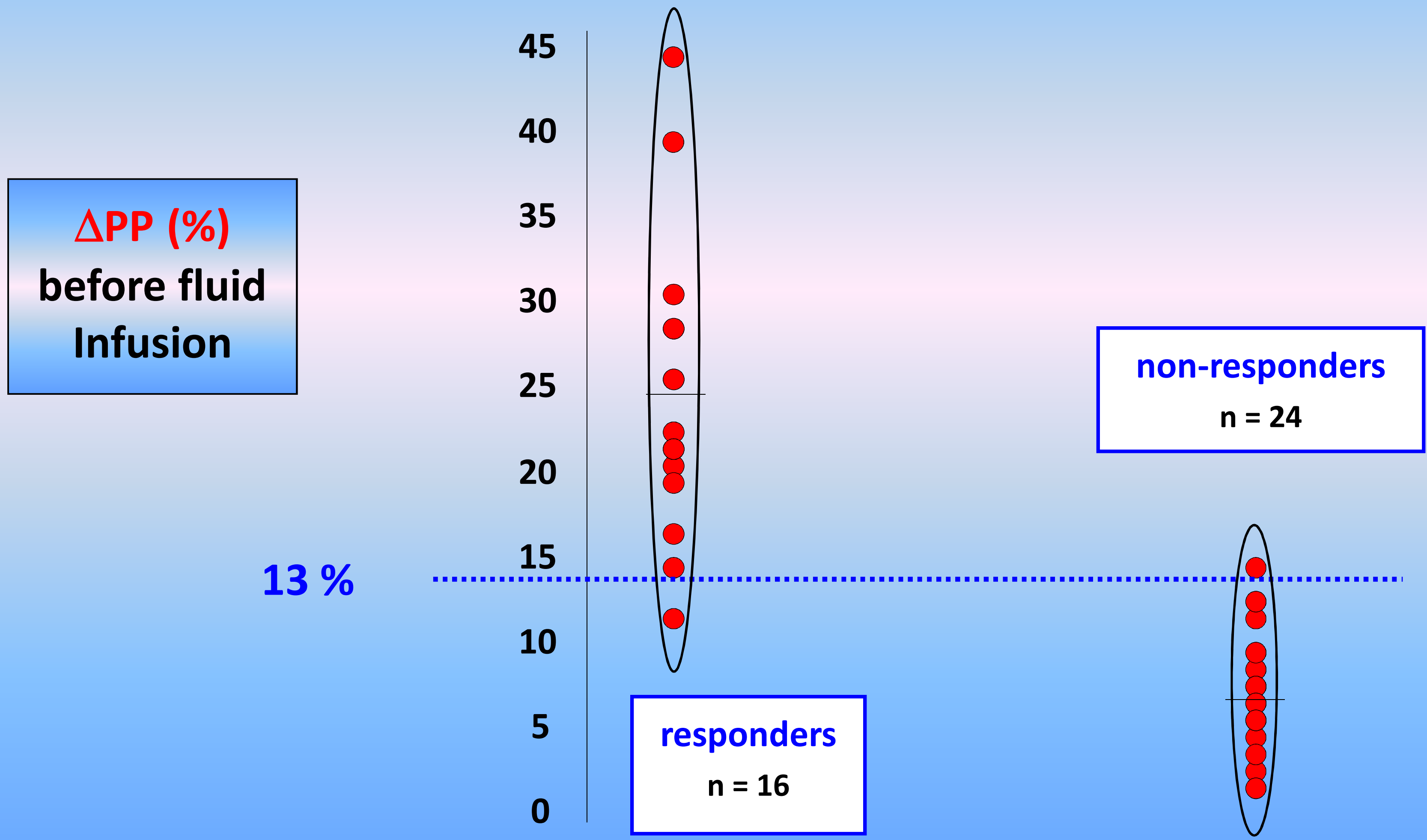
$$PPV = \frac{PP_{max} - PP_{min}}{(PP_{max} + PP_{min})\ /2}$$

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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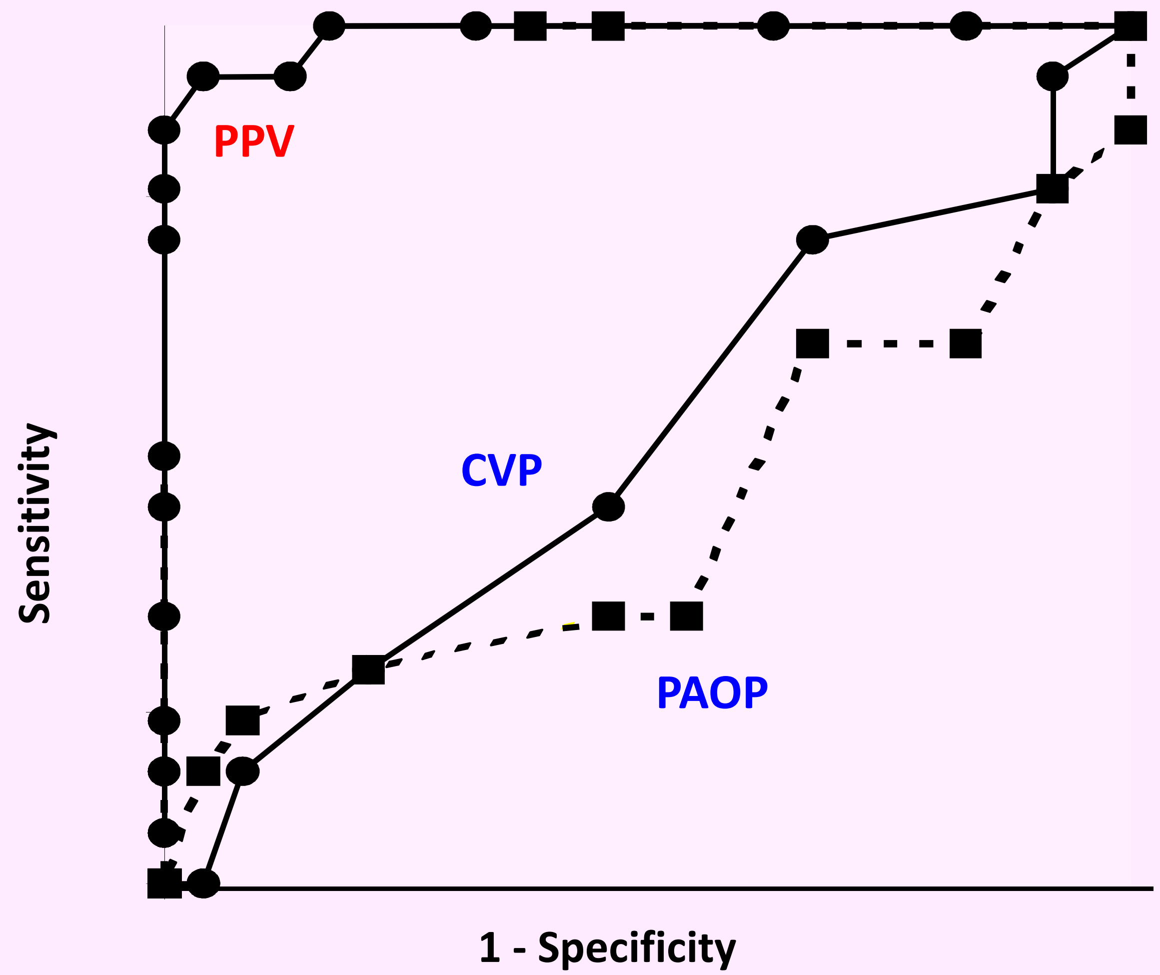

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CHRISTIAN RICHARD, MICHAEL R. PINSKY, and JEAN-L

Intensive Care Med (2004) 30:1734–1739
DOI 10.1007/s00134-004-2361-y

ORIGINAL

Superior
of volume

Stroke Volume and Pulse Pressure

British Journal of Anaesthesia 95 (6): 746–55 (2005)

Validation of pulse pressure variation and corrected flow time as predictors of fluid responsiveness in patients in the prone position

S.-Y. Yang[1], J.-K. Shim[2], Y. Song[2], S.-J. Seo[2] and Y.-L. Kwak[2,3]*

British Journal of Anaesthesia 110 (5): 713–20 (2013)

variation and stroke volume variation predict fluid
s in mechanically ventilated patients experiencing
al hypertension

Fu, Weidong Mi*, Henian Liu, Hong Zhang, Peiji Wang

BioScience Trends. 2013; 7(2):101-108.

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Pulse pressure var
responsiveness in p
volumes

Clarice Daniele Alves de Oliveira-Costa,[I,II] Gilb

Andre
Paul

alg 2011; 113:523-8

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)

ess in the critically ill*

Fadia Haddad, MD,*

cular Anesthesia, 2011

Critical Care 2006, 1

Prediction of fluid r
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M. CECCONI [1], G. MONTI [2], M. A. HAM
M. L. TUCCILLO [1,3], G. DELLA ROCC

Pressure
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ted Postoperative Cardiac

Predictive value of pulse pressure variation for fluid responsiveness in septic patients using lung-protective ventilation strategies

F. G. R. Freitas*, A. T. Bafi, A. P. M. Nascente, M. Assunção, B. Mazza, L. C. P. Azevedo and F. R. Machado

BJA Advance Access published November 15, 2012

The Influence o
Fluid Responsiv

Cyril Charr
Jean-Xavier
Alain R. Ed

Arterial Versus Plet
Responsiveness for

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M. Biais

BJA

f fluid
responsiveness in patients receiving norepinephrine

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

09;108:513-7

to Guide

The Ability of a Novel Al

Comparison of an automated respiratory systolic variation test with dynamic preload indicators to predict fluid responsiveness after major surgery

C. J. C. Trepte[†]*, V. Eichhorn[†], S. A. Haas, K. Stahl, F. Schmid, R. Nitzschke, A. E. Goetz and D. A. Reuter

British Journal of Anaesthesia

-Pressure Variation Predicts Fluid Responsiveness During Heart
Displacement for Off-Pu

an Lee, MD, PhD,* Yunseok Jeon
Kim, MD, PhD,§ Deok

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essure

recording analytic method*

Matthieu Biais, MD; Vincent Cottenceau, MD; Laurent Stecken, MD; Maylis Jean; Laetitia Ottolenghi, MD; Stéphanie Roullet, MD; Alice Quinart, MD; François Sztark, MD, PhD

Crit Care Med 2012;40:1186–1191

Comparison of arterial pressure and plethysmographic waveform-based dynamic preload variables in assessing fluid responsiveness and dynamic arterial tone in patients undergoing major hepatic resection

J. J. Vos*, A. F. Kalmar, M. M. R. F. Struys, J. K. G. Wietasch, H. G. D. Hendriks and T. W. L. Scheeren

British Journal of Anaesthesia 110 (6): 940–6 (2013)

radia

A. Derichard

J.-P. Chambon[2] and B. Vallet[1]

British Journal of Anaesthesia 103 (5): 678–84 (2009)

Assessing the Diagnostic Accuracy of Pulse Pressure Variations for the Prediction of Fluid Responsiveness

A "Gray Zone" Approach

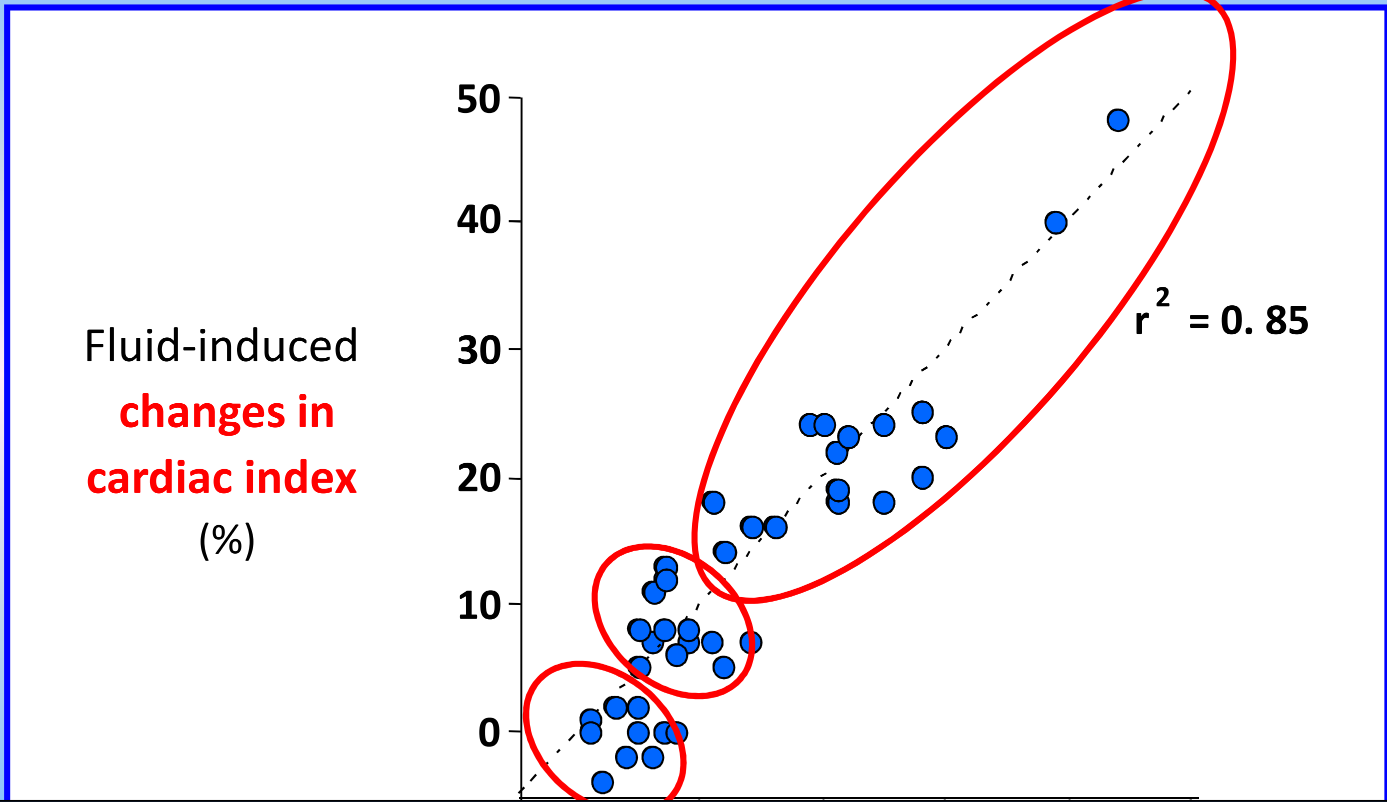
Maxime Cannesson, M.D., Ph.D.,* Yannick Le Manach, M.D., Ph.D.,† Christoph K. Hofer, M.D.,‡ Jean Pierre Goarin, M.D.,§ Jean-Jacques Lehot, M.D., Ph.D.,|| Benoît Vallet, M.D., Ph.D.,# Benoît Tavernier, M.D., Ph.D.#

Anesthesiology 2011; 115:231-41

Conclusion: Despite a strong predictive value, PPV may be inconclusive (between 9% and 13%) in approximately 25% of patients during general anesthesia.

The **larger** the ΔPP ***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

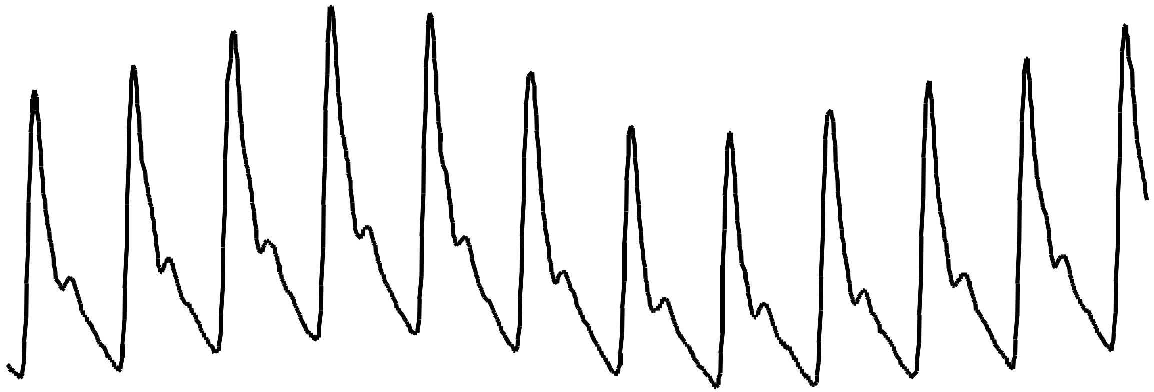
Calculated automatically and **displayed in real-time**

by usual hemodynamic monitors

All these **monitors** are **suitable**

to **display PPV** in real-time

Arterial pressure waveform analysis → **Stroke volume**



Arterial Pressure

Stroke Volume Variation

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

by new hemodynamic monitors

Stroke Volume Variation as a Predictor of Fluid

Uncalibrated pulse contour-derived stroke volume variatio
predicts fluid responsiveness in mechanically ventilated patie
undergoing liver transplantation

M. Biais, K. Na

The Ability of Stroke Volume Variations Obtained with Vigileo/FloTrac System to Monitor Fluid Responsiveness in Mechanically Ventilated Patients

Anesth Analg 2009;108:513–7

Validation of pulse p
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British Journal of Anaesthesia
doi:10.1093/bja/aes373

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X. Monnet[1,2*], L. Guerin[1,2], M. Jozwiak[1,2], A. Bataille

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Prediction of flui

S. Rex[1*], S. Brose[2], S. Me

Xiaomei Liu, Qiang Fu

Journal of International Medical Research 2012 40: 1175

Evaluation of Stroke Volume Variation Obtained by the FloTrac™/Vigileo™ System to Guide Preoperative Fluid Therapy in Patients Undergoing Brain Surgery

J Li, FH Ji and JP Yang

Chest 2005;128;848-854

Automated pulse pressure and stroke volume variations fr

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C. Richard[1,2] and J.-L. Teboul[1,2]

British Journal of Anaesthesia 10

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Stroke Volume Variation for Prediction of Fluid Responsiveness in Patients Undergoing Gastrointestinal Surgery

Comparison of an automated respiratory systolic variation test with dynamic preload indicators to predict fluid responsiveness after major surgery

C. J. C. Trepte[†*], V. Eichhorn[†], S. A. Haas, K. Stahl, F. Schmid, R. Nitzschke, A. E. Goetz and D. A. Reuter

British Journal of Anaesthe

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British Journal of Anaesthesia 110 (6): 940–6 (2013)

Thomas W. Felbinger
Christian Schmidt
Erich Kilger
Oliver Goedje
Peter Lamm
Alwin E. Goetz

of cardiac responsiveness to v
in mechanically ventilated pat
after cardiac surgery

is*, O. Bernard, J. C. Ha, C. Degryse and F. Sztark

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

Author	Year	n	Patient		PPV	SVV	Fluid Challenge	TV (mL/kg)	Device	Cardiac End Point
Tavernier (31)	1998	15	ICU-sepsis	Y	N	N	500 mL HES	8–11	PAC	SVI
Michard (32)	1999	14	ICU-ARDS	N	Y	N	10 PEEP[c]	7–12	PAC	CI
Michard (33)	2000	40	ICU-sepsis	Y	Y	N	500 mL HES	8–12	PAC	CI
Berkenstadt (34)	2001	15	Neurosurg[a]	N	N	Y	100 mL HES[b]	10	PiCCO[e]	SV
Reuter (35)	2002	20	Post C.Surg	Y	N	Y	20 mL × BMI gelatin	—	PiCCO	SVI
Reuter (36)	2002	20	Post C.Surg	N	N	Y	20 mL × BMI gelatin	13–15	PiCCO	CI
Reuter (37)	2003	12	Post C.Surg-a	N	N	Y	10 mL × BMI HES[b]	10	PiCCO	SVI
		14	Post C.Surg-b				10 mL × BMI HES[b]	10	PiCCO	SVI
Bendjelid (38)	2004	16	Post C.Surg	Y	Y	N	10 PEEP[c]	8–10	PAC	SVI
Rex (39)	2004	14	Post C.Surg	N	N	Y	Trendelenburg	8	PiCCO	SVI
Kramer (40)	2004	21	Post C.Surg	Y	Y	N	500 mL blood	8–10	PAC	CO
Marx (41)	2004	10	ICU-sepsis	N	N	Y	500 mL HES	8–10	PiCCO	—
Hofer (42)	2005	35	Post C.Surg	N	Y	Y	[illegible]	10	PiCCO	SVI
Preisman (43)	2005	18	Post C.Surg	Y	Y	Y	[illegible]	PCV	PiCCO	SVI
De Backer (44)[d]	2005	27	ICU-mixed	N	Y	N	[illegible]	8–10	PAC	CI
Wiesenack (45)	2005	20	C.Surg[a]	N	Y	Y	[illegible]	7	PiCCO/PAC	SVI
Feissel (46)	2005	20	ICU-sepsis	N	Y	N	[illegible]	8–10	TTE	CI
Solus-Biguenet (47)	2006	8	Hepatic surgery	N	Y	N	250 mL gelatin[b]	8–10	PAC	SVI
Charron (48)	2006	21	ICU-mixed	N	Y	N	100 mL HES	8–10	TEE	SV
Natalini (49)	2006	22	ICU-mixed	Y	Y	N	500 mL HES	8	PAC	CI
Wyffels (50)	2007	32	Post C.Surg	N	Y	N	500 mL HES	8–10	PAC	CI
Feissel (51)	2007	23	ICU-sepsis	N	Y	N	8 mL/kg HES	8–10	TEE	CI
Lee (52)	2007	20	Neurosurg[a]	N	Y	N	7 mL/kg HES	10	Eso Doppler	SVI
Cannesson (53)	2007	25	C.Surg[a]	N	Y	N	500 mL HES	8–10	PAC	CI
Cannesson (54)	2008	25	C.Surg[a]	N	Y	N	500 mL HES	8–10	PAC	CI
Auler (55)	2008	59	Post C.Surg	N	Y	N	20 mL/kg LR	8	PAC	CO
Belloni (56)	2008	19	C.Surg[a]	Y	Y	Y	7 mL/kg HES	8	LiDCO[f]/PAC	CI
Cannesson (57)	2008	25	C.Surg[a]	N	Y	N	500 mL HES	8–10	PAC	CI
Hofer (58)	2008	40	Post CABG	N	Y	Y	Trendelenburg	8–10	FloTrac[g]/PiCCO	SV
Biasis (59)	2008	35	Liver transplant	N	Y	Y	Albumin 20 mL × BMI	8–10	FloTrac/TEE	CO

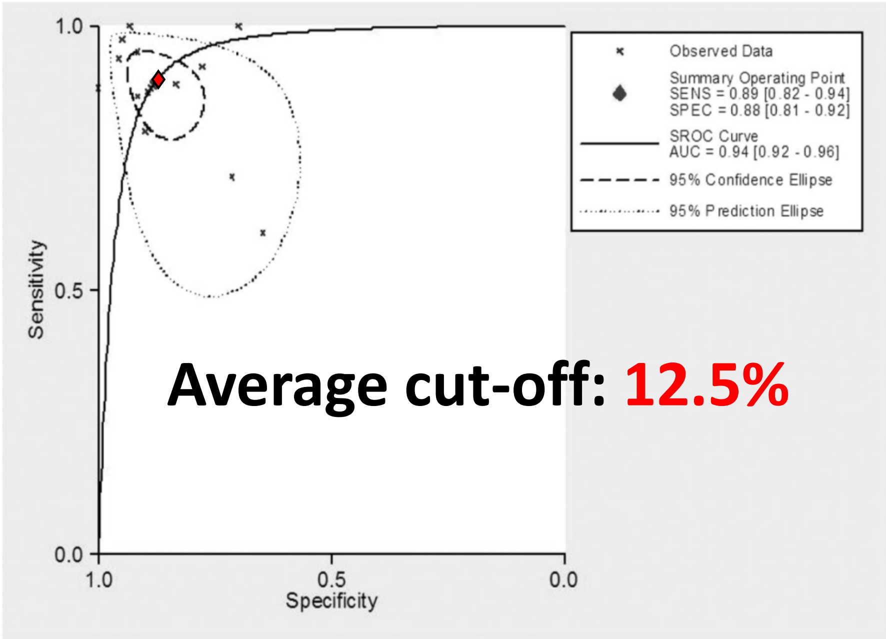
685 pts

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

	AUC
PPV	0.94 (0.93–0.95)



➢ **Fluid Challenge**

➢ **Predictors of fluid responsiveness/unresponsiveness**

- **Static** markers of **preload**
- **Dynamic** markers of **preload responsiveness**
  - o **heart-lung interaction** tests
    - o **variability of stroke volume and of its surrogates**
      - ✓ **Invasive** indices
      - ✓ **Non invasive** indices

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

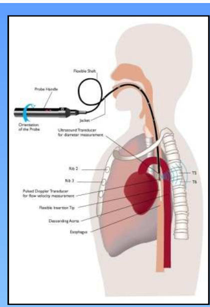
monitoring **device**

Intensive Care Med (2005) 31:1195–1201

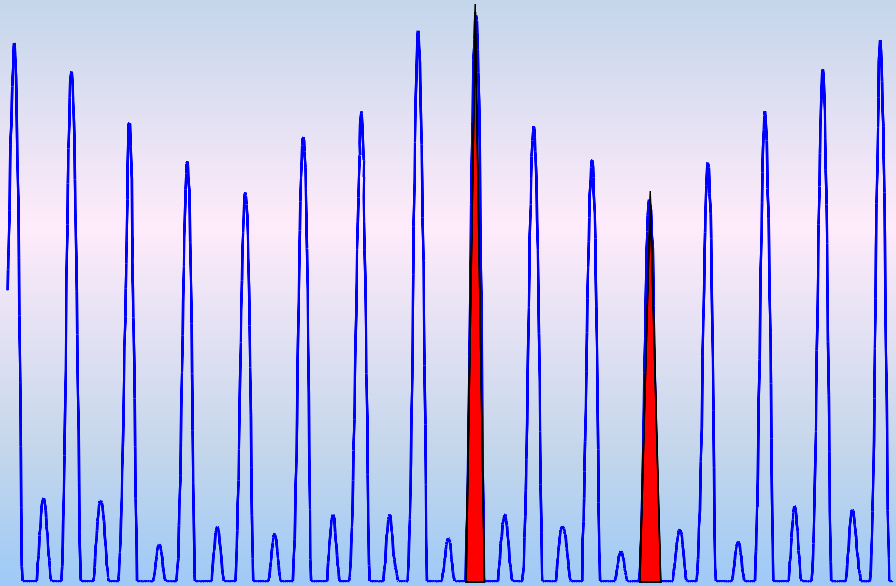
ORIGINAL

Xavier Monnet
Mario Rienzo
David Osman
Nadia Anguel
Christian Richard
Michael R. Pinsky
Jean-Louis Teboul

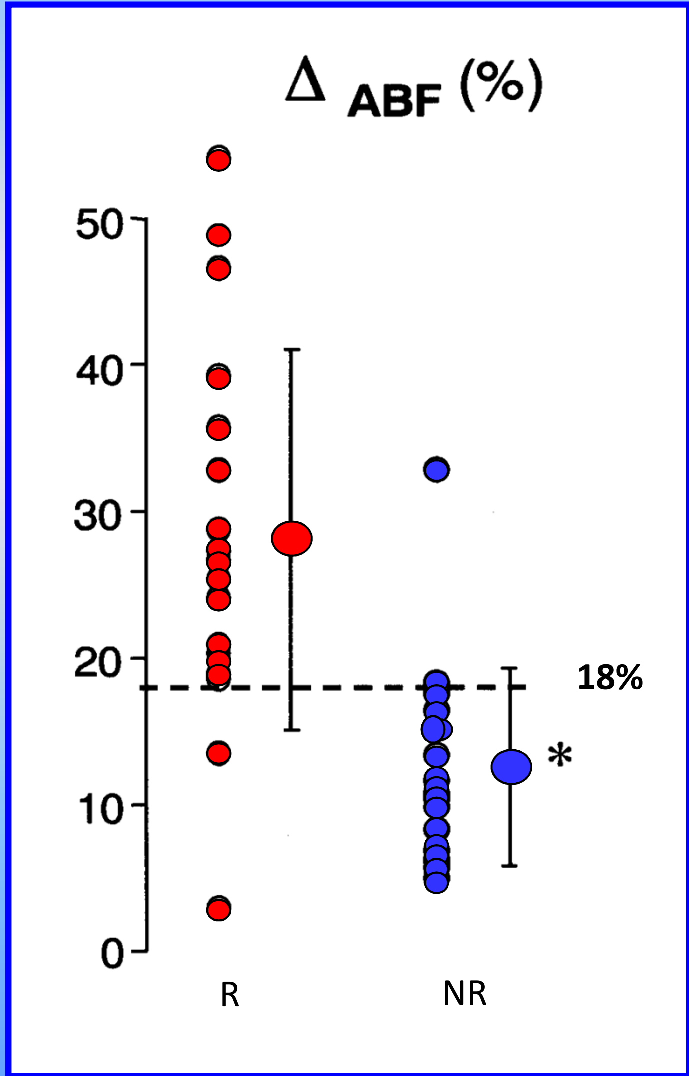
Esophageal Doppler monitoring predicts fluid responsiveness in critically ill ventilated patients



Esophageal Doppler



$$\Delta ABF\,\% = \frac{ABF\ max - ABF\ min}{(ABF\ max + ABF\ min)/2}$$

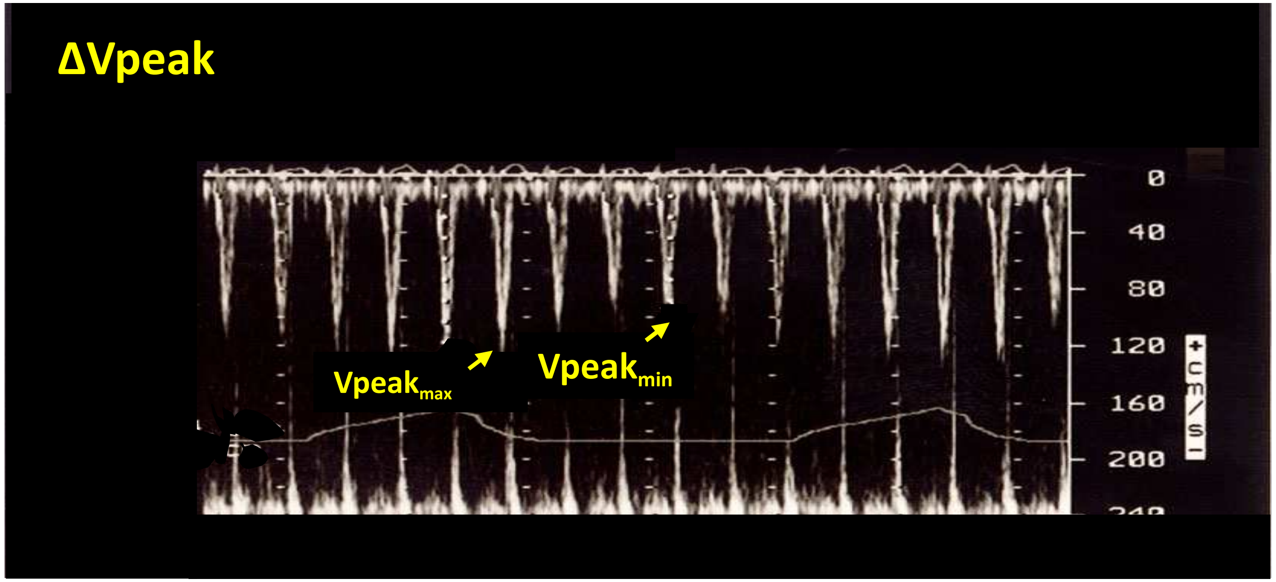


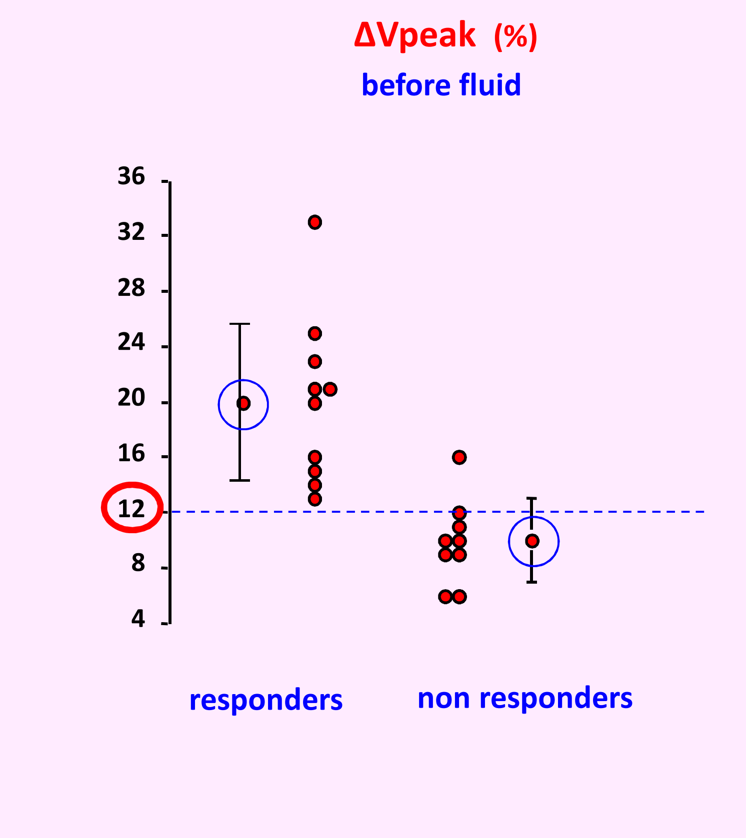
Respiratory Changes in Aortic Blood Velocity as an Indicator of Fluid Responsiveness in Ventilated Patients With Septic Shock*

Marc Feissel, MD; Frédéric Michard, MD; Isabelle Mangin, MD; Olivier Ruyer, MD; Jean-Pierre Faller, MD; and Jean-Louis Teboul, MD, PhD

CHEST 2001; 119:867–873

Doppler-echo





$$\Delta Vpeak = \frac{\text{Vpeak max} - \text{Vpeak min}}{(\text{Vpeak max} + \text{Vpeak min}) / 2}$$

Pulse oximeter

British Journal of Anaesthesia 101 (2): 200–6 (2008)
doi:10.1093/bja/aen133 Advance Access publication June 2, 2008
BJA

Pleth variability index to monitor the respiratory variations in the pulse oximeter plethysmographic waveform amplitude and predict fluid responsiveness in the operating theatre

M. Cannesson[1*†], O. Desebbe[1], P. Rosamel[1], B. Delannoy[1], J. Robin[2], O. Bastien[1] and J.-J. Lehot[1]

	Area under the curve	Cutoff
ΔPP	0.938	12.5%
ΔPOP	0.944	12%
PPV	0.941	10.5%
PVI	0.927	14%
CVP	0.417	12.5 mm Hg
PCWP	0.396	14.5 mm Hg

Intensive Care Med (2012) 38:1429–1437

REVIEW

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

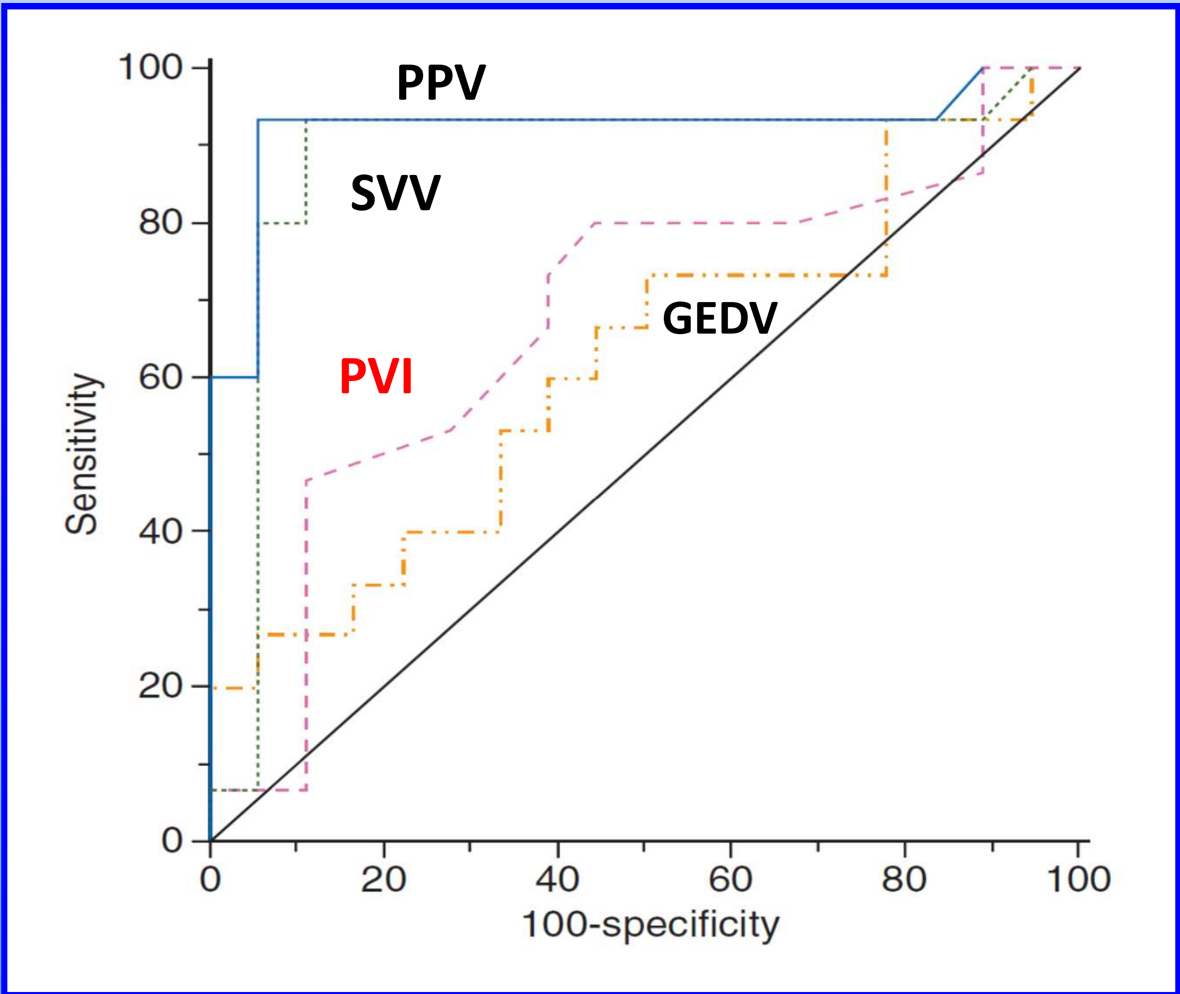
Accuracy of plethysmographic indices as predictors of fluid responsiveness in mechanically ventilated adults: a systematic review and meta-analysis

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)

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

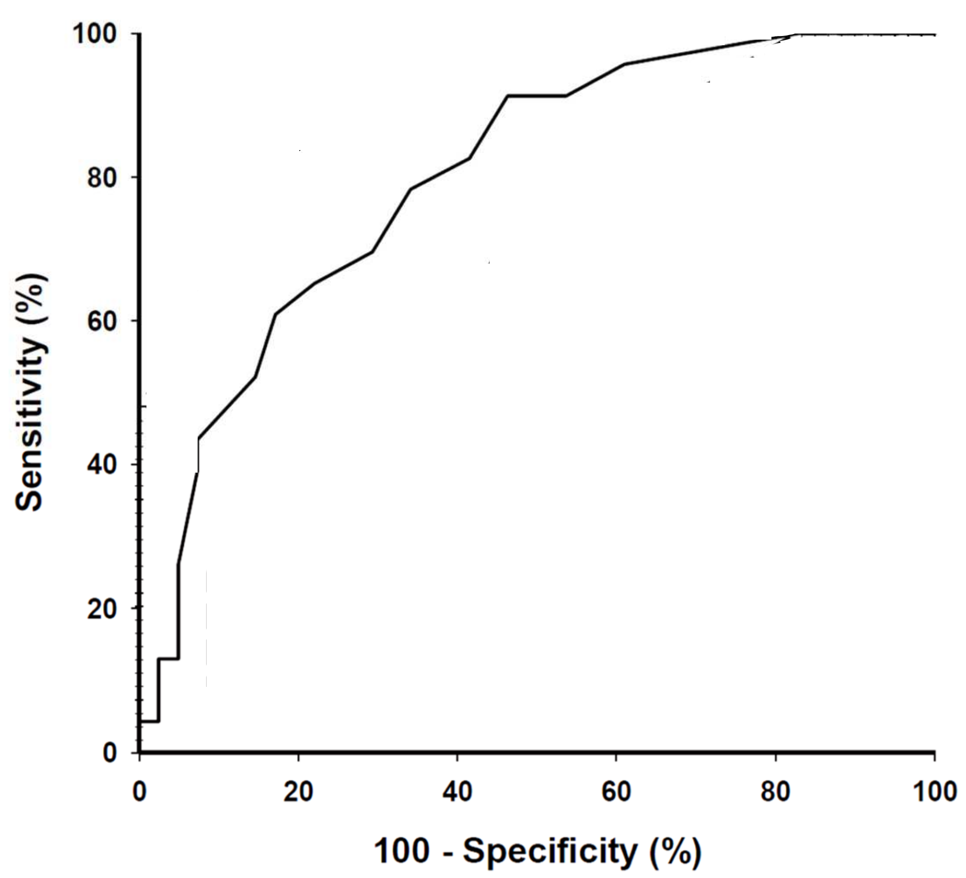
X. Monnet[1,2]*, L. Guérin[1,2], M. Jozwiak[1,2], A. Bataille[1,2], F. Julien[1,2], C. Richard[1,2] and J.-L. Teboul[1,2]



Impact of norepinephrine on the relationship between pleth variability index and pulse pressure variations in ICU adult patients

Matthieu Biais[1,2*], Vincent Cottenceau[3], Laurent Petit[3], Françoise Masson[3], Jean-François Cochard[3] and François Sztark[2,3]

Critical Care 2011, **15**:R168



➢ **Fluid Challenge**

➢ **Predictors of fluid responsiveness/unresponsiveness**

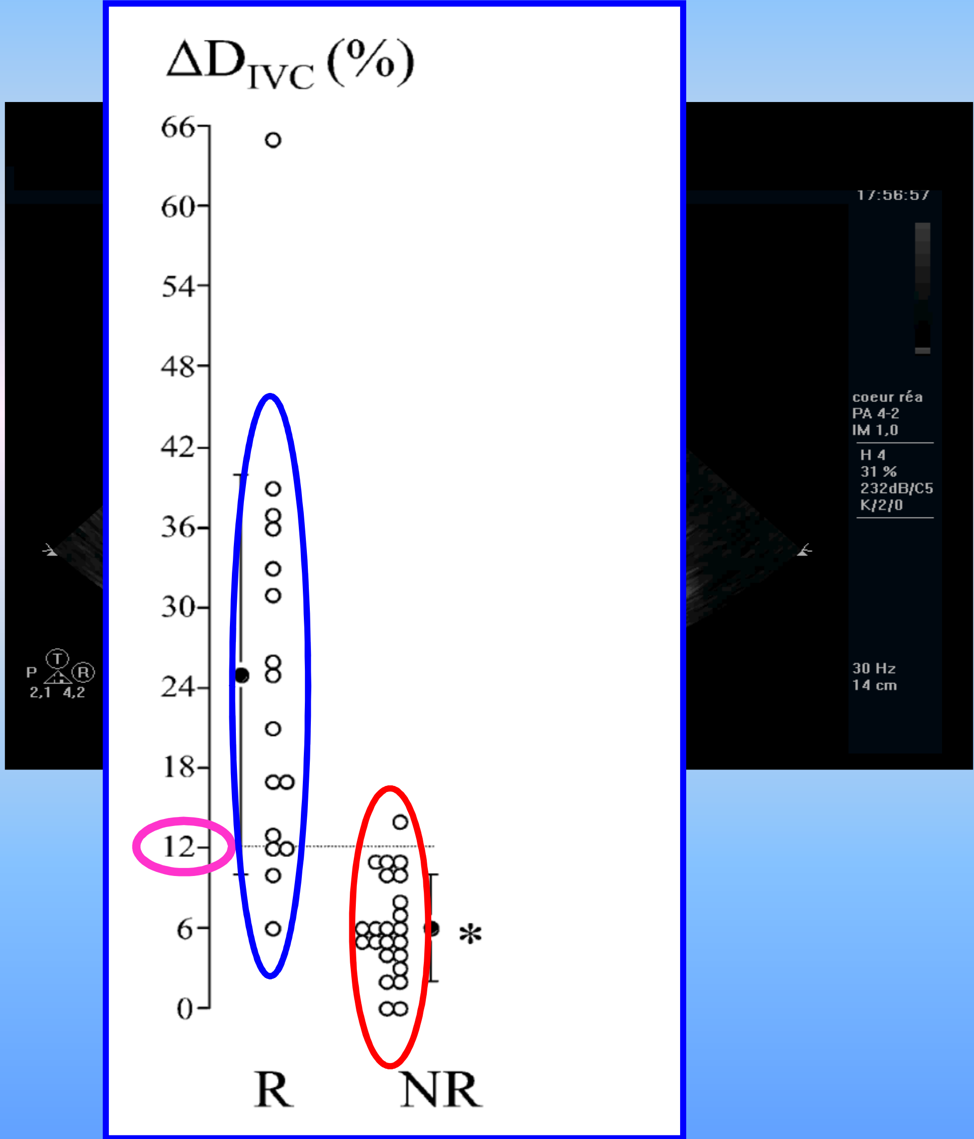
- **Static** markers of **preload**
- **Dynamic** markers of **preload responsiveness**
  - **heart-lung interaction** tests
    - **variability of stroke volume and of its surrogates**
    - **variability of (inferior or superior) vena cava diameter**

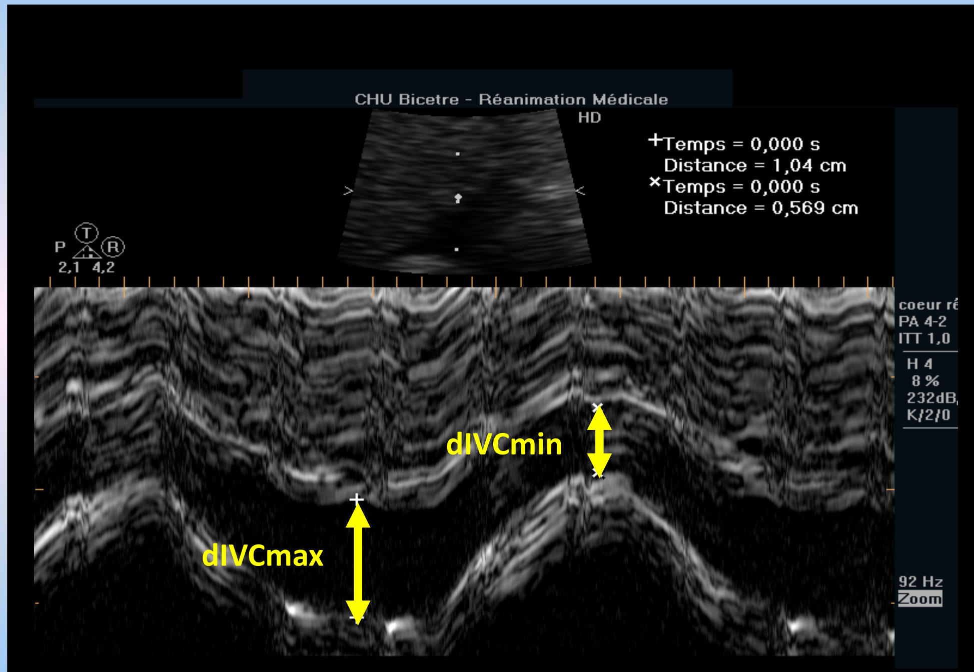
Intensive Care Med (2004) 30:1834–1837

BRIEF REPORT

Marc Feissel
Frédéric Michard
Jean-Pierre Faller
Jean-Louis Teboul

The respiratory variation in inferior vena cava diameter as a guide to fluid therapy





$$\Delta \text{ dIVC \%} = \frac{\text{dIVCmax} - \text{dIVCmin}}{(\text{dIVCmax} + \text{dIVCmin})/2}$$

Intensive Care Med (2004) 30:1734–1739

ORIGINAL

Antoine Vieillard-Baron
Karim Chergui
Anne Rabiller
Olivier Peyrouset
Bernard Page
Alain Beauchet
François Jardin

Superior vena caval collapsibility as a gauge of volume status in ventilated septic patients

66 pts with MV
Systematic fluid loading with 10 mL/kg HES

SVC collabsibility index : 68%
Cardiac Index : 3.11 L/min/m²

SVC collabsibility index : 12%
Cardiac Index : 4.38 L/min/m²

Intensive Care Med (2004) 30:1734–1739

ORIGINAL

Antoine Vieillard-Baron
Karim Chergui
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Alain Beauchet
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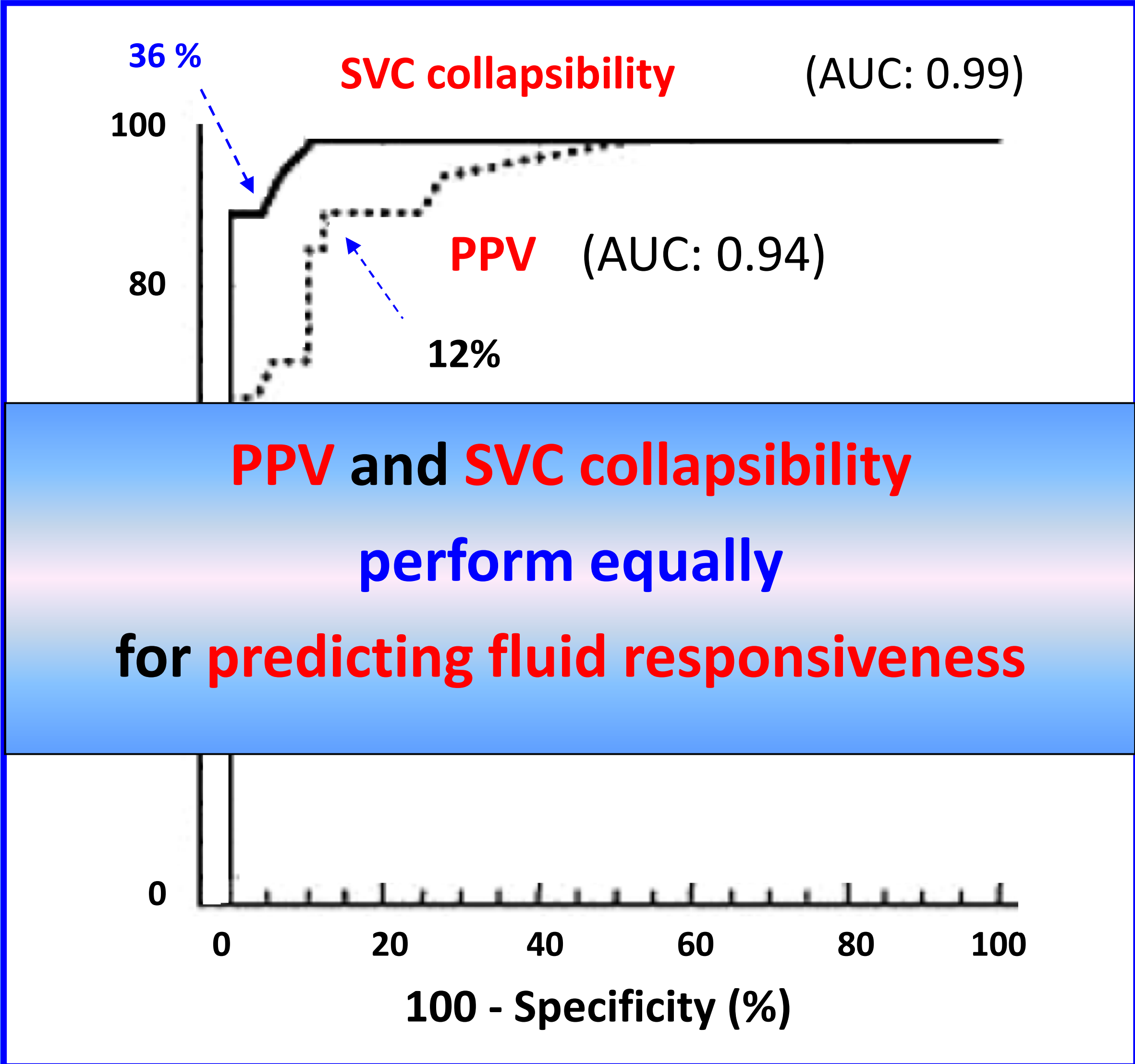
Superior vena caval collapsibility as a gauge of volume status in ventilated septic patients



PPV and SVC collapsibility

perform equally

for predicting fluid responsiveness

Transesophageal approach is required

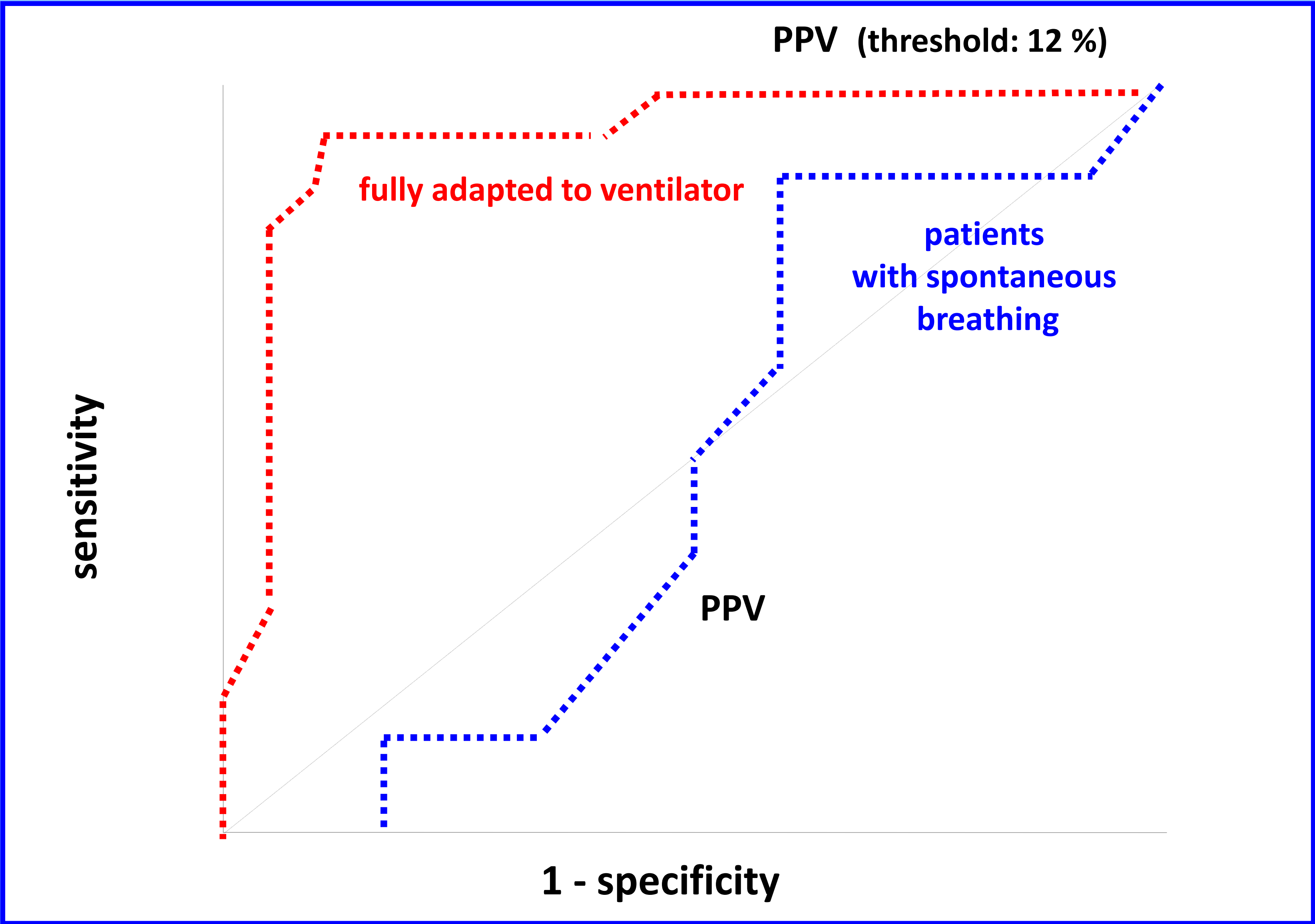
Limitations of respiratory variability indices

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

Passive leg raising predicts fluid responsiveness in the critically ill*

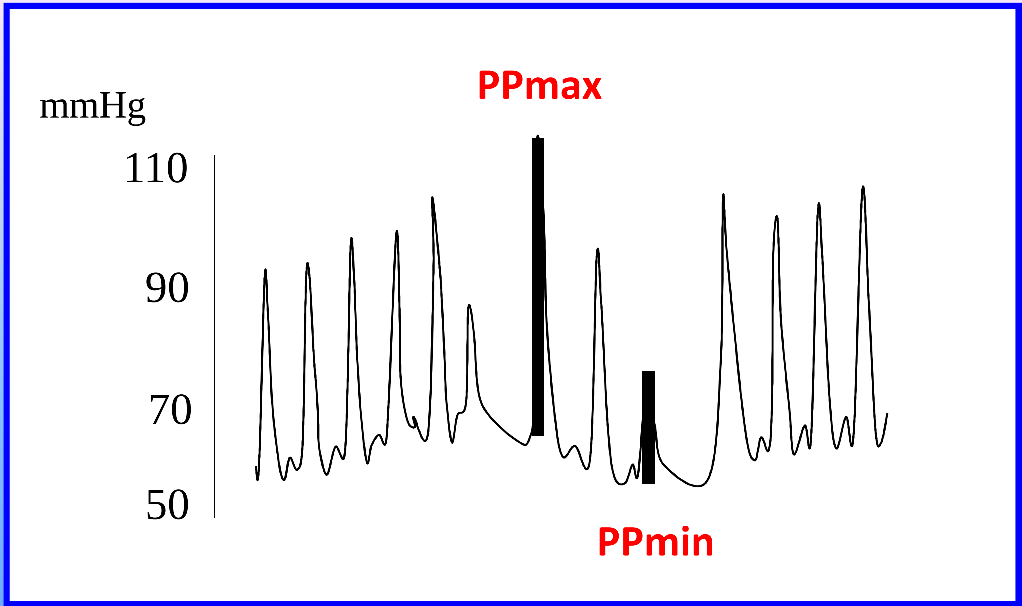
Xavier Monnet, MD, PhD; Mario Rienzo, MD; David Osman, MD; Nadia Anguel, MD; Christian Richard, MD; Michael R. Pinsky, MD, Dr hc; Jean-Louis Teboul, MD, PhD

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

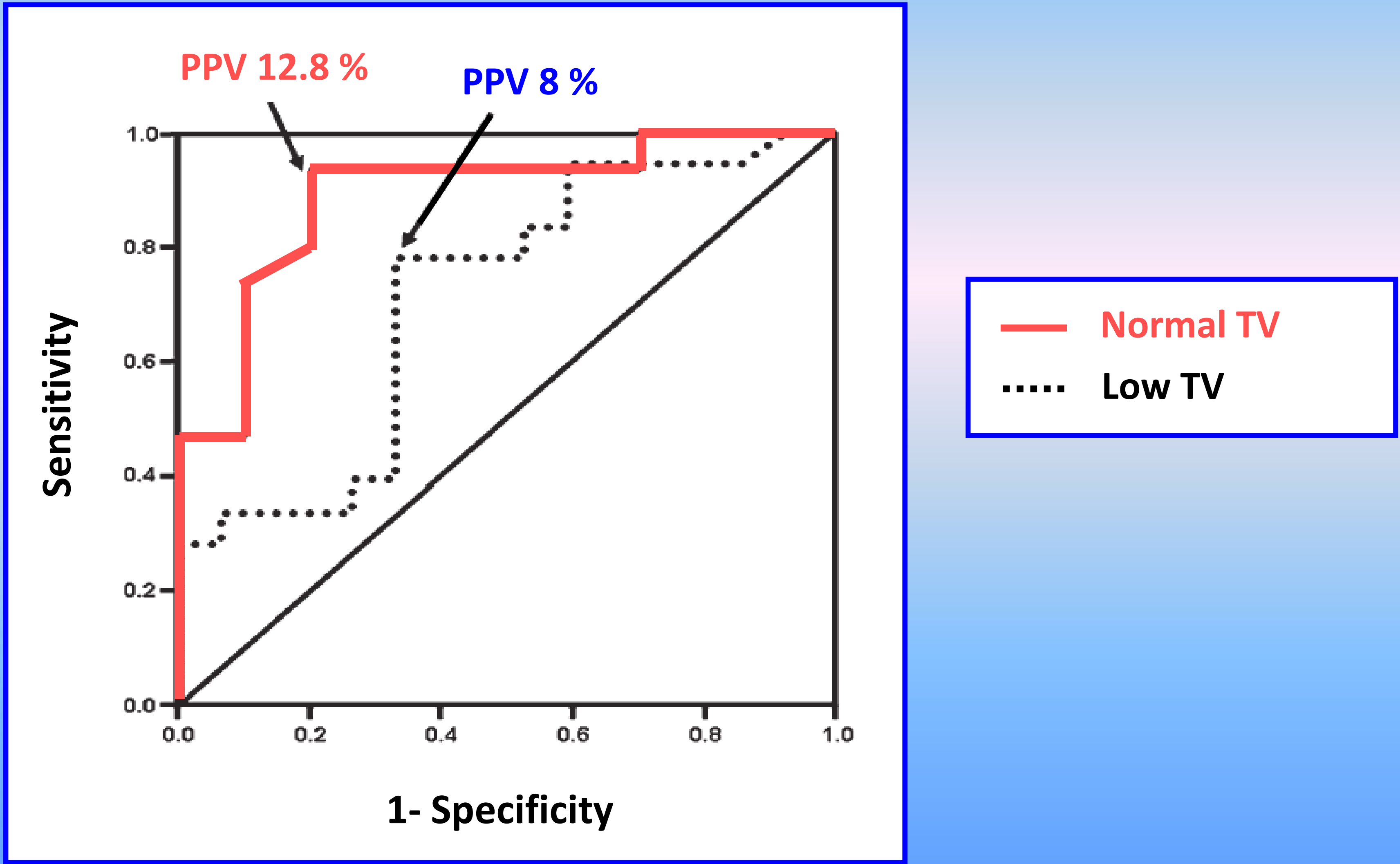
- impossible to interpret in pts with **spontaneous breathing activity**
- impossible to interpret in patients with **arrhythmias**
- difficult to interpret if **tidal volume** is **too low**

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

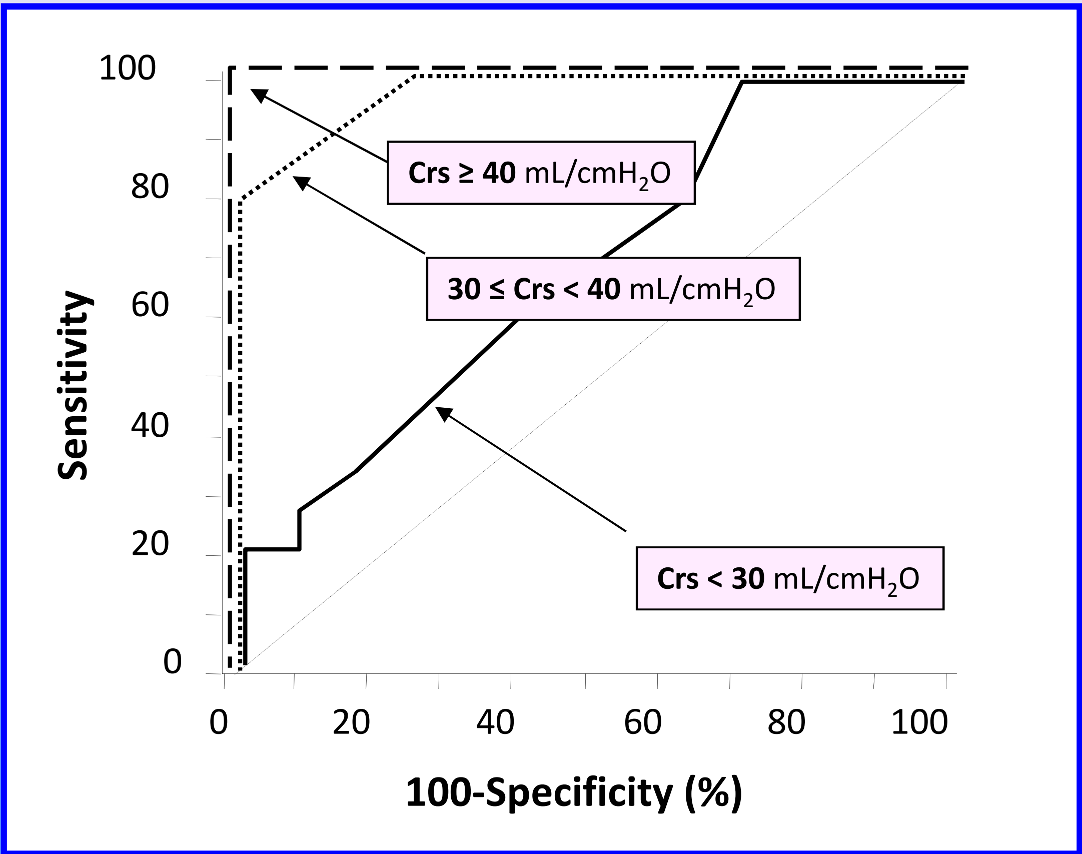
- impossible to interpret in pts with **spontaneous breathing activity**
- impossible to interpret in patients with **arrhythmias**
- difficult to interpret if **tidal volume** is **too low**
- difficult to interpret if **lung compliance** is **too low**

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

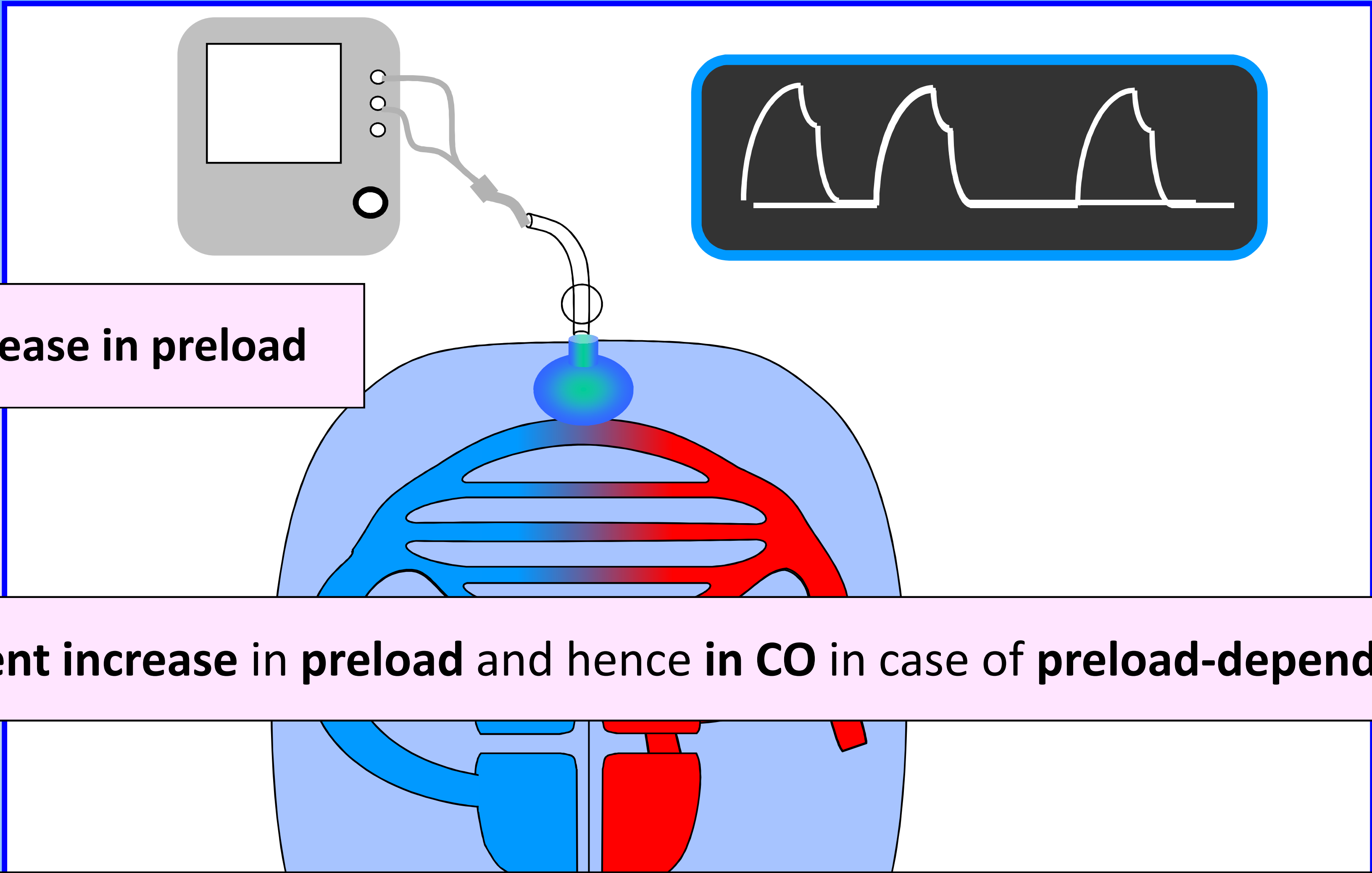
… and are now available

➢ **Fluid Challenge**

➢ **Predictors of fluid responsiveness/unresponsiveness**

- **Static** markers of **preload**
- **Dynamic** markers of **preload responsiveness**
    - **heart-lung interaction** tests
        - **variability of stroke volume and of its surrogates**
        - **variability of (inferior or superior) vena cava diameter**
        - **end-expiratory occlusion** test

End-expiratory occlusion test



Cyclic decrease in preload

Transient increase in **preload** and hence **in CO** in case of **preload-dependency**

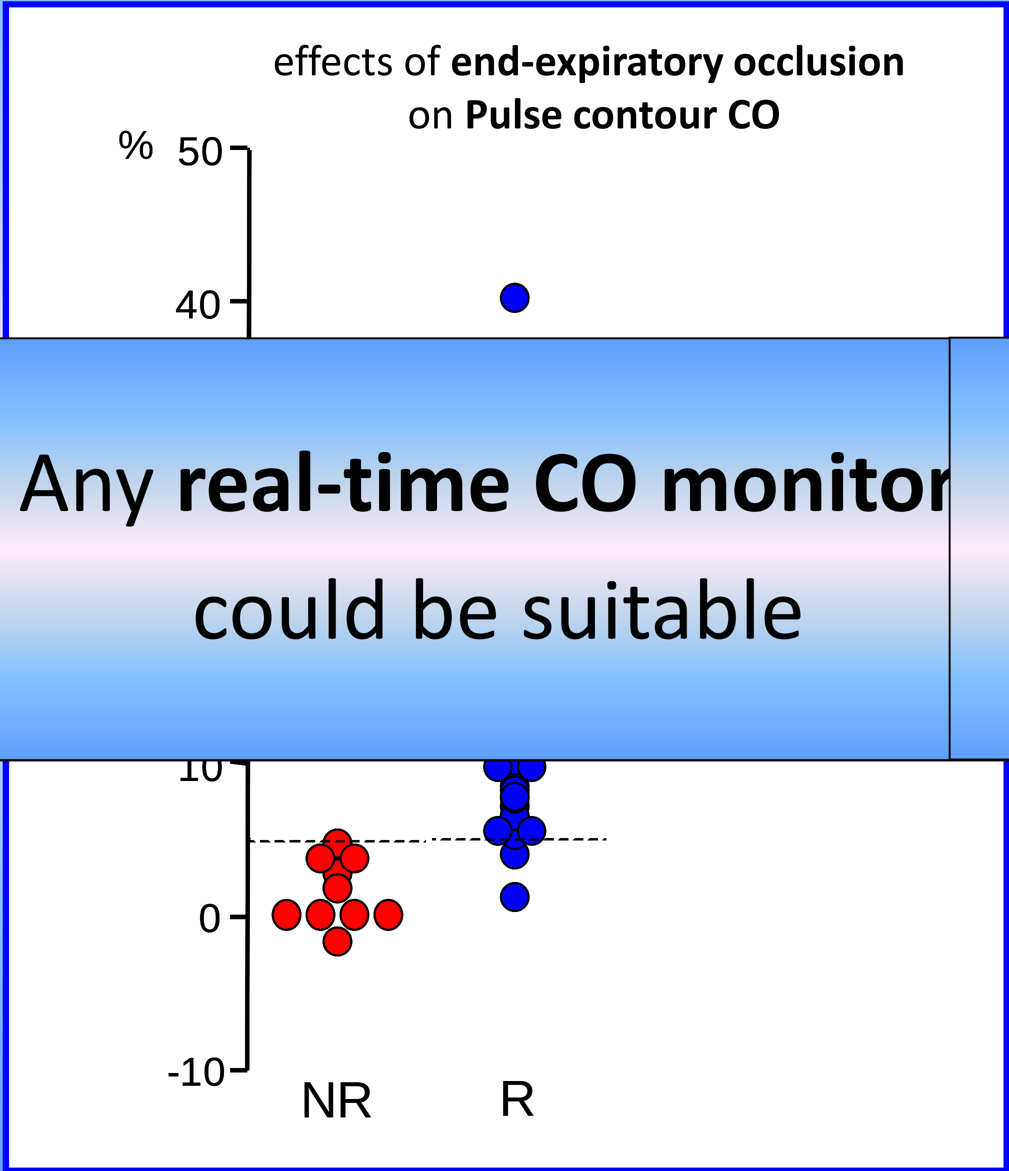
Fluid responders should be identified

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



Any **real-time CO monitor** could be suitable

A simple **arterial catheter** could be suitable

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

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]

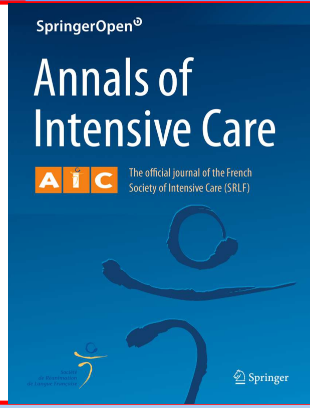
Crit Care Med 2013; 41:1692–1701

- Fluid Challenge
- **Predictors of fluid responsiveness/unresponsiveness**
  - **Static** markers of **preload**
  - **Dynamic** markers of **preload responsiveness**
    - **heart-lung interaction** tests
      - **variability of stroke volume and of its surrogates**
      - **variability of (inferior or superior) vena cava diameter**
      - **end-expiratory occlusion** test
    - **passive leg raising** test

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

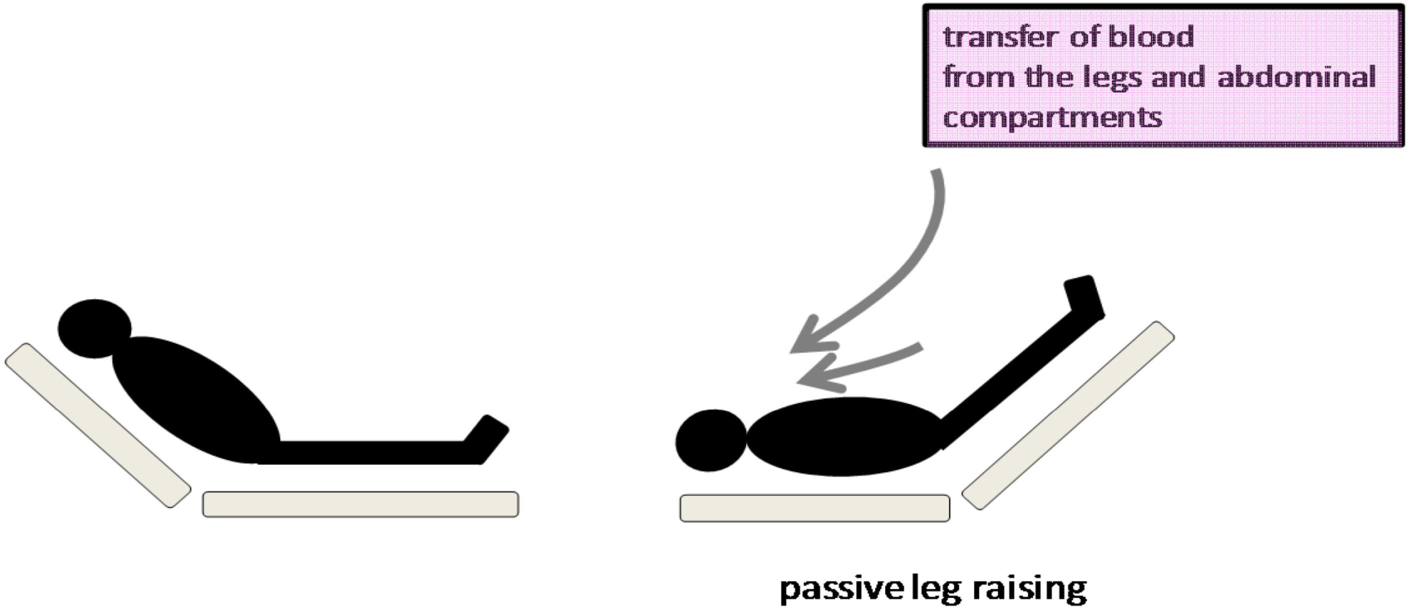
Annals of Intensive Care
a SpringerOpen Journal

REVIEW **Open Access**



Hemodynamic parameters to guide fluid therapy

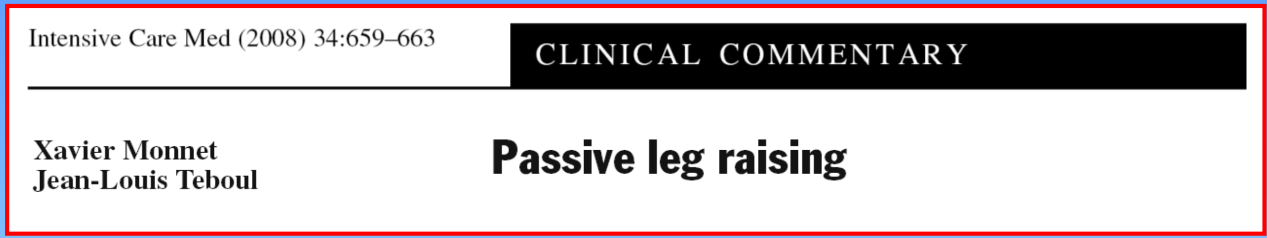
Paul E Marik[1*], Xavier Monnet[2], Jean-Louis Teboul[2]



Passive Leg Raising: the advantages

- **PLR** provides a good **prediction** of **fluid responsiveness**
- **Unlike** fluid challenge, effects of **PLR** are rapidly **reversible**
- **PLR may well assess** fluid responsiveness

  ... in situations where **PPV fails** to do it

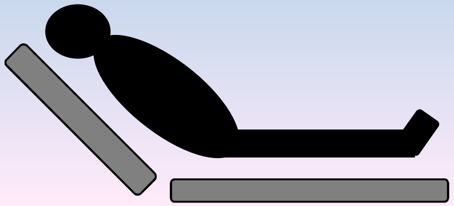


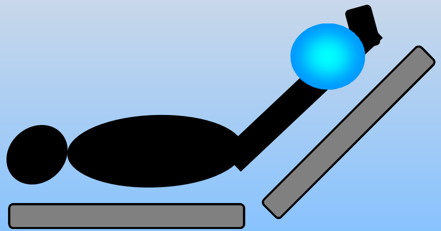
Intensive Care Med (2008) 34:659–663

CLINICAL COMMENTARY

Xavier Monnet
Jean-Louis Teboul

Passive leg raising

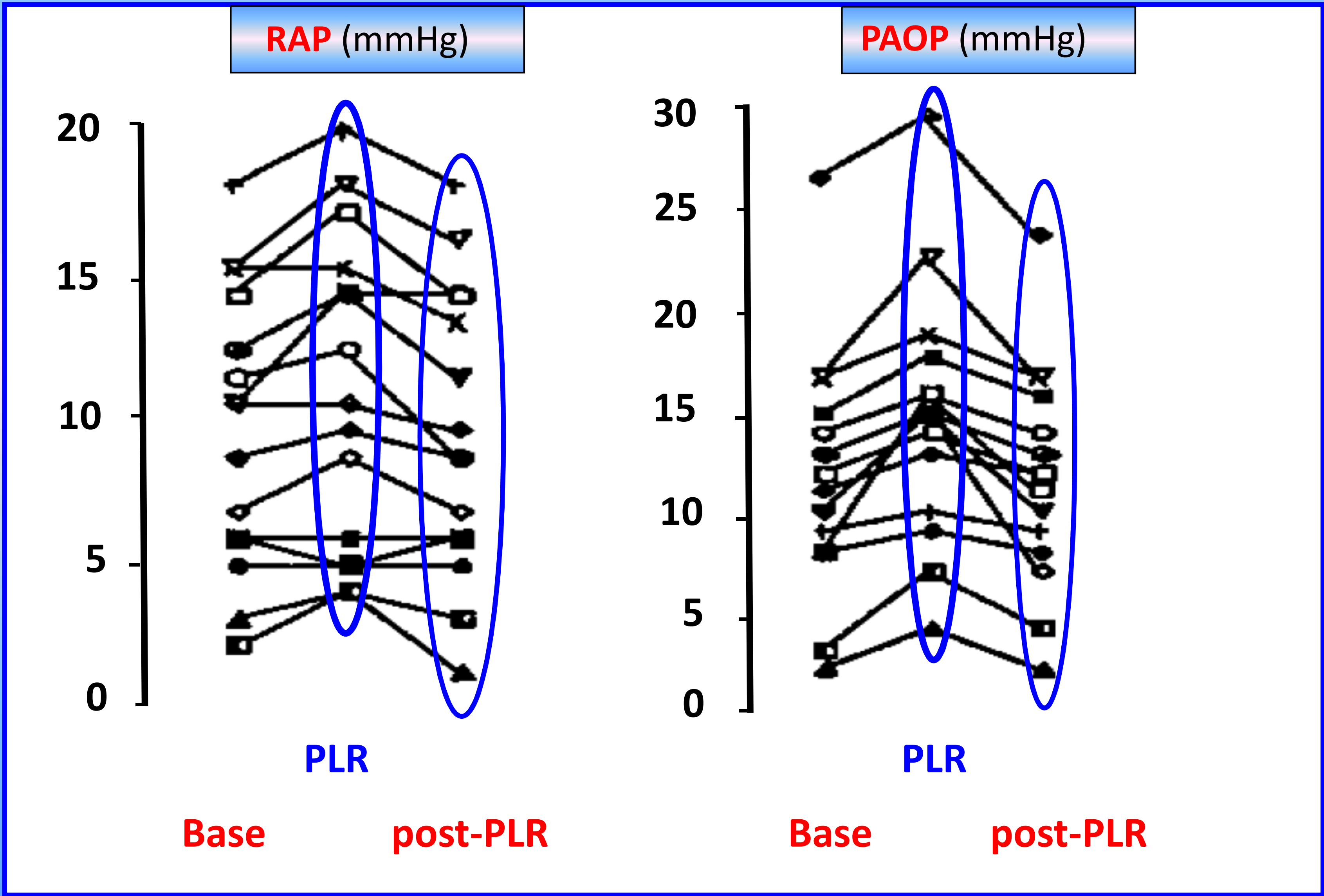




Changes in BP Induced by Passive Leg Raising Predict Response to Fluid Loading in Critically Ill Patients*

Thierry Boulain, MD; Jean-Michel Achard, MD; Jean-Louis Teboul, MD; Christian Richard, MD; Dominique Perrotin, MD; and Guy Ginies, MD

CHEST 2002; 121:1245–1252

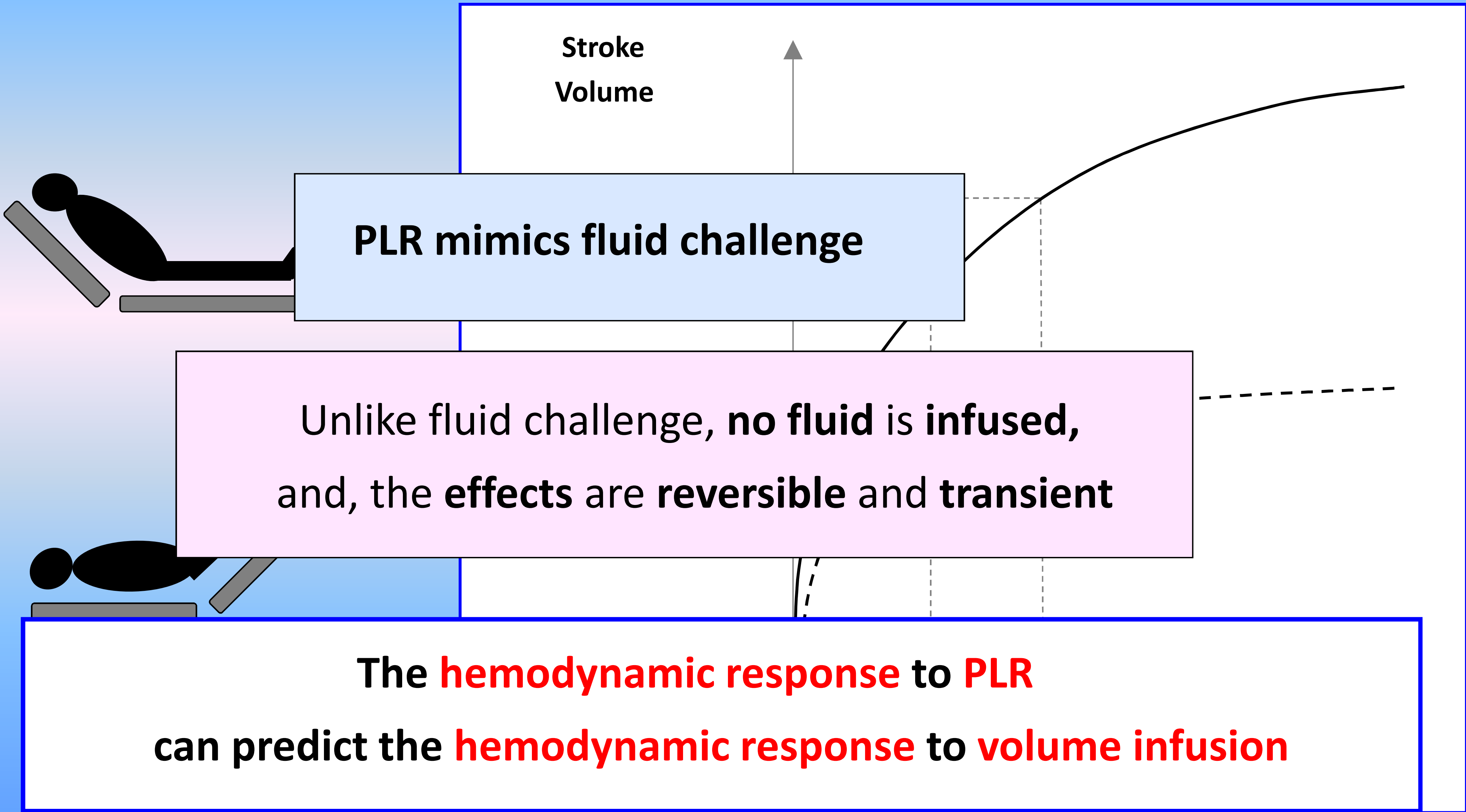


Intensive Care Med (2008) 34:659–663

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**

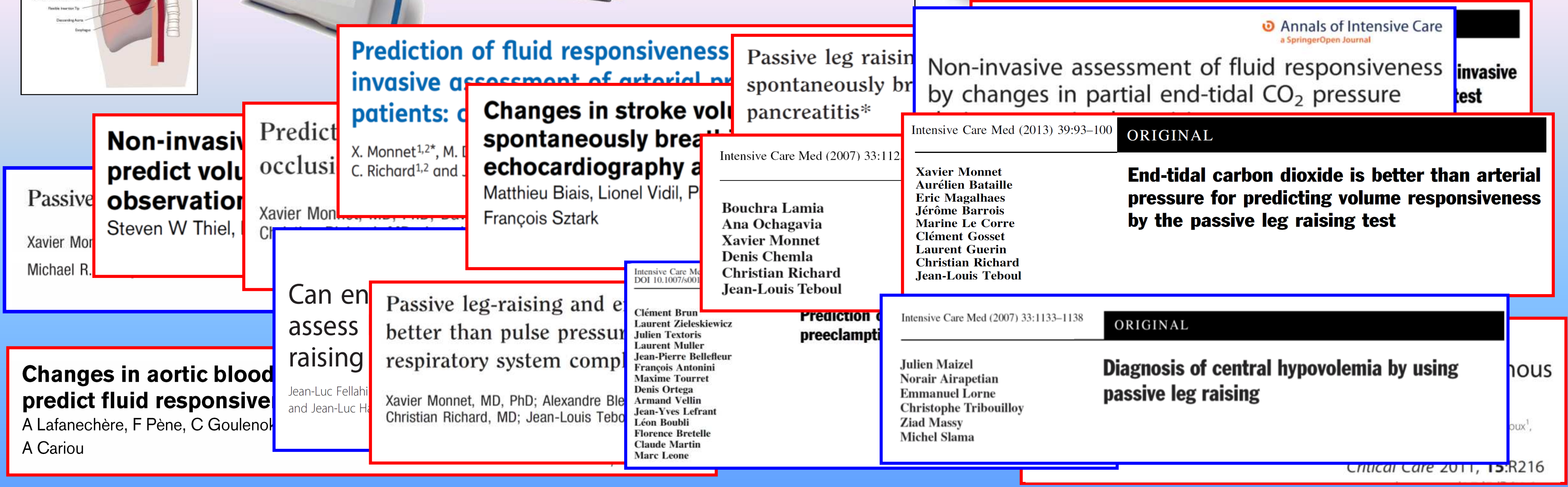
The hemodynamic response to PLR

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

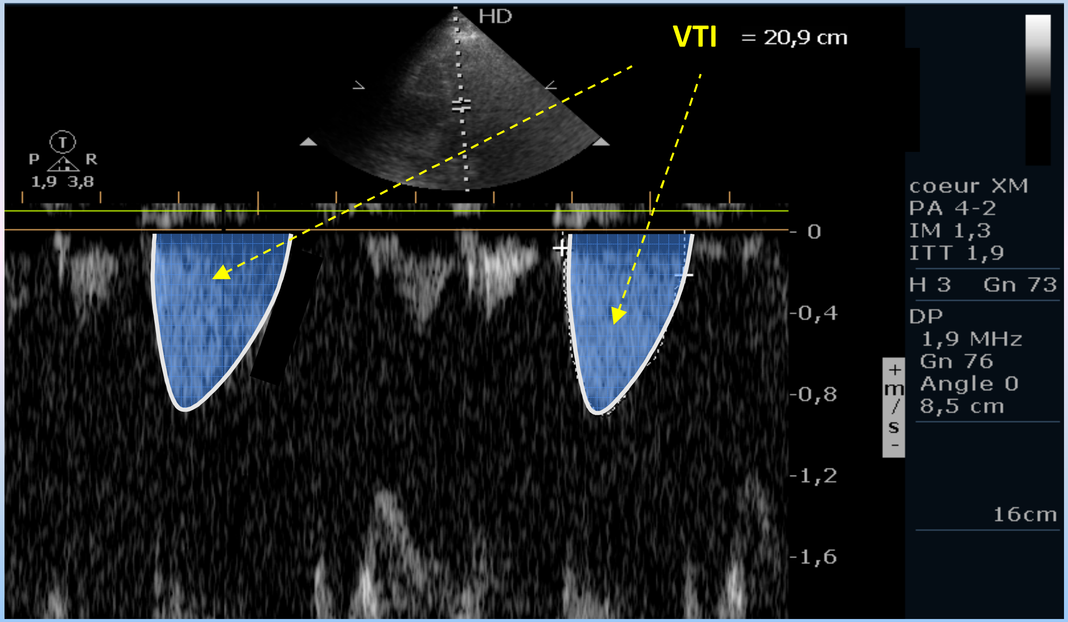


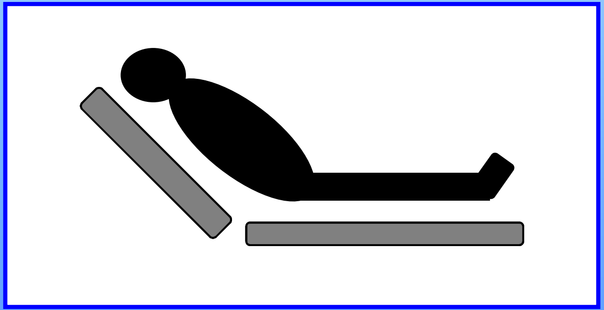
Intensive Care Med (2007) 33:1125–1132

ORIGINAL

Bouchra Lamia
Ana Ochagavia
Xavier Monnet
Denis Chemla
Christian Richard
Jean-Louis Teboul

Echocardiographic prediction of volume responsiveness in critically ill patients with spontaneously breathing activity





Intensive Care Med (2007) 33:1125–1132
DOI 10.1007/s00134-007-0646-7

ORIGINAL

Bouchra Lamia
Ana Ochagavia
Xavier Monnet
Denis Chemla
Christian Richard
Jean-Louis Teboul

Echocardiographic prediction of volume responsiveness in critically ill patients with spontaneously breathing activity

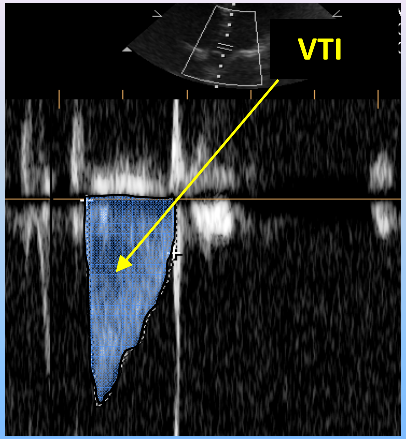
PLR-induced change in **Velocity-Time Integral**

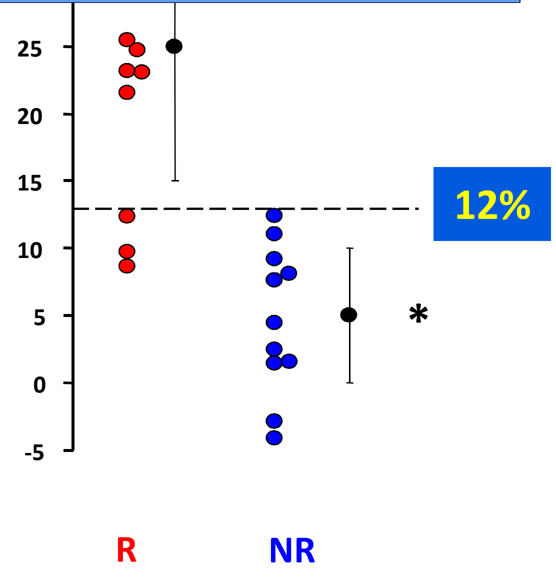
good **prediction**

of **volume responsiveness**

24 pts with circulat

TTE before and aft



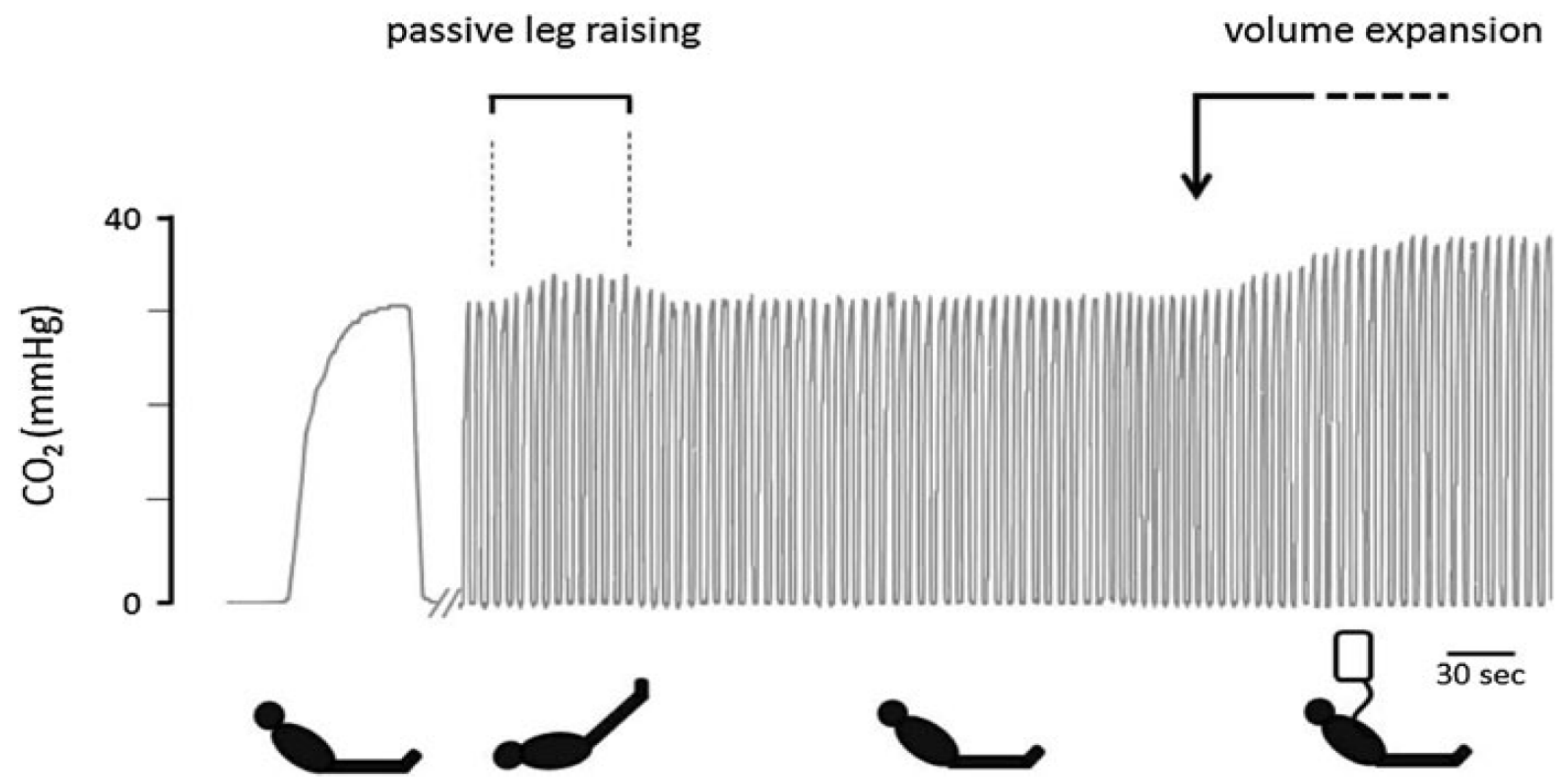


Intensive Care Med (2013) 39:93–100

ORIGINAL

Xavier Monnet
Aurélien Bataille
Eric Magalhaes
Jérôme Barrois
Marine Le Corre
Clément Gosset
Laurent Guerin
Christian Richard
Jean-Louis Teboul

End-tidal carbon dioxide is better than arterial pressure for predicting volume responsiveness by the passive leg raising test



Intensive Care Med (2013) 39:93–100

ORIGINAL

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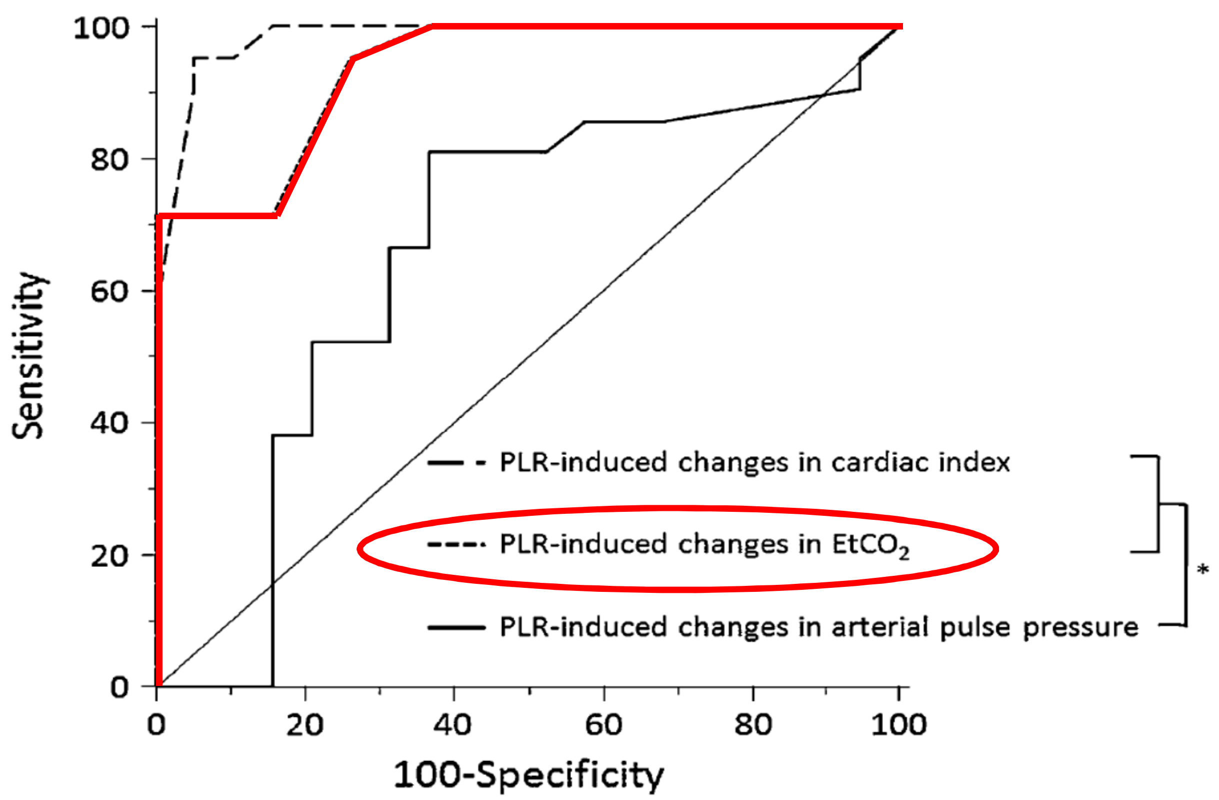

Passive Leg Raising: the advantages

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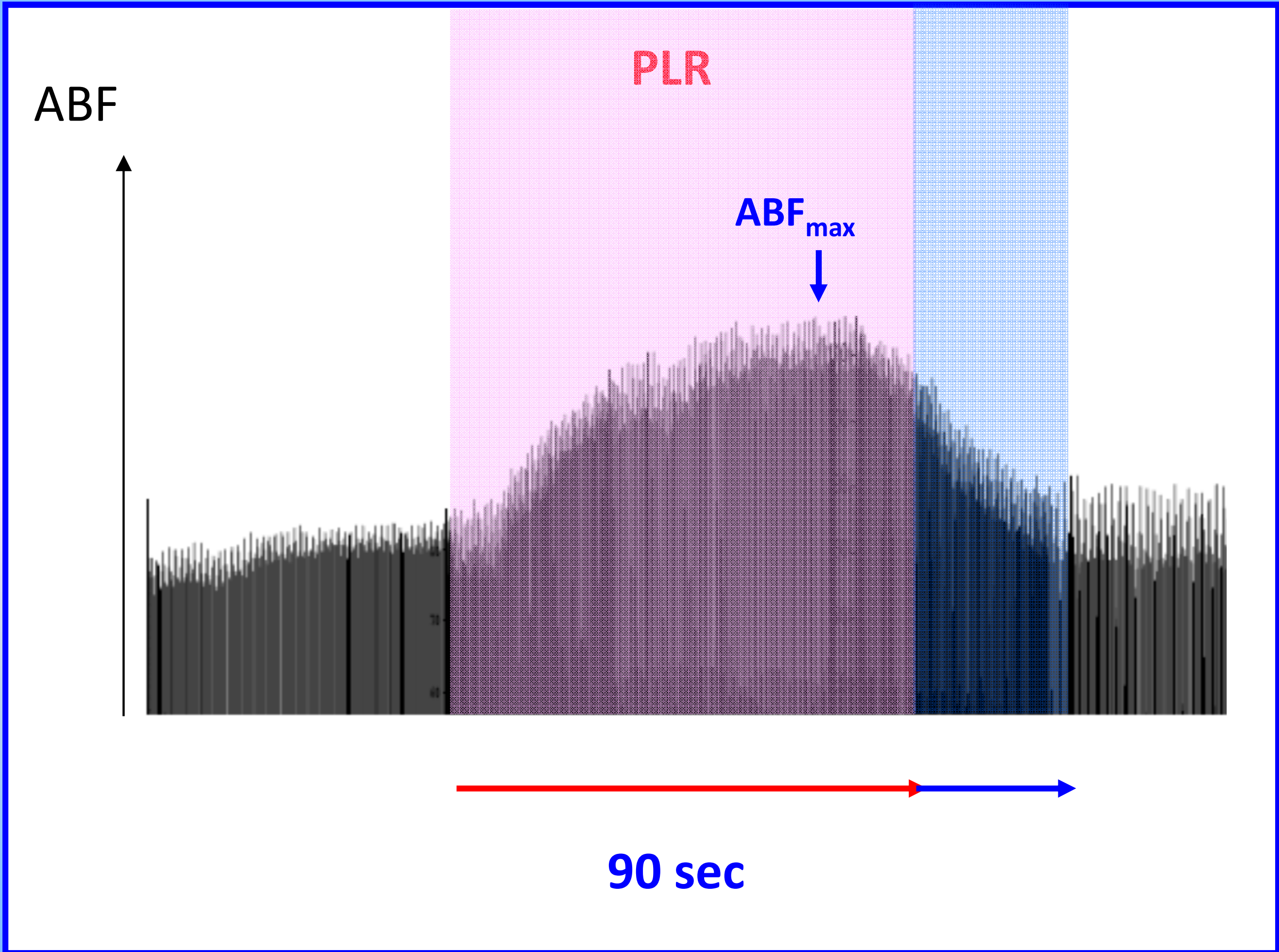
- **Unlike** fluid challenge, effects of **PLR** are rapidly **reversible**

- **PLR may well assess** fluid responsiveness

  … in situations where **PPV fails** to do it

reversible hemodynamic effects



No risk of pulmonary edema

Passive Leg Raising: the advantages

- **PLR** provides a good **prediction** of **fluid responsiveness**
- **Unlike** fluid challenge, effects of **PLR** are rapidly **reversible**
- **PLR** may **well assess** fluid responsiveness

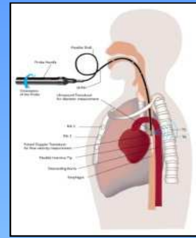
  … in situations where **PPV fails** to do it

    - **Spontaneous Breathing** activity

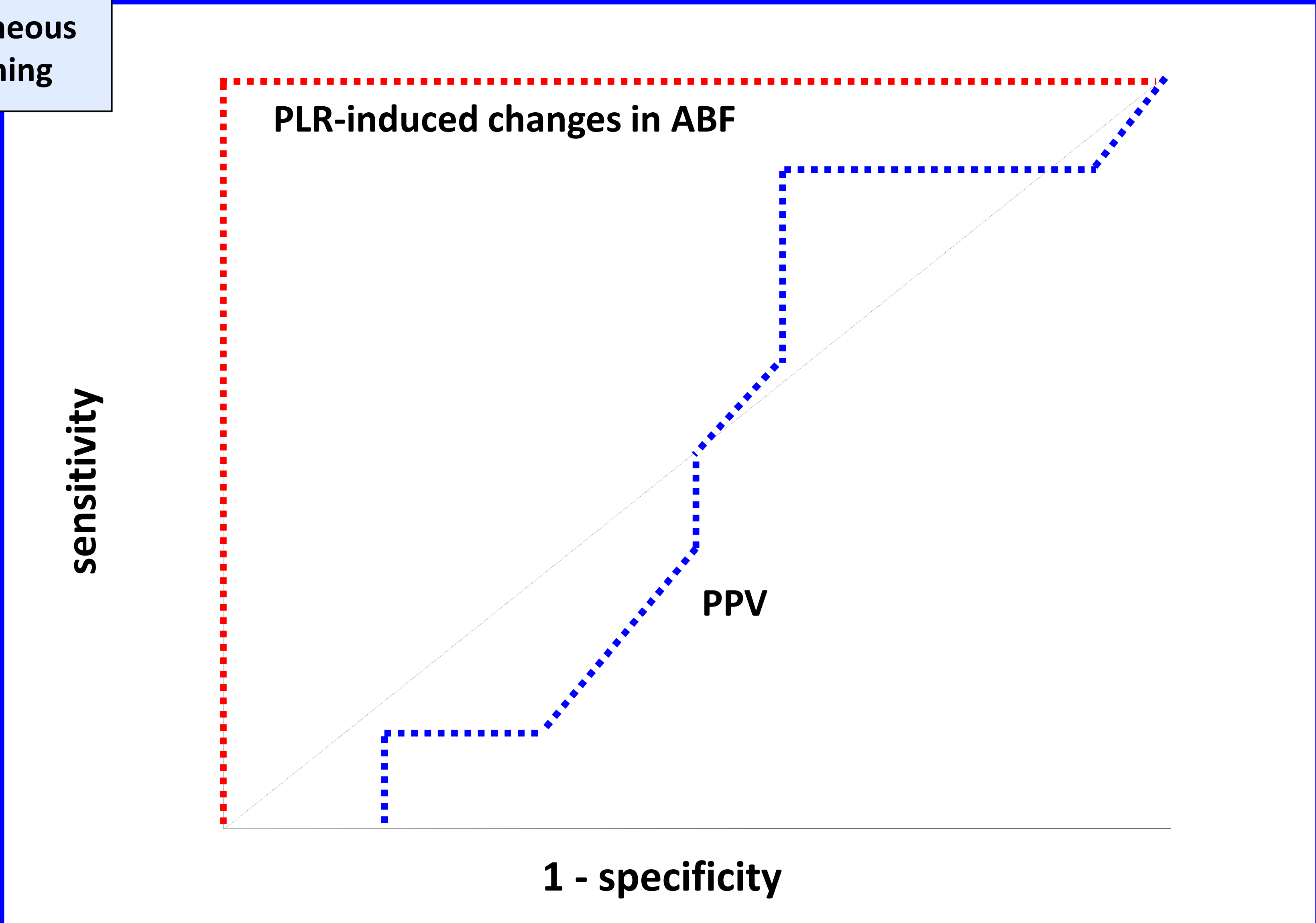
Passive leg raising predicts fluid responsiveness in the critically ill*

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



Pts with **spontaneous breathing**



Passive Leg Raising: The advantages

- **PLR** provides a good **prediction** of **fluid responsiveness**
- **Unlike** fluid challenge, effects of **PLR** are rapidly **reversible**
- **PLR** may **well assess** fluid responsiveness

… in situations where **PPV fails** to do it

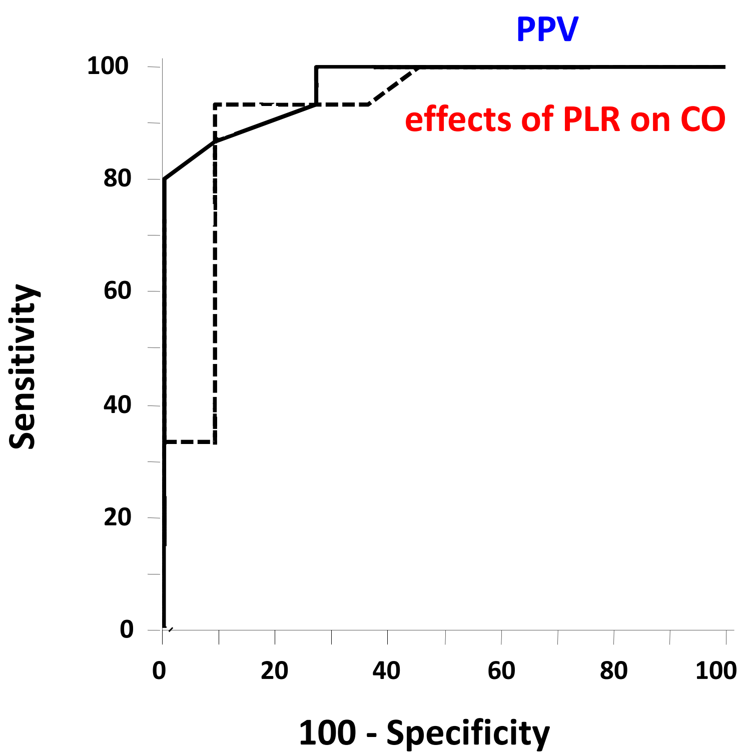
- Spontaneous Breathing activity
- **Low** lung **compliance**

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



Passive Leg Raising: the "limits"

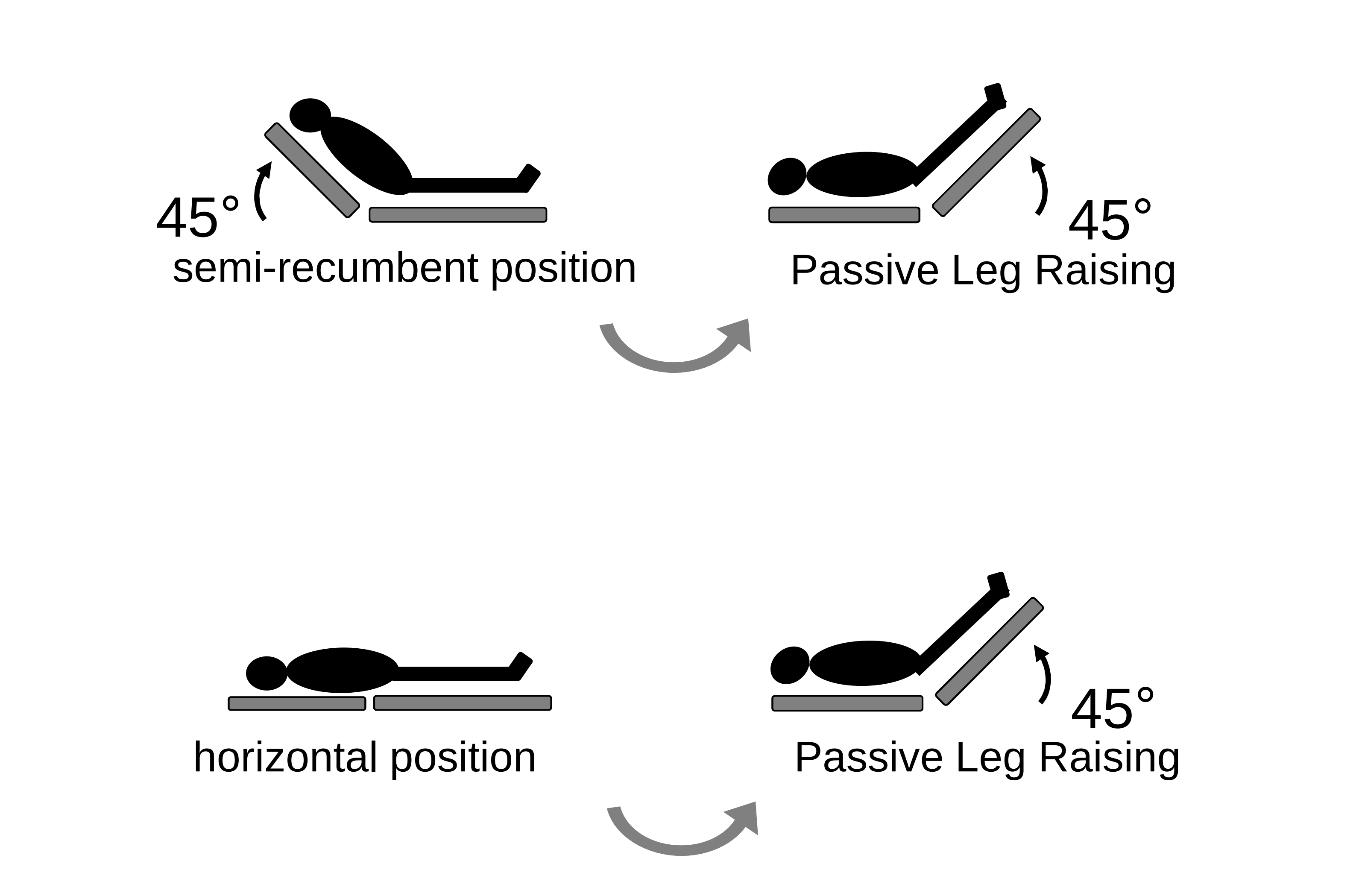
- **PLR** should **not** start from a **horizontal** patient's position but from a **semi-recumbent** position

Intensive Care Med (2009) 35:85–90

ORIGINAL

Julien Jabot
Jean-Louis Teboul
Christian Richard
Xavier Monnet

Passive leg raising for predicting fluid responsiveness: importance of the postural change



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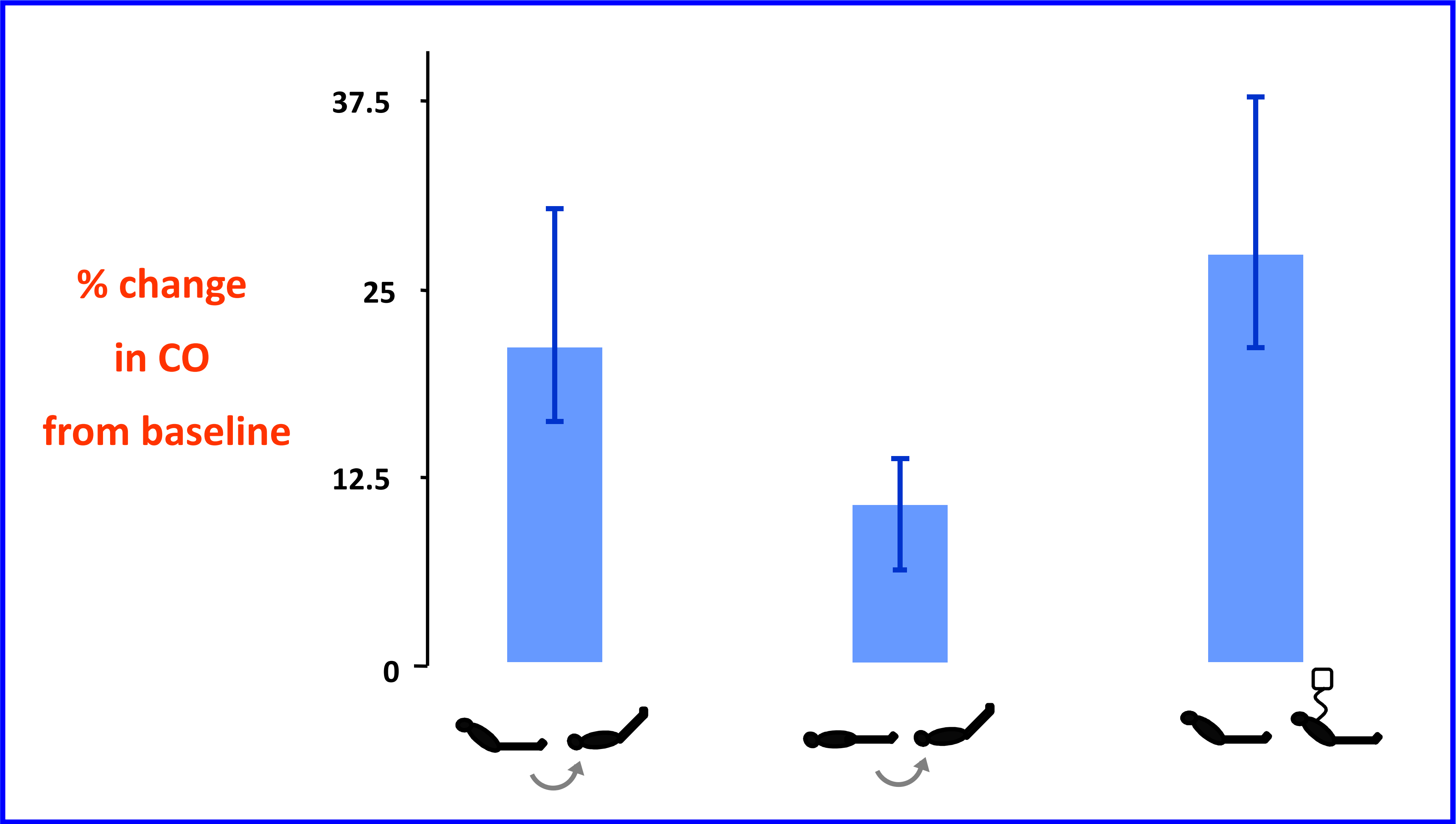

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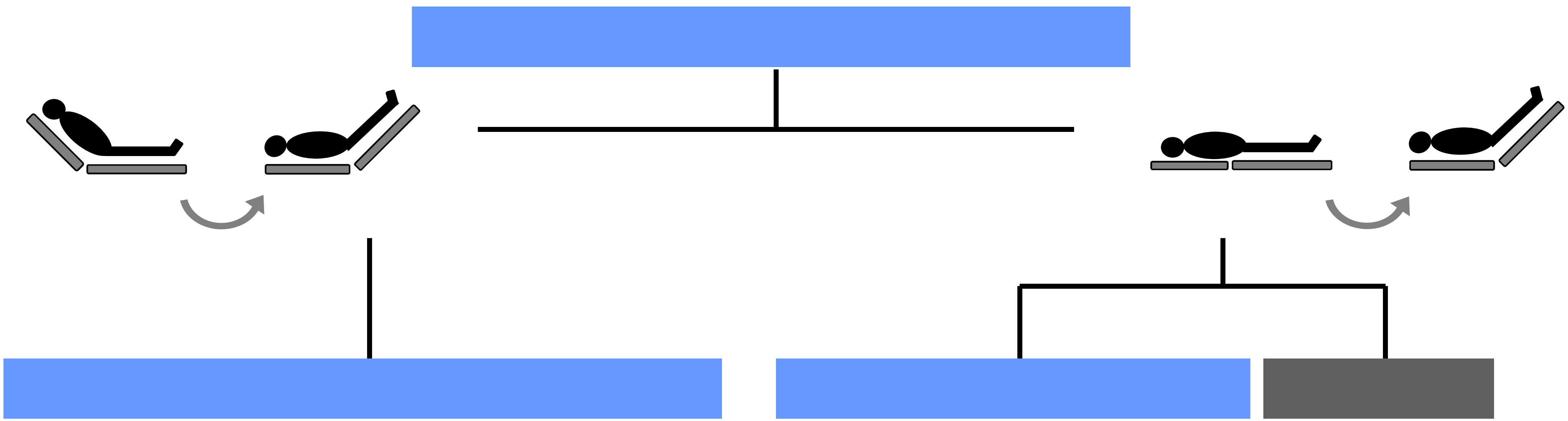
35 patients

(all responders to fluid administration)



35 pts correctly classified as responders

20 pts correctly classified as responders

15 pts classified as nonresponders

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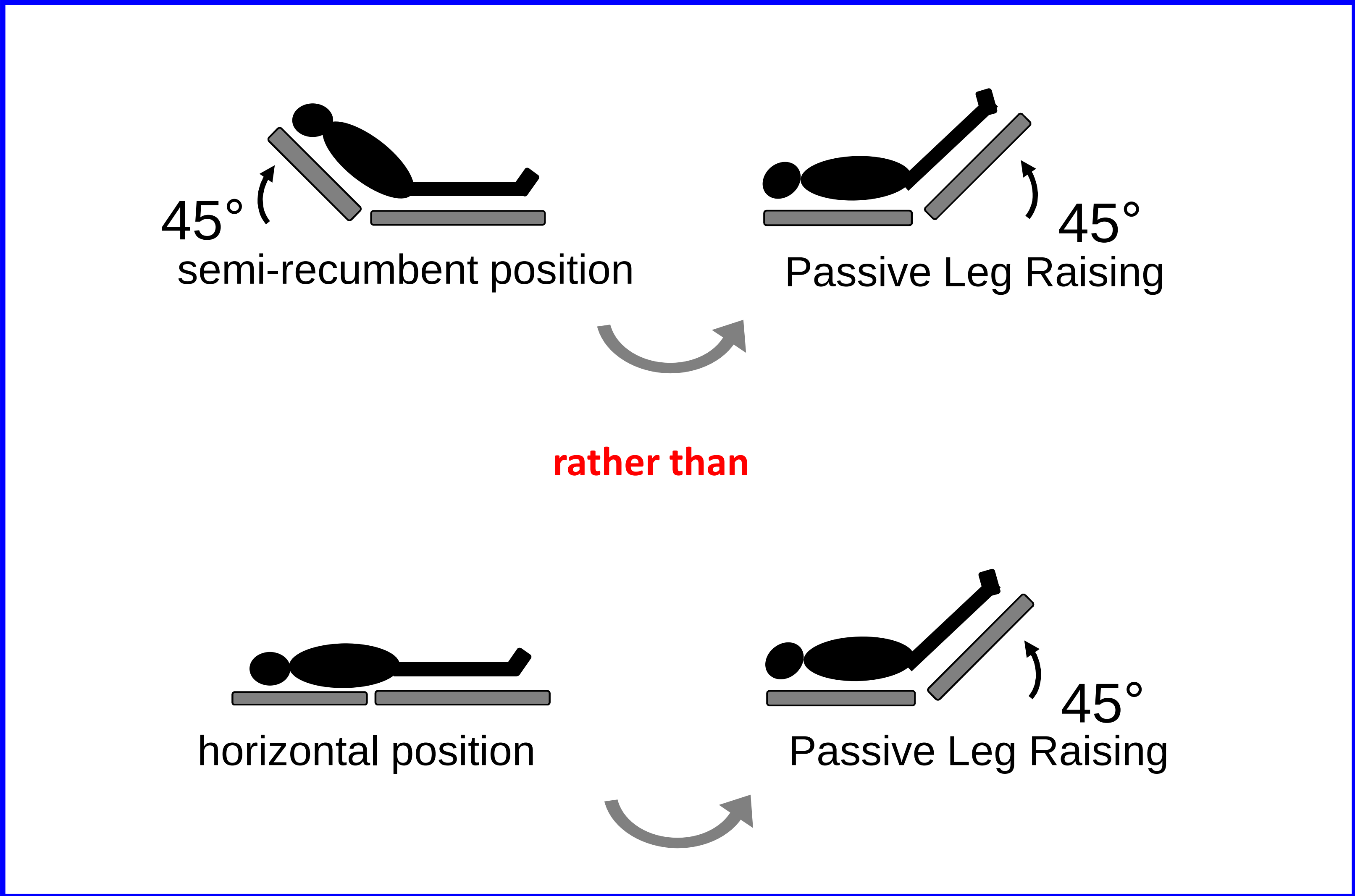

Passive Leg Raising: the "limits"

- **PLR** should **not** start from a **horizontal** patient's position but from a **semi-recumbent** position

- The hemodynamic **response** to **PLR should not** be monitored with **arterial pressure** but **with CO** measurements

Intensive Care Med (2010) 36:1475–1483

REVIEW

Fabio Cavallaro
Claudio Sandroni
Cristina Marano
Giuseppe La Torre
Alice Mannocci
Chiara De Waure
Giuseppe Bello
Riccardo Maviglia
Massimo Antonelli

Diagnostic accuracy of passive leg raising for prediction of fluid responsiveness in adults: systematic review and meta-analysis of clinical studies

PLR-induced changes in CO

Study name	sample size	AUC
Monnet CCM 2006	71	0.96
Lafanéchère CC 2006	22	0.95
Lamia ICM 2007	24	0.96
Maizel ICM 2007	34	0.89
Monnet CCM 2009	34	0.94
Thiel CC 2009	102	0.89
Biais CC 2009	30	0.96
Preau CCM 2010	34	0.94
	351	0.95

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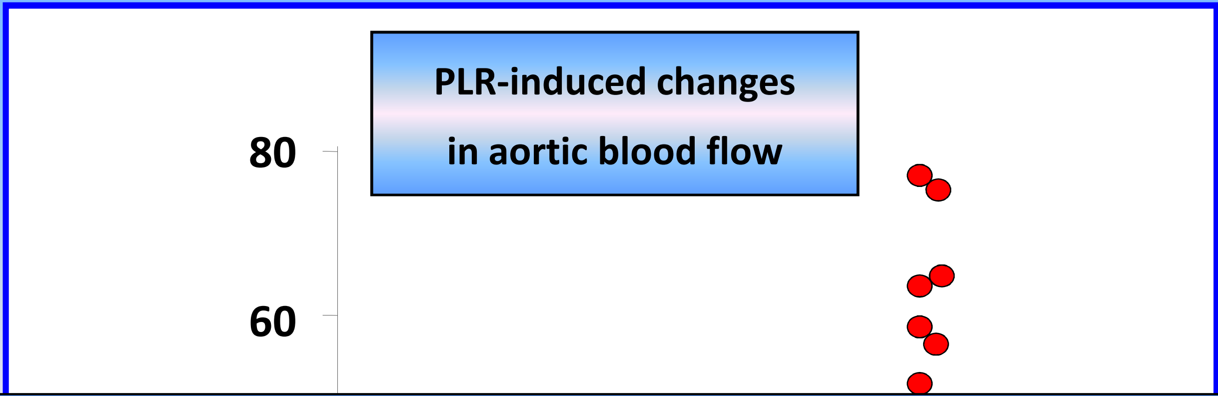

Following the **changes** in **arterial pressure** during PLR is **not suitable**

(false negative cases)

A **real-time CO** monitor is **necessary**

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**

Decision of **stopping fluid** administration

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

*Value of **EVLW** and **PVPI***

Conclusion

Predictors of fluid responsiveness/unresponsiveness

- **Pulse pressure variation** or **stroke volume variation**
- **PLR** or **end-expiratory occlusion** tests

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

by identifying patients **eligible** for fluid infusion

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

patients who would be fluid **unresponsive**

Thank you