Hemodynamic monitoring

in patients with septic shock

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Conflicts of interest

Member of the Medical Advisory Board of **Maquet**

Hemodynamic failure during sepsis: 3 components

hypovolemia

vascular tone depression

myocardial depression

Important of assessing the degree of each component to select and apply the best therapeutic option

fluids

vasopressors

inotropes

presence of associated **ARDS**

Monitoring: from cardiac output monitoring to echocardiography

Mathieu Jozwiak[a,b], Xavier Monnet[a,b], and Jean-Louis Teboul[a,b]

Curr Opin Crit Care 2015, 21

patients with **shock**

- **Central venous catheter**
- **Echocardiography**
- **Arterial catheter**

intermittent measurements of several cardiac function variables

Monitoring: from cardiac output monitoring to echocardiography

Mathieu Jozwiak[a,b], Xavier Monnet[a,b], and Jean-Louis Teboul[a,b]

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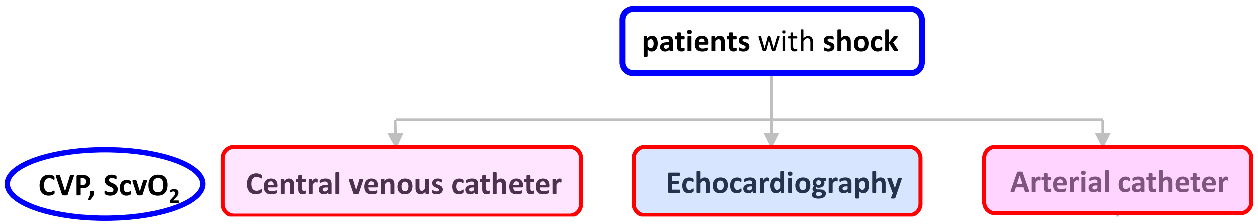
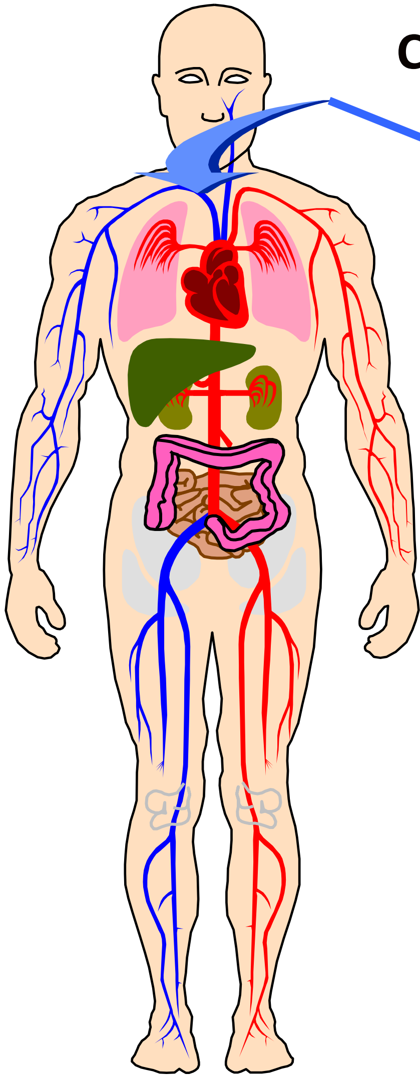
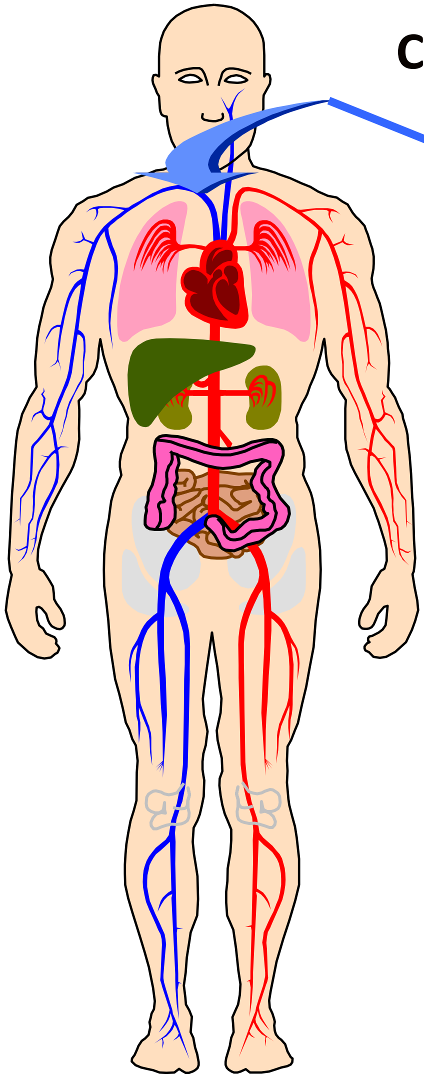




Central venous catheter

CVP and ScvO$_2$

- Helpful to diagnose **RV dysfunction**
- Helpful to **target** the optimal **MAP**
- **Not** helpful to predict **fluid responsiveness**



Central venous catheter

CVP and $ScvO_2$

$$SvO_2 = SaO_2 - \frac{VO_2}{CO \times Hb \times 13.4}$$

SvO_2 indicator of **VO_2 / DO_2 balance**

a low SvO_2 may incite

to elevate DO_2

(mostly through elevation of CO)

Monitoring: from cardiac output monitoring to echocardiography

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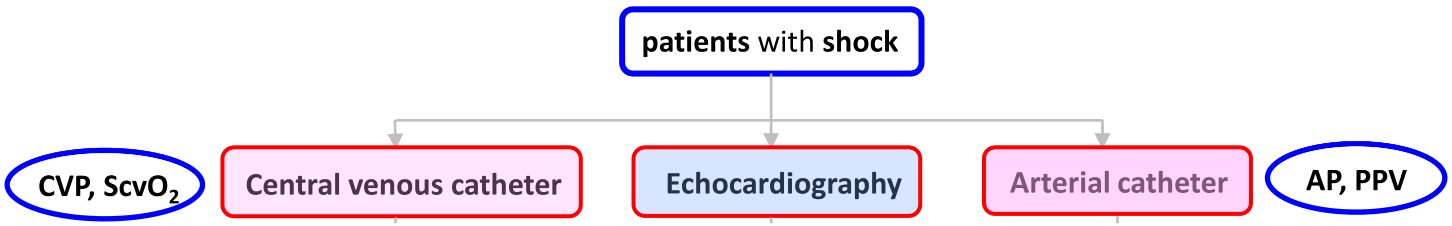
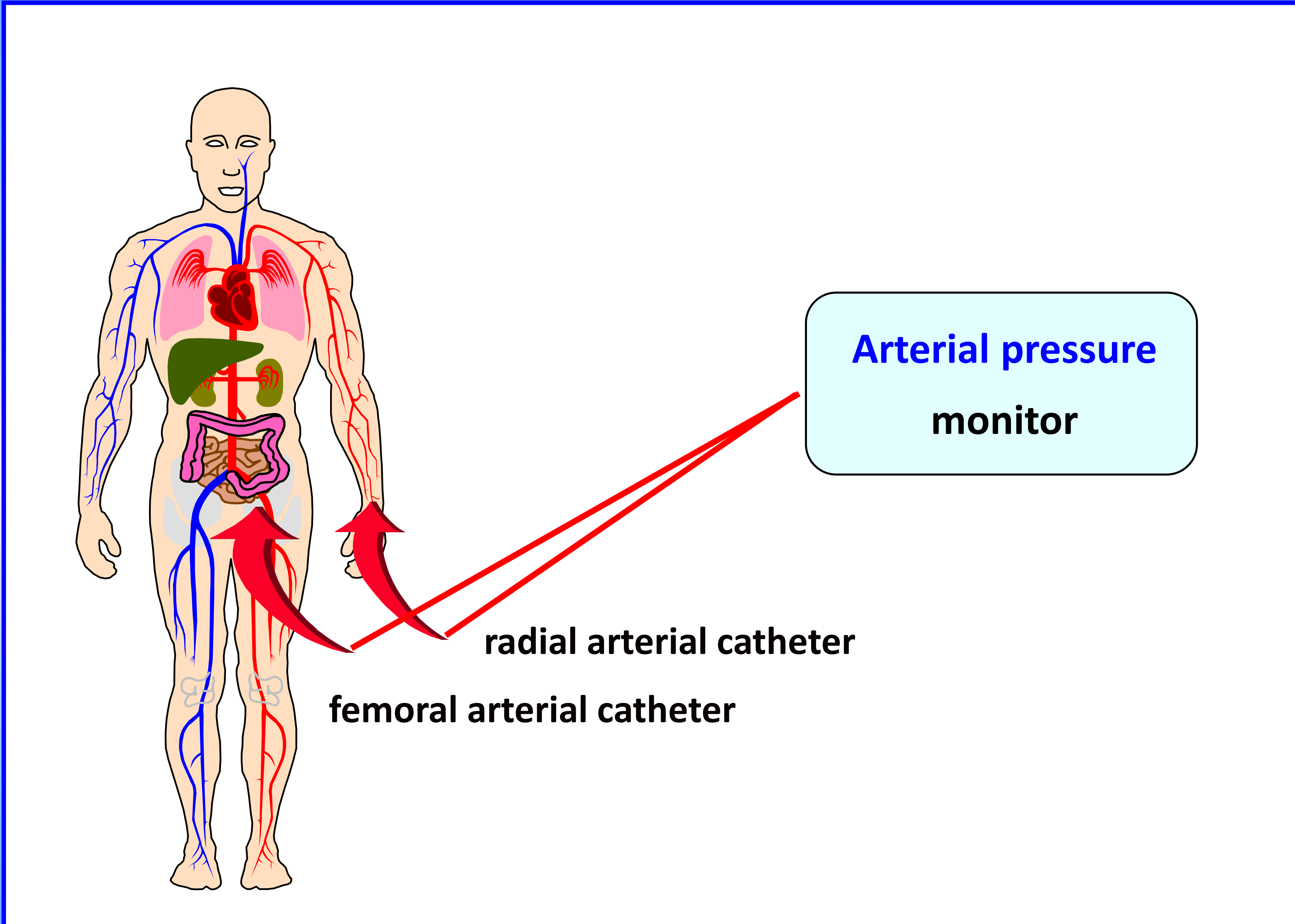
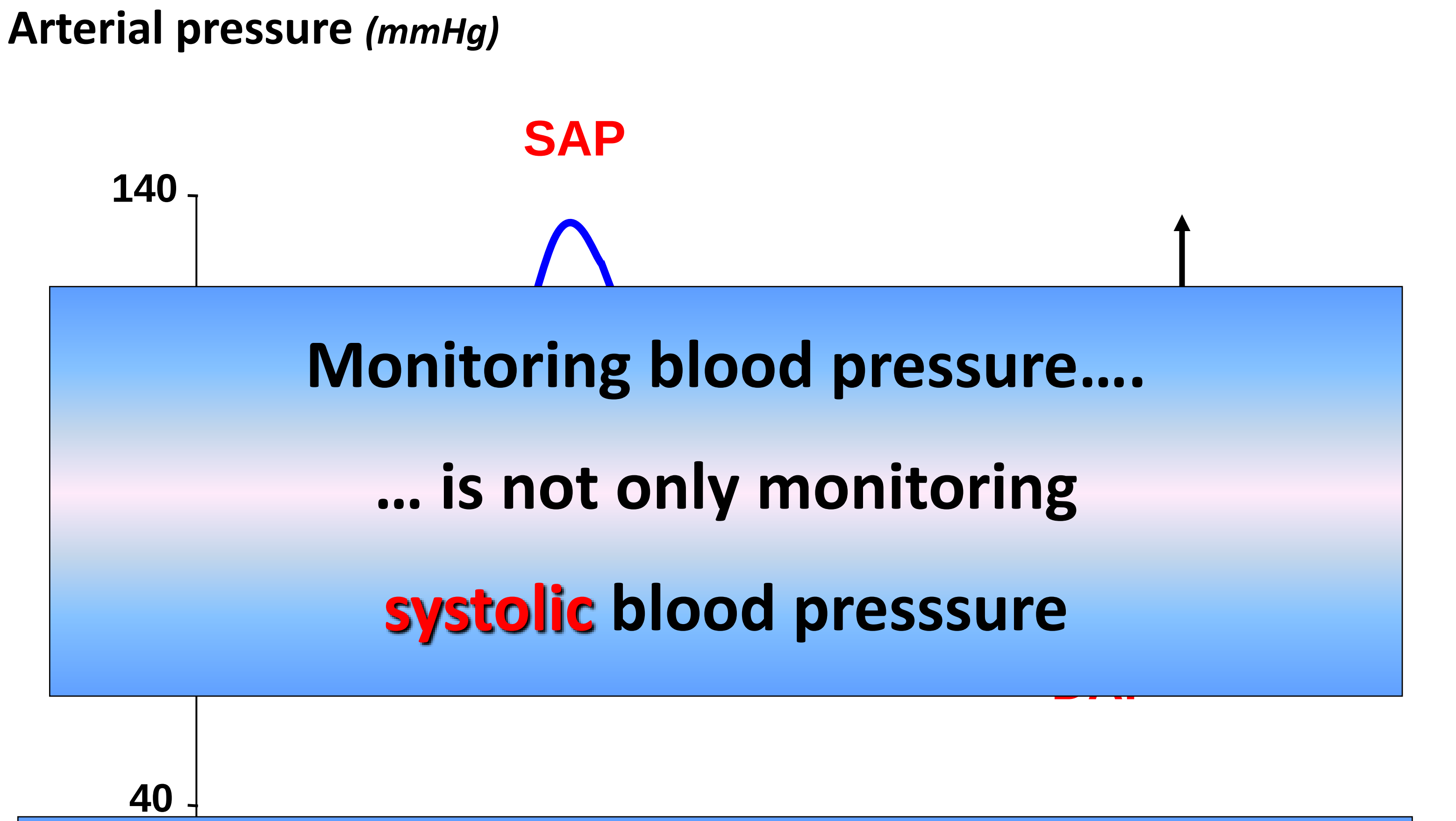



Arterial pressure
monitor
radial arterial catheter
femoral arterial catheter



Monitoring blood pressure….

… is not only monitoring

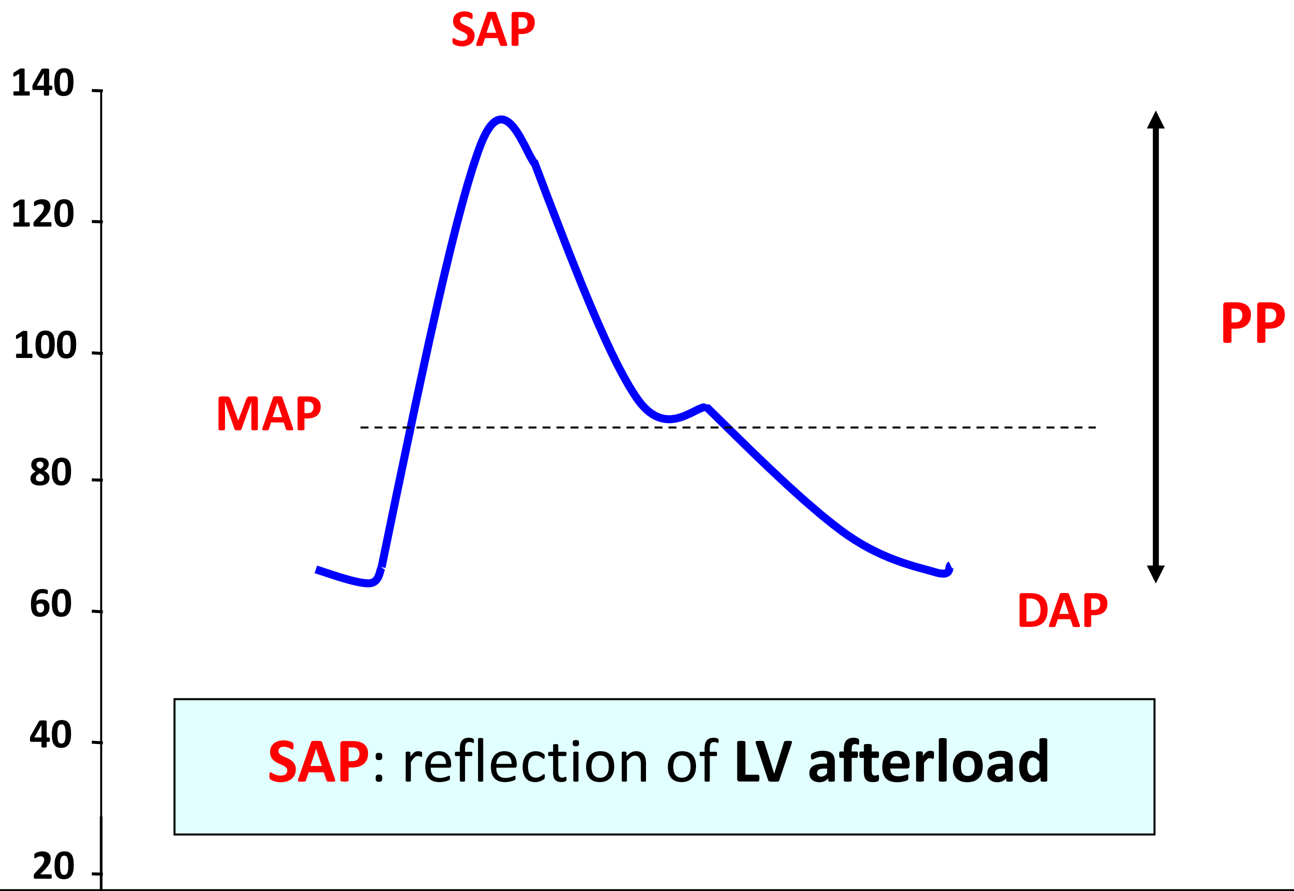
systolic blood presssure

A lot of useful pieces of information can be drawn

from **MAP**, **DAP**, **PP**

and from **analysis** of the **AP waveform**

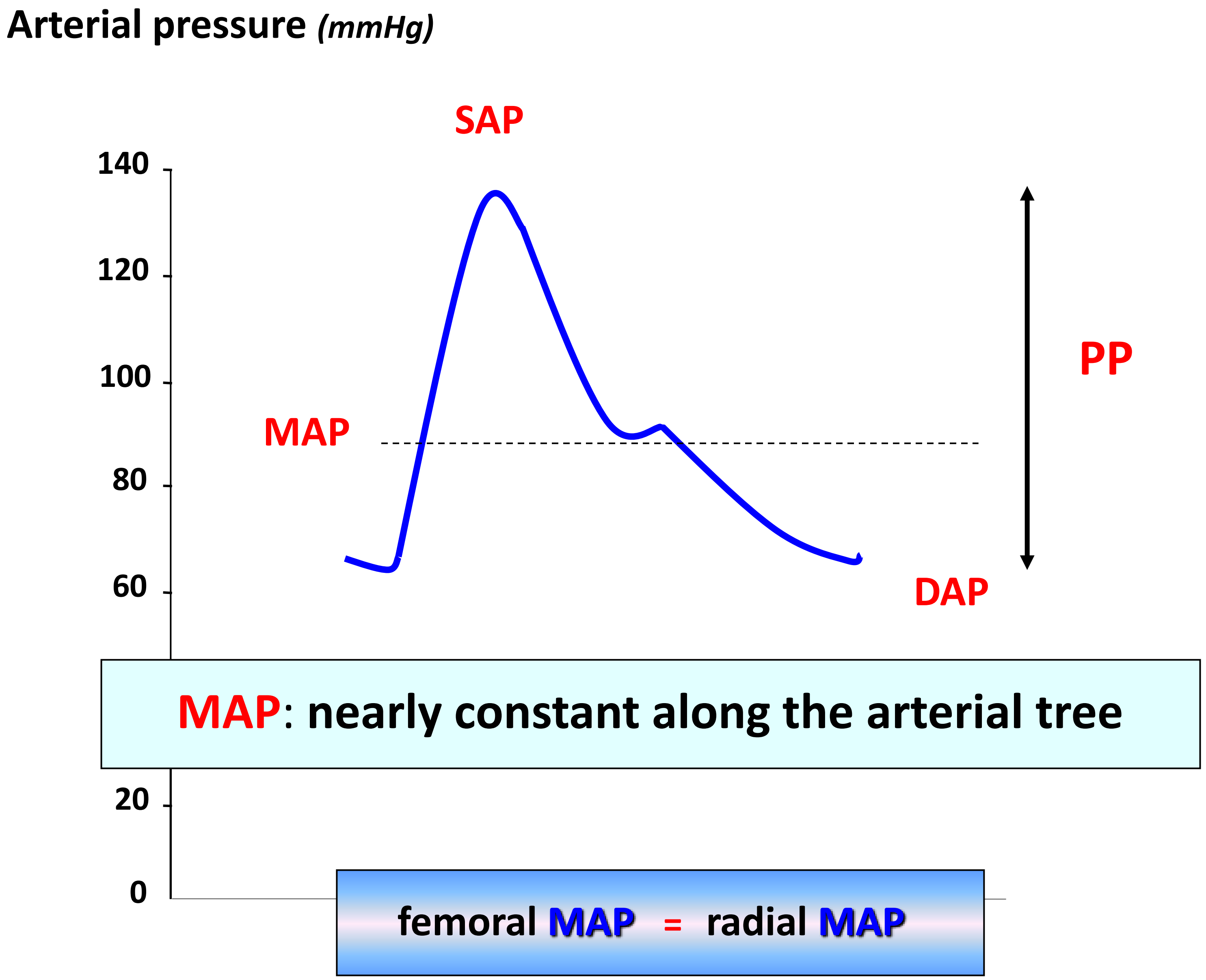
Arterial pressure *(mmHg)*



SAP: reflection of **LV afterload**

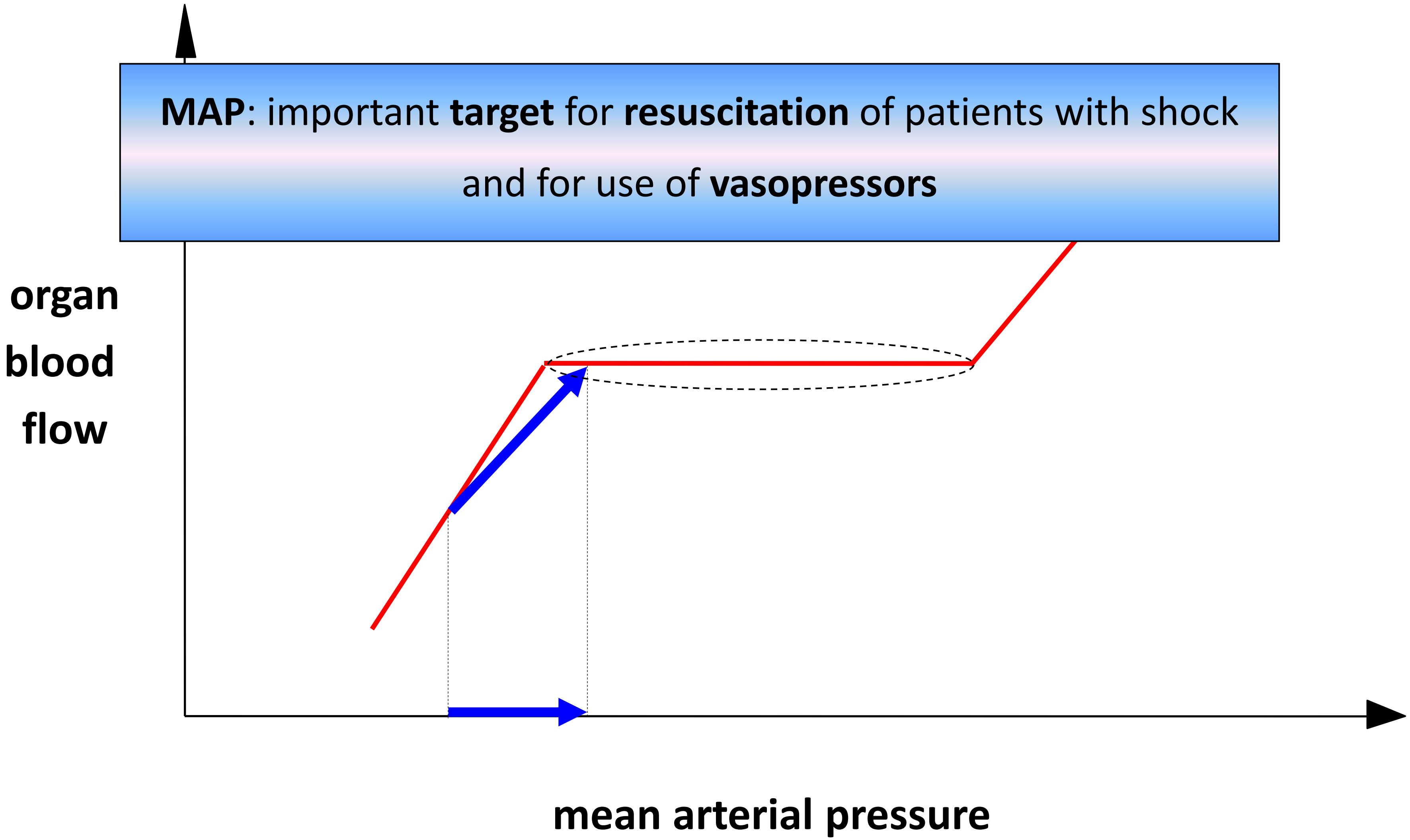
Particularly, if low pulse wave amplification

(**elderly**, **hypertensive**, **vasoconstricted**, etc)

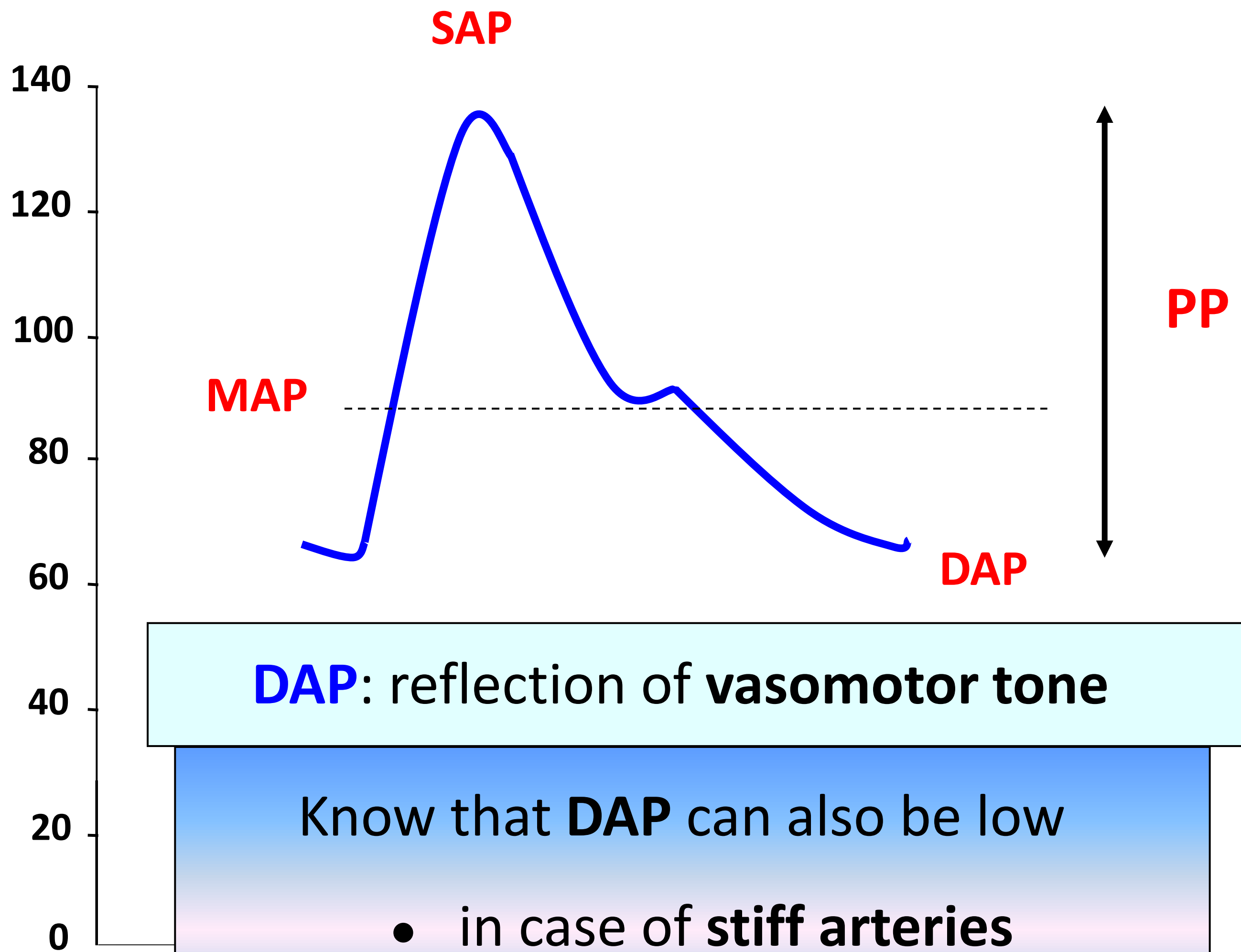

Arterial pressure (mmHg)
SAP
140
120
100
MAP
80
60
20
0
PP
DAP
MAP: nearly constant along the arterial tree
femoral MAP = radial MAP

Autoregulation of organ blood flow

MAP: important **target** for **resuscitation** of patients with shock and for use of **vasopressors**



Arterial pressure ***(mmHg)***

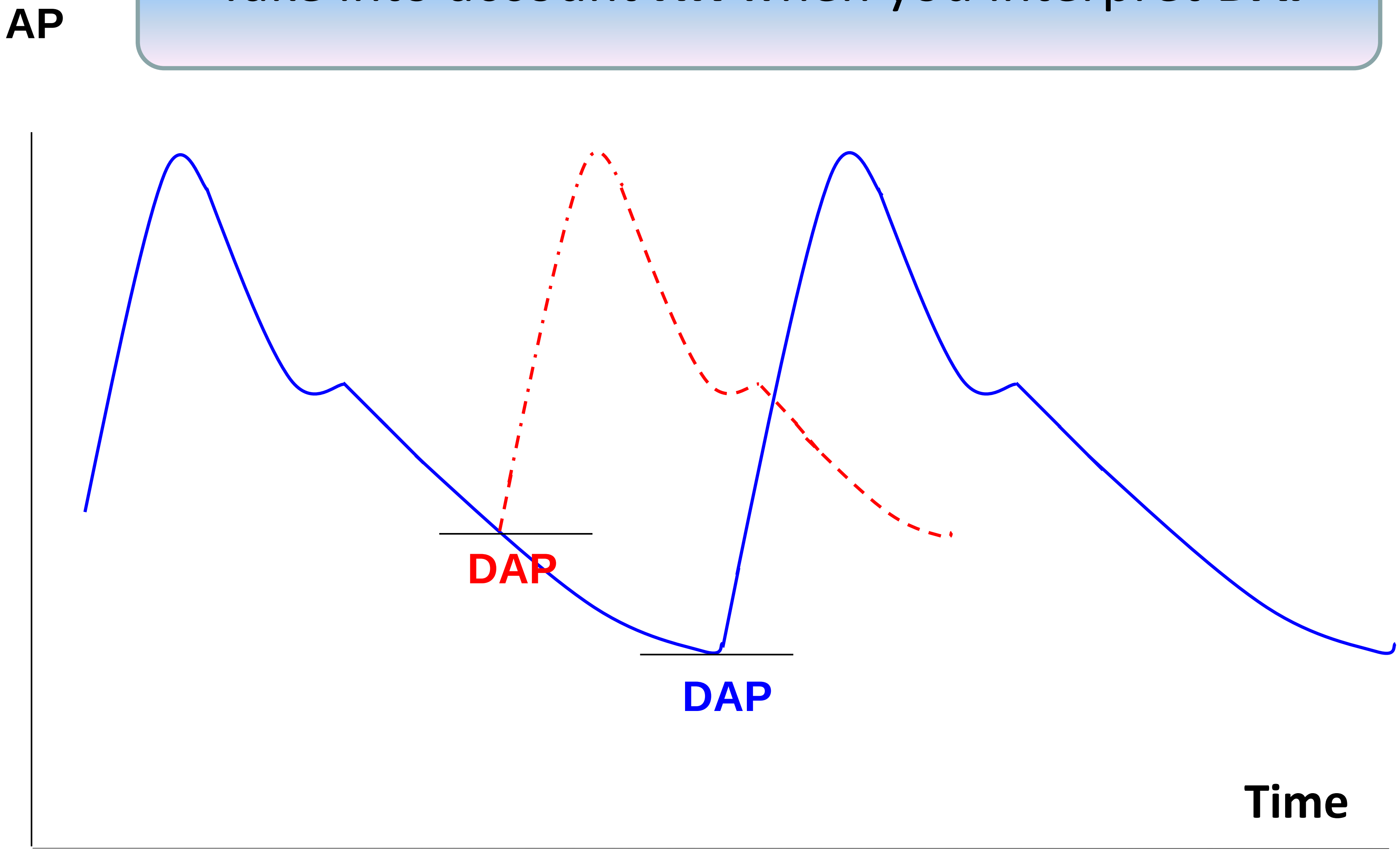


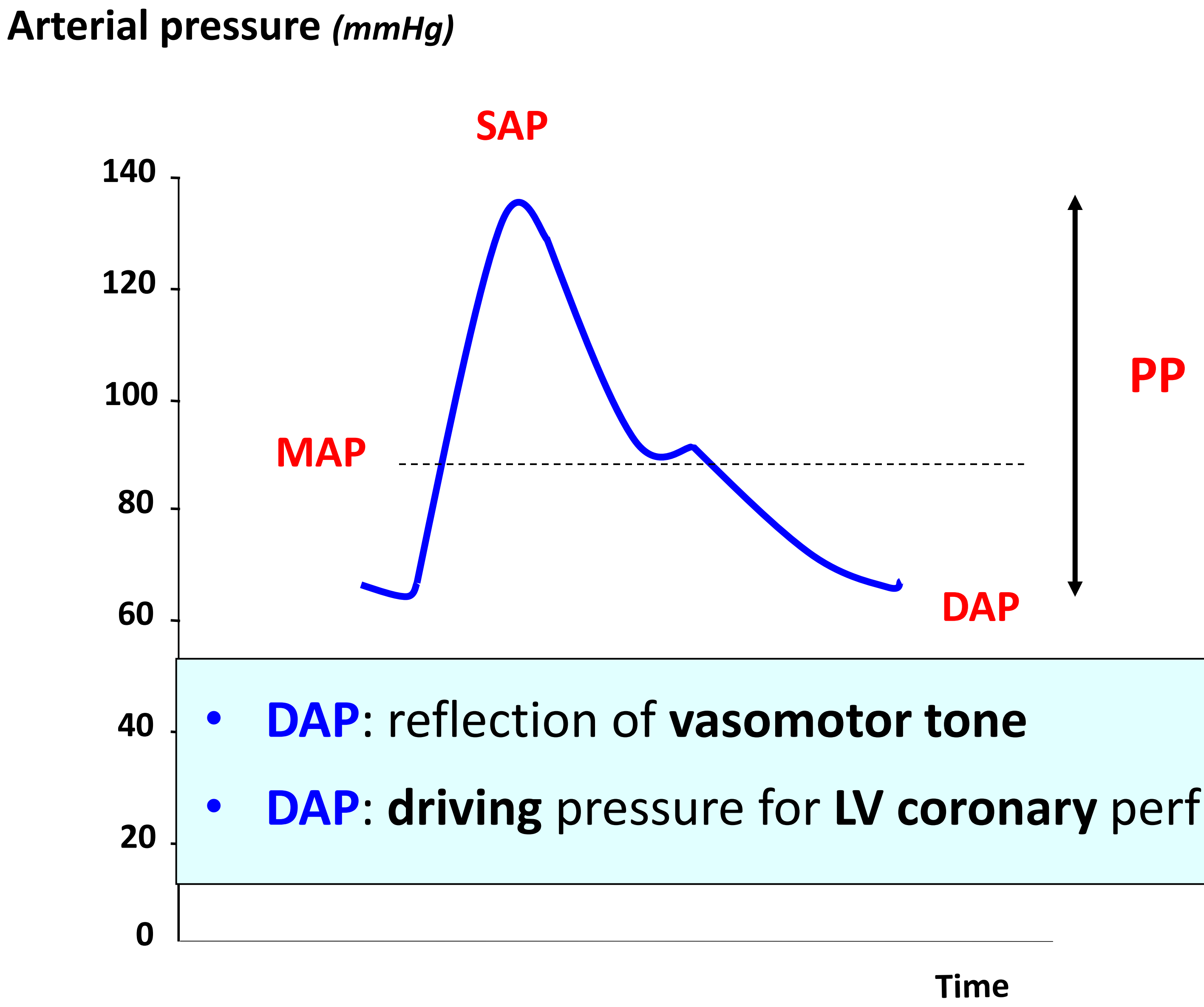
DAP: reflection of **vasomotor tone**

Know that **DAP** can also be low

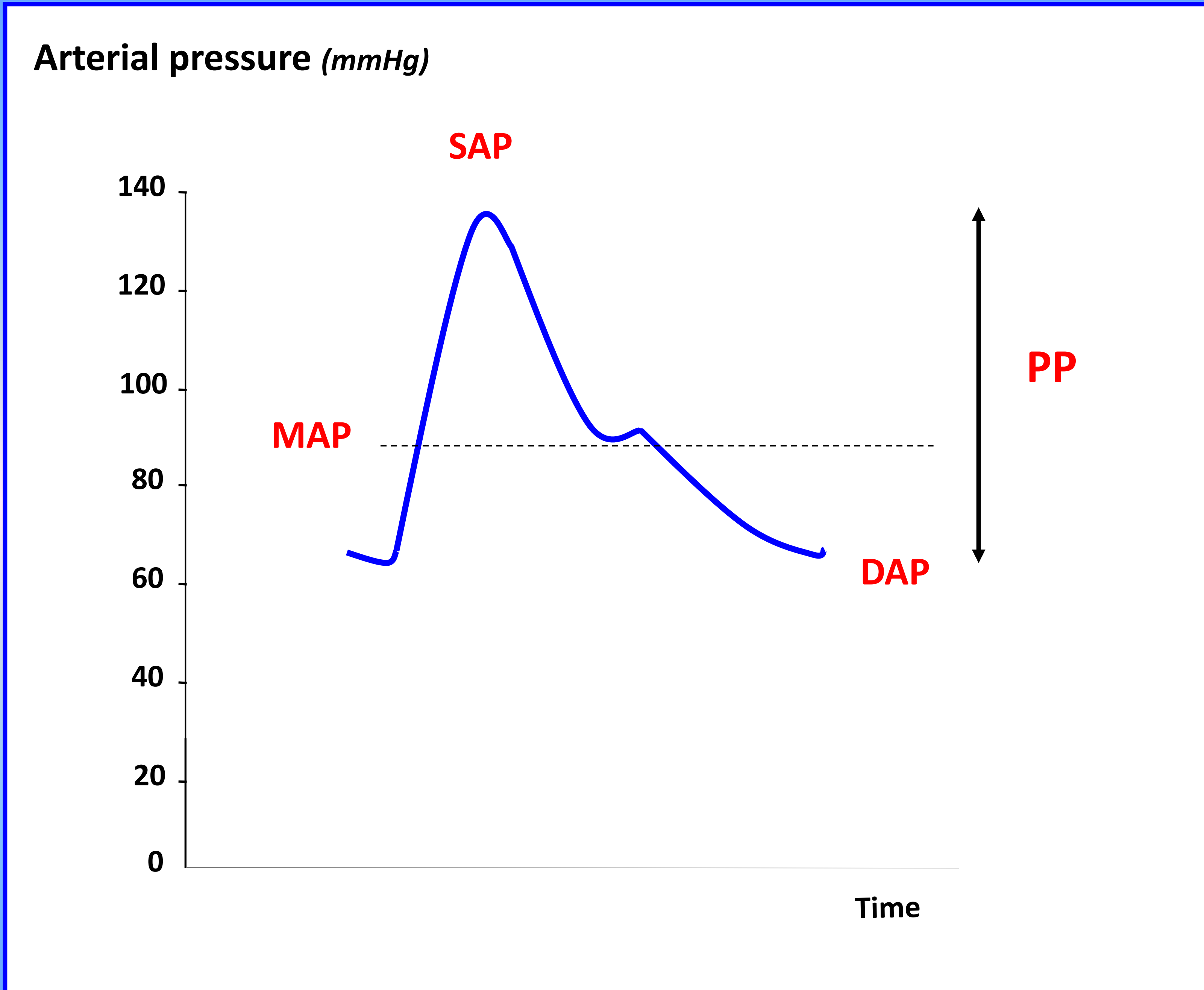
- in case of **stiff arteries**
- in case of **low heart rate**

Take into account **HR** when you interpret **DAP**





- **DAP**: reflection of **vasomotor tone**
- **DAP**: **driving** pressure for **LV coronary** perfusion


Arterial pressure (mmHg)
SAP
140
120
100
MAP
80
60
40
20
0
PP
DAP
Time

Pulse pressure

Aortic PP = k. SV . aortic stiffness

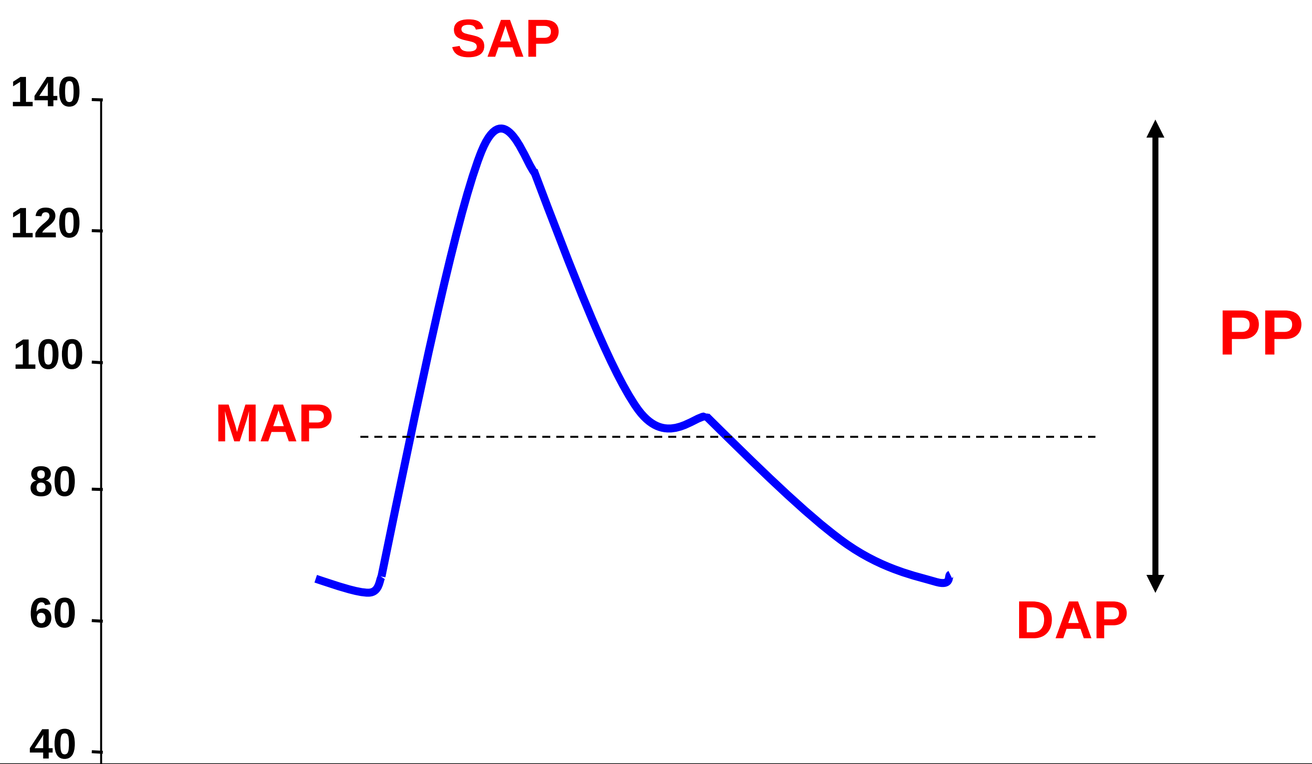
Chemla et al AJP 1998

If **aorta** is **stiff** (elederly, hypertension, diabetes)

PP should be **large** (60-70 mmHg)
for a **normal SV**

A **low PP** (30-40 mmHg)
suggests that the **stroke volume** is **low**

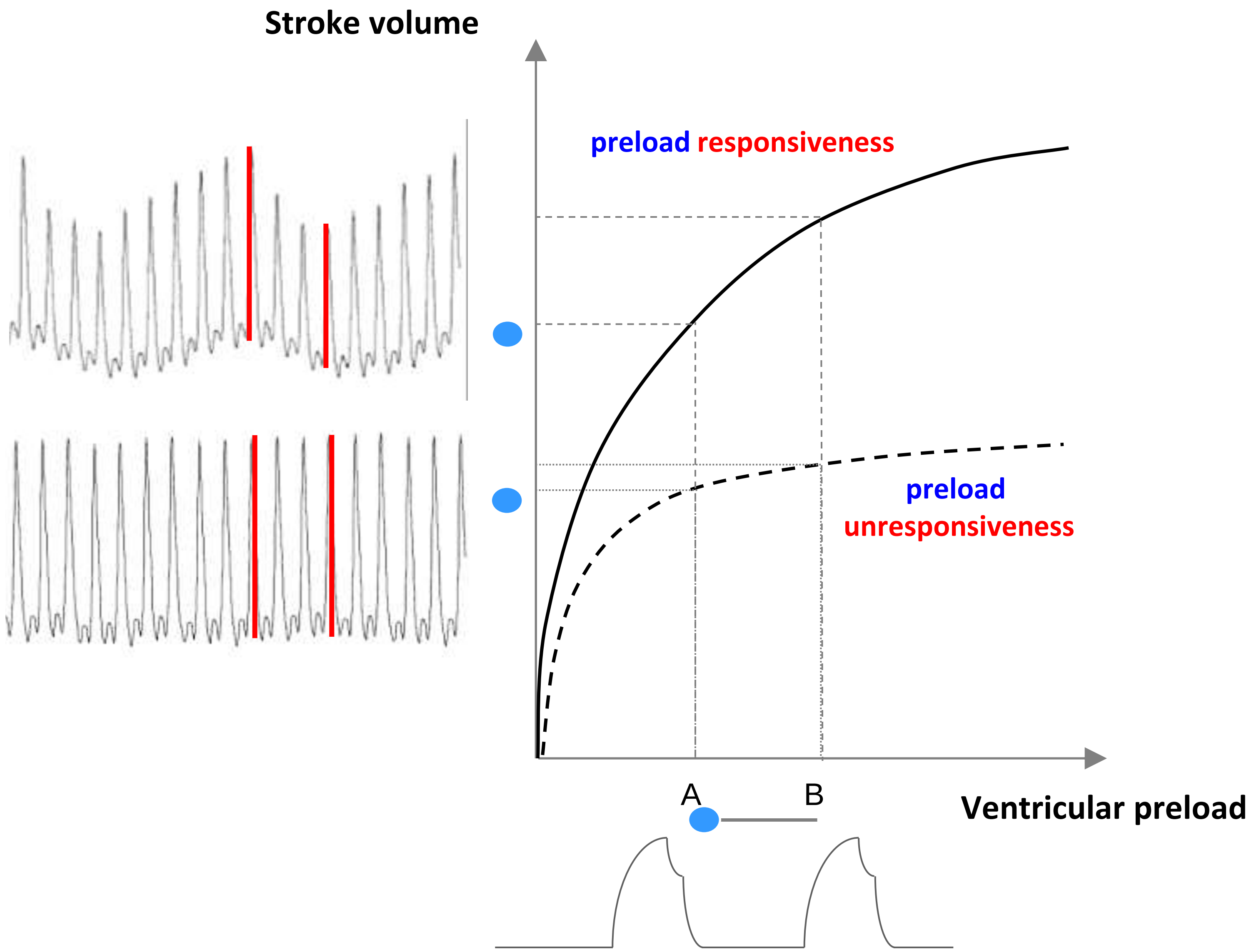
Arterial pressure *(mmHg)*



A lot of useful pieces of information can be drawn

from **MAP, DAP, PP**

and from **analysis** of the **AP waveform**


Stroke volume
preload responsiveness
preload
unresponsiveness
A
B
Ventricular preload

Monitoring: from cardiac output monitoring to echocardiography

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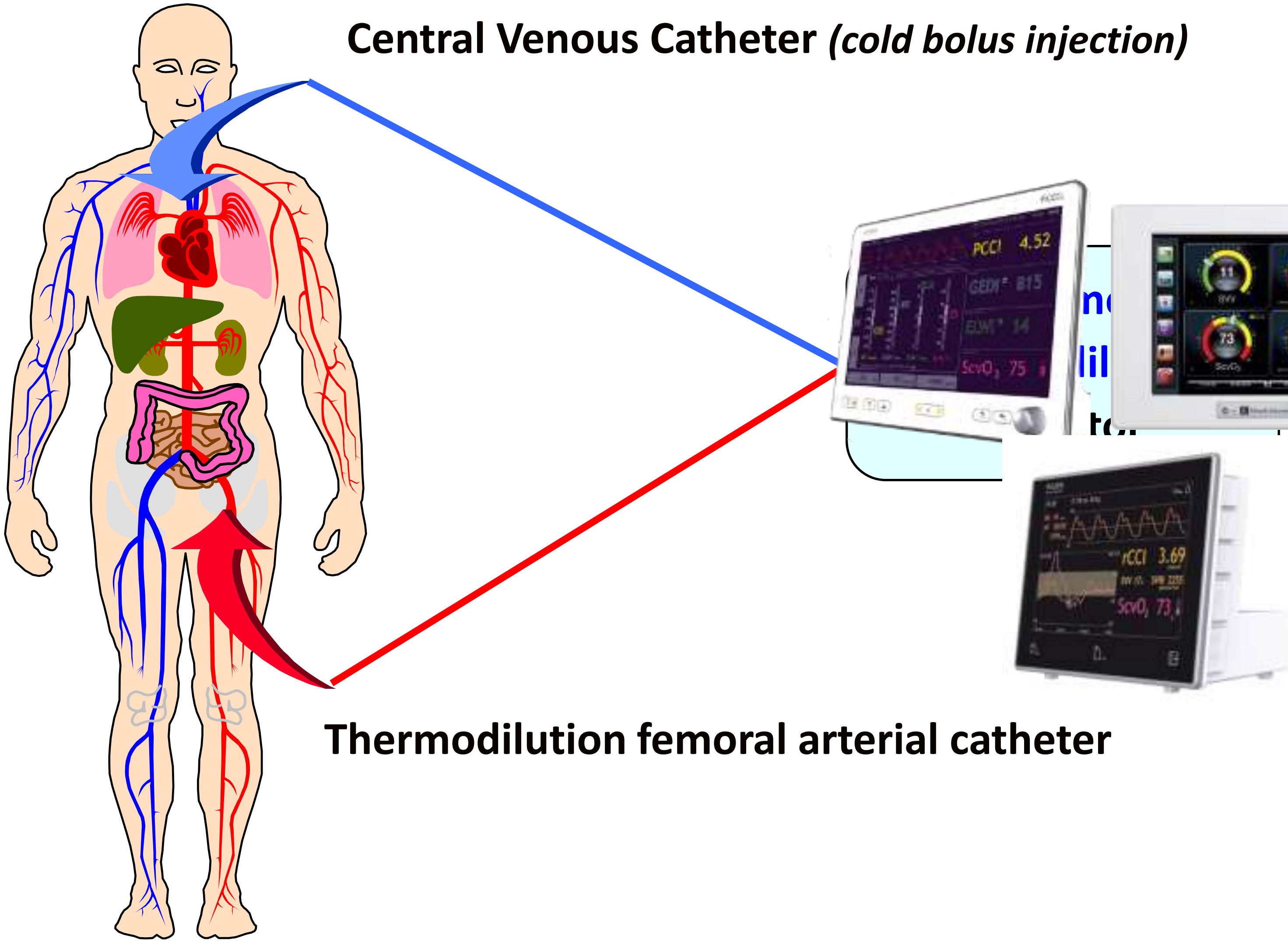
patients with **shock**

- CVP, $ScvO_2$ — Central venous catheter
- Echocardiography
- Arterial catheter — AP, PPV


Central Venous Catheter *(cold bolus injection)*
Thermodilution femoral arterial catheter
PCCI 4.52
GEDI 815
EVLW 14
11
3.6
73
1668
rCCI 3.69

Transpulmonary thermodilution

monitors allow measurements

of cardiac output

Transpulmonary thermodilution

→ **Intermittent cardiac output**

Pulse contour analysis

→ **Continuous cardiac output**

Transpulmonary thermodilution

systems are not

CO monitoring only

GEDV

marker of

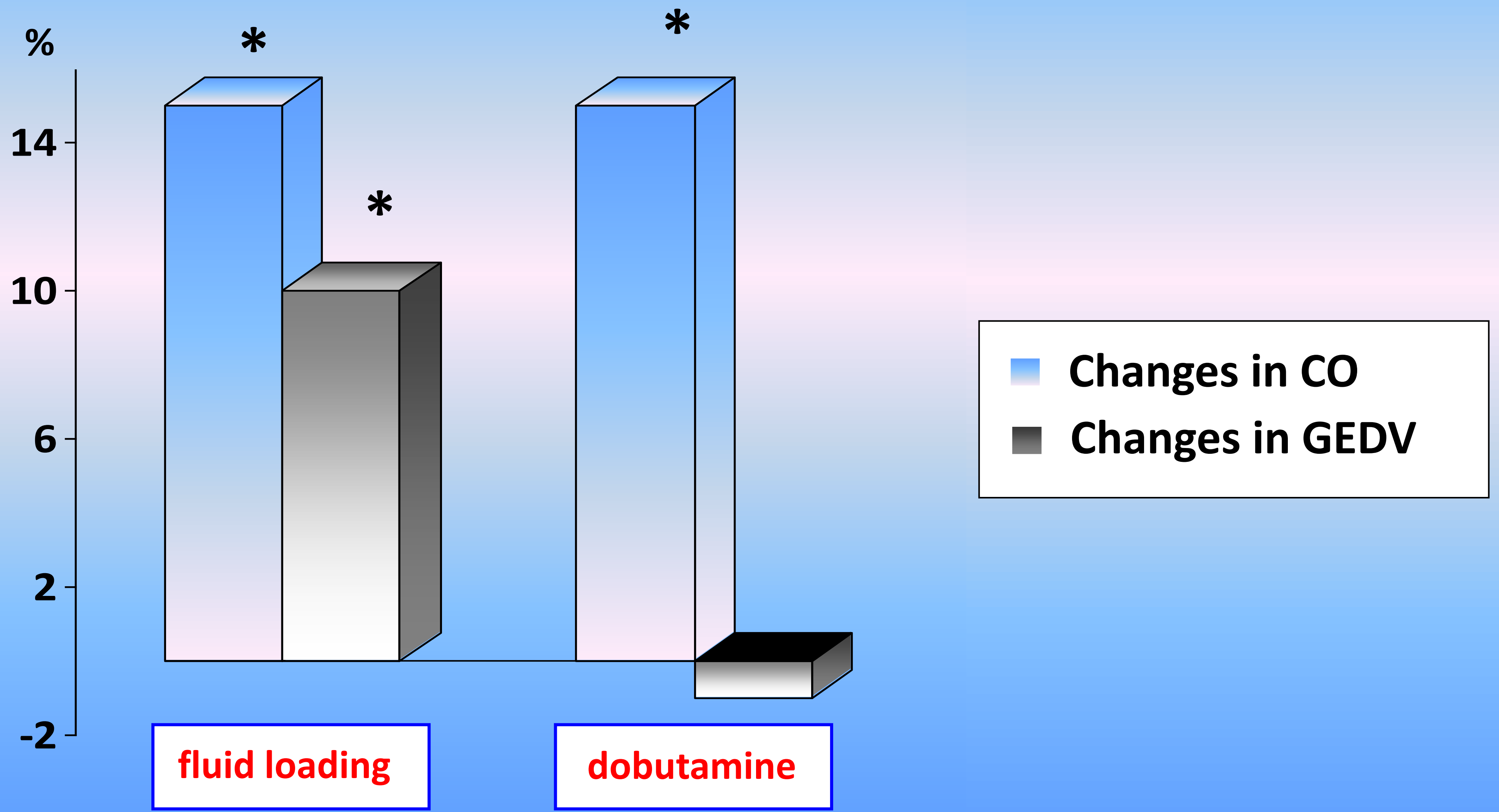
cardiac preload

Global End-Diastolic Volume as an Indicator of Cardiac Preload in Patients With Septic Shock*

Frédéric Michard, MD, PhD; Sami Alaya, MD; Véronique Zarka, MD; Mabrouk Bahloul, MD; Christian Richard, MD; and Jean-Louis Teboul, MD, PhD

CHEST 2003; 124:1900–1908

GEDV behaves as a marker of preload



Transpulmonary thermodilution

- Cardiac output
- Global end-diastolic volume (GEDV)
- **Extravascular lung water (EVLW)**
- Pulmonary vascular permeability index (PVPI)
- Cardiac function index (CFI)

Pulse contour analysis

- Continuous cardiac output (CCO)
- Stroke volume variation (SVV)
- Pulse pressure variation (PPV)

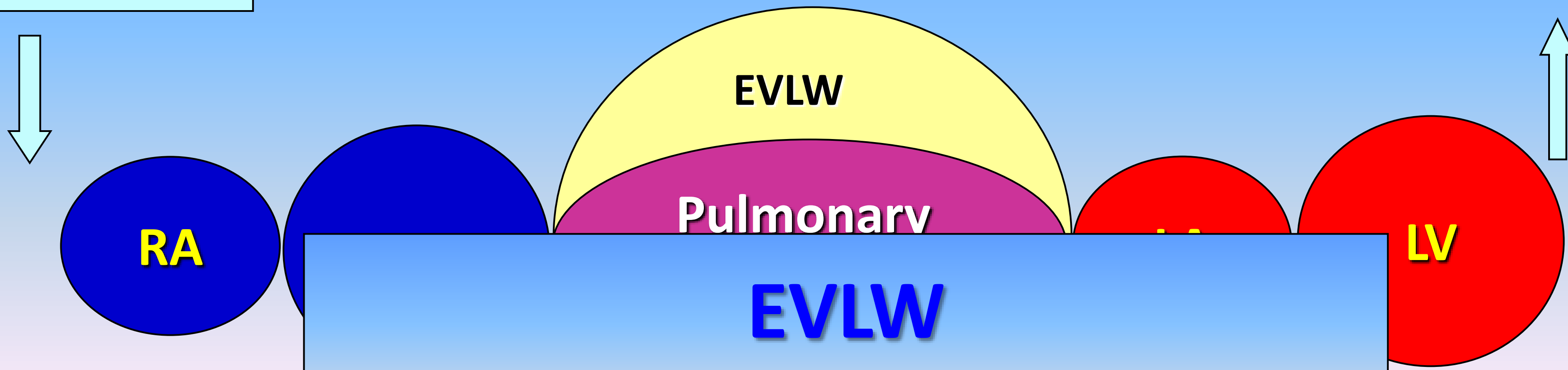
EVLW

a quantitative measure of pulmonary edema

Transpulmonary thermodilution

Central venous access
cold bolus injection

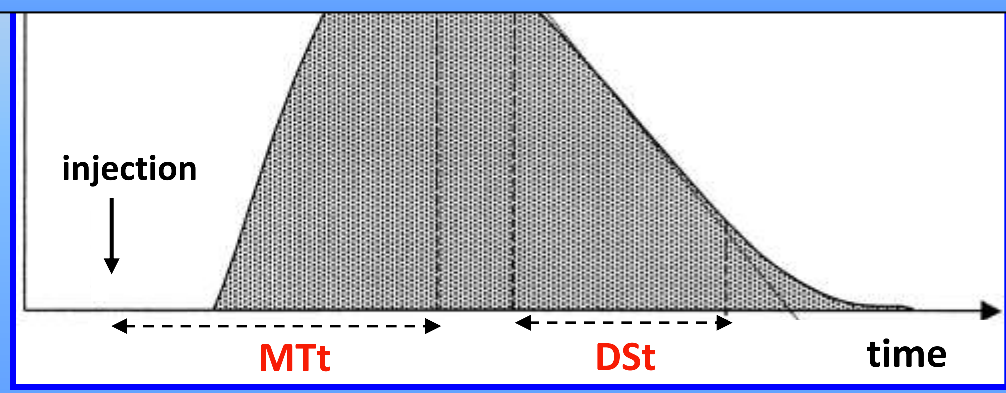
Femoral arterial line
Temperature detection

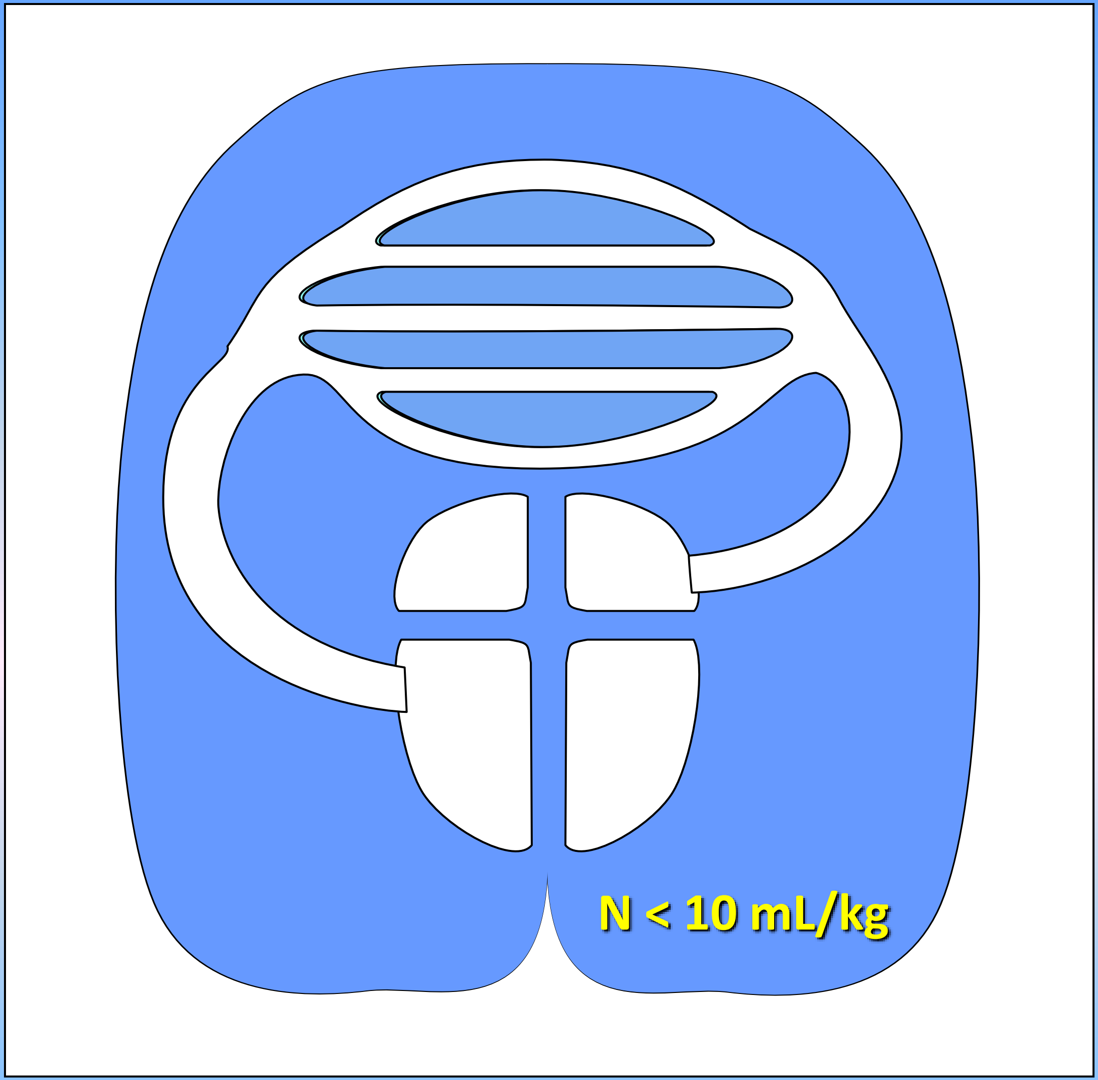


EVLW

calculated from

CO, MTt and Dst values





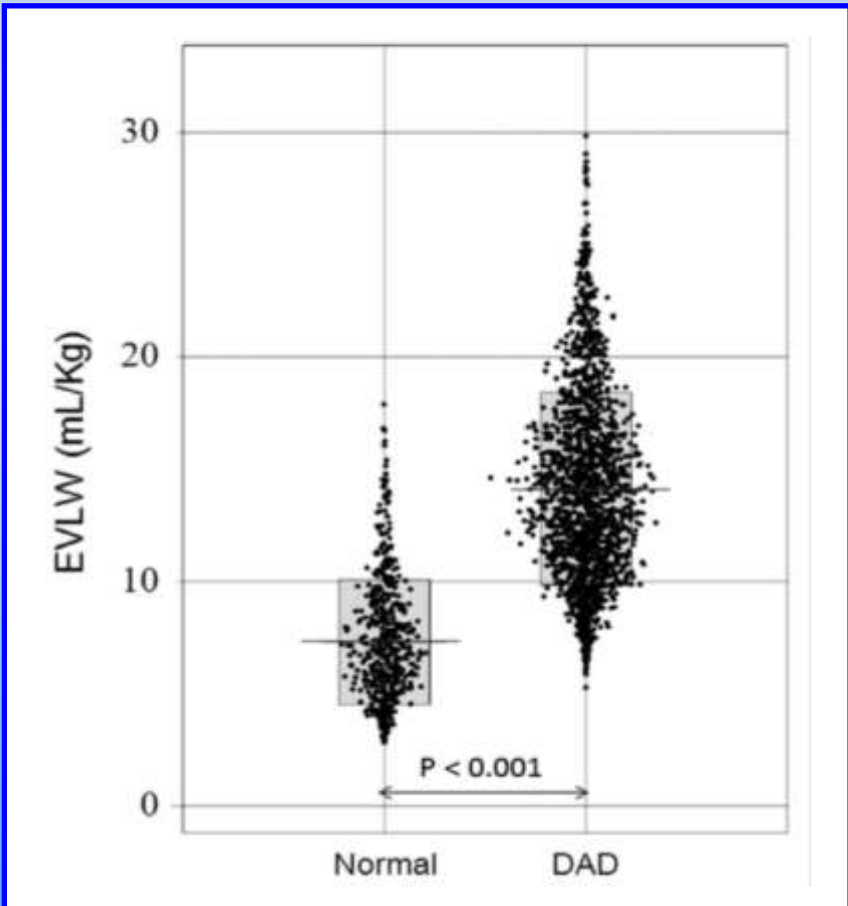
Extravascular Lung Water = amount of pulmonary edema

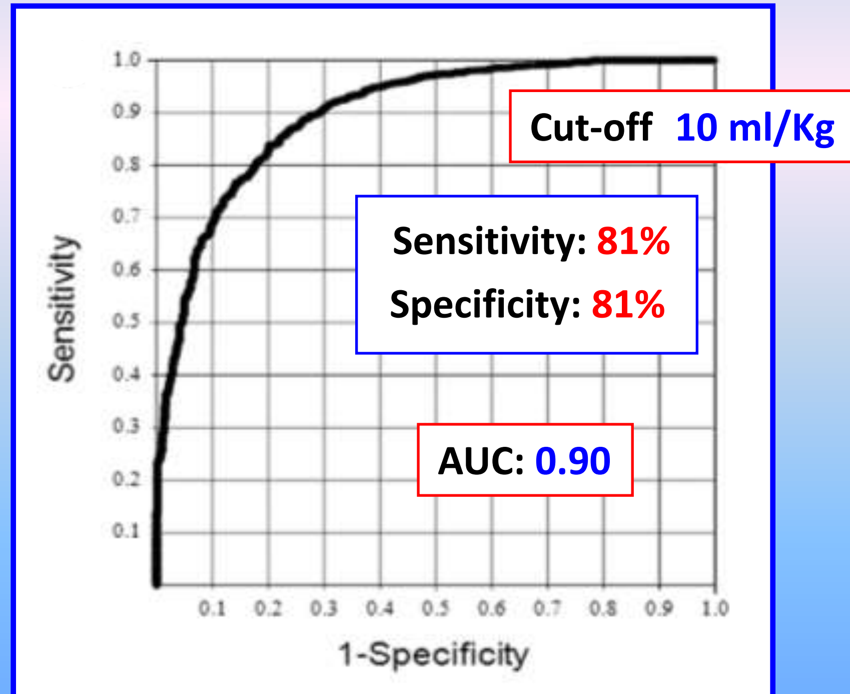
Important index for the routine practice

Quantitative Diagnosis of Diffuse Alveolar Damage Using Extravascular Lung Water*

Takashi Tagami, MD, PhD[1]; Motoji Sawabe, MD, PhD[2]; Shigeki Kushimoto, MD, PhD[3]; Paul E. Marik, MD, FCCM[4]; Makiko N. Mieno, MD, PhD[5]; Takanori Kawaguchi, MD, PhD[6]; Takashi Kusakabe, MD, PhD[6]; Ryoichi Tosa, MD[7]; Hiroyuki Yokota, MD, PhD[1]; Yuh Fukuda, MD, PhD[8]

Crit Care Med 2013; 41:2144-2150

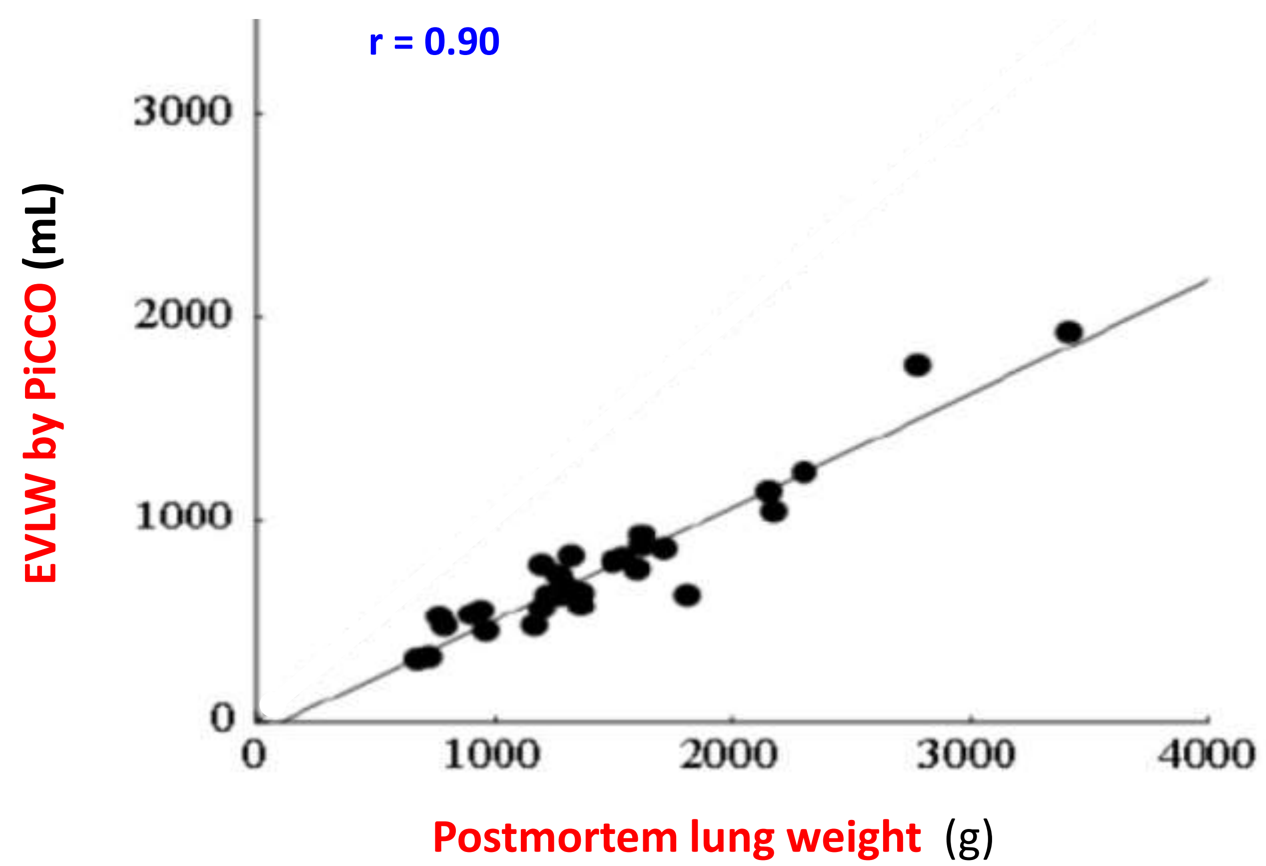




Validation of extravascular lung water measurement by single transpulmonary thermodilution: human autopsy study

Takashi Tagami[1*], Shigeki Kushimoto[2], Yasuhiro Yamamoto[3], Takahiro Atsumi[2], Ryoichi Tosa[1], Kiyoshi Matsuda[4], Renpei Oyama[5], Takanori Kawaguchi[6], Tomohiko Masuno[2], Hisao Hirama[1], Hiroyuki Yokota[2]

Critical Care 2010, **14**:R162



Extravascular Lung Water is an Independent Prognostic Factor in Patients with Acute Respiratory Distress Syndrome

Mathieu Jozwiak, MD; Serena Silva, MD; Romain Persichini, MD; Nadia Anguel, MD; David Osman, MD; Christian Richard, MD; Jean-Louis Teboul, MD, PhD; Xavier Monnet, MD, PhD

Crit Care Med 2013;41:472–480

200 pts

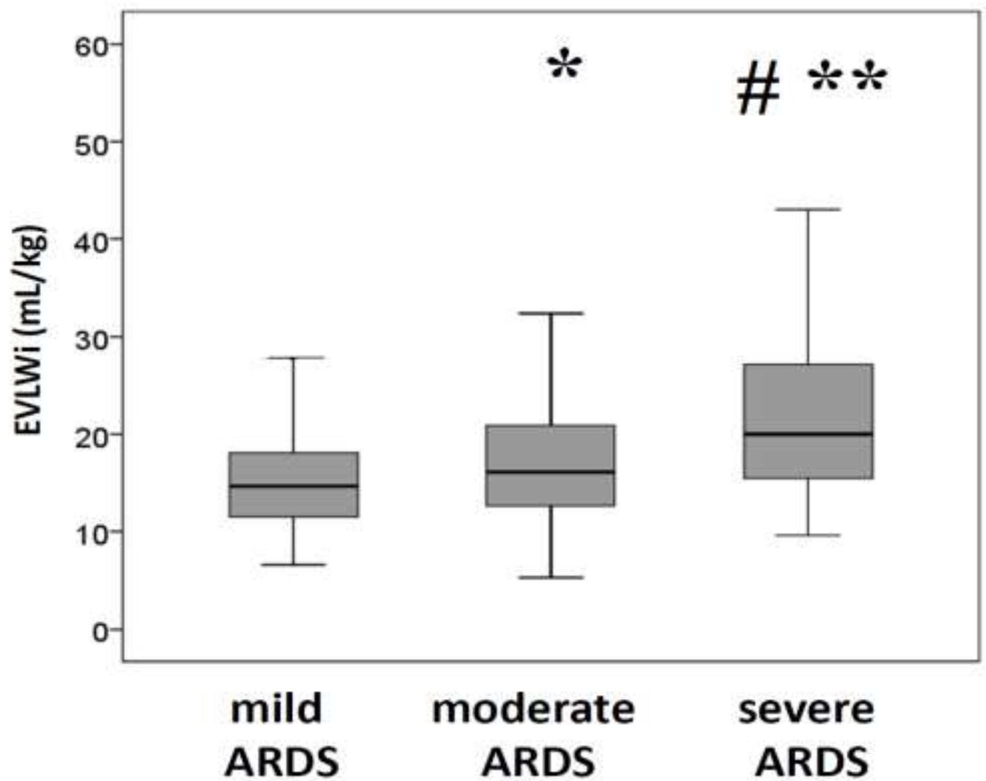
D_{28} mortality: 54%

	Odds Ratio (CI 95%)		p value
Maximal blood lactate	1.29	(1.14 - 1.46)	0.0001
Mean PEEP	0.78	(0.67 – 0.91)	0.002
Minimal PaO_2 / FiO_2	0.98	(0.97 - 0.99)	0.006
SAPS II	1.03	(1.01 - 1.05)	0.02
$EVLW_{max}$	**1.07**	**(1.02 - 1.12)**	**0.007**
Mean fluid balance	1.0004	(1.0001 – 1.0008)	0.02

Relationship between extravascular lung water and severity categories of acute respiratory distress syndrome by the Berlin definition

Shigeki Kushimoto[1*], Tomoyuki Endo[2], Satoshi Yamanouchi[1], Teruo Sakamoto[3], Hiroyasu Ishikura[4], Yasuhide Kitazawa[5], Yasuhiko Taira[6], Kazuo Okuchi[7], Takashi Tagami[8], Akihiro Watanabe[8], Junko Yamaguchi[9], Kazuhide Yoshikawa[10], Manabu Sugita[11], Yoichi Kase[12], Takashi Kanemura[13], Hiroyuki Takahashi[14], Yuuichi Kuroki[15], Hiroo Izumino[16], Hiroshi Rinka[17], Ryutarou Seo[18], Makoto Takatori[19], Tadashi Kaneko[20], Toshiaki Nakamura[21], Takayuki Irahara[22] and Nobuyuki Saito[23], for the PiCCO Pulmonary Edema Study Group

Critical Care 2013, **17**:R132



***, p < .05 vs. mild ARDS**
****, p < .01 vs. mild ARDS**
#, p < .01 vs. moderate ARDS

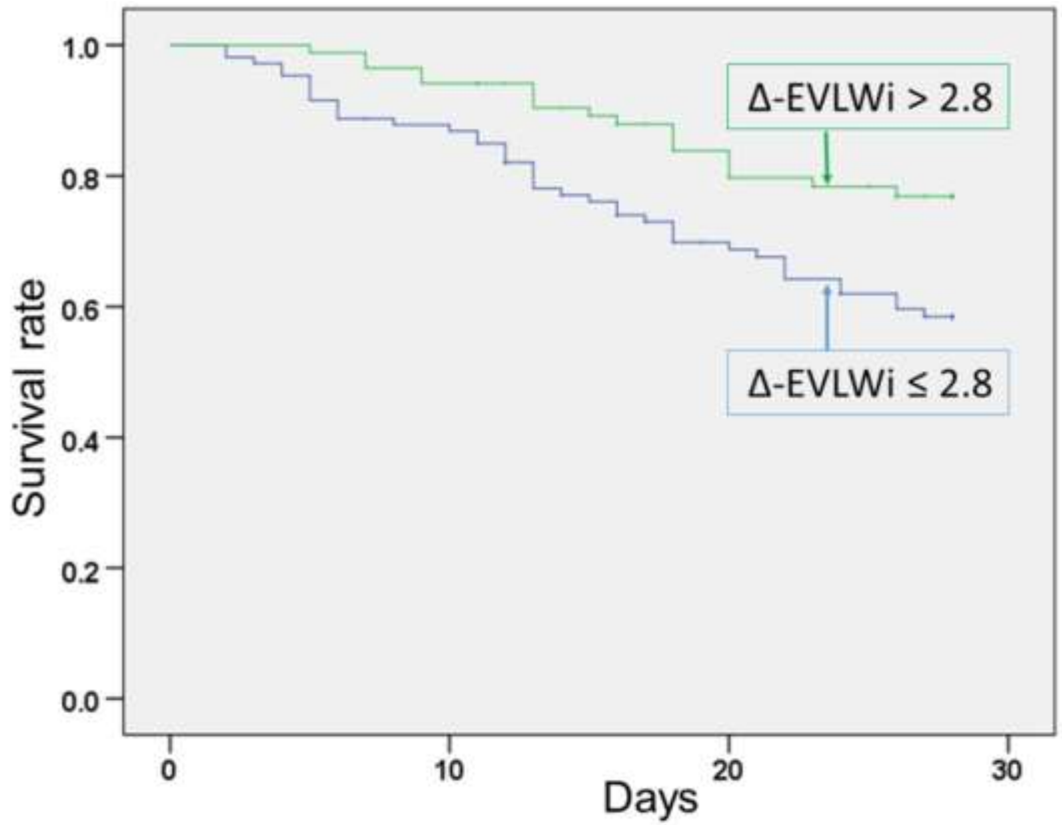
Annals of Intensive Care 2014, **4**:27

Annals of Intensive Care
a SpringerOpen Journal

RESEARCH Open Access

Early-phase changes of extravascular lung water index as a prognostic indicator in acute respiratory distress syndrome patients

Takashi Tagami[1,2*], Toshiaki Nakamura[3], Shigeki Kushimoto[4], Ryoichi Tosa[5], Akihiro Watanabe[1], Tadashi Kaneko[6], Hidetada Fukushima[7], Hiroshi Rinka[8], Daisuke Kudo[4], Hideaki Uzu[9], Akira Murai[10], Makoto Takatori[11], Hiroo Izumino[12], Yoichi Kase[13], Ryutarou Seo[14], Hiroyuki Takahashi[15], Yasuhide Kitazawa[16], Junko Yamaguchi[17], Manabu Sugita[18], Hiroyuki Takahashi[19], Yuichi Kuroki[20], Takashi Kanemura[21], Kenichiro Morisawa[22], Nobuyuki Saito[23], Takayuki Irahara[24] and Hiroyuki Yokota[1]



Transpulmonary thermodilution

- Cardiac output
- Global end-diastolic volume (GEDV)
- Extravascular lung water (EVLW)
- **Pulmonary vascular permeability index (PVPI)**
- Cardiac function index (CFI)

Pulse contour analysis

- Continuous cardiac output (CCO)
- Stroke volume variation (SVV)
- Pulse pressure variation (PPV)

PVPI = EVLW/Pulmonary blood volume

PVPI

marker of

lung µvessels permeability

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Intensive Care Med (2007) 33:448–453
DOI 10.1007/s00134-006-0498-6

ORIGINAL

Xavier Monnet
Nadia Anguel
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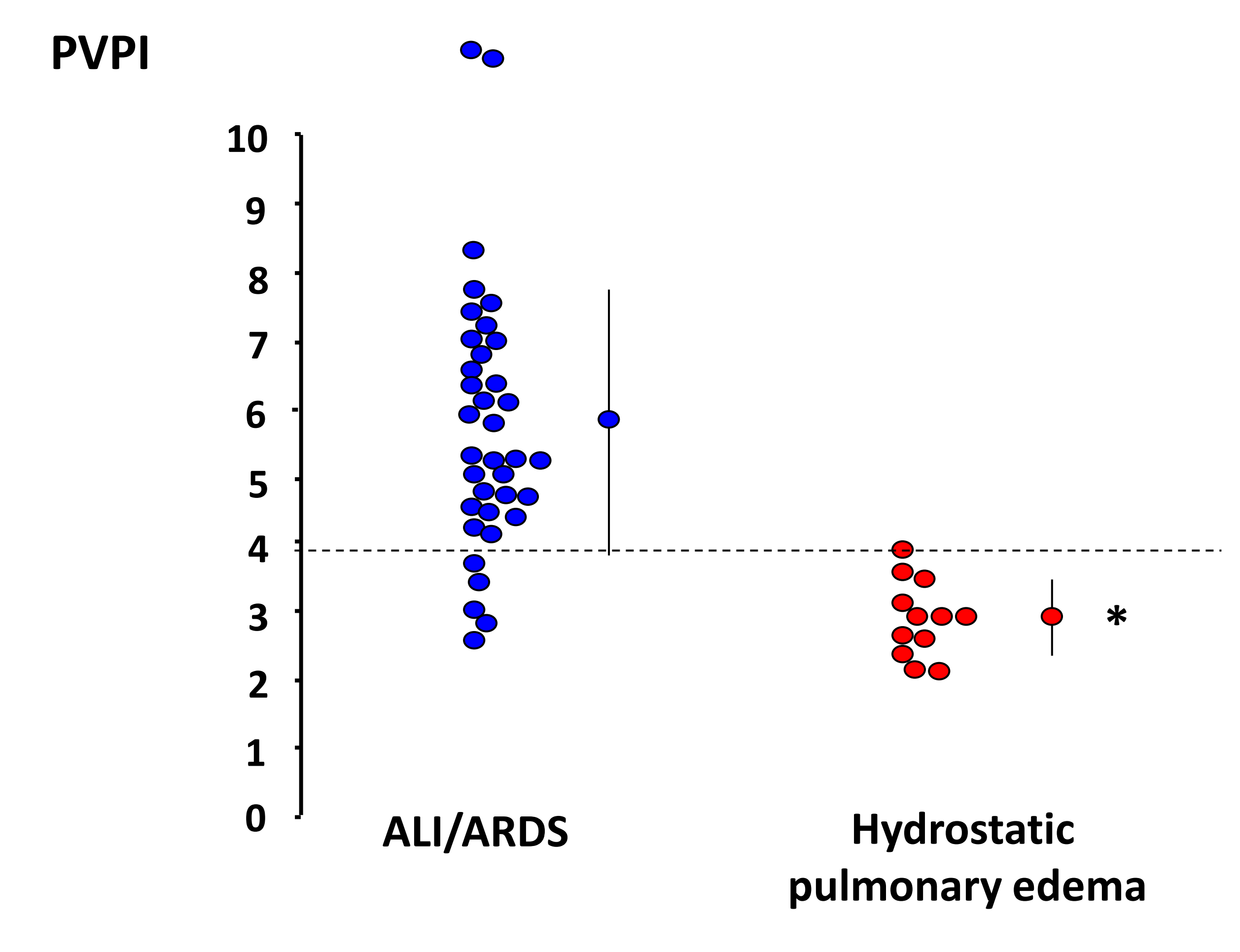
Jean-Louis Teboul

Assessing pulmonary permeability by transpulmonary thermodilution allows differentiation of hydrostatic pulmonary edema from ALI/ARDS



cut-off value = 3

Se = 85 %

Sp = 100 %

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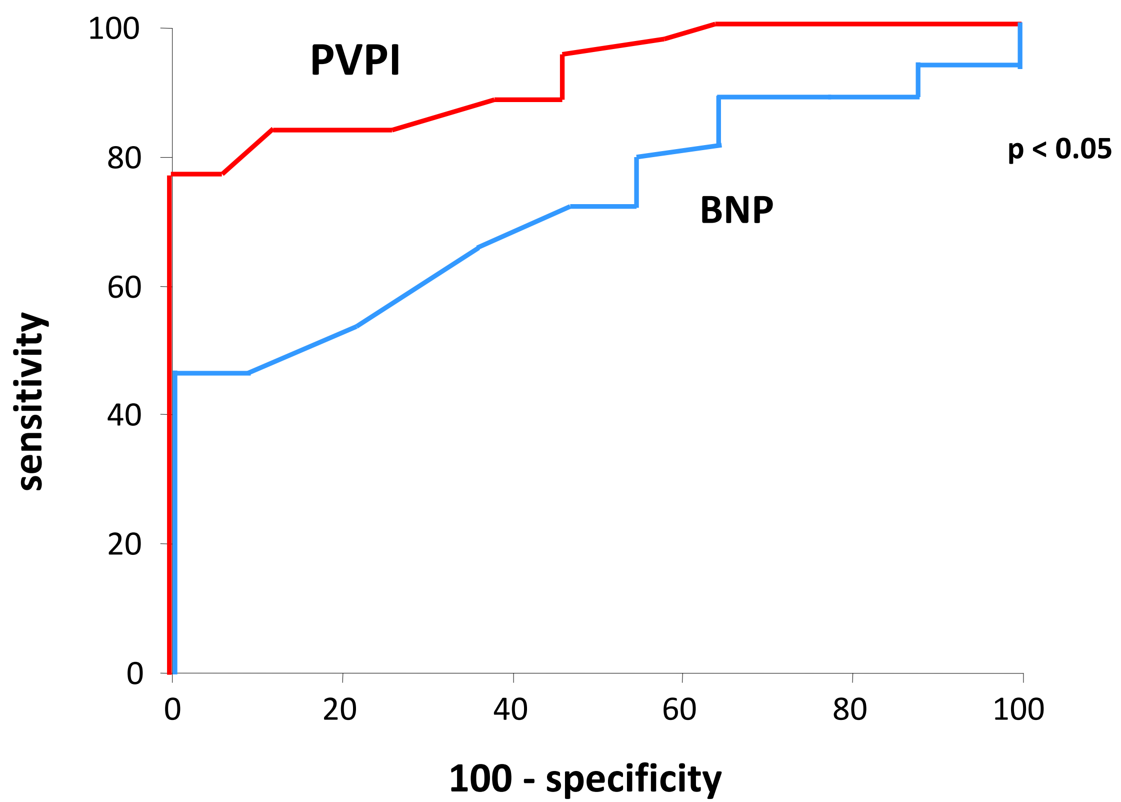

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- **Cardiac function index (CFI)**

Pulse contour analysis

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- Stroke volume variation (SVV)
- Pulse pressure variation (PPV)

Cardiac function index (CFI) = CO/GEDV

CFI

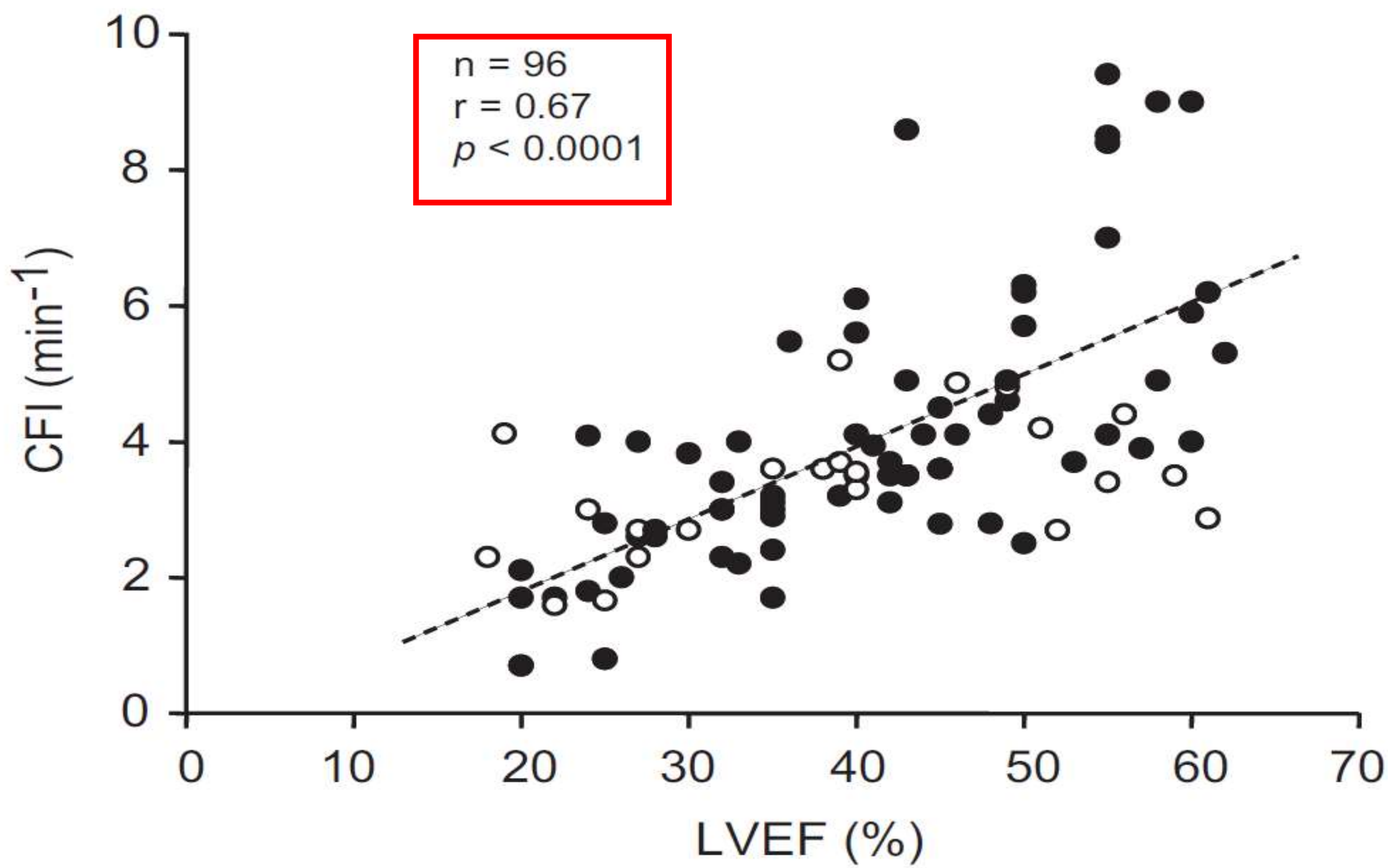
Index of

cardiac systolic function

Cardiac function index provided by transpulmonary thermodilution behaves as an indicator of left ventricular systolic function

Julien Jabot, MD; Xavier Monnet, MD, PhD; Lamia Bouchra, MD, PhD; Denis Chemla, MD, PhD; Christian Richard, MD; Jean-Louis Teboul, MD, PhD

Crit Care Med 2009; 37:2913–2918



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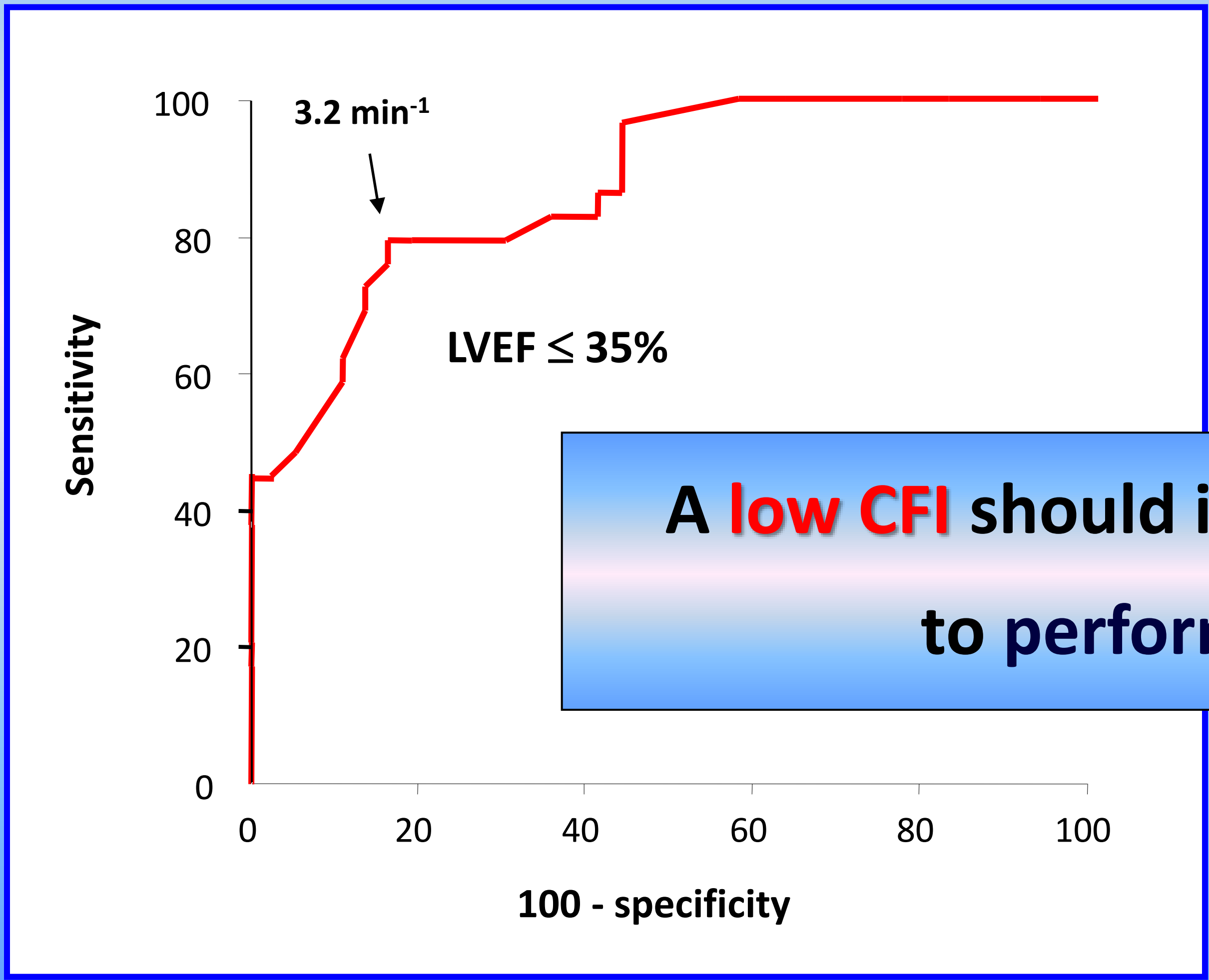

A low CFI should incite the clinician to perform an echo

Transpulmonary thermodilution

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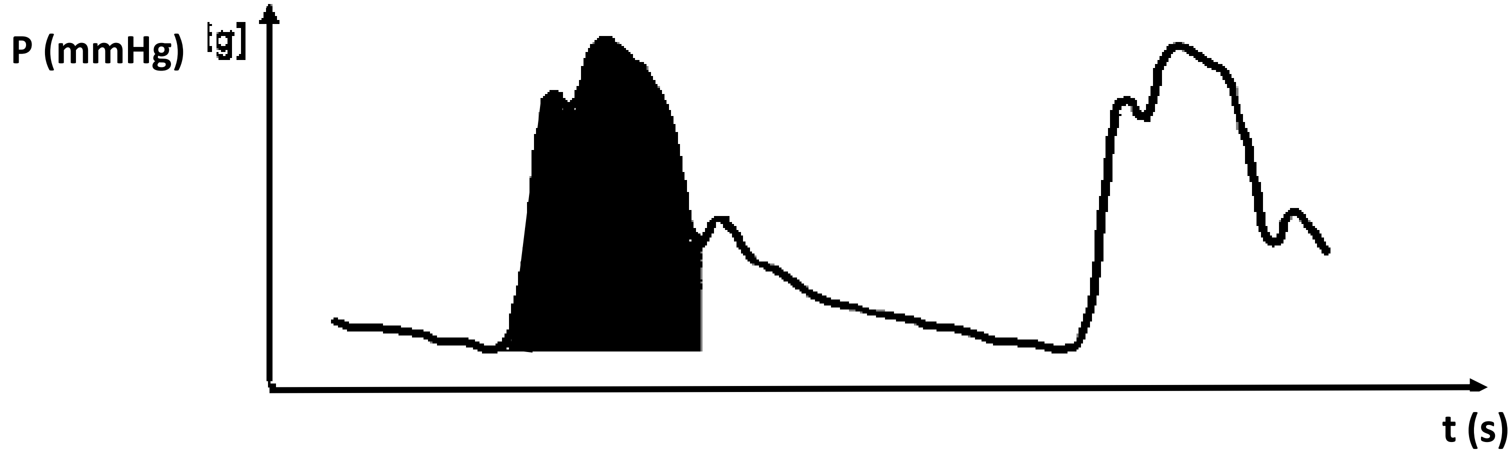
Pulse contour analysis



$$PCCO = cal \cdot HR \cdot \int_{systole} \left(P(t)/SVR + C(p) \cdot dP/dt \right) dt$$

Patient-specific calibration factor (determined with thermodilution)

area of pressure curve

compliance

shape of pressure curve

One frequently asked question

How **often** do we need to **recalibrate**?

Effects of changes in vascular tone on the agreement between pulse contour and transpulmonary thermodilution cardiac output measurements within an up to 6-hour calibration-free period*

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

Crit Care Med 2008; 36:434–440

- **59 patients** (most of of them with septic shock)
- **400** pairs of measurements of CO:

  - **Transpulmonary thermodilution**
  - **Pulse contour** just before calibration

Effects of changes in vascular tone on the agreement between pulse contour and transpulmonary thermodilution cardiac output measurements within an up to 6-hour calibration-free period*

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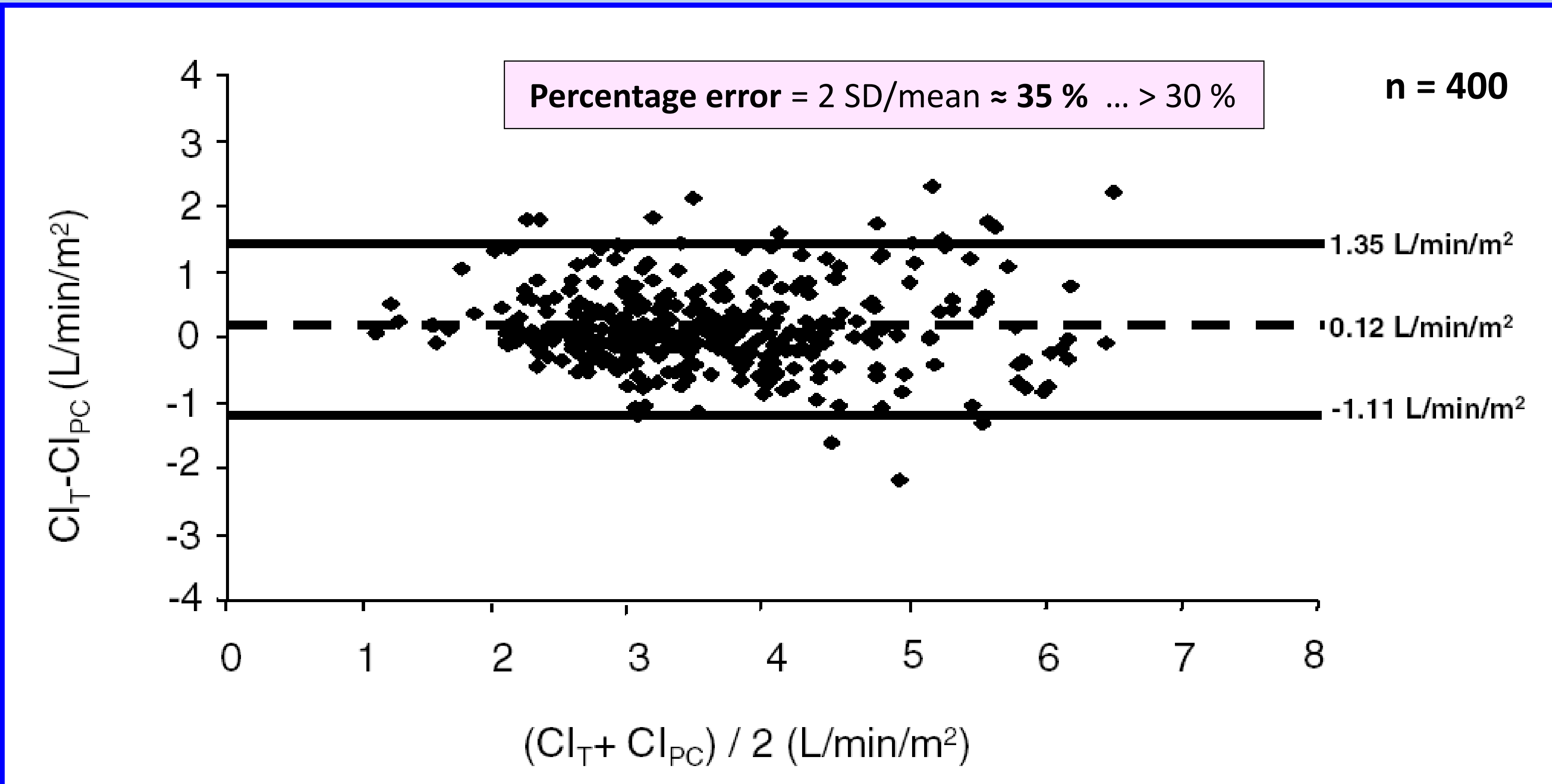

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- **400** pairs of measurements of CO**:**

  - **Transpulmonary thermodilution**
  - **Pulse contour** just before calibration

- **7 time intervals** in function of the **preceding** calibration

  < 30 min, 30min-1h, 1h-2h, 2h-3h, 3h-4h, 4h-5h, 5h-6h

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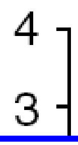
Percentage error = 2 SD/mean ≈ **35 %** **… > 30 %**



Intervals of Time (Elapsed from the Previous Calibration)	n	r^2	p	Bias ± SD, L/min/m²	Percentage Error
Within					27
Betwee					26
Betwee					32
Betwee					37
Betwee					35
Between 4 and 5 hrs	47	.62	<.001	0.14 ± 0.63	35
Between 5 and 6 hrs	51	.62	<.001	0.13 ± 0.66	36

We recommend to **recalibrate**

if the **preceding calibration**

was performed **more than one hour before**

Real-time CO monitoring

Useful to perform **dynamic tests**

- **fluid challenge**
- **passive leg raising** test
- **end-expiratory occlusion** test
- **dobutamine** test
- etc

Transpulmonary thermodilution

- Cardiac output
- Global end-diastolic volume (GEDV)
- Extravascular lung water (EVLW)
- Pulmonary vascular permeability index (PVPI)
- Cardiac function index (CFI)

}Volumetric variables

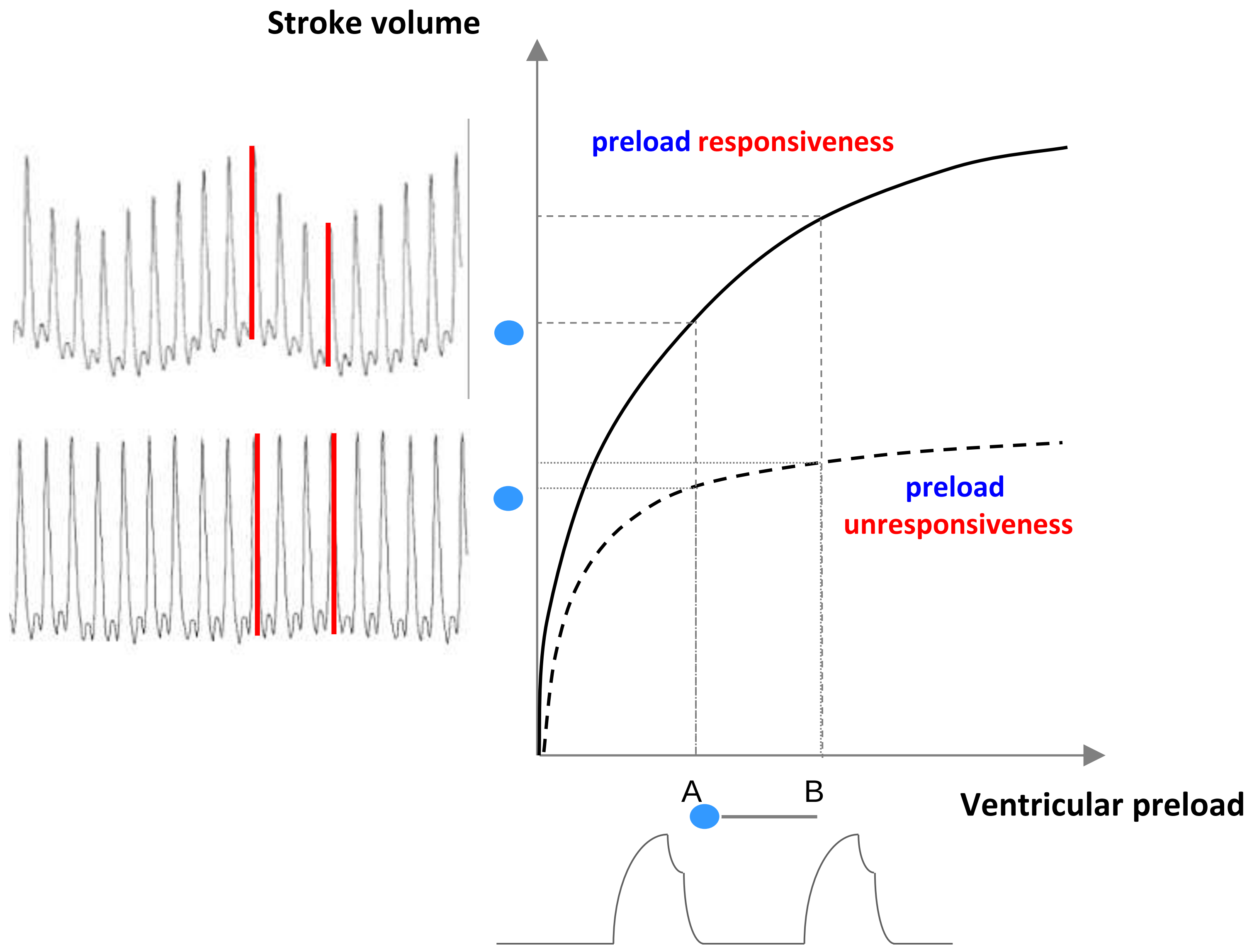
Pulse contour analysis

- Continuous cardiac output (PCCO)
- **Stroke volume variation (SVV)**
- **Pulse pressure variation (PPV)**

PPV and SVV

markers of

fluid responsiveness



Stroke volume
preload responsiveness
preload
unresponsiveness
A
B
Ventricular preload

Complete picture

of the patient's

hemodynamic status

Transpulmonary thermodilution systems

useful tools to deal with **fluid loading** and/or **depletion**

… especially if associated **respiratory** and **circulatory failures**

- **SVV and PPV** to **predict** fluid responsiveness
- **GEDV** to ch

What to do if **PPV** or **SVV** are **not interpretable**?

- **CO** to assess the **real** hemodynamic **response** to **fluid infusion**
- **EVLW** and **PVPI** to assess **lung tolerance** to fluid infusion

- **SVV/PPV**
- **GEDV**
- **CO**
- **EVLW**

to help to decide

To **start** fluid infusion

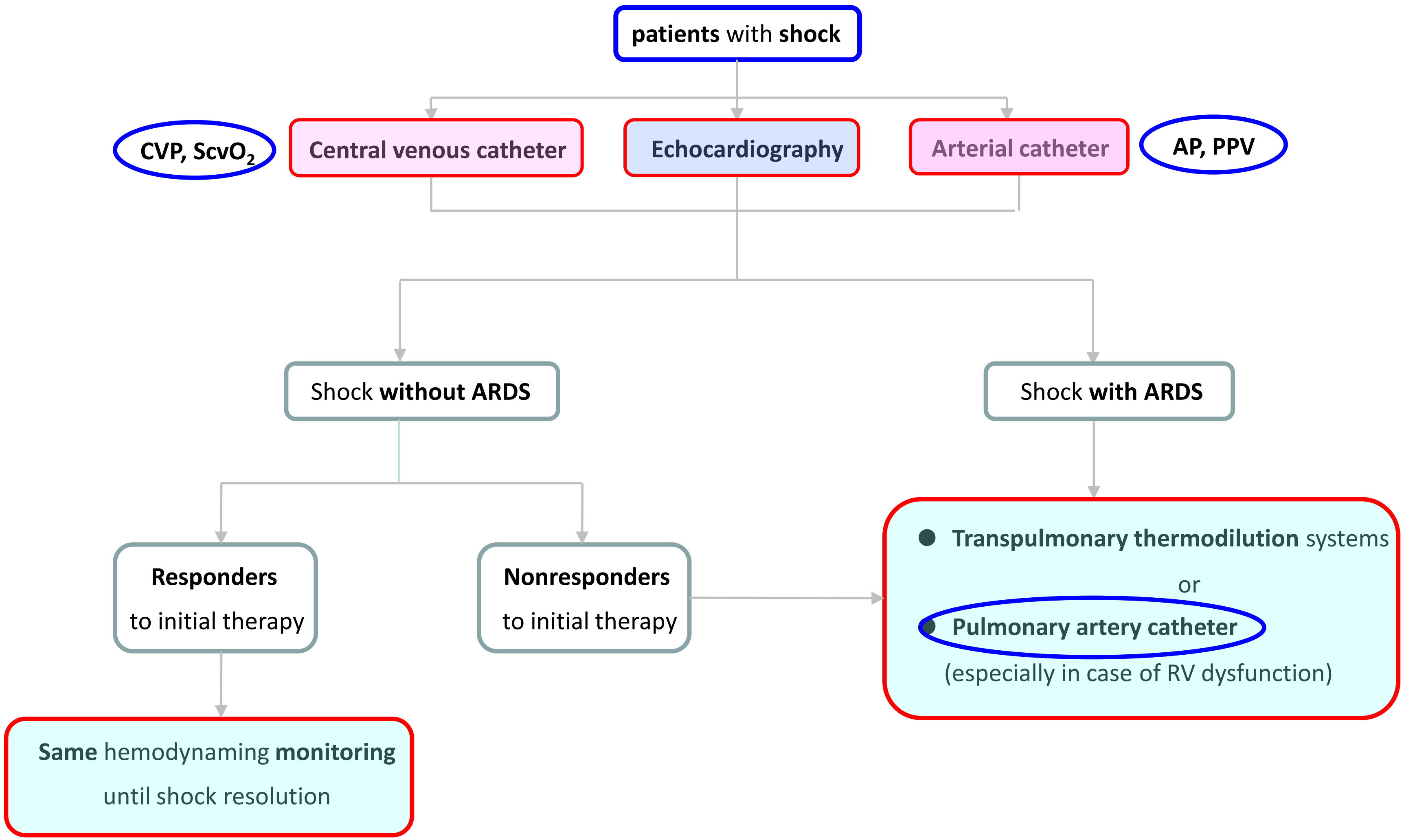
To **continue** fluid infusion

To **stop** fluid infusion

Monitoring: from cardiac output monitoring to echocardiography

Mathieu Jozwiak[a,b], Xavier Monnet[a,b], and Jean-Louis Teboul[a,b]

Curr Opin Crit Care 2015, 21



Continuous CO and SvO_2

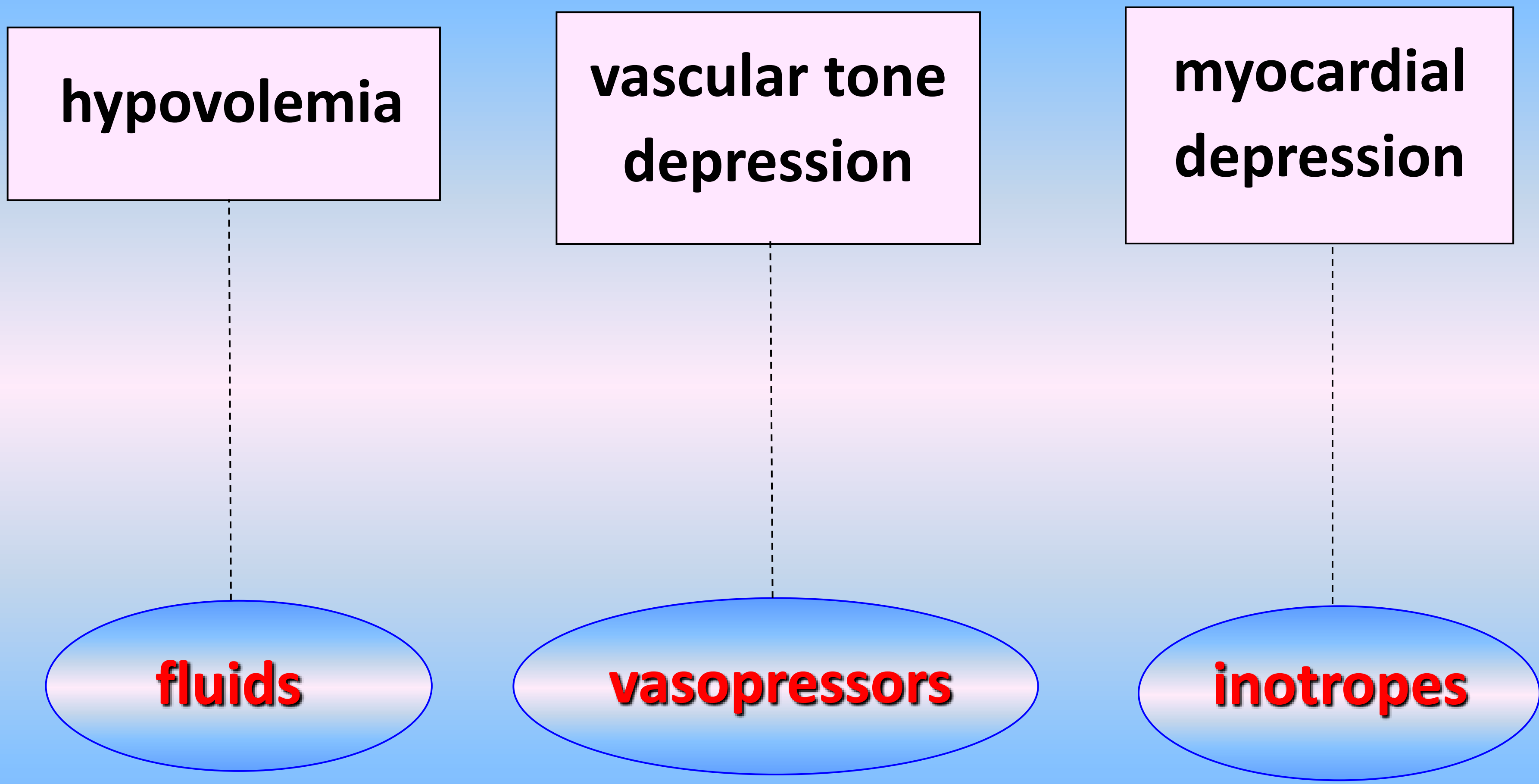
monitoring

+

Intermittent measurements

RAP, PAOP and PAP

Hemodynamic failure in patients with septic shock: 3 components



presence of associated **ARDS**

Hemodynamic failure in patients with septic shock: 3 components

myocardial depression

Echocardiography

+ CFI

inotropes

Hemodynamic failure in patients with septic shock: 3 components

vascular tone depression

Arterial catheter (DAP ++)

vasopressors

Hemodynamic failure in patients with **septic shock**: 3 components

hypovolemia

fluids

Prediction of fluid responsiveness

- **PPV, SVV**
- **PLR** or **end-expiratory occlusion test**

  if SB, arrhythmias, low TV or low lung compliance

Evaluation: real-time CO

Lung tolerance

PAOP **EVLW**

presence of associated **ARDS**

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

- We **suggest** that, when further hemodynamic assessment is needed, **echocardiography** is the **preferred** modality to initially evaluate the type of shock as opposed to more invasive technologies

  Level 2; QoE moderate (B)

- In **complex** patients, we **suggest** to additionally use **PAC** or **transpulmonary thermodilution** to determine the type of shock

  Level 1; QoE moderate (B)

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

- We r**ecommend** measurements of **CO** and **stroke volume** to evaluate the response to fluids or inotropes in patients that are **not responding to initial therapy**

  Level 1; QoE low (C)

- We suggest **PAC** in patients with refractory shock and **RV dysfunction**

  Level 2; QoE low (C)

- We suggest the use of **transpulmonary thermodilution** or **PAC** **i**n patients with severe shock especially in the case of associated **ARDS**

  Level 2; QoE low (C)

Merci