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Division of Cardiac Surgery
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University Health Network

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Toronto, M5G 1L7

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TEE for Volume Assessment

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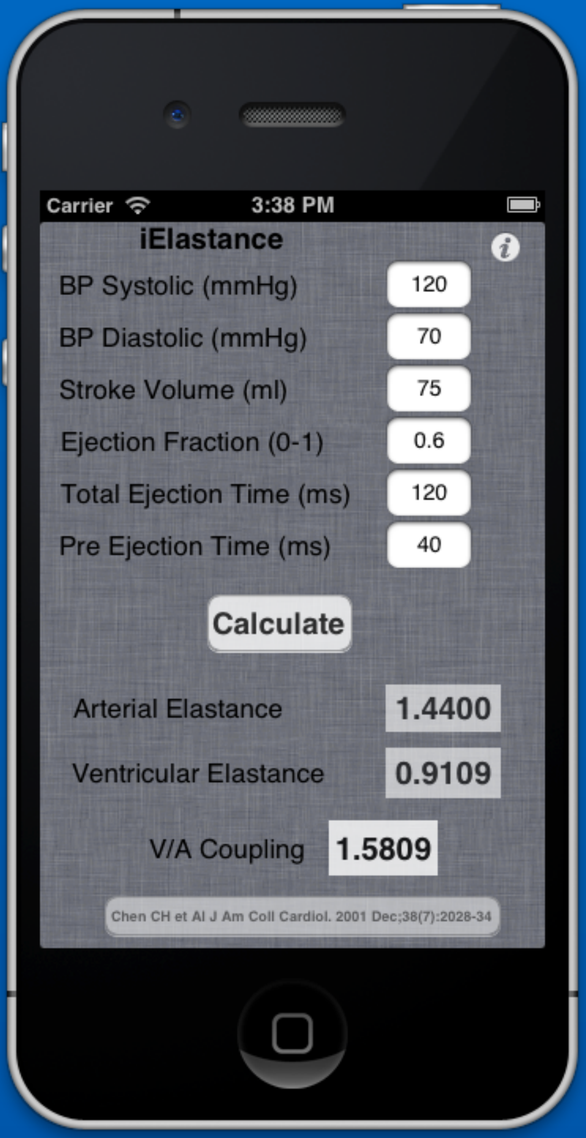
Disclosures

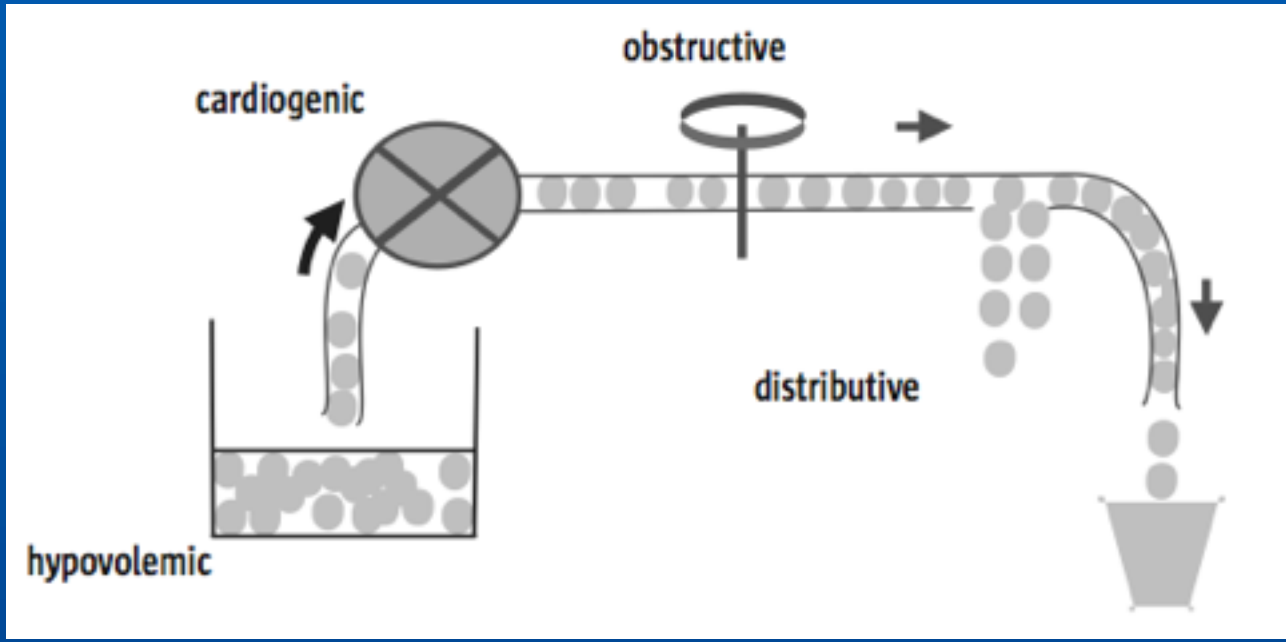
Disclosures:

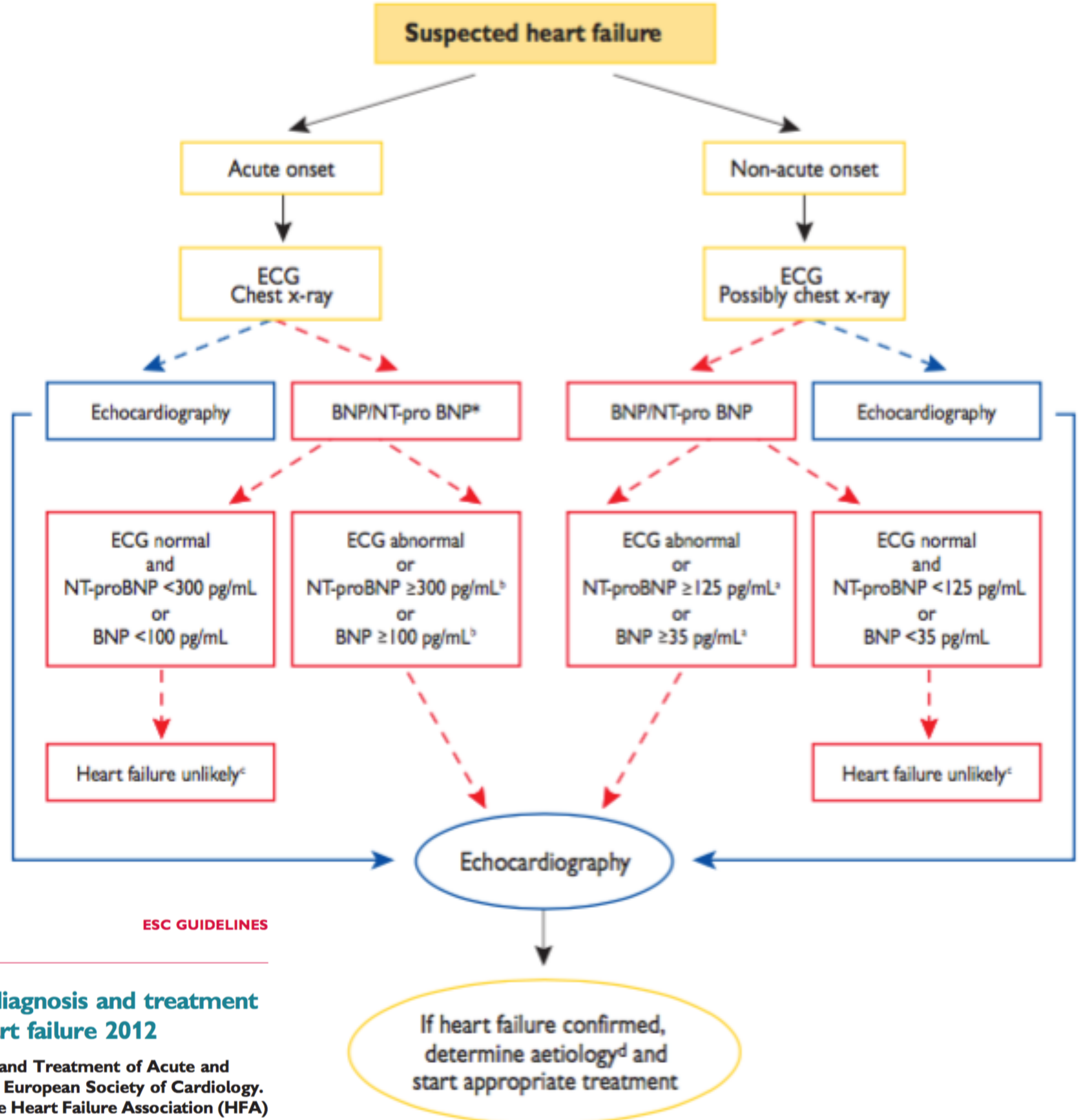
Pietro Bertini is the author of iElastance software



Hemodynamic Impairment

Low BP
Tachycardia ?
Filling Pressures ?
Low Urine Output
Low ScVO2 - Low SVO2
Increased Lactate
Increased BNP
Low PaO2





European Heart Journal (2012) 33, 1787–1847
doi:10.1093/eurheartj/ehs104

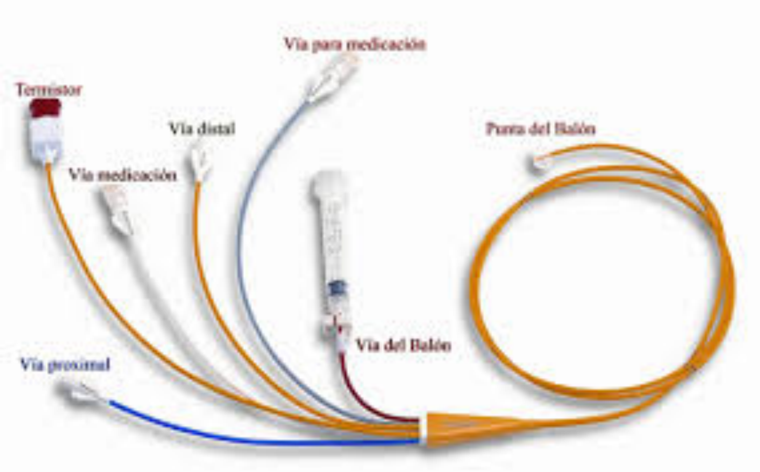
ESC GUIDELINES

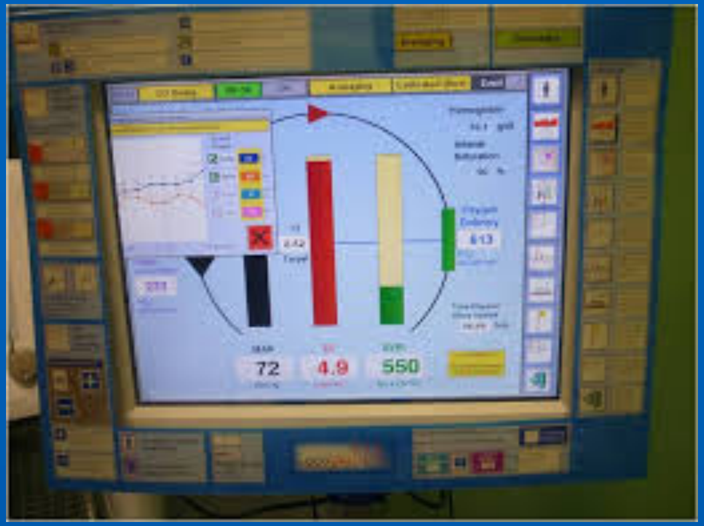
ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure 2012

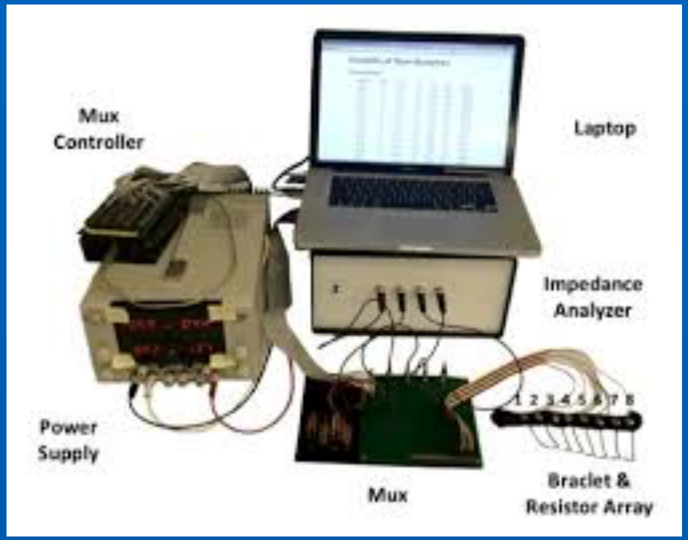
The Task Force for the Diagnosis and Treatment of Acute and Chronic Heart Failure 2012 of the European Society of Cardiology. Developed in collaboration with the Heart Failure Association (HFA) of the ESC

Hemodynamic Monitoring

PICCO
LIDCO
Thermodilution
Pulse Contour Analysis
Bioimpedance
Oesophageal Doppler
Nexfin







Hemodynamic Categorisation

CO + +

CO - -

SVR + +

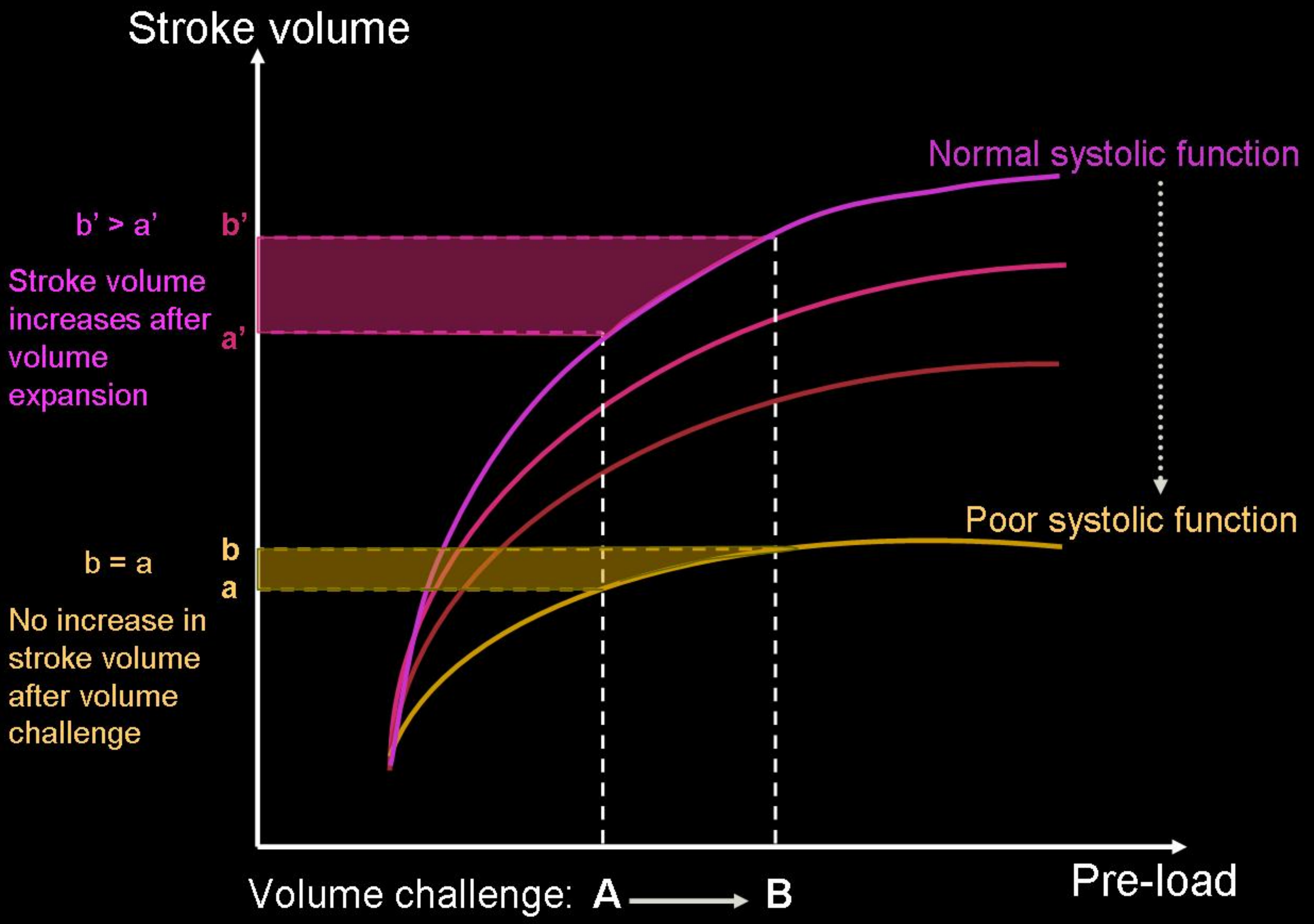
SVR - -

PAP + +

PAP - -

Filling Pressures + +

Filling Pressures - -


Stroke volume
Normal systolic function
b' > a'
b'
Stroke volume increases after volume expansion
a'
Poor systolic function
b = a
b
a
No increase in stroke volume after volume challenge
Volume challenge: A → B
Pre-load

Echodynamics Topics

Fluid Management

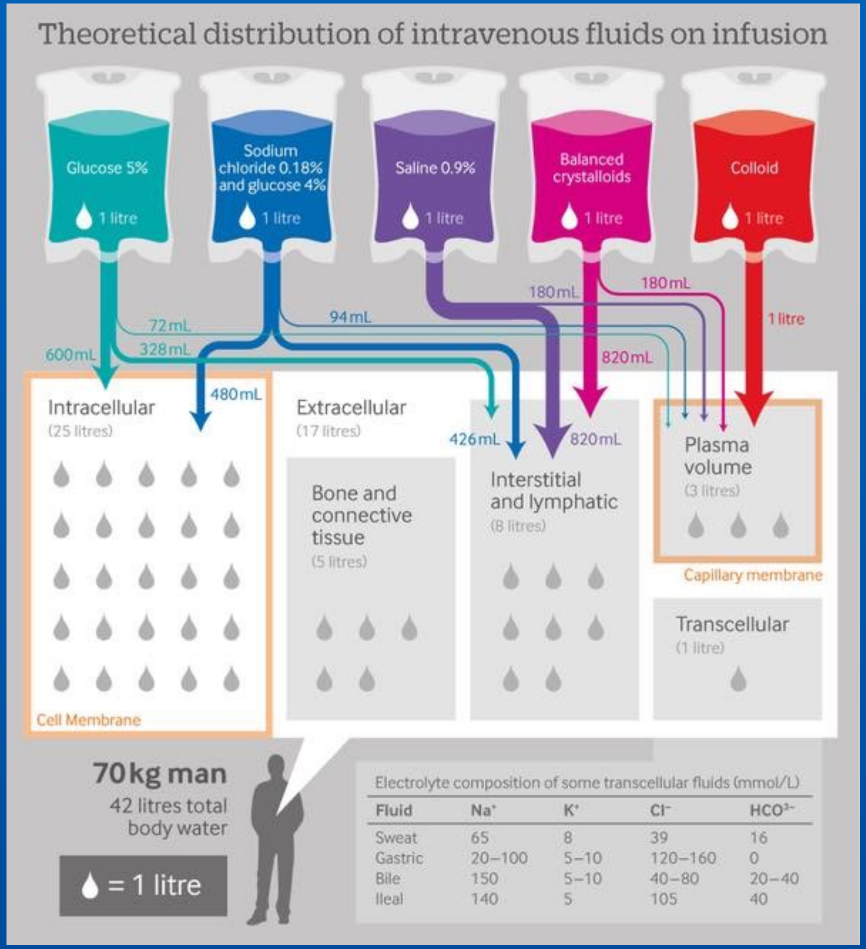
Right ventricle
Weaning Failure /Aid

Fluid Management

Static:
PVC, PaOP, LAP

vs

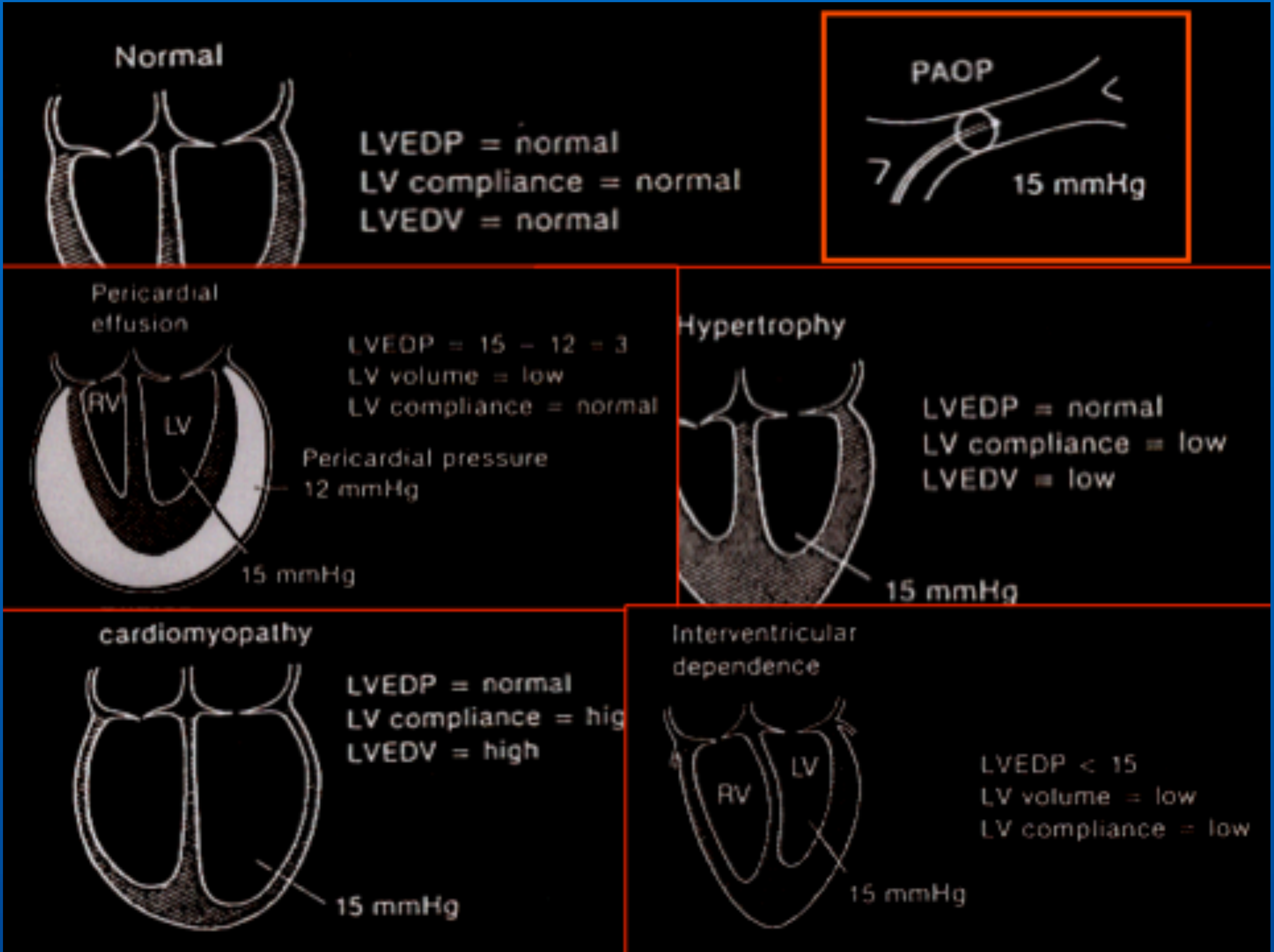
Dynamic:
PPV, SVV, AoDVTI



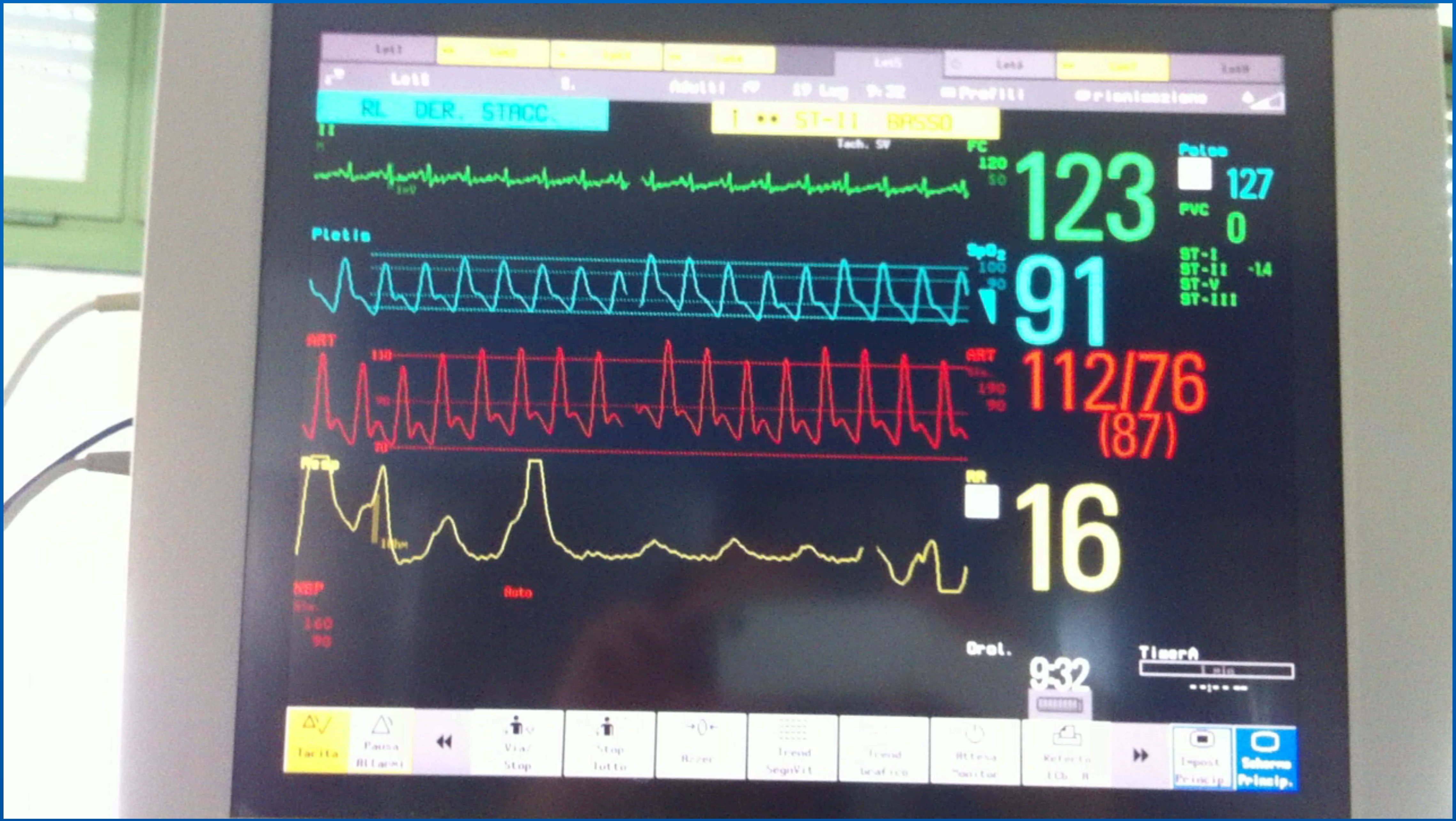
Electrolyte composition of some transcellular fluids (mmol/L)

Fluid	Na^+	K^+	Cl^-	HCO^{3-}
Sweat	65	8	39	16
Gastric	20–100	5–10	120–160	0
Bile	150	5–10	40–80	20–40
Ileal	140	5	105	40

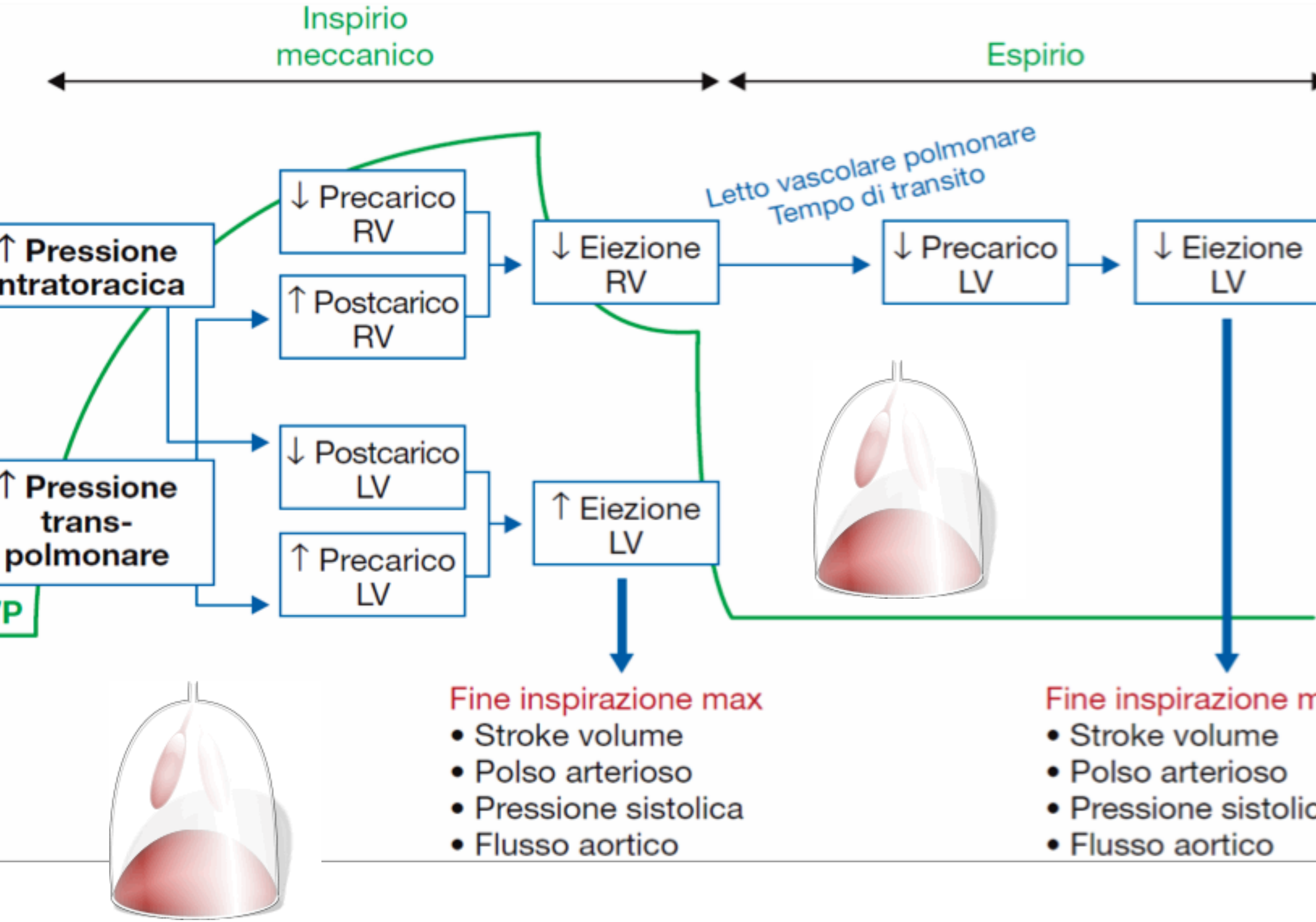
Static Parameters



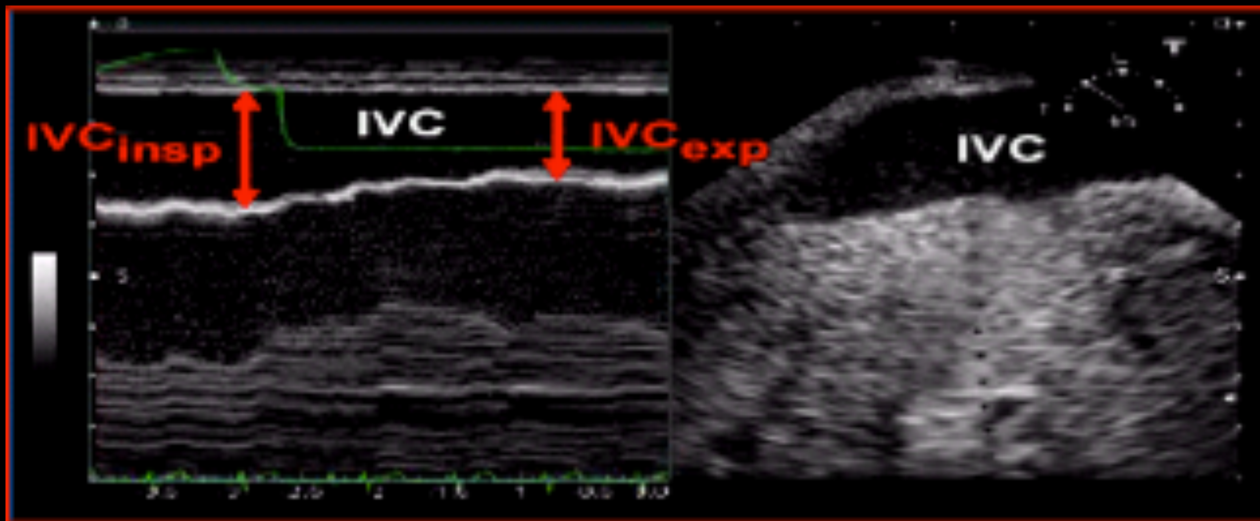
Dynamic Measurements



Full or Empty?


Inspirio meccanico
Espirio
Letto vascolare polmonare
Tempo di transito
↑ Pressione ntratoracica
↑ Pressione trans-polmonare
↓ Precarico RV
↑ Postcarico RV
↓ Postcarico LV
↑ Precarico LV
↓ Eiezione RV
↑ Eiezione LV
↓ Precarico LV
↓ Eiezione LV
Fine inspirazione max
• Stroke volume
• Polso arterioso
• Pressione sistolica
• Flusso aortico
Fine inspirazione
• Stroke volume
• Polso arterioso
• Pressione sistolic
• Flusso aortico

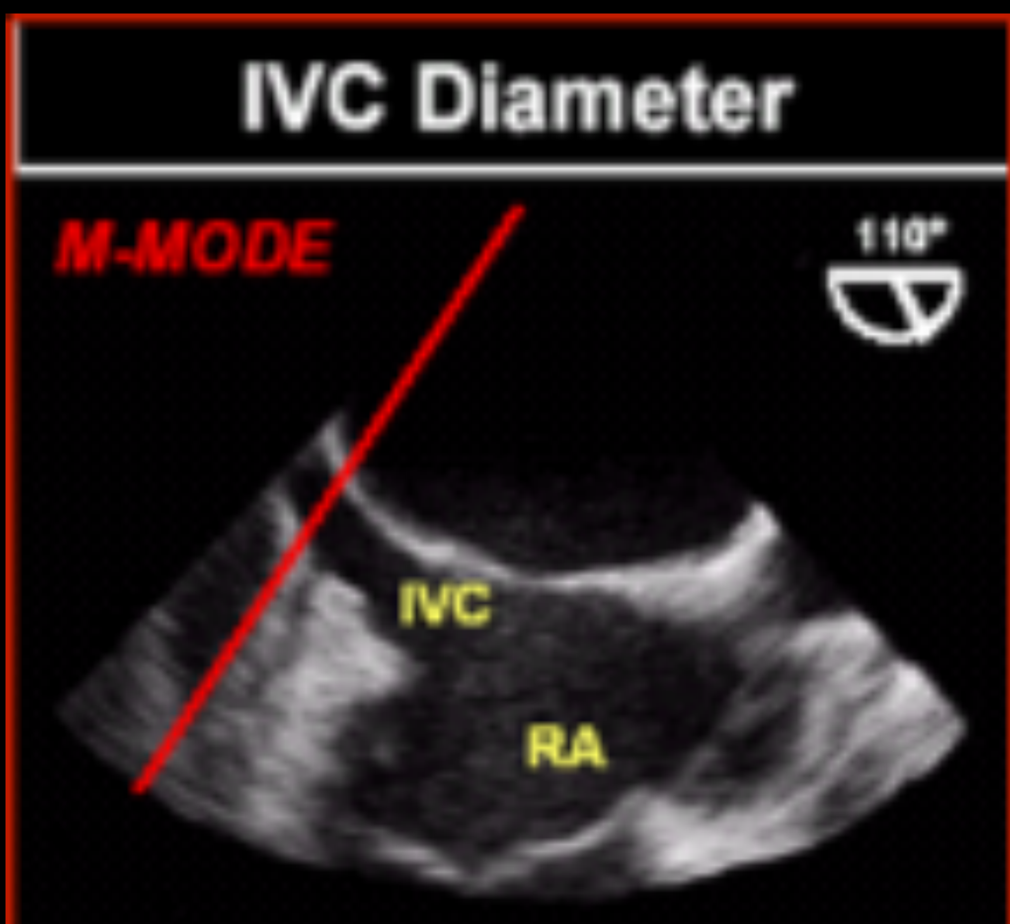
Inferior Vena Cava



IVC distensibility

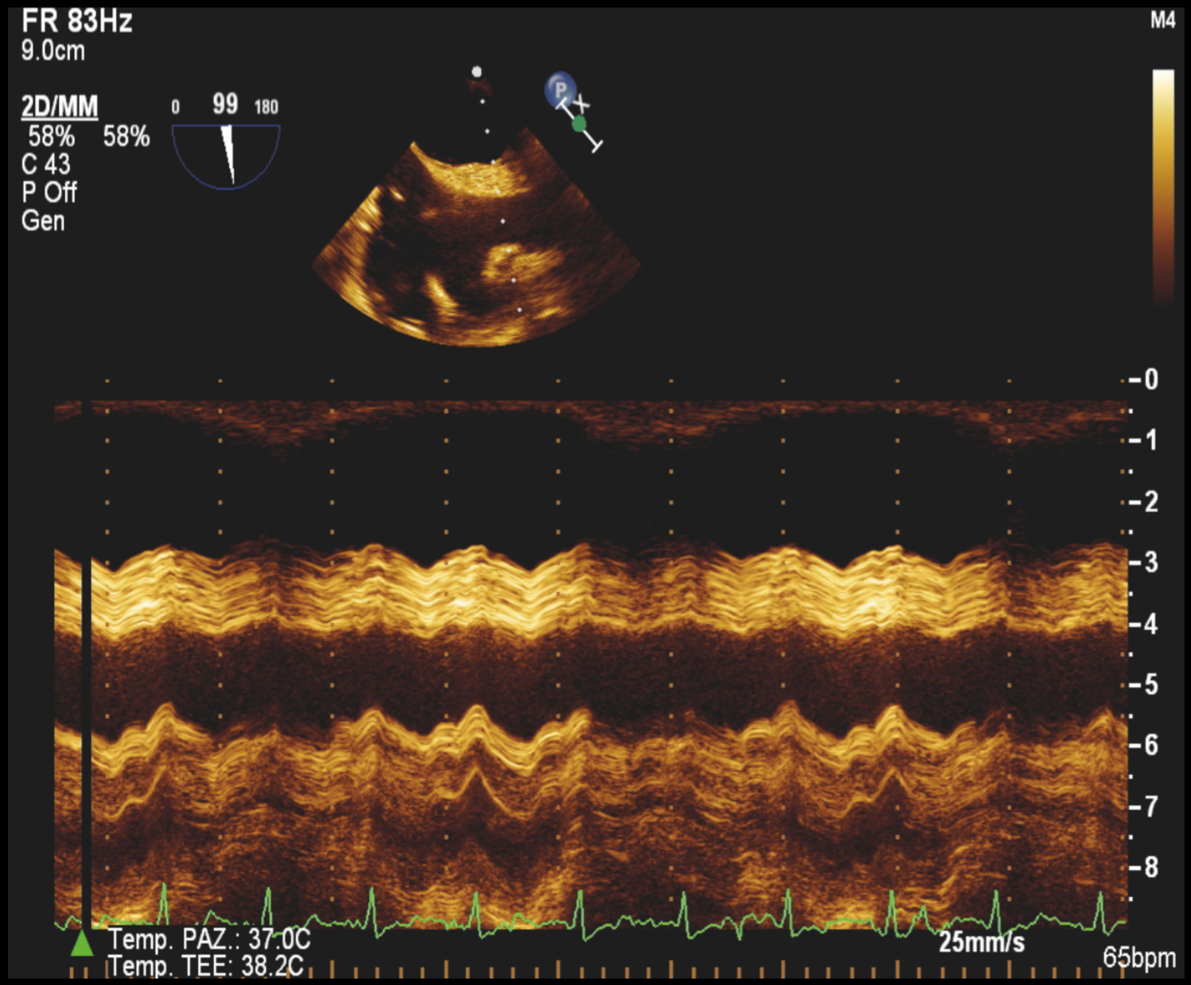
$$\Delta IVC = 100 \times \frac{(IVCinsp - IVCexp)}{IVCinsp}$$

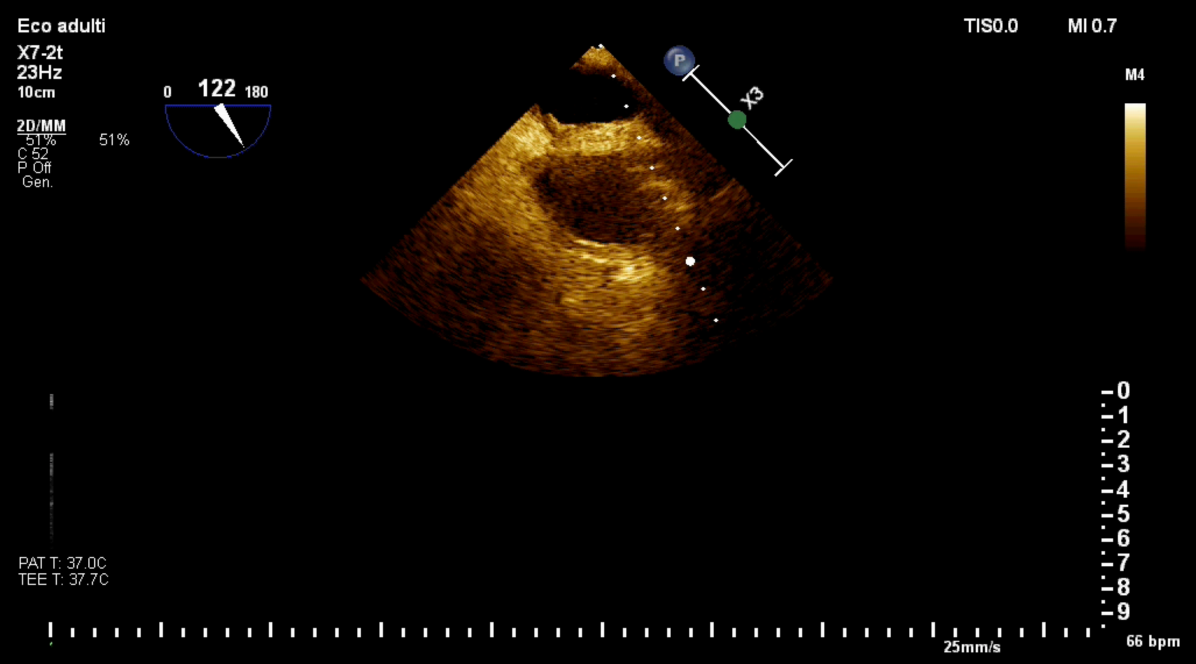
Δ IVC > 18%



Feissel M, Michard F, Faller J-P & Teboul J-L 2004
The respiratory variation in inferior vena cava diameter as a guide to fluid therapy. Intensive Care Medicine 30 1834–1837.

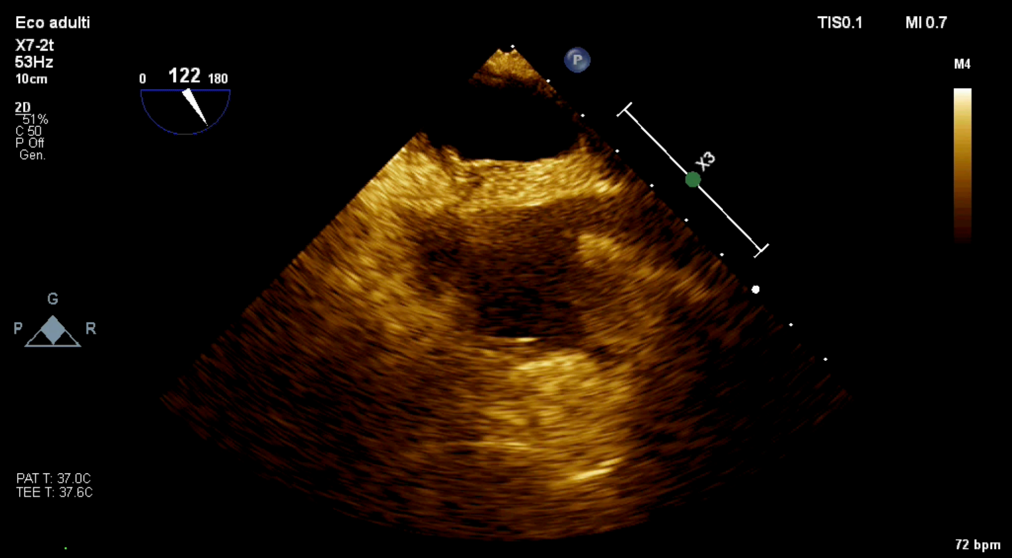
Superior Vena Cava





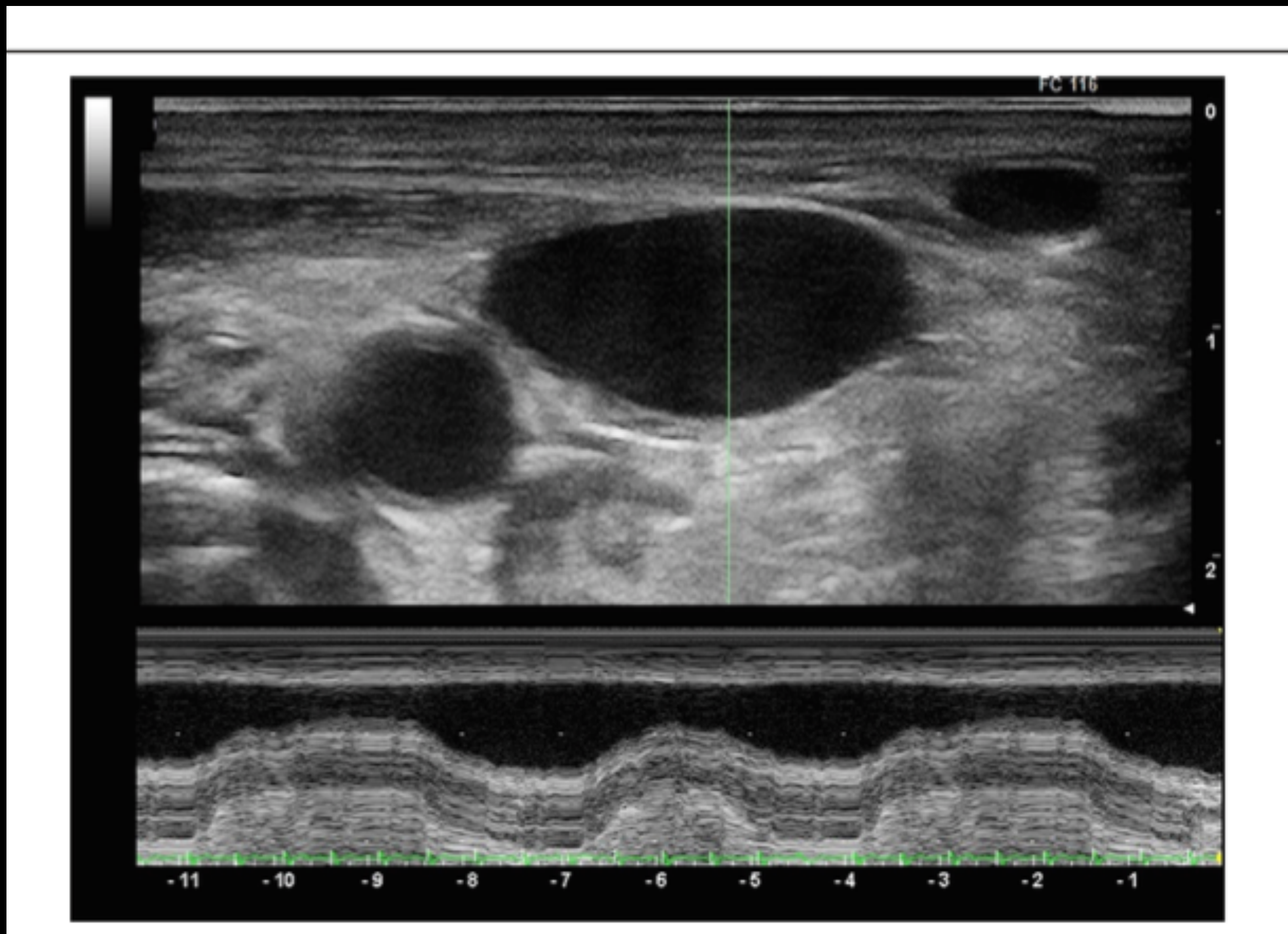
100x(Dmax-Dmin)/Dmin

36%



Vieillard-Baron A, Chergui K, Rabiller A, Peyrouset O, Page B, Beauchet A & Jardin F 2004 Superior vena caval collapsibility as a gauge of volume status in ventilated septic patients. Intensive Care Medicine 30 1734–1739.

Jugular vein?



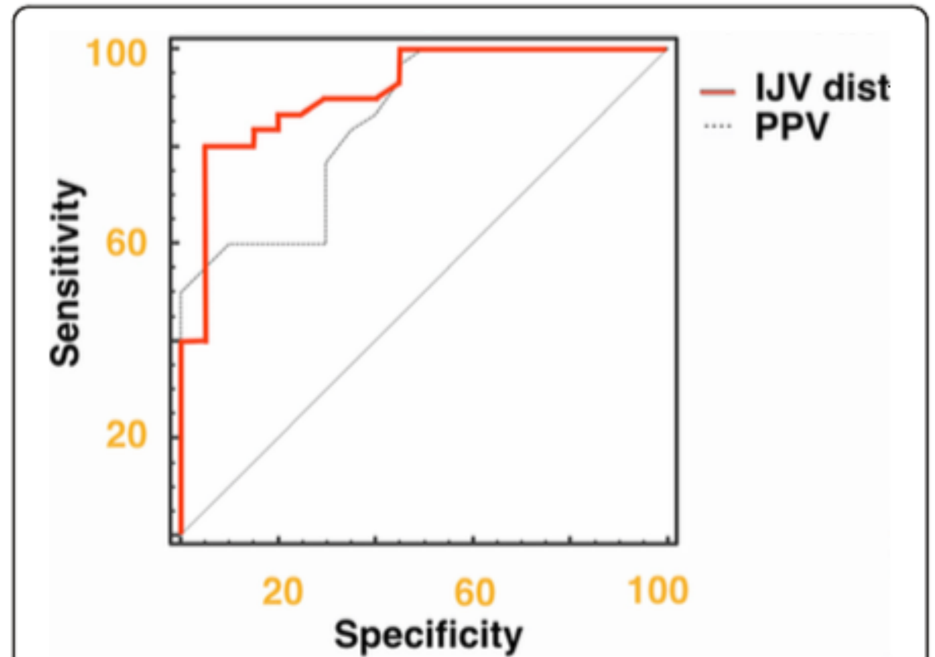


Figure 5 Pairwise comparison of internal jugular vein (IJV) distensibility and pulse pressure variation (PPV) receiver operator characteristic (ROC) curves before fluid administration.

100x(IJVDmax-IJVDmin)/IJVDmin

18%

Guarracino *et al. Critical Care* (2014) 18:647
DOI 10.1186/s13054-014-0647-1

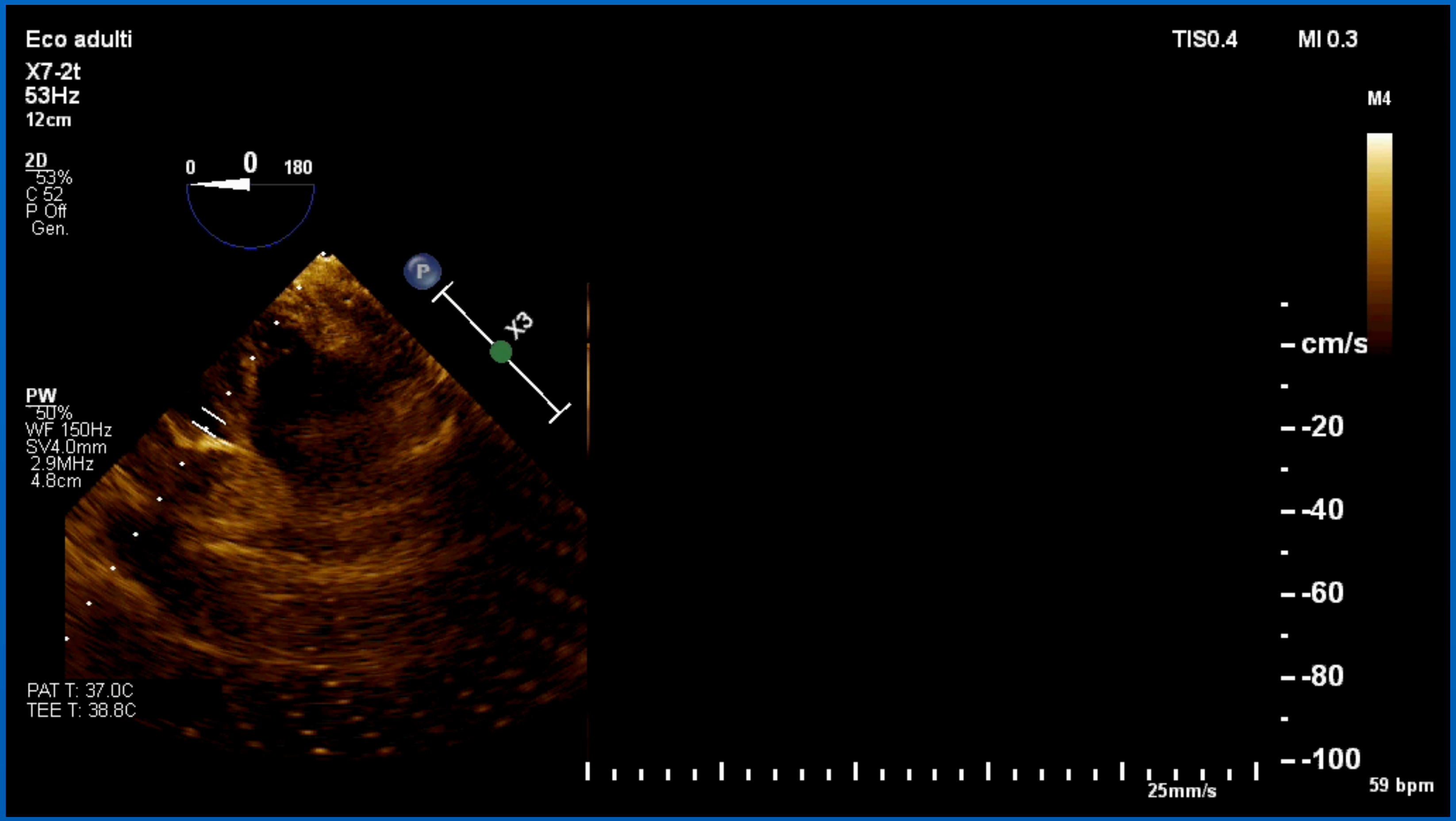
CRITICAL CARE

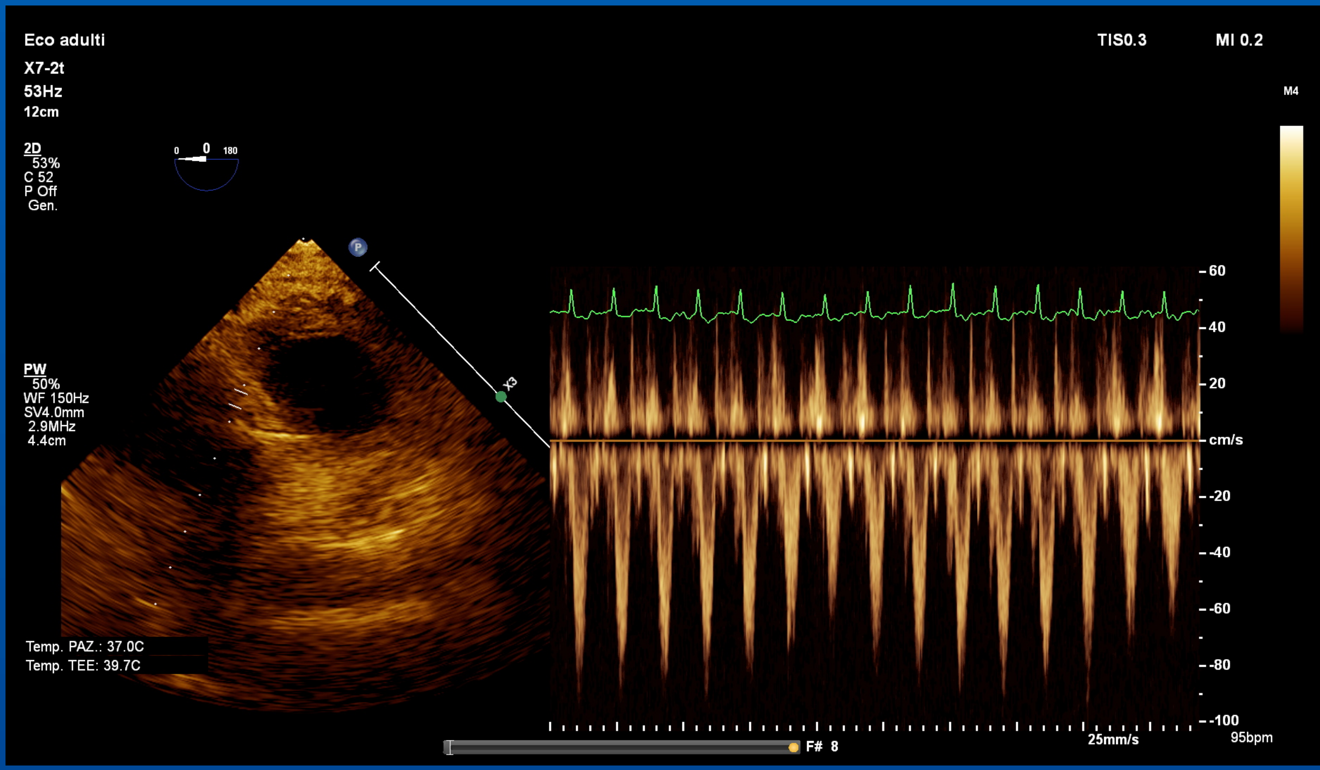
RESEARCH Open Access

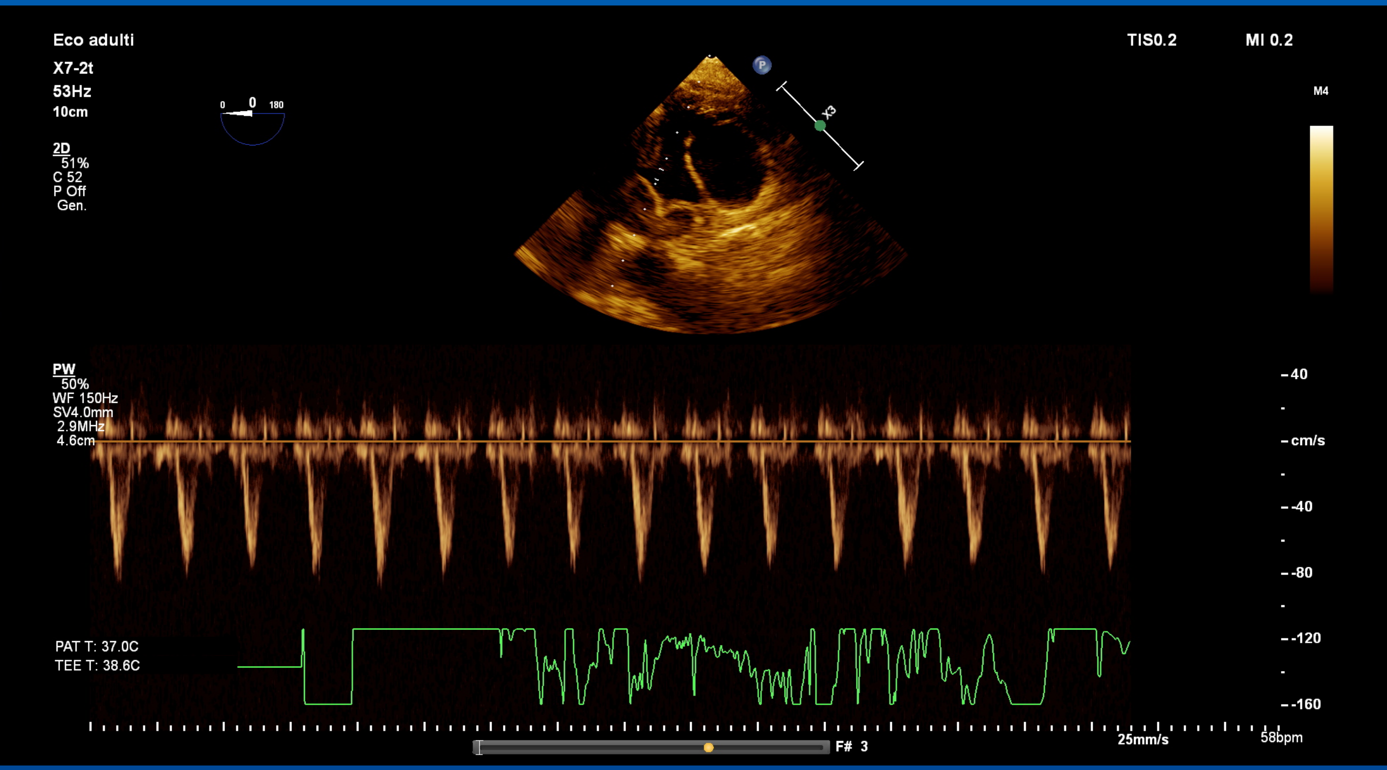
Jugular vein distensibility predicts fluid responsiveness in septic patients

Fabio Guarracino[1*], Baldassarre Ferro[1], Francesco Forfori[2], Pietro Bertini[1], Luana Magliacano[2] and Michael R Pinsky[3]

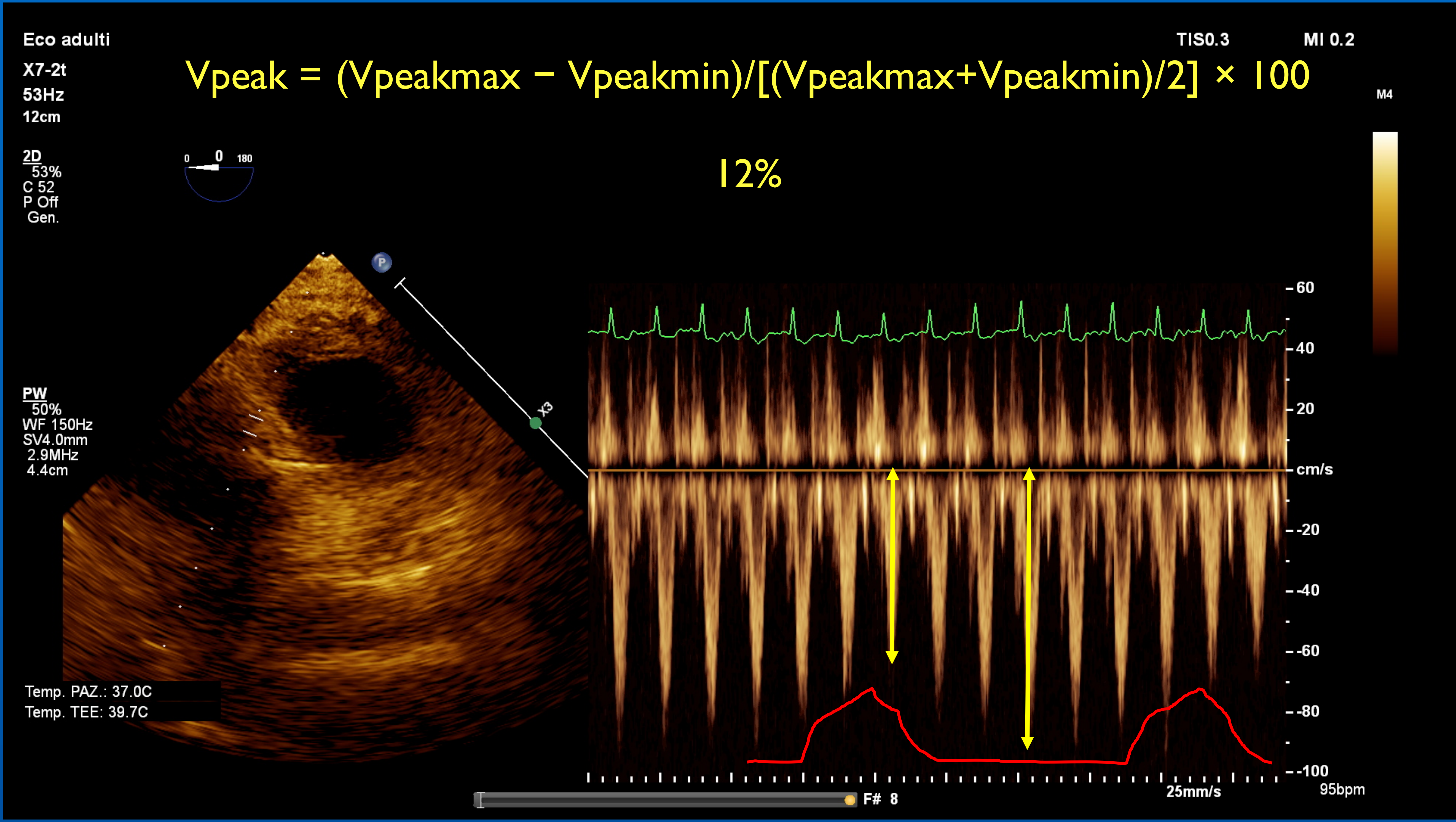
VTI peak Variation



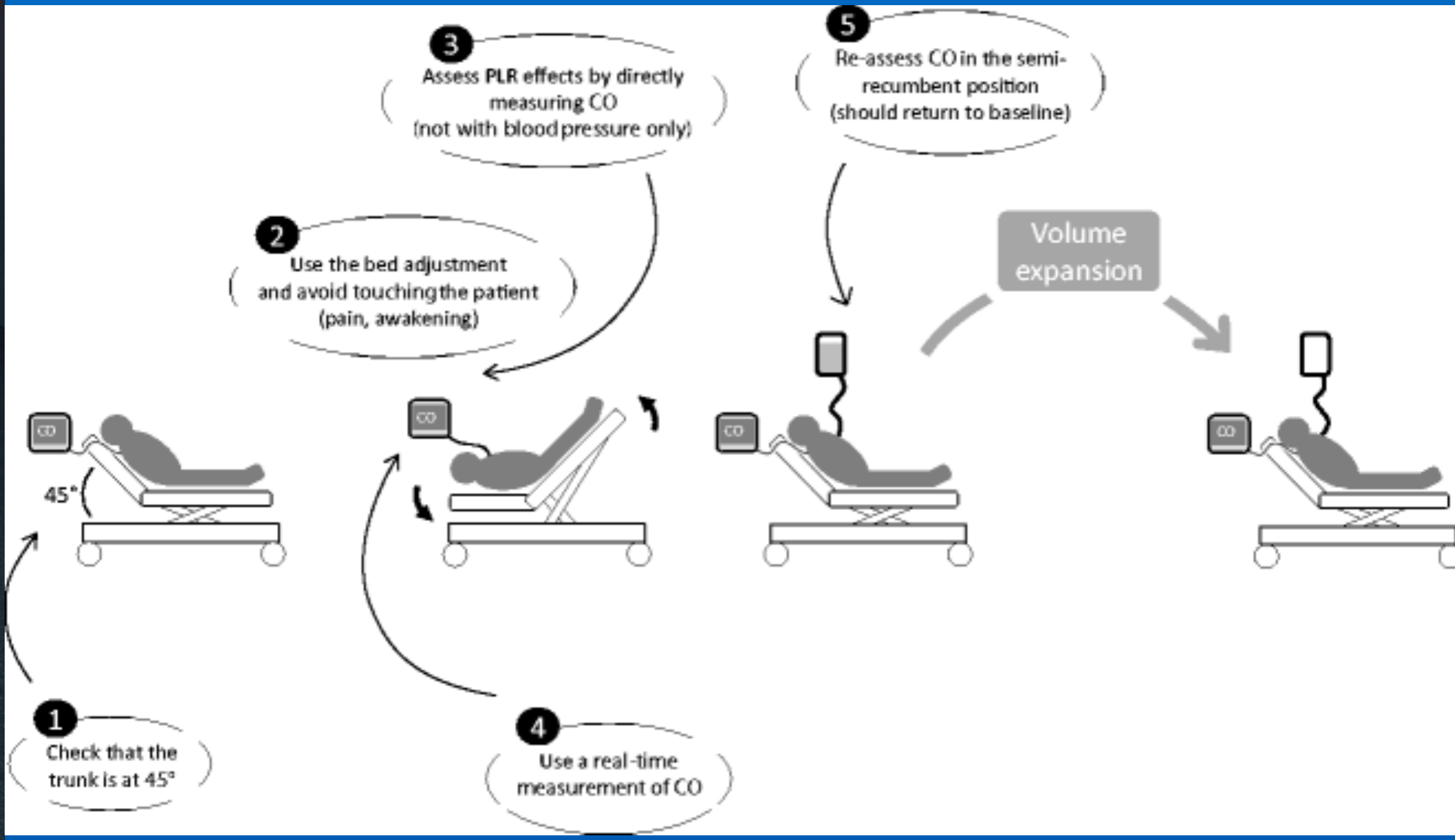




VTI peak Variation



Passive leg raising



Increment of stroke Volume or VTI > 10% indicates fluid responsiveness

Limitations

Mechanical ventilation (8-10 ml/kg VT)
Closed chest
Arrhythmia
Right ventricular dysfunctiom

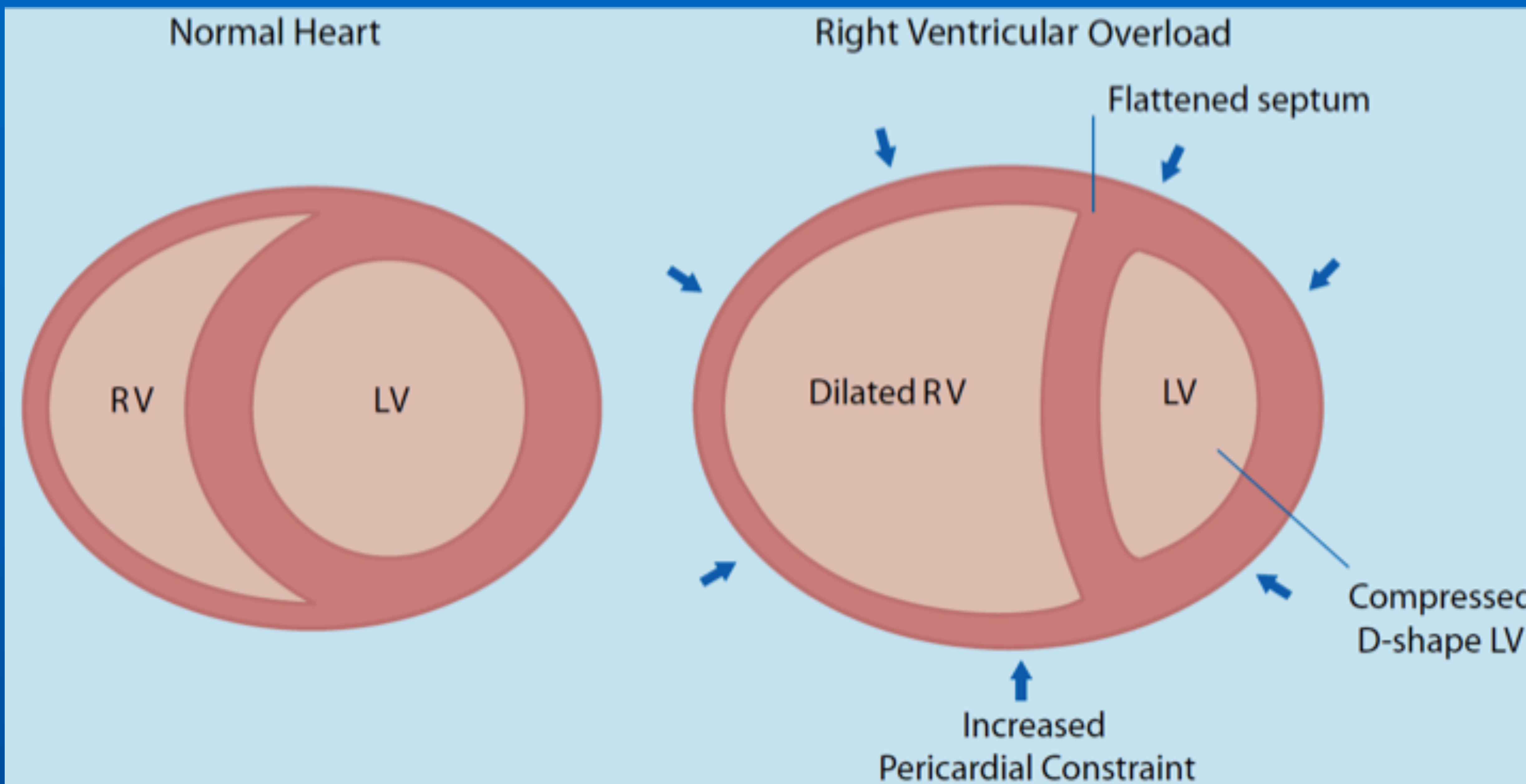
Echodynamics Topics

Fluid Management

Right ventricle

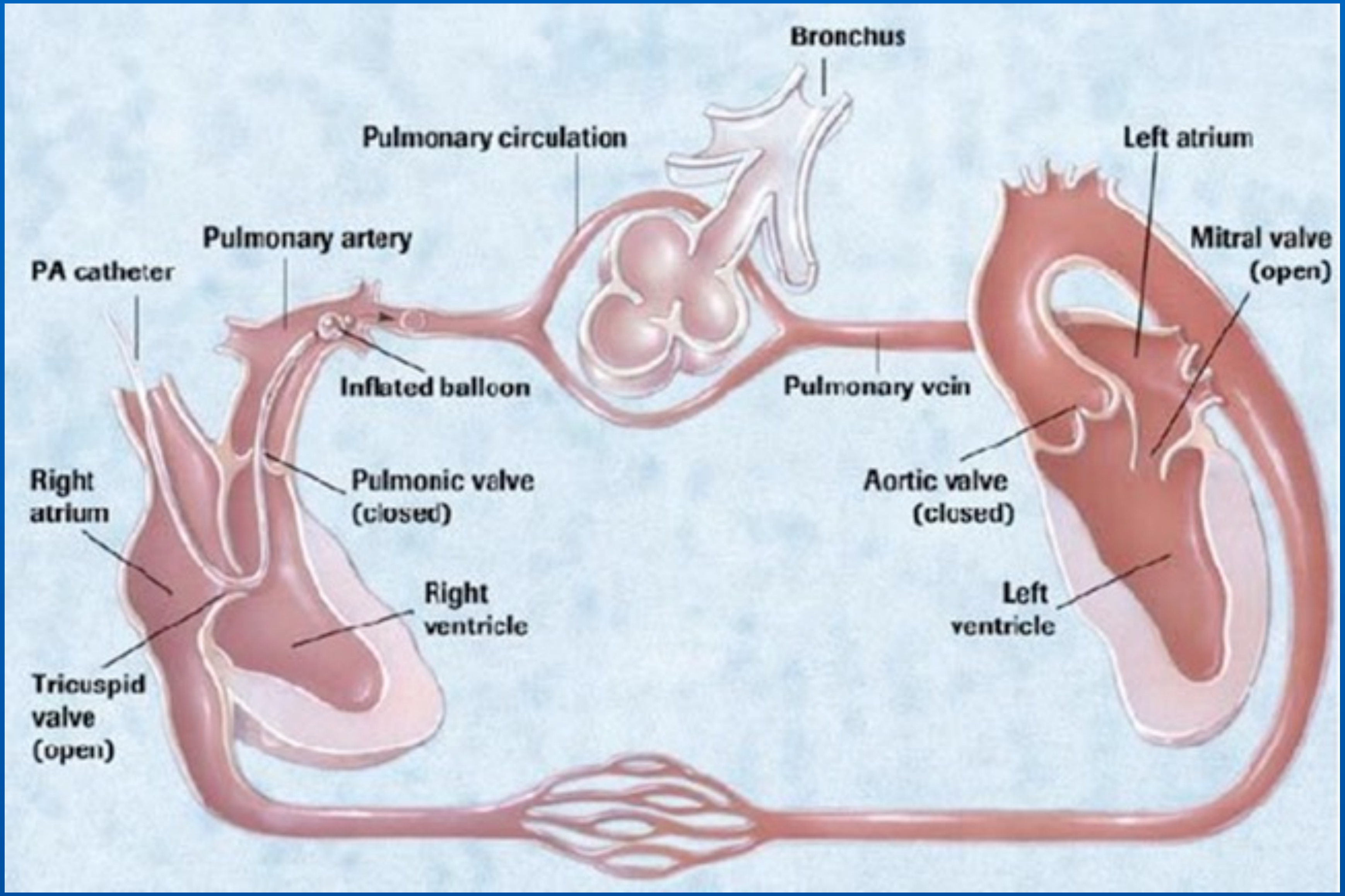
Weaning Failure /Aid

BEWARE OF THE RIGHT SIDE
!!!!!



Haddad et al, circulation 2008;117:1717-1731

The Circuit



Bronchus
Pulmonary circulation
Left atrium
Pulmonary artery
PA catheter
Mitral valve (open)
Inflated balloon
Pulmonary vein
Right atrium
Pulmonic valve (closed)
Aortic valve (closed)
Right ventricle
Left ventricle
Tricuspid valve (open)

The Anatomy

Causes of acute right ventricular dysfunction

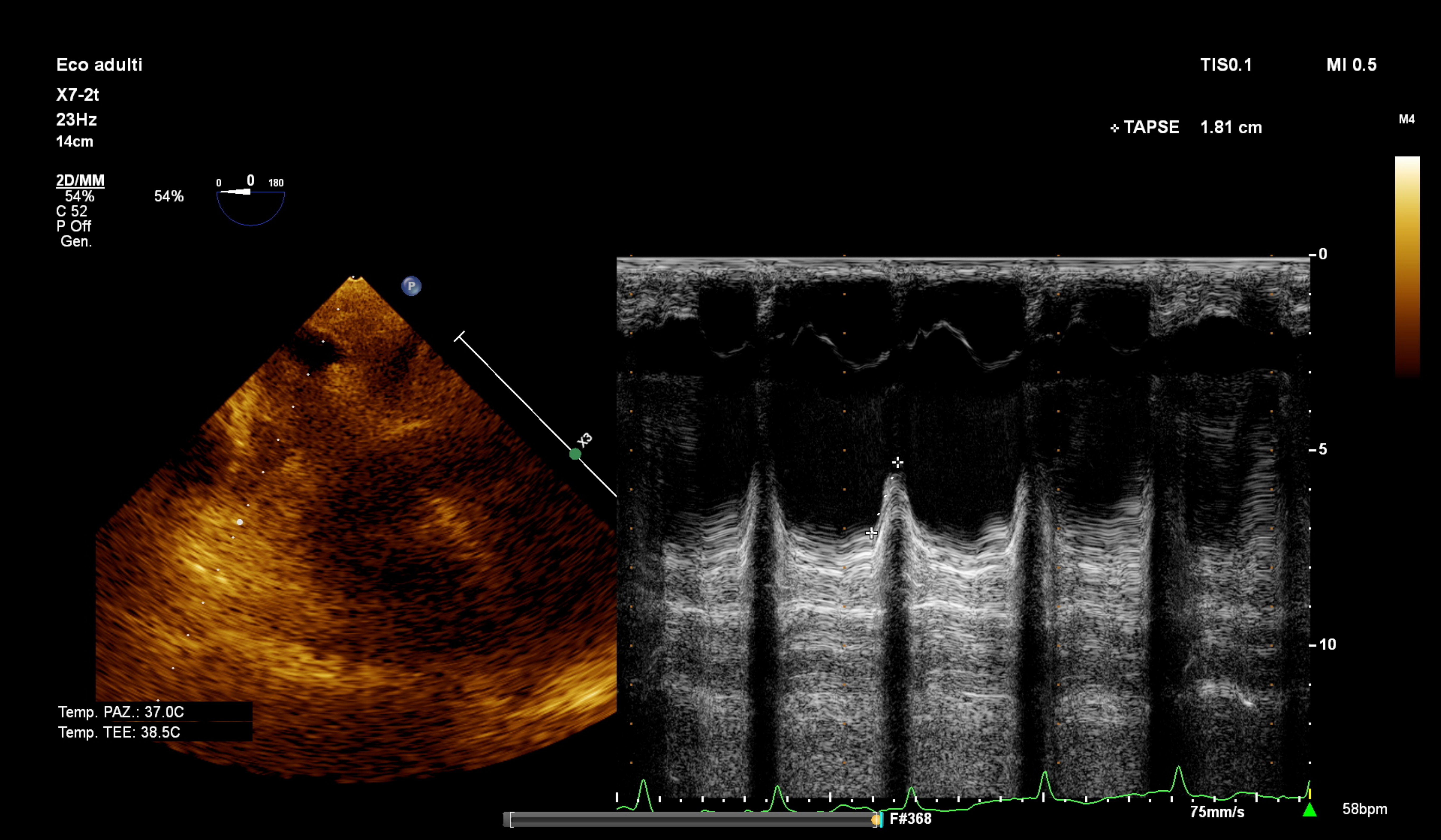
Volume/pressure overload
- Left ventricular failure
- Adult respiratory distress syndrome
- Massive pulmonary embolus
- Amniotic fluid embolus

Mechanical
- Mechanical ventilation

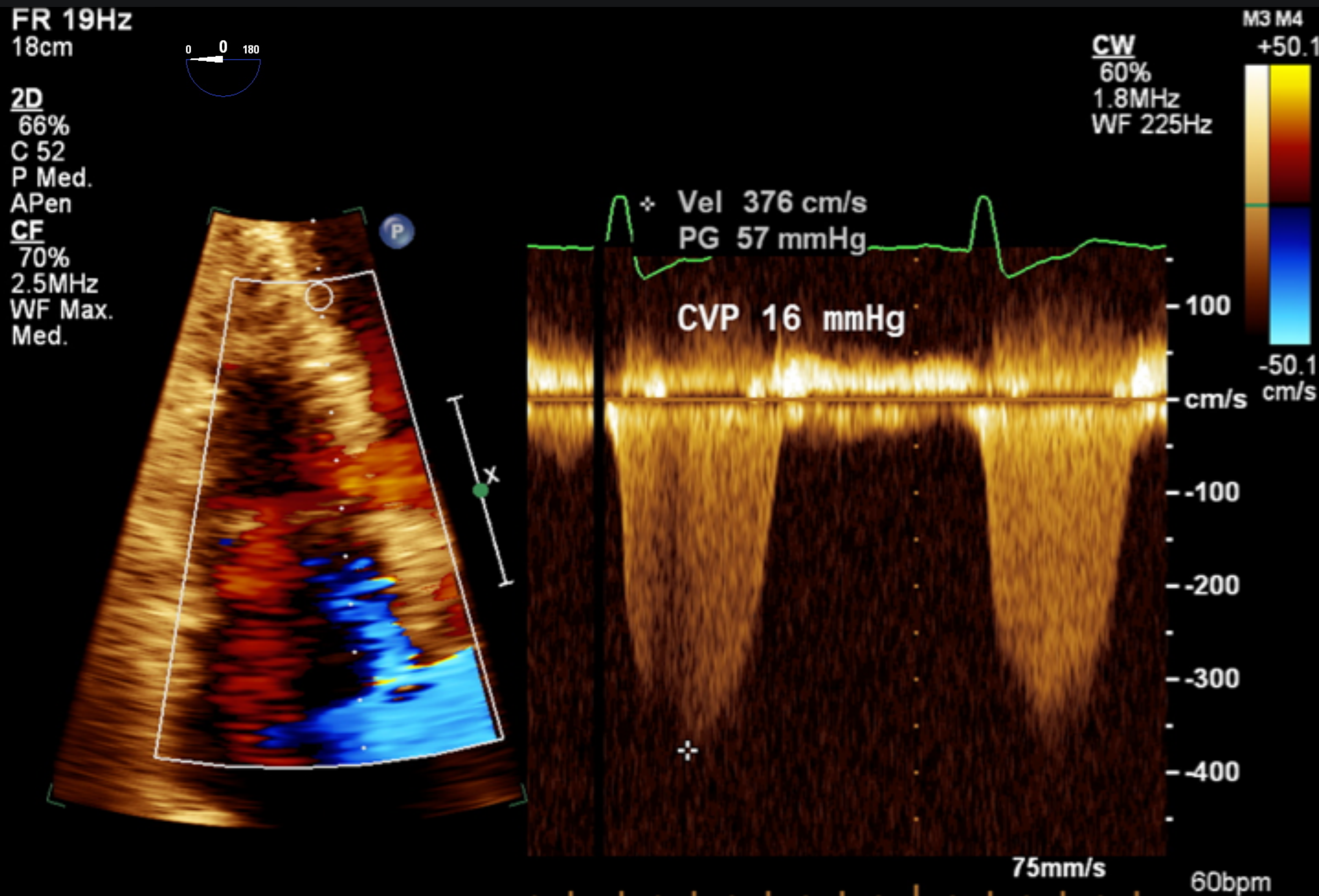
Other
- Sepsis

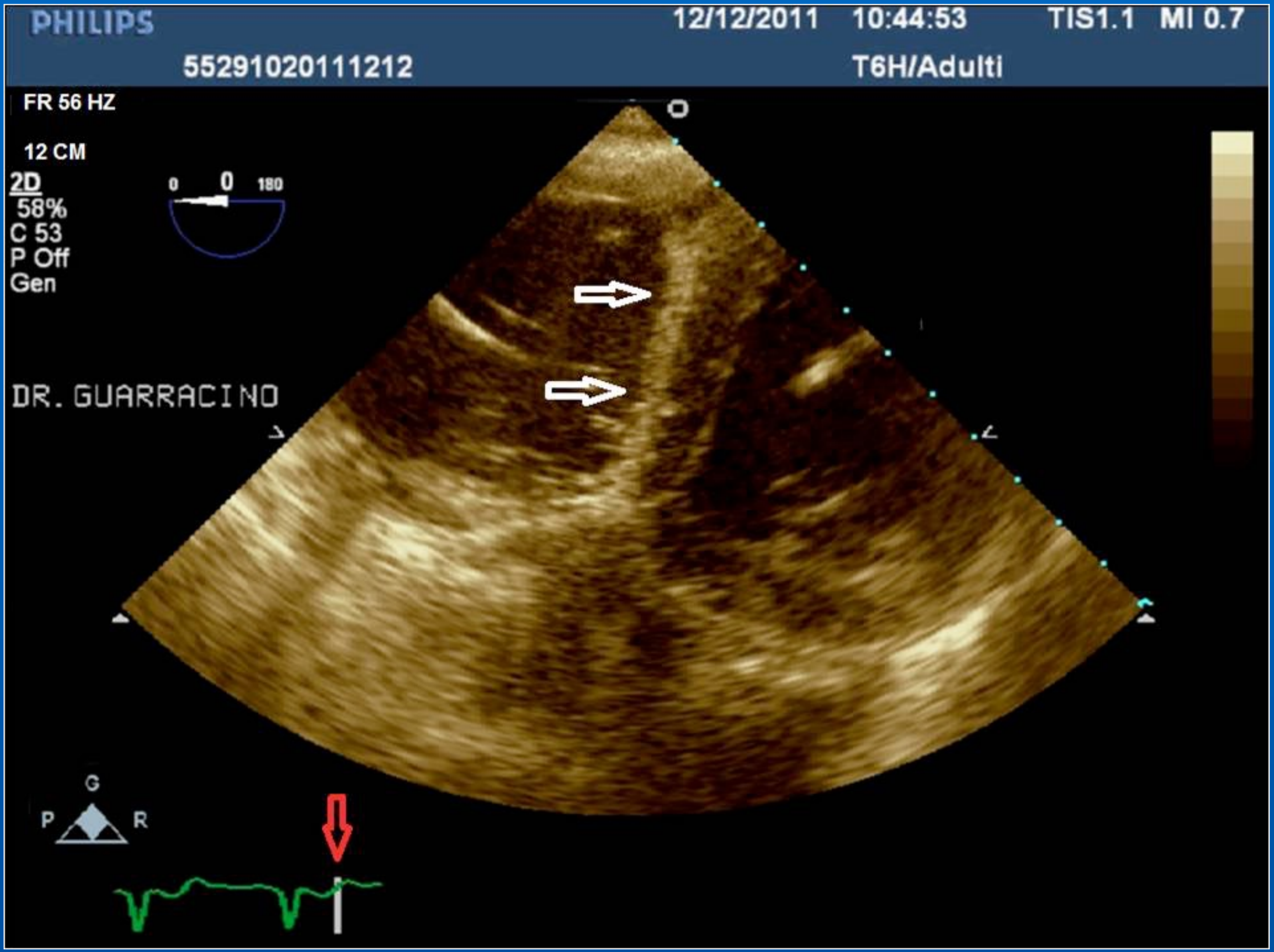
Cardiac
- Cardiomyopathies – dilated ischaemic
- Valvular regurgitation (tricuspid/pulmonary)
- Tricuspid valve rupture (traumatic/infectious)

Curr Opin Crit Care 13:532–540. © 2007

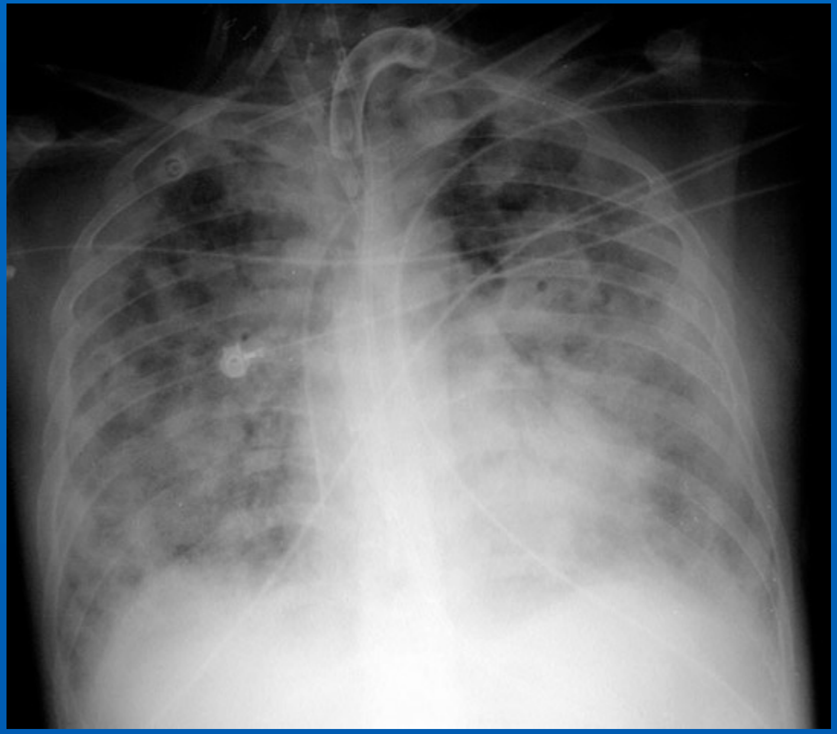


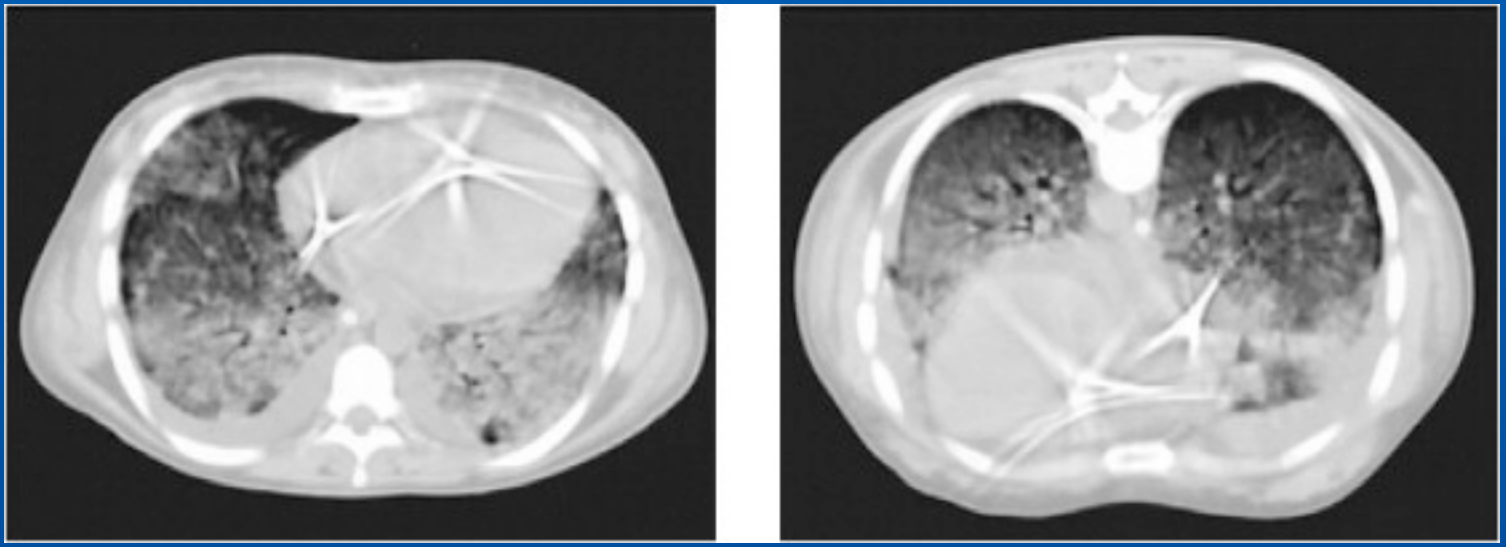
Eco adulti
X7-2t
23Hz
14cm
2D/MM
54%
54%
C 52
P Off
Gen.
0
0
180
TIS0.1
MI 0.5
TAPSE 1.81 cm
M4
0
5
10
Temp. PAZ.: 37.0C
Temp. TEE: 38.5C
F#368
75mm/s
58bpm


FR 19Hz
18cm
2D
66%
C 52
P Med.
APen
CF
70%
2.5MHz
WF Max.
Med.
CW
60%
1.8MHz
WF 225Hz
M3 M4
+50.1
-50.1
cm/s
Vel 376 cm/s
PG 57 mmHg
CVP 16 mmHg
100
cm/s
-100
-200
-300
-400
75mm/s
60bpm


PHILIPS
12/12/2011 10:44:53 TIS1.1 MI 0.7
55291020111212
T6H/Adulti
FR 56 HZ
12 CM
2D
58%
C 53
P Off
Gen
0 0 180
DR. GUARRACINO
G
P R

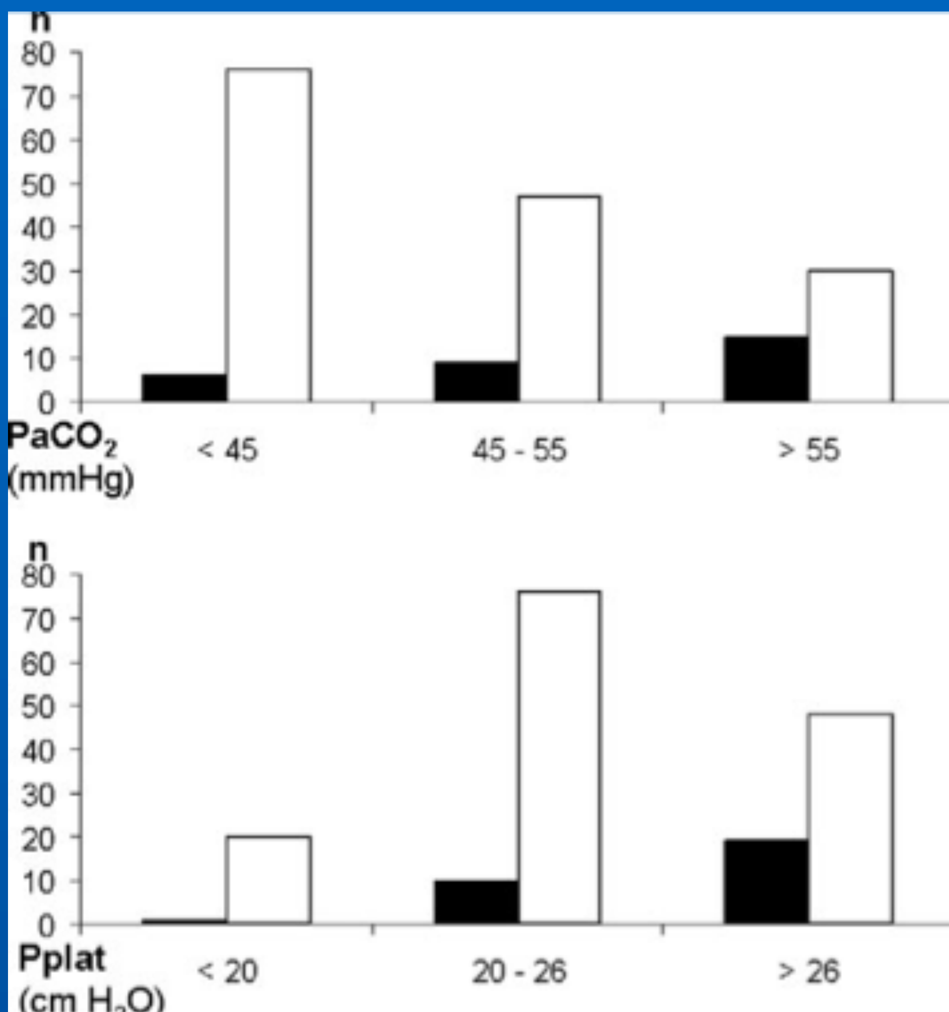
ARDS





Prone Positioning Unloads the Right Ventricle in Severe ARDS*

Antoine Vieillard-Baron, MD; Cyril Charron, MD; Vincent Caille, MD; Guillaume Belliard, MD; Bernard Page, MD; and François Jardin, MD



CHEST 2007; 132:1440–1446

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

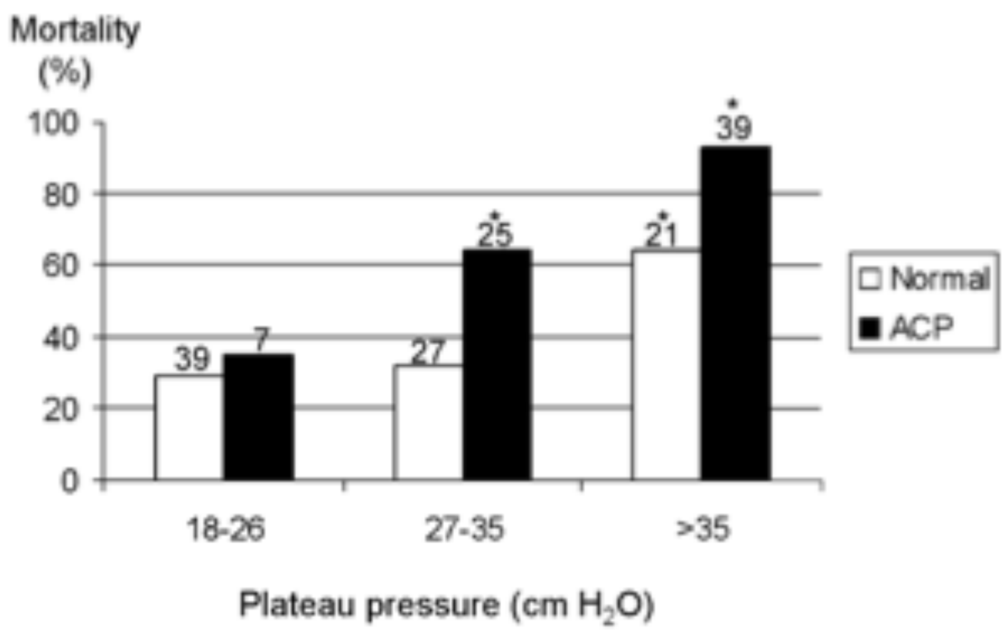


Fig. 2 Mortality rate is plotted against three ranges of plateau pressure (see text), after separating patients with normal bedside echocardiographic findings (normal), and patients exhibiting acute cor pulmonale (*ACP*) detected by echocardiography. Figures are the exact number of patients concerned. $^{*}p < 0.05$, when compared with the preceding range

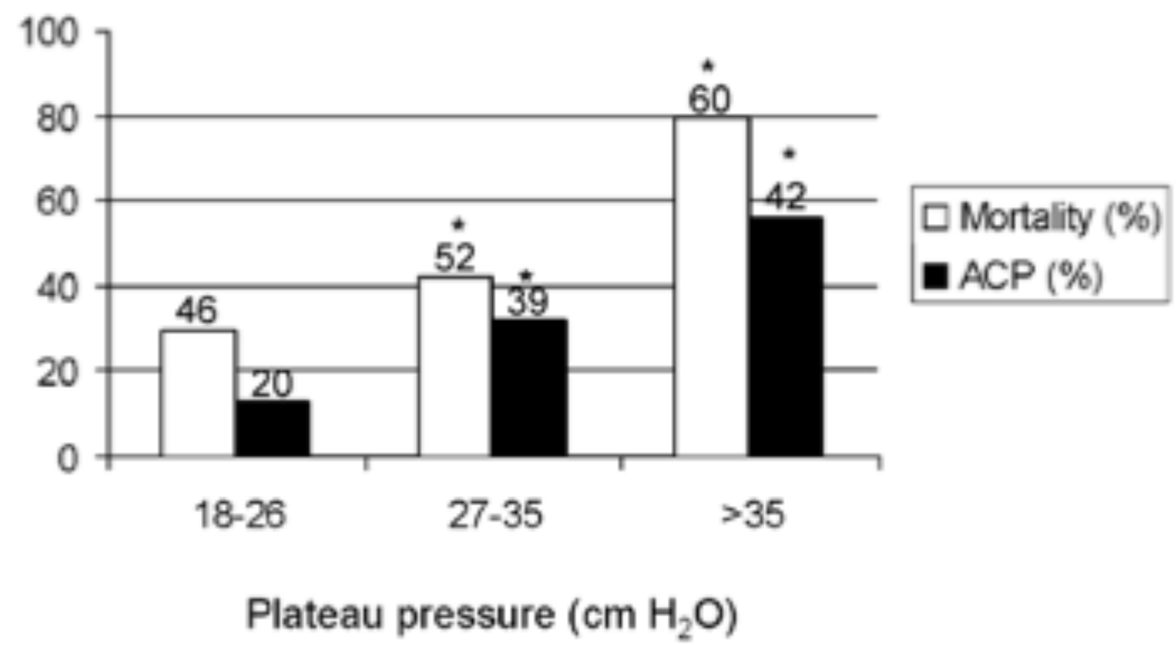
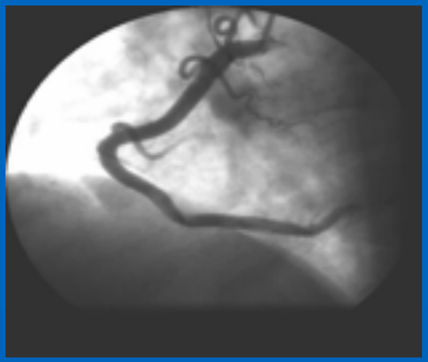
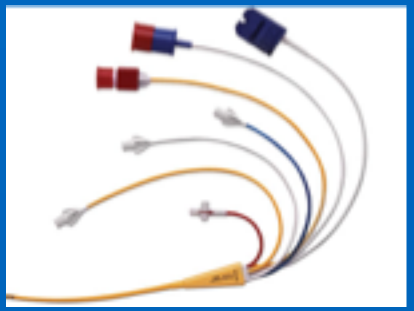


Fig. 1 Mortality rate and incidence of acute cor pulmonale (*ACP*) are plotted against three ranges of plateau pressure (see text). Figures are the exact number of patients concerned. $^{*}p < 0.05$, when compared with the preceding range

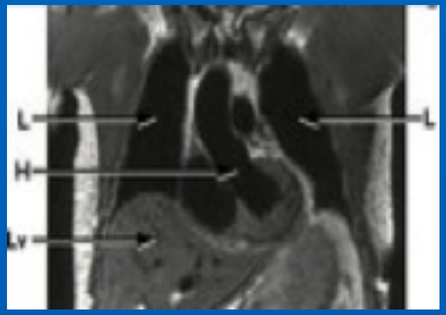
Intensive Care Med (2007) 33:444–447

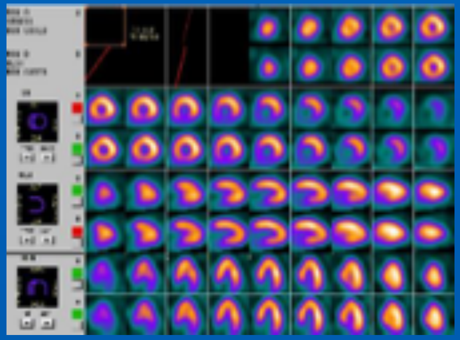
Assessing the Failing RV

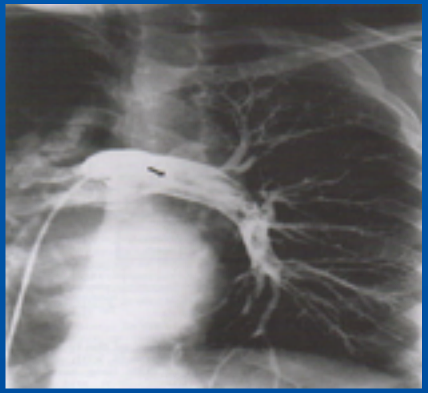


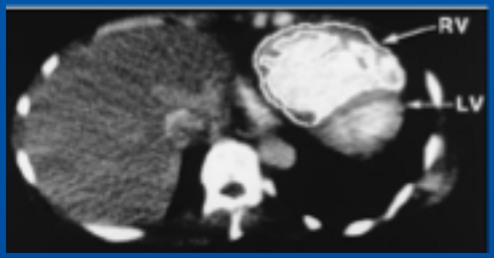


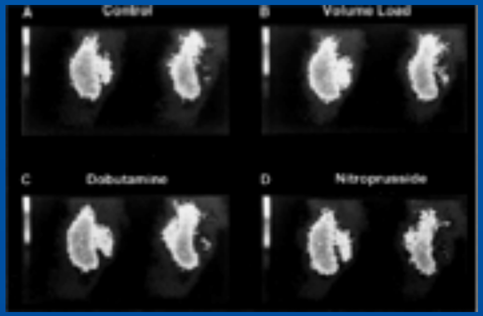
PAC
Contrast Ventriculography
Radionuclide Ventriculography
Echocardiography
Ct Scan
MRI



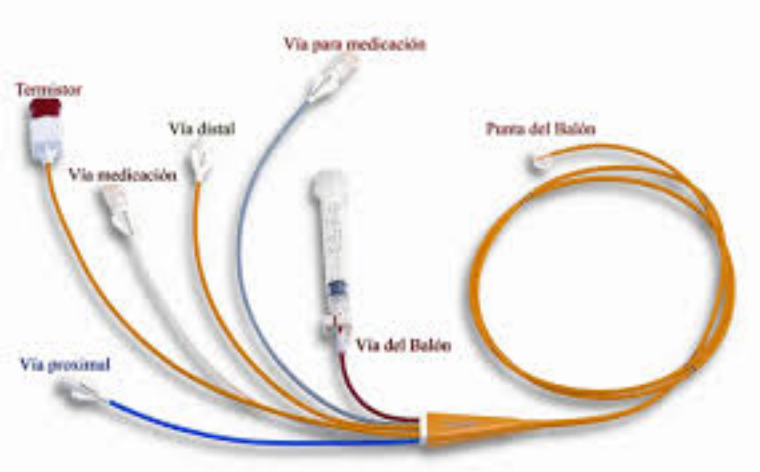




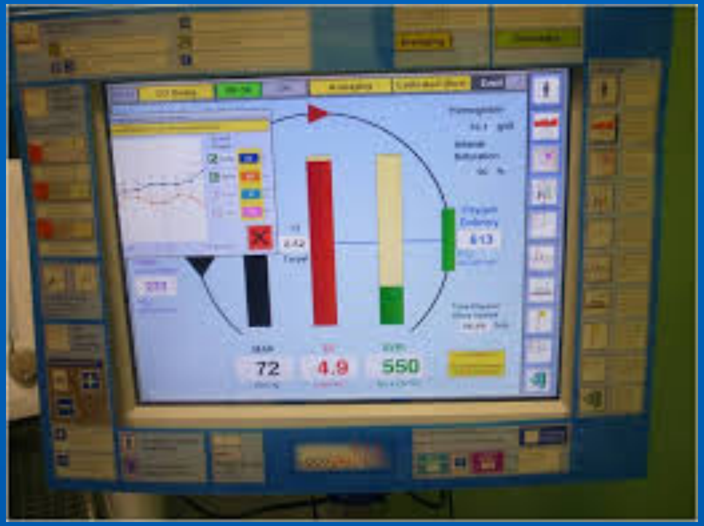


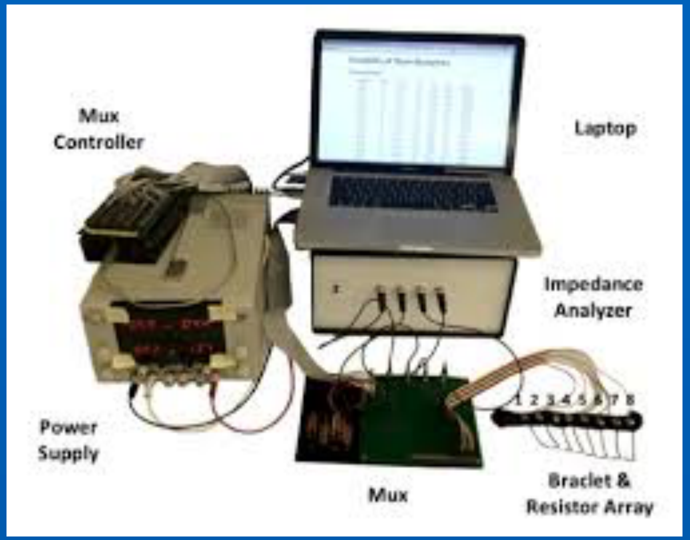


Hemodynamic Monitoring



PICCO
LIDCO
Thermodilution
Pulse Contour Analysis
Bioimpedance
Oesophageal Doppler
Nexfin





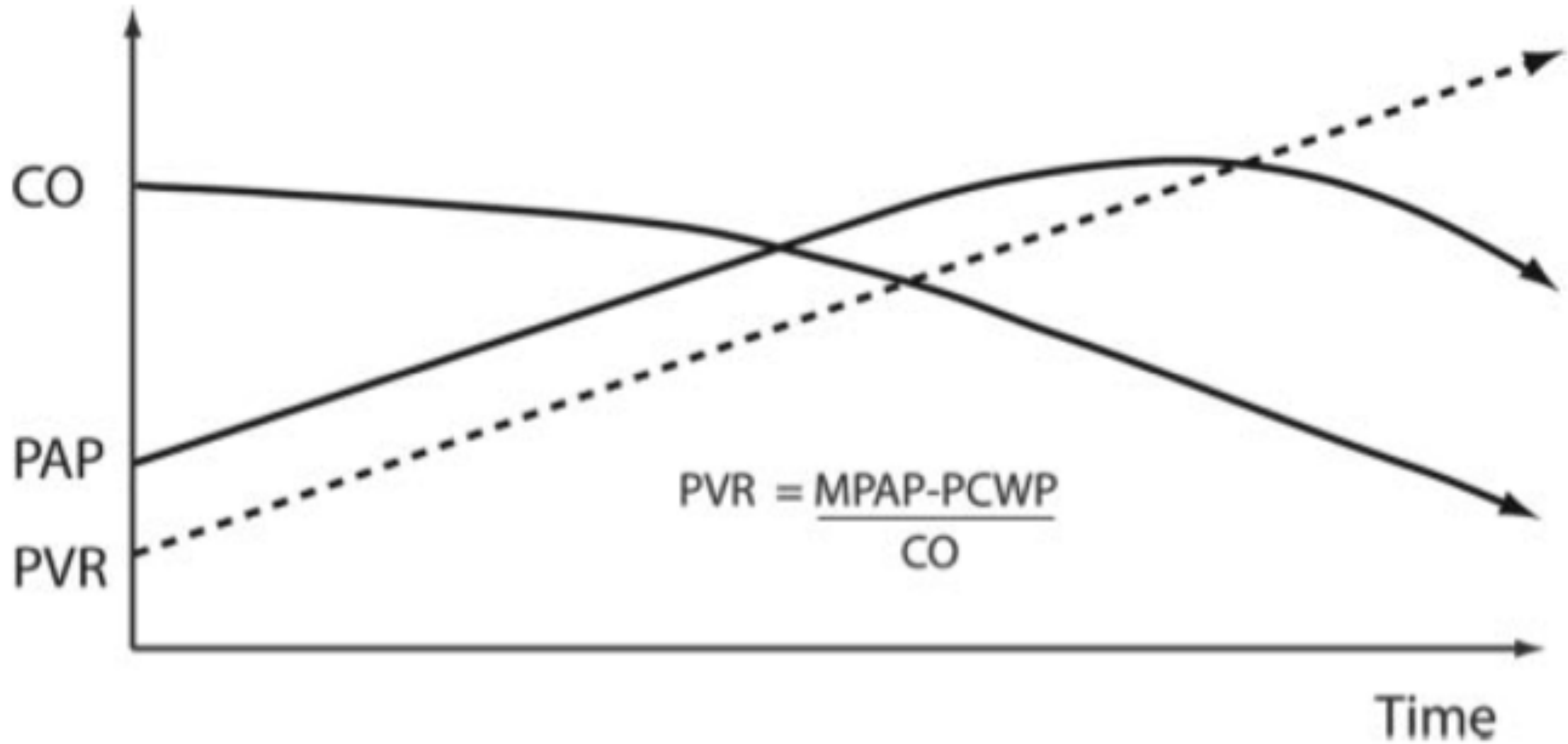


Figure 4. Hemodynamics in progressive pulmonary vascular disease. A decrease in pulmonary arterial pressure (PAP) in patients with PH may be a sign of low cardiac output (CO) and severe RV failure. PVR indicates pulmonary vascular resistance; PCWP, pulmonary artery capillary wedge pressure; and MPAP, mean PAP.

Right Ventricle

Summary

It is easy to underestimate the effects of ventilation on the cardiovascular system, or to misinterpret cardiopulmonary interactions as primary cardiovascular events. We have described how simple ventilatory interventions can some-

Arch Dis Child 1999;**80**:475–480

CURRENT TOPIC

Cardiovascular effects of mechanical ventilation

Lara Shekerdemian, Desmond Bohn

Echodynamics Topics

Fluid Management

Right ventricle

Weaning Failure /Aid

Weaning Failure

Table 4: Patients' characteristics prior to SBT, according weaning success or failure

	Weaning success (n = 94)	Weaning failure (n = 23)	*P* value
SAP (mmHg)	139 (133-147)	132 (115-149)	0.28
HR (bpm)	92 (86-97)	110 (95-120)	**0.007**
SV (mL)	63 (57-70)	60 (39-66)	0.06
CO (L/min/m²)	5.8 (5.2-6.3)	5.4 (3.3-6.5)	0.19
LVEF (%)	51 (43-55)	36 (27-55)	**0.04**
E/A	0.94 (0.82-1.03)	0.88 (0.68-1.65)	0.7
DTE (ms)	170 (150-189)	138 (98-195)	0.07
E/E'	5.6 (5.2-6.3)	7.0 (5.0-9.2)	**0.038**
RVEDA/LVEDA	0.47 (0.44-0.51)	0.48 (0.43-0.52)	0.99

CO, cardiac output; DTE, deceleration time of mitral E wave; HR, heart rate; LVEDA, left ventricular end-diastolic area; LVEF, LV ejection fraction; RVEDA, right ventricular end-diastolic area; SAP, systolic arterial pressure; SV, left ventricular stroke volume.

Teboul *et al. Critical Care* 2010, 14:211
http://ccforum.com/content/14/2/211

CRITICAL CARE

REVIEW

Weaning failure of cardiac origin: recent advances

Jean-Louis Teboul*, Xavier Monnet, and Christian Richard

Caille *et al. Critical Care* 2010, **14**:R120
http://ccforum.com/content/14/3/R120

CRITICAL CARE

RESEARCH Open Access

Echocardiography: a help in the weaning process

Vincent Caille[1,2], Jean-Bernard Amiel[3,4,5], Cyril Charron[1,2], Guillaume Belliard[1,2], Antoine Vieillard-Baron[1,2] and Philippe Vignon*[3,4,5]

Weaning Failure

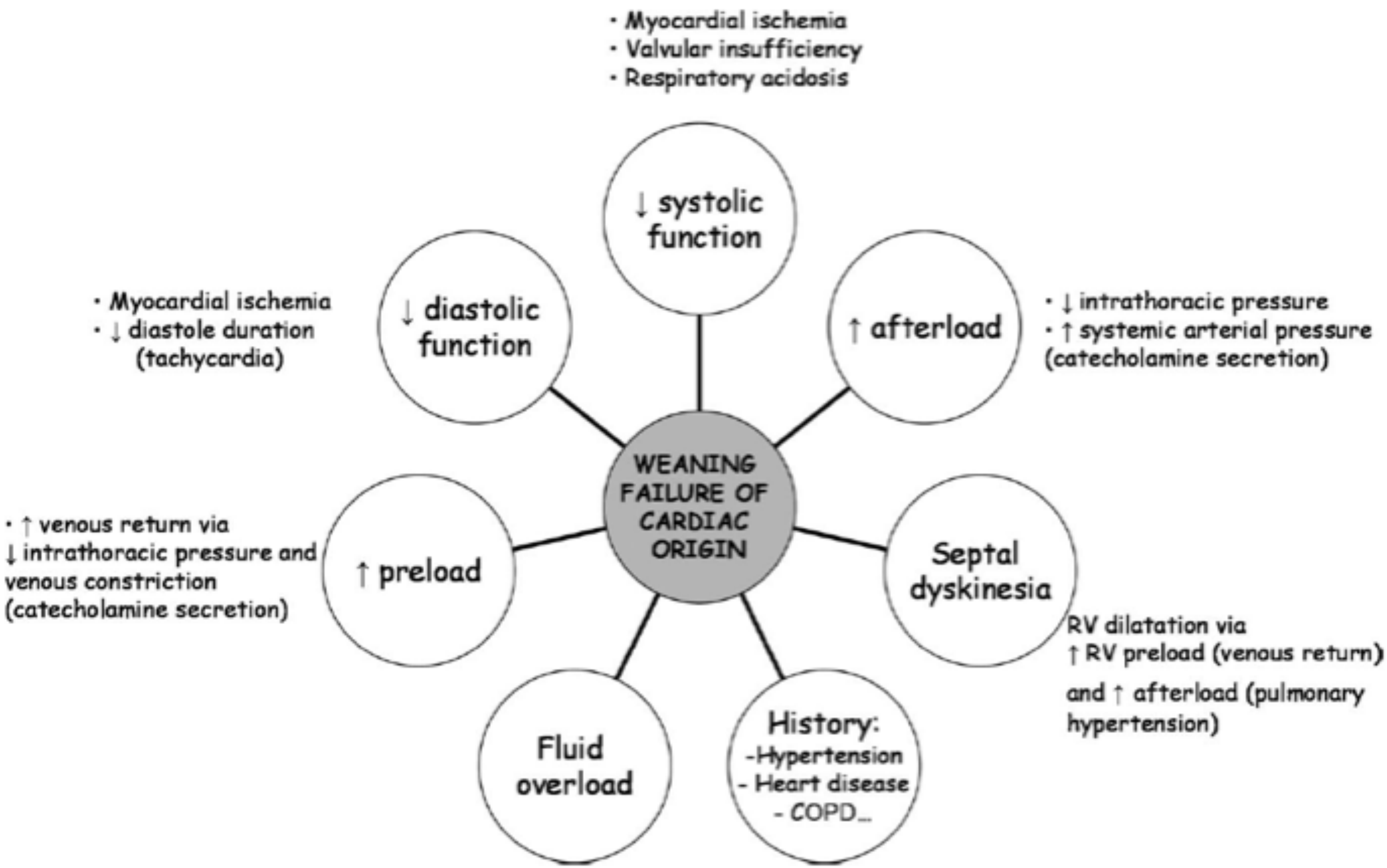
Intensive Care Med (2000) 26: 1164–1166
DOI 10.1007/s001340000619

EDITORIAL

Michael R. Pinsky

Breathing as exercise:

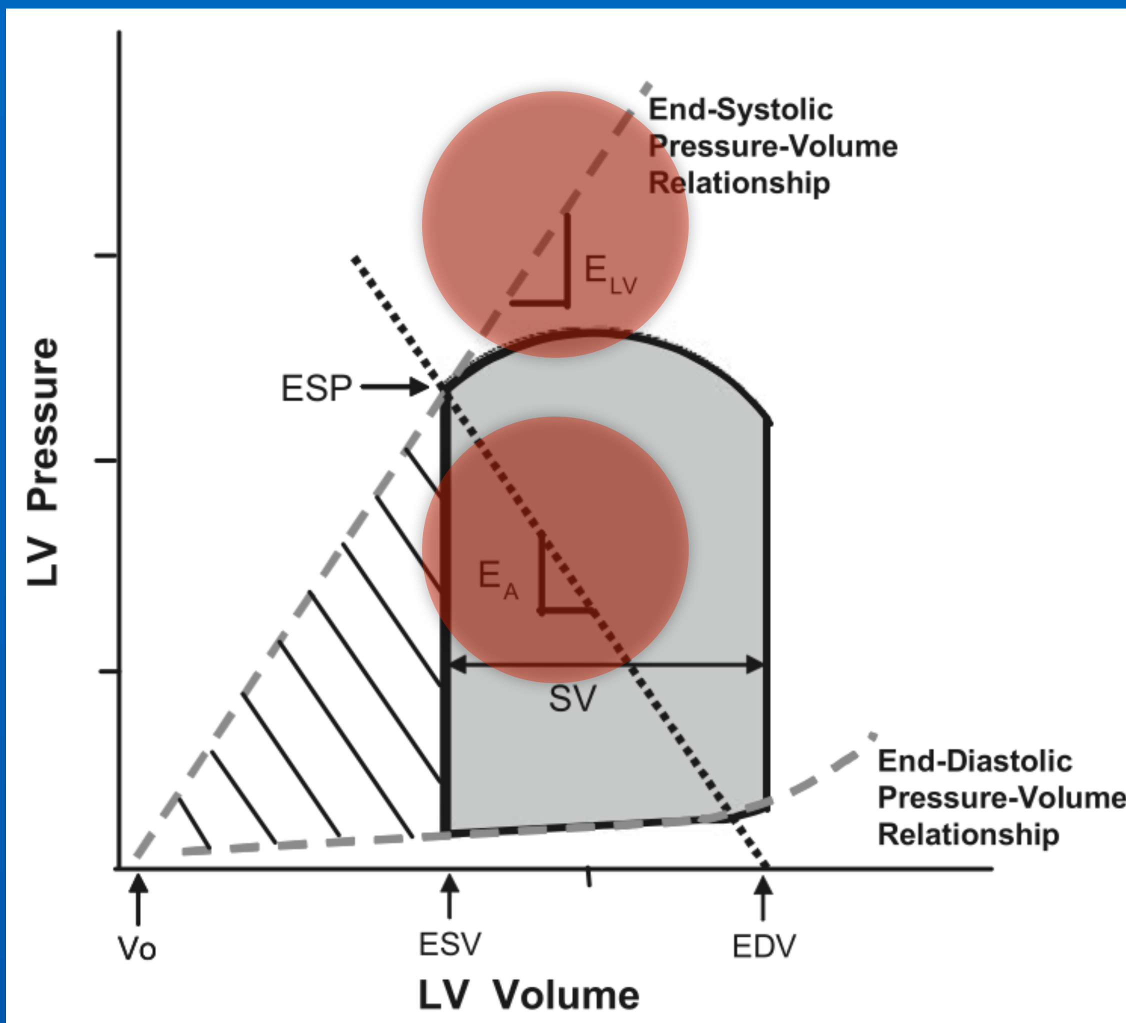
The cardiovascular response to weaning from mechanical ventilation



· Myocardial ischemia
· Valvular insufficiency
· Respiratory acidosis
↓ systolic function
· Myocardial ischemia
· ↓ diastole duration (tachycardia)
↓ diastolic function
↑ afterload
· ↓ intrathoracic pressure
· ↑ systemic arterial pressure (catecholamine secretion)
WEANING FAILURE OF CARDIAC ORIGIN
· ↑ venous return via ↓ intrathoracic pressure and venous constriction (catecholamine secretion)
↑ preload
Septal dyskinesia
RV dilatation via ↑ RV preload (venous return)
and ↑ afterload (pulmonary hypertension)
Fluid overload
History:
-Hypertension
- Heart disease
- COPD...

There is more…

VA Coupling



E_a= ESP / SV

E_{es}= ESP / ESV

Normal Range ~ 1.0 ± 0.36

Normal E_A 2.2 ± 0.8 mmHg / ml
Normal E_{LV} 2.3 ± 1.0 mmHg / ml

Review

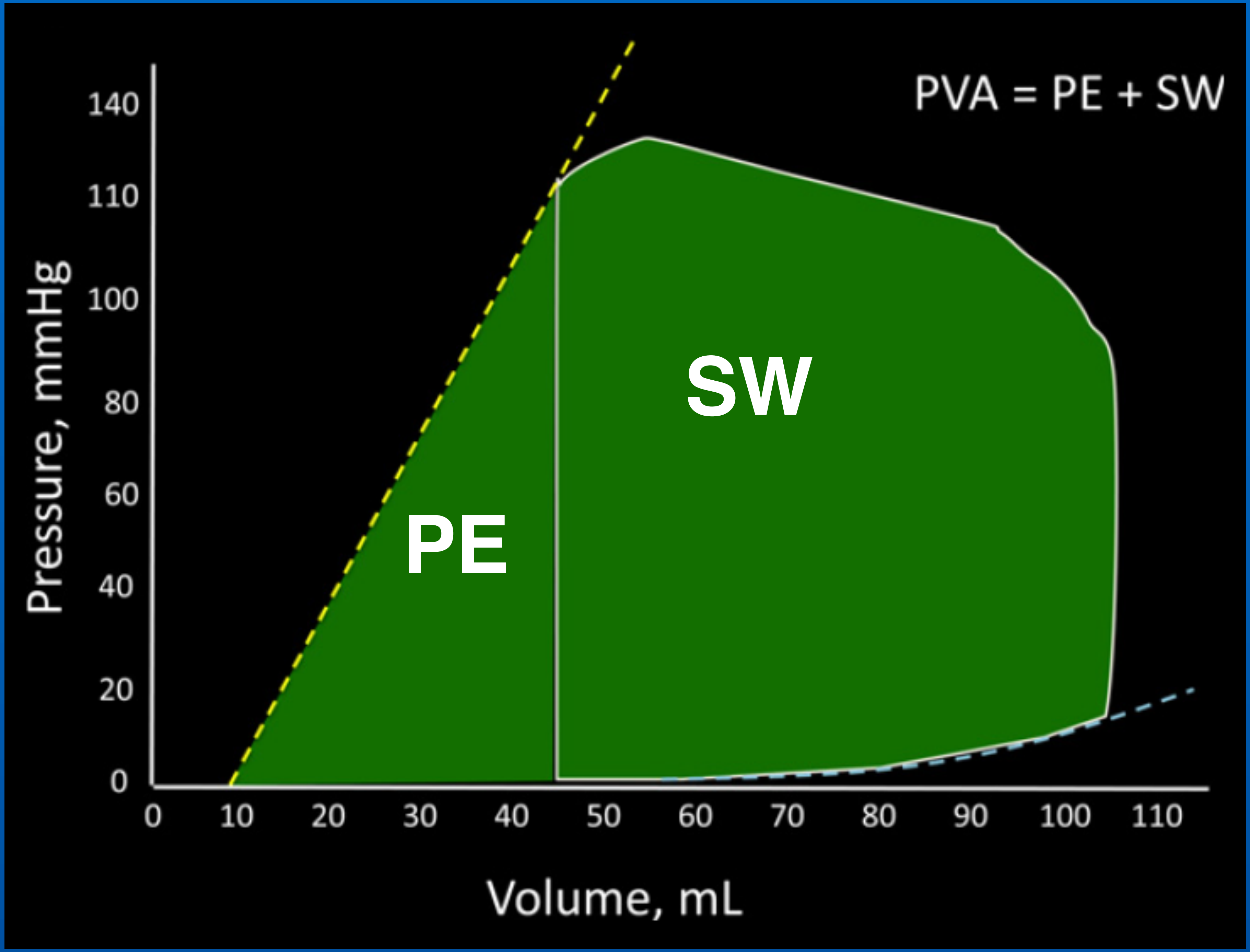
J Appl Physiol 105: 1342–1351, 2008.
First published July 10, 2008; doi:10.1152/japplphysiol.90600.2008.

HIGHLIGHTED TOPIC | *Physiology of the Aging Vasculature*

Arterial-ventricular coupling: mechanistic insights into cardiovascular performance at rest and during exercise

Paul D. Chantler, Edward G. Lakatta, and Samer S. Najjar
Laboratory of Cardiovascular Science, Intramural Research Program, National Institute on Aging, National Institutes of Health, Baltimore, Maryland

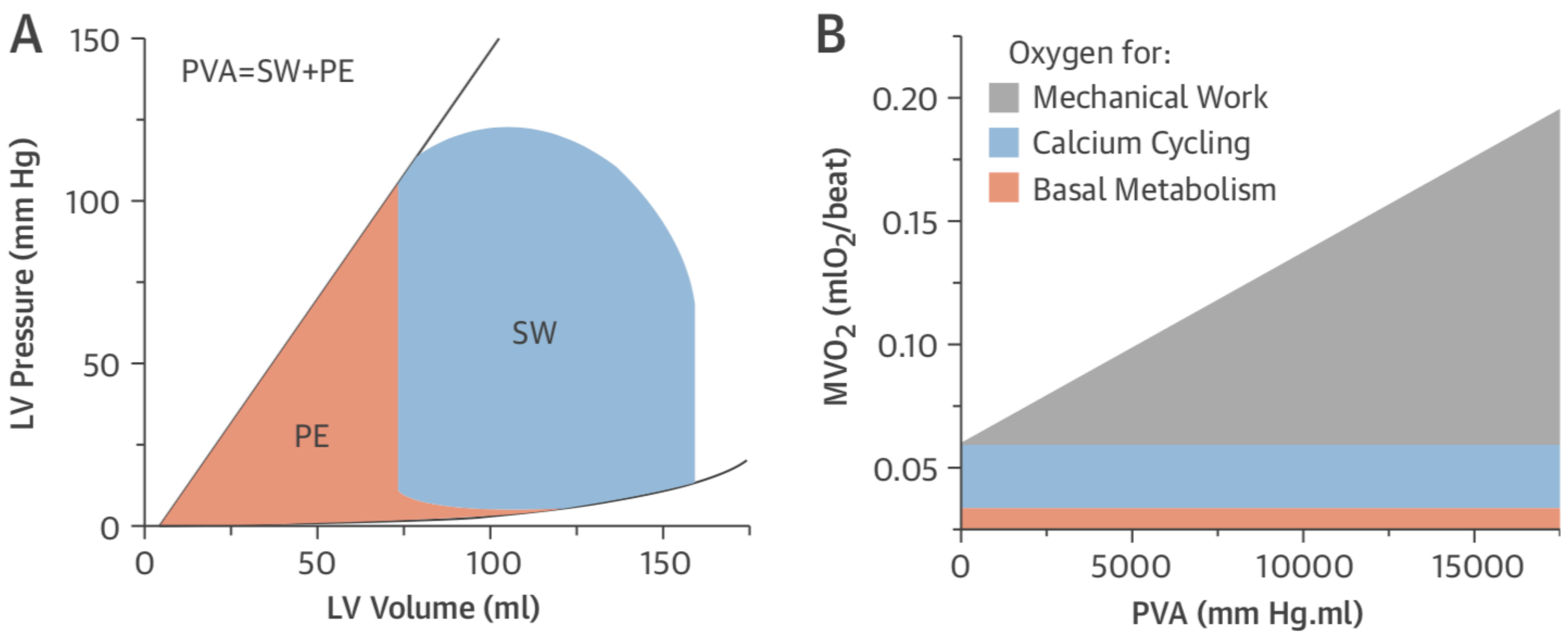
According to the time-varying elastance theory, the PVA represents the total mechanical energy generated by LV contraction until the end of systole.



PVA correlates strongly and linearly with myocardial oxygen consumption (MVO_2) per beat.

SW/PVA $\propto$ LV Efficiency

FIGURE 3 **Myocardial Energetics Assessed on the Pressure-Volume Diagram**

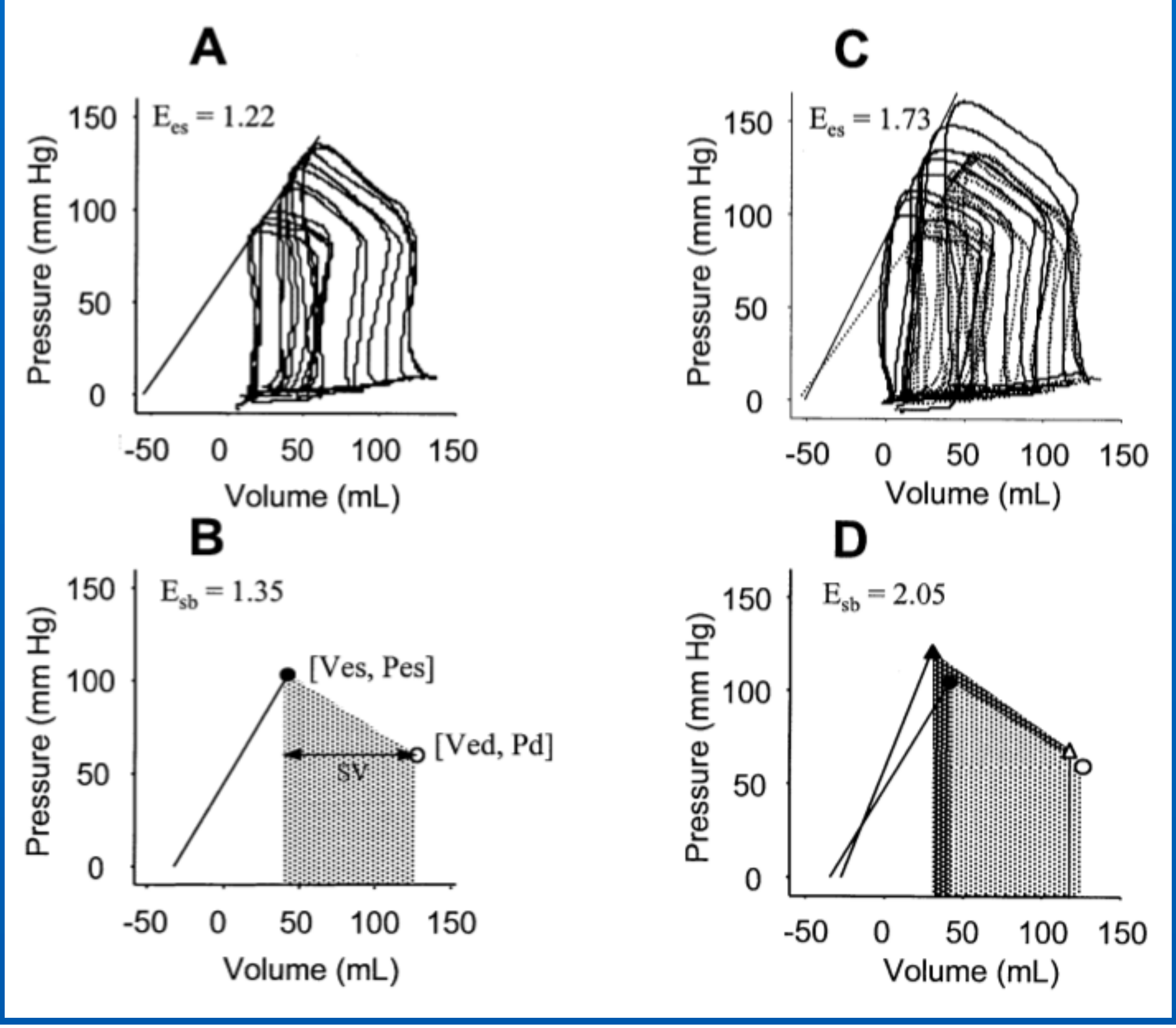


Hemodynamics of Mechanical Circulatory Support

Daniel Burkhoff, MD, PhD,*† Gabriel Sayer, MD,‡ Darshan Doshi, MD,* Nir Uriel, MD‡

JACC JOURNAL CME

VA Coupling



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PII S0735-1097(01)01651-5

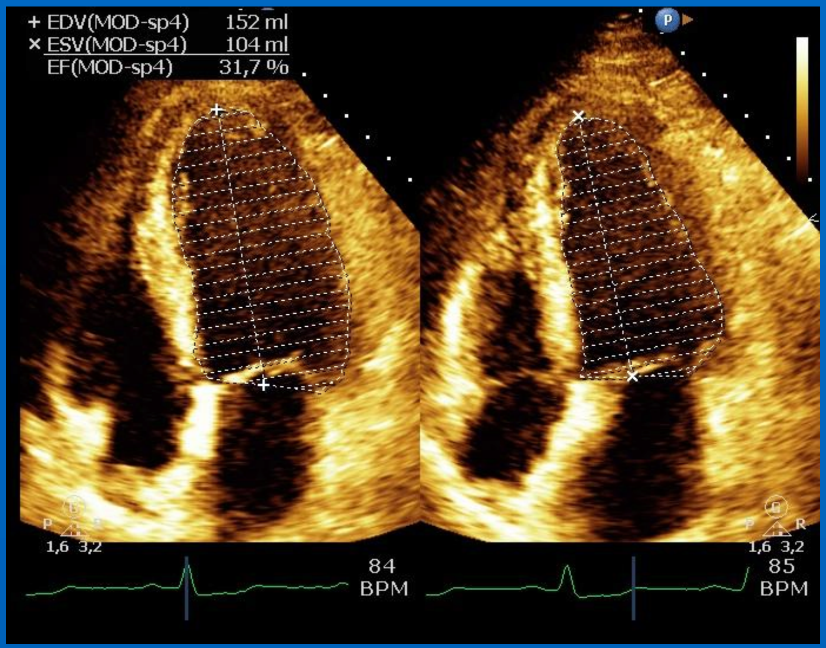
New Methods

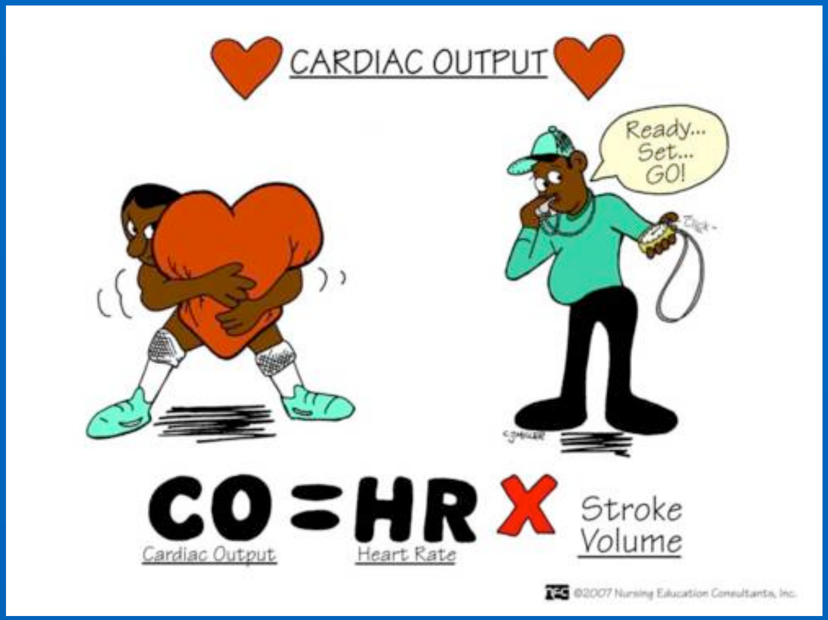
Noninvasive Single-Beat Determination of Left Ventricular End-Systolic Elastance in Humans

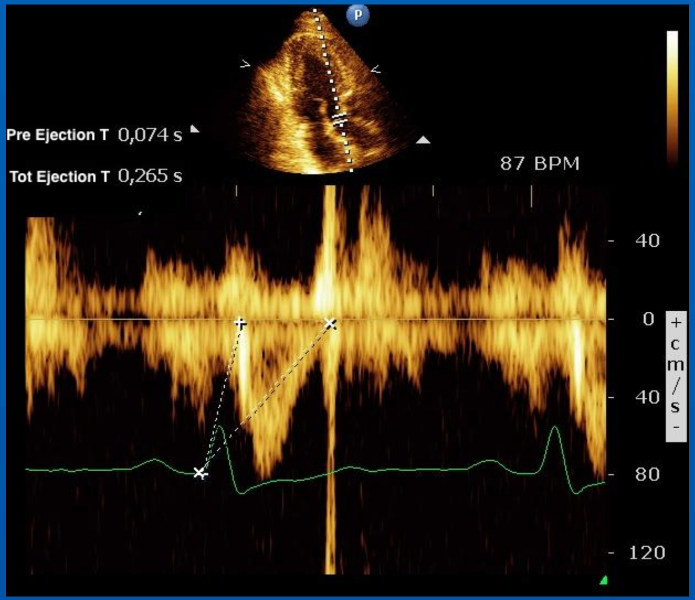
Chen-Huan Chen, MD,*† Barry Fetics, MSE,‡ Erez Nevo, MD, DSc,‡ Carlos E. Rochitte, MD,‡ Kuan-Rau Chiou, MD,*† Phillip Yu-An Ding, MD, PhD,*† Miho Kawaguchi, MD,‡ David A. Kass, MD‡

Taipei, Taiwan; and Baltimore, Maryland

VA Coupling







Guarracino *et al. Cardiovascular Ultrasound* 2013, **11**:13
http://www.cardiovascularultrasound.com/content/11/1/13

CARDIOVASCULAR ULTRASOUND

RESEARCH **Open Access**

Non invasive evaluation of cardiomechanics in patients undergoing MitraClip procedure

Fabio Guarracino[1*], Baldassare Ferro[1,3], Rubia Baldassarri[1], Pietro Bertini[1], Francesco Forfori[1], Cristina Giannini[2], Vitantonio Di Bello[2] and Anna S Petronio[2]

VA Coupling

CALCULATION

$$E_a(Z)=R_T/[t_s+\tau(1-e^{-t_d/\tau})]$$

$$E_a(Z)\approx R_T/T$$

$$E_a(Z)\approx R_T/T=P_{mean}/(CO\cdot T)=P_{mean}/(SV\cdot HR\cdot T)=P_{mean}/SV$$

$$E_a(Z)\approx P_{mean}/SV\approx P_{es}/SV=E_a(PV)$$

Circulation

JOURNAL OF THE AMERICAN HEART ASSOCIATION

American Heart Association

Effective arterial elastance as index of arterial vascular load in humans.

R P Kelly, C T Ting, T M Yang, C P Liu, W L Maughan, M S Chang and D A Kass

Circulation. 1992;86:513-521

$$E_{es(sb)} = [P_d - (E_{Nd(est)} \times P_s \times 0.9)]/[SV \times E_{Nd(est)}]$$

$$E_{Nd(est)} = 0.0275 - 0.165 \times EF + 0.3656 \times (P_d/P_{es}) + 0.515 \times E_{Nd(avg)}$$

$$E_{Nd(avg)} = \sum_{i=0} a_i \times t_{Nd}^{\,i}$$

a_i are (0.35695, −7.2266, 74.249, −307.39, 684.54, −856.92, 571.95, −159.1) for i = 0 to 7

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New Methods

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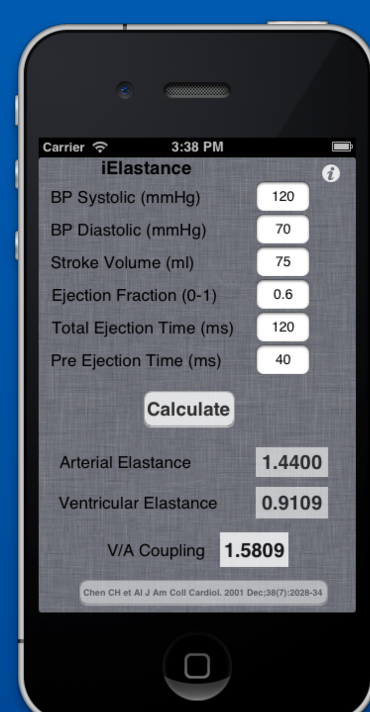
Taipei, Taiwan; and Baltimore, Maryland



RESEARCH **Open Access**

Ventriculoarterial decoupling in human septic shock

Fabio Guarracino[1*], Baldassare Ferro[1], Andrea Morelli[2], Pietro Bertini[1], Rubia Baldassarri[1] and Michael R Pinsky[3]

Septic shock pts   Non septic shock pts

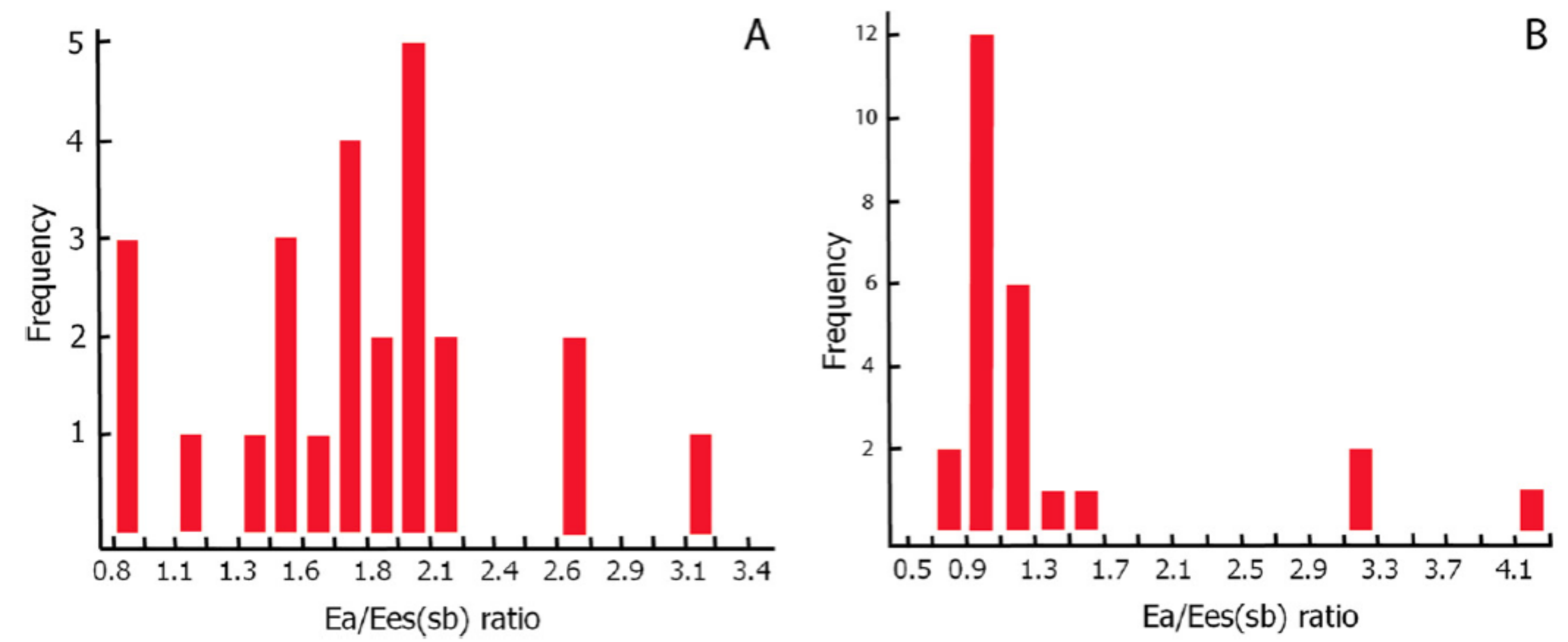


Figure 3 Graphs representing the distribution of ratios of arterial elastance to single-beat end-systolic elastance in newly diagnosed septic shock patients (A) and non–septic shock patients (B).

Critical Care 2014, **18**:R80

CRITICAL CARE

RESEARCH Open Access

Ventriculoarterial decoupling in human septic shock

Fabio Guarracino[1*], Baldassare Ferro[1], Andrea Morelli[2], Pietro Bertini[1], Rubia Baldassarri[1] and Michael R Pinsky[3]

Table 2 Analysis of correlation between ventriculoarterial coupling and left ventricular ejection fraction in septic shock patients[a]

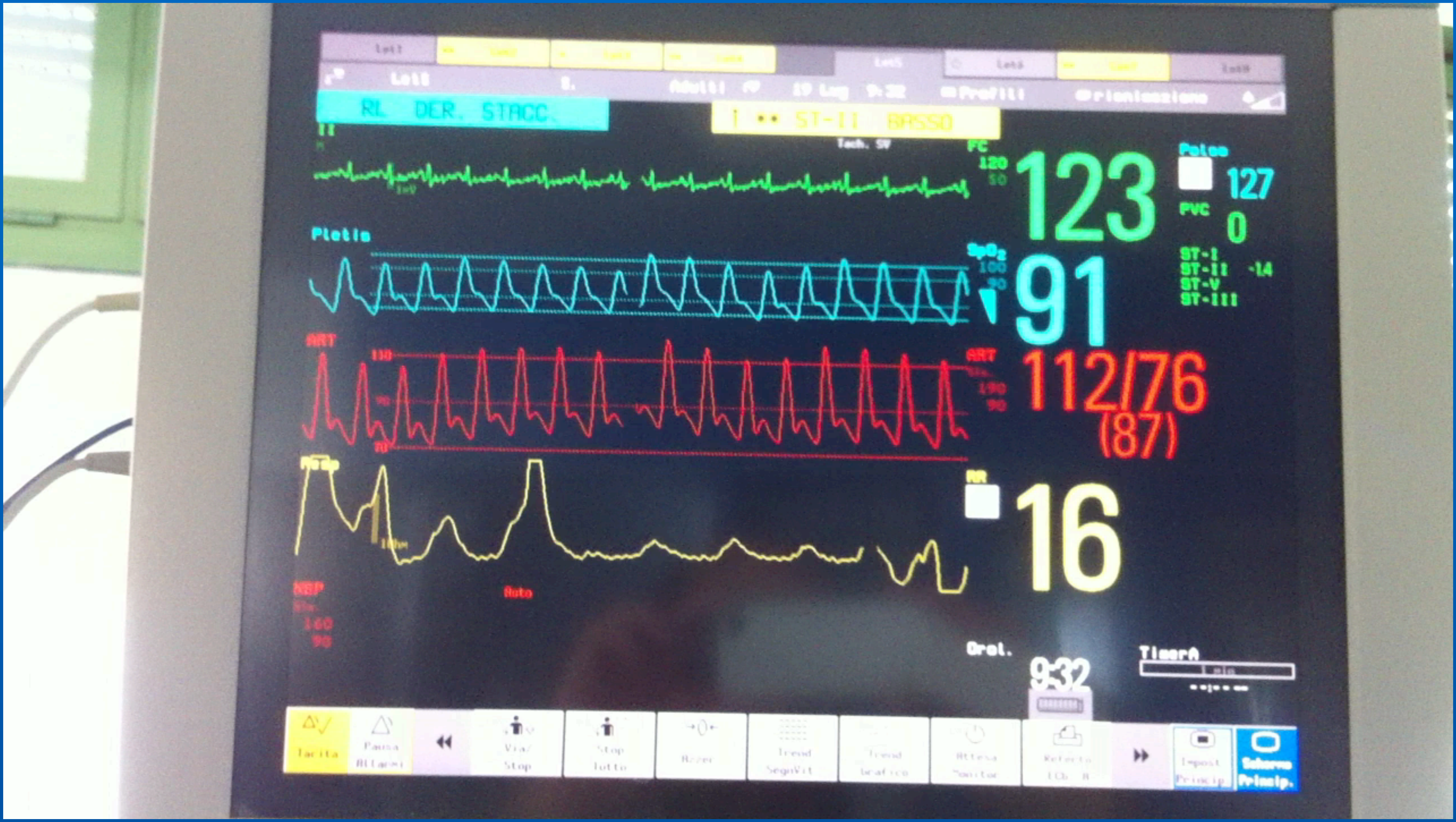
	LVEF normal (≥50%)	LVEF reduced ($<50\%$)
Ea/Ees_{SB} normal (<1.36), *n*	2	2
Ea /Ees_{SB} altered (>1.36), *n*	6	15

[a]*Ea*, Arterial elastance; *Ea/Ees_{SB}*, Single-beat ventriculoarterial coupling; *Ees*, End-systolic elastance; *LVEF*, Left ventricular ejection fraction. $P = 0.5$ by Fisher's exact test.

CRITICAL CARE

Critical Care 2014, **18**:R80

And now?



Full or Empty?