PICCO

Is it a new reference standard for haemodynamic monitoring in ICU?

Puneet Saxena

Outline

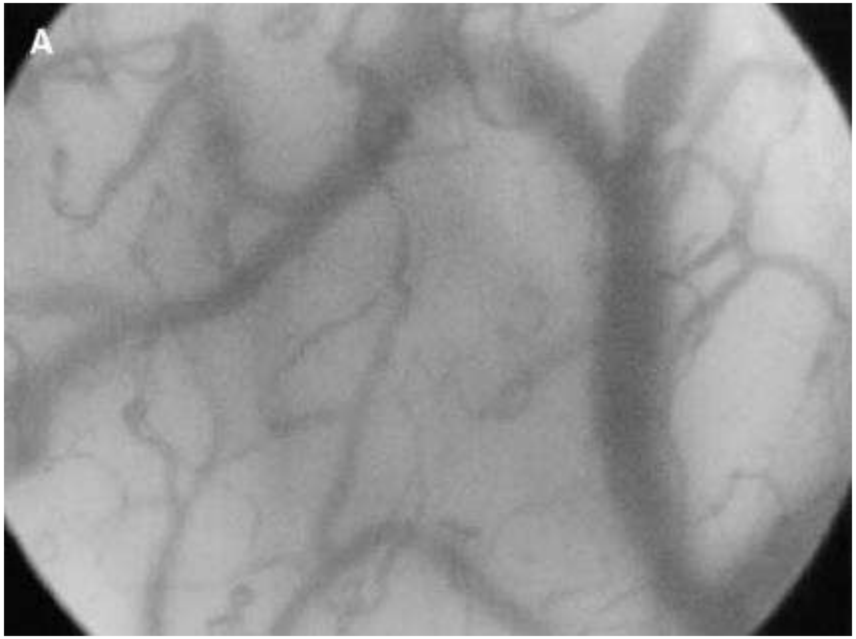
- Backgound
  - Why do we need advanced haemodynamic monitoring
  - Limitations of basic monitoring
- PICCO
  - Set-up
  - Parameters
  - Evidence
- Comparisons

Decision algorithm in a critically ill patient in shock

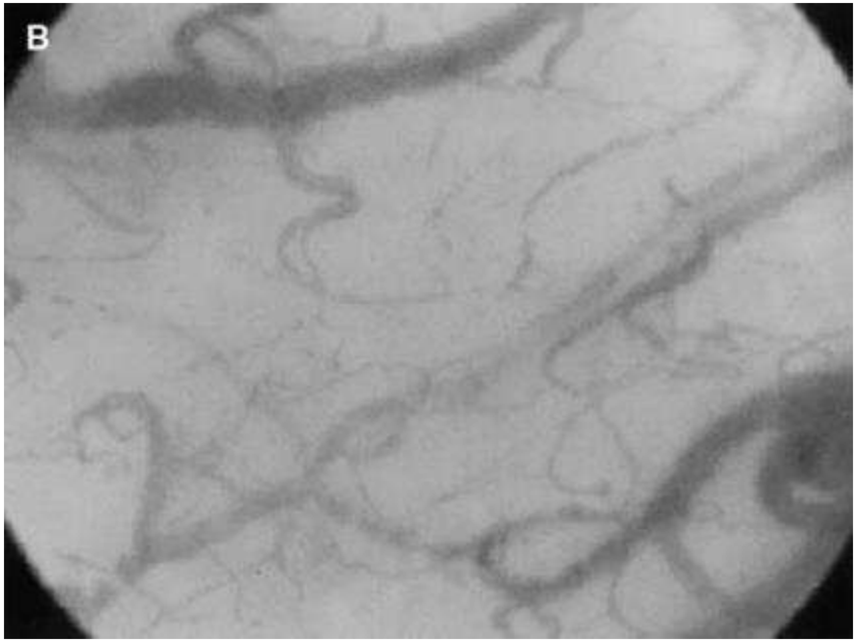
- Fluid responsiveness and volume status
- Maintain MAP
- Cardiac output
- Tissue perfusion

Microcirculation in sepsis

Healthy

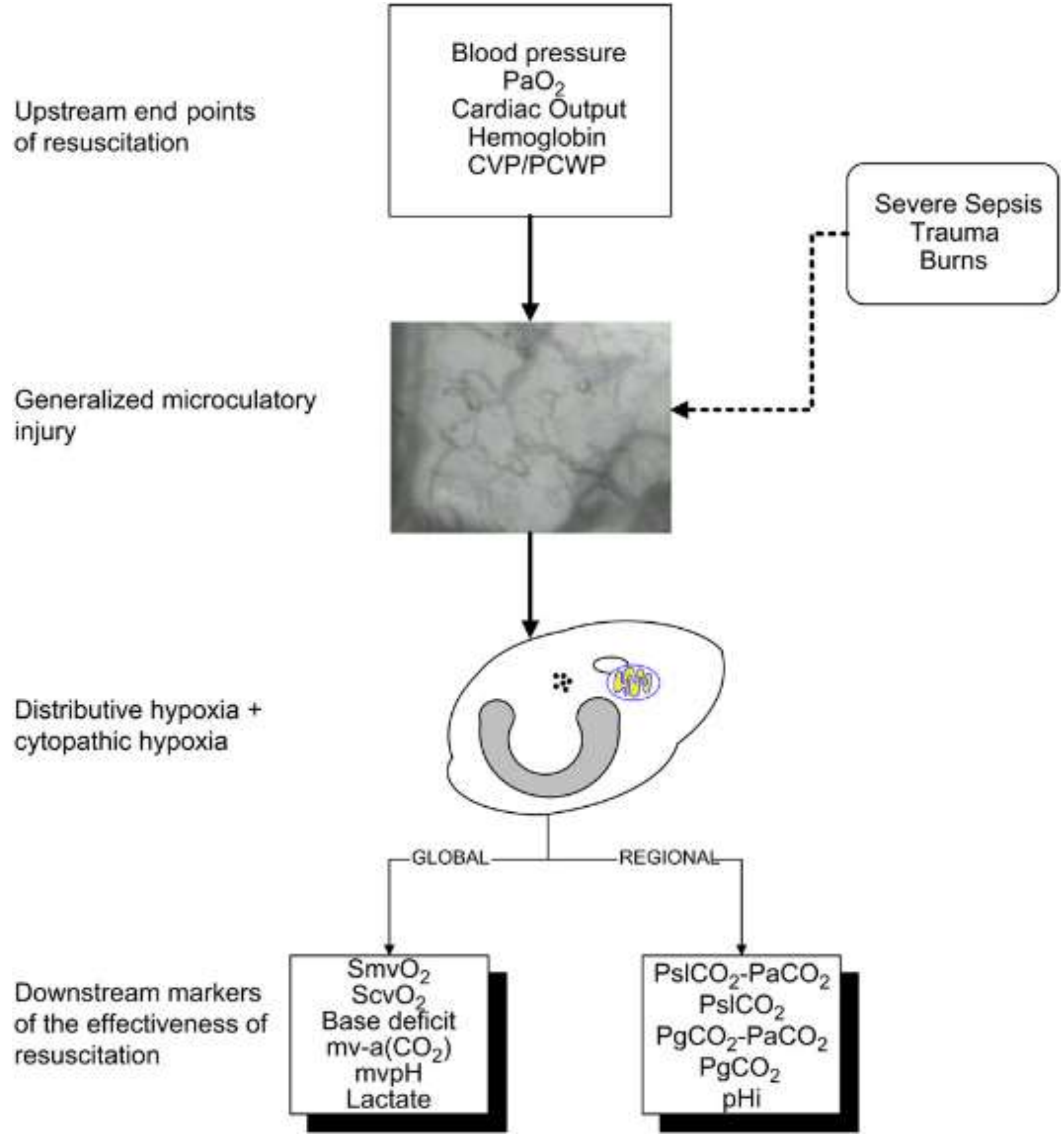


Sepsis



De Backer D et al. Am J Respir Crit Care Med. 2002 Jul 1;166(1):98-104

Upstream and downstream markers



Marik PE et al. Crit Care Clin. 2007 Jul;23(3):383-400.

Decision algorithm in a critically ill patient in shock

- Fluid responsiveness and volume status
- Maintain MAP
- Cardiac output
- Tissue perfusion

PAPER

J R Coll Physicians Edinb 2006; **36**:80–85

Dr Latta of Leith: pioneer in the treatment of cholera by intravenous saline infusion

He described how 'having no precedent to guide me I proceeded with much caution.' His first patient was an elderly woman who had been given 'all the usual remedies' and who had 'apparently reached the last moments of her earthly existence, and now nothing could injure her.' Latta inserted a tube into the basilic vein and injected ounce after ounce of fluid – at first with no visible effect – but then she began to breathe less laboriously and 'soon the sharpened features, and sunken eye, and fallen jaw, pale and cold, bearing the manifest imprint of death's signet, began to glow with returning animation; the pulse returned to the wrist…'. In the space of thirty minutes

N MacGillivr
Retired consultant
Scotland

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ABSTRACT The
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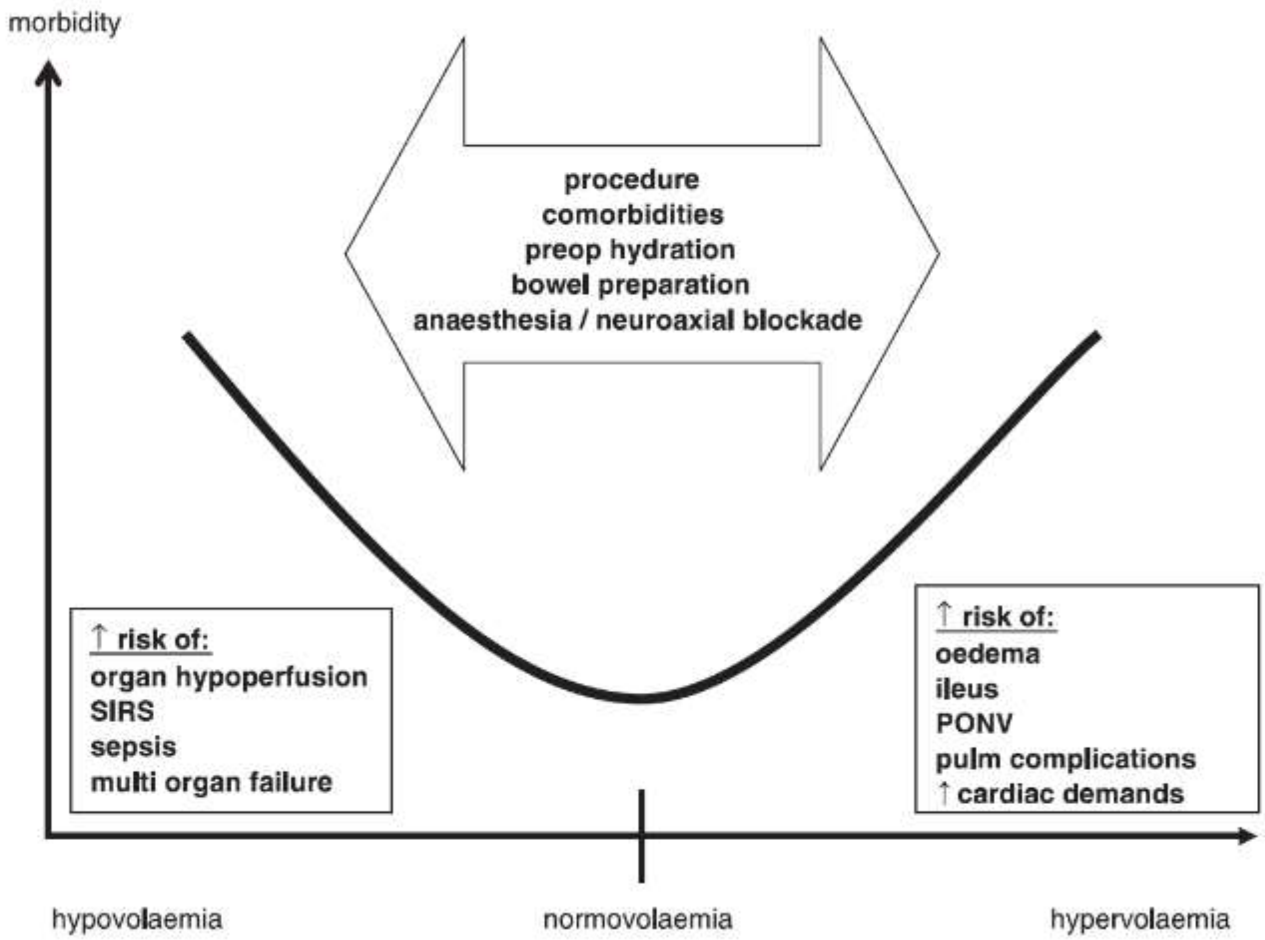
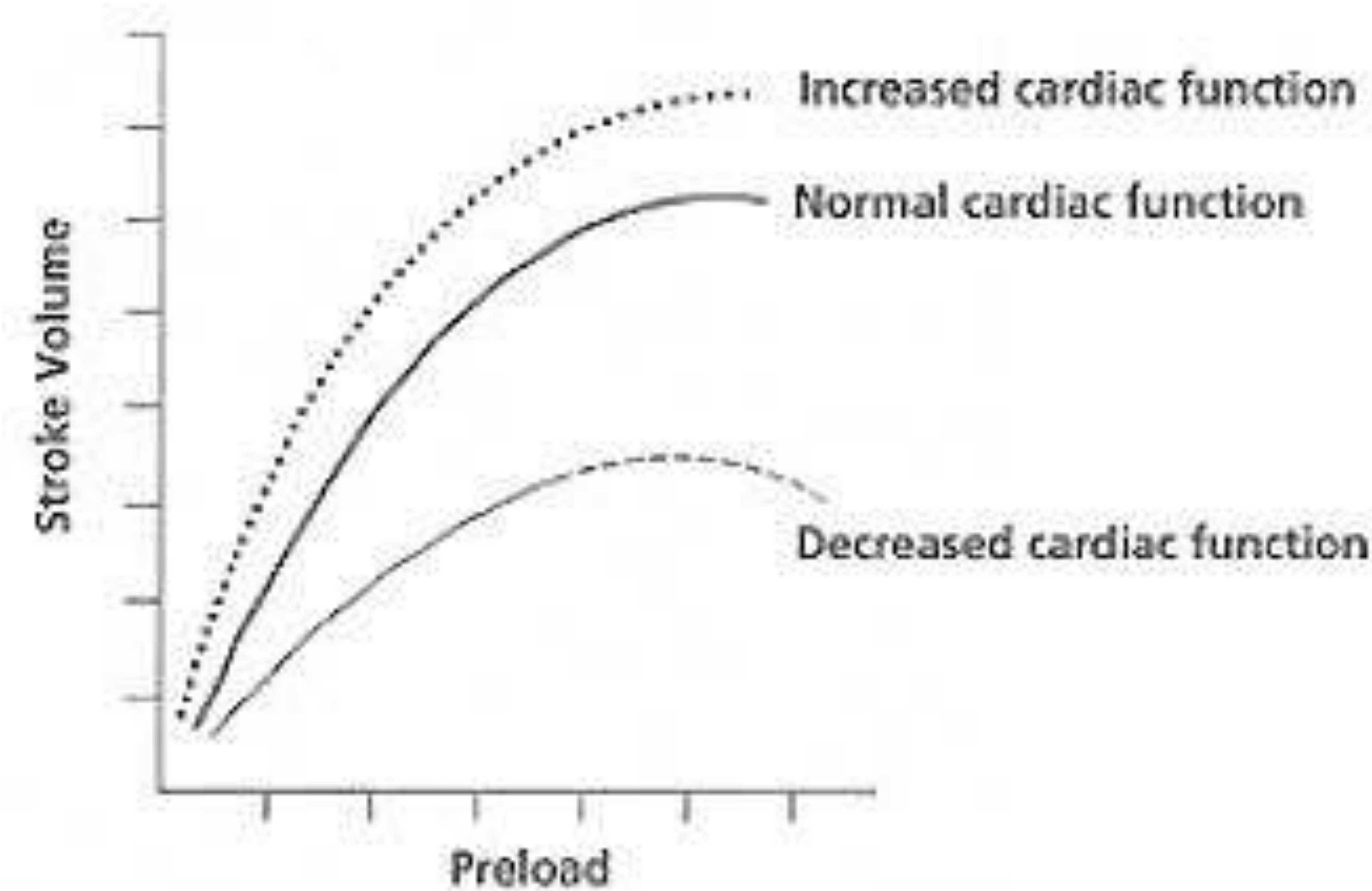
The historiogr
and contempor
In conclusion,
survive his dea

Liberal vs Restrictive

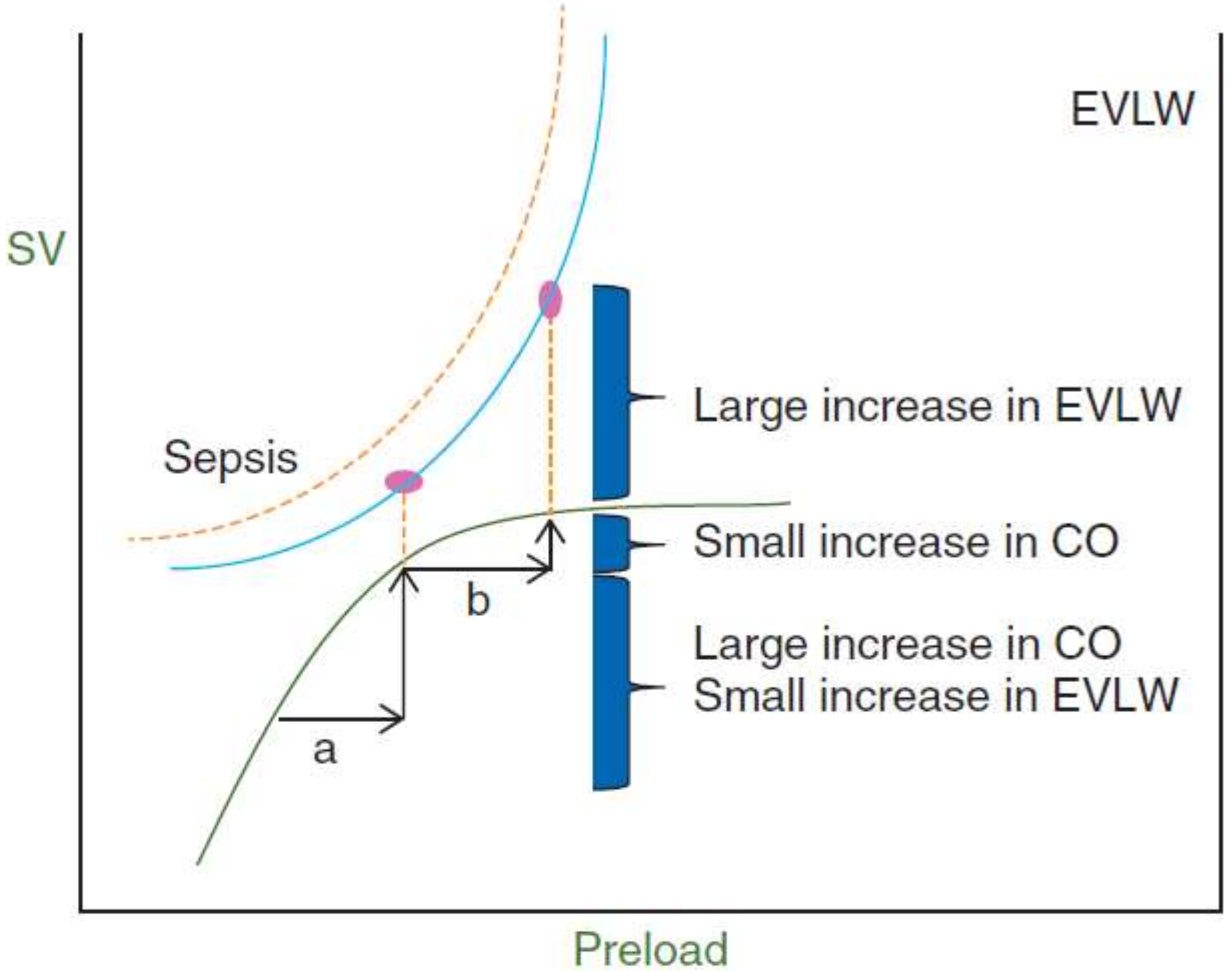


Acta Anaesthesiol Scand. 2009 Aug;53(7):843-51.

Frank-Starling and Marik-Phillips Curves



Frank-Starling and Marik-Phillips Curves



Br J Anaesth. 2016 Mar;116(3):339-49.

Overload states

- High filling pressures
- High venous and capillary pressures
- Release of ANP and BNP
  - Shearing of glycocalyx
  - Decreased lymphatic flow
- Organ edema / Pulmonary edema

De-resuscitation does not help

- Retrospective review of patients admitted to the MICU
- High-dose furosemide is associated with ICU mortality in critically ill patients.
- High-dose furosemide is associated with mortality, regardless of positive fluid balance, particularly in non-oliguric patients.

Lee SJ et al. J Crit Care. 2017;41:36-41.

Techniques for assessing fluid responsiveness

- Static pressure and volume parameters (ROC 0.5–0.6)
  - CVP
  - PAOP
  - IVC/SVC diameter
  - Flow corrected time
  - Right ventricular end-diastolic volume
  - Left ventricular end-diastolic volume
- Dynamic techniques based on heart–lung interactions during mechanical ventilation (ROC 0.7–0.8)
  - SVC/IVC variation during mechanical ventilation
  - PPV
  - SVV
  - Pleth variability index
  - Aortic blood flow (Doppler or echocardiography)
- Techniques based on real or virtual fluid challenge (ROC 0.9)
  - PLR
  - Rapid fluid challenge (100–250 cc)

Br J Anaesth. 2016 Mar;116(3):339-49.

Limitations of CVC and PAC

Inconsistent prediction of fluid responsiveness

- Poor predictive value for predicting fluid responsiveness
  - arbitrarily defined as an increase of at least 15% in CO in response to a 500 mL bolus fluid challenge
- CVP is affected by a number of other physiologic derangements
  - valvular regurgitation
  - right ventricular dysfunction
  - pulmonary hypertension
  - variation in intrathoracic pressure with respiration

Pinsky M. Curr Opin Crit Care. 2014; 20(3): 288–293

CHEST

Special Feature

Does Central Venous Pressure Predict Fluid Responsiveness?*

A Systematic Review of the Literature and the Tale of Seven Mares

Paul E. Marik, MD, FCCP; Michael Baram, MD, FCCP; and Bobbak Vahid, MD

- the relationship between CVP and blood volume
- ability of Δ CVP to predict fluid responsiveness

- 24 (5+19) studies (800 patients) were analysed

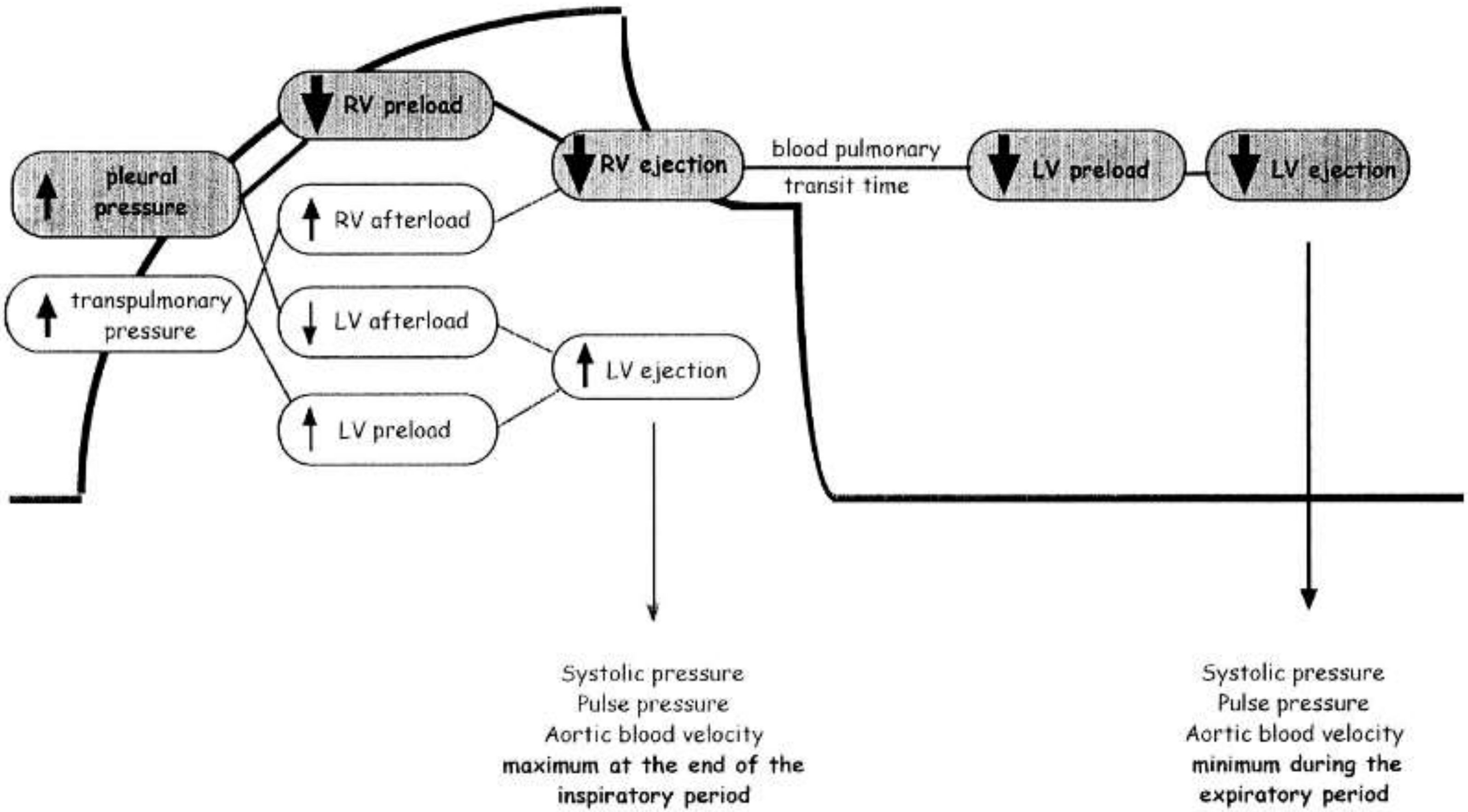
Marik et al. Chest. 2008; 134:172–178

Results

- Correlation coefficient between CVP and measured blood volume
  - 0.16 (95% CI, 0.03 to 0.28)
- Correlation coefficient between baseline CVP and change in stroke index/cardiac index
  - 0.18 (95% CI, 0.08 to 0.28)
- Area under the ROC curve
  - 0.56 (95% CI, 0.51 to 0.61)
- Correlation between Δ CVP and change in stroke index/cardiac index
  - 0.11 (95% CI, 0.015 to 0.21)
- Baseline CVP :
  - 8.7 ±2.32 mm Hg in the responders vs 9.7 ± 2.2 mm Hg in non-responders (not significant)

Marik et al. Chest. 2008; 134:172–178

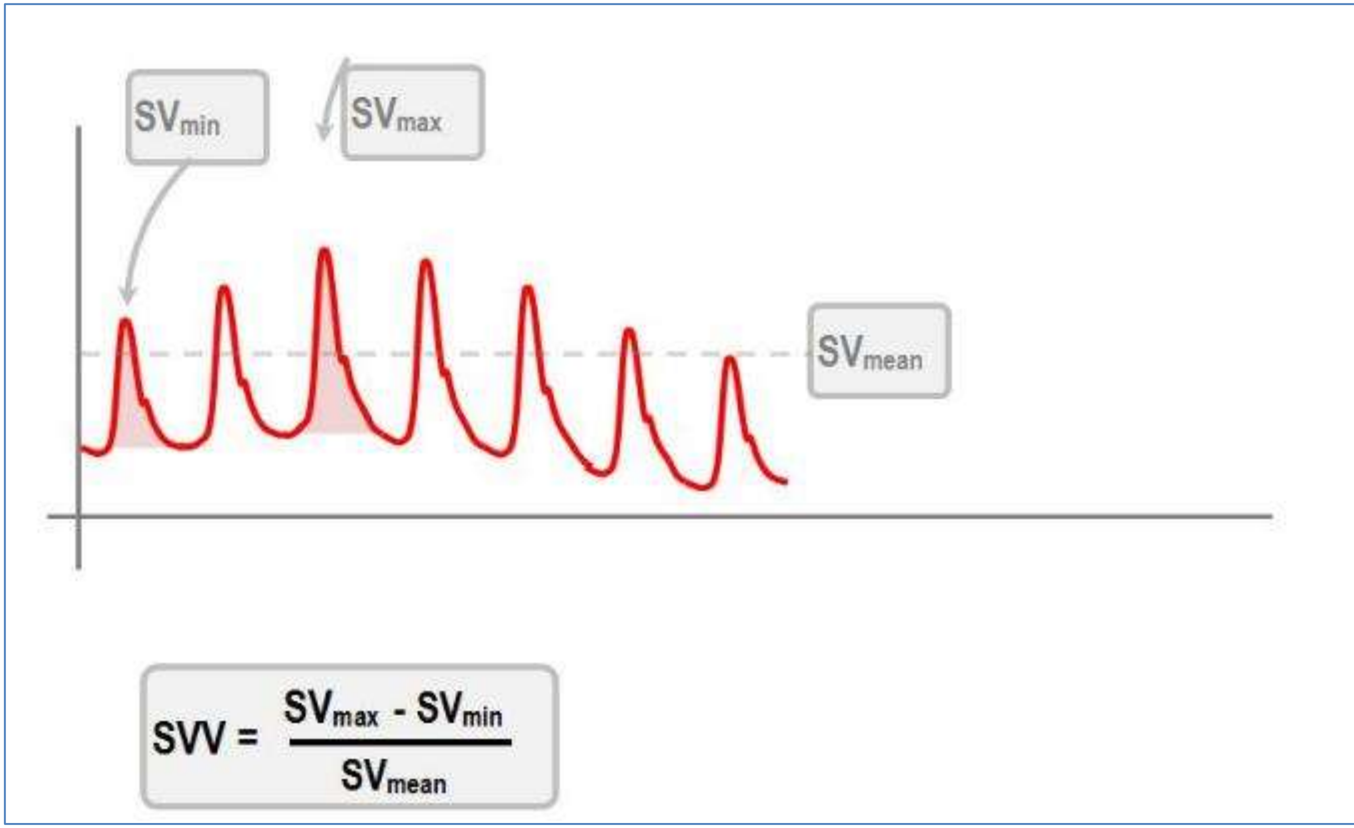
Heart-Lung Interaction



Michard F et al. Crit Care. 2000; 4(5): 282–289.

Pulse contour analysis (fluid responsiveness)

- PPV
- SVV
- PVI



Pulse pressure variation (PPV)

- Position on the Frank-Starling Curve
- $PPV = 100 \times (PP_{max} – PP_{min})/PP_{mean}$
- PPV ≥13 to 15 % strongly associated with volume responsiveness
- Limited to patients who are
  - mechanically ventilated
  - ≥8 mL/kg of tidal volume
  - sinus rhythm
  - **not** spontaneously triggering the ventilator
- IAH doesn’t affect the interpretation

Pinsky MR. Curr Opin Crit Care. 2014 Jun;20(3):288-93

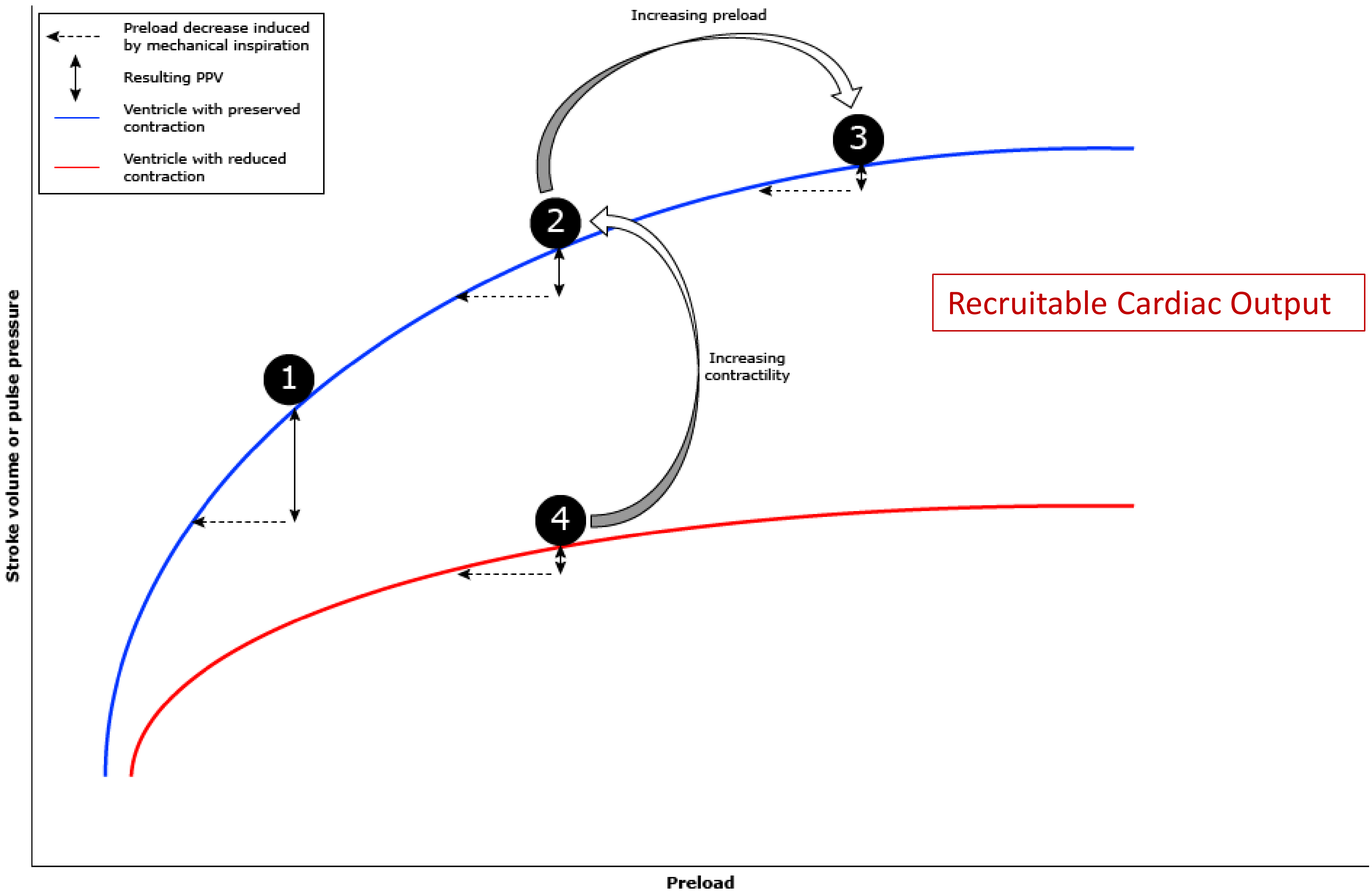
Stroke volume variation (SVV)

- Same physiologic principle as PPV
- $SVV = 100 \times (SV_{max} - SV_{min})/SV_{mean}$
- SVV >10 percent is associated with fluid responsiveness (Sens and sp 94%)
- Same limitations as PPV

Biais M et al. Br J Anaesth. 2008;101(6):761-8.

Oximetric waveform variation

- Pleth Variability Index (PVI) : an automated algorithm that has been shown to modestly predict fluid responsiveness in the operating room
- Not validated for ICU and ER use



Recruitable Cardiac Output

Michard F et al. Crit Care 2007; 11:131

Limitations of PPV/SVV

- Regular cardiac rhythm
- Controlled mechanical ventilation in the absence of spontaneous breathing
- Vt≥8 ml/kg of ideal body weight (IBW)
- HR to RR ratio >3.6
- Total respiratory system compliance (C_{TRS}) >30ml/cm H2O
- Tricuspid annular peak systolic velocity (St) >0.15m/s

Mahjoub Y et al. Br J Anaesth. 2014 Apr;112(4):681-5

Evaluation of pulse pressure variation validity criteria in critically ill patients: a prospective observational multicentre point-prevalence study†

- Prospective, observational, point-prevalence study was performed in 26 French intensive care units (ICUs)
- Only six (2%)patients satisfied all validity criteria
- Only 1 patient (4%) of those assessed for fluid responsiveness satisfied the criteria

Mahjoub Y et al. Br J Anaesth. 2014 Apr;112(4):681-5

Provocative maneuvers

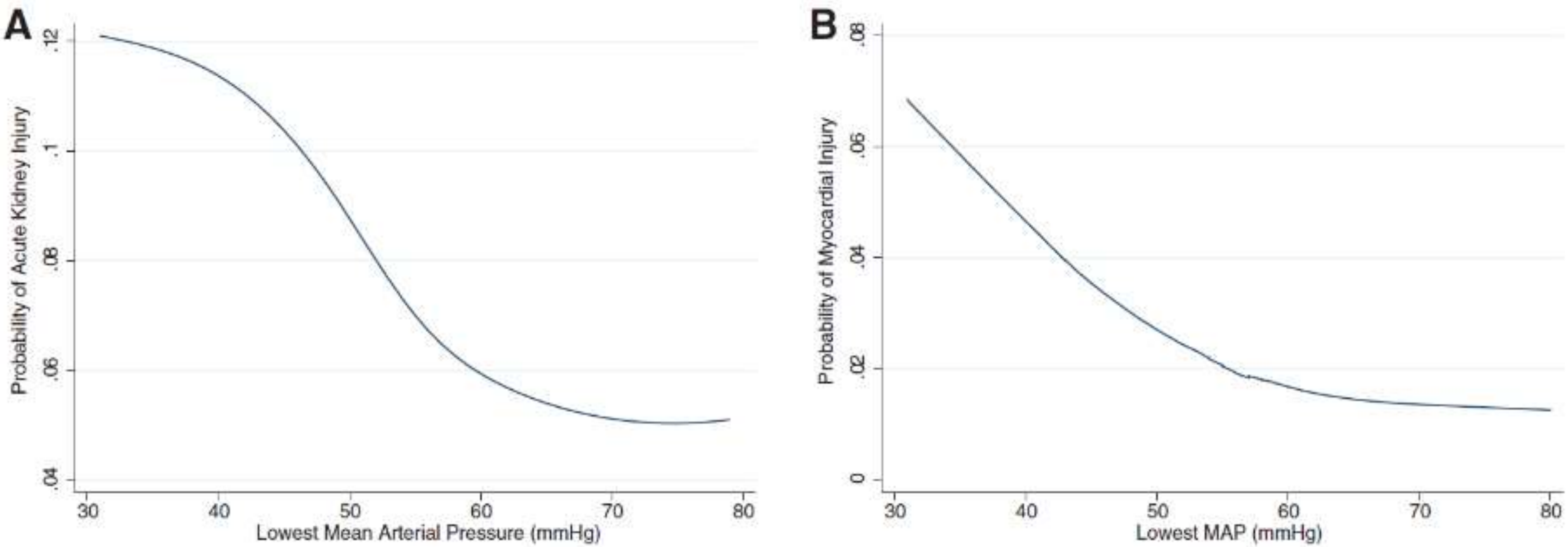
- **Intravenous fluid bolus** –small "test" bolus of IV fluid (250 to 500 mL administered over 5 to 10 minutes)

- **Passive leg raising (PLR)** –bolus of the patient's own intravascular blood from the capacitance veins of the lower extremities into the thorax

Point-of-care bedside ultrasonography (POCUS)

- Vena cava assessment
  - Diameter should be measured approximately 2 cm from the junction of the IVC and RA
  - Change in IVC diameter with respiration of 12 to 18 % has been associated with fluid responsiveness in mechanically ventilated patients
  - Several limitations
- Lung ultrasonography
- Point-of-care echocardiography
- Femoral vein diameter

Clinical outcomes and MAP

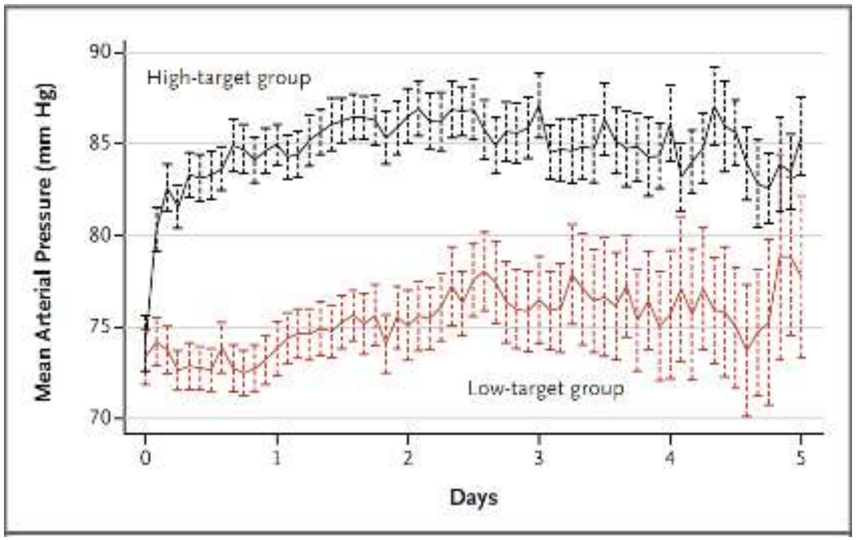


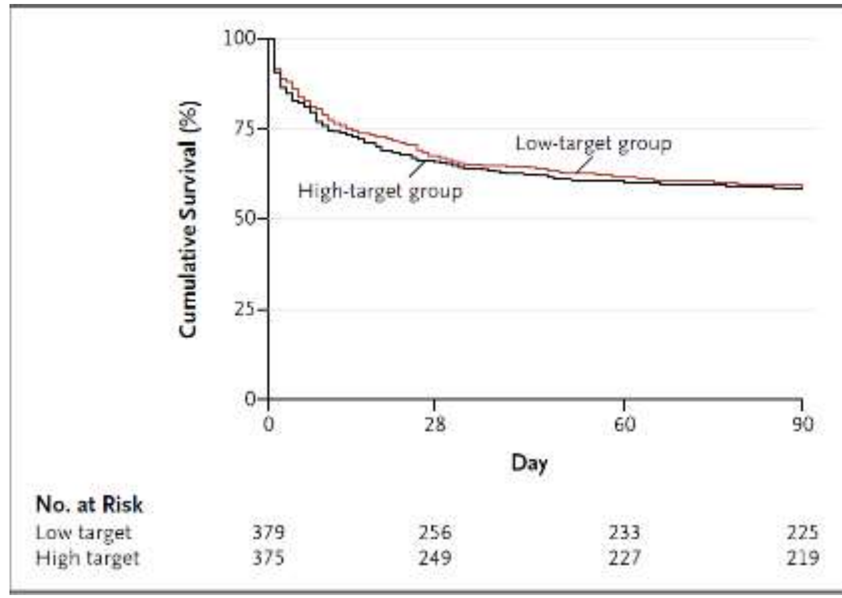
Anesthesiology 2013; 119:507-15

The NEW ENGLAND JOURNAL of MEDICINE

ESTABLISHED IN 1812 APRIL 24, 2014 VOL. 370 NO. 17

High versus Low Blood-Pressure Target in Patients with Septic Shock

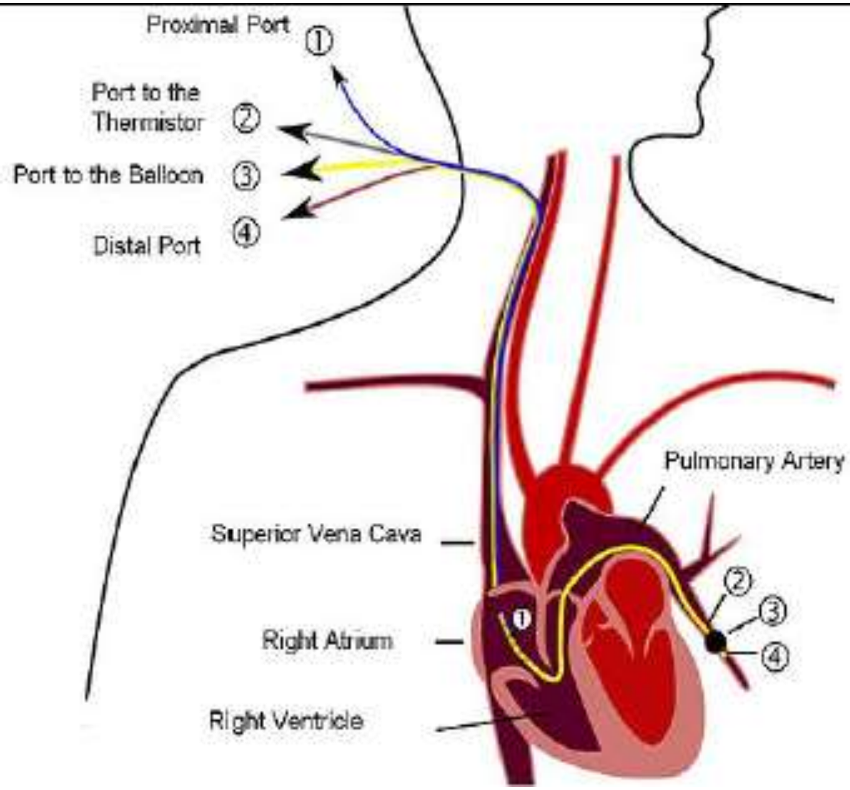




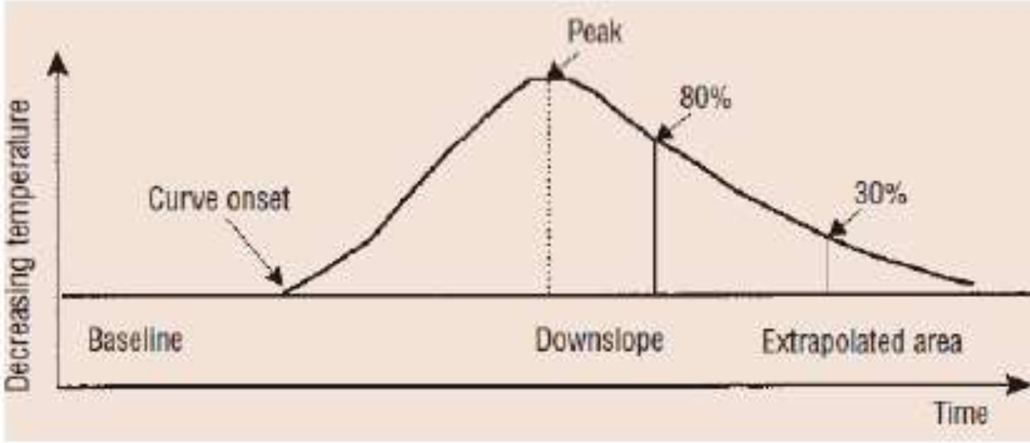
N Engl J Med 2014;370:1583-93

CARDIAC OUTPUT

- PAC
- Pulse Contour analysis
- Bioimpedance and Bioreactance
- Aortic doppler



Pulmonary thermodilution (P-TD) with a PAC



Stewart-Hamilton Formula

Sources of error

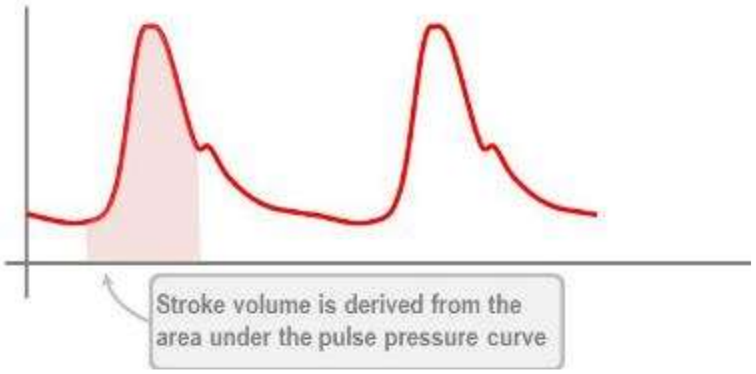
- Loss of indicator prior to, during or after injection
- Cyclic changes in cardiac output
- Transient lowering of the heart rate during cold indicator injection
- Recirculation and detainment of indicator
- Tricuspid regurgitation
- Fluctuations in baseline temperature
- Truncation and extrapolation of TD curves

Limitations of PAC Thermodilution

- Intrinsic limitation of the reproducibility of measurements.
  - Precision around 20%
- Inherent limits on the frequency and number of measurements
- Complications associated with placement and presence of a PAC
- Not real-time

Pulse contour analysis

- Arterial Waveform Analysis
- Transpulmonary thermodilution
- Lithium dilution



Arterial waveform-based devices

LiDCO

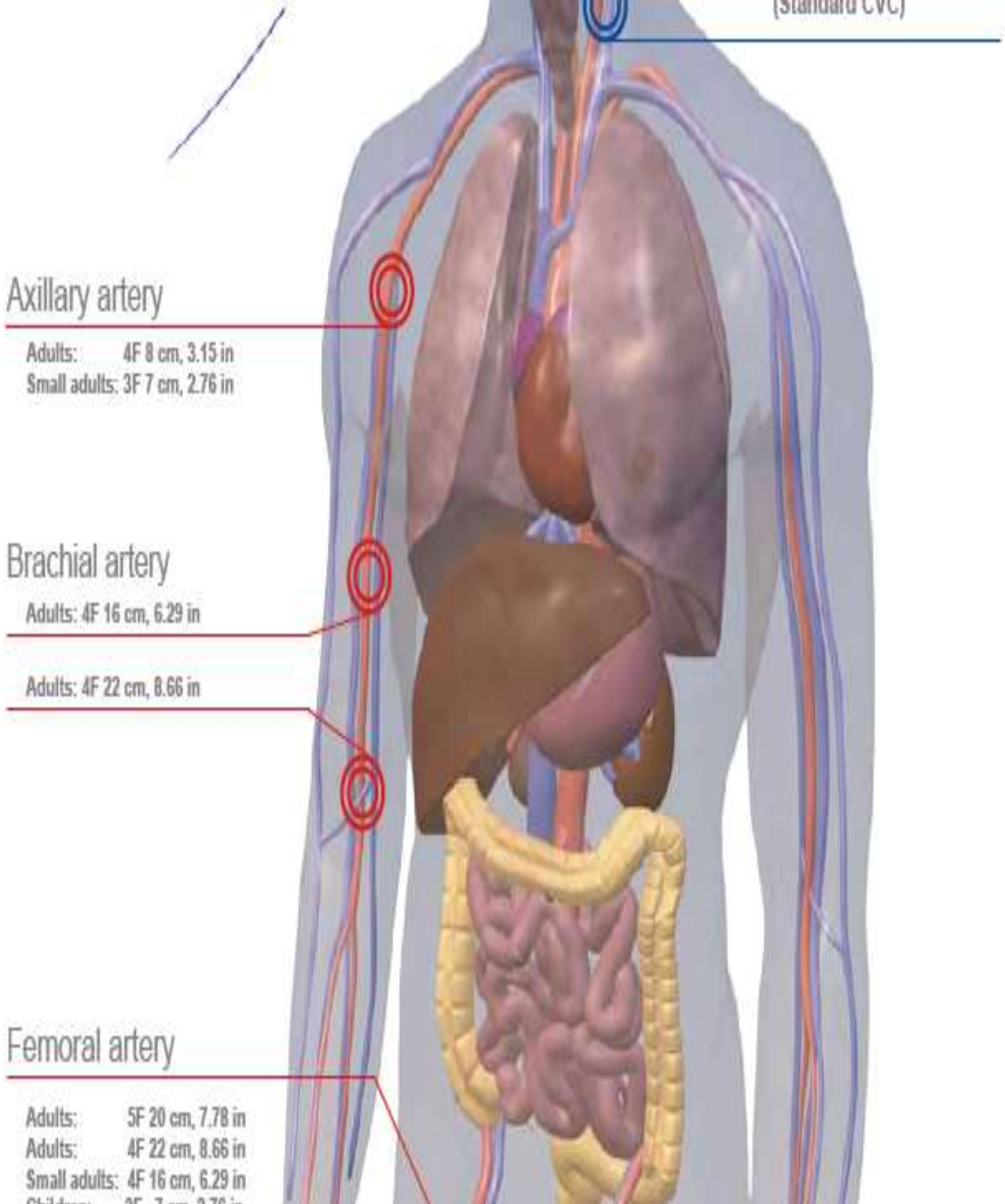
- LiCl: 0.002mmol/l injected into central vein (peripheral administration possible as well)
- Arterial plasma conc. measured by withdrawing blood across lithium selective electrode at 4ml/min
- CO calculated from Li dose and area under primary concentration-time curve before re-circulation

Cardiac Output = (Lithium Dose x 60)/(Area x (1-PCV))

PCV is packed cell volume which may be calculated as hemoglobin concentration (g/dl) / 34

Thermodilution-based devices

PICCO


(Standard CVC)
Axillary artery
Adults: 4F 8 cm, 3.15 in
Small adults: 3F 7 cm, 2.76 in
Brachial artery
Adults: 4F 16 cm, 6.29 in
Adults: 4F 22 cm, 8.66 in
Femoral artery
Adults: 5F 20 cm, 7.78 in
Adults: 4F 22 cm, 8.66 in
Small adults: 4F 16 cm, 6.29 in

Two methods combined for precise monitoring

Transpulmonary thermodilution	Pulse contour analysis

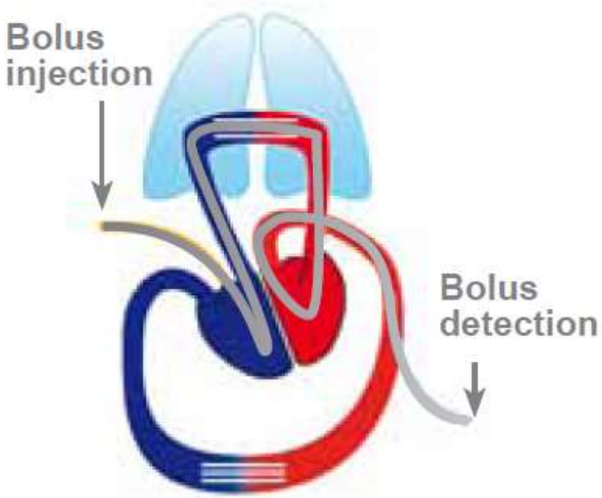
Transpulmonary thermodilution:

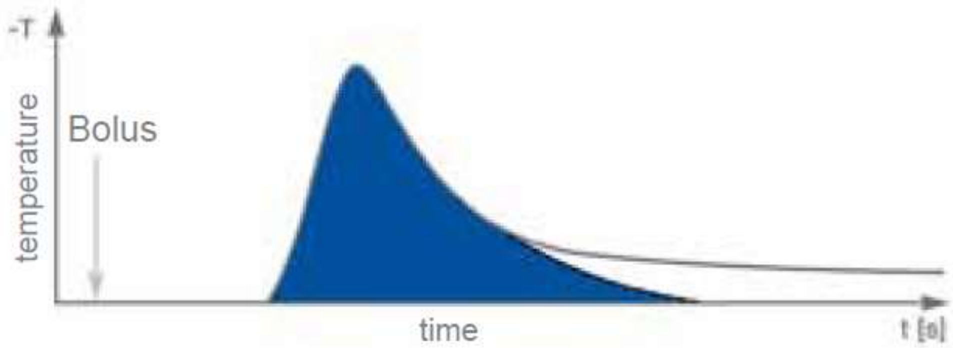
- Thermodilution cardiac output
- Volumetric preload (GEDV - Global End-Diastolic Volume)
- Contractility (CFI - Cardiac Function Index)
- Lung water (EVLW - Extravascular Lung Water)

Pulse contour analysis:

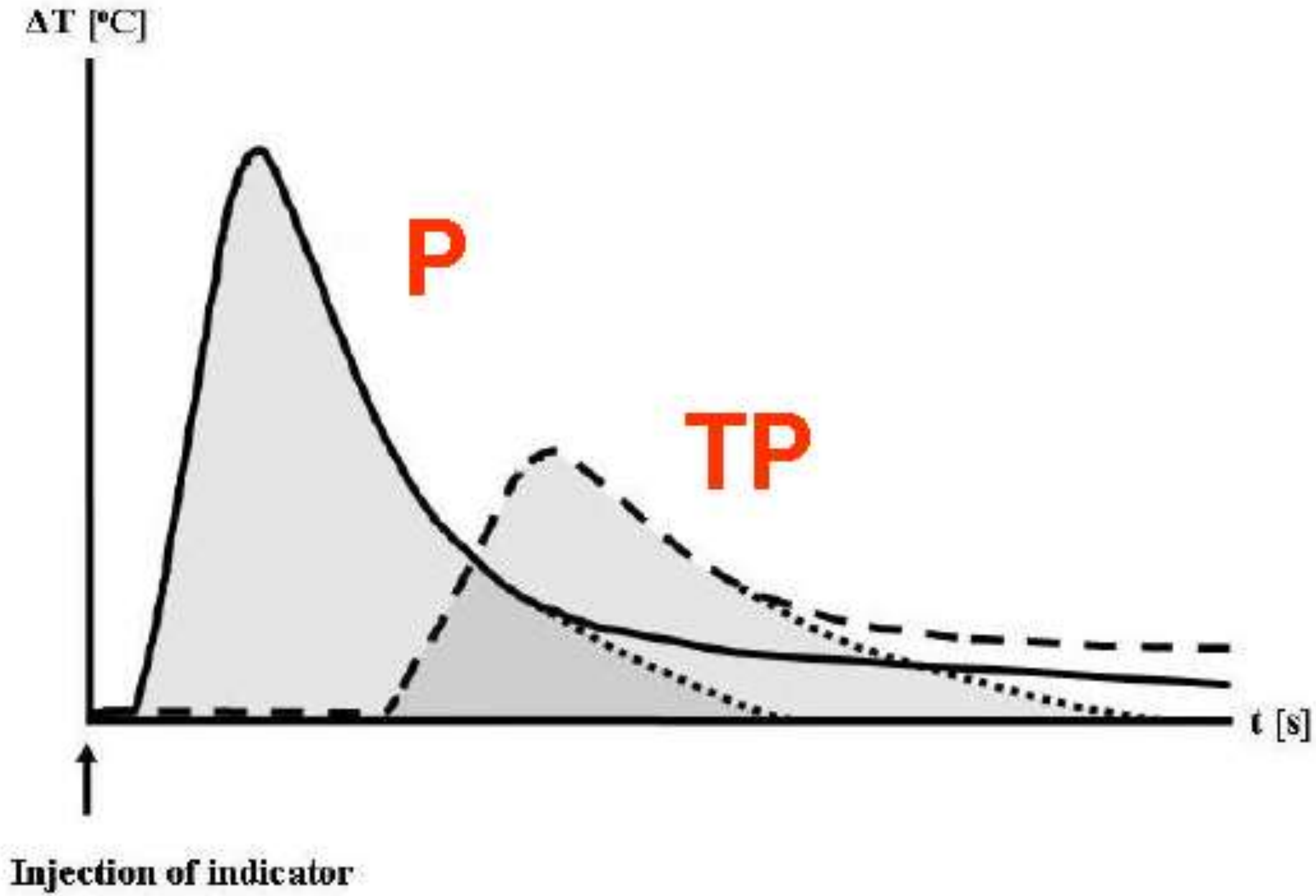
- Continuous cardiac output
- Afterload (SVR - Systemic Vascular Resistance)
- Stroke Volume (SV - Stroke Volume)
- Volume responsiveness (SVV , PPV)

Thermodilution



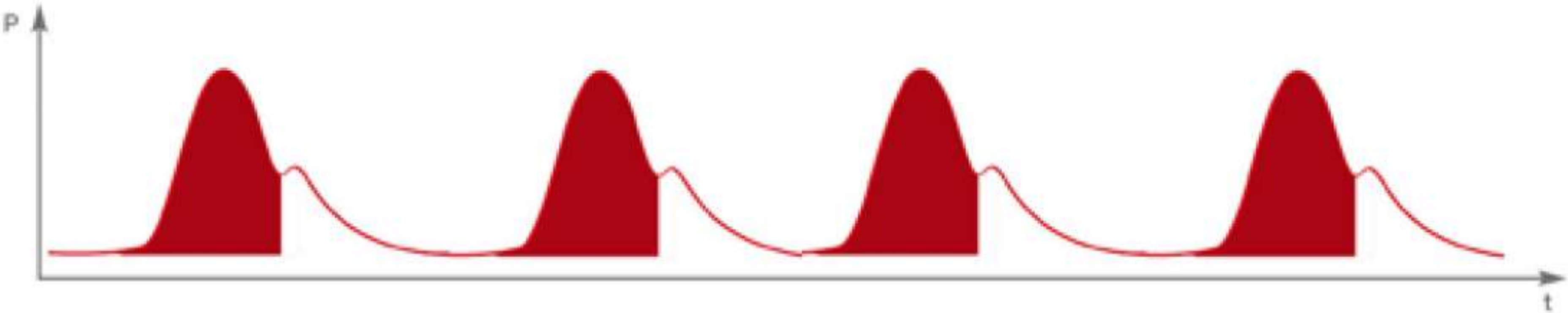


- The cold indicator passes through the right heart, lungs and left heart
- The indicator is detected in a central artery
- Precise cardiac output measurement based on Stewart-Hamilton algorithm
- Breathing cycle independent
- Passage through the heart and lungs allows determination of preload volumes and lung water



- The pulmonary artery TD curve appears earlier and has a higher peak temperature than the femoral artery TD curve.
- Thereafter, both curves soon re-approximate baseline

Pulse contour analysis



- Stroke volume is reflected by the area under the systolic part of the pressure curve of one heart beat
- Cardiac output is calculated beat-by-beat: stroke volume x heart rate

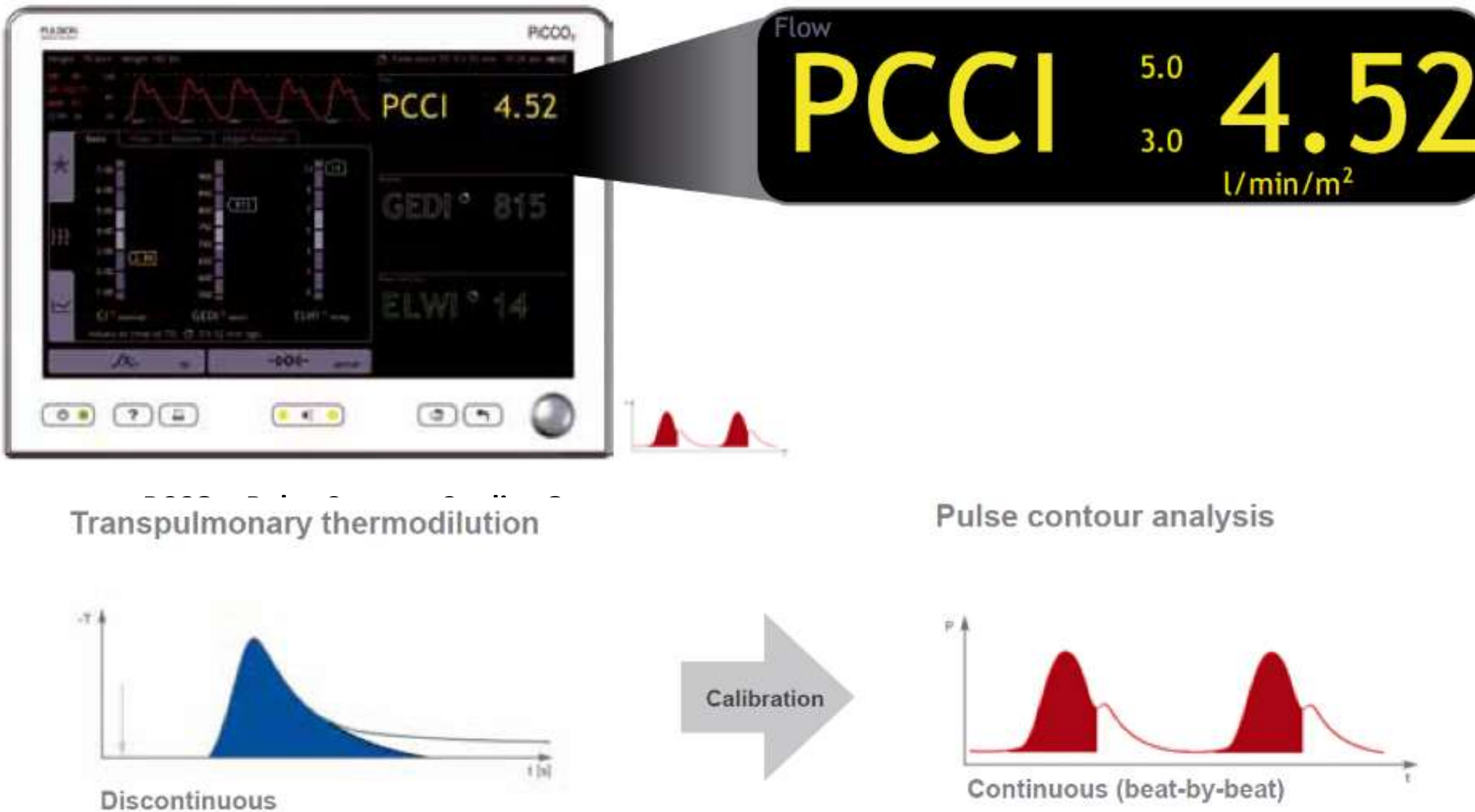
Thermodilution Cardiac Output (CO_{TD})

- Highly precise measurement using the thermodilution technique

$$CO_{TDa} = \frac{(T_b - T_i) \times V_i \times K}{\int \Delta T_b \times dt}$$

T_b =	Blood temperature
T_i =	Injectate temperature
V_i =	Injectate volume
$\int \Delta T_b \times dt$ =	Area under the thermodilution curve
K =	Correction constant, made up of specific weight and specific temperature of blood and injectate

Calibrated Continuous Cardiac Output



J Clin Monit Comput
DOI 10.1007/s10877-016-9823-y

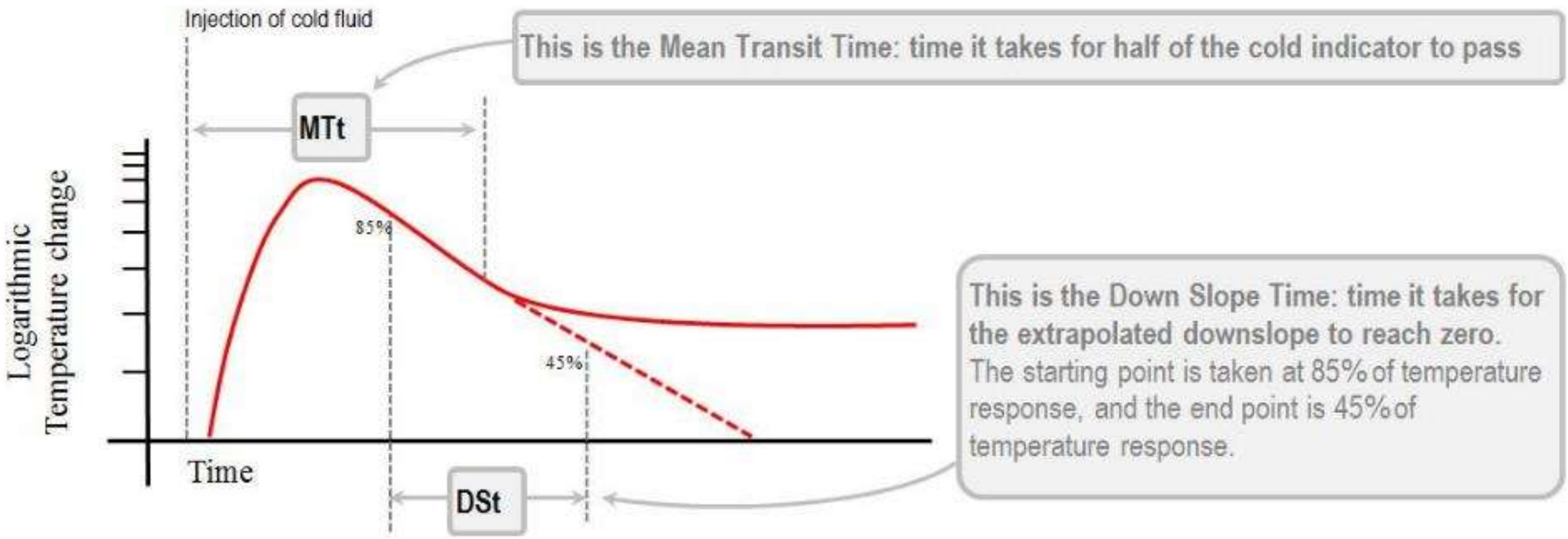
ORIGINAL RESEARCH

Reproducibility of transpulmonary thermodilution cardiac output measurements in clinical practice: a systematic review

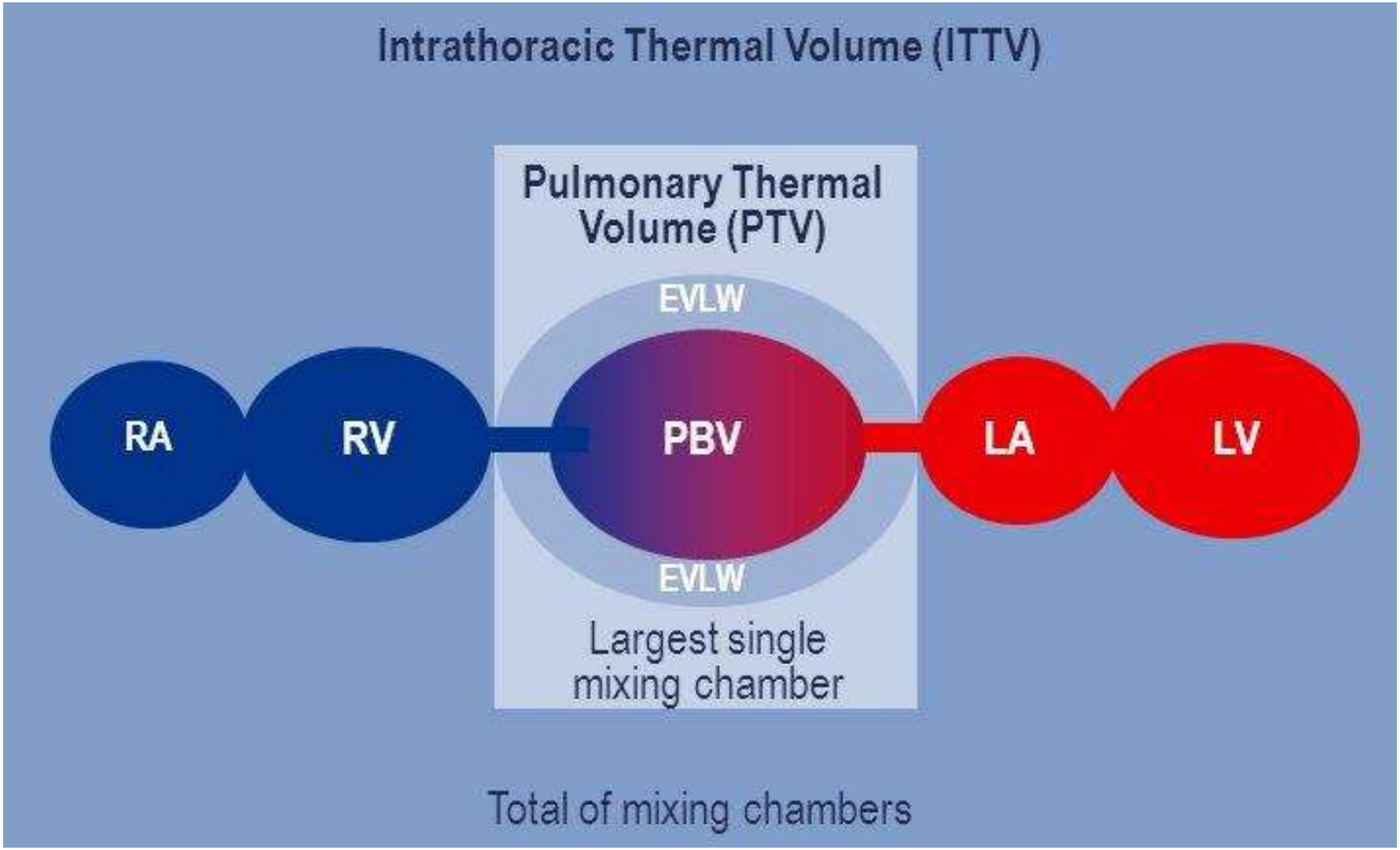
Raphaël Giraud[1,3,4] · Nils Siegenthaler[1,3,4] · Paolo Merlani[1,2] · Karim Bendjelid[1,3,4]

- 14 adult and 2 pediatric studies
- 3432 averaged CO values in the adult and 78 in pediatric population
- Overall reproducibility of $CO\text{-}TP_{TD}$ measurements
  - 6.1 ± 2.0 % in the adult studies
  - 3.9 ± 2.9 % in the pediatric studies
- 3 boluses ideal

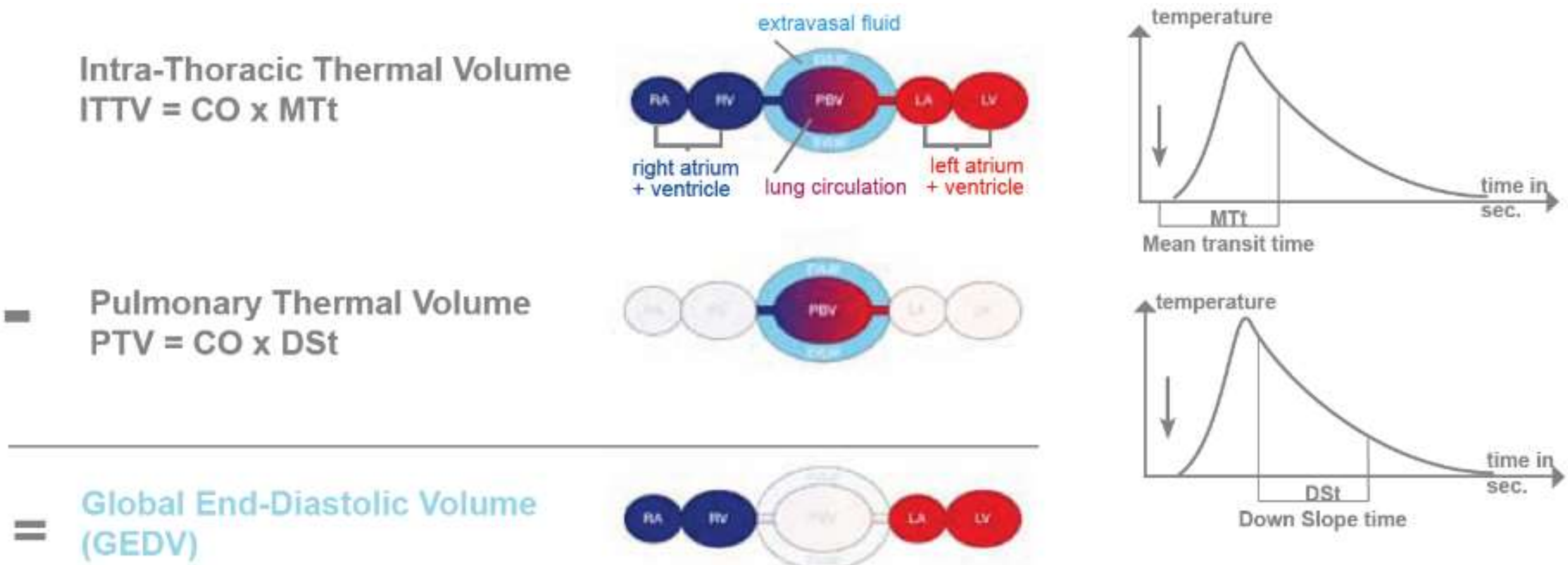
Analysis of thermodilution curve



PiCCO Volumes



Determination of preload



Preload volume instead of filling pressures

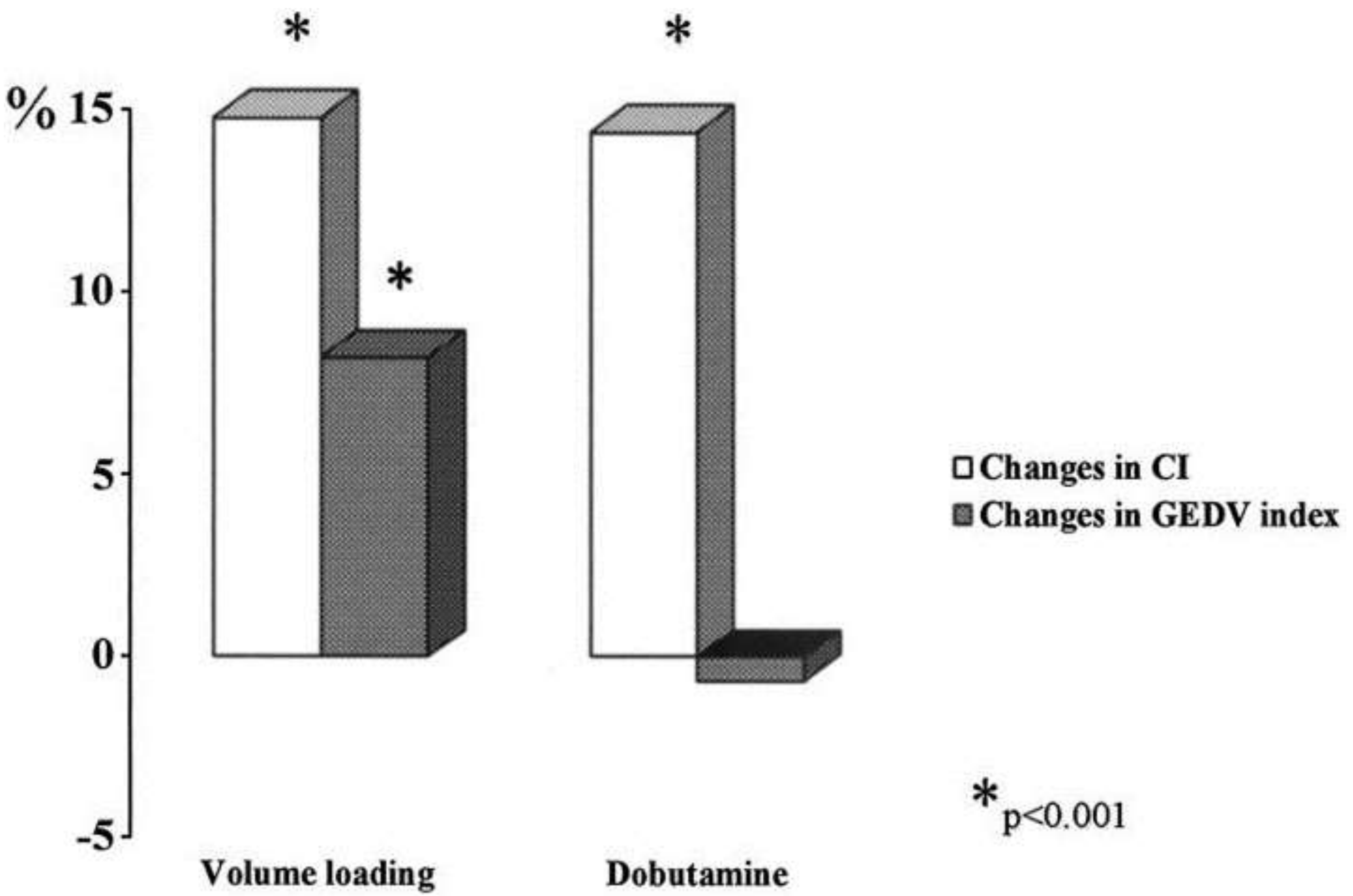
- GEDV – Global End-Diastolic Volume
- GEDI – Global End-Diastolic Volume Index
- Filling volume of all four heart chambers
- GEDI is indexed to “predicted body surface area” *

GEDV as an indicator of Cardiac Preload in Patients With Septic Shock

- Prospective clinical study.
- Medical ICU of a university hospital (20 beds).
- 36 patients with septic shock.
- Volume loading and dobutamine infusion
- Hemodynamic parameters were evaluated in triplicate by the PICCO
  - before and after 66 fluid challenges in 27 patients
  - before and after 28 increases in dobutamine infusion rate in 9 patients

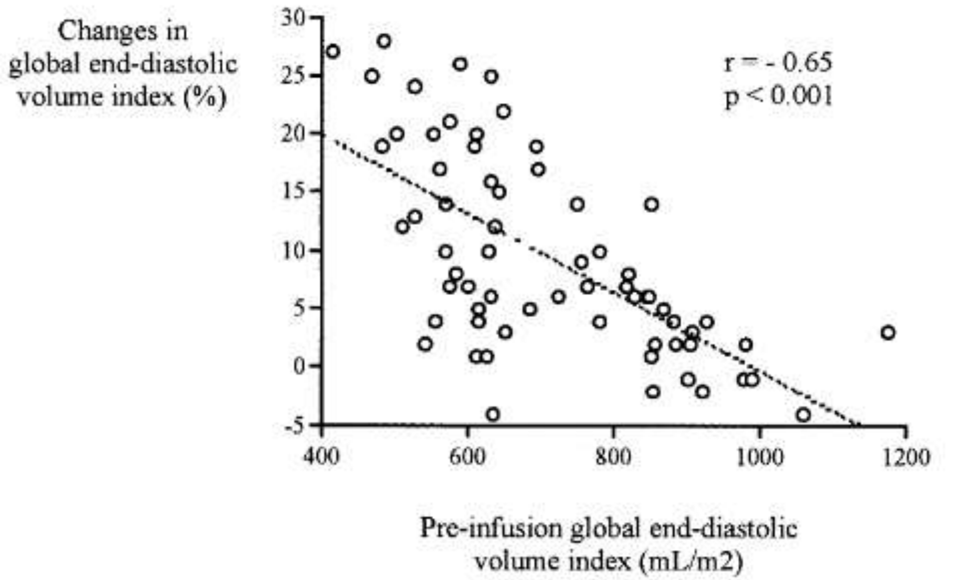
Michard F et al. Chest 2003; 124:1900 –1908

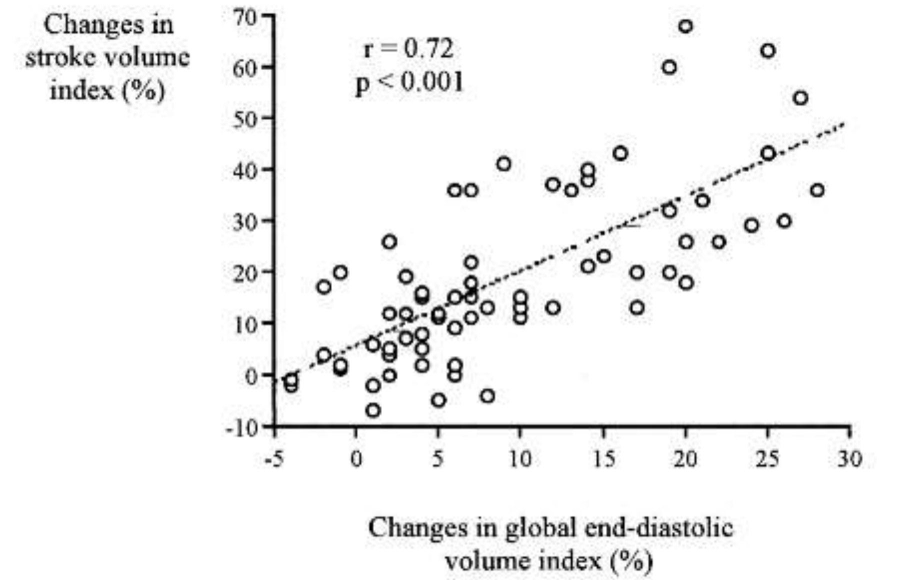
Results



Changes in GEDV index were correlated (r 0.72, $p < 0.001$) with changes in SVI, while changes in CVP were not

Michard F et al. Chest 2003; 124:1900 –1908





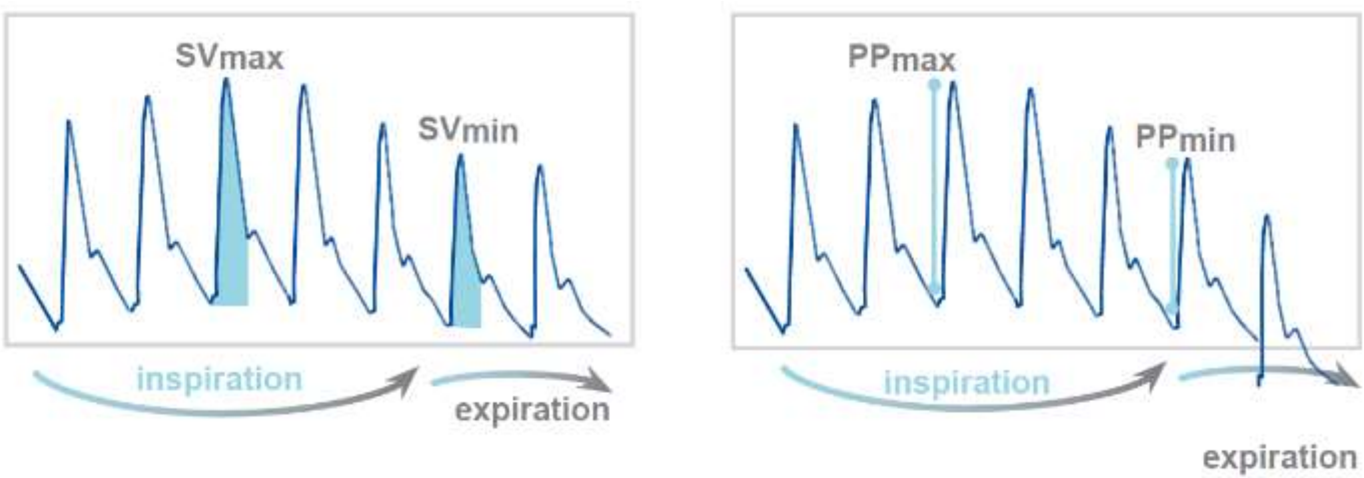
Michard F et al. Chest 2003; 124:1900 –1908

GEDV vs PAC

- GEDV and changes in GEDV correlate better with TEE assessment (LVEDAI) of cardiac preload
- Does not distinguish between left and right cardiac preload
  - in case of right ventricular dilation, GEDV is increased while the left ventricular preload is normal

Hofer CK et al. Anaesthesia. 2006 Apr;61(4):316-21
Hofer CK et al. Br J Anaesth. 2005 Jun;94(6):748-55.

Volume responsiveness



EVLW – Extravascular Lung Water

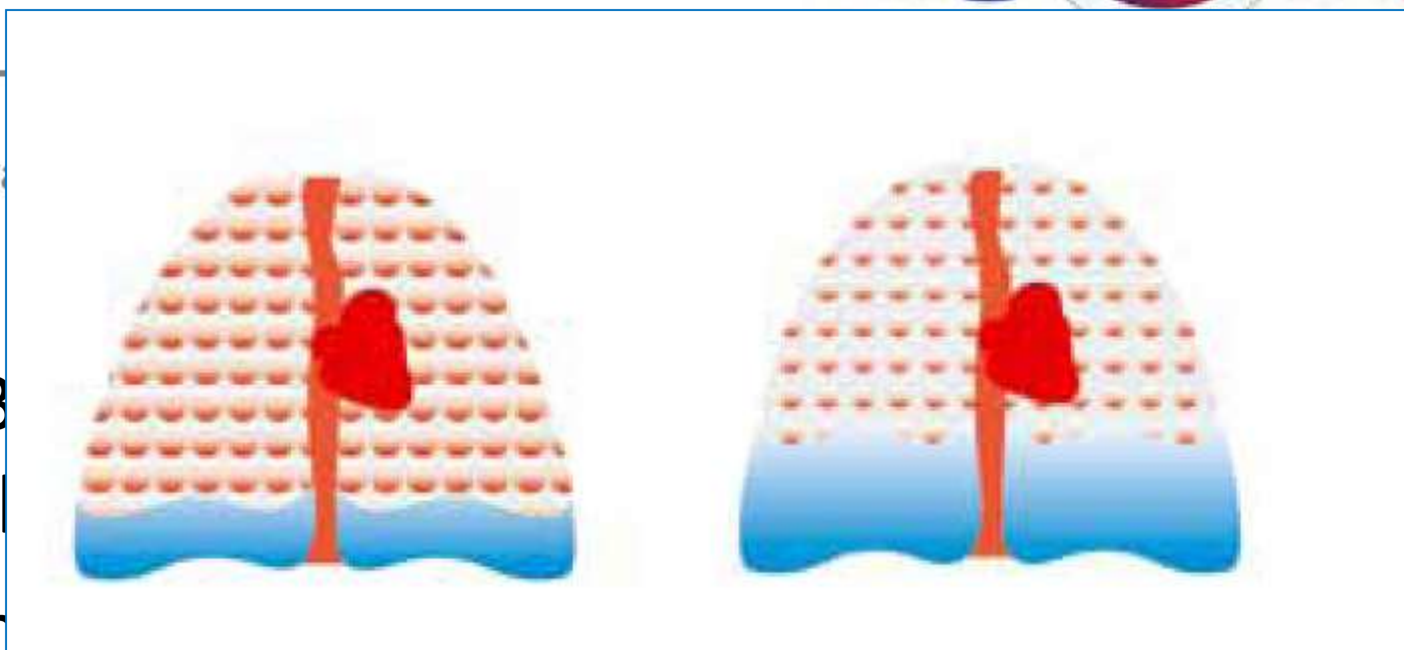
- Extravascular lung water (EVLW) represents the extravascular fluid of the lung tissue
- Includes intra-cellular, interstitial and intra-alveolar water (not pleural effusion)
- ELWI is indexed to "Predicted Body Weight"

Determination of lung water

Intra-Thoracic Thermal Volume (ITTV)

Intra-Thoracic Blood-Volume (ITBV)
ITBV = GEDV x 1.25

Extrava



- ITB ... ne pul
- It h ... 5% higher than GEDV

Validity

- Validated in experimental and clinical studies
- Correlates well with gravimetry
- Independent predictor of mortality
- Effect of high PEEP and large effusions not known
- Not valid in PE, single lung ventilaton, lung resection
- Pulmonary vascular permeability index:
  - ratio of EVLW over pulmonary blood volume
  - Cut off 3

Monnet et al. Critical Care. 2017; 21:147

The role of clinical examination, chest X-ray and central venous pressure in volume assessment in critically ill patients: a comparison with PiCCO-derived data

- 86 patients prospectively analysed
- GEDVI and EVLWI were better predictors of cardiac preload and pulmonary edema than other parameters
- Radiological assessment significantly overestimated the GEDVI and underestimated the ELWI

Huber W. Critical Care 2007

- EVLW is an independent predictor of mortality in critically ill patients
- Demonstrated in several retrospective and prospective studies
- Best validated in ARDS and Sepsis
- Can detect BAL related transient increase in EVLW
- Can detect weaning-induced pulmonary oedema with good accuracy, in particular with 100% specificity
- Using EVLW for fluid management in ARDS is not validated

Monnet et al. Critical Care. 2017; 21:147

Afterload

$$SVRI = \left[\frac{(MAP-CVP)}{CI}\right] \times 80$$

- SVR is the resistance the blood encounters as it flows through the vascular system
- SVRI is indexed to body surface area

Contractility

- **CFI - Cardiac Function Index**
- Parameter of the global cardiac contractility
- The cardiac function index is the ratio of flow and preload

Cardiac Function Index

- Ratio of cardiac output (measured by TPTD) and GEDV
- Global ejection fraction = (SV/GEDV)*4
  - LVEDV is GEDV/4

Thermodilution-derived indices for assessment of left and right ventricular cardiac function in normal and impaired cardiac function*

Constantin J. C. Trepte, MD; Volker Eichhorn, MD; Sebastian A. Haas, MD; Hans Peter Richter, MD; Matthias S. Goepfert, MD; Jens C. Kubitz, MD, PhD; Alwin E. Goetz, MD, PhD; Daniel A. Reuter, MD, PhD

Crit Care Med. 2011 Sep;39(9):2106-12

Research Article

Evaluation of Cardiac Function Index as Measured by Transpulmonary Thermodilution as an Indicator of Left Ventricular Ejection Fraction in Cardiogenic Shock

Jessica Perny,[1] Antoine Kimmoun,[1,2,3] Pierre Perez,[1] and Bruno Levy[1,2,3]

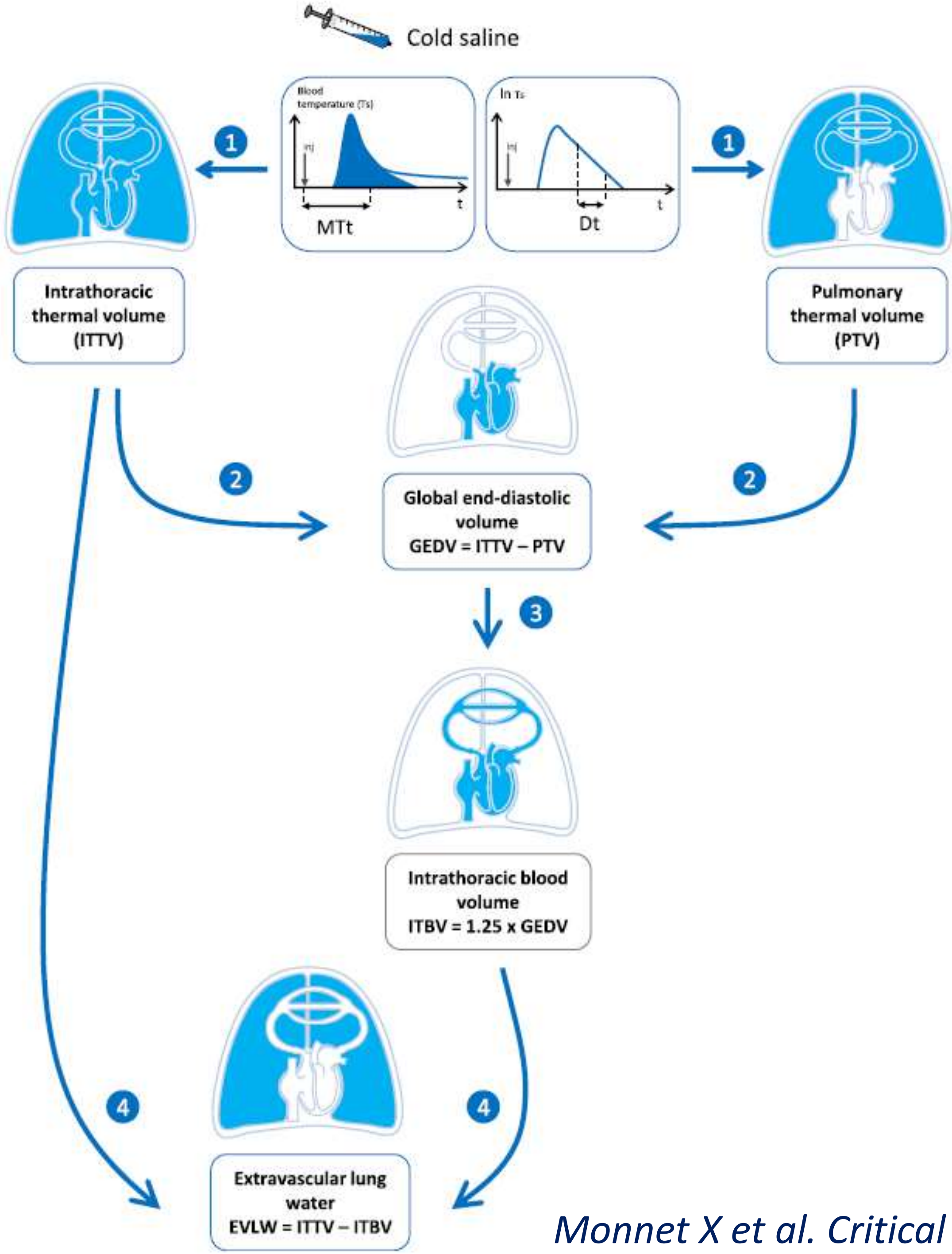
Biomed Res Int. 2014;2014:598029.

Limitations and application of CFI

- May be unreliable in RV dilatation
- Not perfect – may get affected by preload and afterload

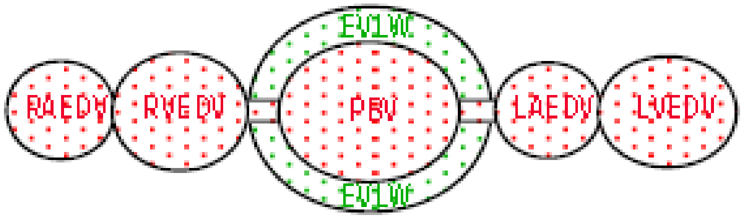
Application:

- Following the trends
- Continuous data

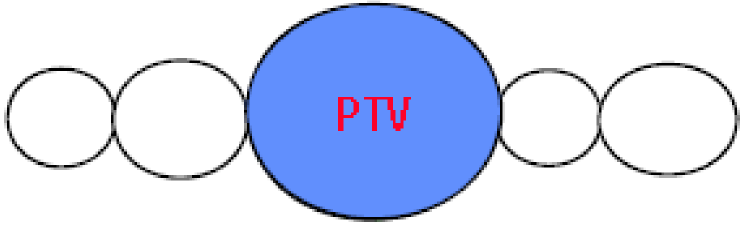


Monnet X et al. Critical Care. 2017; 21:147

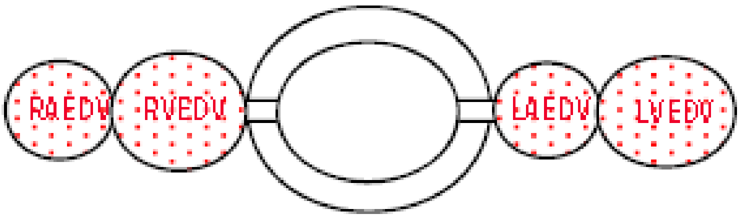
$$ITTV = CO * MTt_{TDa}$$



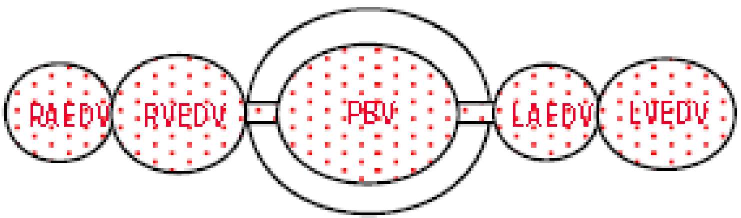
$$PTV = CO * DSt_{TDa}$$



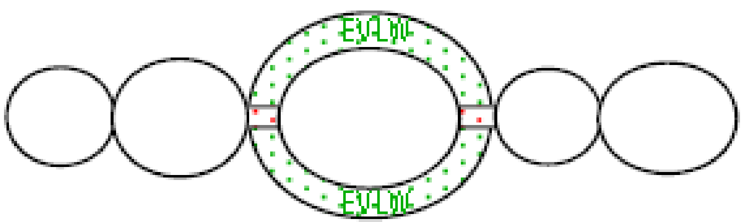
$$GEDV = ITTV - PTV$$

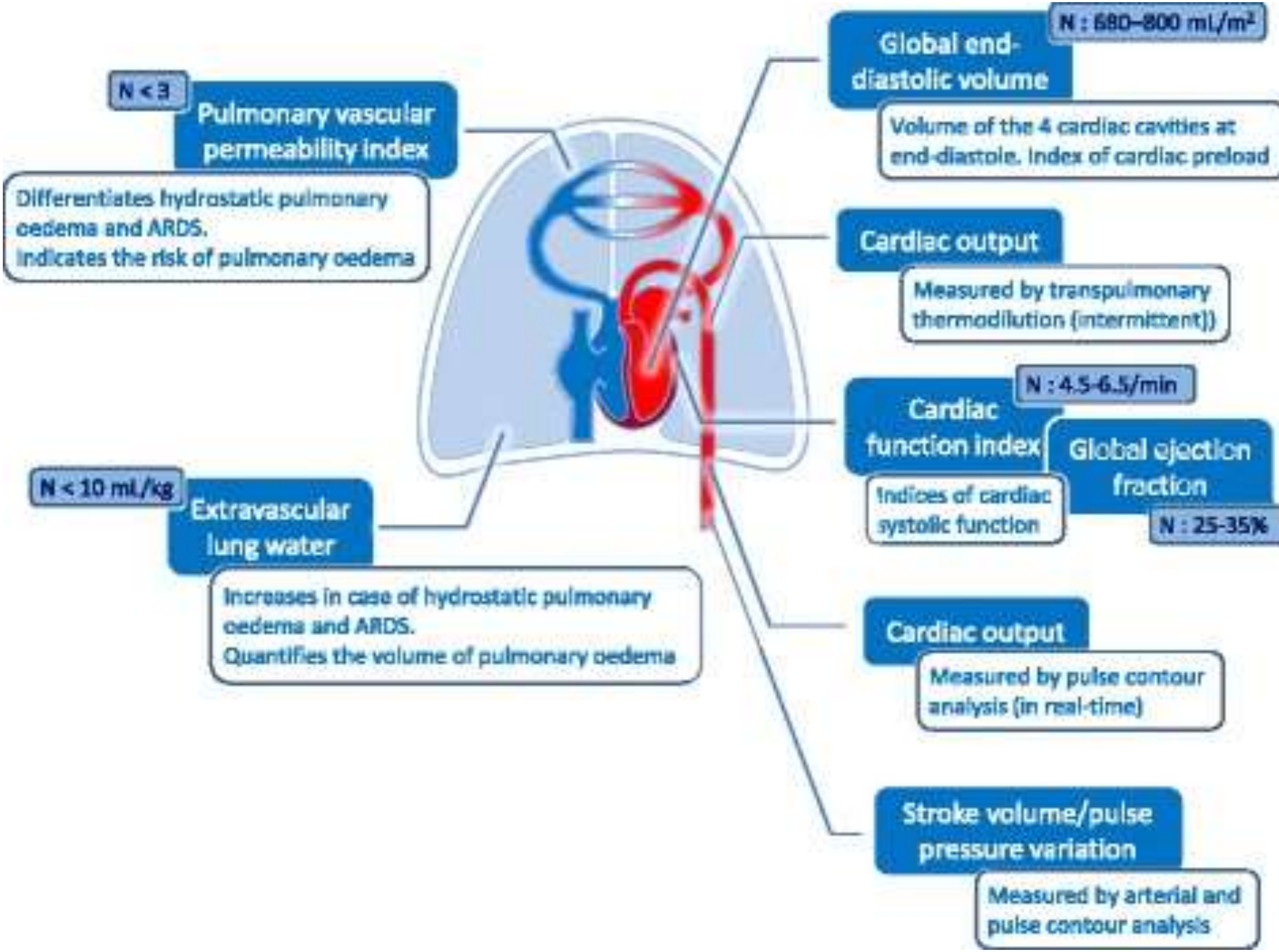


$$ITBV^{*} = 1.25 * GEDV$$



$$EVLW = ITTV - ITBV$$

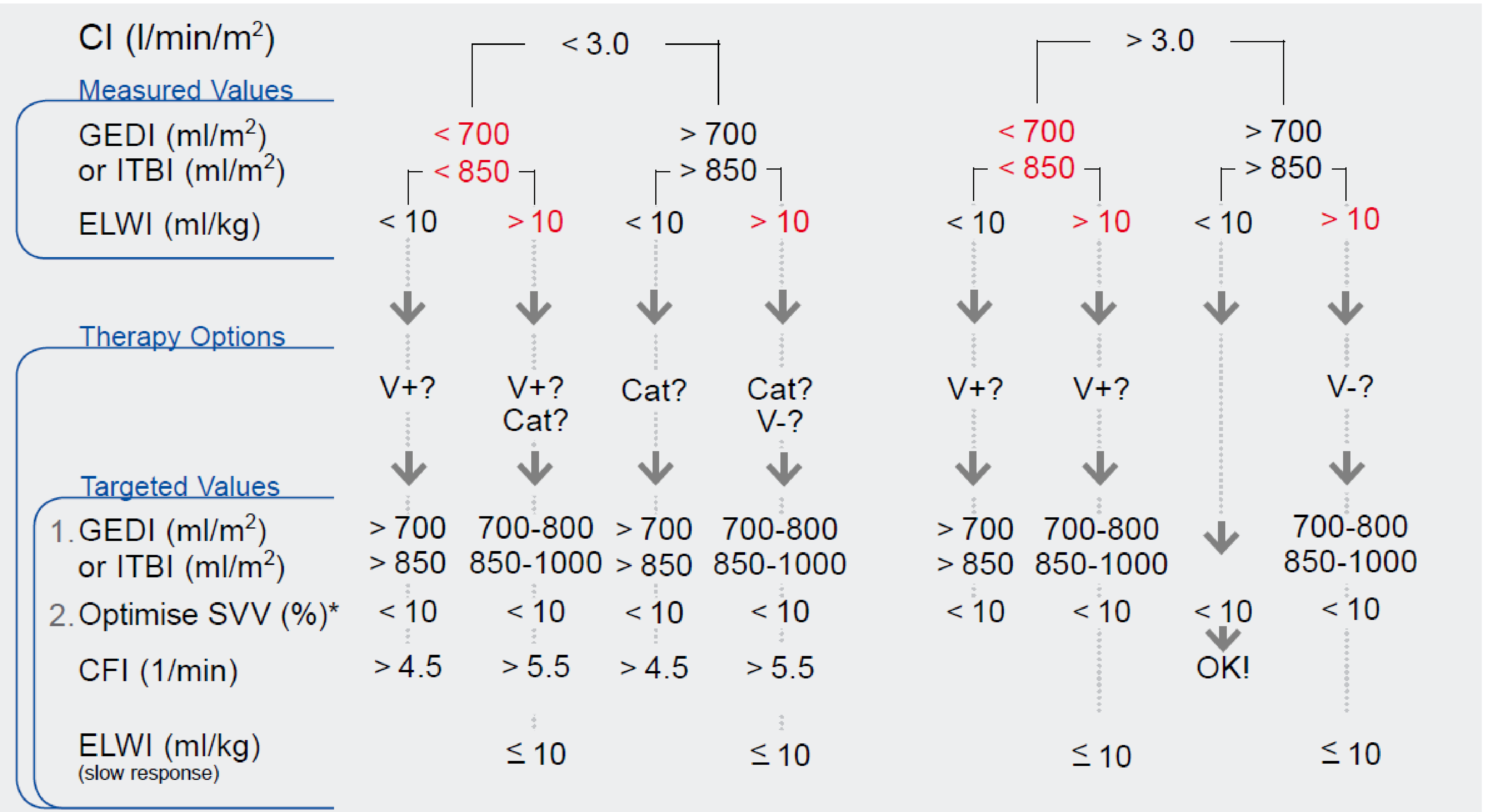



N < 3
Pulmonary vascular permeability index
Differentiates hydrostatic pulmonary oedema and ARDS.
Indicates the risk of pulmonary oedema
N < 10 mL/kg
Extravascular lung water
Increases in case of hydrostatic pulmonary oedema and ARDS.
Quantifies the volume of pulmonary oedema
N : 680–800 mL/m²
Global end-diastolic volume
Volume of the 4 cardiac cavities at end-diastole. Index of cardiac preload
Cardiac output
Measured by transpulmonary thermodilution (intermittent))
N : 4.5-6.5/min
Cardiac function index
Global ejection fraction
Indices of cardiac systolic function
N : 25-35%
Cardiac output
Measured by pulse contour analysis (in real-time)
Stroke volume/pulse pressure variation
Measured by arterial and pulse contour analysis

Abbreviation	Range	Unit
CI	3.0 – 5.0	$l/min/m^2$
SVI	40 – 60	ml/m^2
GEDI	680 – 800	ml/m^2
ITBI	850 – 1000	ml/m^2
SVV	< 10	%
PPV	< 10	%
SVRI	1970 - 2390	$dyn*s*cm^{-5}*m^2$
CFI	4.5 – 6.5	1/min
MAP	70 – 90	mmHg
ELWI	< 10	ml/kg

•Variable	•Main advantage	•Main drawback
•CO by TPTD	•As reliable as pulmonary thermodilution	•Does not provide a continuous measurement
•CO by pulse contour	•Continuous measurement •Assesses short-term and small changes	•Requires regular recalibration
•GEDV	•Better reflects cardiac preload than pressure markers of preload	•Does not distinguish between the right and left ventricles
•SVV	•Continuous automated assessment of fluid responsiveness	•Cannot be used in case of spontaneous breathing, cardiac arrhythmias and ARDS
•CFI, global ejection •fraction	•Can be used as an alarm for decreased LV •systolic function	•Overestimate LV systolic function in case of right ventricular dilation •Indirect markers of cardiac systolic function •Do not precisely assess cardiac structure and function
•EVLW	•Directly estimates the volume of lung oedema	•Unreliable in case of pulmonary embolism, lung resection, large pleural effusions
•Pulmonary vascular permeability index	•Directly estimates lung permeability •Distinguishes hydrostatic from permeability pulmonary oedema	•Same as for extravascular lung water

Decision algorithm



Not valid in…

- Intracardiac shunts
- Aortic aneurysm
- Aortic stenosis
- Pneumonectomy
- Pulmonary embolus
- In the presence of a balloon pump and in unstable arrhythmia
- Spontaneously breathing patients
- Cannot be used with ECMO
  - Continuous venovenous haemofiltration does not affect the reliability of cardiac output measurement by TP_{TD}

Monnet X et al. Critical Care. 2017; 21:147

P-TD vs TP-TD

Investigators (year)	Study parameters				Measures of agreement		
	Patient population	Ages	N	n	r	Bias	Precision
Della Rocca 2002	Liver transplant	24–66	62	186	0.93	+1.9%	11%
Friesecke 2009	Severe heart failure	Ni	29	325	ni	10.3%	27.3%
Goedje 1999	Cardiac surgery	41–81	24	216	0.93	+4.9%	11%
Holm 2001	Burns	19–78	23	109	0.97	+8.0%	7.3%
Kuntscher 2002	Burns	21–61	14	113	0.81	ni	ni
McLuckie 1996	Pediatrics	1 – 8	10	60	ni	+4.3%	4.8%
Segal 2002	Intensive care unit	27–79	20	190	0.91	+4.1%	10%
von Spiegel 1996	Cardiology	0.5–25	21	48	0.97	–4.7%	12%
Wiesenack 2001	Cardiac surgery	43–73	18	36	0.96	+7.4%	7.6%
Zöllner 1998	ARDS	19–75	18	160	0.91	–0.33%	12%

Acta Anaesthesiol Scand 2006; **50**: 1044–1049

ACTA ANAESTHESIOLOGICA SCANDINAVICA
doi: 10.1111/j.1399-6576.2006.01080.x

Cardiac output – pulse contour analysis vs. pulmonary artery thermodilution

M. Østergaard, J. Nielsen, J. P. Rasmussen and P. G. Berthelsen

- To determine the agreement between PA-TD, TP-TD and the pulse contour method, and to test the ability of the pulse contour method to track changes in cardiac output
- Precision and agreement were calculated in 25 cardiac surgery patients

Results

- Precisions of PA-TD and TP-TD were 0.41 l/min [95% CI, 0.07] and 0.48 l/min (95% CI, 0.08), respectively
- The bias and limits of agreement between PA-TD and TP-TD were – 0.46 l/min (95% CI, 0.11) and 1.10 l/min (95% CI, 0.19), respectively
- Post-operatively, the bias and limits of agreement between the PA-TD and pulse contour methods were 0.07 l/min and 2.20 l/min, respectively

Ostergaard M et al. Acta Anaesthesiol Scand 2006; 50: 1044–1049

Acta Anaesthesiol Scand 2006; **50**: 1050–1057

ACTA ANAESTHESIOLOGICA SCANDINAVICA
doi: 10.1111/j.1399-6576.2006.01118.x

Agreement between PiCCO pulse-contour analysis, pulmonal artery thermodilution and transthoracic thermodilution during off-pump coronary artery by-pass surgery

P. S. Halvorsen[1], A. Espinoza[1,2], R. Lundblad[1,3], M. Cvancarova[4], P. K. Hol[1], E. Fosse[1,5] and T. I. Tønnessen[1,2,5]
[1]*The Interventional Centre, Departments of* [2]*Anesthesiology,* [3]*Cardio-Thoracic Surgery and* [4]*Biostatistics at Rikshospitalet-Radiumhospitalet University Hospital and* [5]*University of Oslo, Department Group of Clinical Medicine, Oslo, Norway*

- In OPCAB surgery, limits of agreement comparing thermodilution methods were smaller than comparing PCCI with thermodilution.
- Recalibration of PCCI is therefore advisable.

Mutoh et al. Critical Care 2014, 18:482
http://ccforum.com/content/18/4/482

CRITICAL CARE

RESEARCH Open Access

Impact of transpulmonary thermodilution-based cardiac contractility and extravascular lung water measurements on clinical outcome of patients with Takotsubo cardiomyopathy after subarachnoid hemorrhage: a retrospective observational study

Tatsushi Mutoh[1,2*], Ken Kazumata[3,4], Shunsuke Terasaka[3], Yasuyuki Taki[2], Akifumi Suzuki[1] and Tatsuya Ishikawa[1]

- Retrospective analysis of 46 consecutive postoperative SAH patients who developed TCM

Results

- CFI was significantly correlated with LVEF ($r = 0.82$, $P < 0.0001$)
- CFI had a better ability than CO to detect cardiac dysfunction (LVEF <40%) (ROC: 0.85 ± 0.02; $P < 0.001$)
- A CFI value <4.2 min^{-1} had a sensitivity of 82% and specificity of 84% for detecting LVEF <40%
- CFI <4.2 min^{-1} was associated with delayed cerebral ischemia (OR = 2.14, $P = 0.004$) and poor 3-month functional outcome (OR = 1.87, $P = 0.02$)
- An ELWI >14 ml/kg after day 4 increased the risk of poor functional outcome at 3-month follow-up (OR = 2.10, 95% CI = 1.11 to 3.97; $P = 0.04$).

Advantages of PICCO

- Good correlation with P-TD.
- Less invasive than the PAC, avoiding risks of PA rupture, pulmonary embolism, etc.
- Most critically ill patients do have CVP and art line anyway.
- Simple measurement technique; repeated measurements possible.
- Less influenced by respiratory variations than P-TD.
- Real-time (calibrated) CCO by the pulse contour method (+SVV).
- The PiCCO provides several other important parameters (e.g., GEDV, EVLW, PPV; ScvO2 available).
- May be used in children

Disadvantages of PiCCO

- Cannot be used with IABP
- Should be recalibrated with changes in position, therapy or condition to account for compliance of vascular bed
- EVLW only measured in parts of the lung that are perfused (underestimated post-pneumonectomy)
- Aortic aneurysm raises GEDV and ITBB
- Severe AR may result in an inaccurate thermodilution wash out curve

Cross-comparison of cardiac output trending accuracy of LiDCO, PiCCO, FloTrac and pulmonary artery catheters

Mehrnaz Hadian[1,3], Hyung Kook Kim[1], Donald A Severyn[2], Michael R Pinsky[1*]

- Although PAC (COTD/CCO), FloTrac, LiDCO and PiCCO display similar mean CO values, they often trend differently in response to therapy and show different interdevice agreement.
- In the clinically relevant low CO range (< 5 L/min), agreement improved slightly.
- Thus, utility and validation studies using only one CO device may potentially not be extrapolated to equivalency of using another similar device

Hadian et al. Critical Care 2010, 14:R212

Take home messages

- Fluid management in critical care has to have a holistic approach rather than relying upon a single marker
- PiCCO is a novel technology, relatively safe and validated but has its own limitations
- Data is limited and there's paucity of studies focussing on clinical outcomes
- Existing nomograms are not validated and thus trends become more useful than absolute values of PiCCO parameters

CHEST Postgraduate Education Corner
CONTEMPORARY REVIEWS IN CRITICAL CARE MEDICINE

Hemodynamic Evaluation and Monitoring in the ICU*

Michael R. Pinsky, MD, FCCP

Table 3—*Hemodynamic Monitoring Truths*

Tachycardia is never a good thing.
Hypotension is always pathologic.
There is no such thing as normal cardiac output.
Central venous pressure is only elevated in disease.
Peripheral edema is of cosmetic concern.

Chest 2007; 132:2020 –2029