Seminar

Assessment of Fluid Responsiveness in Mechanically Ventilated Patients

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Perspective

- Why is it important to assess for fluid responsiveness in mechanically ventilated patients?

Perspective

One side of the coin…..

- Restoration and maintenance of adequate circulating blood volume is an essential goal in the proper management of the critically ill patient

- Inadequate cardiac output and reduced organ perfusion may lead to multi-organ dysfunction

Other side…

Comparison of Two Fluid-Management Strategies in Acute Lung Injury

The National Heart, Lung, and Blood Institute Acute Respiratory Distress Syndrome (ARDS) Clinical Trials Network*

RESULTS

The rate of death at 60 days was 25.5 percent in the conservative-strategy group and 28.4 percent in the liberal-strategy group ($P=0.30$; 95 percent confidence interval for the difference, −2.6 to 8.4 percent). The mean (±SE) cumulative fluid balance during the first seven days was −136±491 ml in the conservative-strategy group and 6992±502 ml in the liberal-strategy group ($P<0.001$). As compared with the liberal strategy, the conservative strategy improved the oxygenation index ([mean airway pressure × the ratio of the fraction of inspired oxygen to the partial pressure of arterial oxygen] × 100) and the lung injury score and increased the number of ventilator-free days (14.6±0.5 vs. 12.1±0.5, $P<0.001$) and days not spent in the intensive care unit (13.4±0.4 vs. 11.2±0.4, $P<0.001$) during the first 28 days but did not increase the incidence or prevalence of shock during the study or the use of dialysis during the first 60 days (10 percent vs. 14 percent, $P=0.06$).

CONCLUSIONS

Although there was no significant difference in the primary outcome of 60-day mortality, the conservative strategy of fluid management improved lung function and shortened the duration of mechanical ventilation and intensive care without increasing nonpulmonary-organ failures. These results support the use of a conservative strategy of fluid management in patients with acute lung injury. (ClinicalTrials.gov number, NCT00281268.)

Table 2—*Simplified Algorithm for Conservative Management of Fluids in Patients With ALI, Based on Protocol Used in the FACTT**

CVP, mm Hg (Recommended)	PAOP, mm Hg (Optional)	MAP ≥ 60 mm Hg and Not Receiving Vasopressors for ≥ 12 h	
		Average Urine Output < 0.5 mL/kg/h	Average Urine Output ≥ 0.5 mL/kg/h
> 8	> 12	Furosemide†; reassess in 1 h	Furosemide; reassess in 4 h
4–8	8–12	Fluid bolus as fast as possible‡; reassess in 1 h	Furosemide; reassess in 4 h
< 4	< 8	Fluid bolus as fast as possible‡; reassess in 1 h	No intervention; reassess in 4 h

(CHEST 2007; 131:913–920)

- Even experienced intensivists are correct only 50% of time in predicting fluid responsiveness by conventional parameters

- Enomoto TM et. al. Crit Care Clin 2010;26: 307-21

Can anything help for safe exit from this trap?

Clinical

- Skin Turgor
- Pulse Rate
- Blood Pressure
- Urine Output
- Chest Examination
- Chest Radiograph

Invasive

Static-

- Barometric- CVP, PAOP
- Volumetric- RVEDVI, LVEDVI, GEDVI & ITBVI

Dynamic (Cavallaro's classification)

- Group A- SPV, PPV, SVV
- Group B- IVC diameter, Ventricular pre-ejection period
- Group C- PLR, Valsalva

Basic principle

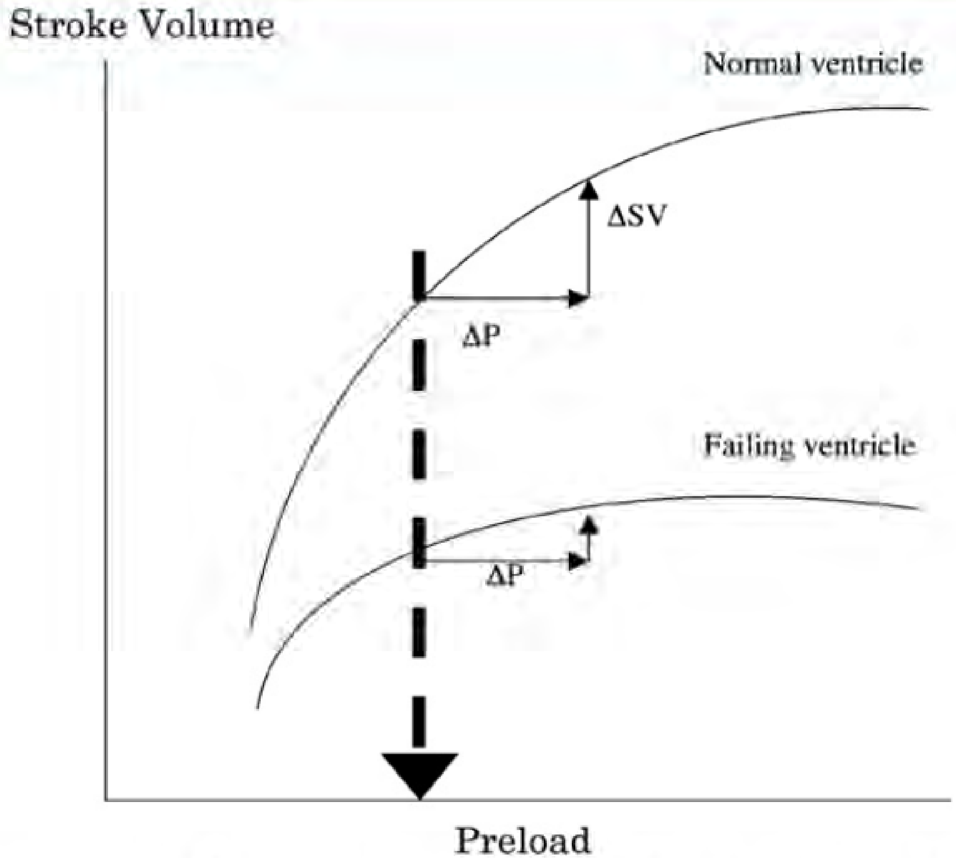


Fig. 1. Frank-Starling curves demonstrating relationship between change in preload to change in SV in a normal and failing ventricles. A given change in preload may cause variable changes in SV, depending on the slope of the curve.

Enomoto TM et. al. Crit Care Clin 2010;26: 307-21

Barometric Indices

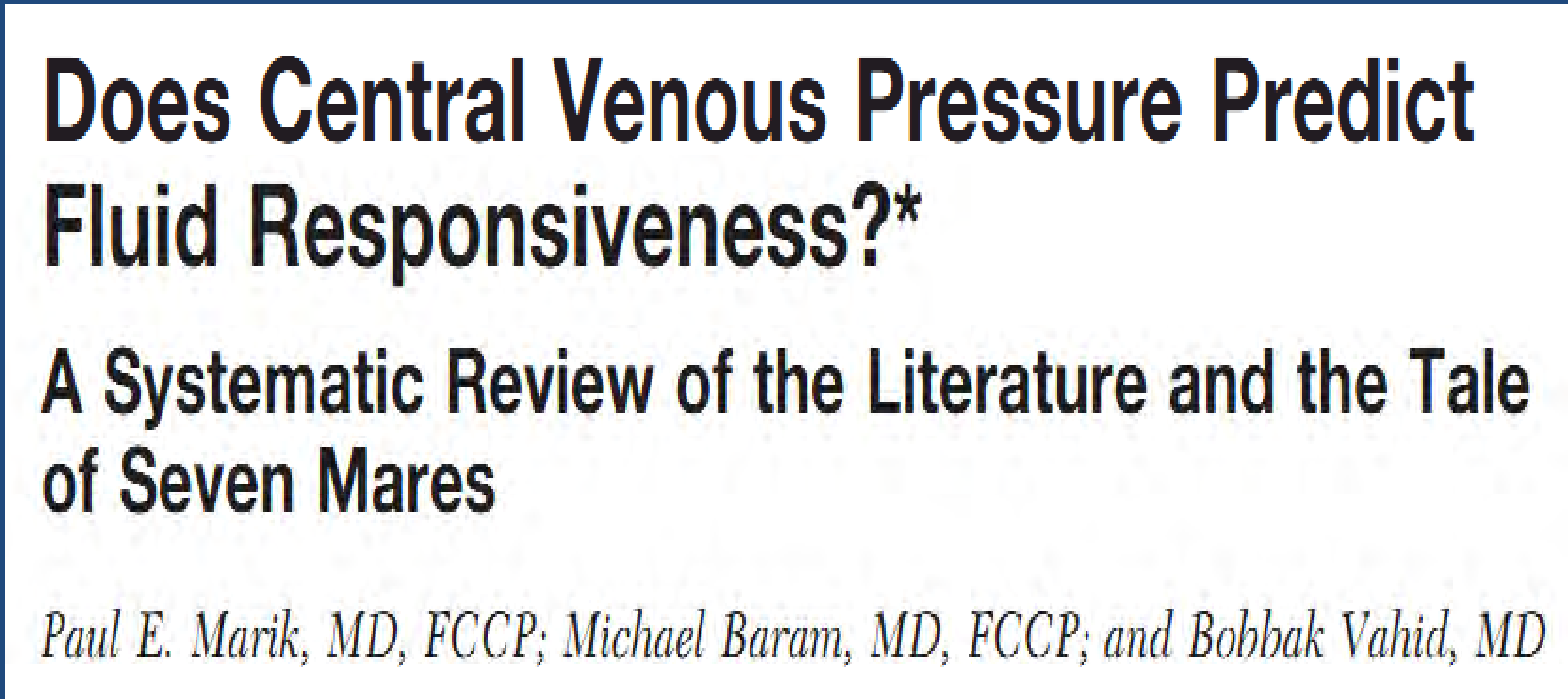
- CVP
- PAOP

CVP

- Low CVP- Volume depletion
- High CVP- Volume overload
- CVP gives clinically relevant information regarding circulatory status
    - Lange cardiovascular physiology. 6th ed.
- The most important application of CVP is to estimate adequacy of circulating blood volume
    - Miller’s anesthesia. 6th ed.

CVP

Is it Really so?


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

Background: Central venous pressure (CVP) is used almost universally to guide fluid therapy in hospitalized patients. Both historical and recent data suggest that this approach may be flawed.
Objective: A systematic review of the literature to determine the following: (1) the relationship between CVP and blood volume, (2) the ability of CVP to predict fluid responsiveness, and (3) the ability of the change in CVP (ΔCVP) to predict fluid responsiveness.
Data sources: MEDLINE, Embase, Cochrane Register of Controlled Trials, and citation review of relevant primary and review articles.
Study selection: Reported clinical trials that evaluated either the relationship between CVP and blood volume or reported the associated between CVP/ΔCVP and the change in stroke volume/cardiac index following a fluid challenge. From 213 articles screened, 24 studies met our inclusion criteria and were included for data extraction. The studies included human adult subjects, healthy control subjects, and ICU and operating room patients.
Data extraction: Data were abstracted on study design, study size, study setting, patient population, correlation coefficient between CVP and blood volume, correlation coefficient (or receive operator characteristic [ROC]) between CVP/ΔCVP and change in stroke index/cardiac index, percentage of patients who responded to a fluid challenge, and baseline CVP of the fluid responders and nonresponders. Metaanalytic techniques were used to pool data.
Data synthesis: The 24 studies included 803 patients; 5 studies compared CVP with measured circulating blood volume, while 19 studies determined the relationship between CVP/ΔCVP and change in cardiac performance following a fluid challenge. The pooled correlation coefficient between CVP and measured blood volume was 0.16 (95% confidence interval [CI], 0.03 to 0.28). Overall, 56 ± 16% of the patients included in this review responded to a fluid challenge. The pooled correlation coefficient between baseline CVP and change in stroke index/cardiac index was 0.18 (95% CI, 0.08 to 0.28). The pooled area under the ROC curve was 0.56 (95% CI, 0.51 to 0.61). The pooled correlation between ΔCVP and change in stroke index/cardiac index was 0.11 (95% CI, 0.015 to 0.21). Baseline CVP was 8.7 ± 2.32 mm Hg [mean ± SD] in the responders as compared to 9.7 ± 2.2 mm Hg in nonresponders (not significant).
Conclusions: This systematic review demonstrated a very poor relationship between CVP and blood volume as well as the inability of CVP/ΔCVP to predict the hemodynamic response to a fluid challenge. CVP should not be used to make clinical decisions regarding fluid management.
(CHEST 2008; 134:172–178)

CVP

- CVP <10mmHg- ~55-60% will respond
- Does that end the story for CVP?
- No
- CVP >10mmHg- Good predictor of non responsiveness
- Most readily available method at bedside
- Relatively low cost, easy & less complications

- Magder S et.al. J Intensive Care Med 2007;22(1)
- Nahouraii RA, Rowell SE Crit Care Clin 2010;26: 295–305

Pulmonary Artery Occlusion Pressure

- Lt. Heart counterpart of CVP
- Shares same caveats as CVP
- PAC has to be in West zone 3
- Review of 9 studies-
  – No significant difference in responders vs Non-responders
  – Poor correlation in Ppao & CI (r= 0.42)
  – No clear cut threshold to identify responders
  – Ppao < 11- Predicts Responsiveness Sn-77%, Sp- 51%, AUC= 0.63

- Michard F, Teboul J. Chest 2002;121:2000-8

Volumetric Indices

- RVEDV/RVEDVI
- LVEDV/LVEDAI
- GEDV (I)
- ITBV (I)

  - Nahouraii RA, Rowell SE Crit Care Clin 2010;26: 295–305

RVEDV, RVEDV Index

- Bing & colleagues first proposed measurement of RV volume in1951
  - Bing R, Heimbecher R, Falholt W. Am Heart J 1951;42:483-502
- Practical use began in 1980s
- SV, CO & RVEF are measured by dye dilution method
- RVEDV is derived from RVEF & SV
    - Nahouraii RA, Rowell SE Crit Care Clin 2010;26: 295–305

RVEDV, RVEDV Index

- RVEDI correlates well with CI and far better predictor of fluid responsiveness than Ppao

  - Diebel LN, Wilson RF, Tagett MG et. al. Arch Surg 1992;127:817-22
  - Durham R, Neunaber K Vogler G et. al. J Trauma 1995;39(2):218-23
  - Nahouraii RA, Rowell SE Crit Care Clin 2010;26: 295–305

RVEDI-

• <90mL/m2	-Sn=64%
• 90-140mL/m2	-Sn=27%
• >140mL/m2	-Sn=0%

  - Diebel LN, Wilson RF, Heins J et. al. J Trauma1994;37(6):950-5

LVEDV, LVEDAI-

- Measured by TEE
- Correlates well with CI but less well as compared to RVEDI
- Not very useful
    - Nahouraii RA, Rowell SE Crit Care Clin 2010;26: 295–305

GEDV Index & ITBV Index

- Hardware-
  - Thermistor tipped arterial catheter- usually in the femoral artery connected to PiCCO system (Pulsion Medical Systems, Germany)
  - CVC

- Method-
  - Cold saline injected through CVC
  - Thermistor in Femoral catheter records thermodilution curve
  - Stewart- Hamilton algorithm used to calculate CI

- GEDV= CO X (Mean transit time – Down slope time)
  - Largest volume of blood in the four chambers of the heart

- ITBV= (a X GEDV) + b
  - GEDV + volume of blood within the pulmonary vessels

GEDV Index & ITBV Index

- PiCCO also provides a continuous pulse contour-derived CO and an estimation of extravascular lung water
- EVLW= IT thermal Vol. - ITBV
- 18 studies compared GEDVI or ITBVI with CI or SVI in diverse patient populations (eg, neurosurgery, cardiac surgery, abdominal and laparoscopic surgery, and intensive care patients)
- In all of these- ITBVI was a better measure of cardiac preload than barometric indices

Dynamic Indices

Cavallaro’s classification

- Group A:
  - Stroke Volume Variability (SVV)
  - Systolic Pressure variability (SPV)
  - Pulse Pressure Variability (PPV)
  - Plethysmigraphic variability index (PVI)
  - Aortic blood flow

- Group B:
  - IVC diameter & Respiratory variation
  - Ventricular pre-ejection period

- Group C:
  - Passive leg raising (PLR)
  - Valsalva manoeuver (Only in non ventilated patients)

– Enomoto TM, Harder L. Crit Care Clin 2010;26: 307-21.

Dynamic Indices

- Rely on physiology of heart lung interactions
- ED pressure or volume- even if measured appropriately, does not determine responsiveness to fluid bolus, e.g. in HF
- Relation between preload & SV is curvilinear, not linear
- Dynamic indices use/apply controlled reversible preload- look for response

  - Enomoto TM et. al. Crit Care Clin 2010;26: 307-21

Group A & B: Physiology

During positive pressure ventilation

- Preload to Rt. Heart is decreased
- RV afterload is increased
  - Decreased RV output- transmitted to Lt. heart over 2-3 beats
- Increased LV preload
- Decreased LV afterload
- Collectively these changes progressively increase BP during inspiration, falls abruptly early in expiration.

-Michard F et. al. Am J Resp Crit Care Med 2000;162:134-8
-Enomoto TM et. al. Crit Care Clin 2010;26: 307-21

Group A & B: Physiological basis

These phasic variations- exaggerated in hypovolemia

- IVC & RA- more collapsible
- More lung in West's Zone 1 or 2- increased RV afterload
- Myocardium on steeper portion of Frank-Starling curve
- SPV- affected both by SVV & Pl Pressure
- PPV- Affected only by SVV
- Theoretically later is more likely to be accurate predictor than former

Group A & B: Caution

- Controlled ventilation
- Sinus rhythm
- Many require invasive monitoring
- One should not be carried by single value
- Effect of vasopressors on indices is not clear
- Effect of extremes of ventilation have not been studied properly
- Only PPV has been studied in single trial in ARDS with LTV ventilation- good predictability of PPV for fluid responsiveness

Stroke Volume Variation (SVV)

Measurement-

- Invasive- Aortic flow probes

- Non invasive- (Pulse contour analysis)
  - PiCCO
  - LiDCO
  - FloTrac Sensor

Eliminates complience- theoretically should be most useful

Better than CVP/PAOP

Systolic Pressure Variation (SPV)

- Pmax-Pmin/ (Pmax+Pmin/2)

- First dynamic index discovered

- Threshold 8.5mmHg- Sn- 82%, Sp-86%

- δUp= SP_{max}- SP_{ref}
  - Insp Increase, esp d/t Extramural aortic pressure component

- Δdown= Sp_{ref} – Sp_{min}
  - Mainly because of expiratory decrease in LV SV
  - More representative of fluid responsiveness
  - Threshold 5mmHg- Sn & Sp 86%, AUC 0.92

Michard F et. al. Am J Resp Crit Care Med 2000;162:134-8

Pulse Pressure Variation (PPV)

- Pulse pressure – determined by SV & Arterial compliance
- PPV determines the degree to which PP is preload dependent
- Threshold of 13%-
  - Sn- 94%, Sp- 96%
- Not affected by vasopressors

Michard F et. al. Am J Resp Crit Care Med 2000;162:134-8
Auler JO et. al. Anesth Analg 2008;106:1201–6

Plethysmographic Variability Index (PVI)

- Respiratory variation in plethysmographic contour can be used for assessment of SV
- Instrument is not standardized
- Many have autogain
- Threshold of 14%- as accurate as PPV >13%
    - Feissel M et al. Crit Care 2009;13:205
    - Loupec T et al. Crit Care Med 2011;39(2):294–9

Pleth variability index predicts fluid responsiveness in critically ill patients*

PVI vs PPV

Thibault Loupec, MD; Hodanou Nanadoumgar, MD; Denis Frasca, MD; Franck Petitpas, MD; Leila Laksiri, MD; Didier Baudouin, MD; Bertrand Debaene, MD; Claire Dahyot-Fizelier, PhD; Olivier Mimoz, PhD

Objective: To investigate whether the pleth variability index, a noninvasive and continuous tool, can predict fluid responsiveness in mechanically ventilated patients with circulatory insufficiency.

Design: Prospective study.

Setting: Surgical intensive care unit of a university hospital.

Patients: Forty mechanically ventilated patients with circulatory insufficiency in whom volume expansion was planned by attending physician. Exclusion criteria included spontaneous respiratory activity, cardiac arrhythmia, known intracardiac shunt, severe hypoxemia (Pa_{O_2}/F_{IO_2} <100 mm Hg), contraindication for passive leg raising, left ventricular ejection fraction of <50%, and hemodynamic instability during the procedure.

Interventions: Fluid challenge with 500 mL of 130/0.4 hydroxyethyl-starch if respiratory variations in arterial pulse pressure were ≥13% or with passive leg raising if variations in arterial pulse pressure were <13%.

Measurements and Main Results: Pleth variability index, variations in arterial pulse pressure, and cardiac output estimated by echocardiography were recorded before and after fluid challenge. Fluid responsiveness was defined as an increase in cardiac output of ≥15%. Twenty-one patients were responders and 19 were nonresponders. Mean ± SD pleth variability index (28% ± 13% vs. 11% ± 4%) and arterial pulse pressure variation (22% ± 11% vs. 5% ± 2%) values at baseline were significantly higher in responders than in nonresponders. The pleth variability index threshold value of 17% allowed discrimination between responders and nonresponders with a sensitivity of 95% (95% confidence interval, 74% to 100%) and a specificity of 91% (95% confidence interval, 70% to 99%). The pleth variability index at baseline correlated (r = .72, p < .0001) with the percentage change in cardiac output induced by fluid challenge, suggesting that a higher pleth variability index at baseline will correlate with a higher percentage change in cardiac output after volume expansion.

Conclusions: The pleth variability index can predict fluid responsiveness noninvasively in intensive care unit patients under mechanical ventilation. (Crit Care Med 2011; 39:294–299)

Key Words: pleth variability index; heart lung interactions; passive leg raising; cardiac output; fluid responsiveness; mechanical ventilation; septic shock; echocardiography; hypovolemia

Accuracy of stroke volume variation compared with pleth variability index to predict fluid responsiveness in mechanically ventilated patients undergoing major surgery

Markus Zimmermann, Thomas Feibicke, Cornelius Keyl, Christopher Prasser, Stefan Moritz, Bernhard M. Graf and Christoph Wiesenack

SVV vs PVI

Background and objective Accurate assessment of a patient's volume status is an important goal for an anaesthetist. However, most variables assessing fluid responsiveness are either invasive or technically challenging. This study was designed to compare the accuracy of arterial pressure-based stroke volume variation (SVV) and variations in the pulse oximeter plethysmographic waveform amplitude as evaluated with the noninvasive calculated pleth variability index (PVI) with central venous pressure to predict the response of stroke volume index (SVI) to volume replacement in patients undergoing major surgery.

Methods We studied 20 patients scheduled for elective major abdominal surgery. After induction of anaesthesia, all haemodynamic variables were recorded immediately before (T1) and subsequent to volume replacement (T2) by infusion of 6% hydroxy-ethyl starch (HES) 130/0.4 ($7\,\mathrm{ml\,kg^{-1}}$) at a rate of $1\,\mathrm{ml\,kg^{-1}\,min^{-1}}$.

Results The volume-induced increase in SVI was at least 15% in 15 patients (responders) and less than 15% in five patients (nonresponders). Baseline SVV correlated significantly with changes in SVI (ΔSVI; $r = 0.80$; $P < 0.001$) as did baseline PVI ($r = 0.61$; $P < 0.004$), whereas baseline values of central venous pressure showed no correlation to ΔSVI. There was no significant difference between the area under the receiver operating characteristic curve for SVV (0.993) and PVI (0.973). The best threshold values to predict fluid responsiveness were more than 11% for SVV and more than 9.5% for PVI.

Conclusion Although arterial pressure-derived SVV revealed the best correlation to volume-induced changes in SVI, the results of our study suggest that both variables, SVV and PVI, can serve as valid indicators of fluid responsiveness in mechanically ventilated patients undergoing major surgery.

Eur J Anaesthesiol 2010;27:555–561

Keywords: fluid responsiveness, major abdominal surgery, pleth variability index, pulse oximeter plethysmography, stroke volume variation

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

Methods: 67 consecutive mechanically ventilated patients in the ICU were prospectively included. Three were excluded. The administration and dosage of NE, heart rate, mean arterial pressure, PVI and ΔPP were measured simultaneously.

Results: In all patients, the correlation between PVI and ΔPP was weak ($r^2 = 0.21$; $p = 0.001$). 23 patients exhibited a ΔPP > 13%. A PVI > 11% was able to identify patients with a ΔPP > 13% with a sensitivity of 70% (95% confidence interval: 47%-87%) and a specificity of 71% (95% confidence interval: 54%-84%). The area under the curve was 0.80 ± 0.06. 35 patients (53%) received norepinephrine (NE(+)). In NE(+) patients, PVI and ΔPP were not correlated ($r^2 = 0.04$, $p > 0.05$) and a PVI > 10% was able to identify patients with a ΔPP > 13% with a sensitivity of 58% (95% confidence interval: 28%-85%) and a specificity of 61% (95% confidence interval:39%-80%). The area under the ROC (receiver operating characteristics) curve was 0.69 ± 0.01. In contrast, NE(-) patients exhibited a correlation between PVI and ΔPP ($r^2 = 0.52$; $p < 0.001$) and a PVI > 10% was able to identify patients with a ΔPP > 13% with a sensitivity of 100% (95% confidence interval: 71%-100%) and a specificity of 72% (95% confidence interval: 49%-90%). The area under the ROC curve was 0.93 ± 0.06 for NE(-) patients and was significantly higher than the area under the ROC curve for NE(+) patients ($p = 0.02$).

Conclusions: Our results suggest that in mechanically ventilated adult patients, NE alters the correlation between PVI and ΔPP and the ability of PVI to predict ΔPP > 13% in ICU patients.

Outcome studies

Only one-

- Goal directed intraoperative volume optimization using PPV as a haemodynamic endpoint has recently been shown to reduce the duration of mechanical ventilation and hospital stay, as well as postoperative complications in high-risk surgical patients

Lopes MR et al. Crit Care 2007

Aortic & Brachial blood flow velocity

- Using Doppler US- beat to beat variation in blood flow velocity can be documented
- Variability > 12% predicts responsiveness with Sn of 100% & Sp 89% in Ventilated patients with septic shock
- Invasive, long learning curve, lack of reproducibility
- Practically difficult to keep probe in position

    - Feissel M et al. Chest 2001;119(3):867–73

Resp Variability of SVC & IVC

- IVC-
  - Intramural pressure = RAP
  - Extramural pressure = IAP

- In positive pressure ventilation-
  - RAP increased disproportionate to IAP- IVC distends
  - When IVC less distended as in dehydration- this phasic variation is increased

- SVC-
  - Mainly intrathoracic
  - During PPV- transmural pressure decreased rather than increased
  - So diameter is decreased

Enomoto TM et. al. Crit Care Clin 2010;26: 307-21

Resp Variability of SVC & IVC

- dIVC= 100 X $D_{max} – D_{min}$ / D_{min}
- >18% - predictive of fluid responsiveness

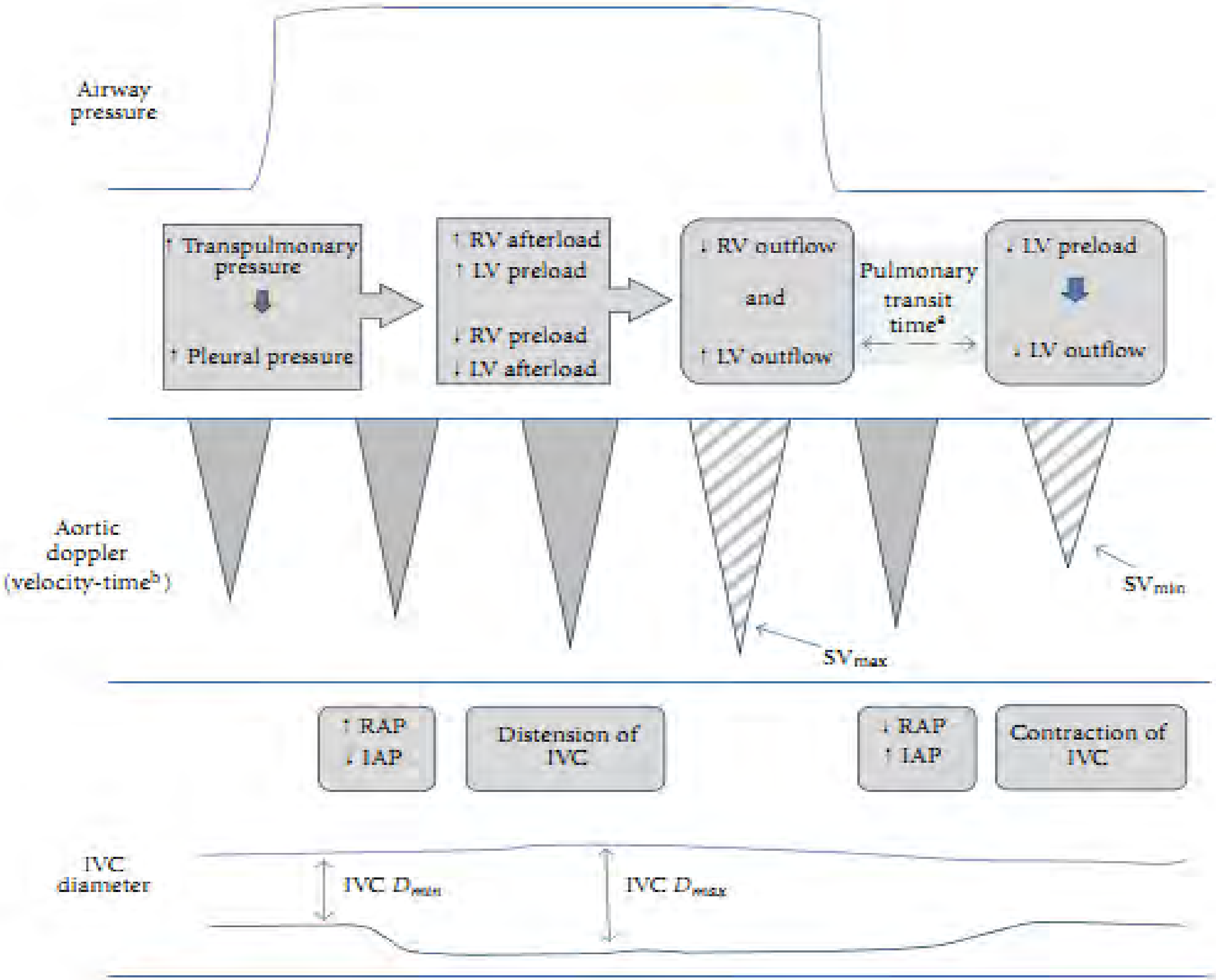
Barbier C et al. Intensive Care Med 2004;30:1740–6

- DD_{IVC} = 100 X $D_{max} – D_{min}/D_{\underline{mean}}$
- > 12% - PPV- 93%, NPV- 92%

Feissel M et al. Intensive Care Med 2004;30:1834–7

- SVC collapsibility index= 100 X $D_{max} – D_{min}/D_{\underline{max}}$
- Threshold of >36%- Sn- 90%, Sp- 100%

Vieillard-Baron A et al. Intensive Care Med 2004;30:1734–9



Mandeville JC, Colebourn CL. Critical Care Research and Practice 2012

Resp Variability of SVC & IVC

- dIVC & DD_{IVC} are appealing as
  - Accurate
  - Feasible
  - Easy to learn
  - Non invasive

- SVC collapsibility index- requires esophageal doppler

- Effect of lower/higher tidal volume and, arrhythmia has not been studied

- Effect of IAP not clearly studied

Enomoto TM et. al. Crit Care Clin 2010;26: 307-21

Review Article

Can Transthoracic Echocardiography Be Used to Predict Fluid Responsiveness in the Critically Ill Patient? A Systematic Review

Introduction. We systematically evaluated the use of transthoracic echocardiography in the assessment of dynamic markers of preload to predict fluid responsiveness in the critically ill adult patient. *Methods*. Studies in the critically ill using transthoracic echocardiography (TTE) to predict a response in stroke volume or cardiac output to a fluid load were selected. Selection was limited to English language and adult patients. Studies on patients with an open thorax or abdomen were excluded. *Results*. The predictive power of diagnostic accuracy of inferior vena cava diameter and transaortic Doppler signal changes with the respiratory cycle or passive leg raising in mechanically ventilated patients was strong throughout the articles reviewed. Limitations of the technique relate to patient tolerance of the procedure, adequacy of acoustic windows, and operator skill. *Conclusions*. Transthoracic echocardiographic techniques accurately predict fluid responsiveness in critically ill patients. Discriminative power is not affected by the technique selected.

Mandeville JC, Colebourn CL. Critical Care Research and Practice 2012

Passive Leg Raising

- Reversible fluid challenge, safe
- Estimated volume is between 150-750mL
- Can be used in spontaneously breathing patients & those not in sinus rhythm
- First demonstrated by Boulain & colleagues in 2002
- Aortic blood flow increase of >10%- Sn 97%, Sp 94%
- PPV also predicts resp. but less accurate than ABF

Enomoto TM et. al. Crit Care Clin 2010;26: 307-21

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

Cavallaro F et al. Intensive Care Med (2010) 36:1475–1483

Abstract *Purpose:* To systematically review the published evidence on the ability of passive leg raising-induced changes in cardiac output (PLR-cCO) and in arterial pulse pressure (PLR-cPP) to predict fluid responsiveness. *Methods:* MEDLINE, EMBASE and the Cochrane Database of Systematic Reviews were screened. Clinical trials on human adults published as full-text articles in indexed journals were included. Two authors independently used a standardized form to extract data about study characteristics and results. Study quality was assessed by using the QUADAS scale. *Results:* Nine articles including a total of 353 patients were included in the final analysis. Data are reported as point estimate (95% confidence intervals). The pooled sensitivity and specificity of PLR-cCO were 89.4% (84.1–93.4%) and 91.4% (85.9–95.2%) respectively. Diagnostic odds ratio was 89.0 (40.2–197.3). The pooled area under the receiver operating characteristics curve (AUC) was 0.95 (0.92–0.97). The pooled correlation coefficient *r* between baseline value of PLR-cCO and CO increase after fluid load was 0.81 (0.75–0.86). The pooled difference in mean PLR-cCO values between responders and non-responders was 17.7% (13.6–21.8%). No significant differences were identified between patients adapted to ventilator versus those with inspiratory efforts nor between patients in sinus rhythm versus those with arrhythmias. The pooled AUC for PLR-cPP was 0.76 (0.67–0.86) and was significantly lower than the AUC for PLR-cCO ($p < 0.001$). The pooled difference in mean PLR-cPP values between responders and non-responders was 10.3% (6.5–14.1%). *Conclusions:* Passive leg raising-induced changes in cardiac output can reliably predict fluid responsiveness regardless of ventilation mode and cardiac rhythm. PLR-cCO has a significantly higher predictive value than PLR-cPP.

Keywords Hemodynamics · Shock · Cardiac output · Blood volume · Blood pressure · Fluid therapy

Respiratory systolic variation test (RSVT)

- 3-4 consecutive PC breaths with increasing peak pressure are given
- Minimum SBP after each breath is noted
- Results are plotted against airway pressure
- Steeper slope- suggests fluid responsiveness, AUC 0.96
- Independent of tidal vilume

Respiratory systolic variation test (RSVT)