FLUID RESPONSIVENESS & TOLERANCE

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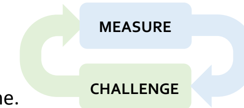
DEFINITIONS:

- Fluid resuscitation can be beneficial when required or harmful in excess. Methods to **predict fluid responsiveness** enable parsimonious administration of fluids, resulting in reduced fluid balance, shorter duration of vasopressors, and lower risk of renal failure.
- ***Fluid responsive (FR)*** a 10-15% increase in cardiac output (CO) when fluid administered; fluid responsiveness does not mean fluid is "needed" only the CO will increase with volume.
- Importantly, only about 50% of septic patients are FR but FR can be assessed in most pts.
- Clinical parameters (hourly UOP, MAP) tend to lag and do not reliably predict FR.
- ***Fluid tolerance (FT)*** the absence of harm (e.g. pulmonary edema) when fluid administered

TYPES OF FLUID RESPONSIVENESS TEST:



Some **MEASUREMENTS** predict **FR** in isolation (respiratory variation in PPV or LVOT VTI); others must be combined w/ a **CHALLENGE** maneuver (NICOM or ETCO2 with PLR). The level of evidence varies for each combination →

CHALLENGE MANEUVERS \ MEASUREMENTS	PAC CCO	Pulse Contour	LVOT VTI	Carotid VTI	NICOM	ETCO2
PLR	dark green	dark green	yellow	yellow	green	yellow
Mini-Bolus	green	green	yellow	?	?	red
PEEP	yellow	yellow	?	?	yellow	?
EEO	dark green	green	yellow	peach	?	
Resp Variation		dark green	light green	green		

LEVEL OF EVIDENCE: (white) unable to perform; (?) unknown; (peach) single small study; (yellow) a few small studies; (green) multiple/larger studies

FR tests can be **STATIC** (e.g. CVP, PCWP) or **DYNAMIC** (PPV). Generally, **DYNAMIC** measurements are better at predicting FR. Some are usable in spontaneously (S) breathing or prone (P) pts.

USING INVASIVE CATHETERS

ARTERIAL LINE

Pulse Pressure Variation (PPV) — P — DYNAMIC

Principle: variation in pulse pressure (PPV) with the respiratory cycle suggests fluid responsiveness due to heart lung interactions.

Requires:
- Sinus rhythm w/o significant ectopy
- Mechanically ventilated w/o spontan breaths
- TV > 6 ml/kg (unreliable in low TV; measure PPV 1 min after increasing TV to 6 mL/kg IBW)
- Absence of RV failure
- Closed chest

Interpretation: >12% increase in PPV suggests FR

Performance: good (AUROC > 0.92) but lower in prone position (AUROC 0.79) or APRV (AUROC 0.79)

$$PPV(\%) = 100 \times \frac{(PP_{max} - PP_{min})}{PP_{mean}}$$

Pulse Contour Cardiac Output — S — P — DYNAMIC

Principle: analysis of the waveform can be used to estimate ***stroke volume variation*** (SVV) or ***cardiac output*** (CO) using proprietary formulas. Some are uncalibrated (FloTrac), or calibrated (LiDCO [Li dilution], PiCCO [transpulmonary thermodilution using a temperature sensing arterial line]

Interpretation: has same caveats as PPV; optimal threshold to predict FR varies by device (~10-15%)

Performance: good (AUROC 0.8 -0.95)

CENTRAL VENOUS LINE

Central Venous Pressure (CVP) — STATIC

Principle: Measures CVP as a surrogate for RV filling pressure. Many limitations: Affected by volume status, RV function & tricuspid valve function.

Performance: poor (AUROC 0.56); likely unusable

PULMONARY ARTERY CATHETER

Thermodilution CO/CI — S — P — CHALLENGE

Principle: Thermodilution measurement of CO via a PAC, which can be either continuous (via heating) or intermittent (via cold saline injection).

Interpretation: 10-15% increase in CO/CI before/after PLR, bolus, EEO, or PEEP challenge.

Performance: CCO PAC is gold standard in many studies. Many potential causes of error: catheter malposition, variation in injectate temp, shunt, respiratory effect, very low CO, or valvulopathy.

PAOP/PCWP — STATIC

Principle: PAOP/PCWP approximates LAP. Patients w/ a low LAP may benefit from fluids.

Interpretation: PCWP < 12

Performance: poor (AUROC 0.56)

Mixed Venous O2 Saturation (S_vO_2) — DYNAMIC

Principle: An increase in SvO_2 suggests improved CO, however high baseline SvO_2 does not preclude FR.

Interpretation: 2% rise in SvO_2 after fluid challenge, suggests FR. Unknown if ΔSvO_2 useful w/ maneuvers.

Performance: poor-adequate (AUROC 0.73)

POINT OF CARE ULTRASOUND

IVC Size & Distensibility — DYNAMIC

Principle: IVC size reflects RA pressure, similar to CVP. Thus measuring the IVC size & phasic variation with respiration might predict FR. Distensibility is defined as the ***Δ*** in IVC size with respiration.

Interpretation: >15% distensibility is best threshold

Performance: Poor (AUROC 0.69 – 0.71) overall; may be better in intubated pts w/o spontaneous breaths & complete IVC collapse may be more sensitive for FR

LV End Diastolic Area (LVEDA) — STATIC

Principle: measure the cross sectional area of the LV at the end of diastole (reflects adequate filling); "kissing papillary muscles" is the extreme

Performance: poor (AUROC 0.64)

LVOT VTI — DYNAMIC — CHALLENGE

Measure outflow of blood from the LV. Variability in VTI is analogous to PPV, absolute values can be compared before/after a challenge maneuver. CO can also be calculated (with LVOT diameter & HR)

Interpretation: >15% increase in LVOT VTI predicts FR with good performance (AUROC 0.92) but may be technically difficult to perform

$$CO = VTI \times \frac{\pi}{2} Diameter^2 \times HR$$

Carotid VTI — DYNAMIC — CHALLENGE

Principle: Similar to LVOT VTI but easier to measure carotid facilitating repeat measurements. Carotid flow time may also provide useful data. Patch based monitors may enable continuous monitoring.

Doppler of Portal vein, hepatic vein, renal arteries

The **VeXUS Protocol** is a technique that integrates multiple POCUS measurements. Studies ongoing.

MINIMALLY INVASIVE

BIOREACTANCE/NICOM: — S — P — CHALLENGE

Principle: detection of blood flow in the chest by application of an external electric field. Averages blood flow over 8-30 seconds. Combine with a challenge (PLR, microbolus) to measure ΔSV.

Interpretation: 10% increase in SV predicts FR

Performance: adequate-good (AUROC 0.75 – 0.88) also works with similar performance when prone

END TIDAL CO2 — P — CHALLENGE

Principle: An increase cardiac output causes increases delivery of CO2 to the lungs, increasing exhaled CO2.

Interpretation: ΔETCO2 ≥5% with PLR predicts fluid responsiveness. ΔETCO2 <2 mmHg is unlikely fluid responsive. Combine with PLR (but NOT Micro-bolus)

Performance: Good (AUROC 0.85) in MV patients but not in spontaneous breathing patients.

PULSE OXIMETRY WAVEFORM ANALYSIS

Principle: analysis of the plethysmographic waveform is analogous to PPV measurement using arterial line: a high degree of respiratory variation predicts FR.

Interpretation: 15% variability in PPV

Performance: poor (AUROC 0.63); limited studies

PULMONARY A vs B LINE PATTERN

Principle: sonographic lung changes precede other signs of volume overload. An A-line predominant lung US pattern suggests **fluid tolerance (FT)** a bolus can be given w/o risk of pulmonary edema.

PASSIVE LEG RAISE (PLR)

Principle: positioning a patient flat (0°), then raising legs to 45°) quickly (30-90 sec) returns a reservoir of ~300 ml of venous blood to the central circulation. Patient must be able to (painlessly) elevate legs

Protocol:
1. Measure CO while semi-recumbent w/ HOB up 45°
2. Lower the body, elevated the legs to 45° for 1 min and repeat CO measurement.

Interpretation: >10% increase in CO with PLR predicts FR. May be the most reliable challenge maneuver (AUROC >0.9) w/ CO measurement; change in pulse pressure w/ PLR is not a reliable predictor of FR.

MINI-BOLUS & MICRO BOLUS

Principle: observing the hemodynamic response to the rapid infusion of a small volume 50-100ml) of fluid can predict the response to a larger bolus

***Protocol*: Administer 50 ml over 1 min** (microbolus) or **100 ml over 1 min** (Mini-bolus) while measuring CO (PAC, A-line, NICOM, etc)

Interpretation: >10% increase in CO immediate after the bolus suggests FR.

Performance: good (AUROC 0.83 micro & 0.95 mini) compared to 250cc fluid bolus

HIGH PEEP CHALLENGE

Principle: for patients on MV increasing PEEP can identify FR by identifying a decrease in MAP.

Protocol: Increase PEEP from 10 to 20 cmH2o for 1 min while contininuously measuring CO and MAP

Interpretation: 8%↓ MAP or 10% ↓ CO suggests FR

Performance: good (AUROC 0.92) but has only been validated in a small number of studies.

END EXPIRATORY OCCLUSION (EEO)

Principle: For MV patients, each breath increases intrathoracic pressure & impedes venous return. Interrupting MV at end expiration transiently increases preload. Decrease in CO during a 15 sec expiratory hold maneuver predicts FR

Requires:
- Mechanically ventilated at 8ml/kg TV
- Able to tolerate 15 sec apnea
- Continuous CO measurement (Aline, PAC, etc)

Interpretation: a 5% increase in CO during EEO maneuver compared to baseline suggest FR

Performance: Good (AUROC >0.9) if Tv > 8 ml/kg; spont respirations disrupt test. Unreliable if prone