Original Article

Passive Leg Raising: Simple and Reliable Technique to Prevent Fluid Overload in Critically ill Patients

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Abstract

Background: Dynamic measures, the response to stroke volume (SV) to fluid loading, have been used successfully to guide fluid management decisions in critically ill patients. However, application of dynamic measures is often inaccurate to predict fluid responsiveness in patients with arrhythmias, ventricular dysfunction or spontaneously breathing critically ill patients. Passive leg raising (PLR) is a simple bedside maneuver that may provide an accurate alternative to guide fluid resuscitation in hypovolemic critically ill patients. **Methods:** Pertinent medical literature for fluid responsiveness in the critically ill patient published in English was searched over the past three decades, and then the search was extended as linked citations indicated. **Results:** Thirty-three studies including observational studies, randomized control trials, systemic review, and meta-analysis studies evaluating fluid responsiveness in the critically ill patient met selection criteria. **Conclusions:** PLR coupled with real-time SV monitors is considered a simple, noninvasive, and accurate method to determine fluid responsiveness in critically ill patients with high sensitivity and specificity for a 10% increase in SV. The adverse effect of albumin on the mortality of head trauma patients and chloride-rich crystalloids on mortality and kidney function needs to be considered when choosing the type of fluid for resuscitation.

Keywords: *Colloids, critically ill patients, crystalloids, fluid responsiveness, passive leg raising, stroke volume*

Introduction

Intravenous fluid administration (IVF) is the cornerstone of the resuscitation therapy in critically ill patients.[1] The appropriateness of the selected intervention to guide the fluid management is often crucial to avoiding the deleterious effect of over, under, or inappropriate resuscitation. Over-resuscitation with fluid may result in pulmonary edema. Under resuscitation would result in hypoperfusion of the tissue with complications of end-organ damage or dysfunction such as renal failure.[2,3]

Traditionally, hemodynamic monitoring parameters such as heart rate, central venous pressure (CVP), and mean arterial pulse pressure (MAP) are often insensitive and sometimes misleading in the assessment of circulating blood volume. Moreover, studies have shown that only approximately 50% of critically ill patients in whom the fluid is administered do exhibit an increase in blood flow and that half of the patients will receive unnecessary fluid loading.[4-11]

Dynamic measures, the response to stroke volume (SV) to fluid loading, have shown to accurately predict fluid responsiveness in critically ill patients as compared to static parameters such as CVP and MAP.[4,12,13] SV variation, when used with controlled mechanical ventilation, is considered a sensitive and specific indicator in determining whether the patient is preload responsive. SV variation is the result of heart-lung interaction.[4,12,13] Depending on the patient's fluid status, the positive pressure breath compressing the inferior and superior vena cava resulting in a decreased venous return, which after transmitting to heart and lungs causes of variation in the SV and the corresponding swing in arterial pressure tracing. Although SV variation is a sensitive indicator of preload responsiveness, it has its limitations. A regular heart rhythm and controlled mechanical ventilation without spontaneous breathing and large tidal volumes >8 mL/kg are required for dynamic parameters to accurately predict volume responsiveness.

Passive leg raising (PLR) in combination with SV is currently considered superior in

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predicting fluid responsiveness in mechanically ventilated critically ill patients despite cardiac arrhythmias and spontaneous breathing activity compared with dynamic measures such as CVP and MAP.[14-16]

This article reviews the pertinent literature describing the use of PLR for fluid responsiveness in critically ill patients with circulatory failure.

Methods

Current medical literature including PubMed, MEDLINE, EMBASE, Cochrane Central Register of Controlled Trials and Google Scholar search databases were searched for the primary search terms as fluid resuscitation, fluid responsiveness, and fluids types published in English from April 1989 to October 2016 and then the search was extended as linked citations indicated.

Results

PLR, a simple bedside maneuver, and analysis of the variation in SV-induced by positive pressure ventilation is currently the most accurate and noninvasive method to managing fluid administration in hypovolemic critically ill patients who are mechanically ventilated despite cardiac dysfunctions. There is no convincing evidence to suggest the superiority of colloids over crystalloids fluid resuscitation in hypovolemic critically ill patients.

Discussion

Defining fluid responsiveness

Fluid responsiveness has been defined by at least 10% increase in SV in response to rapid infusion of 20–30 mL/kg or 500 mL of fluids over 10–15 min.[17,18] The resuscitation fluid increases the mean circulating filling pressure greater than the increase in CVP and thereby increasing the gradient for venous return.[14]

Assessment of fluid responsiveness

Static measures of resuscitation fluids

In the static parameters, the fluid responsiveness is arbitrarily defined as an increase in urine output >0.5 mL/kg/h, the CVP of 8–12 mmHg, or the MAP >65 mmHg, following fluid bolus (usually 20–30 mL/kg) over 10–15 min.[19,20] However, these measures are unable to determine fluid responsiveness and may be associated with significant volume overload and higher mortality rate due to aggressive volume expansion.[19,20] Clinical signs such as poor tissue perfusion, low blood pressure, delayed capillary refill, hypotension, tachycardia, and narrow pulse pressure are also unreliable to predict fluid responsiveness.[10] However, several studies have shown a poor correlation between CVP and blood volume changes and no relationship between cardiac filling pressure and fluid volume changes during the resuscitation.[4,5] Further, critically ill patients have limited filling pressure compared with normal individuals

when given a similar amount of resuscitation fluids, and nearly half of hemodynamically unstable patients respond to a fluid bolus.[4,5,8,21,22]

Dynamic measures of resuscitation fluids

The gold standard method for assessing volume status and to predict fluid responsiveness is the change in SV following a fluid bolus.[23-27] The use of SV variation to guide fluid resuscitation allows for the appropriate use of fluid and the maximum benefit while mitigating complications. However, there can be considerable variability to different methods of determining SV/cardiac output.

Dynamic parameters can predict changes in SV after a fluid challenge and are based on the interactions between intrathoracic pressure changes with each breath and the left ventricular end-diastolic volume and cardiac output.[17,28-30]

As the lung inflate from a positive pressure breath, in the hypovolemic patient the vasculature compresses impeding venous return which is reflected in the variation of the SV which result in a swing in arterial pressure tracing. An SV variation of more than 13% indicates the patient is fluid responsive and should benefit from the additional fluid.[26,27,31] Once the patient has been resuscitated with volume and the SV is <12% and the patient is euvolemic, the positive pressure breath no longer compress the inferior and superior vena cava reducing the venous return and variation of the SV and corresponding arterial pressure tracing is minimize. This will be reflected in an SV reading of <12% indicating another intervention such as inotrope or vasopressor may be selected other than volume.[25,28]

Dynamic parameters can be measured by esophageal Doppler monitoring for aortic blood flow and transthoracic measurements of the left ventricular outflow tract velocities for the estimation of SV. Recently, the use of point-of-care ultrasound (POCS) has been proposed as viable simple and less invasive tool to guide fluid.[28] The validity of the POCS fluid responsiveness guide, however, requires further study to comparing results obtained from various other dynamic methods to further validate the POCS benefits and limitations.

Although dynamic parameters are very sensitive indicator of preload responsiveness, it has several limitations. First, dynamic techniques are invasive, operator dependent, and require considerable expertise,[12,23,25-27,31-33] second, controlled mechanical ventilation must be present in patients to induce the required changes in SV, third, dynamic parameters were found inaccurate to predict fluid responsiveness in patients with arrhythmias, ventricular dysfunction, and spontaneously breathing critically ill patients with tidal volume <8 mL/kg.[4,12,13]

Passive leg raising

When clinicians are unable to use SV other volume challenge maneuvers can be employed. PLR is a

simple bedside technique that can be used to assess fluid responsiveness. This maneuver can be used as a pseudo-fluid challenge of an approximately of 150–300 mL by placing patient head down flat and feet up at a 45° angle. Blood from the lower extremities translocate to intrathoracic compartment where increases right and left ventricular preload and if the patient is responsive increases SV and cardiac output. An increase in SV of more than 10% indicates the patient is preload responsive with the high sensitivity and specificity.

PLR in combination with cardiac output monitoring is the most accurate method to determine fluid responsiveness by tracking changes in SV-induced by positive pressure ventilation in critically ill patients with 86% sensitivity and 90% specificity for a 10% increase in SV.[16] The PRL maneuver is easy to perform taking <5 min to complete and can be repeated after each volume infusion to see if additional volume would be beneficial without any risk of pulmonary edema.[16]

Choices in type of resuscitation fluids

There is no convincing evidence to suggest the superiority of colloids over crystalloids fluid resuscitation in hypovolemic critically ill patients.[33-39]

A choice between colloids and crystalloids and the different impact of chloride-rich versus balanced solutions can impact the patient outcomes receiving fluid resuscitation. Albumin and 0.9% sodium chloride (NaCl) appear to have similar effects on mortality in critically ill patients, with the exception of patients with traumatic brain injury [Table 1].[40]

The 2004 Saline versus Albumin Fluid Evaluation trial is the largest clinical trial to date comparing 5% albumin and 0.9% NaCl in a heterogeneous group of 6997 adult patients requiring fluid resuscitation. Authors found no difference in the primary outcome of 28-day all-cause mortality between the albumin and crystalloids, but in the 492 (7%) patients with traumatic brain injuries, the relative risk of death was significantly greater with albumin compared to saline. Further, analyses by the same investigators indicated that this detrimental effect was limited only to patients with severe traumatic brain injuries. While crystalloid appears to be the fluid of choice for trauma patients, colloid is a more

protective IVF among patients with severe infection and septic shock.[37,40,41]

Colloid solutions

Human albumin (5%) in saline is the most frequently used colloids in clinical practice. The oncotic pressure gradient generated by albumin infusion will draw fluid from interstitial fluid into the intravascular space, therefore, increasing the efficiency of intravascular expansion relative to a comparable amount of crystalloid.[17] Although albumin is safe for use as a resuscitation fluid in patients with sepsis, its use is associated with increased mortality among patients with traumatic brain injury [Table 1].[40]

The use of hydroxyethyl starch solutions (HES), a synthetic colloid, is associated with high rates of acute kidney injury (AKI) and renal replacement therapy among patients with volume shock.[42,43] Thus, the current guideline discourages the use of HES in patients with volume shock due to higher rates of mortality.[44-47]

Crystalloid solutions

Balanced salt solutions have shown mortality and morbidity benefits over normal saline in critically ill patients.[28,46,47] Normal saline (0.9% NaCl) is the most widely used crystalloids for the resuscitation in the critically ill patients. The use of normal saline in large amount has been shown to induce renal vasoconstriction, AKI, nonanion gap metabolic acidosis, and increased inflammatory cytokines release.[48-51]

Optimal dosing of fluid therapy after resuscitation

Maintenance fluid therapy should be used in volume-responsive patients when end-organ perfusion

Table 2: Calculation of obligatory urine volume and electrolyte-free water excretion

Solute load to be excreted (mOsm/day)	Obligatory urine volume (liter/day)	Electrolytr-free water excretion (liter/day)
800	4	2
400	2	1
200	1	0.5

§The osmolar contribution of electrolytes is the urine [Na mEq/L + K mEq/L] x 2 + [urea mg/dL÷2.8]. Assuming the urine osmolality is 200 mOsm/kg and the tonicity is 140 mOsm/kg

Table 1: Comparison of different colloid and crystalloid fluids with plasma

Variable	5% Albumin/L	Plasma-Lyte A/L	0.9% NaCl	Lactated Ringer's/L	Plasma/L
Na$^+$/mmol/L	130-160	140	154	131	140
Cl-/mmol/L	0	98	154	111	100
K$^+$/mmol/L	<2	5	0	5.4	5
Ca^{++}/mmol/L	0	0	0	2	2.2
Mg^{++}/mmol/L	0	1.5	0	1	1
Lactate/mmol/L	0	0	0	29	1
Acetate/mmol/L	0	27	0	0	0
Gluconate	0	23	0	0	0
pH	7.4	7.4	5.4	6.5	7.4

goals are met. Patients with hypovolemic shock are often acute renal injury and excrete hypotonic urine because of a defect in urinary diluting ability. Healthy children and adults should be able to lower urinary osmolality below 100 mOsm/kg. The daily solute load that needs to be excreted in adults on a normal diet is 500–1000 mOsm, which consists of urea generated from metabolism of dietary protein, and electrolytes.[52]

Patients with circulatory failure are unable to lower urine osmolality below 100 mOsm/kg. The low solute intake in such patients who already have a urinary dilution defect will lead to increased free water retention and hyponatremia.[53] Therefore, a strategy to determine appropriate maintenance fluid dosing is needed to avoid volume overload and hyponatremia after the initial fluid resuscitation. In this strategy, the electrolyte-free water clearance is dependent on the obligate urine output that, in turn, is dependent on the daily solute load that needs to be excreted.[53]

To appreciate this, consider a hypothetical patient who is unable to lower urine osmolality below 200 mOsm/kg and has a urine Na^+ concentration of 50 mEq/L (osmolality 100 mOsm/kg), K^+ 20 mEq/L (osmolality 40 mOsm/kg), and urea 168 mg/dL (osmolality 60 mOsm/kg). The effective osmolality or tonicity of the urine is 140 mOsm/kg (the sum of the Na^+, and K^+, osmolality) since urea is an ineffective solute. Thus, the urine in this particular patient is half isotonic compared with plasma osmolality, or one can say each liter of urine contains 0.5 L of free water.

If this hypothetical patient had a daily solute load of 800 mOsm, he would excrete 4 L obligate urine daily (800 mOsm/200 mOsm/kg) and hence 2.0 L of electrolyte-free water clearance (approximately half of the serum tonicity). This patient would be highly unlikely to become hyponatremic with a normal daily water intake of 2.5 L. If, on the other hand, the daily solute load were lowered to 400 mOsm, the daily obligatory urine output would be 2.0 L (400 mOsm/200 mOsm/kg), the daily electrolyte-free water excretion would be only 1.0. In this situation, a restriction of water intake to approximately 1.5 L daily would be needed to avoid progressive hyponatremia.[54] Finally, a patient with a daily solute load of 200 mOsm would have a daily urine output of 1 L (200 mOsm/200 mOsm/kg) and electrolyte-free water excretion of 0.5 L and would likely become progressively hyponatremic despite severe restriction of water intake[54,55] [Table 2].

Conclusions

PLR, when used with SV variation, is a highly sensitive and specific indicator in predicting fluid responsiveness in critically ill patients who are mechanically ventilated despite cardiac dysfunctions. There is no convincing evidence to suggest the superiority of colloids over crystalloids fluid resuscitation in hypovolemic critically ill patients.

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