# Central venous pressure is a stopping rule, not a target of fluid resuscitation

Michael R Pinsky, John A Kellum and Rinaldo Bellomo

The determinants of cardiovascular homoeostasis are complex and more related to effective circulating blood volume and vasomotor tone than to cardiac pump function. The heart will pump out all it receives until the moment it fails, independent of the level of contractility. Contractility and ventricular distension only define the limits to maximal cardiac output in response to volume loading, beyond which decompensated heart failure occurs.

Since the right atrial pressure (often approximated as central venous pressure [CVP]) is at the fulcrum between venous return and right ventricular filling, it would be impossible for CVP to not be closely related to all aspects of right-sided cardiovascular physiology.[1] However, because it is at this fulcrum, it is directly affected by the upstream driving pressure and resistance of venous return, and also by right ventricular responsiveness. Regrettably, both the ease of measuring CVP and the lack of understanding of its determinants have led to the widespread misinterpretation of its meaning. The recent Surviving Sepsis Campaign guidelines still include a CVP of 8 mmHg as a resuscitation target,[2] even though there are no clinical data to support this claim[3] and no physiological basis to defend it. A possible exception is if CVP is $<8$ mmHg and increases in positive end-expiratory pressure (PEEP) are contemplated. Under such circumstances, the patient may need additional fluids to remain haemodynamically stable.[4] To use CVP as a measure of intravascular volume or to define volume responsiveness or the cardiac output response to volume challenges is not only incorrect but potentially dangerous. CVP remains an insensitive predictor of preload responsiveness.[5]

The primary force returning blood to the right ventricle from the body is the ratio between the pressure gradient for venous return (dVR) and the resistance to venous return (RVR). CVP is the downstream pressure for dVR. However, its only relevance exists in relation to the upstream pressure, the mean systemic (venous) pressure, defined by the effective circulating blood volume. Mean systemic pressure is a function of the total blood volume and its distribution among the various venous capacitance units of the periphery. Different vascular beds have varying unstressed volumes that do not contribute to mean systemic pressure. Furthermore, with increases and decreases in vasomotor tone, as often occur in cardiovascular insufficiency states and their management, unstressed volume may also vary widely. For example, in sepsis, when vasodilation occurs, both the total vascular capacitance and unstressed volume of the vasculature increase. This is why most patients presenting with sepsis may respond to fluid resuscitation; not because they have lost intravascular volume (which they may do later from capillary leak) but because of the increased unstressed volume. This, in turn, decreases the mean systemic pressure and causes dVR to decrease.

Since normal right ventricular ejection pumps blood forward with minimal increases in back pressure, fluid loading increases dVR by increasing the mean systemic pressure through an increase in stressed volume while CVP remains constant. If, however, volume overdistends the right ventricle, or increased pulmonary artery pressure impedes right ventricular ejection, then the physiological equivalent of acute cor pulmonale occurs. From a physiological perspective, this is because as the mean systemic pressure is increased by fluid loading, the CVP also increases by an equivalent amount resulting in minimal or no change in cardiac output. Thus, rising CVP in response to fluid resuscitation should be a "stopping rule" because further fluid loading would only over distend the right ventricle, compromising left ventricular filling and cardiac output.

Since CVP is the back pressure to venous return from the body, and CVP is normally close to zero, it normally does not impede passive venous return. In circulatory failure states, CVP increases. If the CVP is $\geqslant 8$ mmHg, then some degree of hypervolaemia must be present, because mean systemic pressure needs to be greater still to maintain an adequate dVR for flow. Since several techniques have been validated to measure mean systemic pressure at the bedside,[6,7] the future analysis of critically ill patients should include estimating dVR.

But how is it possible for cardiac output to increase without a change in CVP? In normal conditions, the right ventricle fills below its unstressed volume, such that the right ventricular transmural pressure remains constant and right ventricular volumes increase.[8,9] Presumably, conformational changes in the right ventricular free wall allow for this increased volume without increased wall stress. This explains why the right ventricular ejection fraction always decreases with fluid loading.[10]

The other forgotten part of the venous return equation defining steady state cardiac output is the resistance to venous return. Venous resistance is primarily a function of conductance (the ease with which a fluid is transported within vessels) rather than direct resistance, because venous

flow is slow and laminar. Accordingly, increasing the number of parallel venous vessels or individual vessel diameter will both decrease resistance to venous return. Thus, for the same dVR and CVP, cardiac output will be higher with decreased resistance to venous return. Assuming CVP and dVR were to remain constant but the RVR decreased due to increased parallel vascular circuit perfusion, cardiac output would increase. In practice, mean systemic pressure and RVR often vary inversely in response to vasodilator and vasoconstrictor therapies, such that the net effect of these agents on cardiac output is often negligible.[11,12]

At the bedside, CVP has primary value as a dynamic parameter to define when to stop giving fluids. If fluid loading causes CVP to increase, the right ventricle is filling above its unstressed volume and going into the physiological equivalent of acute cor pulmonale. This should be a stopping rule for bolus infusion. What level of CVP increase is needed to define this point is unclear but will be very small, probably less than 3 mmHg, since right ventricular diastolic compliance is great and such small increases in CVP will connote massive right ventricular dilation. Developing and then maintaining such an overloaded physiological state has a likely serious clinical cost in all types of conditions from cardiac failure to severe sepsis.[13,14]

## Competing interests

None declared.

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