Letter to the editor: Why persist in the fallacy that mean systemic pressure drives venous return?

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TO THE EDITOR: The work of Berger et al. (3), recently published in the American Journal of Physiology-Heart and Circulatory Physiology, has at its core the idea that steady-state venous return (F) is driven through the resistance to venous return (Rven) by the difference between mean systemic filling pressure (MSFP) and right atrial pressure (Pra)—what they refer to as “Guyton’s model.”

That idea comes from the “venous return curves” introduced in a seminal 1955 article (7). They were plots of steady-state F and Pra data obtained at various levels of total blood volume in dogs, a different plot for each volume. F was recorded as the output of a pump that forced blood collected at the right atrium into the pulmonary artery, never venous return as distinguished from cardiac output since these were equal when data was recorded. Pra at zero F was MSFP (by definition), the greater the volume, the greater the MSFP. With increase in F, Pra fell proportionately until it became close to zero. They elected to plot the data with Pra on the x-axis.

Thus plotted, the data fit the pattern that would appear if Pra were the independently variable pressure at the outlet of a resistive outflow tract draining a chamber kept at a constant pressure set at MSFP; in quantitative terms, \( F = (MSFP - \text{Pra}) \) divided by a constant with dimensions of resistance. This appearance supported the interpretation that MSFP - Pra is the pressure head that drives venous return and that reducing Pra would be the key to increasing venous return.

But it was actually the height of a Starling resistor that was the independent variable in the experiments of Guyton et al. (7), not Pra. This variable resistance throttled the pump output to bring F to the level at which the resultant Pra was consistent with the vertical position of the resistor relative to heart level [for exposition of this point, see Brengelmann (5)]. In short, it was F that set Pra, not vice versa. When Levy (8) took the approach of controlling F and recording Pra without the incorporation of a variable resistor in the circuit, he found the same proportionality between Pra and F in the range of Pra between zero and MSFP (8).

More recent articles have followed Levy in arguing that what we might call the F = (MSFP - Pra) / Rven view is a misinterpretation. (1, 2, 4). Nonetheless, the notion expressed in Berger et al. (3) persists. They and other adherents of this view evidently believe that MSFP exists physically within the vasculature at constant pressure, MSFP? The only answer consistent with the steady-state assumption is that its outflow is matched by inflow that keeps its volume and associated distending pressure constant.

If the volume and pressure within the vascular compartment at MSFP do not change, that means that the elastic energy stored in the walls of the compartment is not what drives its outflow. It cannot deliver energy to the flow moving through it; that would require shortening of its elastic fibers.

Therefore, even if there is such a thing as a compartment that stays at MSFP despite changes in F, it cannot be the source of the work expended in driving F through the venous resistance. It is merely a passive conduit. The elastic energy stored in its walls is untapped. In the absence of other energy sources such as the pumping action of respiration and of contracting skeletal muscle, all the work expended in forcing blood through the vasculature comes from the cardiac pump.\(^1\)

Mean systemic pressure in models. But what is really meant by “Guyton’s model”? Not a single compartment at MSFP and single outflow resistance, but a circuit of resistors and capacitors formed the analog of the peripheral vasculature from which Guyton et al. (7) derived their expression relating F, Pra, and the parameter called “impedance to venous return.” Though that electrical analog predicts the decline in Pra from MSFP that accompanies increase in F, none of its capacitors remain at constant voltage. Likewise, in other electrical or hydraulic analogs that quantitatively show the inverse F:Pra relationship, there is no physical representation of a persistent MSFP in any of the elastic components (10, 11).

What about the physical models one sees offered as teaching aids that represent MSFP as the hydrostatic pressure in a container (6, 9) from which venous return drains into the heart? For example, in one such conceptual model intended to represent the zero-flow condition with Pra equal to MSFP [Fig. 1A (9)], MSFP is meant, presumably, to be taken as the pressure at the bottom of the container. But the heart is shown positioned at the level of the surface of the liquid, where pressure would be zero, not MSFP. In Fig. 1B (9), the high-flow condition with Pra well below MSFP is illustrated with the heart positioned below the level of the bottom of the container. But there the pressure at the entrance to the heart would be MSFP plus the

\(^{1}\) This is not to deny that stored elastic energy in vascular compartments is important in buffering temporary imbalances between venous return and cardiac output; findings of Berger et al. (3) show this phenomenon in action, revealing inconsistency with the idea of a single driving pressure and resistance for venous return.

\(^{2}\) A misnomer. The parameter, a combination of the resistances and capacitances of the circuit, was a fixed quantity with the dimensions of resistance, not a frequency-dependent impedance. It reflected the proportional redistribution of volume among the capacitive components as F changed.
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hydrostatic head due to the difference in height minus the pressure loss associated with flow through the resistance of the connecting tube. How that can result in the pressure at the level of the heart being lower than that at the bottom of the container is not explained.

Also, such open-container models show the output of the heart discharging from a tube above the liquid level, as if arterial pressure were zero. The cardiac output simply falls into the container, keeping its level constant by virtue of the assumption that whatever flows into the heart is pumped out of it. Nothing of the pressure:flow:volume relationships in the vasculature upstream of the locus of MSFP is represented.

Perhaps such models can be called intuitive, but the physical relationships are a far cry from the physics of the peripheral vasculature. Using gravity as the potential energy tapped for driving flow rather than the mechanical energy supplied by the heart and the stored elastic energy of stressed vascular segments is misleading.

The model implicit in overlay of cardiac output and venous return curves. For the actual model of Guyton, manifest in his thinking, turn to his use of the intersection of venous return curves with cardiac output curves. He took the intersection as the prediction of the steady $P_{ra}$ and $F$ simultaneously consistent with the total blood volume, the properties of the cardiac pump, and the properties of the peripheral vasculature.

That analysis depends on two assumptions: 1) that a “cardiac output curve” shows the $F$ that occurs for a given $P_{ra}$ and the present heart rate, contractility, and afterload, i.e., that cardiac function can be approximated by this simple dependence of $F$ on $P_{ra}$, other things being constant, and 2) that a “venous return curve” shows the functional dependence of $P_{ra}$ upon $F$, provided that total system volume and the state of peripheral vascular tone remain constant.

Given equations for these two functions, one could solve them simultaneously to obtain the one $(F,P_{ra})$ data point simultaneously consistent with both. Alternatively, one could simply overlay their graphical representations, as Guyton did, to reveal the stability point as the intersection of the two curves.

Is this not the real Guyton model? That is, the concept that peripheral vasculature and cardiac pump subsystems are counterposed. In one, elevated $P_{ra}$ tends to result in increased $F$; in the other, elevated $F$ tends to result in decreased $P_{ra}$. When connected together, they stabilize at the single $F$ and $P_{ra}$ simultaneously consistent with their individual properties.

Conclusion. In the context of analyses that reveal the particular $F$ and $P_{ra}$ simultaneously consistent with properties of the cardiac and vascular subdivisions of the cardiovascular system, one sees MSFP as reflecting the volume within the peripheral vasculature, not a pressure physically present in some actual compartment of the peripheral vasculature at any $F$ greater than zero.

Accordingly, the potential value of an estimate of MSFP obtained by techniques such as those of Berger et al. (3) that do not resort to reducing $F$ to zero does not lie in revealing the driving pressure for venous return, but in indirectly estimating the volume contained within the vasculature. The estimate of MSFP itself is undoubtedly complicated by the effect of external forces acting on the vascular container such as those due to pulmonary pressures in Berger et al. (3). Translating MSFP to volume, in turn, is complicated by the variability of peripheral vascular tone. Perhaps obtaining a direct measure of volume, as through dye dilution, would be a more useful objective. Then abnormal pressures in central veins could be assessed for evidence of maldistribution of volume.

The findings of Berger et al. (3) reveal features of the complexity of the peripheral vasculature. Their recognition of differences in dynamics of the vasculatures drained via the superior versus inferior vena cava, the importance of the volume reserves of the splanchnic vasculature, and the effects of forces due to respiratory movements are far removed from a view of venous return as driven from a reservoir at fixed pressure upstream of a single venous resistance. Their observation of the transient period between successive states of steady $F$ sheds light on how changes in volume of organ vascular compartments buffer temporary discrepancies between cardiac output and venous return.

Why then persist in perpetuating the $(\text{MSFP} − P_{ra})/R_{\text{ven}}$ fallacy?

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