Supplementary Materials

Solutions to the model

We derive the control equations for the heart rate F and the total reserve volume V^0_{total} for all modalities of partial venous collapse.

Case I

Since $P_{\text{RA}} = P_{\text{thorax}} + (\Delta P_{\text{RA}})^*$ by equation (32), the condition for validity of case I can be stated as follows:

$$P_{\text{thorax}} \leq -(\Delta P_{\text{RA}})^* \tag{35}$$

Substituting the controlled value for P^{u}_{sa} into equation (18) yields

$$P^{\text{l}}_{\text{sa}} = (P^{\text{u}}_{\text{sa}})^* + \rho g (H^{\text{u}} - H^{\text{l}}) \tag{36}$$

Using equations (14), (15) and (36), the systemic pressures specify the flows

$$\begin{aligned}
Q^{\text{u}}_{\text{s}} &= \frac{1}{R^{\text{u}}_{\text{s}}} \left(P^{\text{u}}_{\text{sa}} - P^{\text{u}}_{\text{sv}}\right) && (37)\\
&= \frac{1}{R^{\text{u}}_{\text{s}}} \left(P^{\text{u}}_{\text{sa}}\right)^* && (38)\\
Q^{\text{l}}_{\text{s}} &= \frac{1}{R^{\text{l}}_{\text{s}}} \left(P^{\text{l}}_{\text{sa}} - P^{\text{l}}_{\text{sv}}\right) && (39)\\
&= \frac{1}{R^{\text{l}}_{\text{s}}} \left((P^{\text{u}}_{\text{sa}})^* + \rho g H^{\text{u}}\right) && (40)
\end{aligned}$$

With both upper and lower systemic flows known, the cardiac output is simply their sum by equation (17):

$$Q = \left(\frac{1}{R^{\text{u}}_{\text{s}}} + \frac{1}{R^{\text{l}}_{\text{s}}}\right) (P^{\text{u}}_{\text{sa}})^* + \frac{\rho g H^{\text{u}}}{R^{\text{l}}_{\text{s}}} \tag{41}$$

Then, by using equation (12) and substituting (32) and (41), an equation for heart rate as a function of parameters can be obtained:

$$\begin{aligned}
F &= \frac{Q}{C_{\text{RVD}} \left(P_{\text{RA}} - P_{\text{thorax}}\right)} && (42)\\
&= \frac{\left(\frac{1}{R^{\text{u}}_{\text{s}}} + \frac{1}{R^{\text{l}}_{\text{s}}}\right) (P^{\text{u}}_{\text{sa}})^* + \frac{\rho g H^{\text{u}}}{R^{\text{l}}_{\text{s}}}}{C_{\text{RVD}} \left(\Delta P_{\text{RA}}\right)^*} && (43)
\end{aligned}$$

The pulmonary pressures can be solved for by setting equations (9) and (10) equal to each other and substituting equation (32):

$$\begin{aligned}
C_{\text{LVD}}(P_{\text{pv}} - P_{\text{thorax}}) &= C_{\text{RVD}} \left(\Delta P_{\text{RA}}\right)^* && (44)\\
P_{\text{pv}} - P_{\text{thorax}} &= \frac{C_{\text{RVD}}}{C_{\text{LVD}}} \left(\Delta P_{\text{RA}}\right)^* && (45)
\end{aligned}$$

We know from equation (13) that $P_{\text{pa}} - P_{\text{pv}} = Q R_{\text{p}}$ and adding this quantity to both sides of (45) results in:

$$P_{\text{pa}} - P_{\text{thorax}} = \frac{C_{\text{RVD}}}{C_{\text{LVD}}} \left(\Delta P_{\text{RA}}\right)^* + Q R_{\text{p}} \tag{46}$$

Using equation (5) and our case I assumptions, we also arrive at an expression for total reserve volume as a function of parameters:

$$V^0_{\text{total}} = V_{\text{total}} - C_{\text{p}} \frac{C_{\text{RVD}}}{C_{\text{LVD}}} \left(\Delta P_{\text{RA}}\right)^* - \left(T_{\text{p}} G_{\text{s}} + C_{\text{sa}}\right) (P^{\text{u}}_{\text{sa}})^* - \left(\frac{T_{\text{p}}}{R^{\text{l}}_{\text{s}}} + C^{\text{l}}_{\text{sa}}\right) \rho g H^{\text{u}} - C^{\text{l}}_{\text{s}} \rho g \left(-H^{\text{l}}\right) \tag{47}$$

where the arterial compliance is the sum of the compartment compliances:

$$C_{\mathrm{sa}} = C_{\mathrm{sa}}^{\mathrm{u}} + C_{\mathrm{sa}}^{\mathrm{l}}, \tag{48}$$

the conductance term G_{s} is the sum of the upper and lower conductances (reciprocal resistances):

$$G_{\mathrm{s}} = G_{\mathrm{s}}^{\mathrm{u}} + G_{\mathrm{s}}^{\mathrm{l}} = \frac{1}{R_{\mathrm{s}}^{\mathrm{u}}} + \frac{1}{R_{\mathrm{s}}^{\mathrm{l}}}, \tag{49}$$

the pulmonary time constant T_{p} is

$$T_{\mathrm{p}} = C_{\mathrm{pa}} R_{\mathrm{p}} \tag{50}$$

and the pulmonary compliance, C_{p} is

$$C_{\mathrm{p}} = C_{\mathrm{pa}} + C_{\mathrm{pv}}. \tag{51}$$

Case II

Similarly, case II is defined by the following inequality:

$$0 < P_{\mathrm{RA}} < \rho g H^{\mathrm{u}} \tag{52}$$

which can be rewritten as

$$-(\Delta P_{\mathrm{RA}})^{*} < P_{\mathrm{thorax}} < \rho g H^{\mathrm{u}} - (\Delta P_{\mathrm{RA}})^{*}. \tag{53}$$

by equation (32). Since $P_{\mathrm{RA}} < \rho g H^{\mathrm{u}}$, there is partial collapse of the upper systemic veins (not extending all the way down to the heart). Thus, similar to case I, we have that $P_{\mathrm{sv}}^{\mathrm{u}} = 0$, but because right atrial pressure is nonnegative, there is no systemic venous collapse below the heart, yielding the following:

$$\begin{aligned} P_{\mathrm{sv}}^{\mathrm{l}} &= \rho g(-H^{\mathrm{l}}) + P_{\mathrm{RA}} && (54)\\ &= \rho g(-H^{\mathrm{l}}) + P_{\mathrm{thorax}} + (\Delta P_{\mathrm{RA}})^{*} && (55) \end{aligned}$$

The upper and lower systemic arterial pressures are the same as in case I, given by equations (31) and (36), and the upper and lower systemic flows follow:

$$\begin{aligned} Q_{\mathrm{s}}^{\mathrm{u}} &= \frac{1}{R_{\mathrm{s}}^{\mathrm{u}}}\left((P_{\mathrm{sa}}^{\mathrm{u}})^{*} + \rho g(H^{\mathrm{u}} - H^{\mathrm{l}})\right) && (56)\\ Q_{\mathrm{s}}^{\mathrm{l}} &= \frac{1}{R_{\mathrm{s}}^{\mathrm{l}}}\left((P_{\mathrm{sa}}^{\mathrm{u}})^{*} + \rho g\left(H^{\mathrm{u}} - H^{\mathrm{l}}\right)\right) - \rho g(-H^{\mathrm{l}}) - P_{\mathrm{thorax}} - (\Delta P_{\mathrm{RA}})^{*}\Big) && (57)\\ &= \frac{1}{R_{\mathrm{s}}^{\mathrm{l}}}\left((P_{\mathrm{sa}}^{\mathrm{u}})^{*} + \rho g H^{\mathrm{u}} - P_{\mathrm{thorax}} - (\Delta P_{\mathrm{RA}})^{*}\right) && (58) \end{aligned}$$

Adding the upper and lower systemic flows together yields the cardiac output:

$$Q = \left(\frac{1}{R_{\mathrm{s}}^{\mathrm{u}}} + \frac{1}{R_{\mathrm{s}}^{\mathrm{u}}}\right)(P_{\mathrm{sa}}^{\mathrm{u}})^{*} + \frac{1}{R_{\mathrm{s}}^{\mathrm{l}}}\left(\rho g H^{\mathrm{u}} - P_{\mathrm{thorax}} - (\Delta P_{\mathrm{RA}})^{*}\right) \tag{59}$$

which in turn allows us to solve for heart rate by equation (32) and (59) into (12):

$$F = \frac{\left(\frac{1}{R_{\mathrm{s}}^{\mathrm{u}}} + \frac{1}{R_{\mathrm{s}}^{\mathrm{u}}}\right)(P_{\mathrm{sa}}^{\mathrm{u}})^{*} + \frac{1}{R_{\mathrm{s}}^{\mathrm{l}}}\left(\rho g H^{\mathrm{u}} - P_{\mathrm{thorax}} - (\Delta P_{\mathrm{RA}})^{*}\right)}{C_{\mathrm{RVD}}}(\Delta P_{\mathrm{RA}})^{*} \tag{60}$$

The pulmonary pressures can be solved by setting equations (9) and (10) equal to each other after solving for pressure difference:

$$\begin{aligned} C_{\mathrm{LVD}}(P_{\mathrm{pv}} - P_{\mathrm{thorax}}) &= C_{\mathrm{RVD}}(\Delta P_{\mathrm{RA}})^{*} && (61)\\ P_{\mathrm{pv}} - P_{\mathrm{thorax}} &= \frac{C_{\mathrm{RVD}}}{C_{\mathrm{LVD}}}(\Delta P_{\mathrm{RA}})^{*} && (62) \end{aligned}$$

We know from equation (13) that $P_{\text{pa}} - P_{\text{pv}} = QR_{\text{p}}$ and adding this quantity to both sides results in:

$$P_{\text{pa}} - P_{\text{thorax}} = \frac{C_{\text{RVD}}}{C_{\text{LVD}}} (\Delta P_{\text{RA}})^* + QR_{\text{p}} \tag{63}$$

$$= \frac{C_{\text{RVD}}}{C_{\text{LVD}}} + R_{\text{p}} \left(\left(\frac{1}{R_{\text{s}}^{\text{u}}} + \frac{1}{R_{\text{s}}^{\text{u}}} \right) (P_{\text{sa}}^{\text{u}})^* + \frac{1}{R_{\text{s}}^{\text{l}}} \left(\rho g H^{\text{u}} - P_{\text{thorax}} - (\Delta P_{\text{RA}})^* \right) \right) \tag{64}$$

Following the same procedure from case I, we can solve for V_{total}^0 in terms of parameters using equation (**??**) and our case II assumptions:

$$\begin{aligned} V_{\text{total}}^0 = V_{\text{total}} - C_{\text{p}} \frac{C_{\text{RVD}}}{C_{\text{LVD}}} (\Delta P_{\text{RA}})^* - \left(T_{\text{p}} G_{\text{s}} + C_{\text{sa}} \right) (P_{\text{sa}}^{\text{u}})^* - (T_{\text{p}} G_{\text{s}}^{\text{l}} \\ + C_{\text{sa}}^{\text{l}}) \rho g H^{\text{u}} - C_{\text{s}}^{\text{l}} \rho g (-H^{\text{l}}) - (C_{\text{sv}}^{\text{l}} - T_{\text{p}} G_{\text{s}})(P_{\text{thorax}} + (\Delta P_{\text{RA}})^*) \end{aligned} \tag{65}$$

$$(T_{\text{p}} G_{\text{s}}^{\text{l}} + C_{\text{sa}}^{\text{l}}) \rho g H^{\text{u}} + C_{\text{s}}^{\text{l}} \rho g (-H^{\text{l}}) + = V_{\text{total}} - V_{\text{total}}^0 C_{\text{p}} \frac{C_{\text{RVD}}}{C_{\text{LVD}}} (\Delta P_{\text{RA}})^* - \left(T_{\text{p}} G_{\text{s}} + C_{\text{sa}} \right) (P_{\text{sa}}^{\text{u}})^* - (C_{\text{sv}}^{\text{l}} - T_{\text{p}} G_{\text{s}})(P_{\text{thorax}} + (\Delta P_{\text{RA}})^*) \tag{66}$$

Case III

Repeating the procedure from the previous two cases, we can derive analytical solutions for heart rate and total reserve volume in case III where there is no venous collapse. The defining inequality for this case is

$$\rho g (H^{\text{u}}) < P_{\text{RA}} = P_{\text{thorax}} + (\Delta P_{\text{RA}})^* \tag{67}$$

which subsequently gives the condition for validity on P_{thorax}:

$$\rho g H^{\text{u}} - (\Delta P_{\text{RA}})^* \leq P_{\text{thorax}} \tag{68}$$

The upper and lower systemic venous pressures are defined as:

$$P_{\text{sv}}^{\text{u}} = P_{\text{RA}} - \rho g H^{\text{u}} = P_{\text{thorax}} + (\Delta P_{\text{RA}})^* - \rho g H^{\text{u}} \tag{69}$$

$$P_{\text{sv}}^{\text{l}} = P_{\text{RA}} + \rho g (-H^{\text{l}}) = P_{\text{thorax}} + (\Delta P_{\text{RA}})^* + \rho g (-H^{\text{l}}) \tag{70}$$

The upper and lower systemic arterial pressures are the same as the other two cases as given by given by equations (31) and (36) and combining them with equations (14) and (15) result in:

$$\begin{aligned} Q_{\text{s}}^{\text{u}} &= \frac{1}{R_{\text{s}}^{\text{u}}} ((P_{\text{sa}}^{\text{u}})^* - (P_{\text{thorax}} + (\Delta P_{\text{RA}})^* - \rho g H^{\text{u}})) \\ &= \frac{1}{R_{\text{s}}^{\text{l}}} ((P_{\text{sa}}^{\text{u}})^* + \rho g H^{\text{u}} - P_{\text{thorax}} - (\Delta P_{\text{RA}})^*) \end{aligned} \tag{71}$$

$$\begin{aligned} Q_{\text{s}}^{\text{l}} &= \frac{1}{R_{\text{s}}^{\text{l}}} \left((P_{\text{sa}}^{\text{u}})^* + \rho g (H^{\text{u}} - H^{\text{l}})) - (P_{\text{thorax}} + (\Delta P_{\text{RA}})^* + \rho g (-H^{\text{l}})) \right) \\ &= \frac{1}{R_{\text{s}}^{\text{l}}} ((P_{\text{sa}}^{\text{u}})^* + \rho g H^{\text{u}} - P_{\text{thorax}} - (\Delta P_{\text{RA}})^*) \end{aligned} \tag{72}$$

Since the upper and lower pressure differences are the same, the sum of the upper and lower systemic flows results in the following equation for cardiac output:

$$Q = \left(\frac{1}{R_{\text{s}}^{\text{u}}} + \frac{1}{R_{\text{s}}^{\text{l}}} \right) ((P_{\text{sa}}^{\text{u}})^* + \rho g H^{\text{u}} - P_{\text{thorax}} - (\Delta P_{\text{RA}})^*) \tag{73}$$

Then, heart rate is given in the same way by rearranging equation (12) and plugging in Q from equation (73):

$$F = \frac{\left(\frac{1}{R_{\text{s}}^{\text{u}}} + \frac{1}{R_{\text{s}}^{\text{l}}} \right) ((P_{\text{sa}}^{\text{u}})^* + \rho g H^{\text{u}} - P_{\text{thorax}} - (\Delta P_{\text{RA}})^*)}{C_{\text{RVD}} (\Delta P_{\text{RA}})^*} \tag{74}$$

Then, we use the pulmonary pressures from (62) and (63) and plug in our case III value for Q from equation (73) into the latter:

$$P_{\text{pa}} - P_{\text{thorax}} = \frac{C_{\text{RVD}}}{C_{\text{LVD}}} (\Delta P_{\text{RA}})^* + \left(\frac{1}{R_{\text{s}}^{\text{u}}} + \frac{1}{R_{\text{s}}^{\text{l}}} \right) ((P_{\text{sa}}^{\text{u}})^* + \rho g H^{\text{u}} - P_{\text{thorax}} - (\Delta P_{\text{RA}})^*) R_{\text{p}} \tag{75}$$

Finally, we can write the total reserve volume for case III with the following familiar expression from equation (**??**):

$$\begin{aligned} V_{\text{total}}^0 = V_{\text{total}} - C_{\text{p}} \frac{C_{\text{RVD}}}{C_{\text{LVD}}} (\Delta P_{\text{RA}})^* - \left(T_{\text{p}} G_{\text{s}} + C_{\text{sa}}\right) (P_{\text{sa}}^{\text{u}})^* - (T_{\text{p}} G_{\text{s}} + \\ C_{\text{sa}}^{\text{l}} - C_{\text{sv}}^{\text{u}}) \rho g H^{\text{u}} - C_{\text{s}}^{\text{l}} \rho g (-H^{\text{l}}) - (C_{\text{sv}}^{\text{l}} - T_{\text{p}} G_{\text{s}})(P_{\text{thorax}} + (\Delta P_{\text{RA}})^*) \end{aligned} \tag{76}$$

Note that when the equality

$$P_{\text{thorax}} + (\Delta P_{\text{RA}})^* = \rho g H^{\text{u}}. \tag{77}$$

holds, we are in the borderline between case II and III. Setting equations (60) and (74) equal gives:

$$F = \frac{G_{\text{s}} (P_{\text{sa}}^{\text{u}})^*}{C_{\text{RVD}} (\Delta P_{\text{RA}})^*}. \tag{78}$$

Setting the total reserve volume equations for these two cases, (65) and (76), equal to each other, it is clear that they only differ with the terms $\rho g H^{\text{u}}$ and $P_{\text{thorax}} + (\Delta P_{\text{RA}})^*$. Thus, heart rate and total reserve volume are continuous functions in the transition between case II and III.

Parameters

The tables below include all input parameters used in our simulation. These could be obtained for a specific patient if that data is available.

Input Parameters

In our simulations, we choose the upper compartment height: H^{u} to be the heart-brain distance measured vertically from right atrium (third intercostal space) to center of pupil. However the mathematical model does not impose any restriction as to the precise definition of what that height is. For instance, if simulations in a larger cohort were to show that H^{u} measured as (third intercostal space) to the top of the cranium yielded better predictions, the parameter value can easily be changed in the code. Likewise, we were interested in subjects being launched seated so the lower compartment height, H^{l} was measured from the base of seat. Depending on the context in which one is applying this model it could be measured farther down or up.

Control Parameters

The model aims to keep the following parameters at these set values. These can be customized to each patient if needed.

Blood pressure is typically measured at heart level, sitting upright. The blood pressure eye-level will be lower in 1G (typically decreased by about 25 mmHg)[11]. Assuming a column of blood to have the same density as water (approximately $\rho = 1$ g/mL) and using the hydrostatic equation for an incompressible fluid[12], the eye-level blood pressure is $P_{\text{eye}} = P_{\text{heart}} - \rho g (H_{\text{eye}} - H_{\text{heart}})$. For an individual with systolic blood pressure of 108 mmHg, an eye-heart distance of 32 cm, $\Delta P = 23.5$ mmHg. Thus, the blood pressure at the level of the eye would be approximately 85 mmHg. However, because in this model the height of the upper compartment is set at midpoint (16 cm), the estimated average upper compartment blood pressure would be 96 mmHg. For simplicity and to account for excitement of the subject on the day of the centrifuge run (compared to on the day of the ultrasound), this was rounded up to 100 mmHg.

Normal right atrial pressure ranges from 0-5 mmHg, with normal usually being chosen as 3 mmHg[7]. On ultrasound, no indications of abnormal fluid volume were noted. A right atrial pressure of on the lower side of normal (2 mmHg) was chosen as the subject was noted to have reported being normal to slightly volume-depleted during the study.

Calibration for a specific patient

In this section, we provide additional detail on the parameters used in the model simulations and how they were obtained and calculated for a specific patient.

Centrifuge Methods

De-identified data was used from the previously described centrifuge study[13] with handheld ultrasound[14].

Parameter Name	Value (units)	Description	Source / Reference
g	980 cm/s	Gravitational acceleration on Earth	[1]
ρ	1 g/cm^2	Density of blood	[2]
H^{u}	32 cm	Heart-brain distance measured vertically from right atrium (third intercostal space) to center of pupil of subject	Clinical measurement
H^{l}	42 cm	Heart-seat distance measured vertically from base of seat to right atrium (third intercostal space) for a subject in seated position	Clinical measurement
V_{total}	3.7 L	Total blood volume calculated from the Lemmons, Bernstein, and Brody formula (inputs are height, weight, and biological sex)	Clinical measurement for height, weight, sex. Volume calculated with formula.[3,4]
R_{s}	16.49 mmHg/(L/min)	Resistance of systemic arteries	Systemic vascular resistance of the entire vascular tree, assuming that the arterial microvasculature accounts for the majority of resistance[5–7]
R_{p}	1.61 mmHg/(L/min)	Resistance of pulmonary arteries	[8,9]
C_{RVD}	0.035 L/mmHg	Right ventricular diastolic compliance	[9]
C_{LVD}	0.00583 L/mmHg	Left ventricular diastolic compliance	[9]
C_{sa}	0.00175 L/mmHg	Compliance of systemic arteries	[9]
C_{sv}	0.09 L/mmHg	Compliance of systemic veins	[2]
C_{pa}	0.00412 L/mmHg	Compliance of pulmonary arteries	[9]
C_{pv}	0.08 L/mmHg	Compliance of pulmonary veins	[9]

Table 1. Parameters needed to run the model code

Parameter	Description	Value	Units	Reference
PSA_u^*	systemic arterial pressure (upper)	100	mmHg	Estimated from subject systolic blood pressure
dP_RA*	right atrial pressure	2	mmHg	Normal range of 0 to 5 mmHg[7,10]

Table 2. Control parameters

Ultrasound Methods

Sonographic measurements were taking using a standard echocardiography approach. Subjects were placed in a comfortable, reclined position and examined in the parasternal long and short axes, then again in the apical 2- and 4-chamber views. Subjects were re-positioned as needed to achieve optimal windows. The adjusted apical 4-chamber view was used to calculate the velocity time integral (VTI), a proxy for stroke volume and thus correspondent to cardiac output. VTI was calculated using the GE Venue GO, which contains a proprietary artificial intelligence tool for measuring VTI and was then manually confirmed by the sonographer (John Davis). This research was approved by the University of Texas Medical Branch Institutional Research Board (IRB 22-0300).

Subject-Specific Parameter Estimation

Systemic Vascular Resistance

Systemic vascular resistance reflects resistance of blood across the entire systemic circulation from aorta to right atrium. The resistance is controlled by blood vessel circumference, which decreases in response to epinephrine and norepinephrine causing contraction of the muscle layer in the vessel walls[5, 15]. Analogous to electric resistances of metallic conductors, hydraulic resistances of vascular beds are considered to obey Ohm's law if their potential differences are linearly related to their flows (i.e. resistances are constant and independent of changes in potential differences and flow): $R_{vasc} = \Delta P/Q$, where R_{vasc} is the vascular resistance, ΔP is the hydraulic pressure difference, and Q is blood flow. Although this simplification disregards features of blood flow such as viscosity, vascular distensibility, pulse wave reflections, and fluid turbulence[16], this equation is typically used for medical calculations of systemic vascular resistance as follows[5]:

$$\mathrm{SVR} = \frac{(\mathrm{MAP} - \mathrm{CVP})}{\mathrm{CO}} \tag{79}$$

Here, systemic vascular resistance (SVR) is measured in mmHg min/L; mean arterial pressure (MAP), and central venous pressure (CVP) are measured in mmHg; and cardiac output (CO) is a flow measured in L/min. The MAP is the average of systolic and diastolic blood pressure (mmHg), and central venous pressure is the estimated right atrial pressure (mmHg)[5].

For the subject presented in the article, the SVR was calculated using the following parameters:

Cardiac output (CO) was calculated as the product of estimated stroke volume (SV) from ultrasound and heart rate (HR). Although clinical calculators exist that can estimate these values based on anthopometry, we opted to measure these variables using bedside transthroacic echocardiography. SV was derived from ultrasound measurements of the left ventricular outflow tract (LVOT) measured in the parasternal long view. SV was found using the product of the LVOT area and the Doppler Volume-Time Integral (VTI)[17] using the Dopppler Method[18], which estimates the stroke volume as a cylinder with a circular base estimated as LVOT area and the height estimated as VTI:

$$\mathrm{SV} = A_{\mathrm{LVOT}} h = \pi (r_{\mathrm{LVOT}})^2 \mathrm{VTI} \tag{80}$$

The LVOT radius was estimated to be 1.29 cm and VTI to be 17.4 cm, for a CO of 0.091 L.

Choosing Systemic Compliance Coefficients

The compliance of the systemic arterial tree can be approximated using $C_{\mathrm{sa}} = \Delta V/\Delta P$. We make the following assumptions to obtain a value for the compliance of the total systemic arterial system:

- The change in volume of the arterial tree is equivalent to the stroke volume: $\Delta V = 0.070$ L
- The change in blood pressure is the difference between diastolic (80 mmHg) and systolic (120 mmHg): $\Delta P = 40$ mmHg

Thus, $C_{\mathrm{sa}} = V_{str}/\Delta P = 0.00175$ L/mmHg. These values can be customized, if desired, to the specific patient. For this particular patient, $C_{\mathrm{sa}} = 0.0906/(108-68) = 0.00265$.

In a compartmental model, the compliance of a chamber is additive over all parts of the chamber. This follows from the fact the approximation of compliance as dV/dP, and that volume is additive. Thus, given a value for the total systemic arterial compliance, the upper and lower systemic arterial compliances should to add up to this value. Therefore the values of $C_{\mathrm{sa}}^{\mathrm{u}}$ and $C_{\mathrm{sa}}^{\mathrm{l}}$ in our model should be fractional with respect to the reference value for C_{sa}. We arbitrarily chose to multiply C_{sa} by $1/3$ for the upper systemic circulation and $2/3$ for the lower systemic circulation. These scaling factors were approximated based on human anthropometry[19] and the corresponding geometry of the arterial system as follows:

- For males of approximately 60 kg total lean body mass, the lean body mass of the legs was approximately 20 kg and that of the trunk was approximately 30 kg[19]. Assuming that approximately 1/3 of the mass of the trunk was above heart level and 2/3 was below, the total lower body mass would be approximately 40 kg and the upper lean body mass 20 kg. We

Parameter	Description	Value	Units	Reference
SBP	systolic blood pressure	108	mmHg	Clinical Measurement
DBP	diastolic blood pressure	68	mmHg	Clinical Measurement
MAP	mean arterial pressure	81.3	mmHg	Calculated from Clinical Measurements ($MAP = (SBP + DBP)/2$)[5]
CVP	central venous pressure = right atrial pressure	2	mmHg	Normal range of 0 to 5 mmHg[7,10]
CO	cardiac output	4.80	L/min	Calculated $CO = SV * HR$ using clinical measures (HR) and parameters derived from transthoracic echocardiography (SV)[17,18]
HR	heart rate	53	min^{-1}	Clinical measurement obtained during transthoracic echocardiography
SV	stroke volume	0.0906	L	Calculated from transthoraic echocardiography using Doppler method[17,18]
r_{LVOT}	radius of the left ventricular outflow tract	1.29	cm	Estimated from parasternal long view from handheld transthoracic echocardiography
VTI	velocity time integral of left ventricular outflow tract, equivalent to height of the LVOT cylinder of volume	17.4	cm	Estimated from transthoracic echocardiography

Table 3. Parameters used to calculate systemic vascular resistance

assume that the ratio of blood to lean mass is constant[20]. Therefore, we chose a smaller fraction of 1/3 to approximate the blood volume of the torso and remaining body portions above the heart and the larger fraction of 2/3 to approximate the blood volume of the portions of the body below the heart, i.e. the lower torso/abdomen and lower extremities. Although we picked a generic factor to reflect the approximate distribution of lean body mass and therefore blood volume and compliance between upper and lower compartments, this could theoretically be customized to individuals or populations (e.g. sex, age) with different anthropometric proportions.

- Although compliance of a single vessel (for example, the aorta) will likely be constant or nearly constant along its length, the model uses the overall compliance of the entire upper and lower arterial trees as input for the model. Because the lower arterial tree is larger and contains branches into each of the lower extremities, as a whole, the system has a comparatively larger ability to compensate for volume changes with pressure. Additionally, smaller arterial branches likely have less compliance than the aorta itself. Thus, the lower system will be closer to the aortic compliance than the upper system.

The same argument is applied to the compliances of the upper and lower systemic venous subcompartments.

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Parameter Name	Description
C_{LVD}	Left ventricular diastolic compliance
C_{pa}	Compliance of pulmonary arteries
C_{pv}	Compliance of pulmonary veins
C_{RVD}	Right ventricular diastolic compliance
C_{sa}	Compliance of systemic arteries
C_{sv}	Compliance of systemic veins
ΔP^{*}_{RA}	Target right atrial pressure and thoracic pressure differential
F	Heart rate
F_{max}	Maximum heart rate for a given subject.
F_{min}	Minimum heart rate for a given subject.
g	Gravitational acceleration
G_{s}	Sum of the upper and lower conductances (reciprocal resistances)
G^{u}_{s}	Upper conductance
G^{l}_{s}	Lower conductance
H^{l}	Lower compartment measurement. Can be arbitrarily set to base of seat to right atrium or feet to right atrium depending on the use case for the model
H^{u}	Upper compartment measurement. Can be arbitrarily set to right atrium to eye, right atrium to top of cranium, right atrium to carotid
P_{pv}	Pulmonary venous pressure (converted to dynes/cm^2 for unit coherence)
P_{pa}	Pulmonary arterial pressure (converted to dynes/cm^2 for unit coherence)
P_{RA}	Right atrial pressure (converted to dynes/cm^2 for unit coherence)
P^{u}_{sa}	Upper mean arterial pressure (converted to dynes/cm^2 for unit coherence)
$P^{\text{u}\,*}_{\text{sa}}$	Target upper mean arterial pressure (converted to dynes/cm^2 for unit coherence)
P^{l}_{sa}	Lower mean arterial pressure (converted to dynes/cm^2 for unit coherence)
P^{u}_{sv}	Upper systemic venous pressure (converted to dynes/cm^2 for unit coherence)
P^{l}_{sv}	Lower systemic venous pressure (converted to dynes/cm^2 for unit coherence)
P_{thorax}	Intra-thoracic pressure (converted to dynes/cm^2 for unit coherence)
Q	Cardiac output, flow through any resistance vessel.
Q_{s}, Q_{sa} , Q_{sv}	flow through the systemic arteries and systemic veins
Q^{u}_{s}	Flow in the upper compartment
Q^{l}_{s}	Flow in the lower compartment
ρ	Density of blood
R_{p}	Resistance of the pulmonary veins
R^{l}_{s}	Systemic vascular resistance of the lower compartment
R^{u}_{s}	Systemic vascular resistance of the upper compartment
T_{p}	Pulmonary time constant (cf eq: 50)
V_{pa}	Volume of blood in pulmonary arteries
V_{pv}	Volume of blood in pulmonary veins
V_{sa}	Volume of blood in systemic arteries
V_{sv}	Volume of blood in systemic veins
V_{total}	Total blood volume
V^{0}_{total}	Total reserve blood volume

Table 4. Index of parameters

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