The Impact of a Fenestration on Blood Flow in Fontan Circulation

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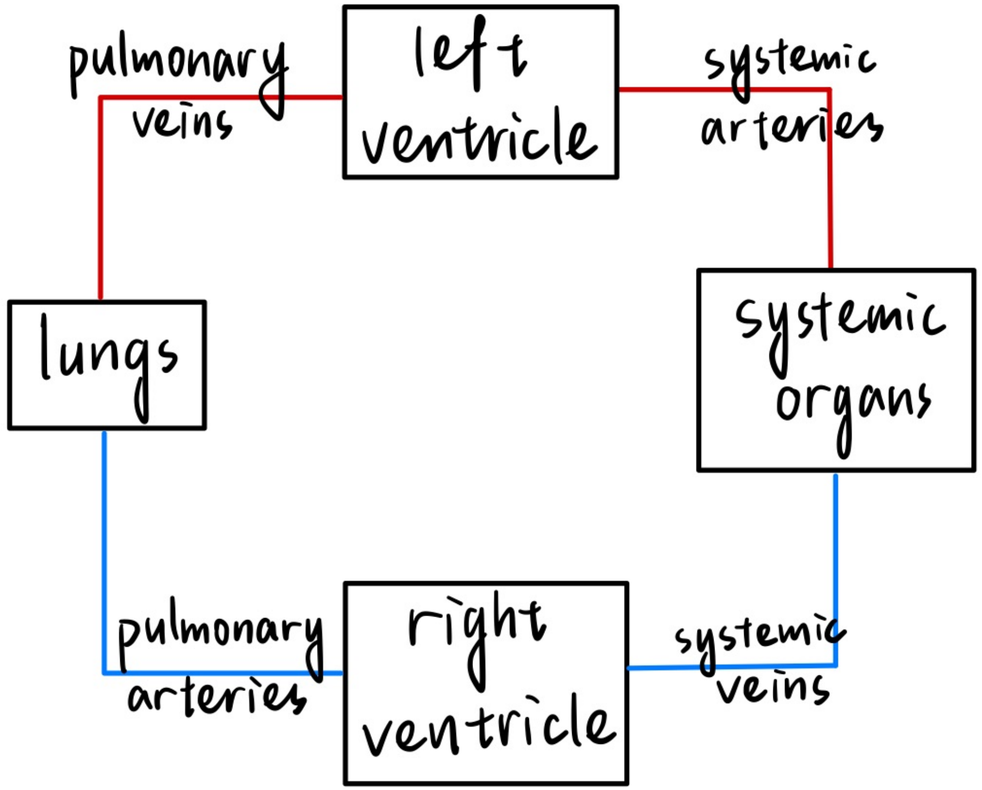
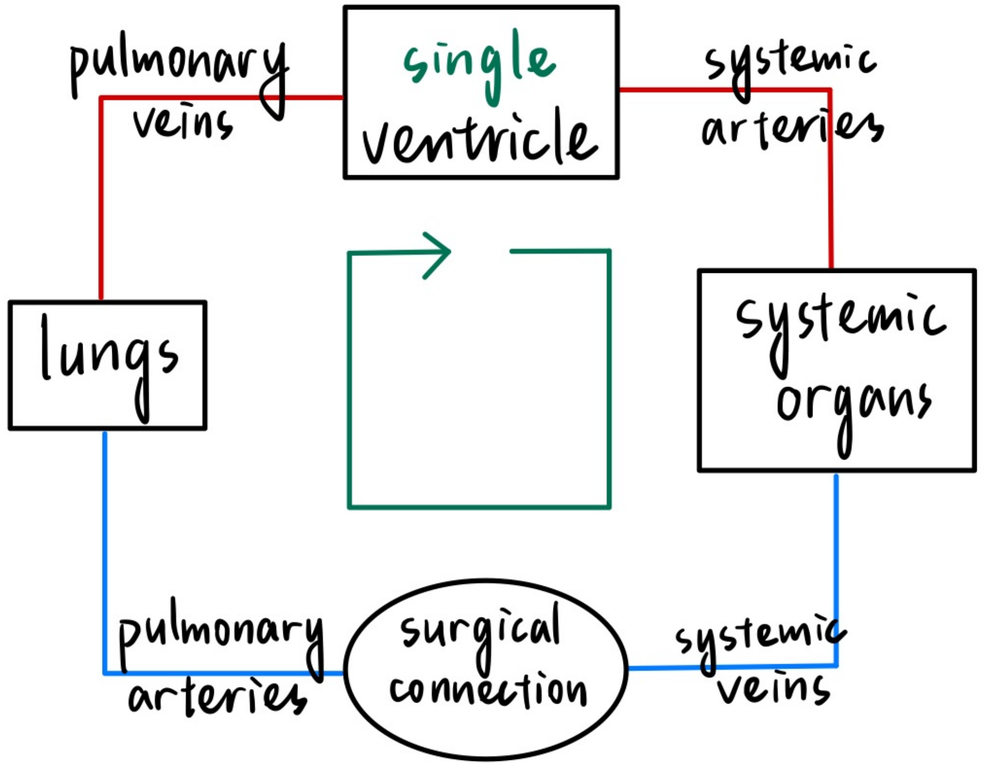
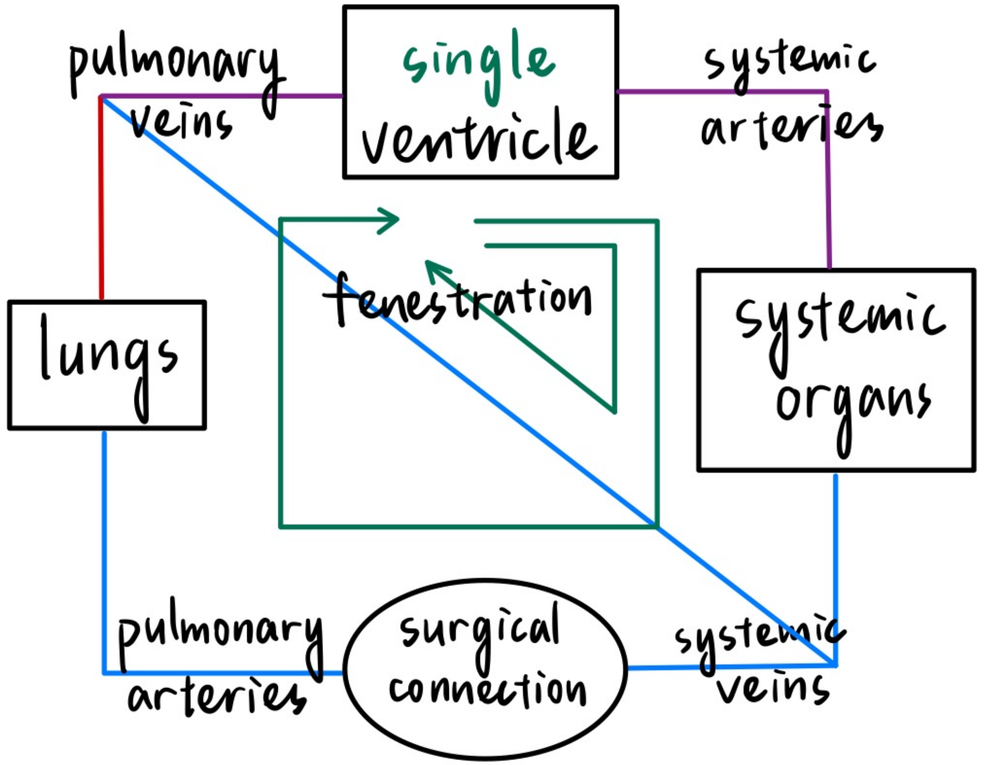
Person with a normal heart



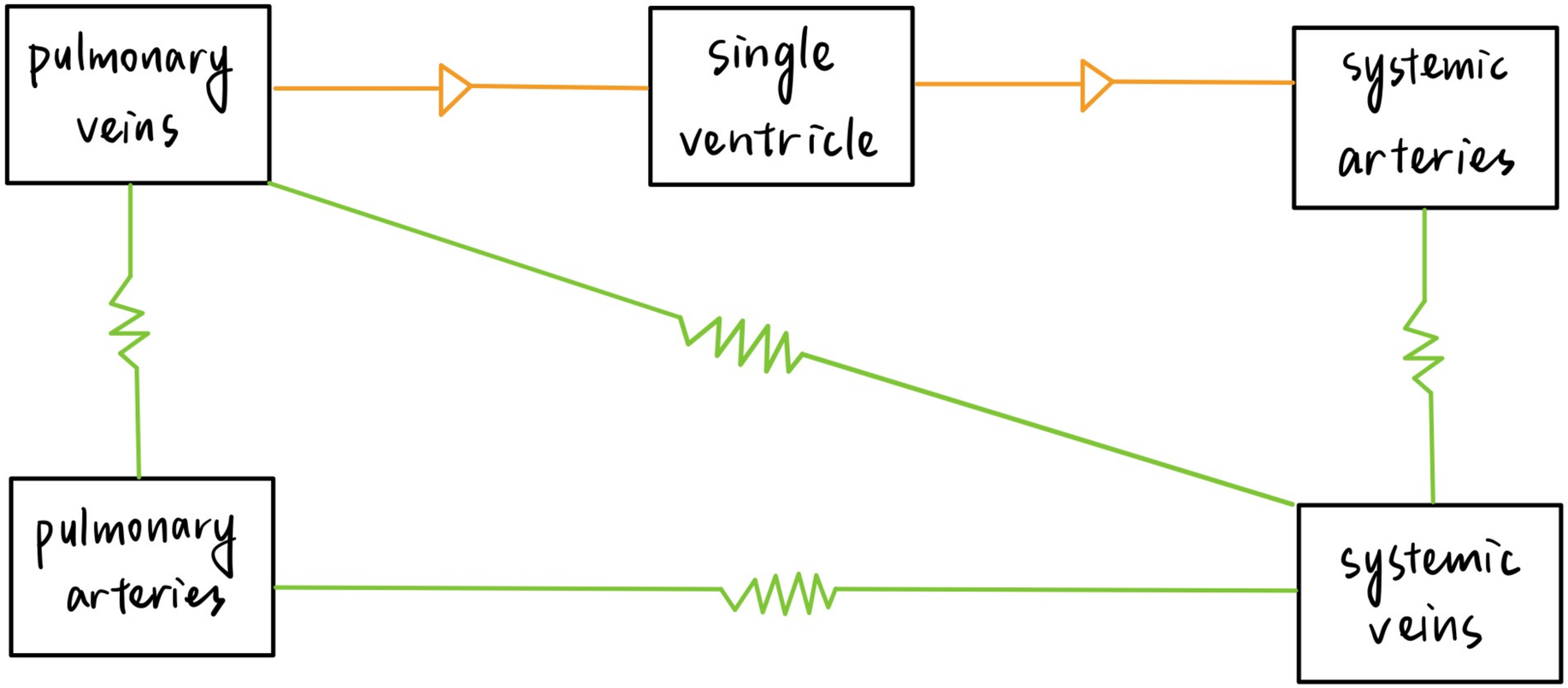
Hypoplastic left heart syndrome - Fontan circulation



Fenestrated Fontan circulation



Fenestrated Fontan circulation



Equations of the heart

$$E_{ventricle}(t) = k\frac{g_1(t)}{1+g_1(t)}\left(\frac{1}{1+g_2(t)} - \frac{1}{1+g_2(T)}\right) + E_{min} \tag{1}$$

$$g_i(t) = \begin{cases} \left(\frac{t}{\tau_{systole}}\right)^{m_i} & \text{if } i = 1 \\ \left(\frac{t}{\tau_{diatole}}\right)^{m_i} & \text{if } i = 2 \end{cases} \tag{2}$$

$$k = \frac{E_{max} - E_{min}}{max_{t\in[0,T]}\left[\frac{g_1(t)}{1+g_1(t)}\left(\frac{1}{1+g_2(t)} - \frac{1}{1+g_2(T)}\right)\right]} \tag{3}$$

Equations of the circulation

Conservation of volume:

$$\frac{dV_i}{dt} = \sum_{j=1}^{N} Q_{ji} - Q_{ij} \tag{4}$$

Compliance relation for each chamber:

$$V_i = (V_d)_i + C_i P_i \tag{5}$$

Equations of the circulation

Pressure-flow relationship for each pair of chambers

$$Q_{ij} = S_{ij} G_{ij} (P_i - P_j) \tag{6}$$

$$G_{ij} = \frac{1}{R_{ij}} \tag{7}$$

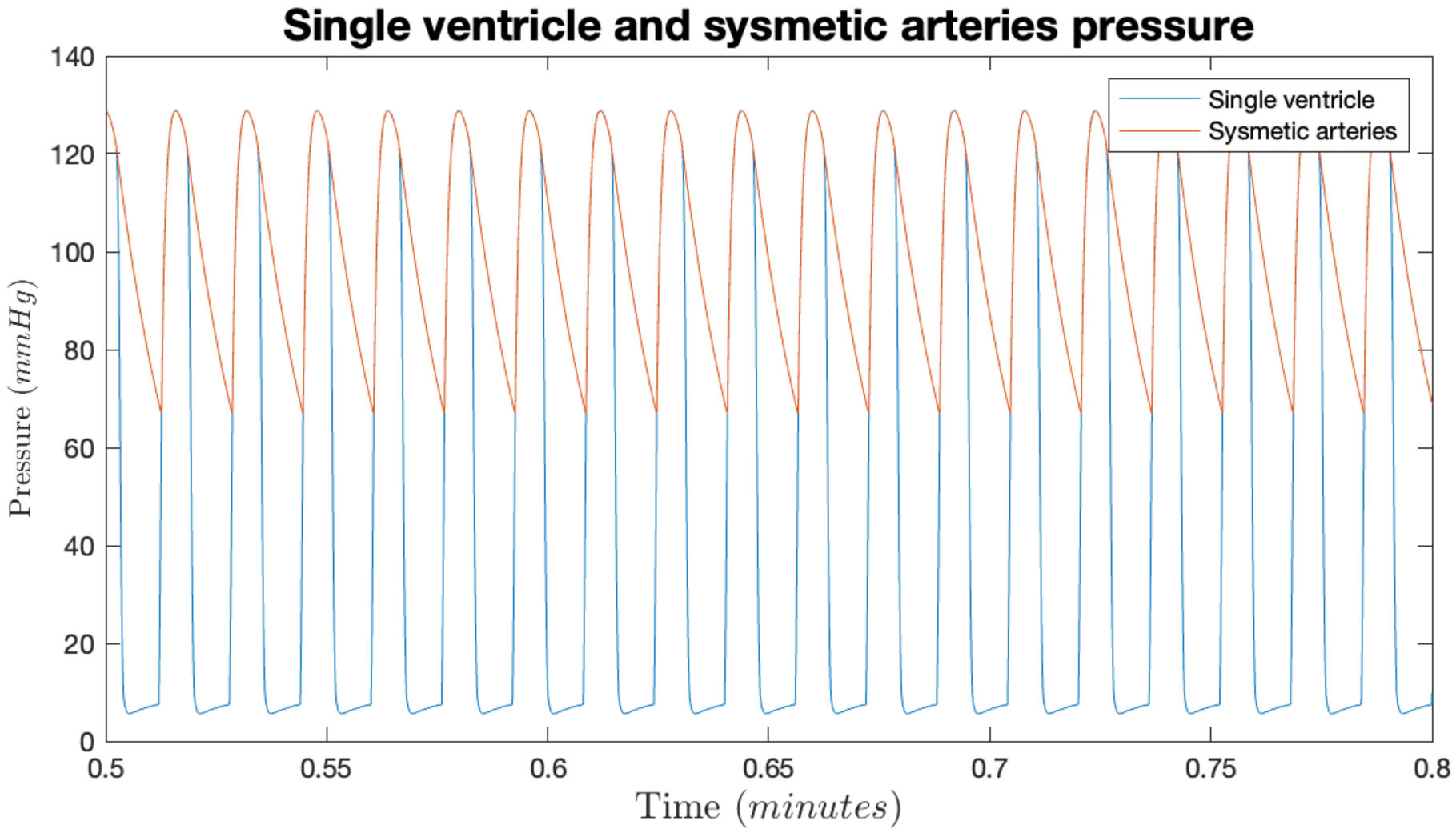
$$S_{ij} = \begin{cases} 1 & \text{if } P_j > P_i \\ 0 & \text{if } P_j \leq P_i \end{cases} \tag{8}$$

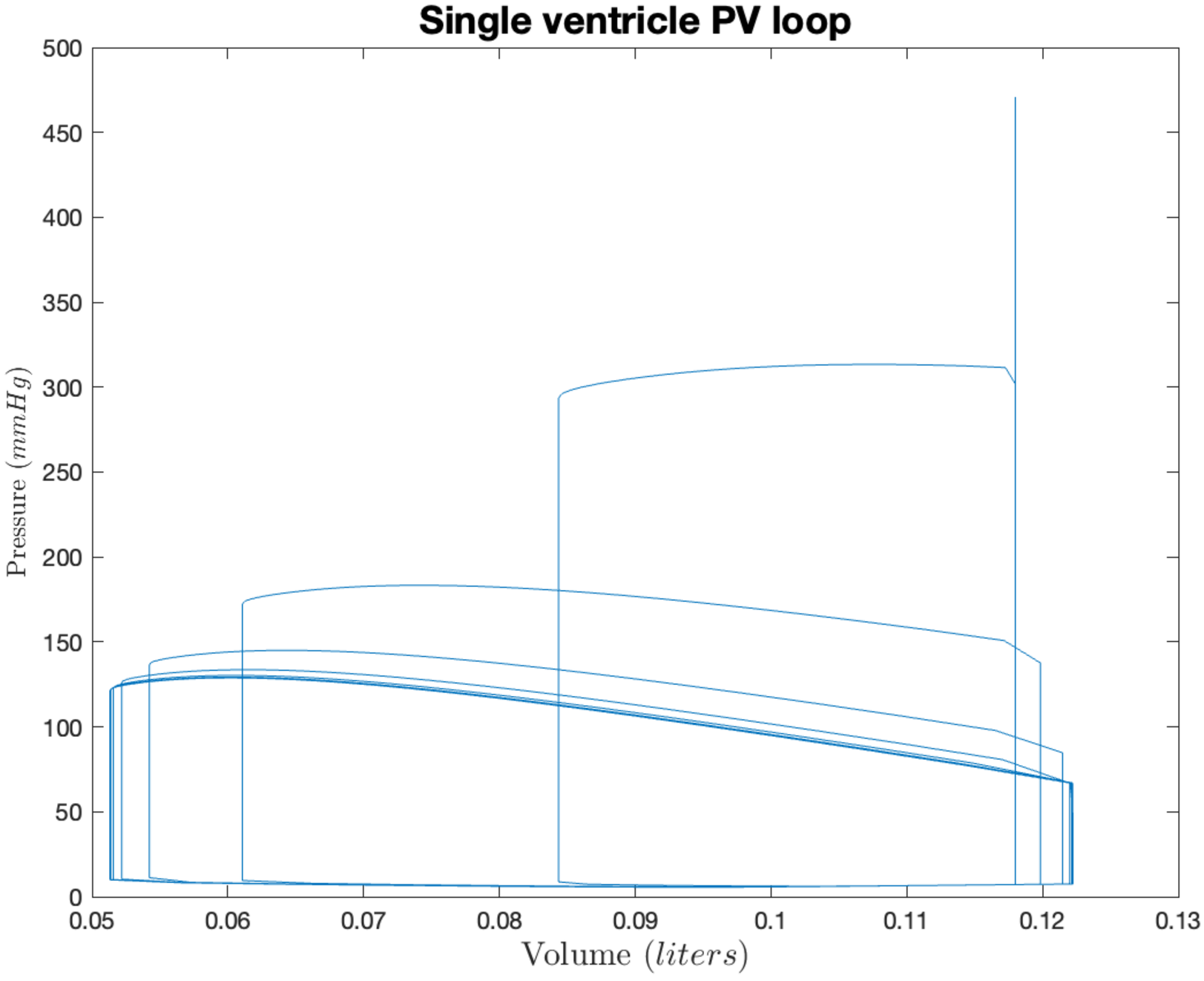
Equations of the circulation

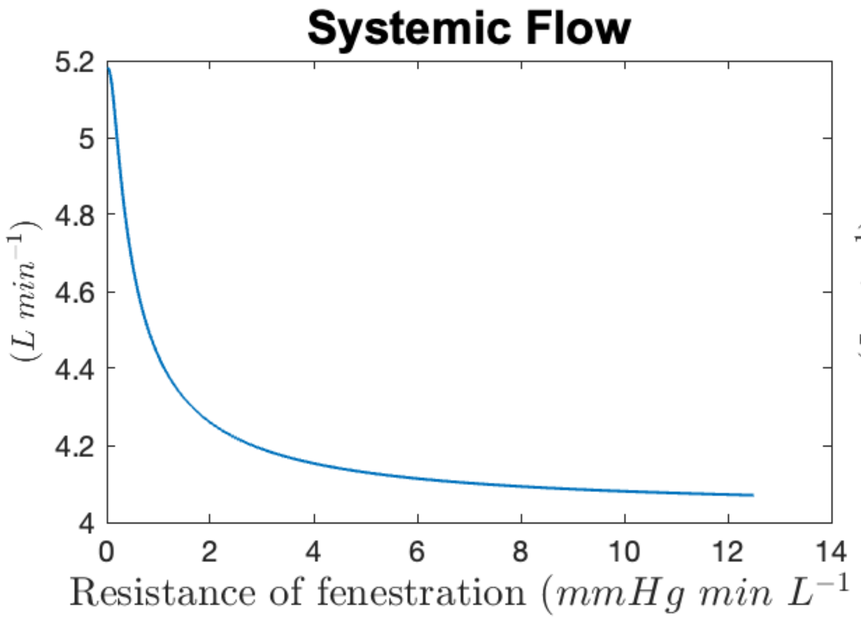
$$\frac{d}{dt}(C_i P_i) = \sum_{j=1}^{N} (S_{ij} G_{ij} + S_{ji} G_{ji})(P_j - P_i) \tag{9}$$

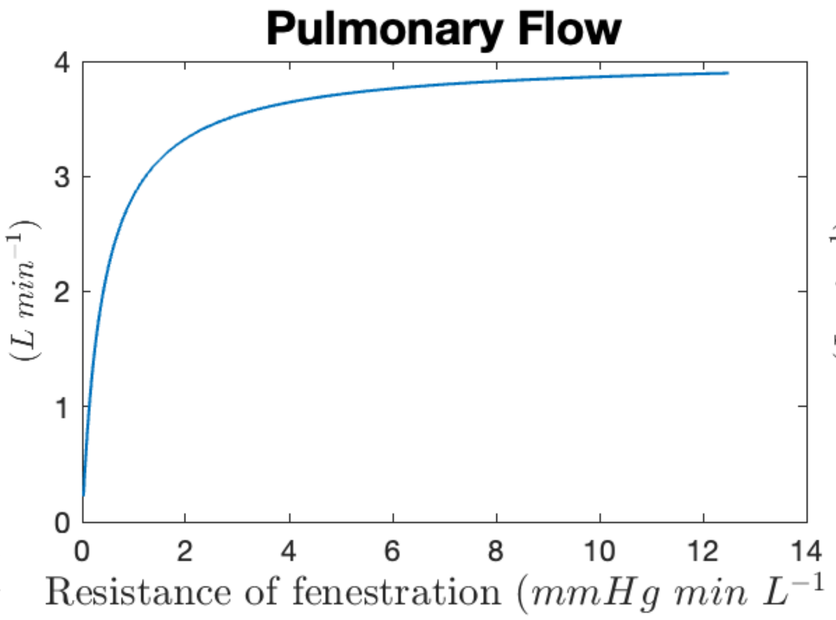
Numerical method: backward Euler

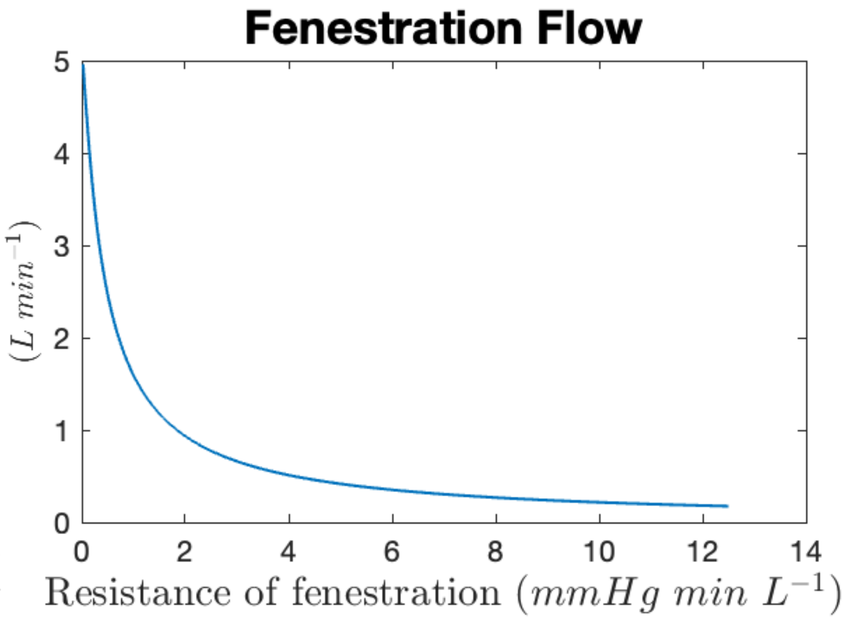
$$\frac{C_i(t)P_i(t) - C_i(t-\Delta t)P_i(t-\Delta t)}{\Delta t} = \sum_{j=1}^{N}(S_{ij}(t)G_{ij} + S_{ji}(t)G_{ji})(P_j(t) - P_i(t)) \tag{10}$$

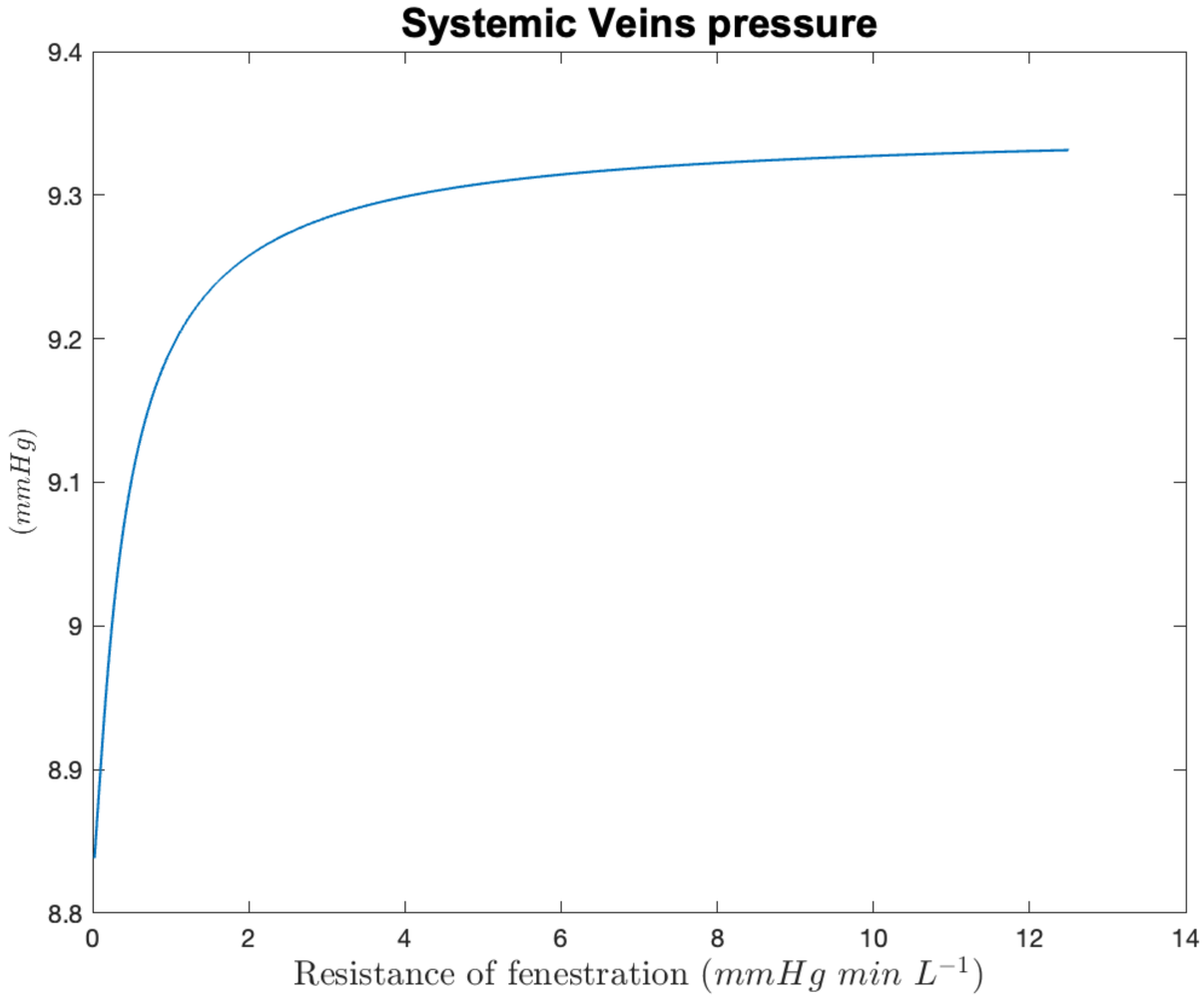

Single ventricle and sysmetic arteries pressure
Single ventricle
Sysmetic arteries
Pressure (mmHg)
Time (minutes)
140
120
100
80
60
40
20
0
0.5
0.55
0.6
0.65
0.7
0.75
0.8

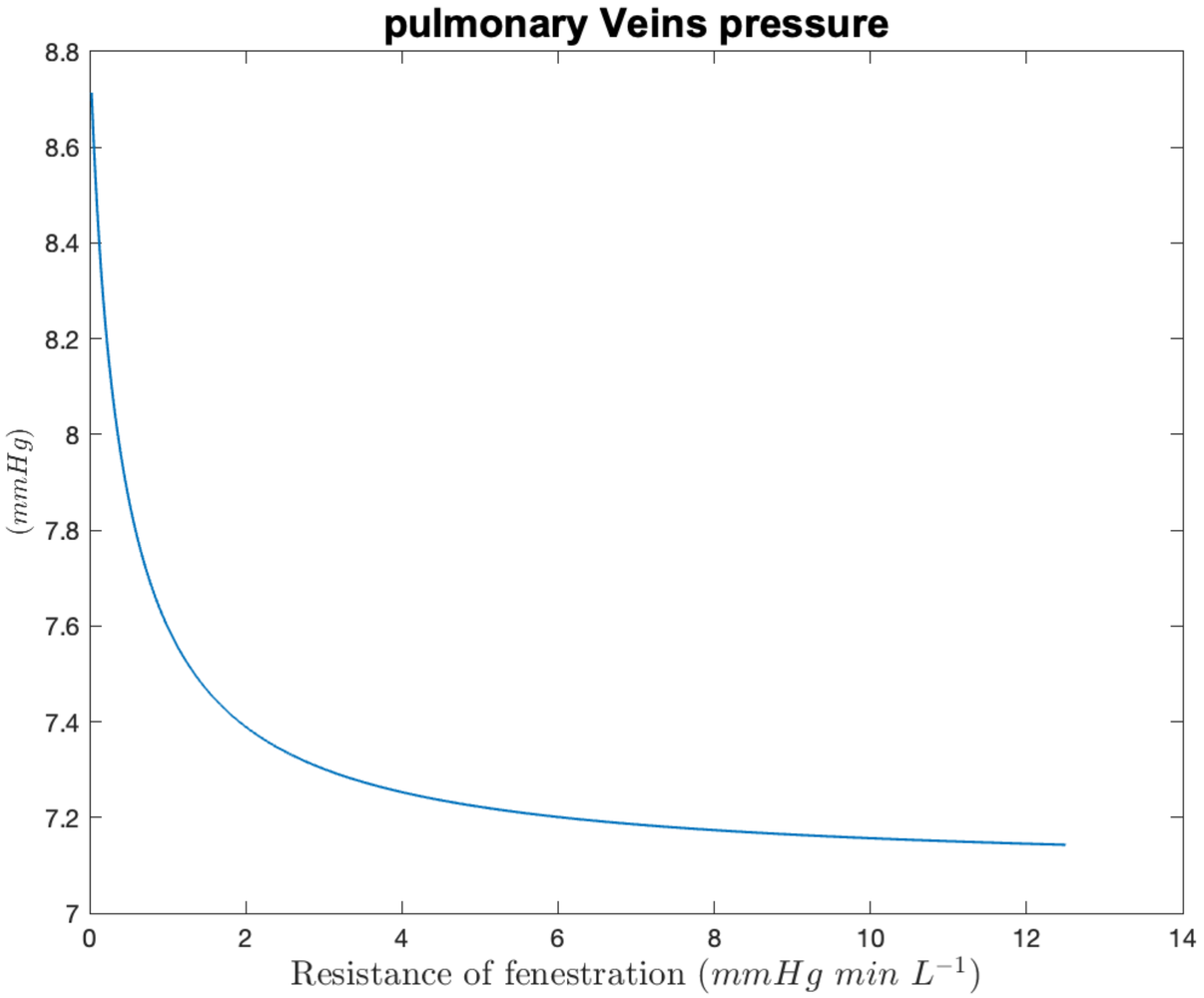

Single ventricle PV loop
500
450
400
350
300
250
200
150
100
50
0
Pressure $(mmHg)$
0.05
0.06
0.07
0.08
0.09
0.1
0.11
0.12
0.13
Volume $(liters)$


Systemic Flow
5.2
5
4.8
4.6
4.4
4.2
4
$(L\ min^{-1})$
0
2
4
6
8
10
12
14
Resistance of fenestration $(mmHg\ min\ L^{-1}$


Pulmonary Flow
4
3
2
1
0
$(L\ min^{-1})$
0
2
4
6
8
10
12
14
Resistance of fenestration $(mmHg\ min\ L^{-1}$


Fenestration Flow
5
4
3
2
1
0
$(L\ min^{-1})$
0
2
4
6
8
10
12
14
Resistance of fenestration $(mmHg\ min\ L^{-1})$


Systemic Veins pressure
9.4
9.3
9.2
9.1
9
8.9
8.8
$(mmHg)$
0
2
4
6
8
10
12
14
Resistance of fenestration $(mmHg\ min\ L^{-1})$


pulmonary Veins pressure
8.8
8.6
8.4
8.2
8
7.8
7.6
7.4
7.2
7
$(mmHg)$
0
2
4
6
8
10
12
14
Resistance of fenestration $(mmHg\ min\ L^{-1})$