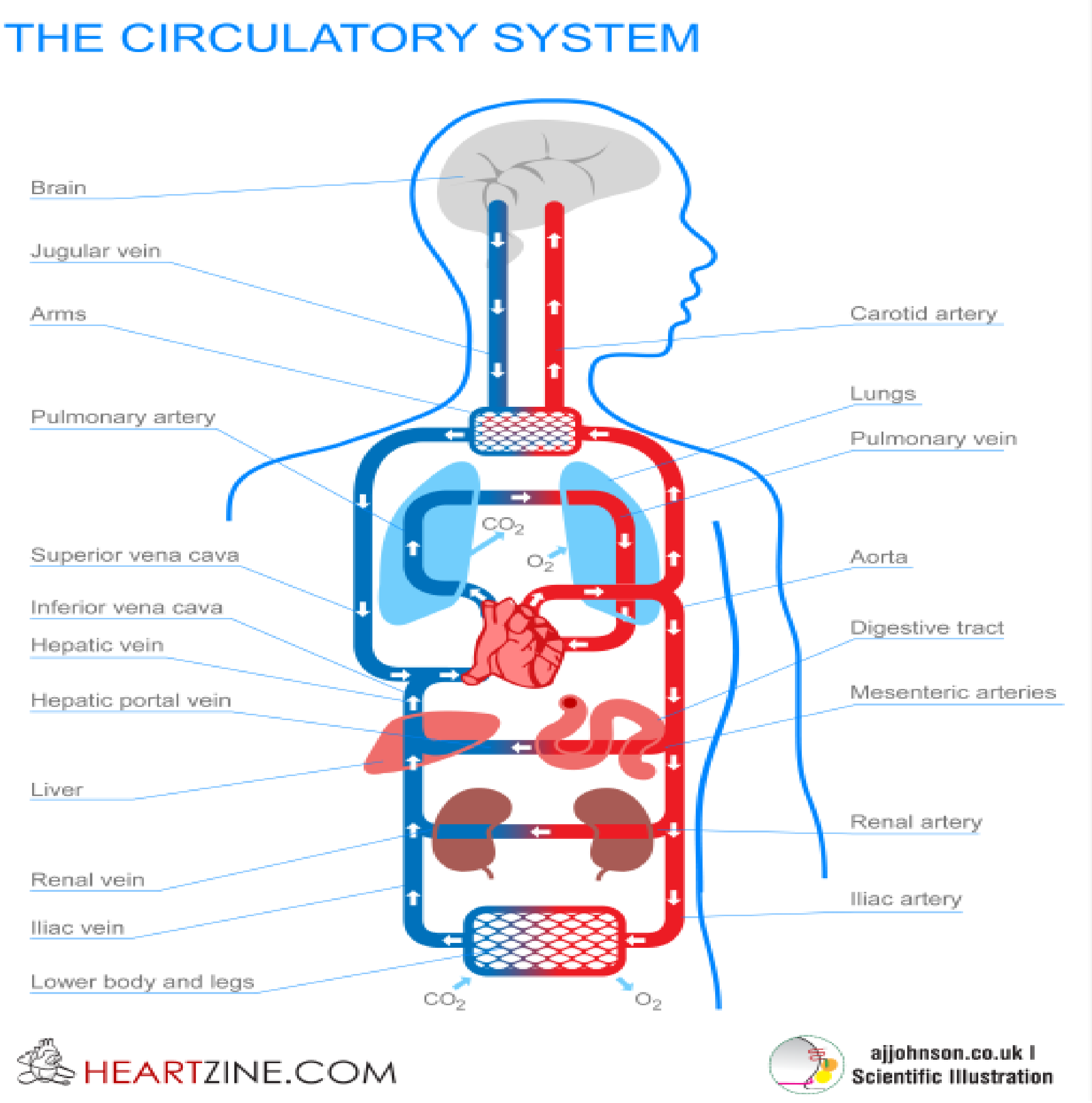
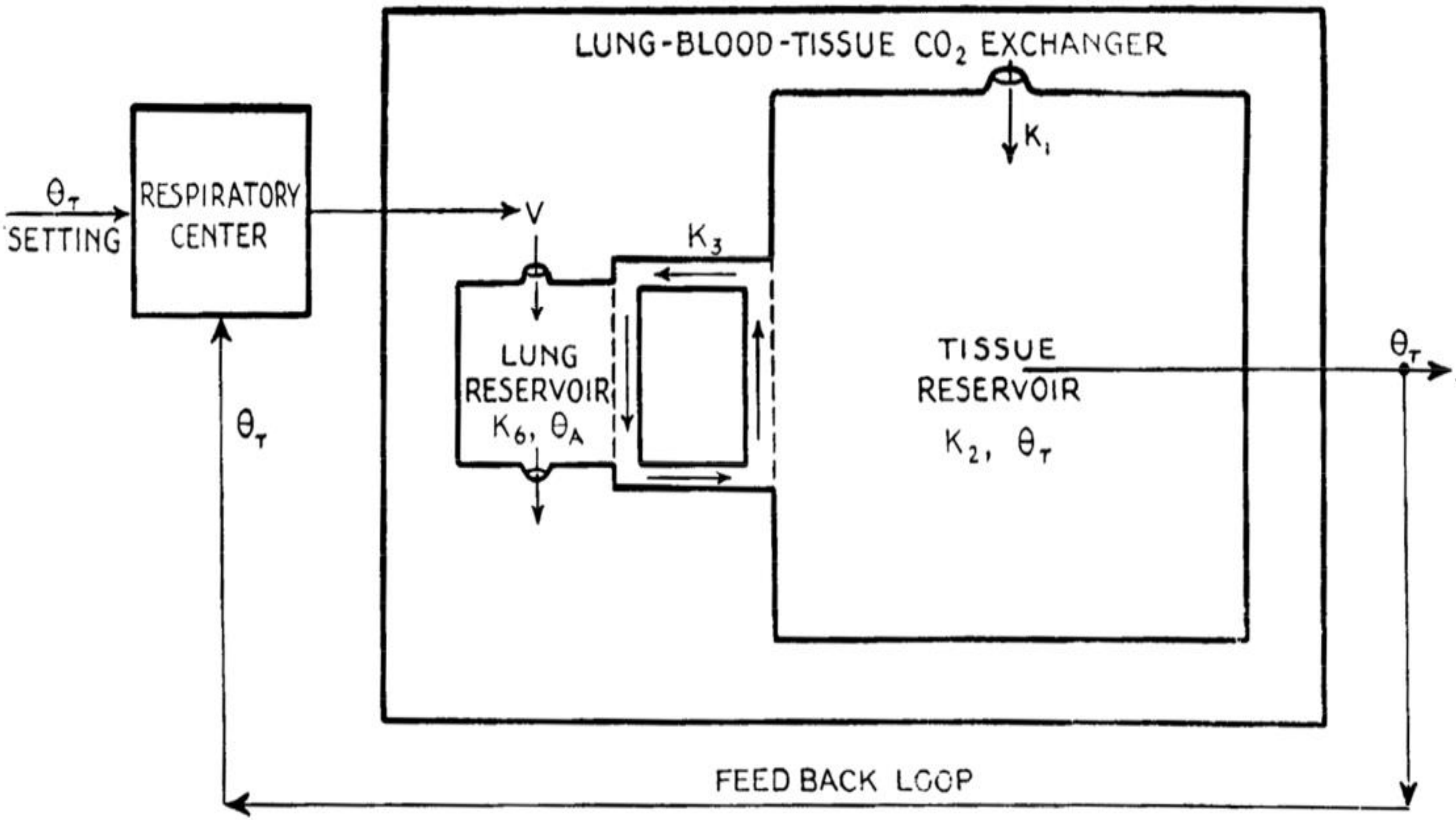
Modeling of the Human Respiratory System

Jurandir Itizo Yanagihara

Human Respiratory System



Respiratory System Model (Grodins et al. , 1954)



Albuquerque et al. (2008)

11 compartments:

Alveolar air space compartment

Pulmonary capillaries compartment

Body is divided into two regions:

a) Cerebral region:

Arterial compartment

Tissue compartment

Capillaries tissue compartment

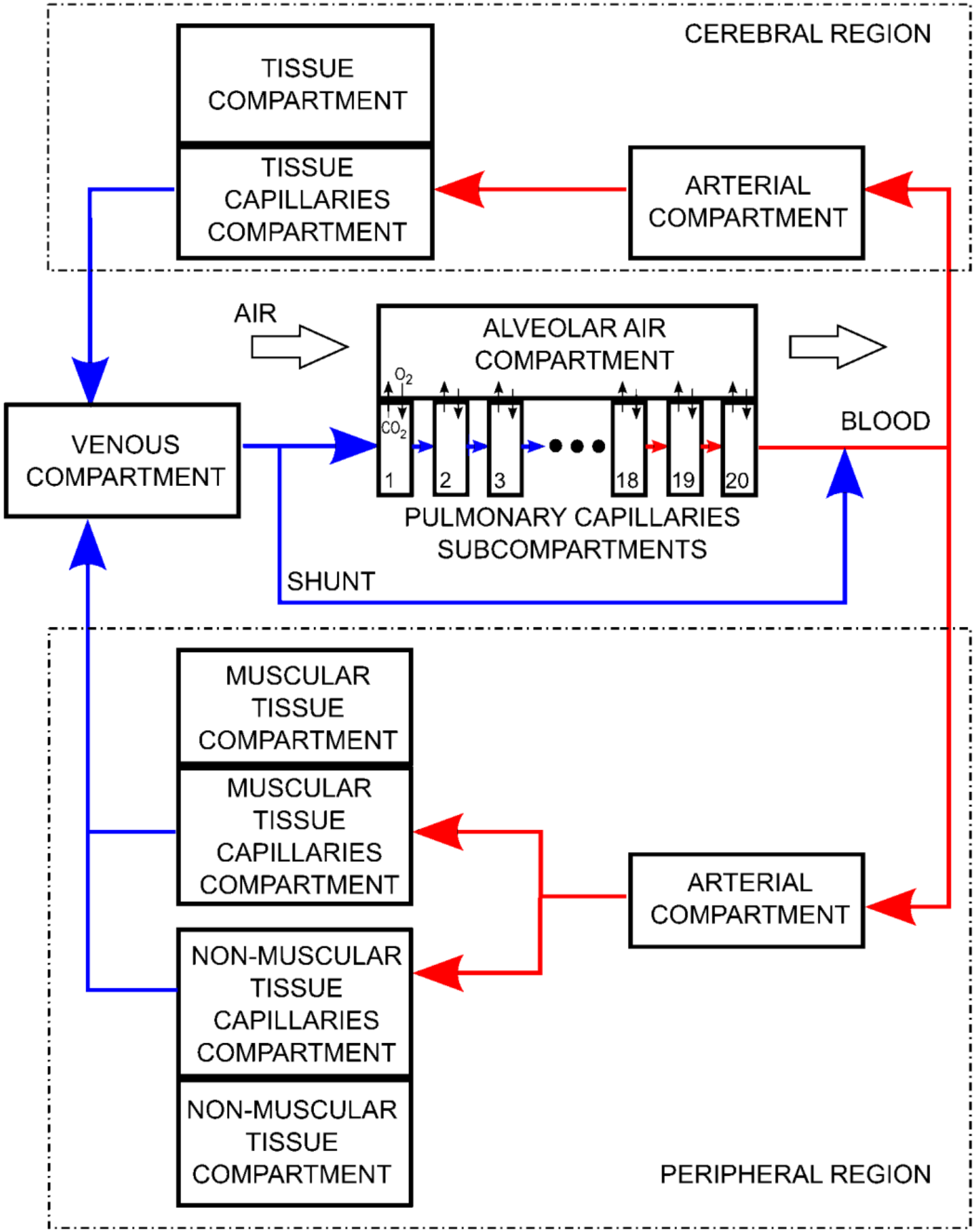
b) Peripheral region

Arterial compartment

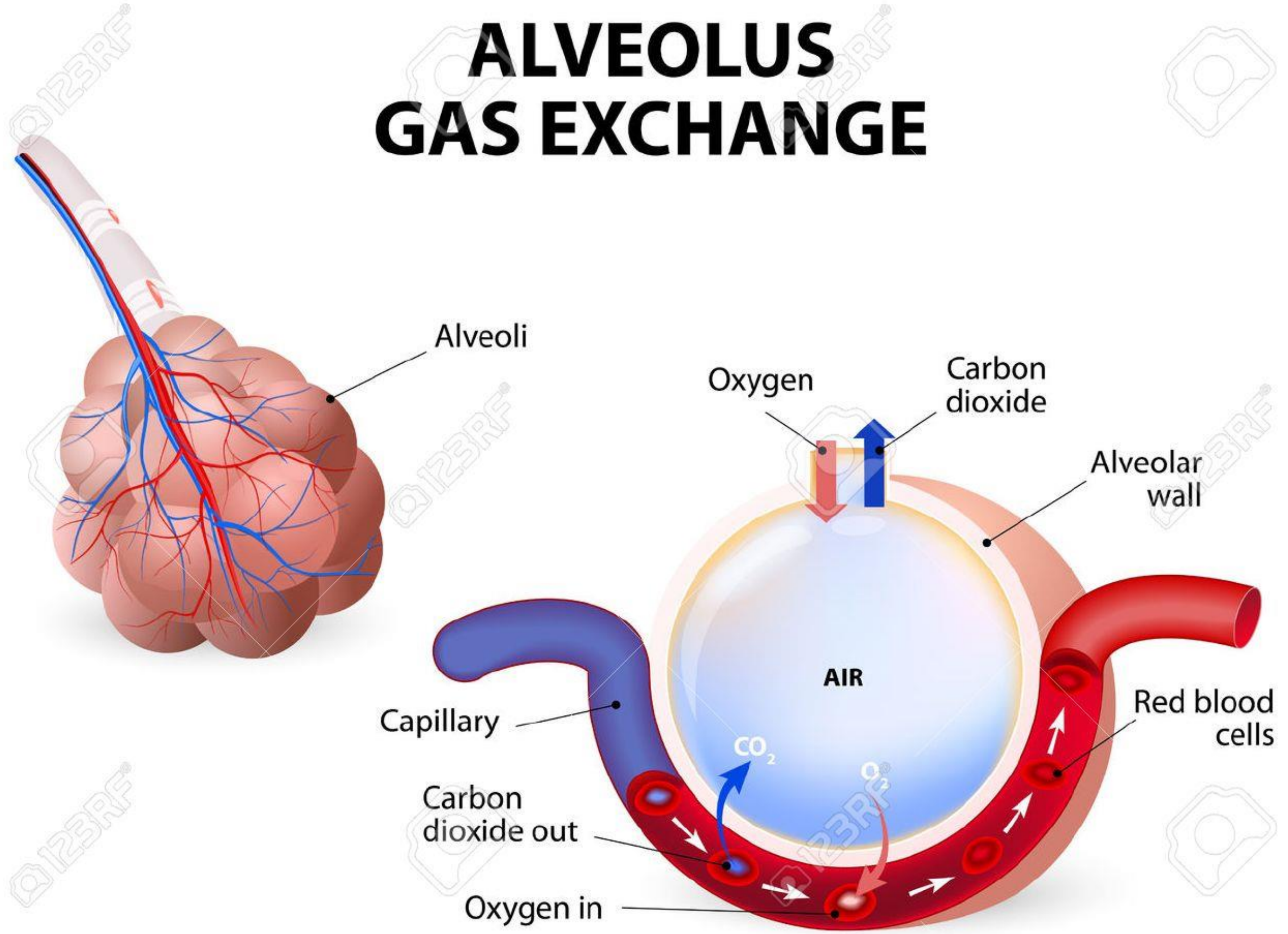
Two subregions:

b.1) muscular tissues

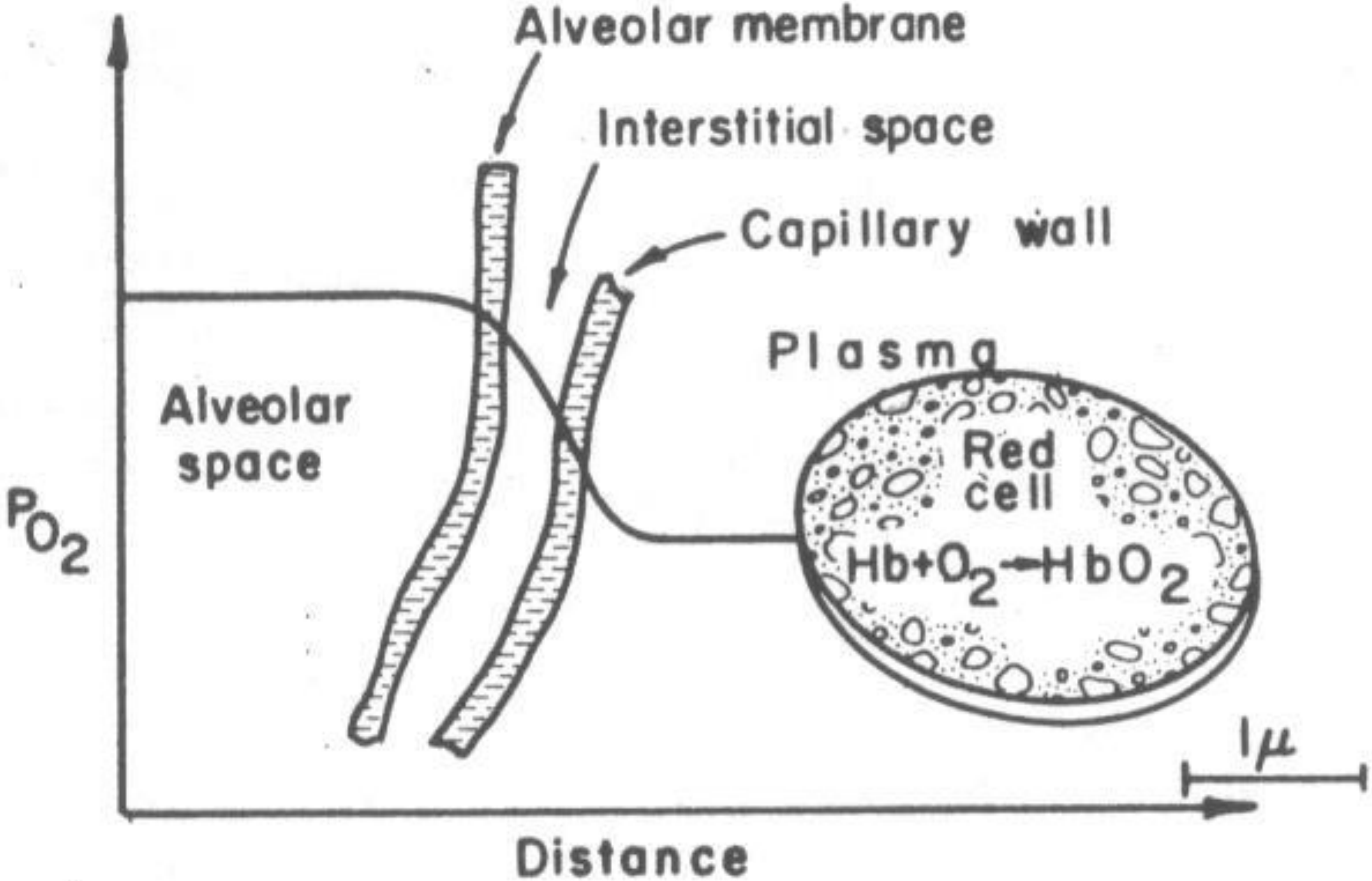
b.2) non-muscular tissues



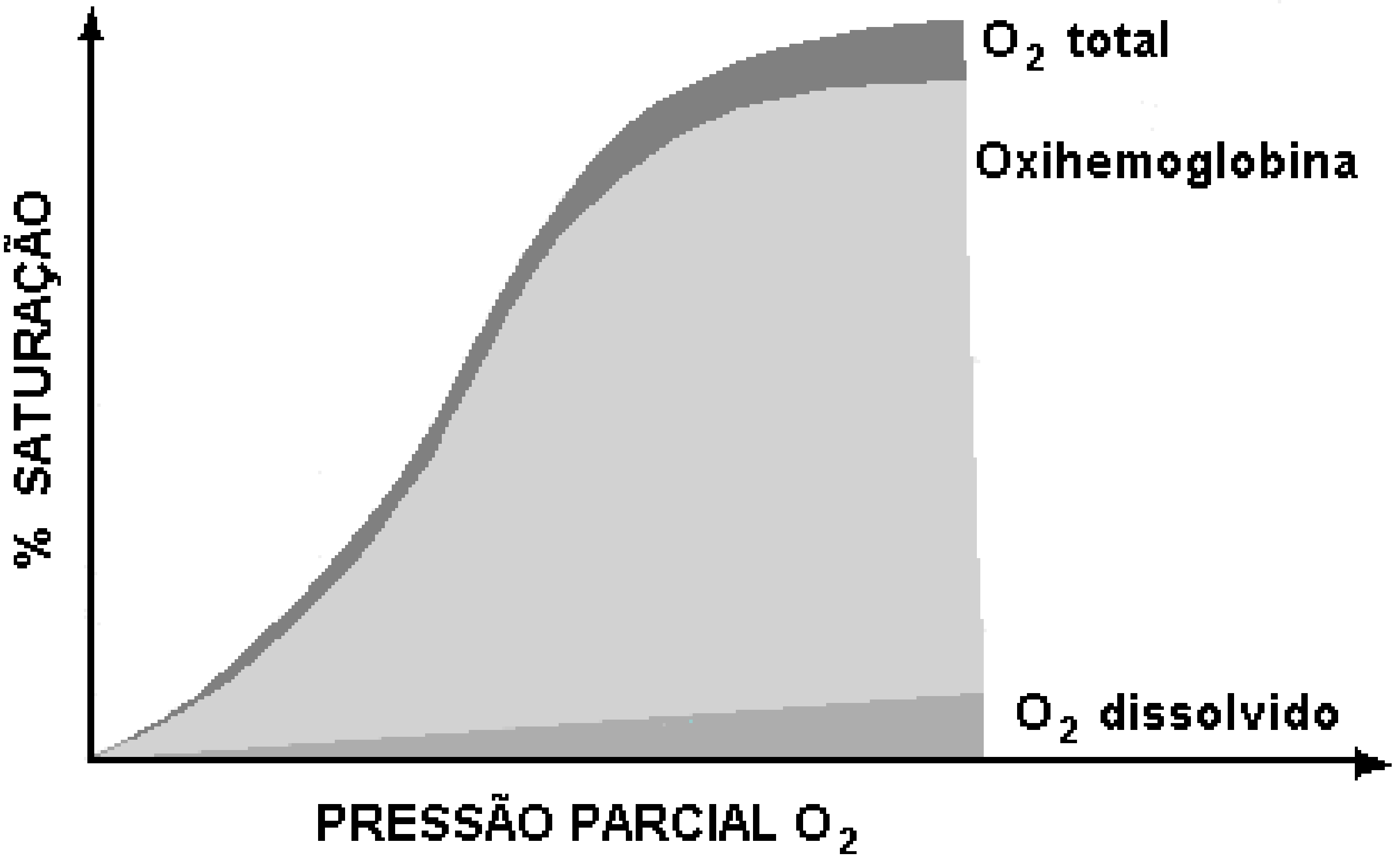
Alveolus Gas Exchange



Oxygen Diffusion in the Alveolus



Transport of O_2



Transport of O_2

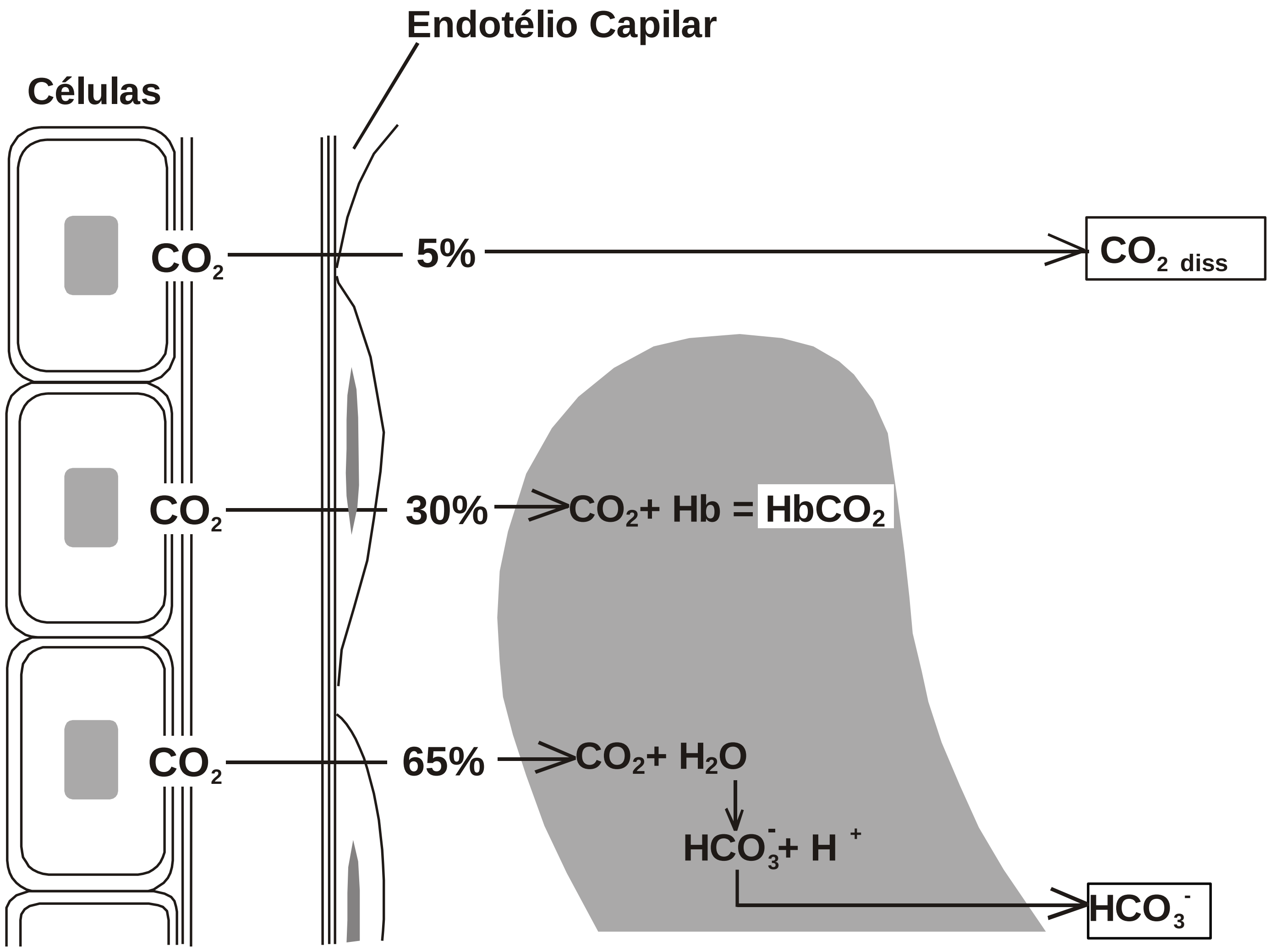
Douglas et al (1988):

$$x_{O_2,s} = (0{,}003105 \times P_{O_2} + 1{,}34 \times [Hb] \times \frac{S_{O_2}}{100}) \times \frac{1}{100}$$

$$S_{O_2} = \frac{N^4 - 15N^3 + 2045N^2 + 2000N}{N^4 - 15N^3 + 2400N^2 - 31100N + 2{,}4 \times 10^6}$$

$$N = P_{O_2} \cdot 10^{(0{,}48 \cdot (pH - 7{,}4) - 0{,}024 \cdot (T - 37) - 0{,}0013 \cdot BE)}$$

Transport of CO_2

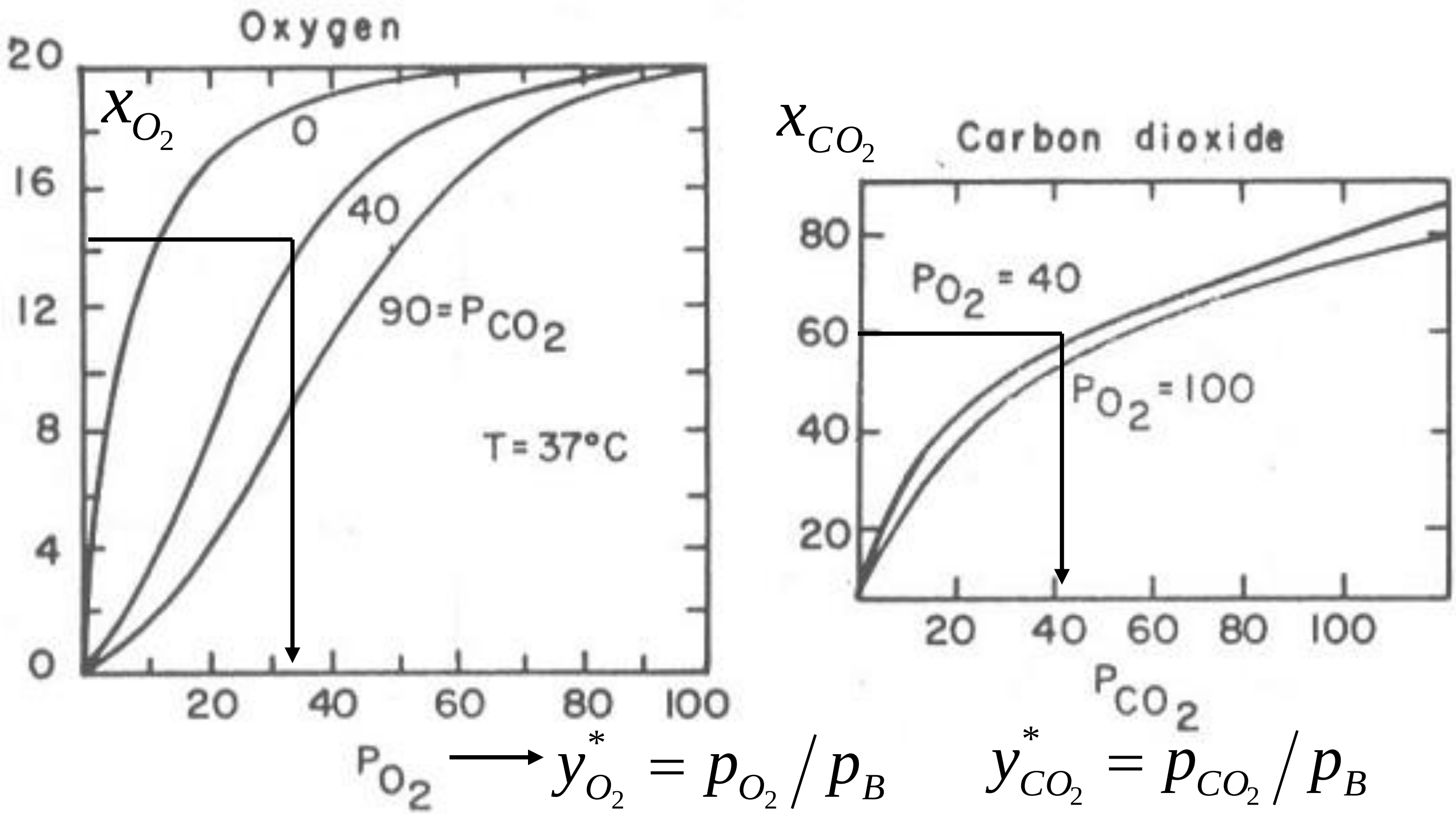


Transport of CO_2

Kelman (1966):

$$x_{CO_2,pl} = 0{,}02568 \cdot 0{,}0301 \cdot P_{CO_2} \cdot (1 + 10^{(pH - 6{,}1)})$$

$$x_{CO_2,s} = x_{CO_2,pl} \cdot \left(1 - \frac{0{,}0289 \cdot Hb}{(3{,}352 - 0{,}456 \cdot S_{O_2}/100) \cdot (8{,}142 - pH)}\right)$$



$$y^*_{O_2} = p_{O_2} / p_B \qquad y^*_{CO_2} = p_{CO_2} / p_B$$

P*CO2a

$$[HCO_3] = 24 + \frac{BE - (9{,}5 + 1{,}63 \cdot Hb)(pH - 7{,}4)}{1 - 0{,}014 \cdot Hb}$$

$$[HCO_3] = 0{,}0301 \cdot P_{CO_2} \cdot 10^{(pH-6{,}1)}$$

$$x_{CO_2,pl} = 0{,}02226 \cdot 0{,}0301 \cdot P_{CO_2} \cdot (1 + 10^{(pH-6{,}1)})$$

$$N = P_{O_2} \cdot 10^{(0{,}48 \cdot (pH-7{,}4) - 0{,}024 \cdot (T-37) - 0{,}0013 \cdot BE)}$$

$$S_{O_2} = \frac{N^4 - 15N^3 + 2045N^2 + 2000N}{N^4 - 15N^3 + 2400N^2 - 31100N + 2{,}4 \times 10^6}$$

$$x_{CO_2,s} = x_{CO_2,pl} \cdot \left(1 - \frac{0{,}0289 \cdot Hb}{(3{,}352 - 0{,}456 \cdot S_{O_2}/100) \cdot (8{,}142 - pH)}\right)$$

$P*_{CO_2,s,\infty}$

pH

$HCO3^-$

$x_{CO_2,pl}$

N

$P*_{O_2,s,\infty}$

S_{O_2}

P*O2a

$$[HCO_3] = 24 + \frac{BE - (9{,}5 + 1{,}63 \cdot Hb)(pH - 7{,}4)}{1 - 0{,}014 \cdot Hb}$$

$$[HCO_3] = 0{,}0301 \cdot P_{CO_2} \cdot 10^{(pH - 6{,}1)}$$

$$N = P_{O_2} \cdot 10^{(0{,}48 \cdot (pH - 7{,}4) - 0{,}024 \cdot (T - 37) - 0{,}0013 \cdot BE)}$$

$$S_{O_2} = \frac{N^4 - 15N^3 + 2045N^2 + 2000N}{N^4 - 15N^3 + 2400N^2 - 31100N + 2{,}4 \times 10^6}$$

$$x_{O_2,s} = (0{,}003105 \times P_{O_2} + 1{,}34 \times [Hb] \times \frac{S_{O_2}}{100}) \times \frac{1}{100}$$

pH

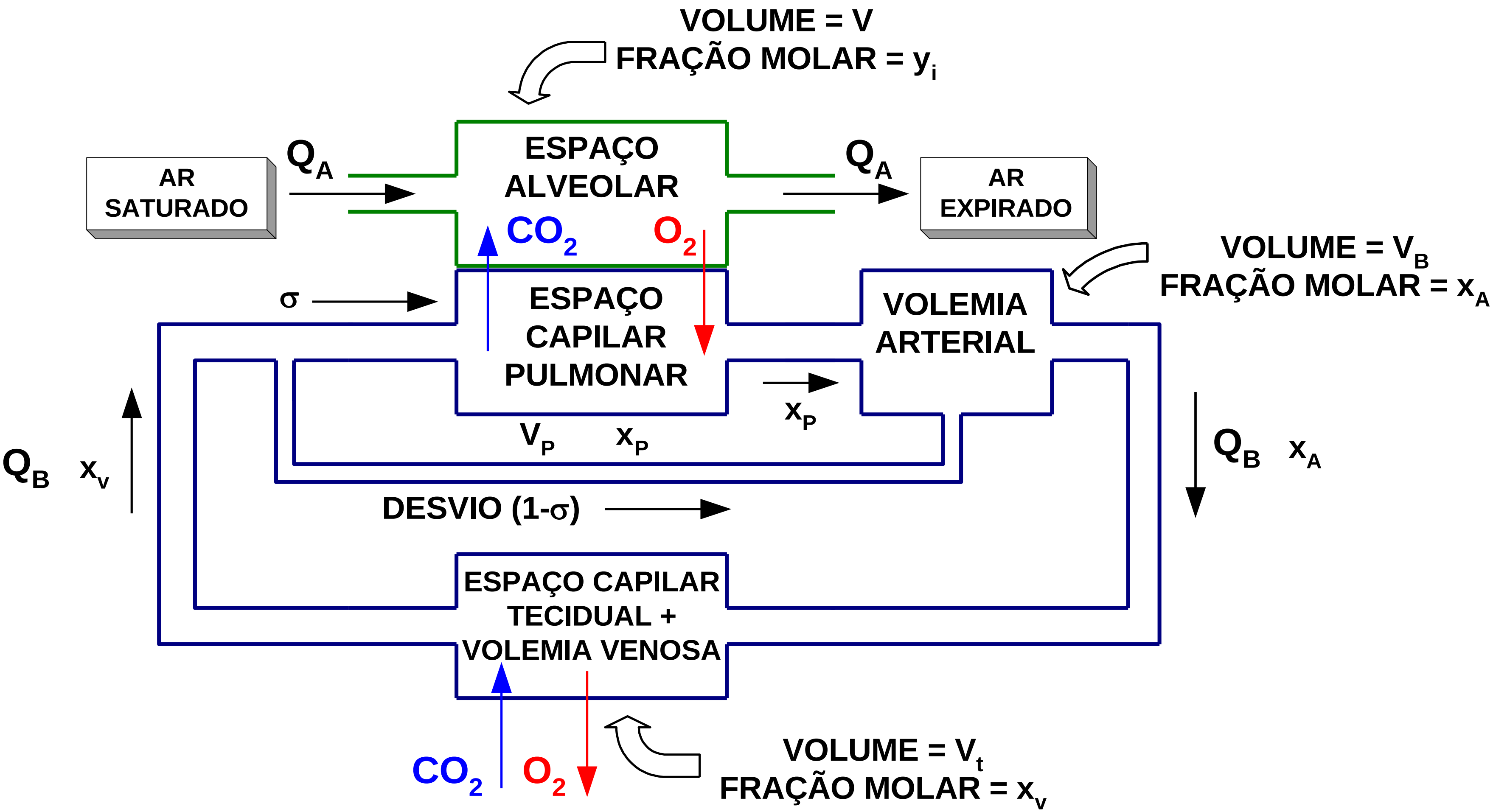
$HCO3^-$

N

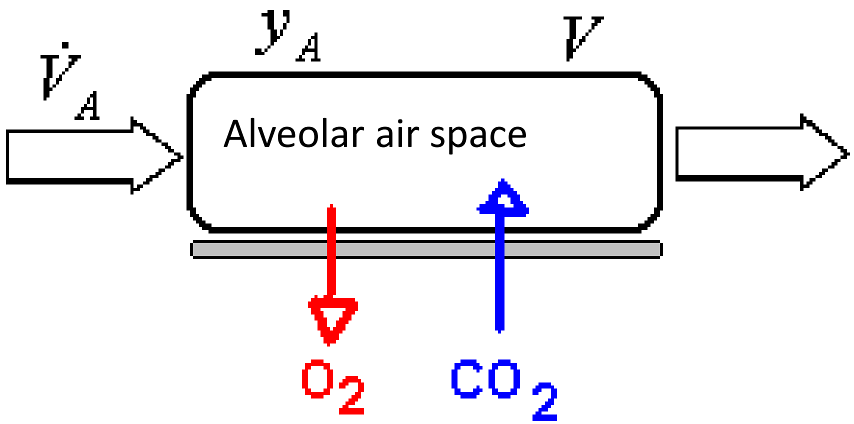
$P^*_{O_2,s,\infty}$

S_{O_2}

Cardio-Respiratory Model



Alveolar Air Space Mass Conservation Analysis



Model Perturbation

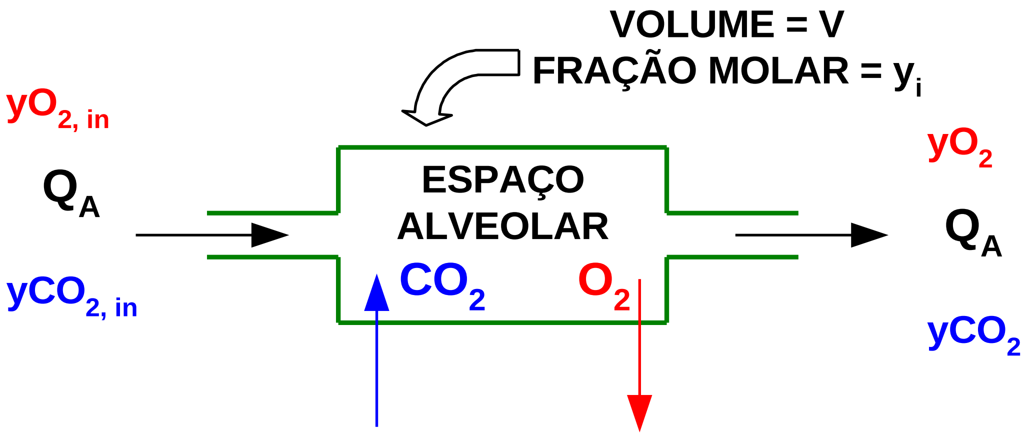
$$\frac{dy_{O_2}}{dt} = \frac{P_B}{760}\frac{273}{310}\frac{\dot{V}_A}{V}\cdot(y_{O_2,in} - y_{O_2}) - \sum_{i=1}^{20}\frac{D_{LO_2(i)}P_B}{20V}(y_{O_2} - y^*_{O_2,i})$$

Net mass balance

Convective mass transport balance

Diffusive mass transport balance

Mass Balance in the Alveolar Space



OXIGÊNIO:

$$\frac{dy_{O_2}}{dt} = \frac{Q_A}{V}.(y_{O_2,in} - y_{O_2}) - k_{O_2}.a.(y_{O_2} - y_{O_2}^*)$$

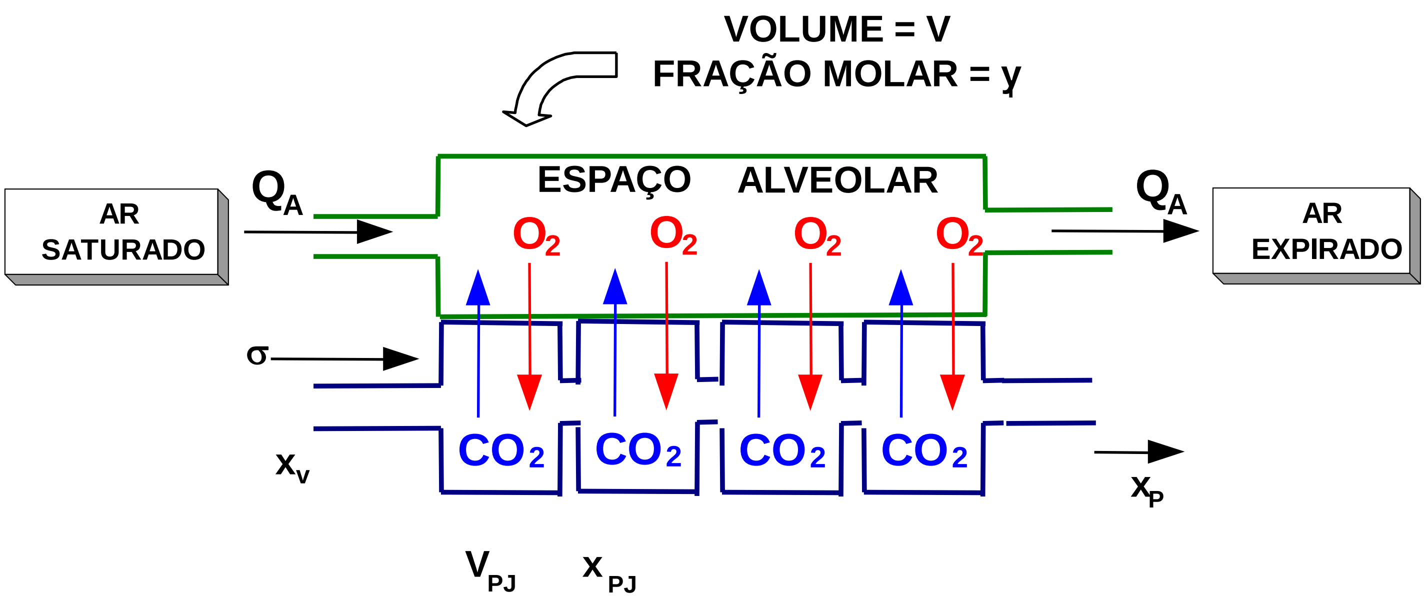
RESPOSTA DO SISTEMA DE CONTROLE

COEFICIENTES DE DIFUSÃO

GÁS CARBÔNICO:

$$\frac{dy_{CO_2}}{dt} = \frac{Q_A}{V}.(y_{CO_2,in} - y_{CO_2}) + k_{CO_2}.a.(y_{CO_2}^* - y_{CO_2})$$

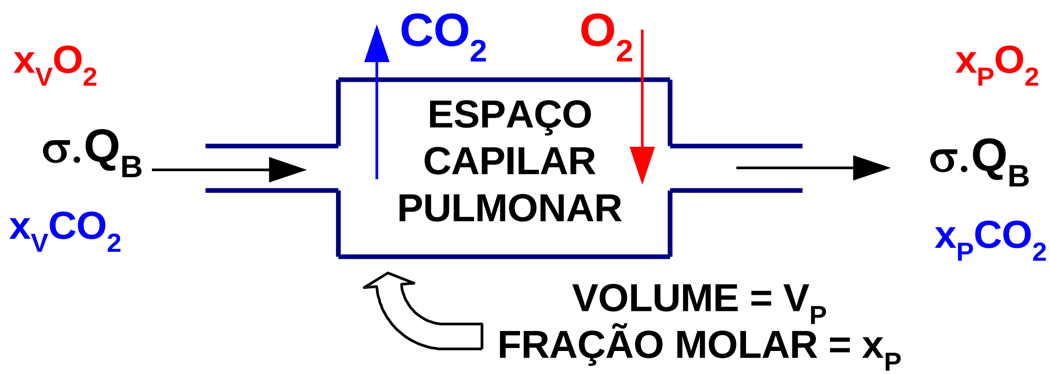
Gas Transport in the Alveolus Use of Local Coefficients



ESPAÇO CAPILAR PULMONAR

SUB-COMPARTIMENTALIZADO

Mass Balance in the Lung Blood Space

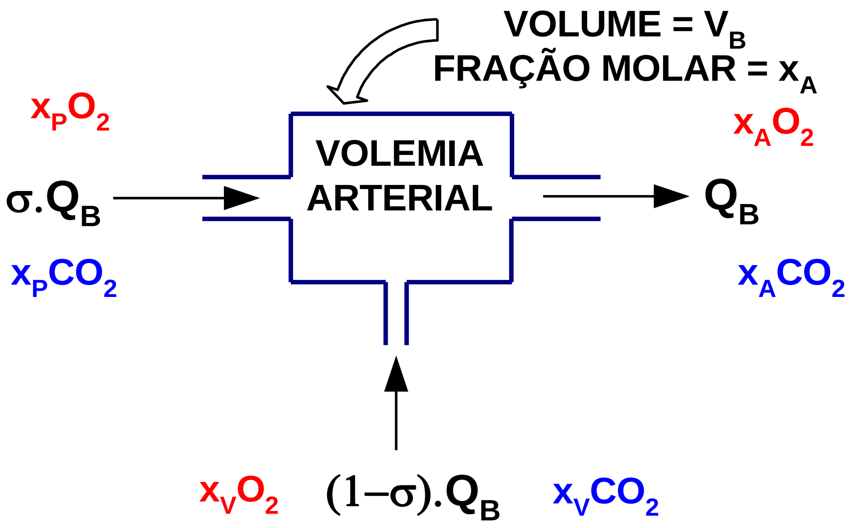


OXIGÊNIO: $$V_p \cdot \frac{dx_{p,O_2}}{dt} = Q_B.\sigma.(x_{v,O_2} - x_{p,O_2}) + k_{O_2} \cdot a.(y_{O_2} - y_{O_2}^{\ *}).V$$

RESPOSTA DO
SISTEMA DE CONTROLE

GÁS CARBÔNICO: $$V_p \cdot \frac{dx_{p,CO_2}}{dt} = Q_B.\sigma.(x_{v,CO_2} - x_{p,CO_2}) - k_{CO_2}.a.(y_{CO_2}^{\ *} - y_{CO_2})$$

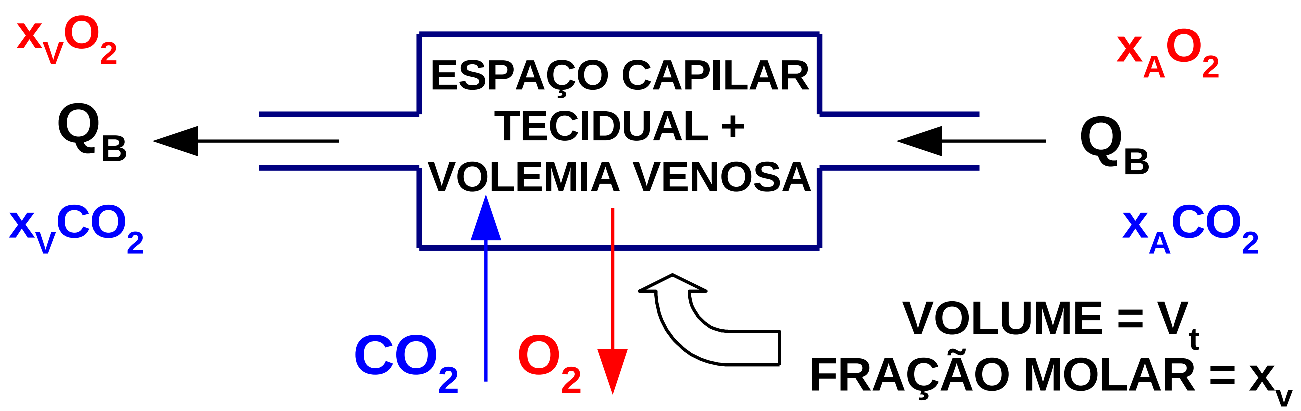
Mass Balance in the Blood Space



OXIGÊNIO: $$V_b.\frac{dx_{A,O_2}}{dt} = Q_B.\left[(1-\sigma).x_{v,O_2} + \sigma.x_{p,O_2} - x_{A,O_2}\right]$$

GÁS CARBÔNICO: $$V_b.\frac{dx_{A,CO_2}}{dt} = Q_B.\left[(1-\sigma).x_{v,CO_2} + \sigma.x_{p,CO_2} - x_{A,CO_2}\right]$$

Mass Balance in the Tissue Space



CONSUMO DE OXIGÊNIO

OXIGÊNIO:

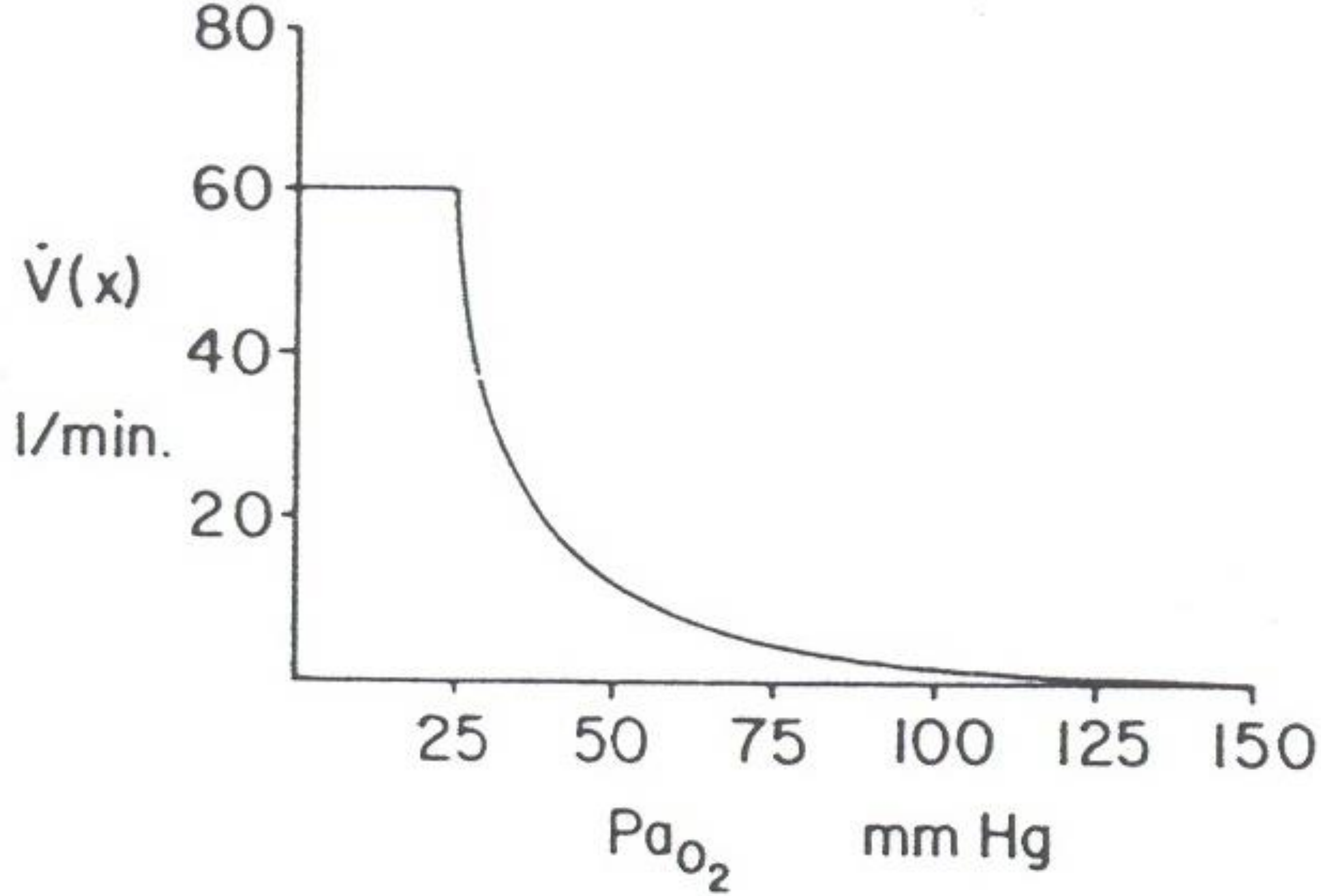
$$V_t \cdot \frac{dx_{v,O_2}}{dt} = Q_B.(x_{A,O_2} - x_{v,O_2}) - M_{O_2}$$

PRODUÇÃO DE GÁS CARBÔNICO

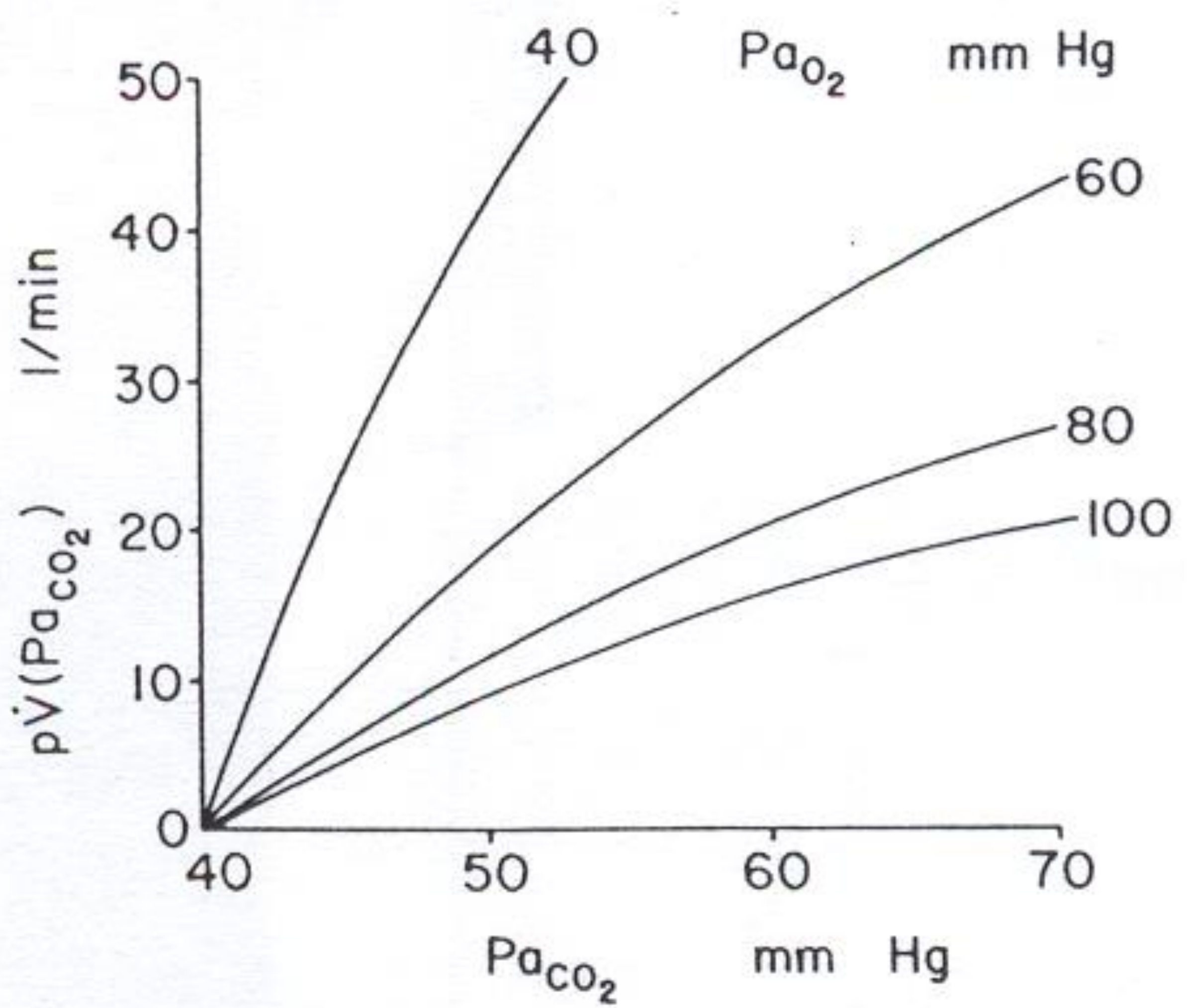
GÁS CARBÔNICO:

$$V_t \cdot \frac{dx_{v,CO_2}}{dt} = Q_B.(x_{A,O_2} - x_{v,O_2}) + R.M_{O_2}$$

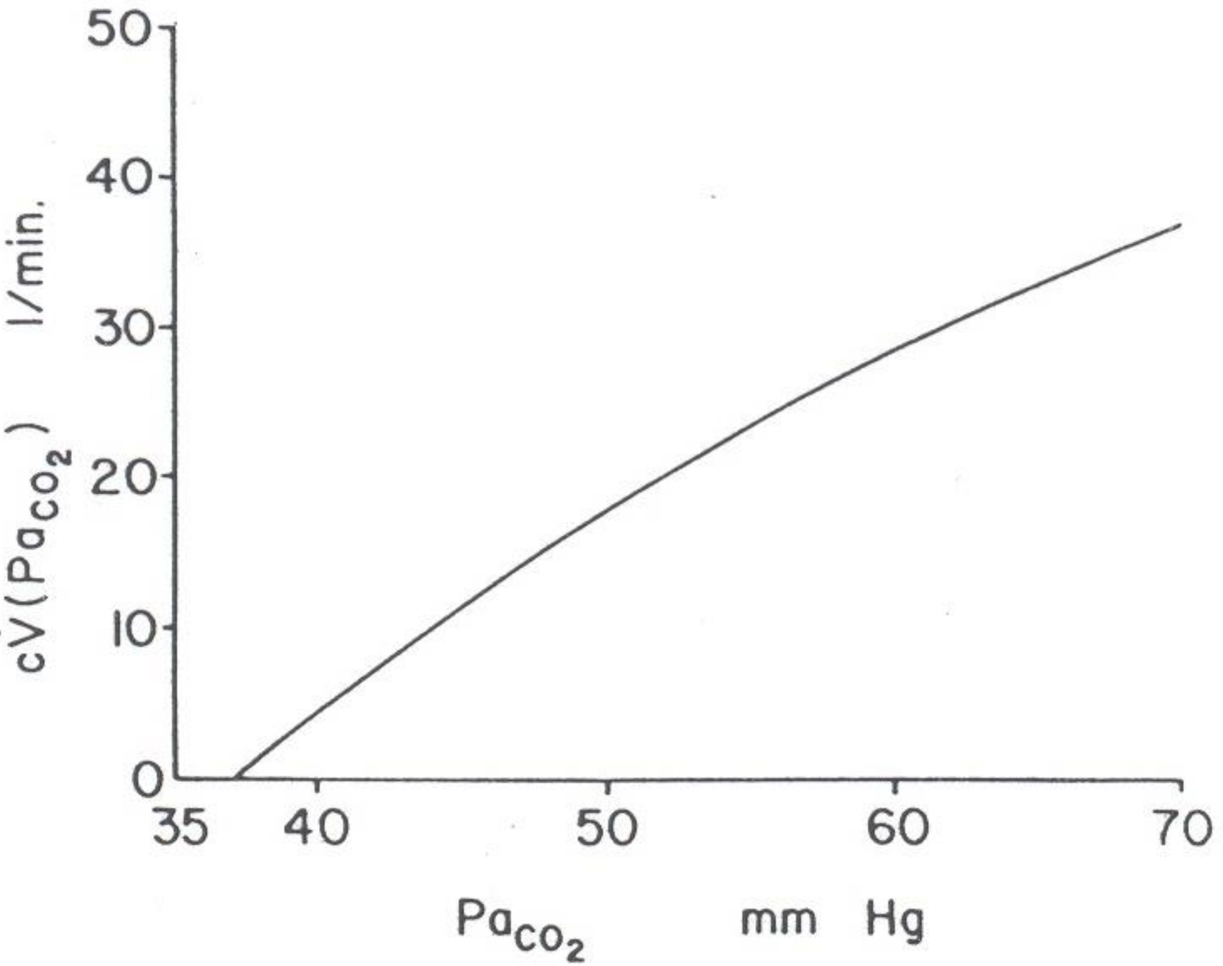
Alveolar Ventilation – Effect of PO_2a

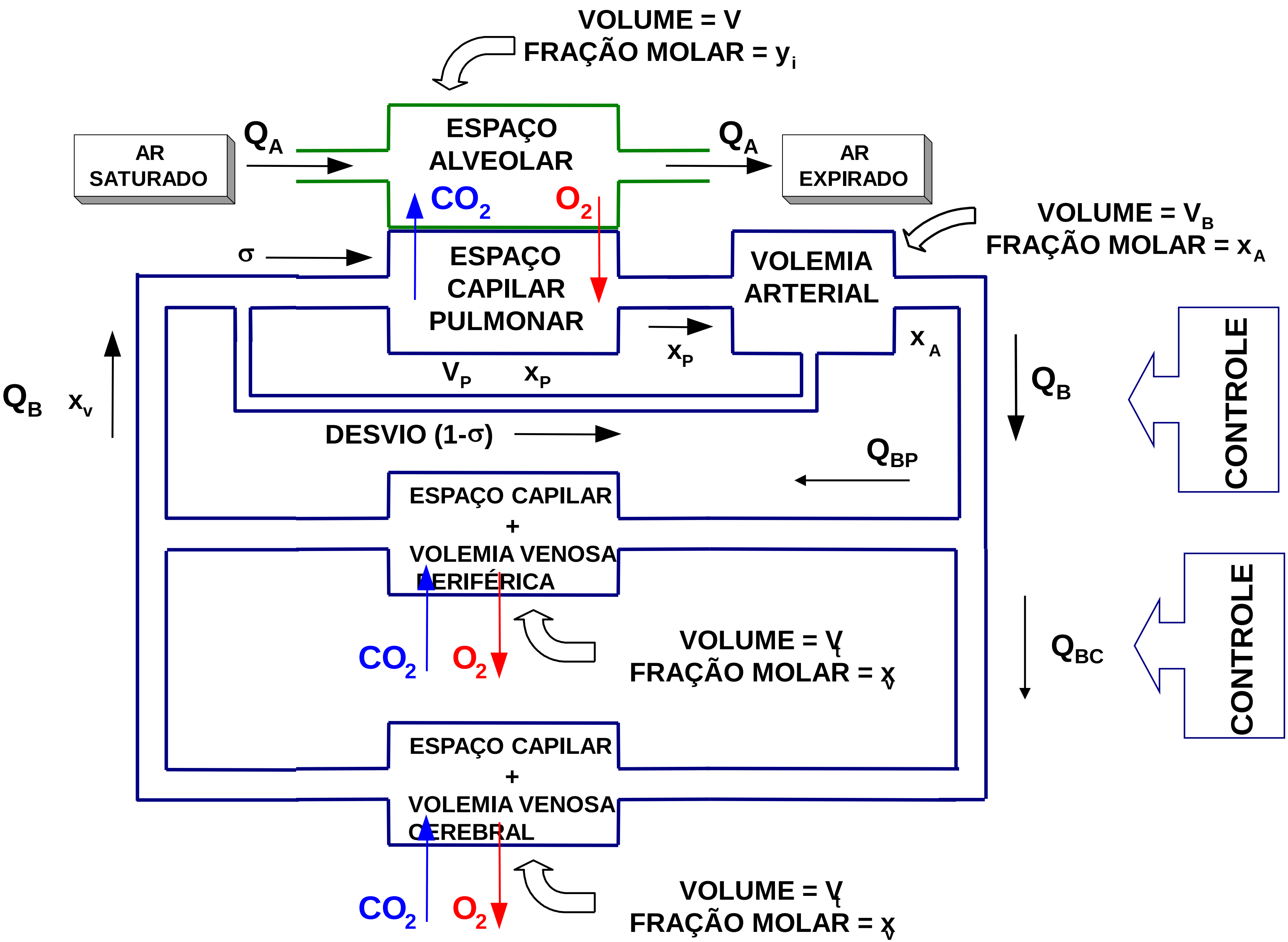


Alveolar Ventilation – Effect of Peripheral PCO_2a



Alveolar Ventilation – Effect of Central PCO_2a




VOLUME = V
FRAÇÃO MOLAR = y_i
AR SATURADO
Q_A
ESPAÇO ALVEOLAR
CO_2
O_2
Q_A
AR EXPIRADO
VOLUME = V_B
FRAÇÃO MOLAR = x_A
σ
ESPAÇO CAPILAR PULMONAR
VOLEMIA ARTERIAL
x_P
x_A
V_P
x_P
Q_B
x_v
Q_B
CONTROLE
DESVIO (1-σ)
Q_{BP}
ESPAÇO CAPILAR
+
VOLEMIA VENOSA
PERIFÉRICA
CO_2
O_2
VOLUME = V_t
FRAÇÃO MOLAR = x_V
Q_{BC}
CONTROLE
ESPAÇO CAPILAR
+
VOLEMIA VENOSA
CEREBRAL
CO_2
O_2
VOLUME = V_t
FRAÇÃO MOLAR = x_V