AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Sleep apnoea: A model of airway drying during nasal positive air pressure breathing

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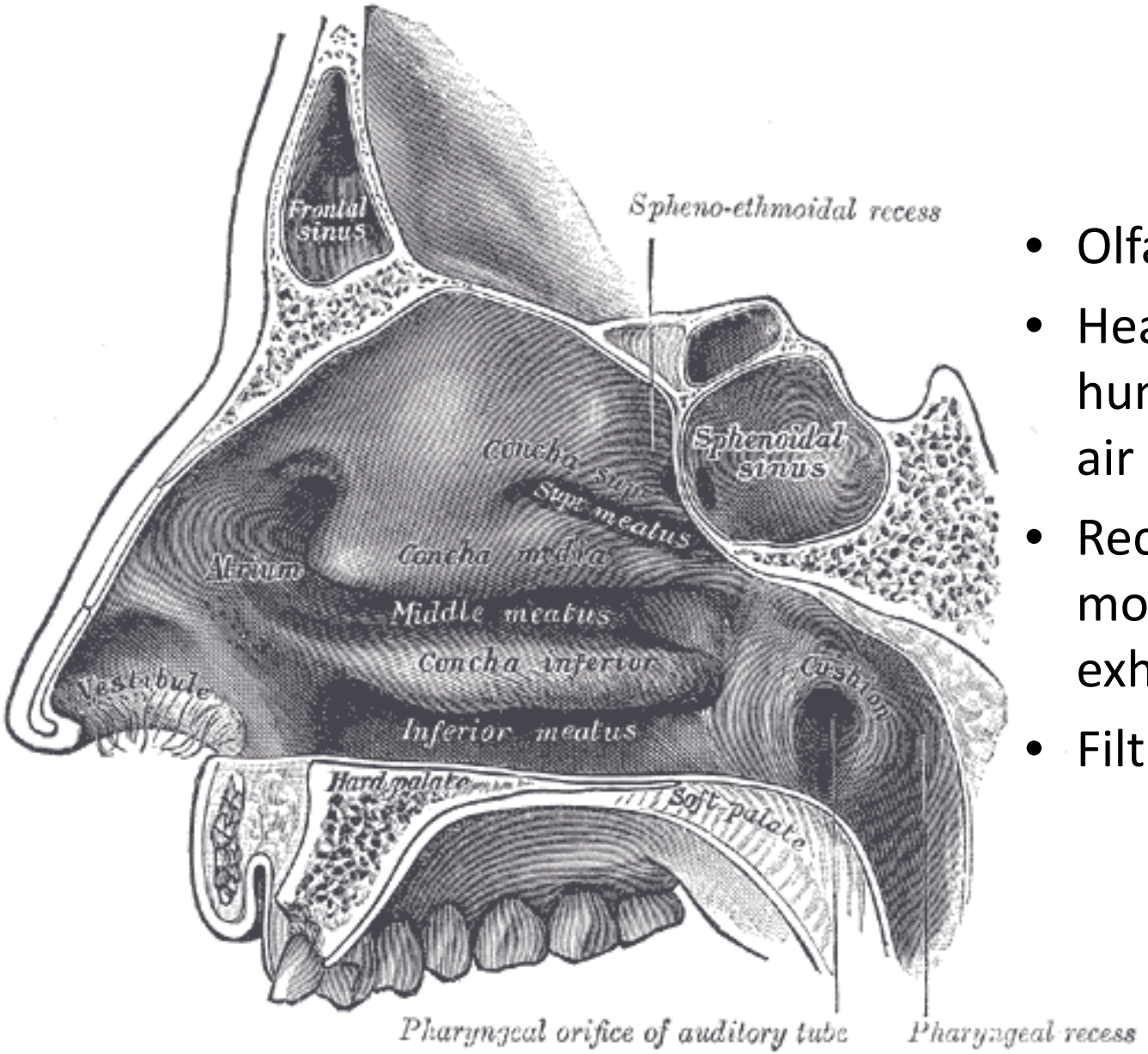
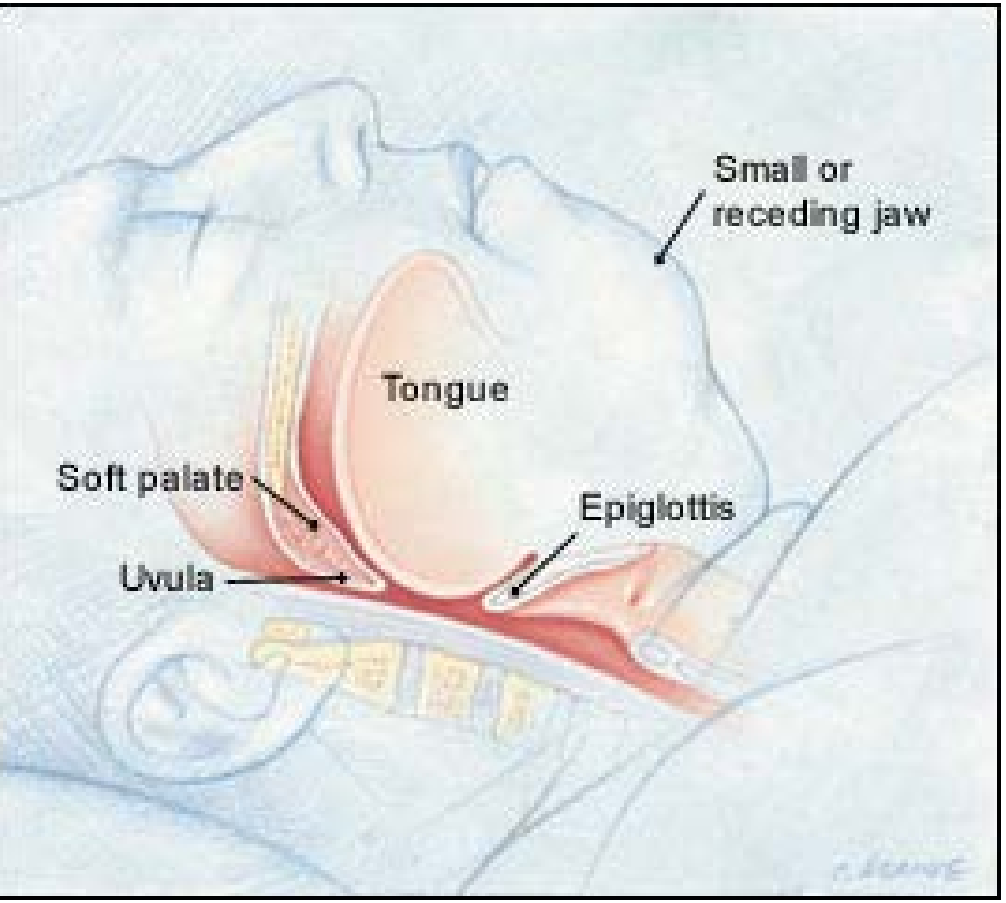
School of Engineering

Role of the nose



- Olfaction
- Heating and humidifying inhaled air
- Recovering heat and moisture from exhaled air
- Filtration

Obstructive Sleep Apnoea (OSA)



Affects 6% of adult population.

- 3 times as likely to have car accidents.
- Causes excessive sleepiness whist awake.

Suffer other symptoms such as:

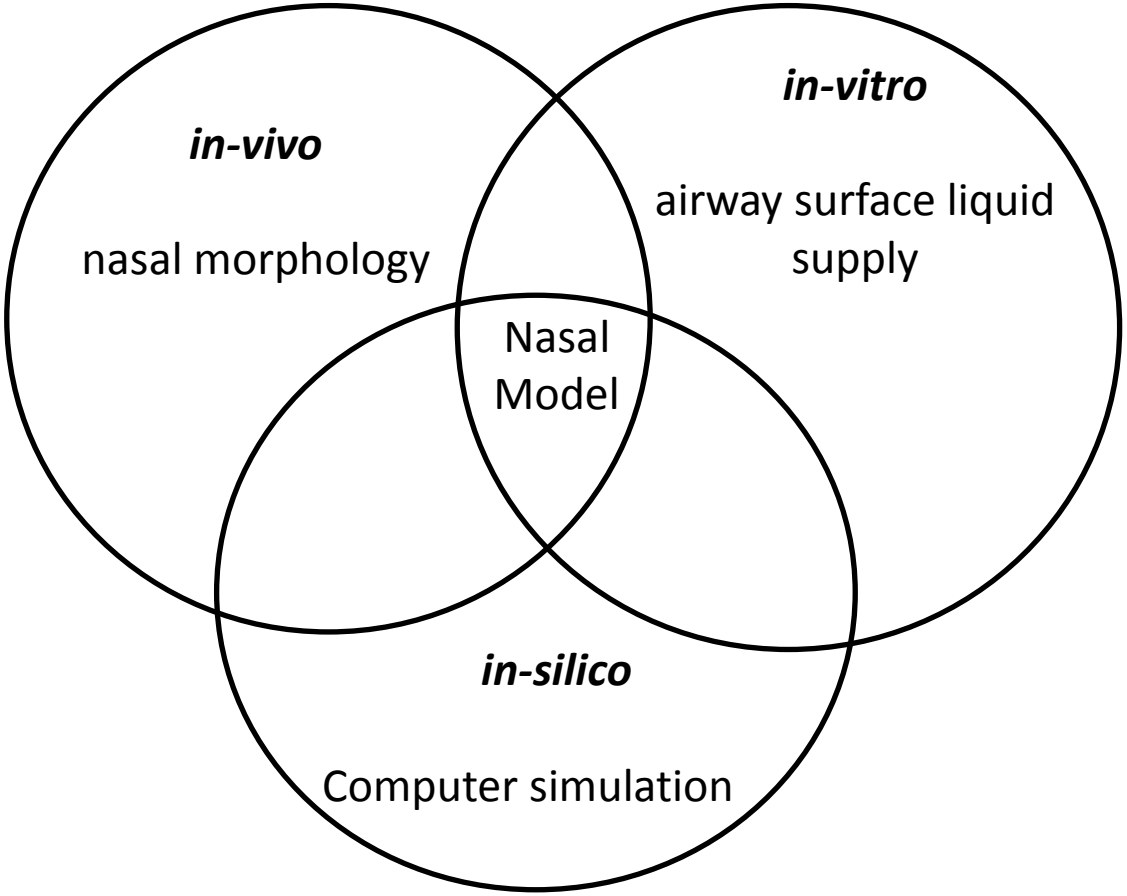
- irritability
- Depression
- sexual dysfunction
- Learning
- memory difficulty

associated with:

- irregular heartbeat
- high blood pressure
- heart attack
- Stroke

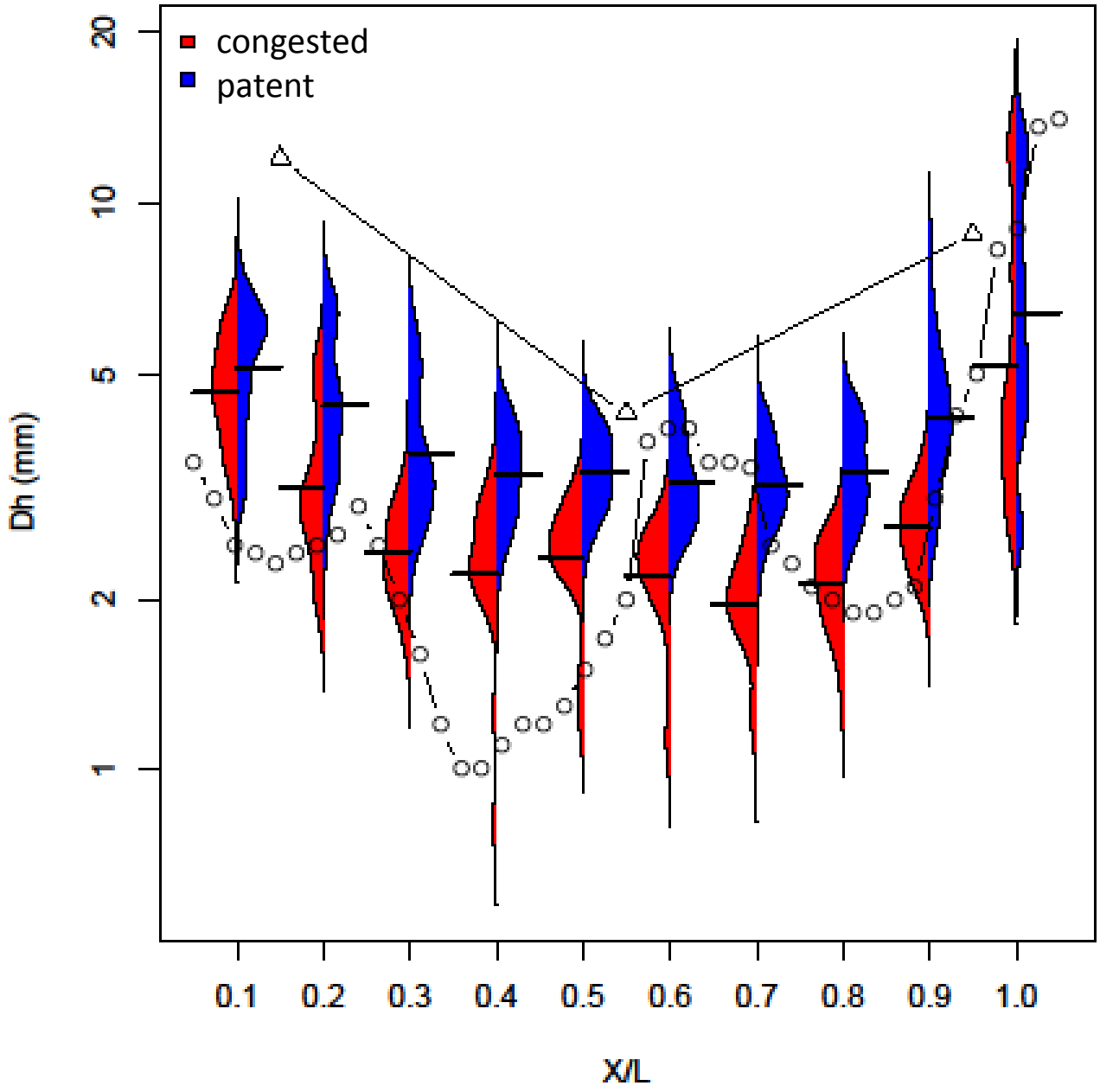
Many n-CPAP patients use supplementary humidification to relieve airway drying symptoms.

Produce a computational model for use by engineers and physiologists to investigate nasal conditions during ambient and pressurised breathing.



(in-vivo) Nasal Geometric Properties

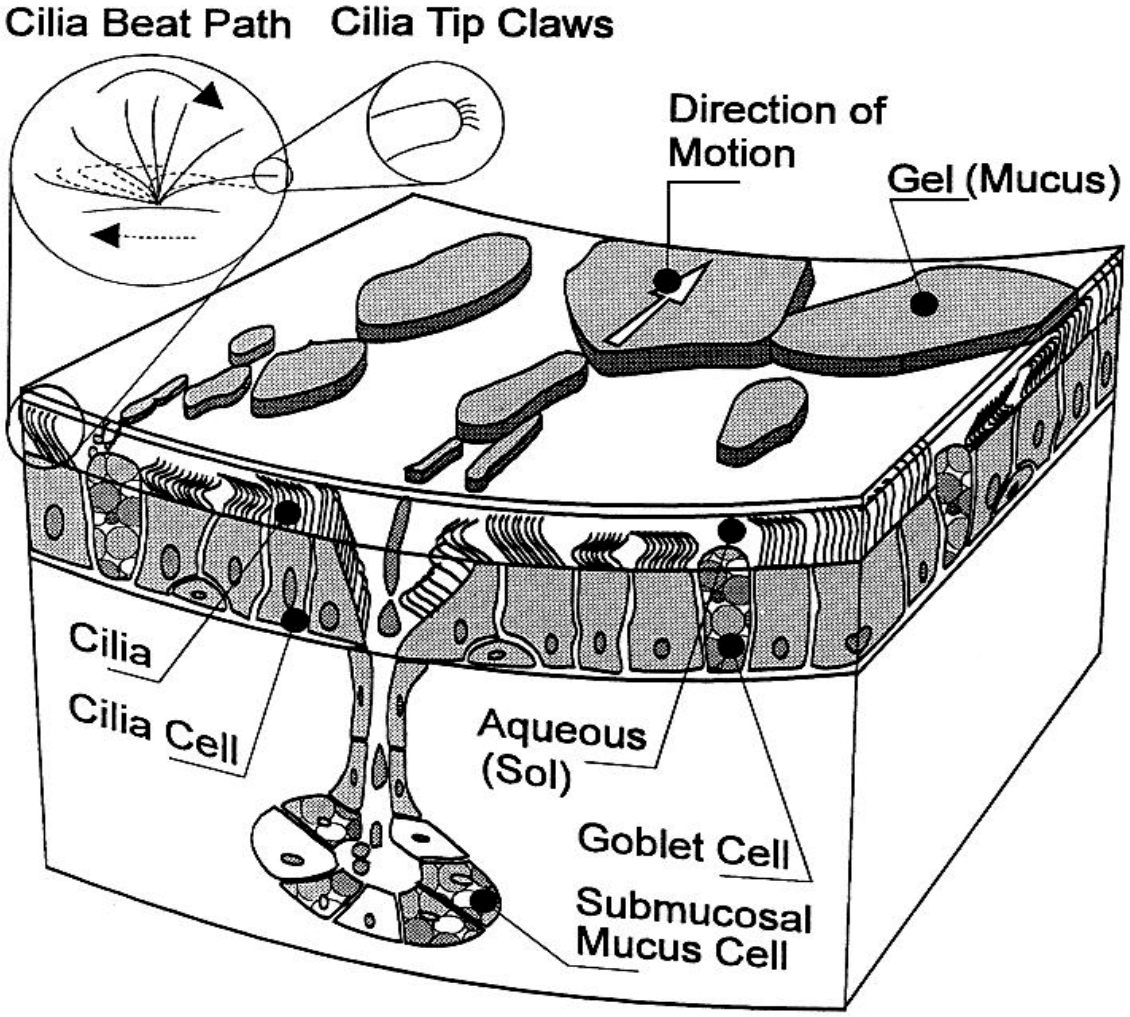
Cross-Sectional Area
Cross-Sectional Perimeter
Volume
Surface Area



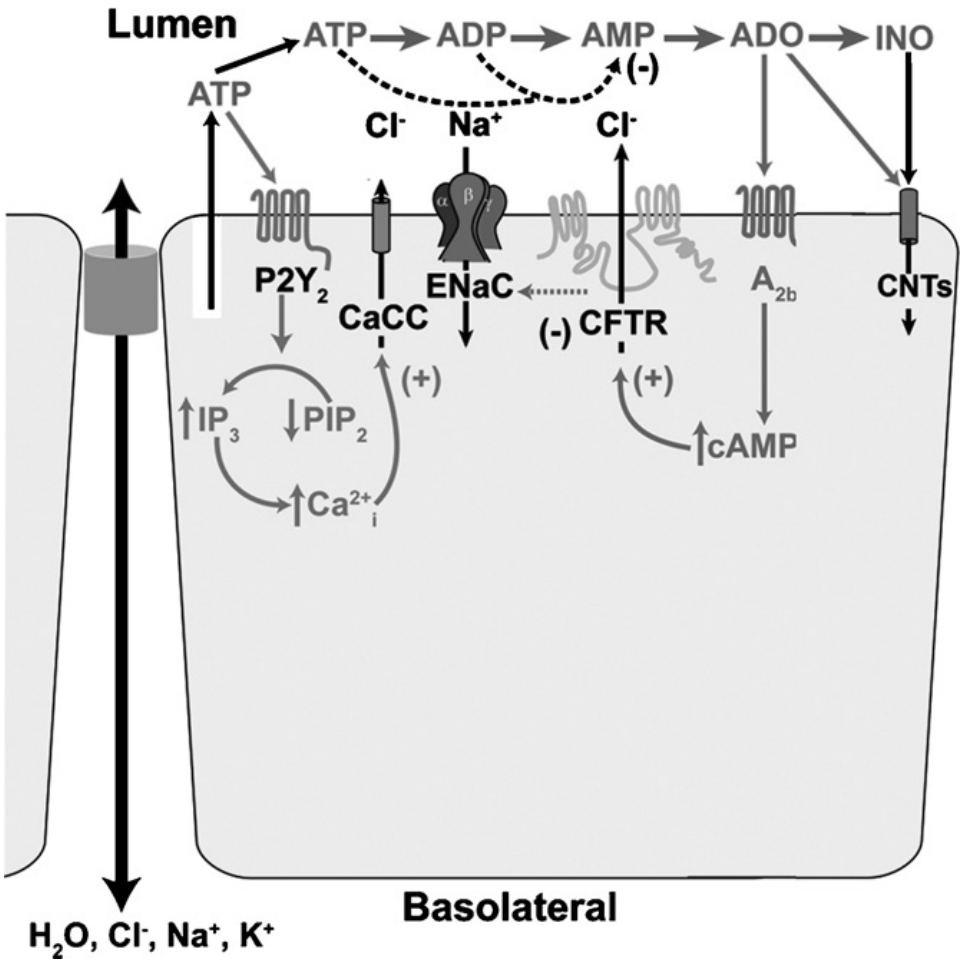
Δ = Hanna (1983),
○ = Craven *et al.* (2007).

Hydraulic diameter distribution along patent and congested airways at ambient pressure.

(in-vitro) ASL Water Supply



Purinergic Regulation



ASL top up

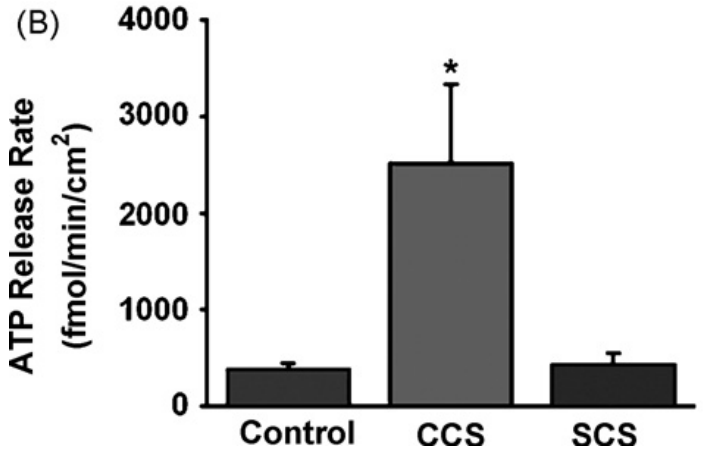
When ADO>200nM
P1 receptor A2b opens Cl^- channel – fluid leaves cell
Na^+ channel closes – no extracellular fluid entry
CBF increases

When ATP>1nM
P2Y2 receptor open Cl^- channel – fluid leaves cell
CBF increases

ASL reduction

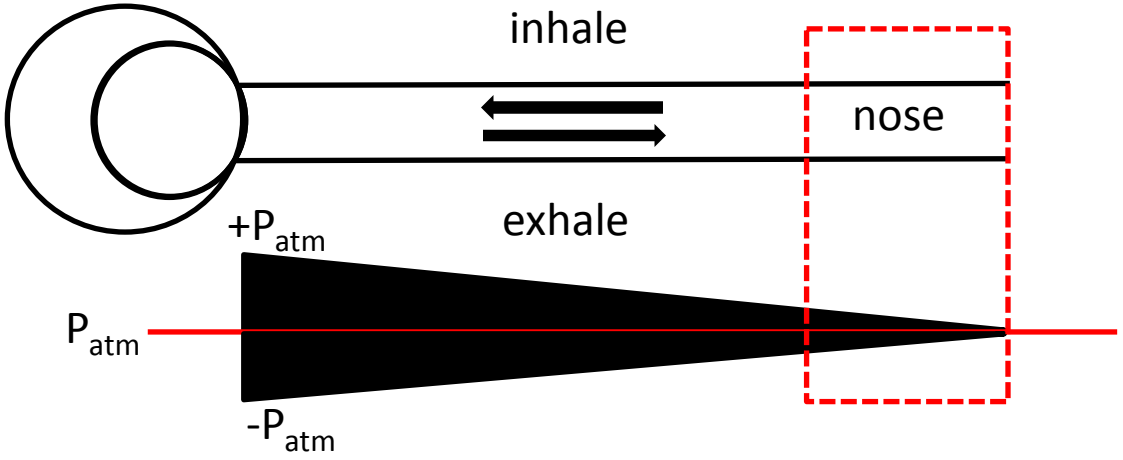
When ADO<200nM
P1 receptor A2b closes Cl^- channel – no fluid exit
Na^+ channel opens – extracellular fluid enters cell
CBF decreases

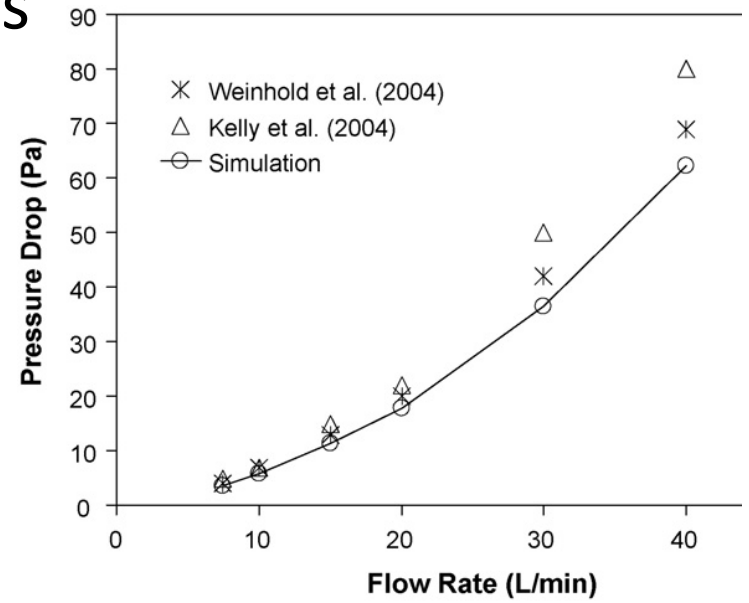
When ATP<1nM
P2Y2 receptor closes Cl^- channel – no fluid exit
CBF decreases

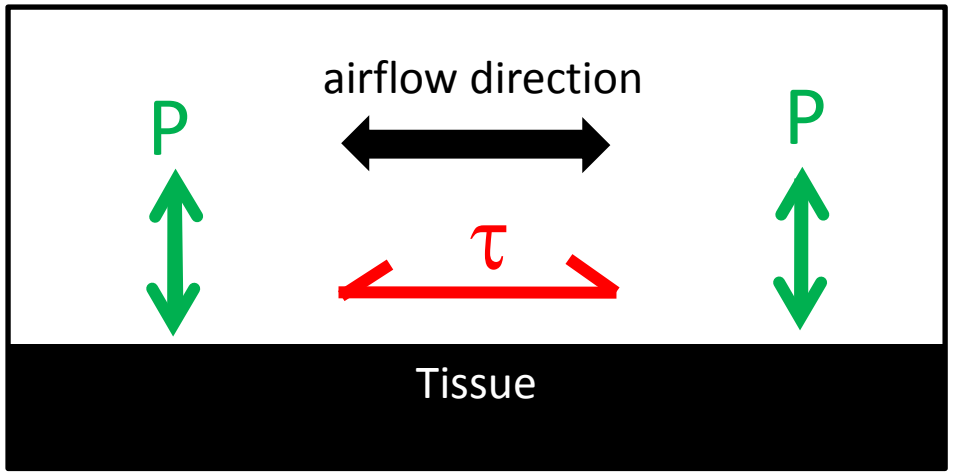


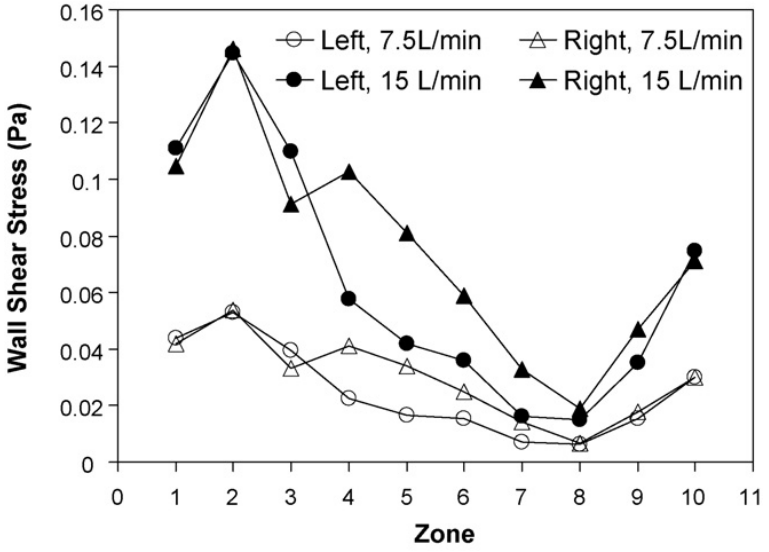
Button, B. & Boucher, R.C. (2008)

Tissue Pressure and Shear Tidal Forces



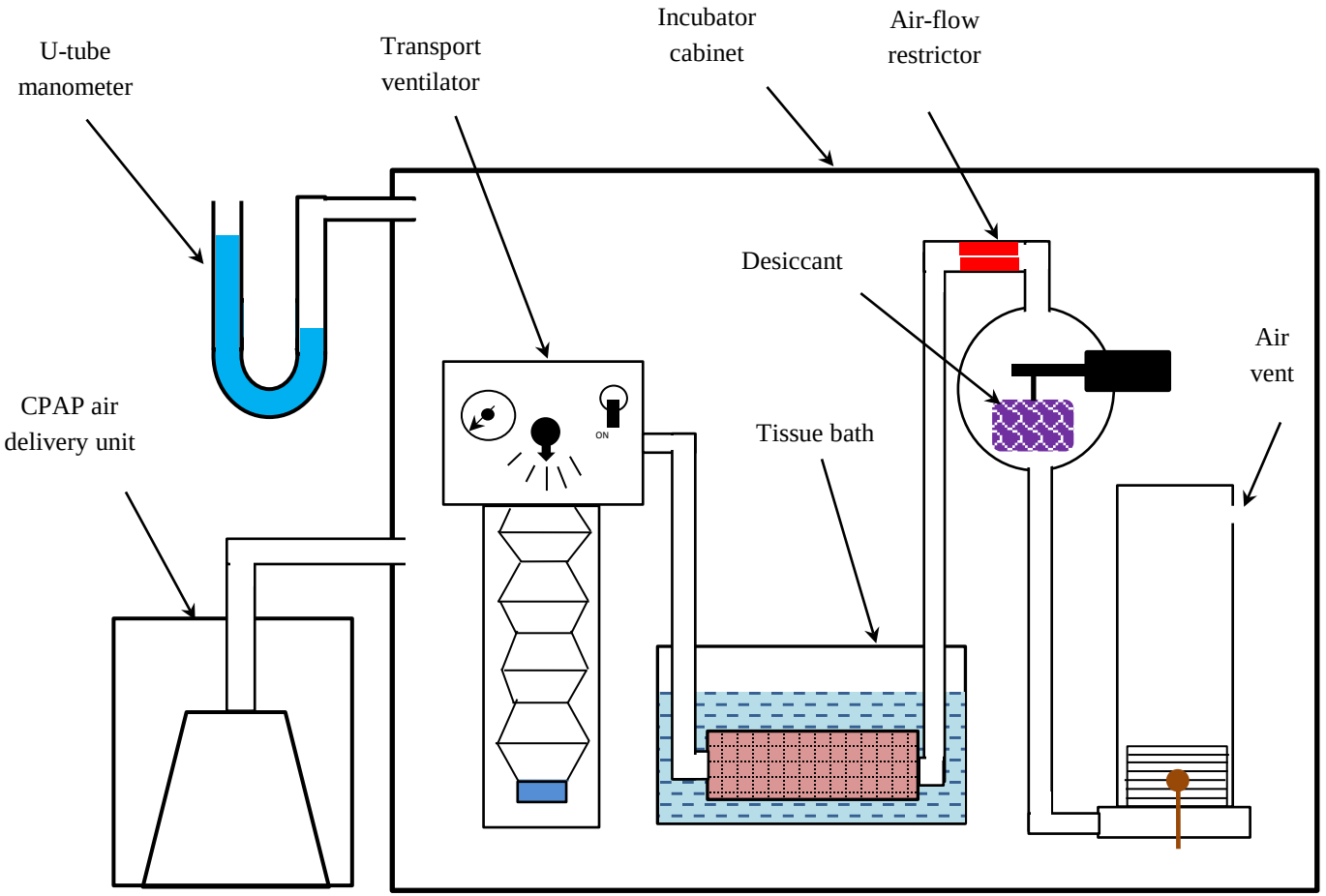


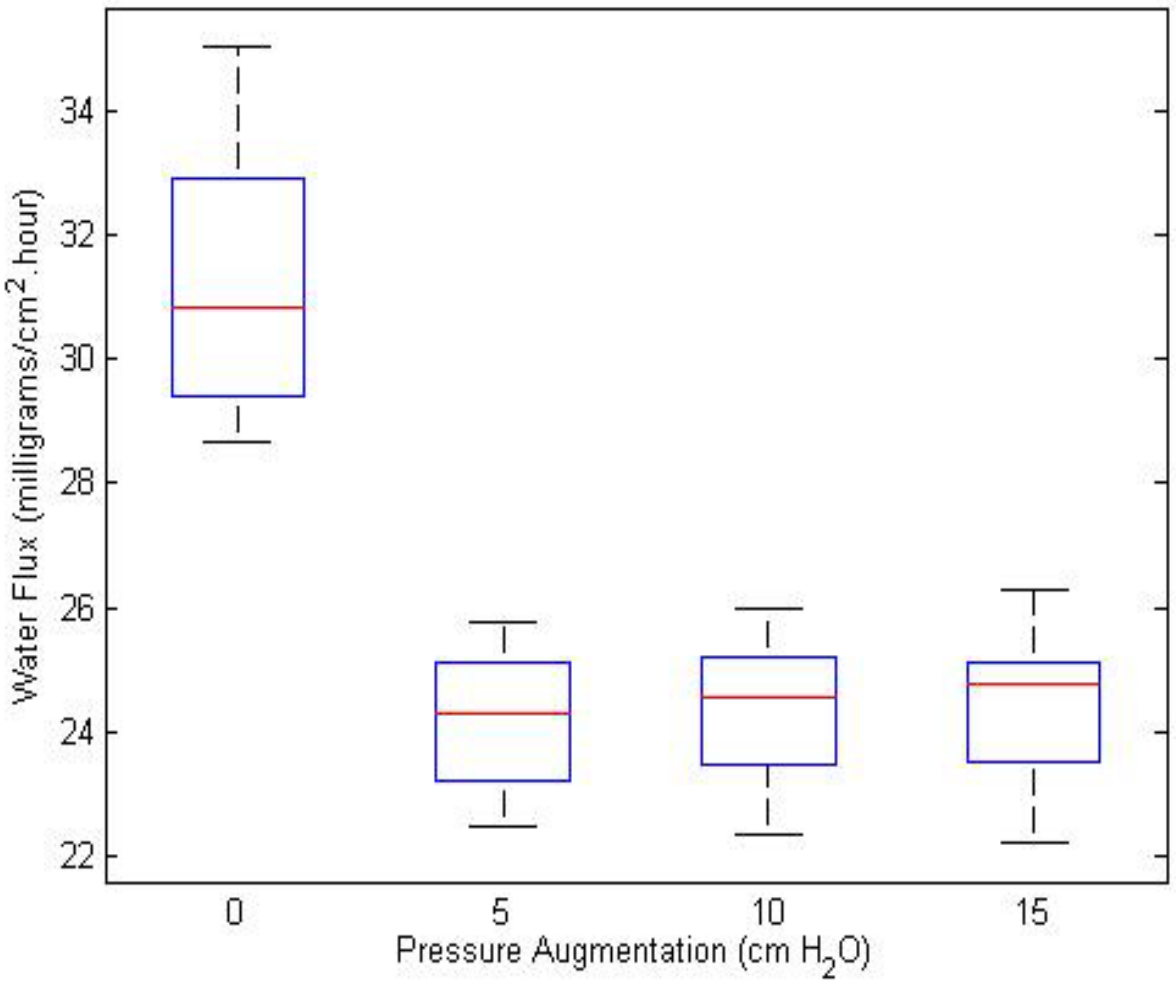




Wen, J. et al. (2008)

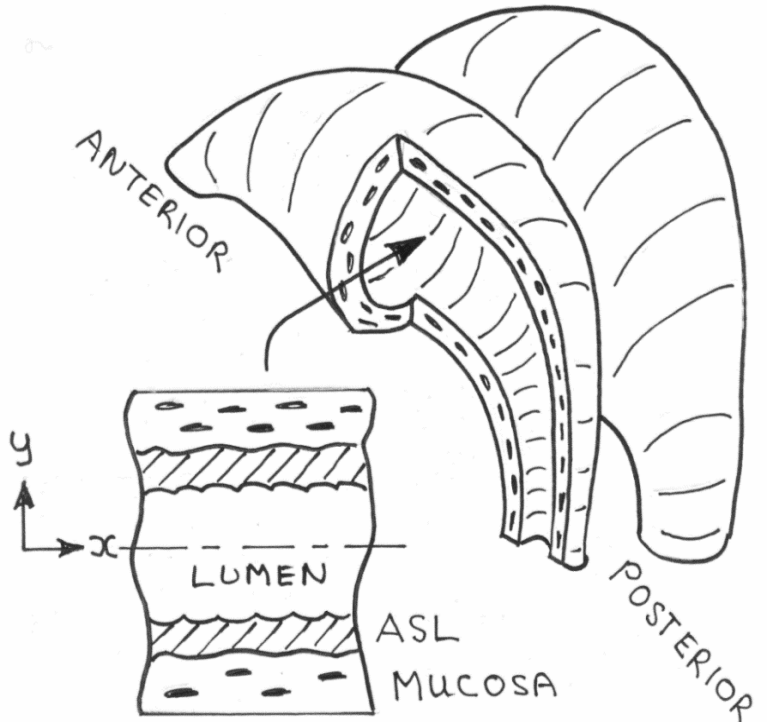
Schematic representation of apparatus set up

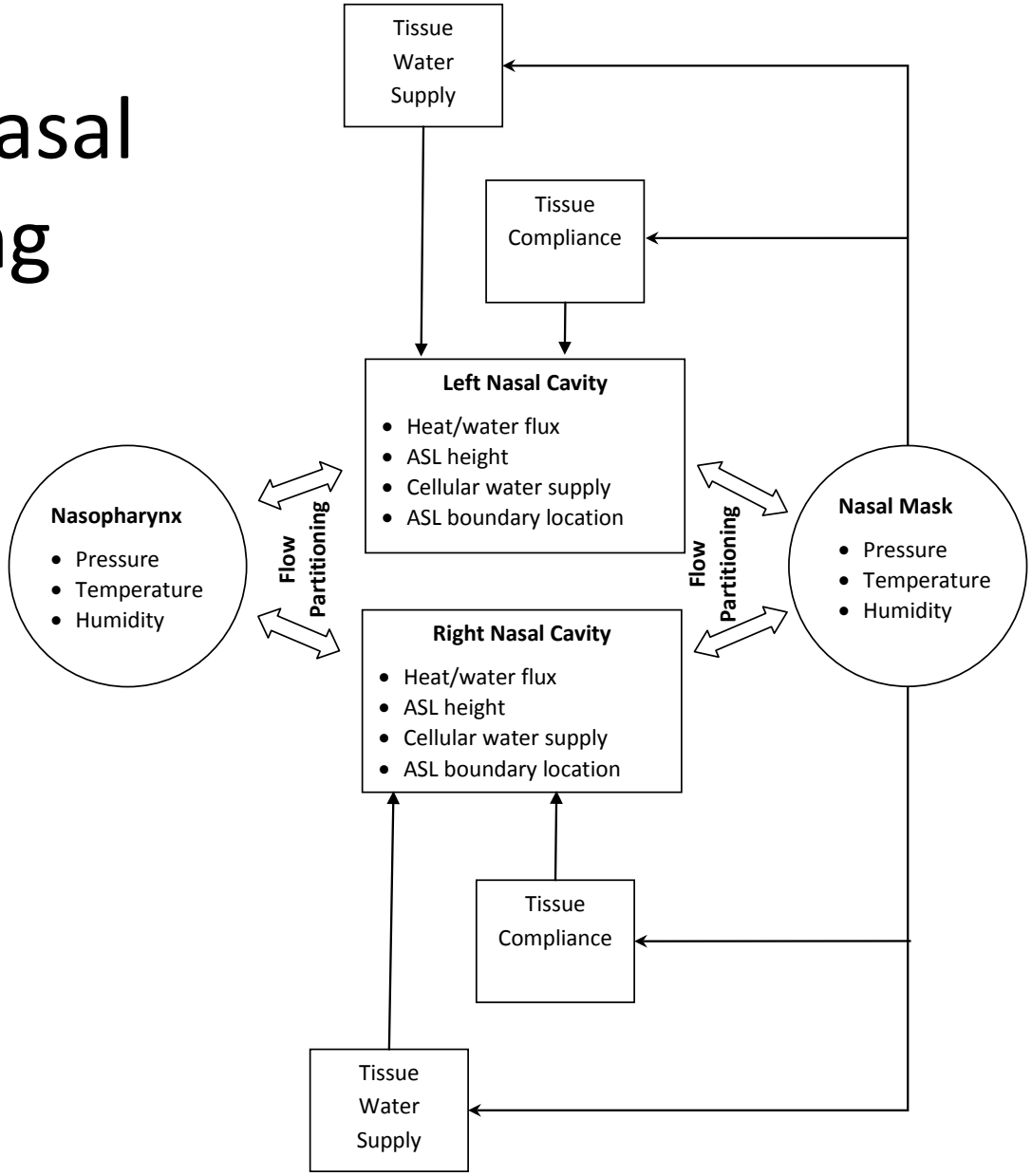


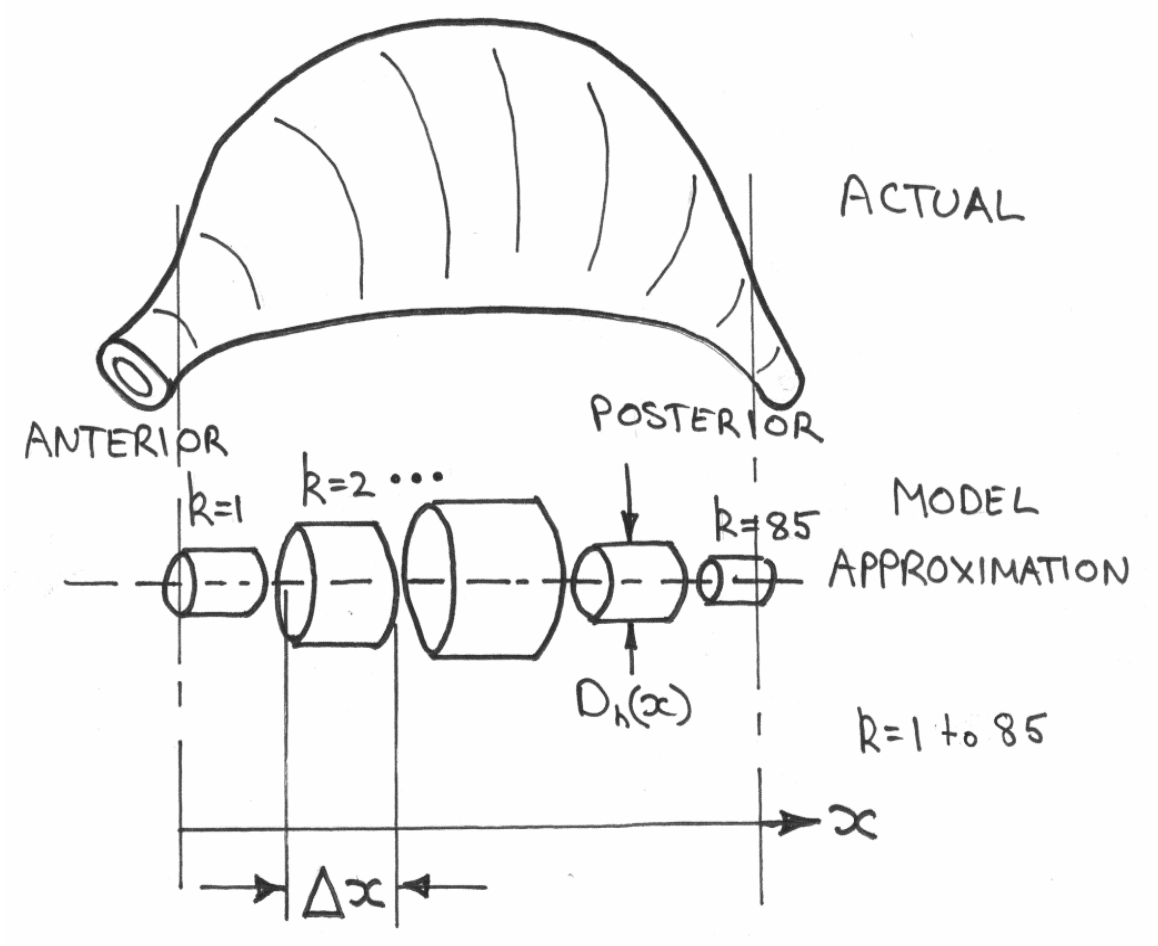


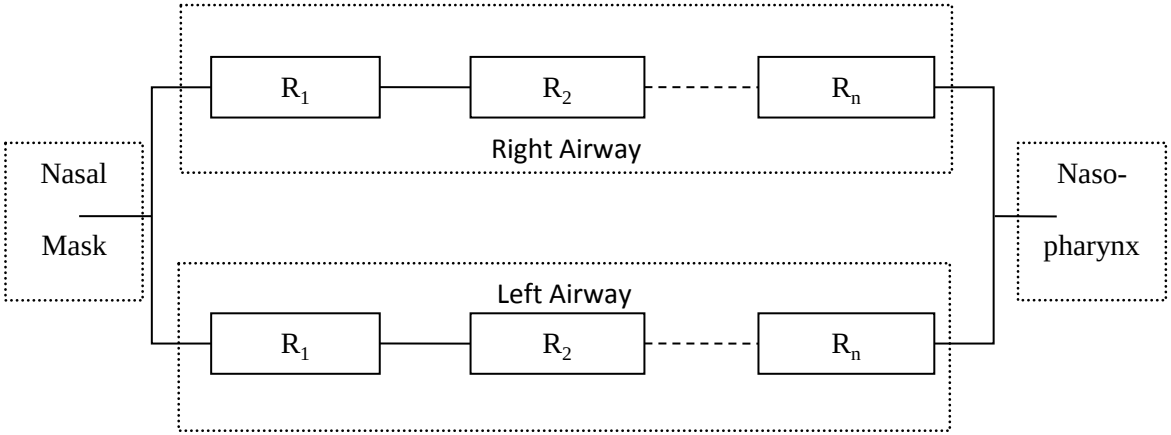
Bovine tracheal maximal water flux during ambient and augmented pressure

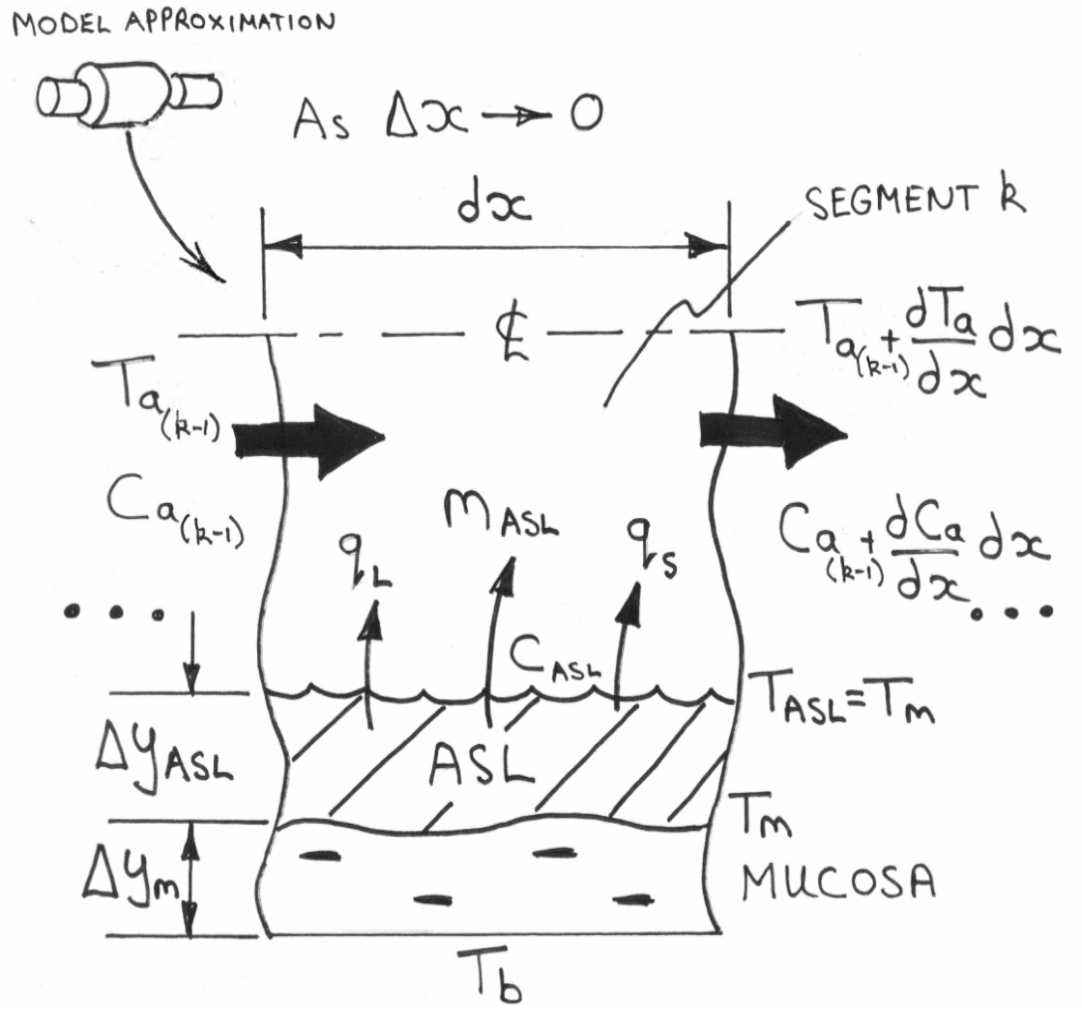
(in-silico) Computational Nasal Air-Conditioning Model

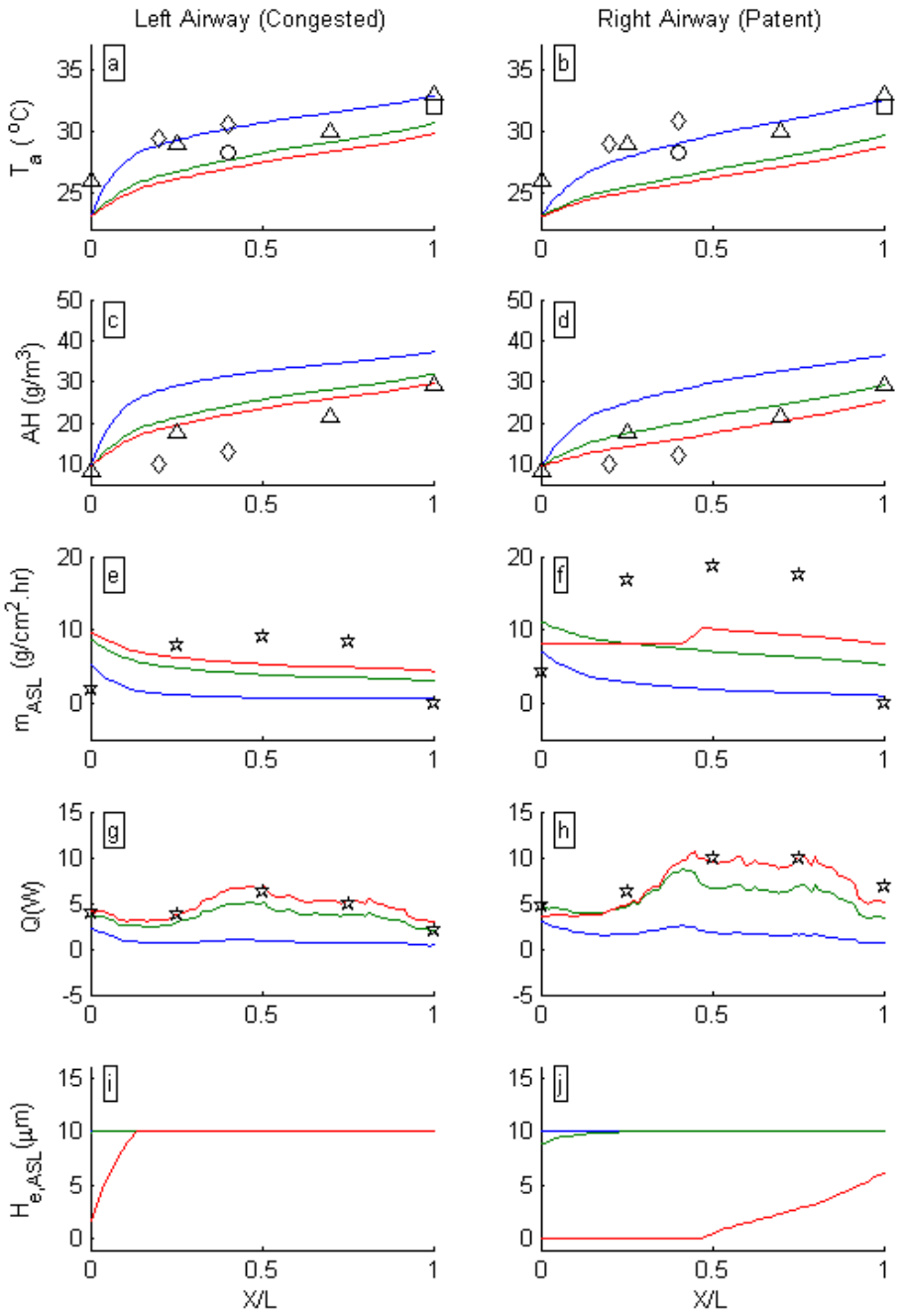


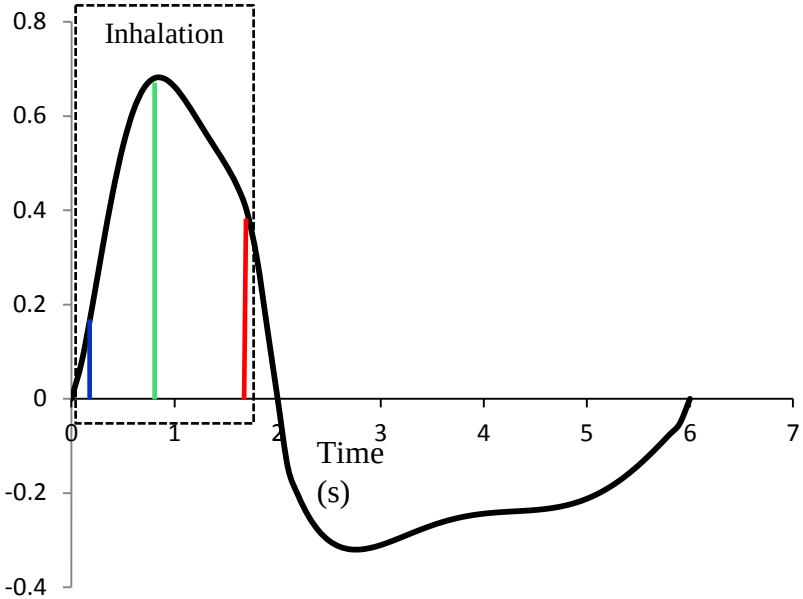



ACTUAL
ANTERIOR
POSTERIOR
k=1
k=2 ...
k=85
MODEL
APPROXIMATION
$D_h(x)$
k=1 to 85
x
Δx


R_1
R_2
R_n
Right Airway
Nasal
Mask
Naso-
pharynx
Left Airway
R_1
R_2
R_n

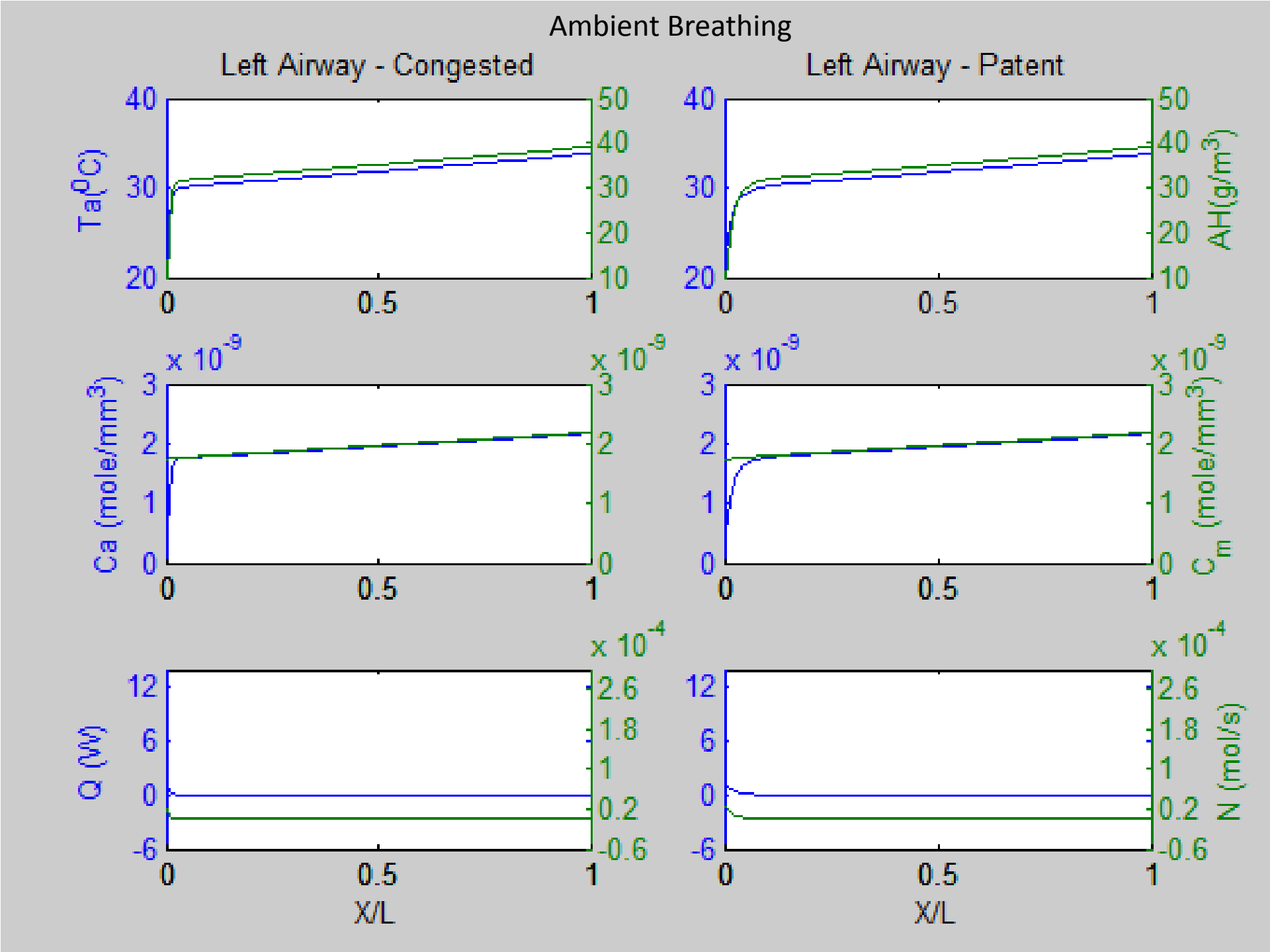

MODEL APPROXIMATION
As Δx → 0
dx
SEGMENT k
$T_{a_{(k-1)}} + \frac{dT_a}{dx} dx$
$T_{a_{(k-1)}}$
$C_{a_{(k-1)}}$
$C_{a_{(k-1)}} + \frac{dC_a}{dx} dx$
m_{ASL}
q_L
q_S
C_{ASL}
$T_{ASL} = T_m$
Δy_{ASL}
ASL
T_m
Δy_m
MUCOSA
T_b

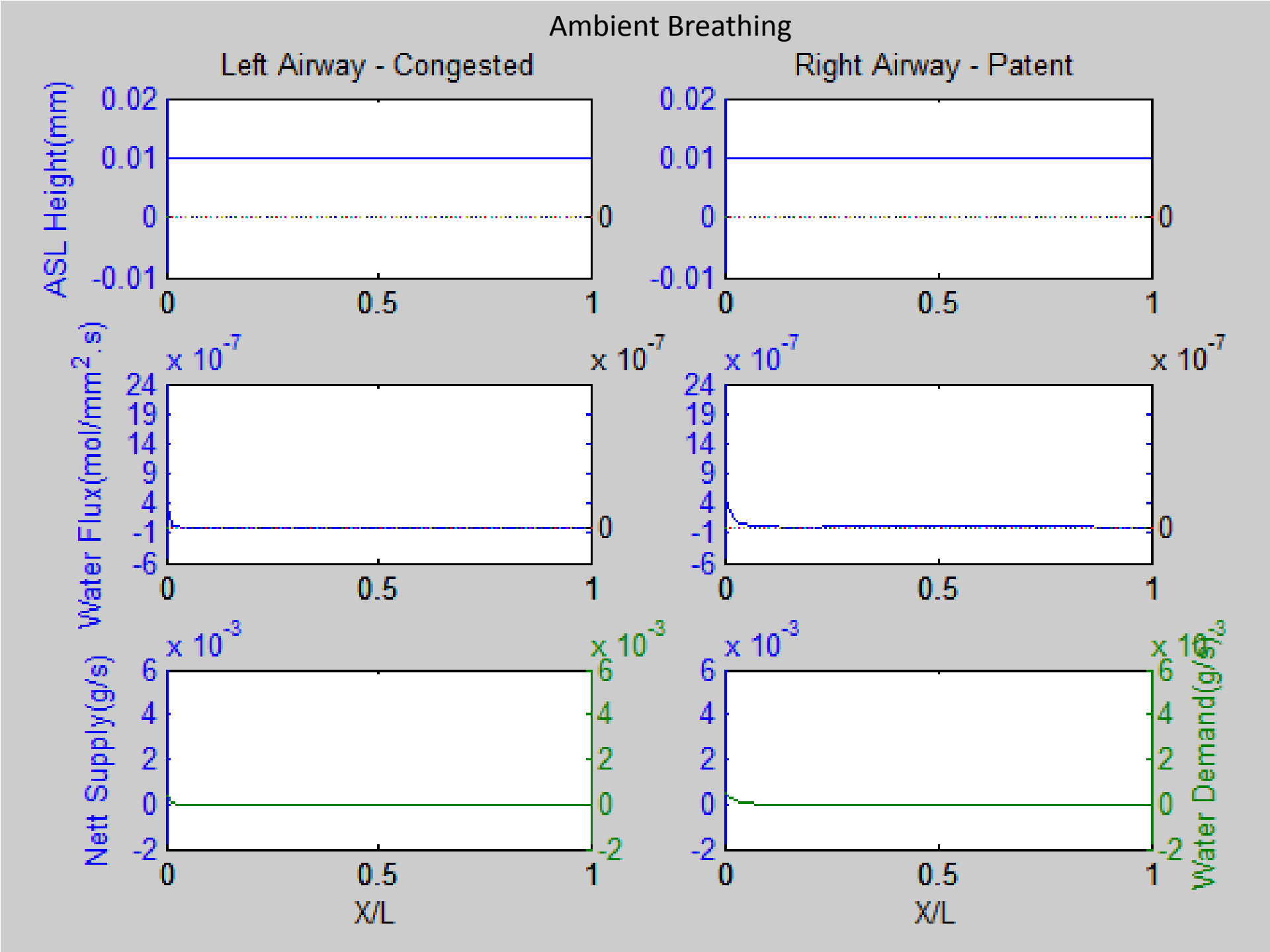


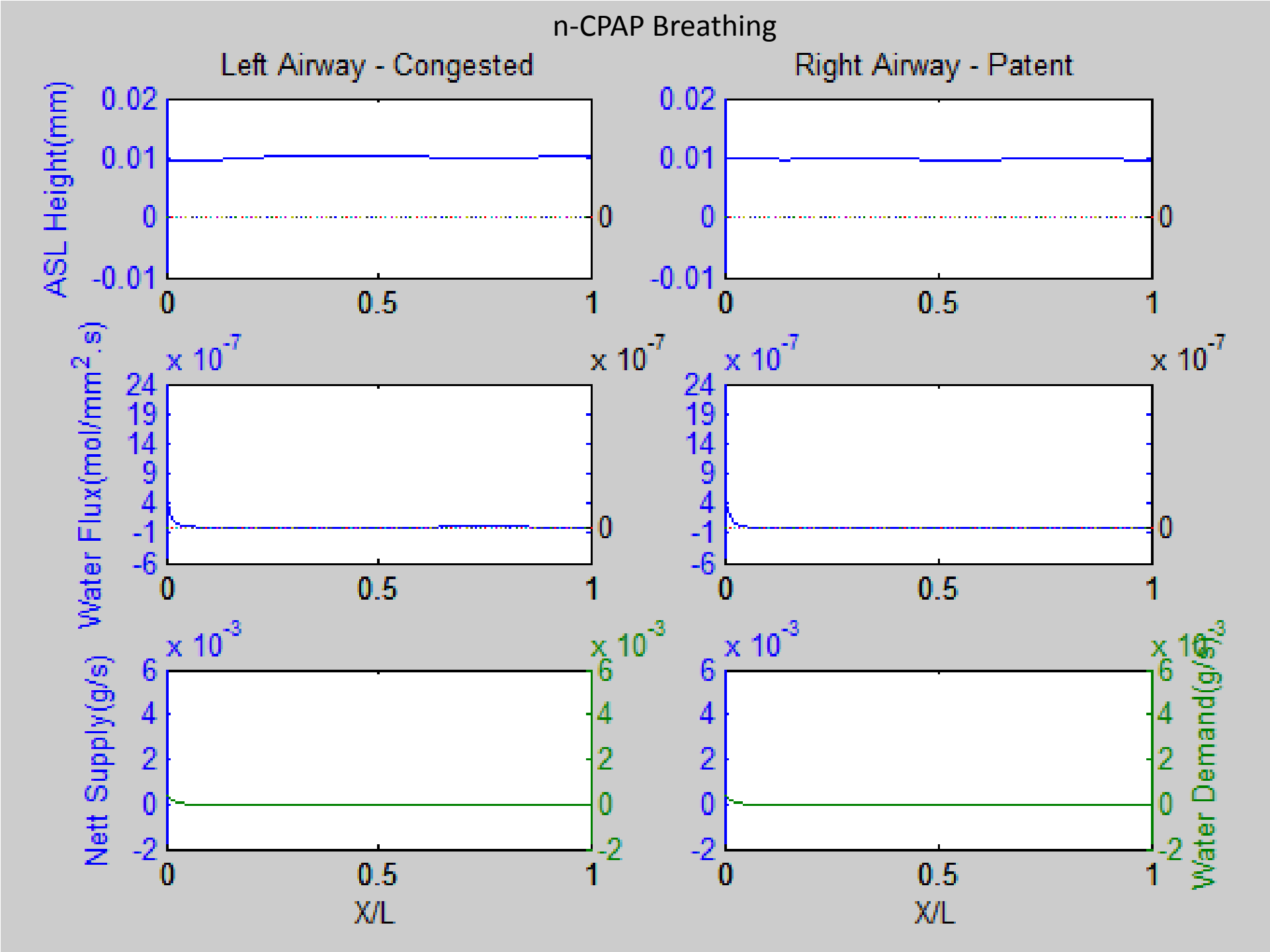


Inhalation inter-airway temperature (T_a), absolute humidity (AH), molar water flux (N), heat flux (Q) and ASL water equivalent height ($H_{e,ASL}$) distribution from rest to maximal change.
Mask pressure ambient, AH=9.2g H_2O/m^3 dry air (T=23°C, RH=45%).

Δ = Keck *et al.* (2000),
○ = Wiesmiller *et al.* (2007),
◊ = Lindemann et al. (2001),
☆ = Hanna (1983),
□ = Lindemann *et al* (2002).


Ambient Breathing
Left Airway - Congested
Left Airway - Patent
Ta(°C)
AH(g/m3)
Ca (mole/mm3)
Cm (mole/mm3)
Q (W)
N (mol/s)
x 10-9
x 10-4
X/L
40
30
20
50
40
30
20
10
3
2
1
0
12
6
0
-6
2.6
1.8
1
0.2
-0.6
0
0.5
1


Ambient Breathing
Left Airway - Congested
Right Airway - Patent
ASL Height(mm)
0.02
0.01
0
-0.01
0
0.5
1
Water Flux(mol/mm2.s)
x 10-7
24
19
14
9
4
-1
-6
Nett Supply(g/s)
x 10-3
6
4
2
0
-2
Water Demand(g/s)
X/L


n-CPAP Breathing
Left Airway - Congested
Right Airway - Patent
ASL Height(mm)
0.02
0.01
0
-0.01
0
0.5
1
Water Flux(mol/mm2.s)
x 10-7
24
19
14
9
4
-1
-6
Nett Supply(g/s)
x 10-3
6
4
2
0
-2
Water Demand(g/s)
X/L

Acknowledgements

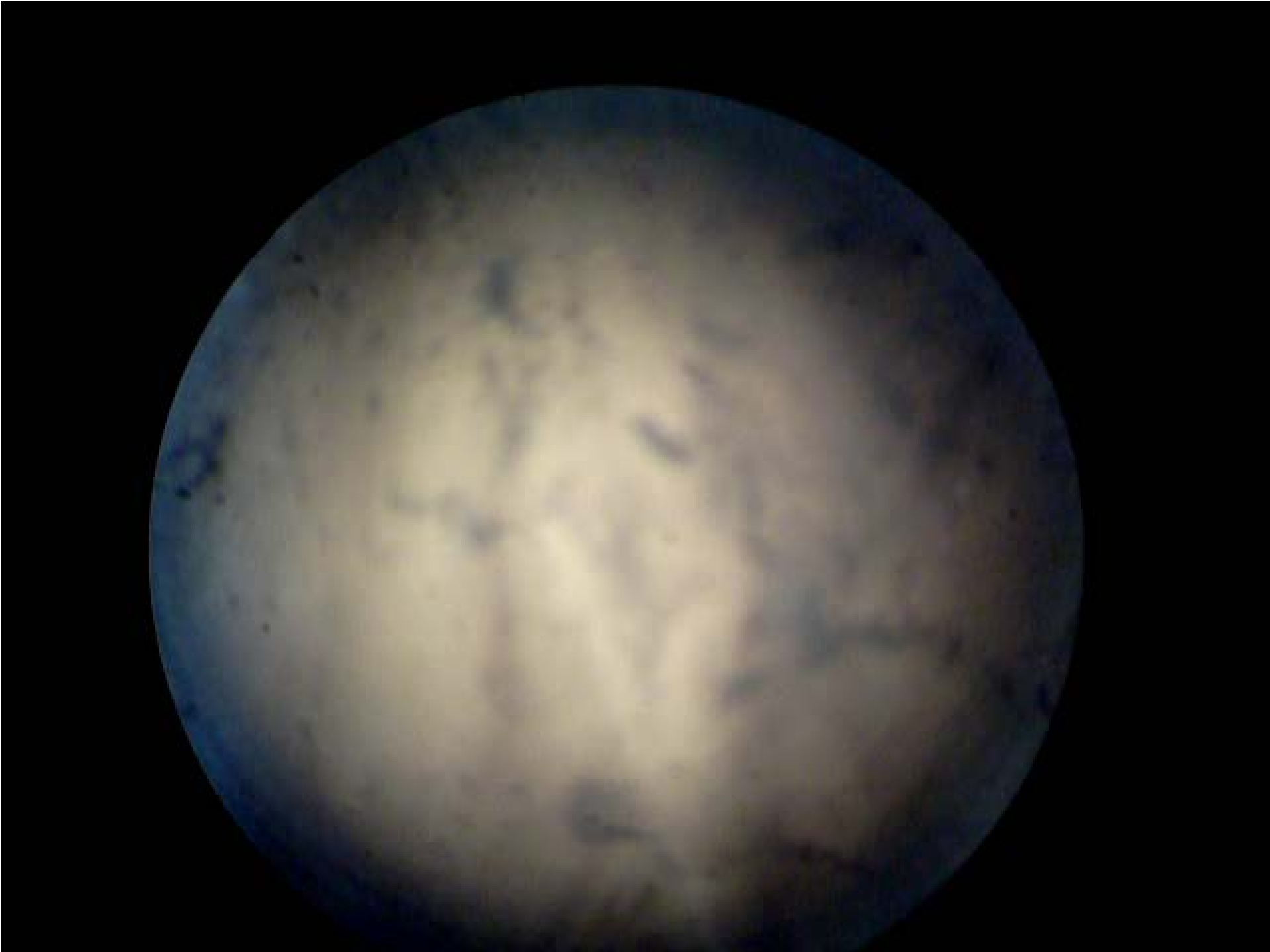
Dr Jim Bartley & Dr Randall Morton, Counties Manukau District Health Board & University of Auckland .

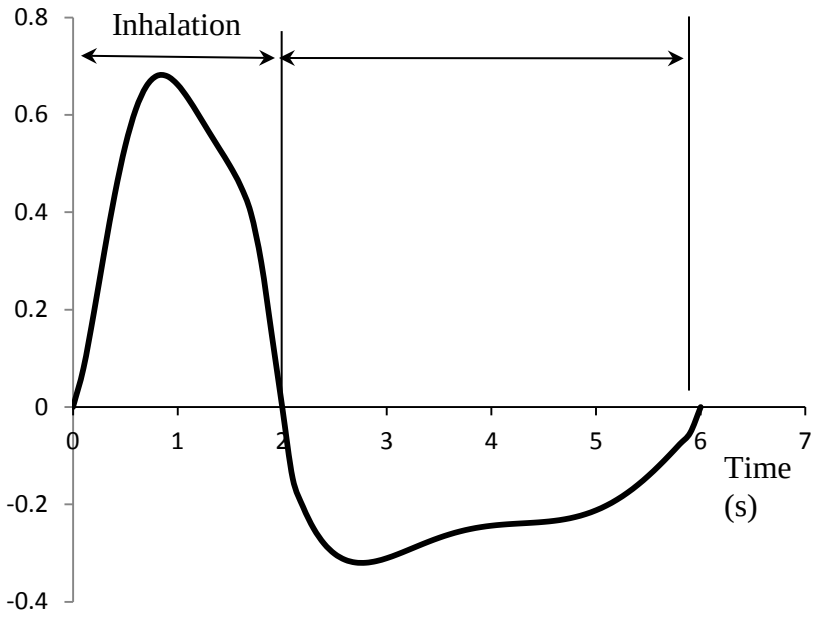
Dr Susan McGlashan, University of Auckland

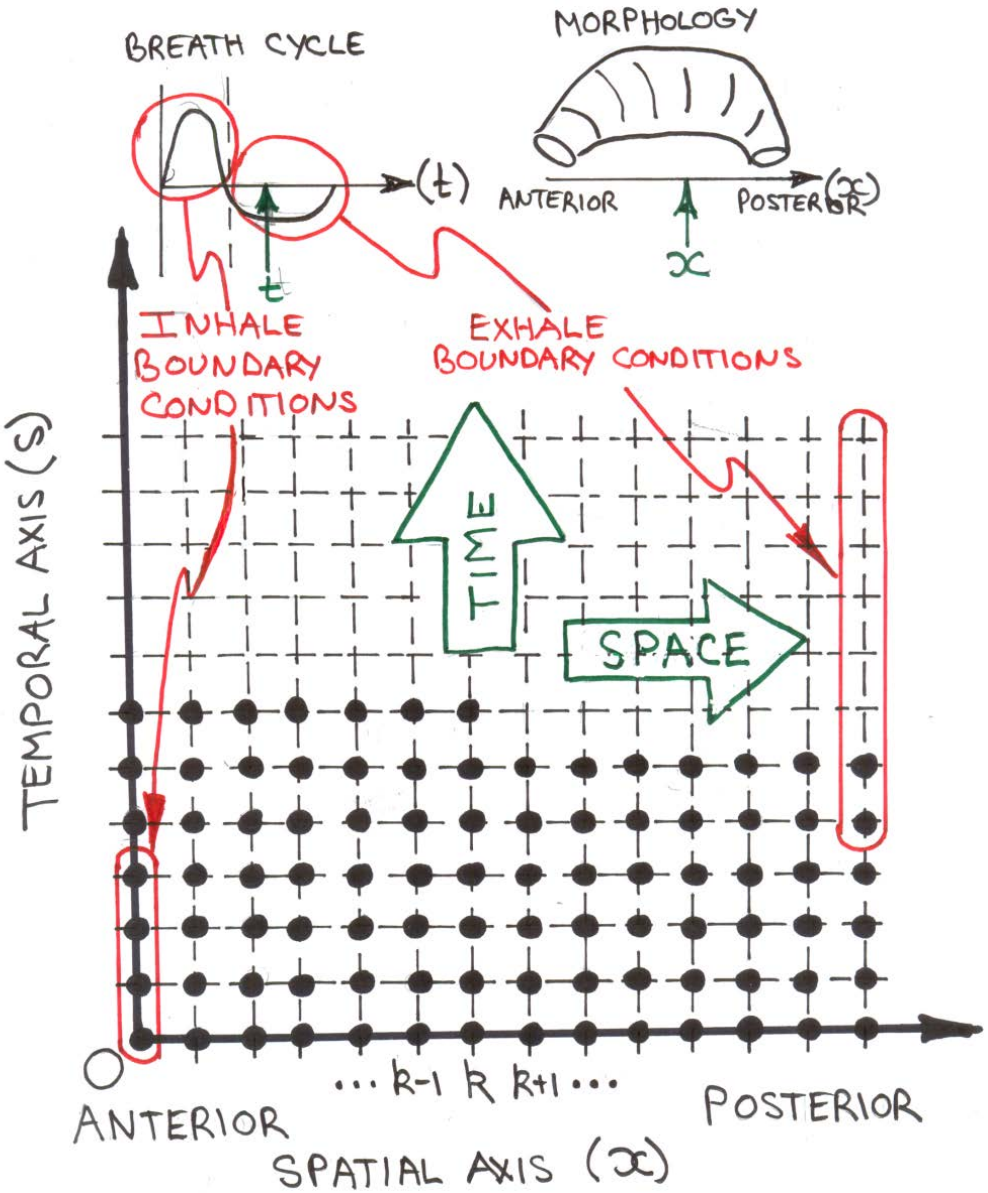
Assoc. Prof. Brett Cowan and Dr Beau Pontré, both from the Centre for Advanced MRI (CAMRI), University of Auckland.

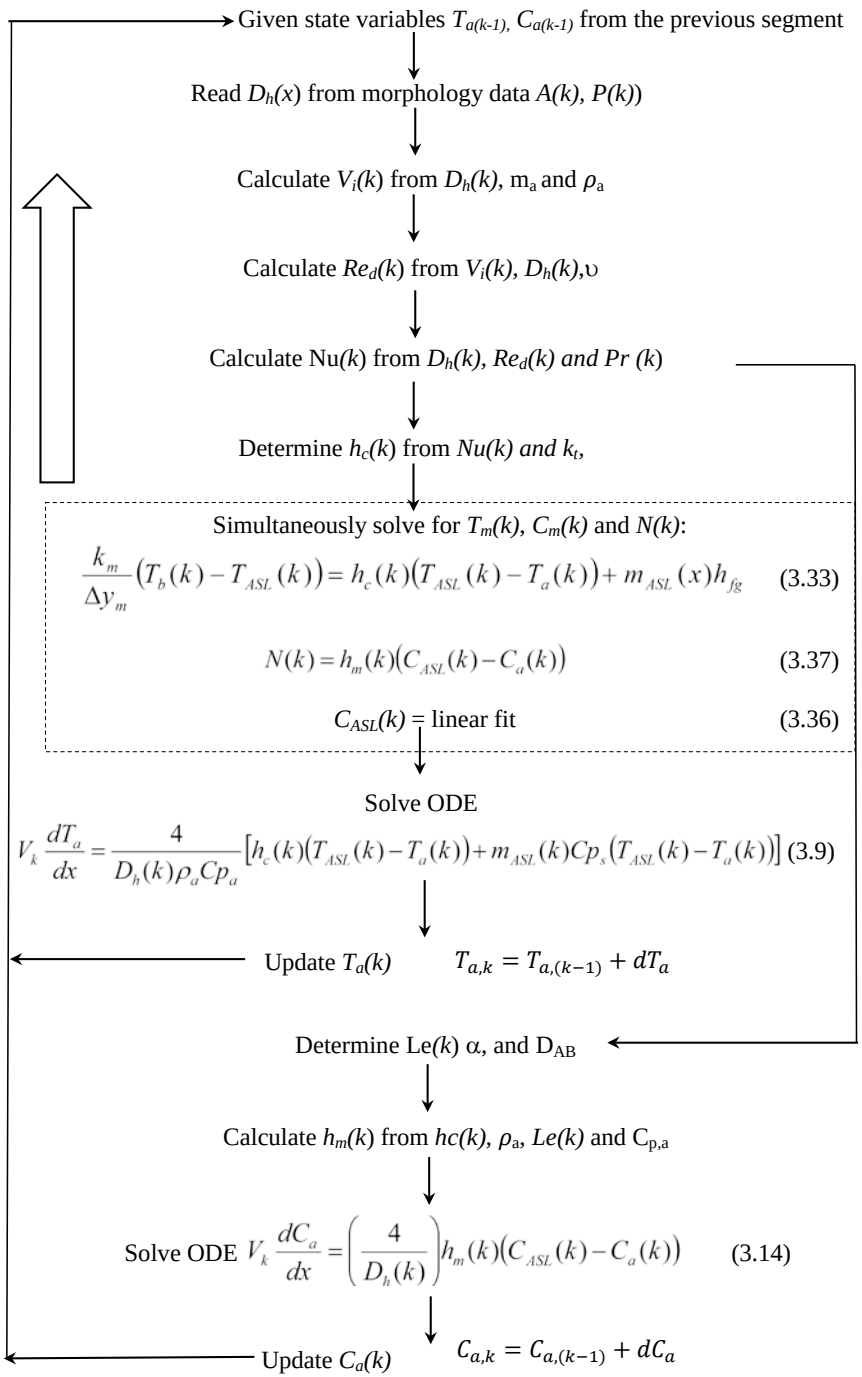
Dr Robin Hankin, School of Computing and Mathematical Sciences, AUT.

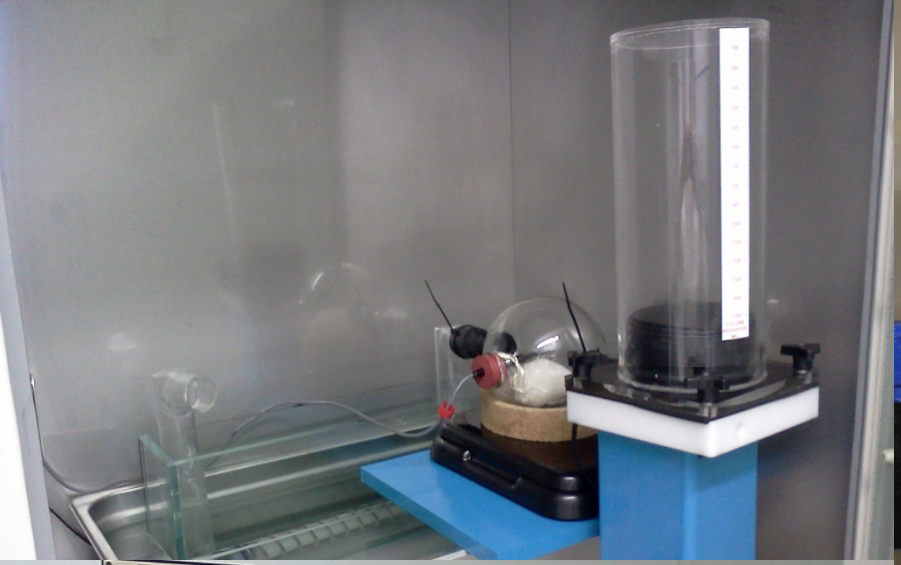
in-vivo Nasal Morphology



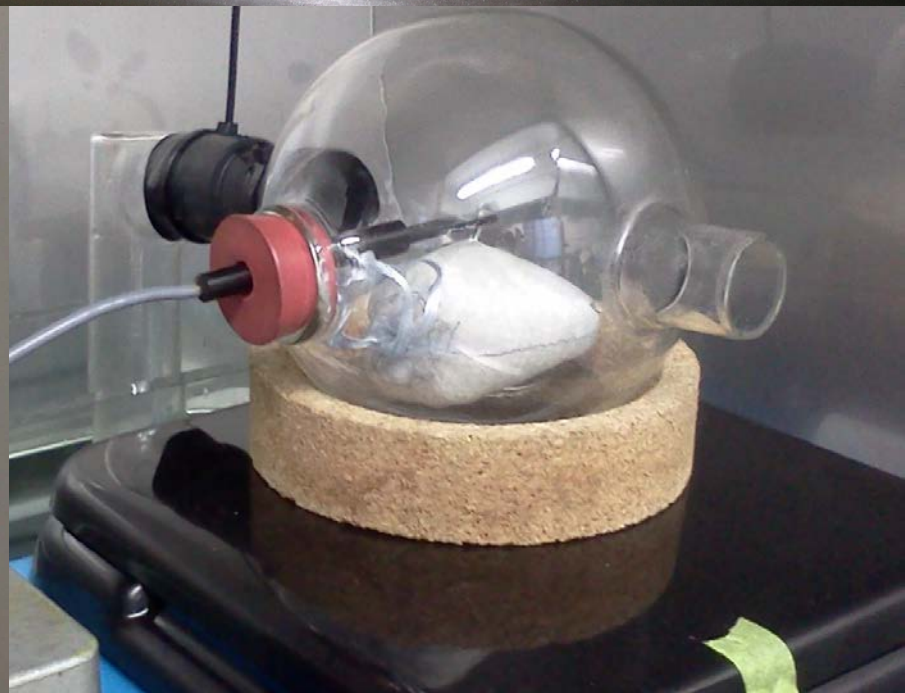

Inhalation
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0
1
2
3
4
5
6
7
Time
(s)

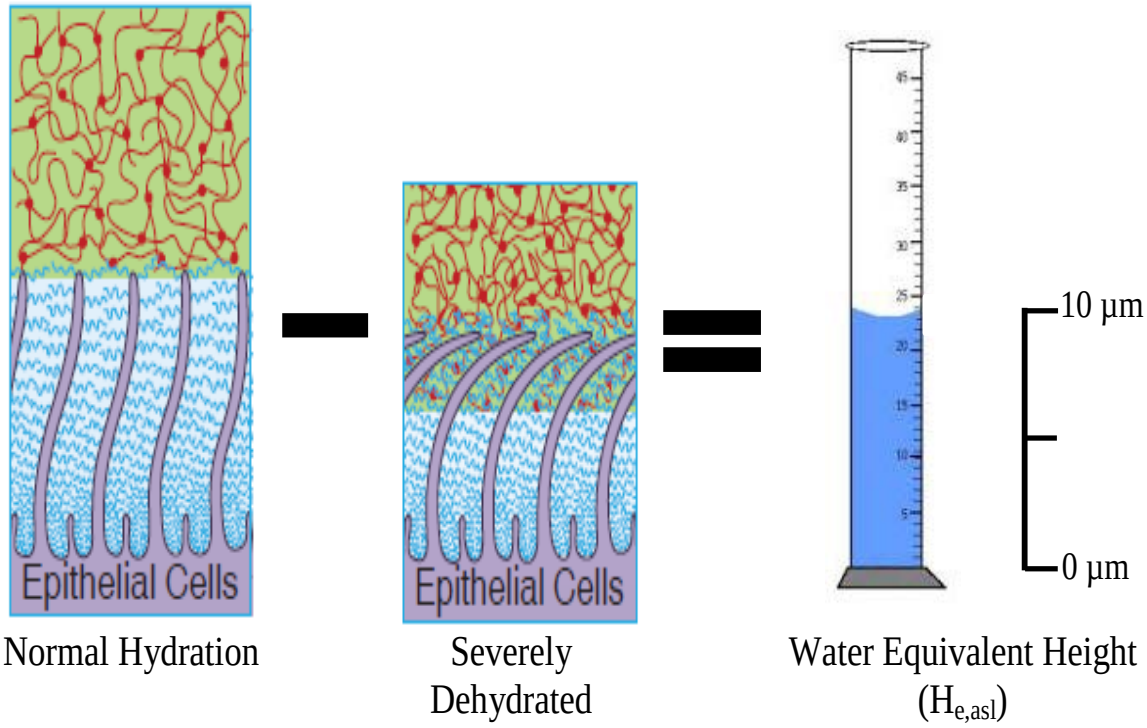

BREATH CYCLE
MORPHOLOGY
(t)
t
ANTERIOR
POSTERIOR
(x)
x
INHALE BOUNDARY CONDITIONS
EXHALE BOUNDARY CONDITIONS
TIME
SPACE
TEMPORAL AXIS (s)
... k-1 k k+1 ...
ANTERIOR
POSTERIOR
SPATIAL AXIS (x)


Given state variables $T_{a(k-1)}$, $C_{a(k-1)}$ from the previous segment
Read $D_h(x)$ from morphology data $A(k)$, $P(k)$)
Calculate $V_i(k)$ from $D_h(k)$, m_a and ρ_a
Calculate $Re_d(k)$ from $V_i(k)$, $D_h(k)$,υ
Calculate Nu(k) from $D_h(k)$, $Re_d(k)$ and $Pr(k)$
Determine $h_c(k)$ from $Nu(k)$ and k_t,
Simultaneously solve for $T_m(k)$, $C_m(k)$ and $N(k)$:
$\frac{k_m}{\Delta y_m}\left(T_b(k)-T_{ASL}(k)\right)=h_c(k)\left(T_{ASL}(k)-T_a(k)\right)+m_{ASL}(x)h_{fg}$ (3.33)
$N(k)=h_m(k)\left(C_{ASL}(k)-C_a(k)\right)$ (3.37)
$C_{ASL}(k)$ = linear fit (3.36)
Solve ODE
$V_k\frac{dT_a}{dx}=\frac{4}{D_h(k)\rho_a Cp_a}\left[h_c(k)\left(T_{ASL}(k)-T_a(k)\right)+m_{ASL}(k)Cp_s\left(T_{ASL}(k)-T_a(k)\right)\right]$ (3.9)
Update $T_a(k)$ $T_{a,k}=T_{a,(k-1)}+dT_a$
Determine Le(k) α, and D_{AB}
Calculate $h_m(k)$ from $hc(k)$, ρ_a, $Le(k)$ and $C_{p,a}$
Solve ODE $V_k\frac{dC_a}{dx}=\left(\frac{4}{D_h(k)}\right)h_m(k)\left(C_{ASL}(k)-C_a(k)\right)$ (3.14)
Update $C_a(k)$ $C_{a,k}=C_{a,(k-1)}+dC_a$



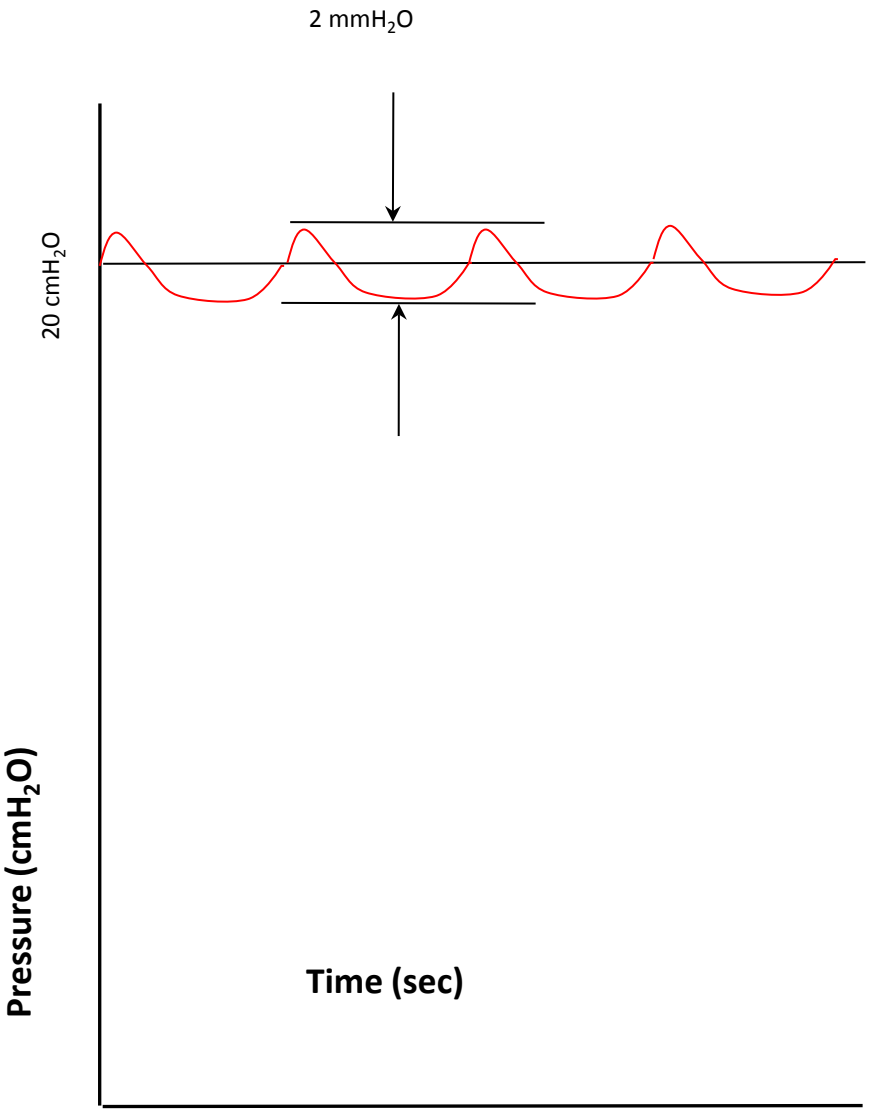

STERI-CULT
INCUBATOR





Schematic representation of ASL water equivalent height of 10 µm representing the hydration difference between normal and severely dehydrated ASL.
Diagram adapted from Button et al (2012).

Airflow Stress Stimulation



Factor of 100 x