RESPIRATORY PHYSIOLOGY RELEVANT TO HFOV

Physiology of HFOV
What is HFOV?

- Ventilation using a relatively high continuous distending pressure at the airway opening, around which an oscillatory wave is generated to assist with gas exchange
  - CPAP with a “wiggle”
  - CPAP with a twist
  - Super CPAP

HFOV = pressure + wiggle
Role of transpulmonary pressure in the transition to extra-uterine life

Important in:
• clearance of the water-filled lung
• establishment of an adequate FRC
• decreasing PVR
• overcoming the inefficiencies of the bellows
• overcoming relatively low lung compliance
Spontaneous breathing

Positive pressure ventilation
What does the pressure do?

OVERCOMES AIRWAY AND TISSUE RESISTANCE

\[ P(\text{resist}) = R \times (\hat{V}) \]
where \( R \) = resistance

- Energy lost as heat
- Resistive pressure drop is significant during HFOV

What does the pressure do?

OVERCOMES INERTIA

\[ P(\text{inert}) = I \times (\dot{V}) \]
where \( I \) = inertance

- Work done to accelerate gas and tissue
- Negligible during CMV
- Much more important during HFOV
**What does the pressure do?**

**INDUCES CHANGE IN LUNG VOLUME**

\[ P(\text{vol}) = \frac{1}{C} \times (V) \]

where \( C \) = compliance

- Work done to overcome the viscoelastic forces of the lung and chest wall

**Relationship between pressure and volume**

Lung volume computation

\[ V = V_{\text{max}} \left( 1 - e^{-\frac{P}{h}} \right) \]

- \( V_{\text{max}} \) = maximum lung volume
- \( P \) = applied pressure
- \( h \) = half opening pressure

*Salazar & Knowles J Appl Physiol 1964*
Lung at full term

ALVEOLAR VOLUME
Micromechanics of the lung

Alveolar volume computation

\[ V = V_{\text{max}} \left( 1 - e^{-\frac{P}{h}} \right) \]

- \( V_{\text{max}} \) = maximum alveolar volume
- \( P \) = applied pressure
- \( h \) = half opening pressure
ALVEOLAR VOLUME
Micromechanics of the lung

Alveolar opening pressure (inflation): pressure at which alveolus opens from a volume of zero to a volume as determined by the Salazar-Knowles relationship.
ALVEOLAR VOLUME
Micromechanics of the lung

Alveolar closing pressure (deflation): pressure at which alveolus closes to a volume of zero

Applied pressure (cm H₂O)

Alveolar volume (% of Vmax)

14/04/15
Ventilation within the PV relationship

Rimensberger *CCM* 1999

Ventilation within the PV relationship

Dargaville *ICM* 2010
Measurement of lung volume during CMV

![Graph showing thoracic gas volume (%TLC) against pressure.]

CMV at PEEP 6 cm H₂O

CMV at PIP 28 cm H₂O

Physiology of HFOV

![Diagram showing airway pressure waveforms for HFOV and CMV.]

AIRWAY PRESSURE WAVEFORMS

HFOV

CMV
**Measurement of lung volume during HFOV**

Paw 22 cm H₂O for 4 mins

**HFOV – sustained recruitment**

Pellicano et al  *Intens Care Med* 2009
Mechanisms of gas exchange during HFOV

What does the wiggle do?

Mechanisms of gas exchange
Conventional ventilation

• Two mechanisms
  • A volume of gas (tidal volume) is delivered into the airways via convective (bulk) flow
  • When the volume reaches the respiratory bronchioles, CO$_2$ and O$_2$ are exchanged by molecular diffusion
• Expiration occurs secondary to passive recoil of the lung and chest wall
• For this process to provide effective alveolar ventilation, the volume of gas delivered must be greater than the anatomic dead space of the airways
• “Apnoeic respiration” with no tidal ventilation inevitably results in CO$_2$ retention
On the basis of these first results we believe we have found a new way of proceeding for any length of time in thoracic surgery and in bronchoscopy by "rested" ventilation without excursions of the thoracic cage.
Mechanisms of gas exchange
High frequency oscillatory ventilation

Six mechanisms
- Convective (bulk flow)
- Asymmetrical velocity profiles
- Taylor dispersion
- Pendeluft
- Cardiogenic mixing
- Molecular diffusion

HK Chang J Appl Physiol 1984

Mechanisms of gas exchange
HFOV

Convective (bulk flow) ventilation
- Even with small tidal volumes, direct alveolar ventilation occurs to short path length units that branch off of the primary airways.
Asymmetrical velocity profile

- During inspiration, the high frequency pulse creates a “bullet” shaped profile, with the central molecules moving further down the airway than those molecules found on the periphery of the airway.

Asymmetrical velocity profile

- On exhalation, the velocity profile is blunted so that at the completion of each return, the central molecules remain further down the airway and the peripheral molecules move towards the mouth of the airway.
Mechanisms of gas exchange

HFOV

Taylor dispersion
- Convective flow superimposed on a diffusive process, results in increased dispersion of the tracer molecules
- The high velocity spike of gas moves down the center of the tube, leaving the molecules on the periphery unmoved. Gas diffuses evenly through the tube when flow stops

Pendeluft
- At high frequencies, distribution becomes strongly influenced by time constant inequalities. Gas from fast units (short time constants) will empty into the slow (long time constants) units
Molecular diffusion
- One of the major mechanisms for gas exchange in the alveolar regions
- Responsible for the gas exchange across the AC membrane and also contributes to the transport of $O_2$ and $CO_2$ in the gas phase near the membrane

Mechanisms of gas exchange
HFOV

Cardiogenic mixing
- The heart beat adds to the peripheral gas mixing
Mechanisms of gas exchange
HFOV - Summary

• ‘If you talk too much about convection and diffusion, the result in the end is both defective and confusing’
  — Froese 1981; attributed to HK Chang
SUMMARY

Continuous distending pressure during HFOV:
- Recruits the lung if sufficient pressure is applied on initiation to open most lung units
- Exploits hysteresis
- Retains lung volume if sufficient pressure is maintained to keep most lung units open

The oscillatory waveform during HFOV:
- Facilitates diffusion
- Promotes gas exchange by other mechanisms