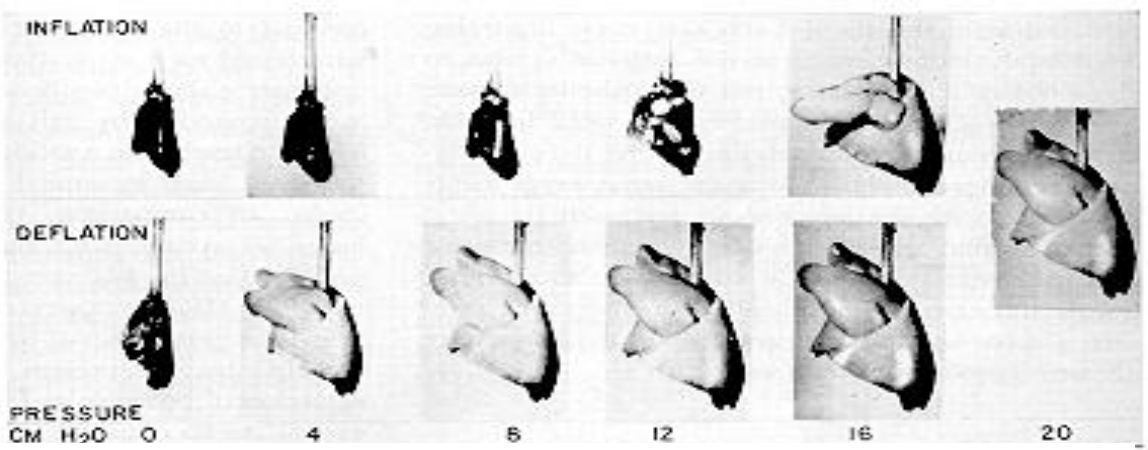
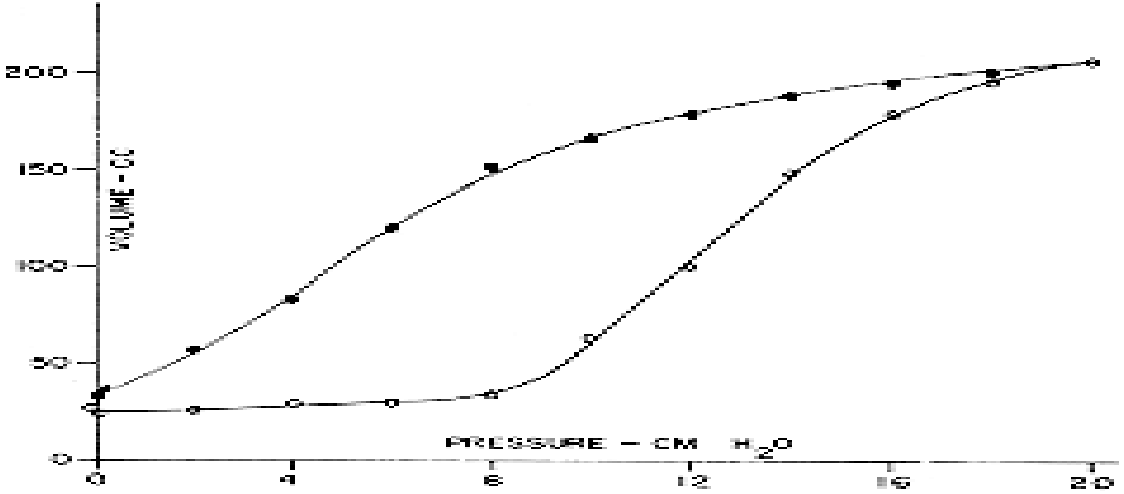
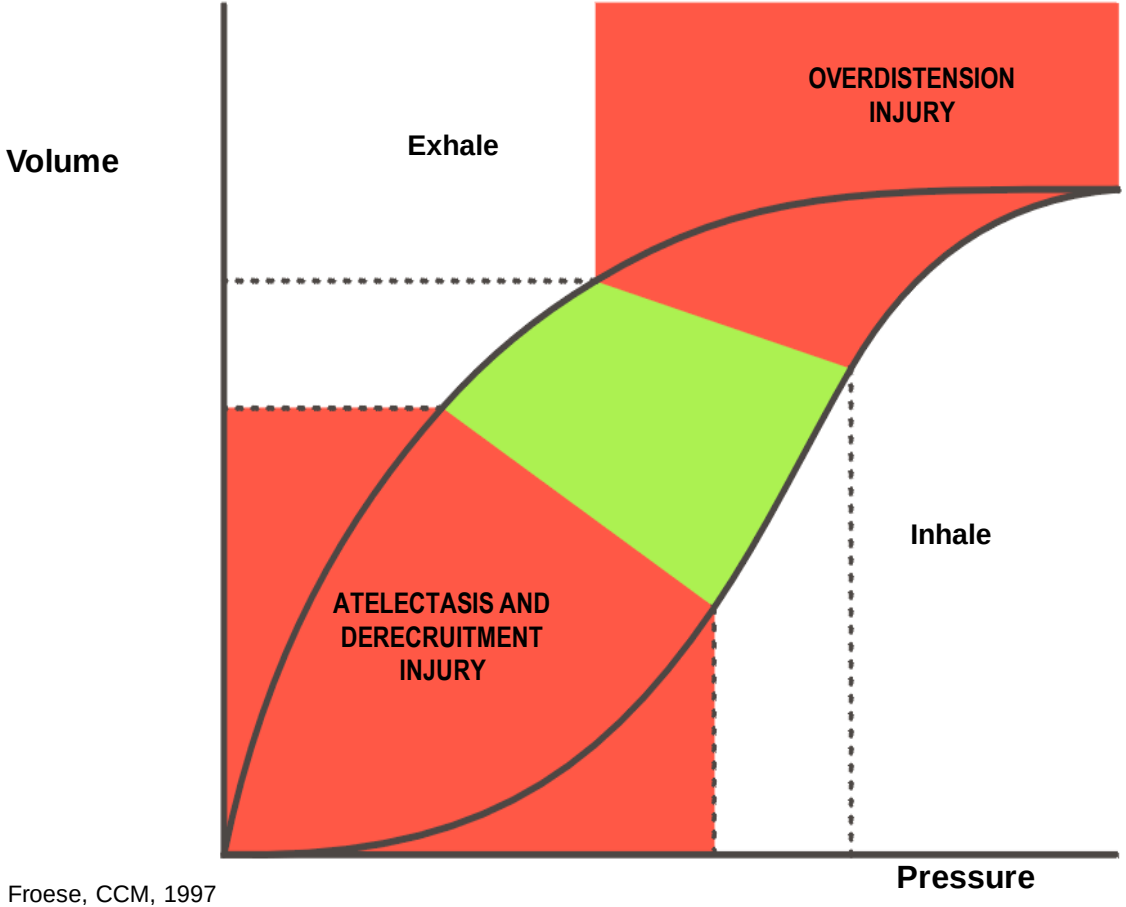
High Frequency Ventilation

Steve Hepditch, Clinical Educator, Duke Hospital


INFLATION
DEFLATION
PRESSURE
CM H2O 0
4
8
12
16
20


200
150
100
50
0
VOLUME - CC
PRESSURE – CM H2O
0
4
8
12
16
20

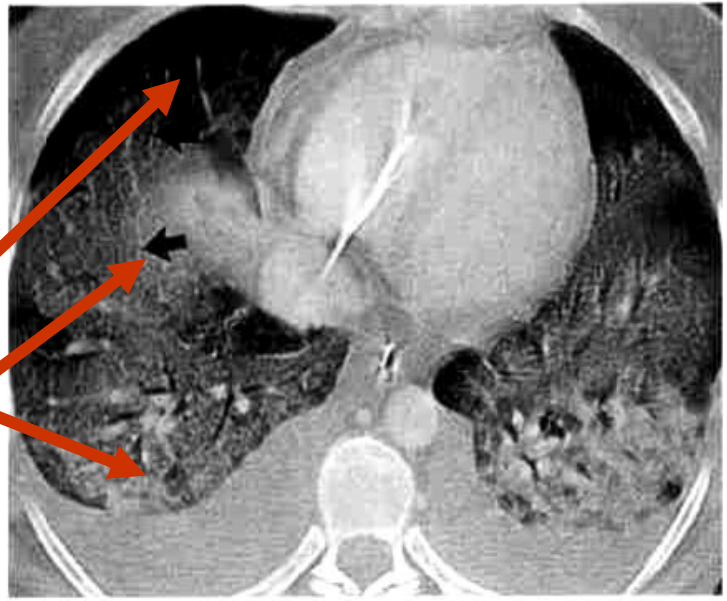


Froese, CCM, 1997

Lung Injury is Non-Homogeneous

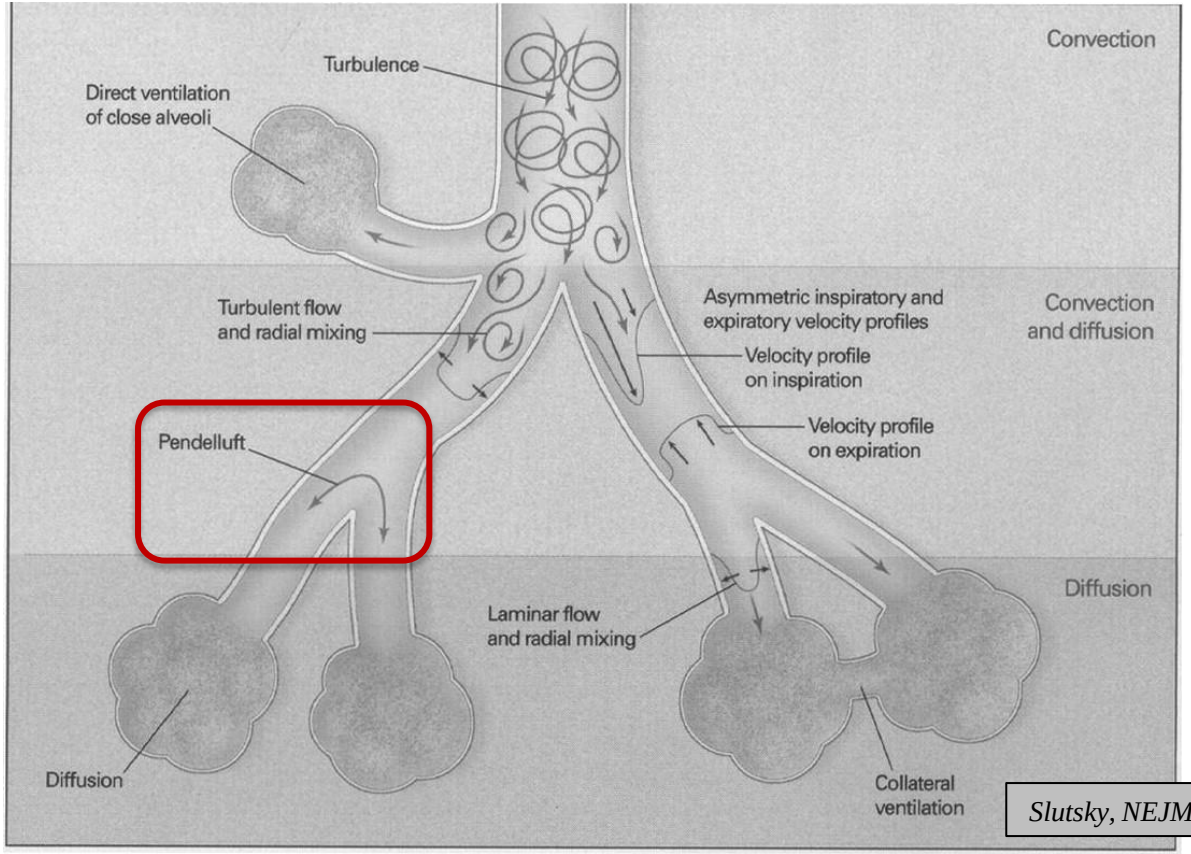
In acute lung injury (ALI) there are 3 regions of lung tissue:

- Severely diseased regions with a limited ability to "safely" recruit.
- Uninvolved regions with normal compliance. Possibility of overdistension with increased ventilatory support.
- Intermediate regions with reversible alveolar collapse and edema.



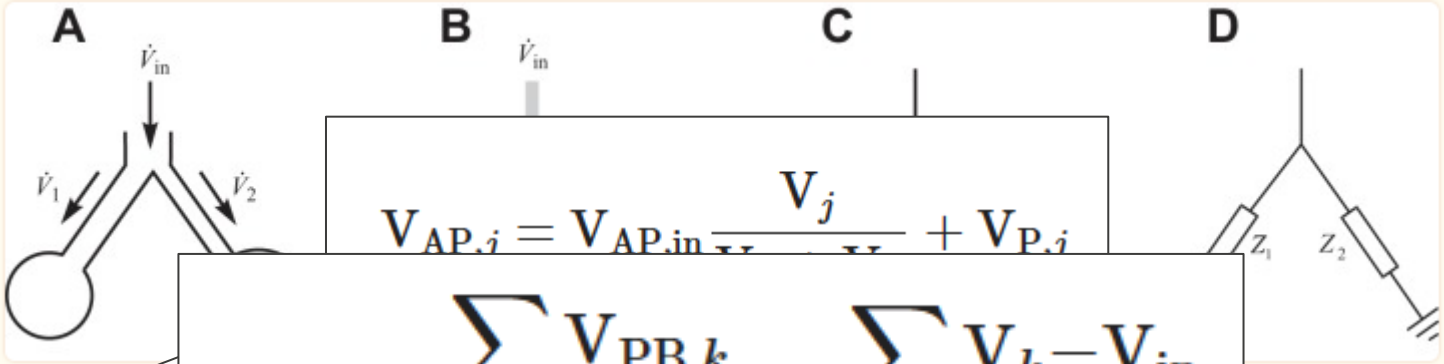
Ware et al., NEJM, 2000

Gas-Transport Mechanisms during High-Frequency Ventilation



Slutsky, NEJM 2002

Pendelluft



$$V_{AP,j} = V_{AP,in}\frac{V_j}{\ldots} + V_{P,j}$$

$$\frac{V_P}{V_{in}} = \frac{\sum_{k\in\beta} V_{PB,k}}{V_{in}} = \frac{\sum_{k\in T} V_k - V_{in}}{V_{in}}$$

$$V_x = \ldots$$

$$\ldots + V_2 - V_{in}$$

$$V_{in}$$

$$V_{P,j} = \begin{cases} \ldots \\ 0; & \operatorname{sgn}(\dot{V}_1) = \operatorname{sgn}(\dot{V}_2) \end{cases}$$

S

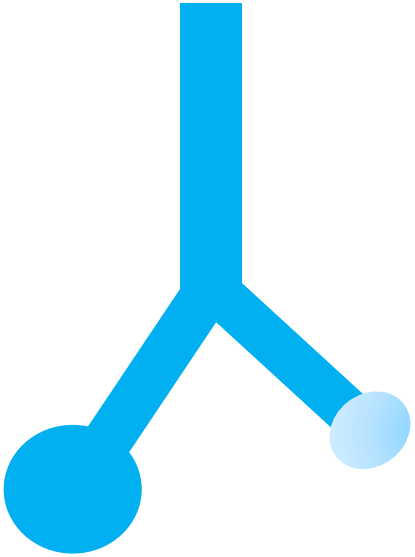
flo

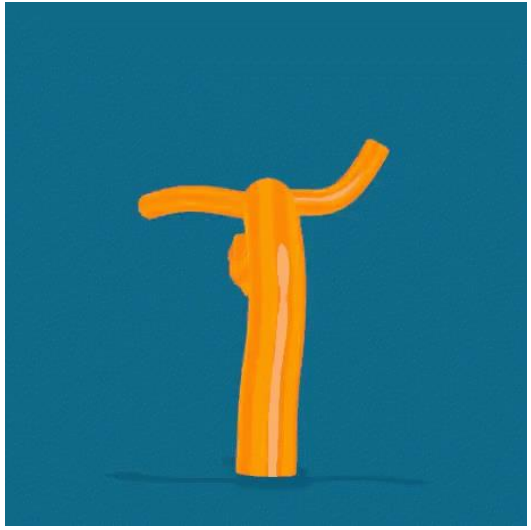
from

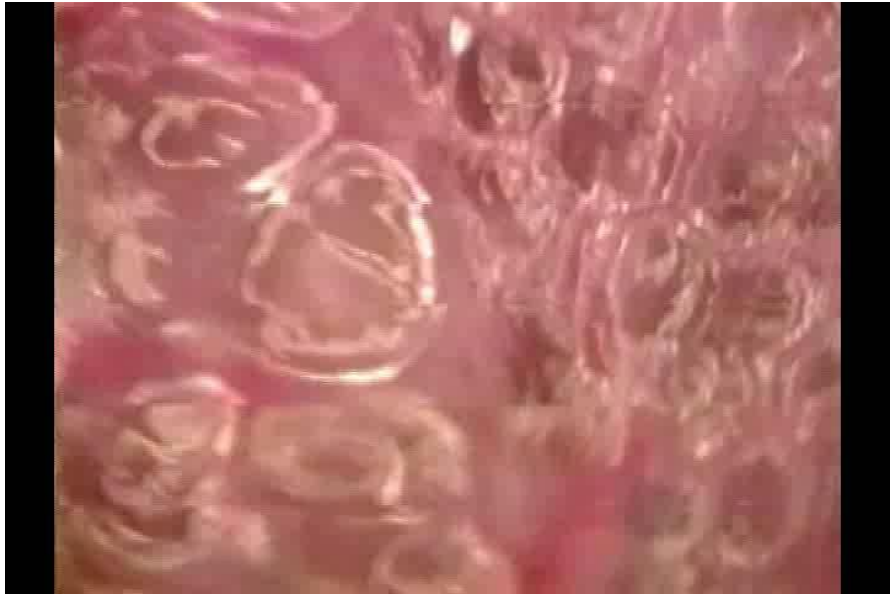
daugh

impedance model of a bifurcation. For definitions of abbreviations, please refer to the Glossary.

Greenblatt et al, J Appl Physiol, 2014







A. Slutsky, University of Toronto

History of HFV

1915: Yandell Henderson notes dog's ability to pant

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VOL. 38 JULY 1, 1915 No. 1

THE RESPIRATORY DEAD SPACE

RSON, F. P. CHILLINGWORTH AND J. L. WHITNEY

hysiological Laboratory of the Yale Medical School

Received for publication April 13, 1915.

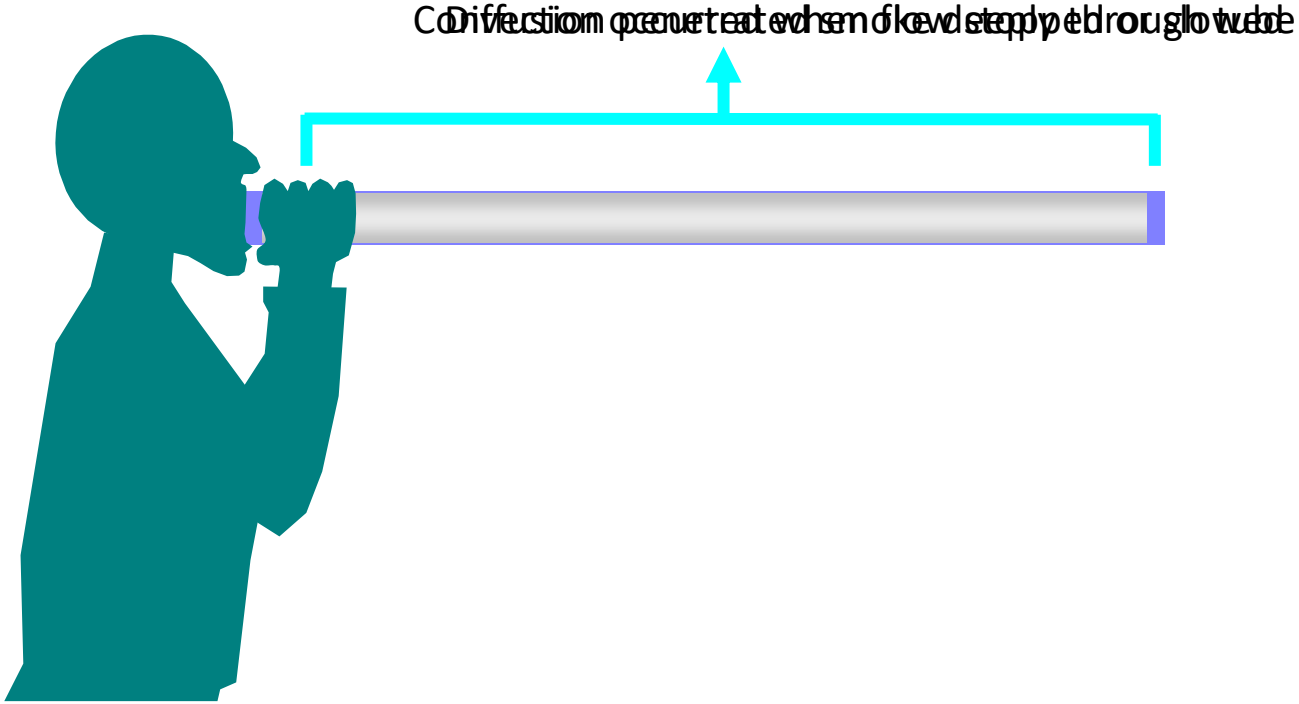
nation of the volume of the respiratory dead space is importance in connection with many of the prob- lation of breathing and related topics. The interpreta- a accumulated by many investigators depends upon the question whether the dead space is a fixed or a variable the latter is the case, what are the nature, cause, and rol of such variations?

earlier investigators recognized the dead space as a factor s.[1] Loewy,[2] seems to have been the first to report a measure- By means of a plaster cast of the cavity of the mouth, rachea, bronchi and bronchioles of a cadaver he found a vol- 4 cc. He noted, however, that in the living subject even in tion much smaller than the volume of the dead space there are always to be found considerable amounts of CO_2, and that as expira- tion progresses the percentage of CO_2 in successive portions increases gradually, not abruptly: facts which later investigators have not always kept in mind.

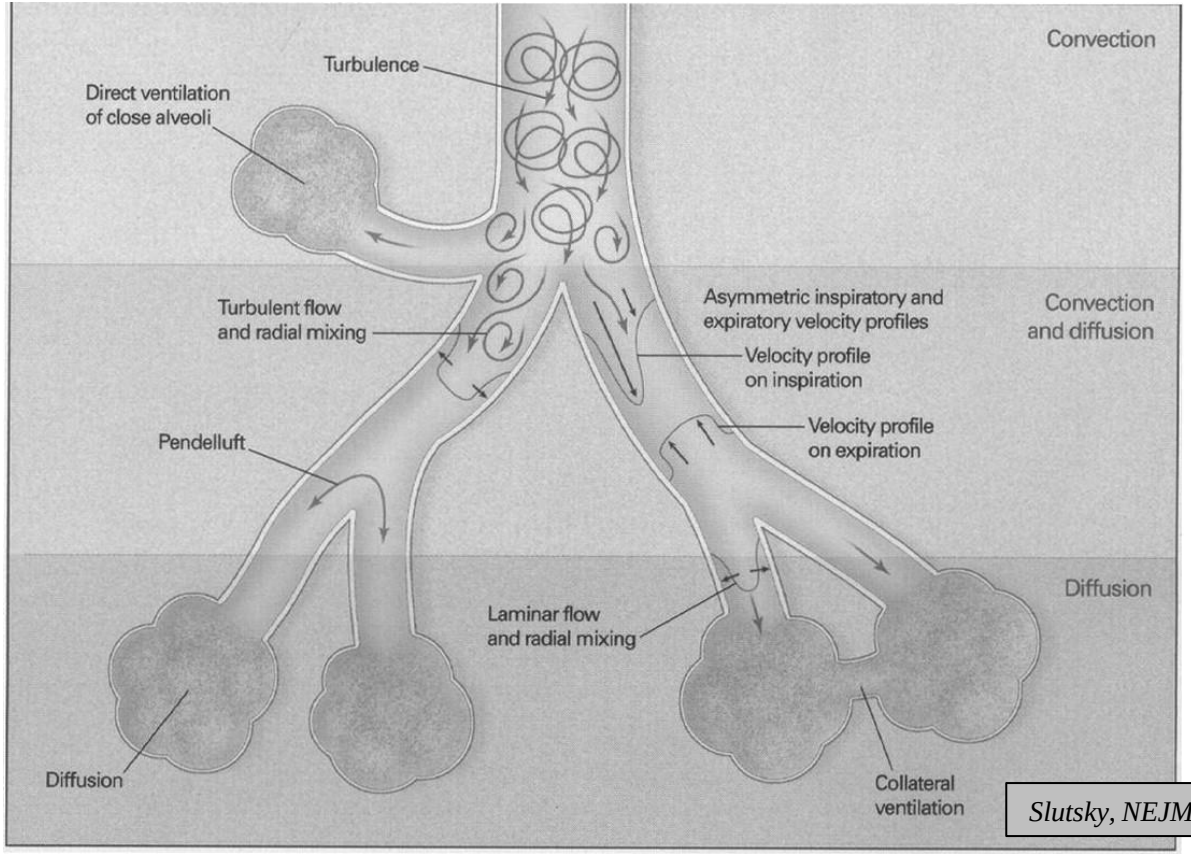
Basing their opinion upon these observations, Zuntz and his col- laborators in their extensive investigations have assumed the dead space to be an unvarying volume—the same no matter whether the sub- ject were at rest, or breathing deeply from physical exertion, or on a mountain. All of their calculations of the alveolar ventilation and of the composition of the alveolar air involve this assumption. The method employed by them was based on the proportion: the composi-

1

Smoke Studies

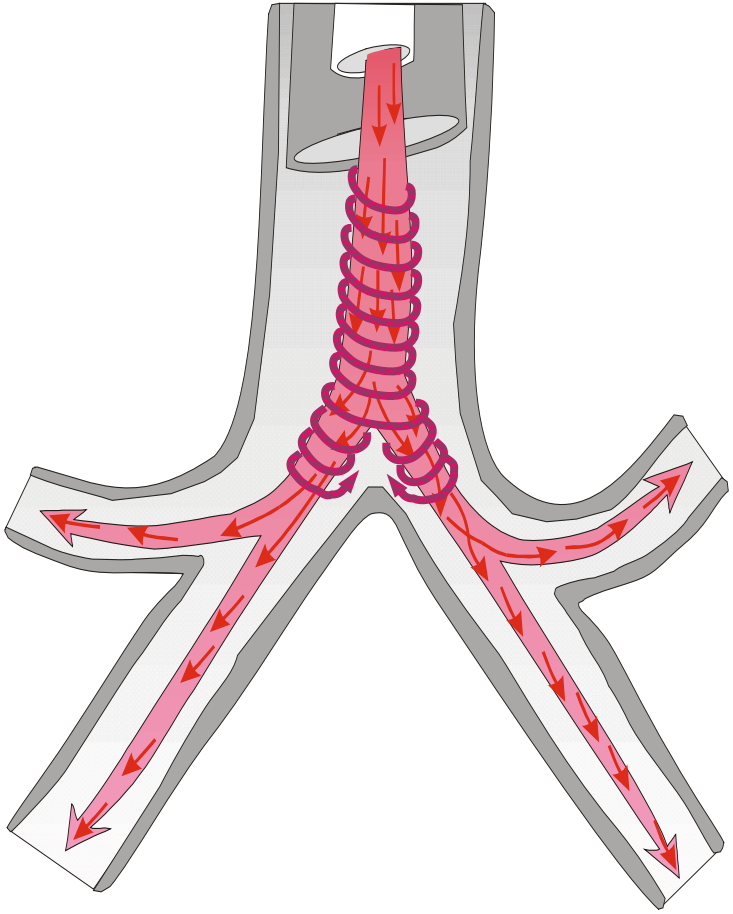


Gas-Transport Mechanisms during High-Frequency Ventilation



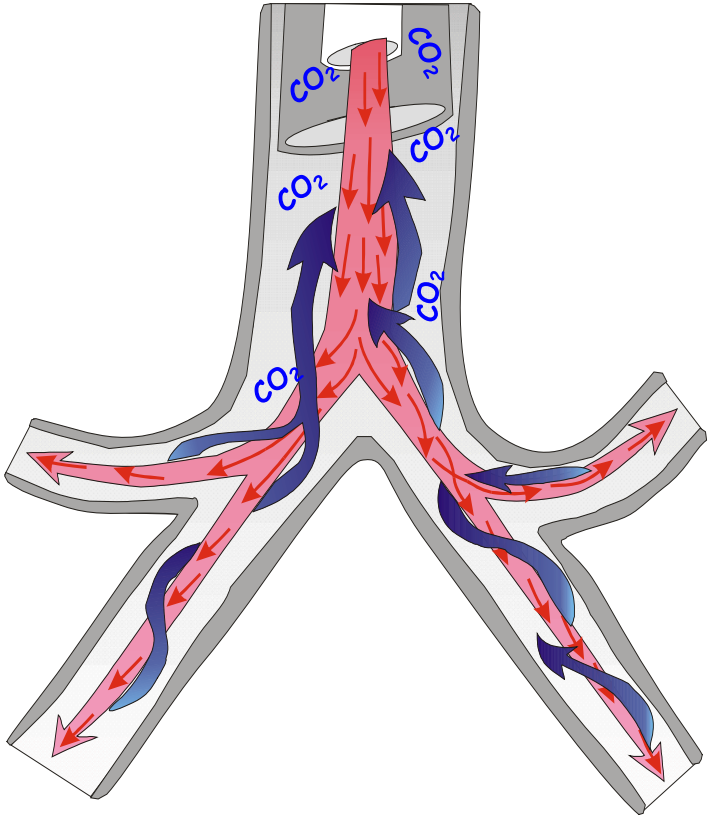
Slutsky, NEJM 2002

Good Air In



Bunl.com

Bad Air Out



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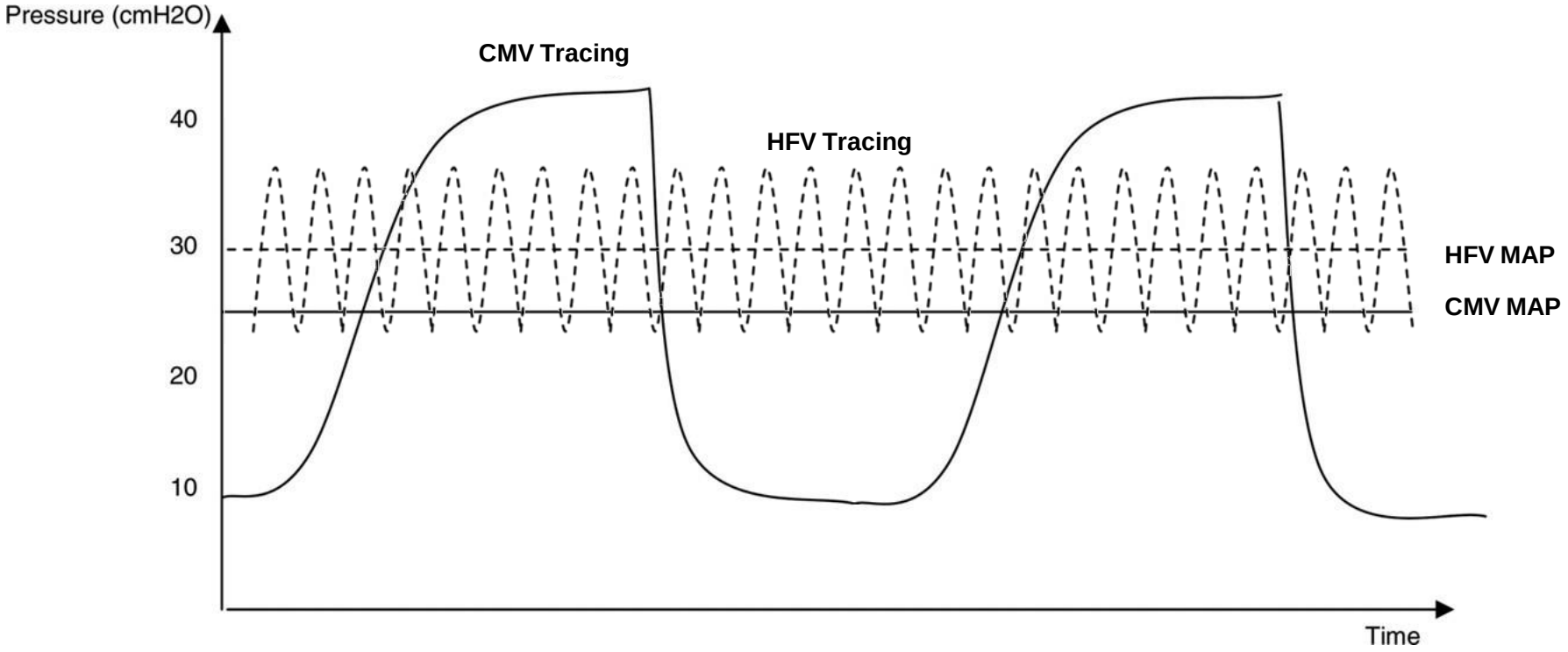
Pressure (cmH2O)
40
30
20
10
CMV Tracing
HFV Tracing
HFV MAP
CMV MAP
Time

When to HFV

- Diffuse alveolar diseases:
  - ARDS & ALI
  - Airleak syndrome
  - Alveolar Hemorrhage

When to HFV

- Diffuse alveolar diseases:
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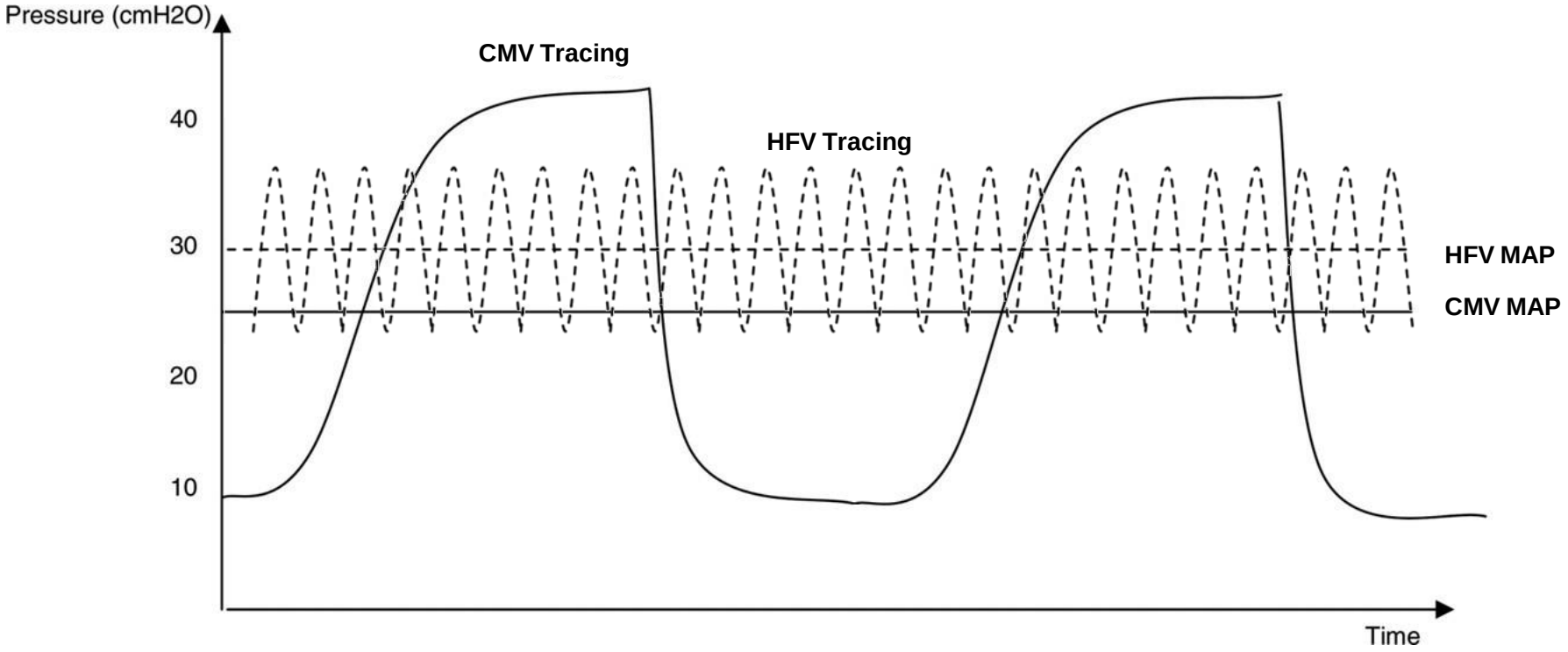
$$OI = \frac{O_2\% \times MAP}{PO_2}$$

- Oxygen Index (OI) > 13 on 2 ABG's within 6 hrs
    - OI > 20, consider ECMO
  - FiO2 > 0.60
  - PIP > 30-32 cm H2O
  - MAP > 15 cm H2O

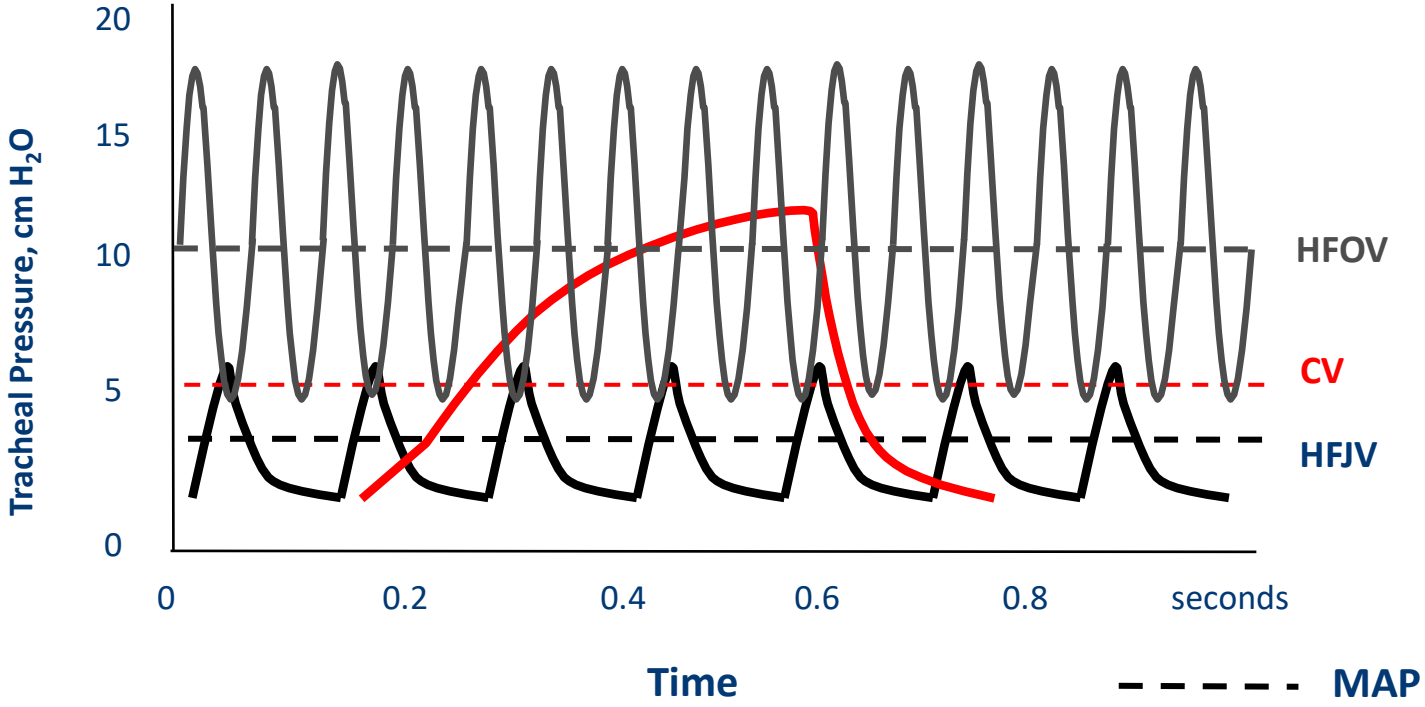
HFV Gas Exchange

- Oxygenation is primarily controlled by:
  - FiO2
  - Mean Airway Pressure (P_{aw})
- Ventilation, as defined by CO2 clearance, is primarily controlled by:
  - Tidal/Stroke Volume
  - Frequency/RR

HFV Oxygenation: MAP



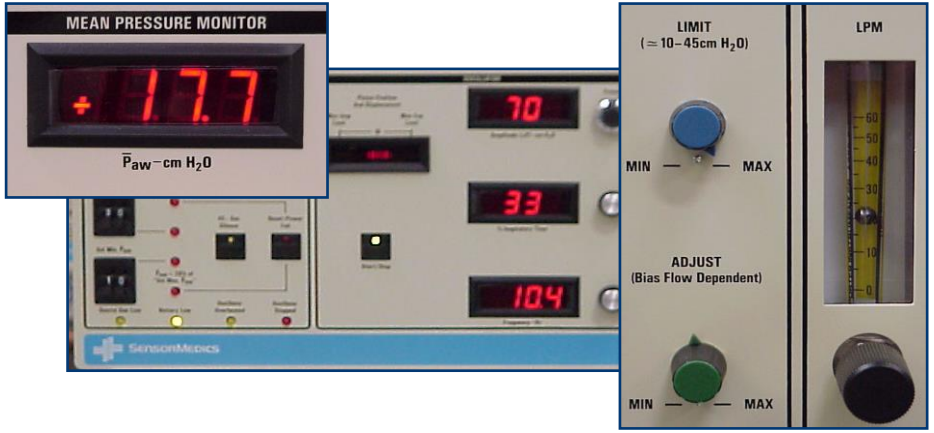
HFV Oxygenation: MAP



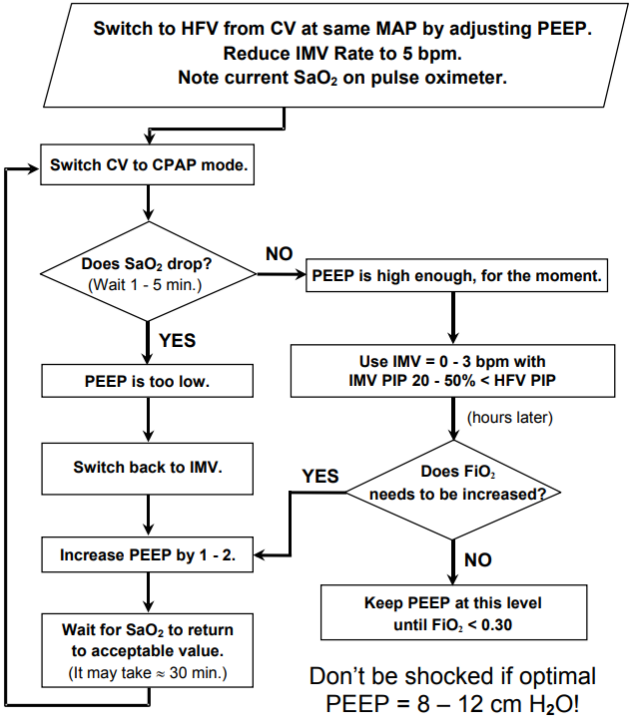
Three Ventilators, Same Blood Gas

Boros, et al. Ped Pulm. 1989

HFV Oxygenation: MAP



Finding Optimal PEEP during HFV *



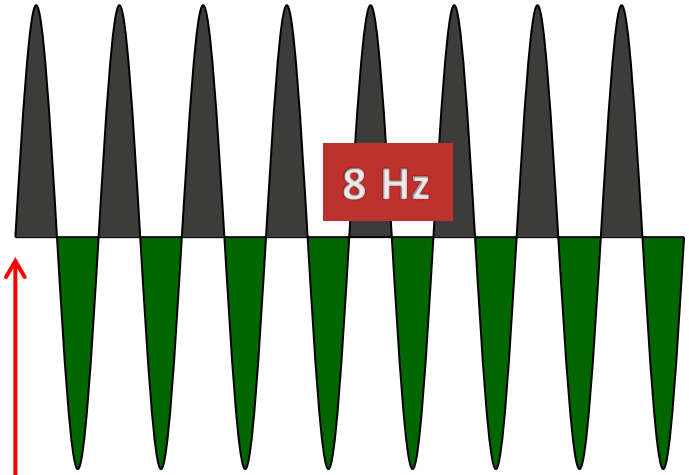
Don't be shocked if optimal PEEP = 8 – 12 cm H_2O!

Ventilation = CO2 Clearance

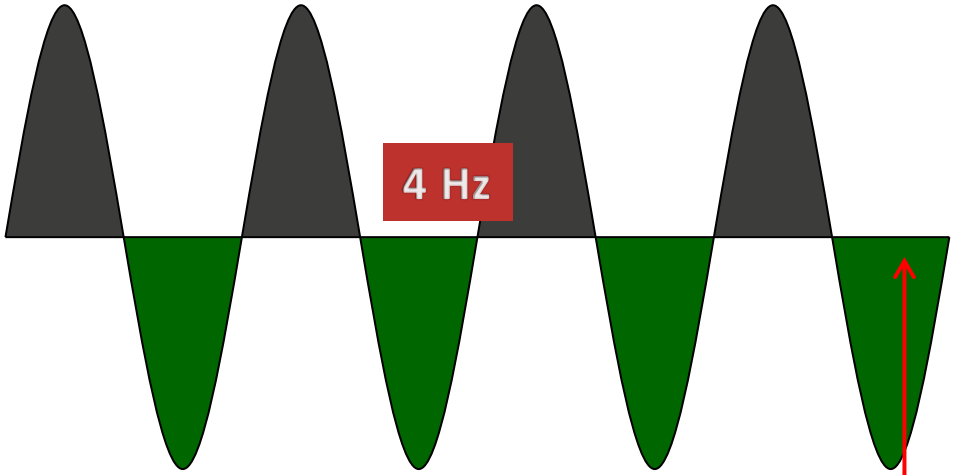
- During CMV minute ventilation is defined as: f x Vt
- During HFV minute ventilation is defined as: f x $Vt^{1.5-2.5}$
  - Changes in tidal volume delivery have the most significant effect on ventilation.

Ventilation = CO2 Clearance

- During CMV minute ventilation is defined as: f x Vt
- During HFV minute ventilation is defined as: f x $Vt^{1.5-2.5}$
  - Changes in tidal volume delivery have the most significant effect on ventilation.
- HFOV Tidal Volume can be affected by:
  - Power (Amplitude is <u>not</u> a setting)
  - Frequency
  - Percent Inspiratory Time



vs.

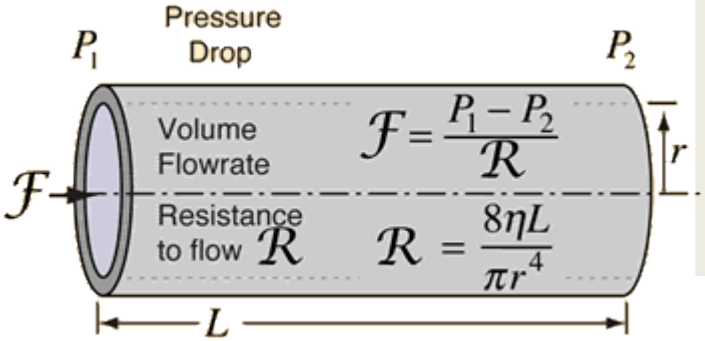


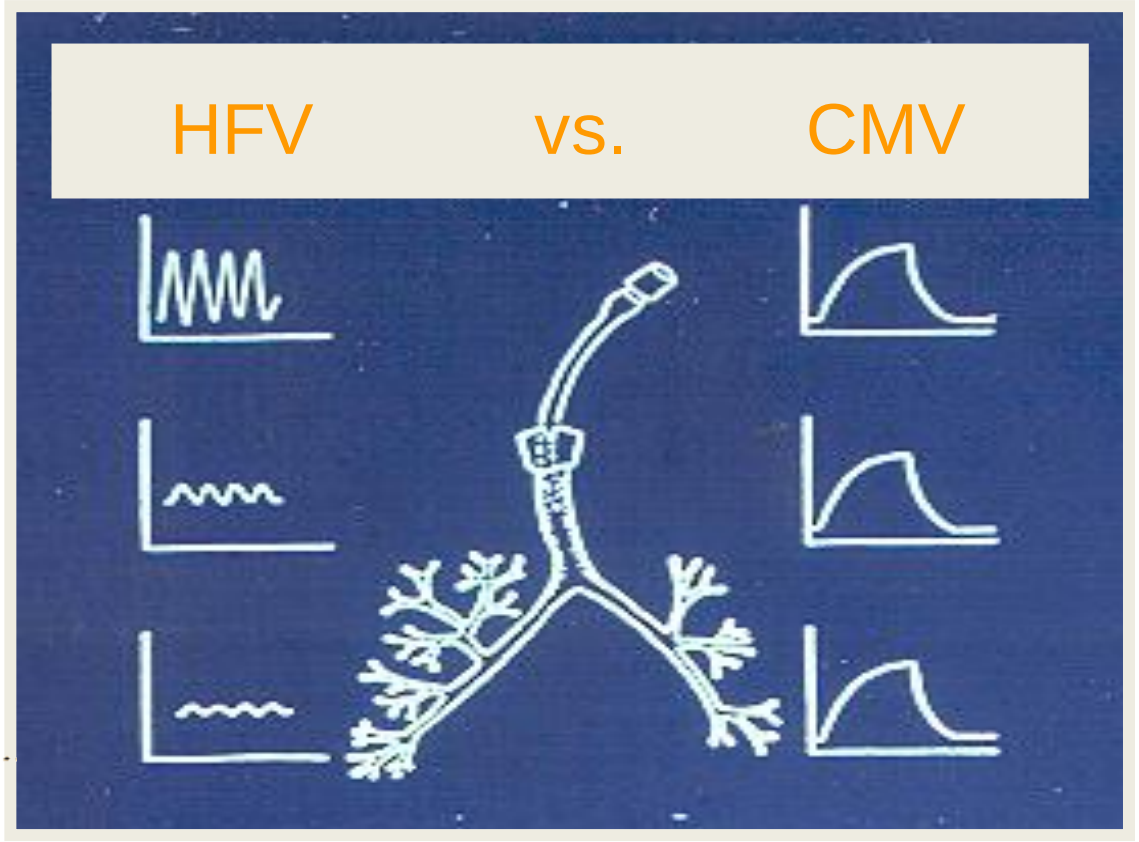
Frequency controls the time allowed (distance) for the piston to move.

Therefore:

the <u>higher</u> the frequency setting, the <u>smaller</u> the volume displacement.

the <u>lower</u> the frequency setting, the <u>larger</u> the volume displacement.


Pressure Drop
P_1
P_2
Volume Flowrate
$\mathcal{F} = \frac{P_1 - P_2}{\mathcal{R}}$
$\mathcal{F}$
Resistance to flow $\mathcal{R}$
$\mathcal{R} = \frac{8\eta L}{\pi r^4}$
r
L


HFV
vs.
CMV

Gerstmann, D.

Frequency

Weight-based table per manufacturer's recommendations

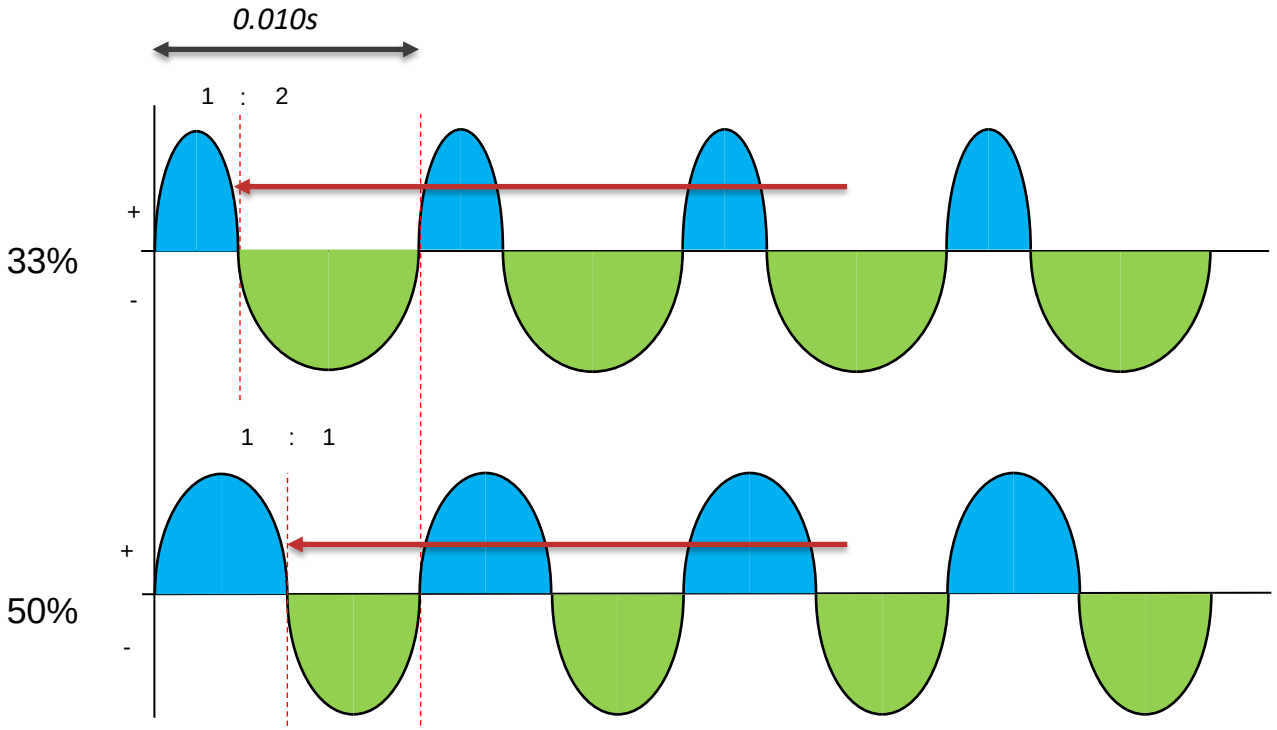
500-1500g	15hz
1500-2000g	12hz
2-5kg	10hz
5-12kg	9hz
12-20kg	8hz
21-30kg	7hz
>30kg	6hz

HFOV: Changes in Percent Inspiratory Time

10Hz= 600bpm
600bpm = 0.10s cycle time

At 33%
Ti = 0.033
Te = 0.066

At 50%
Ti = 0.05
Te = 0.05



CO2 Clearance in HFV

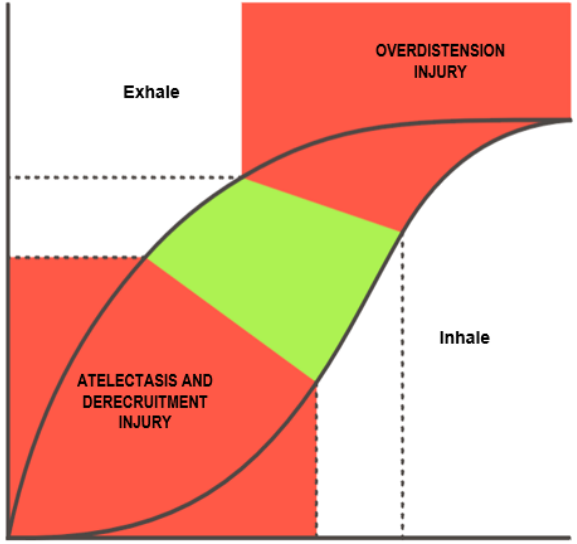
- Changing Vt is the primary method of controlling PCO_2
  - For HFOV:
    - Increase power setting (amplitude is <u>still</u> not a setting)
    - Decrease frequency
    - Increase T_i%
  - For HFJV: increase PIP
- Secondary control of CO2 is the frequency setting
  - For HFOV: lower rates = higher Vt = more applied pressure
  - For HFJV: increase rate = higher Ve at same applied pressure*

HFV Initiation

	HFJV	HFOV
MAP	Maintain CMV PEEP	3-5 above current CMV
	Follow CXR to prevent over-inflation or atelectasis	
PIP/Power	At or above current CMV	Power 2-4
	Adjust both for “Chest Wiggle Factor”	
Rate/Frequency	Start at 420 unless air trapping	Weight-based table
On-Time/Ti%	0.020	33%
FiO2	As needed for SpO2 goals	1.0 unless otherwise indicated
CMV Rate	Start 3-5, lower as able	
CMV PIP	Keep below HFJV PIP	

HFV Management: Initial

- Titrate P_{aw} to optimal lung volume.
  - ~8 ribs expansion per CXR
- Perfusion must be matched to ventilation for adequate oxygenation, monitor for overdistension vs. atelectasis

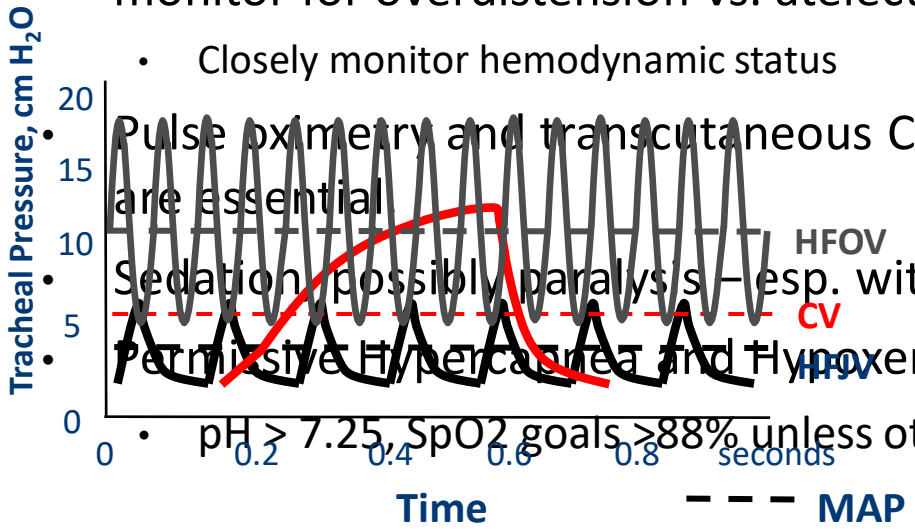


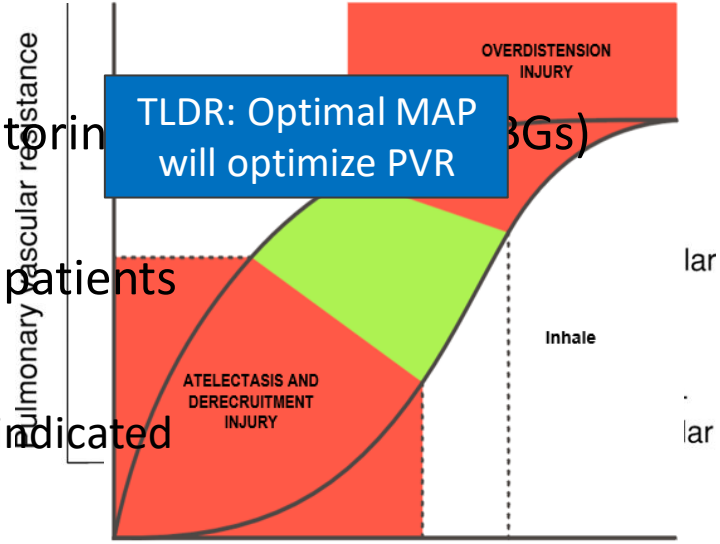
High-Frequency Jet Ventilation in Infants With Congenital Heart Disease

Andrew G Miller, Briana L Scott, Rachel M Gates, Kaitlyn E Haynes,
Denise A Lopez Domowicz, and Alexandre T Rotta

BACKGROUND: High-frequency jet ventilation (HFJV) is primarily used in neonates but may also have a role in the treatment of infants with congenital heart disease and severe respiratory failure. We hypothesized that HFJV would result in improved gas exchange in these infants.
METHODS: We retrospectively reviewed the records of all pediatric patients with complex congenital heart disease treated HFJV in our pediatric cardiac ICU between 2014 and 2018. Patients in whom HFJV was started while on extracorporeal membrane oxygenation (ECMO)

- ventilation for adequate oxygenation, monitor for overdistension vs. atelectasis
  - Closely monitor hemodynamic status
- Pulse oximetry and transcutaneous CO2 monitorin BGs) are essential
- Sedation, possibly paralysis – esp. with larger patients
- Permissive Hypercapnea and Hypoxemia
  - pH > 7.25, SpO2 goals >88% unless otherwise indicated





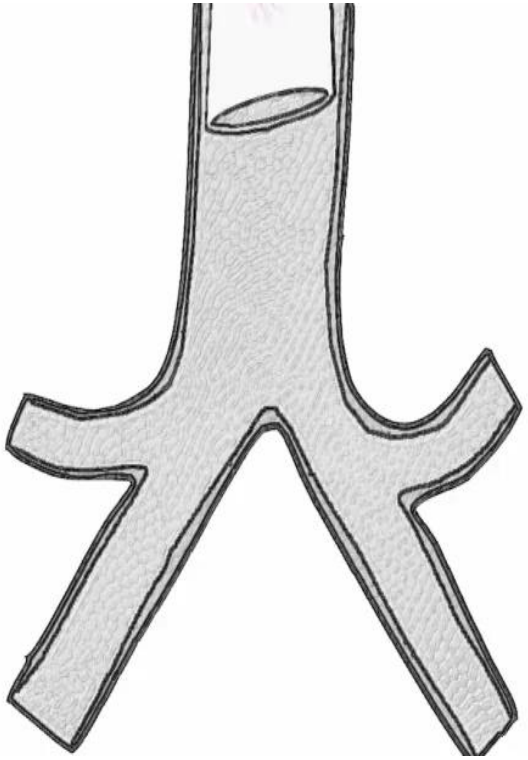
HFV Management: Ongoing

<u>Titration for Oxygenation</u>

- Are you recruited?
  - Titrate PEEP/MAP as needed to recruit atelectasis & prevent overdistension
  - If increasing CMV rate improves oxygenation, you're not on enough PEEP

<u>Titration for Ventilation</u>

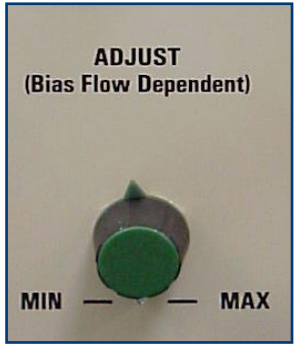
- Tidal volume optimized?
- Rate optimized?

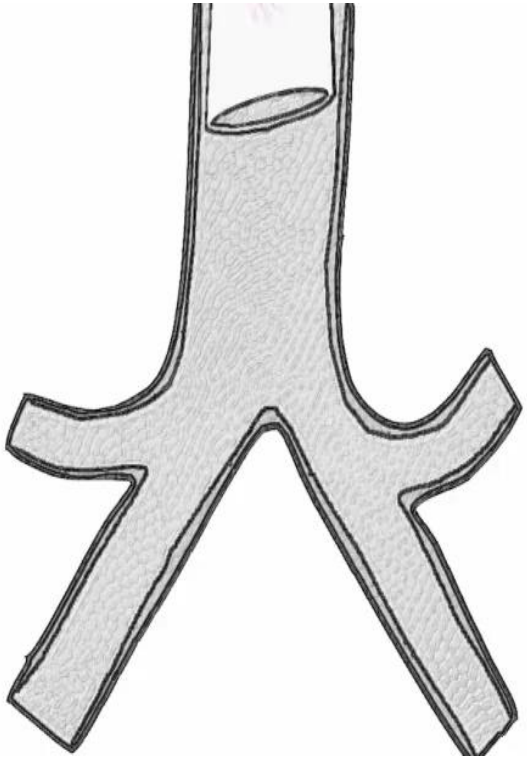


HFOV Management

<u>HFOV</u>

- If CO2 retention persists, decreasing cuff pressure will allow gas to escape around ETT
  - Ventilation will improve, but oxygenation may suffer
- May consider changing Ti%
- ?Bias flow changes





Practical Considerations

- What to do if you have decreased "wiggle"
  - Results from decreased compliance or mechanical issue
    - Tube displacement
    - Lung compliance decreased (secretions, fluid, pneumo, bronchospasm)
    - Vent mechanical issue
    - Variable leak re: partially inflated cuff or pt reposition
      - Reassess patient after all repositions and interventions
  - Suction patient q12h minimum to ensure patency of ETT and prevent occlusion
      - Routine suction generally not indicated unless secretions are a known issue

Thank You For Your Time!

Stephen.Hepditch@duke.edu