Today’s menu:

High Frequency Oscillatory Ventilation

Dan Waisman, MD
Newborn Unit, Department of Neonatology
Carmel Medical Center
Clinical Skills Cluster – Dep. of Medical Education
Faculty of Medicine, Technion – IIT
Haifa, Israel.


ואחרי שלמדתי
את כל התשובות
משנים לי את
השאלות???!!!

- 28/40 GA
- BW 1 kg
- Intubated at 1 hr
- **P_{aw} 12 cmH_2O**
- **FiO_2 1.0**
- **SpO_2 86%**
- Pa_{O2} 45 mmHg
- Pa_{CO2} 55 mmHg

Initiating HFOV

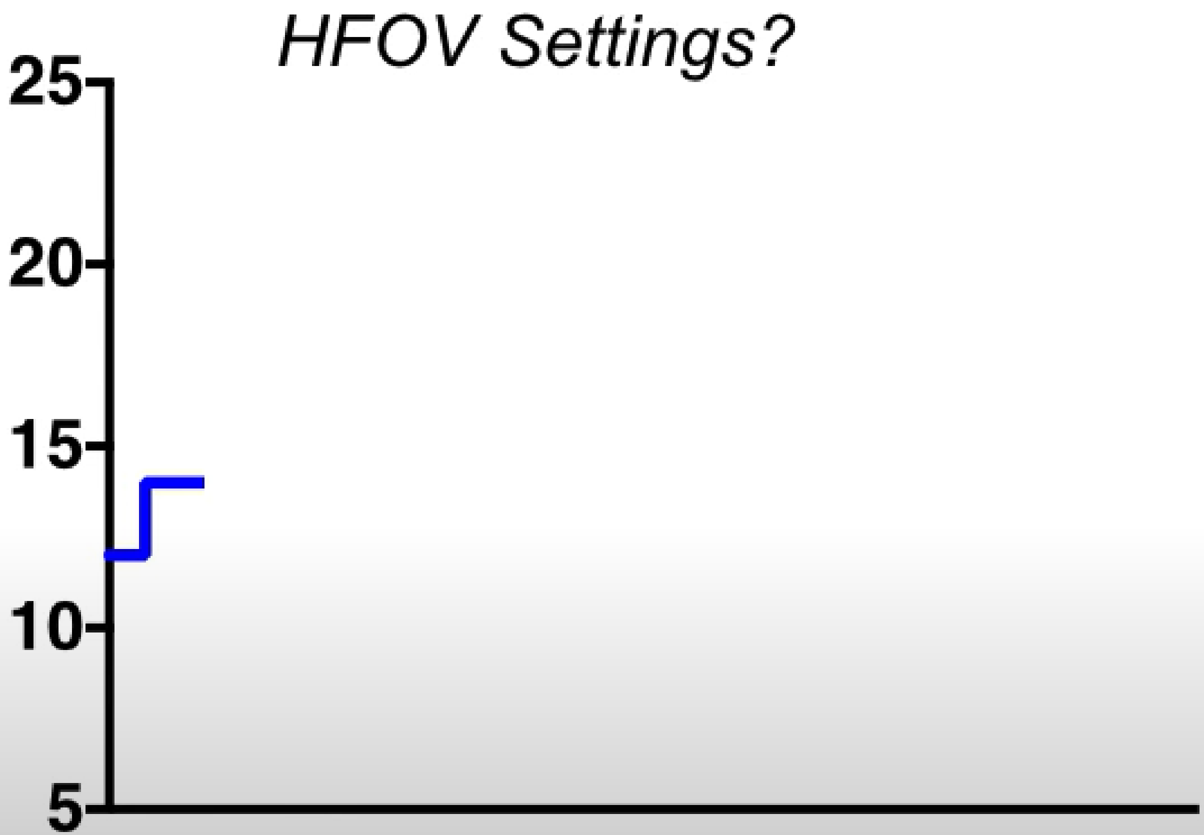
איך נגדיר את המצב של התינוק?

- 28/40 GA
- BW 1 kg
- Intubated at 1 hr
- **P_{aw} 12 cmH_2O**
- **FiO_2 1.0**
- **SpO_2 86%**
- Pa_{O2} 45 mmHg
- Pa_{CO2} 55 mmHg

Initiating HFOV

Preterm Infant

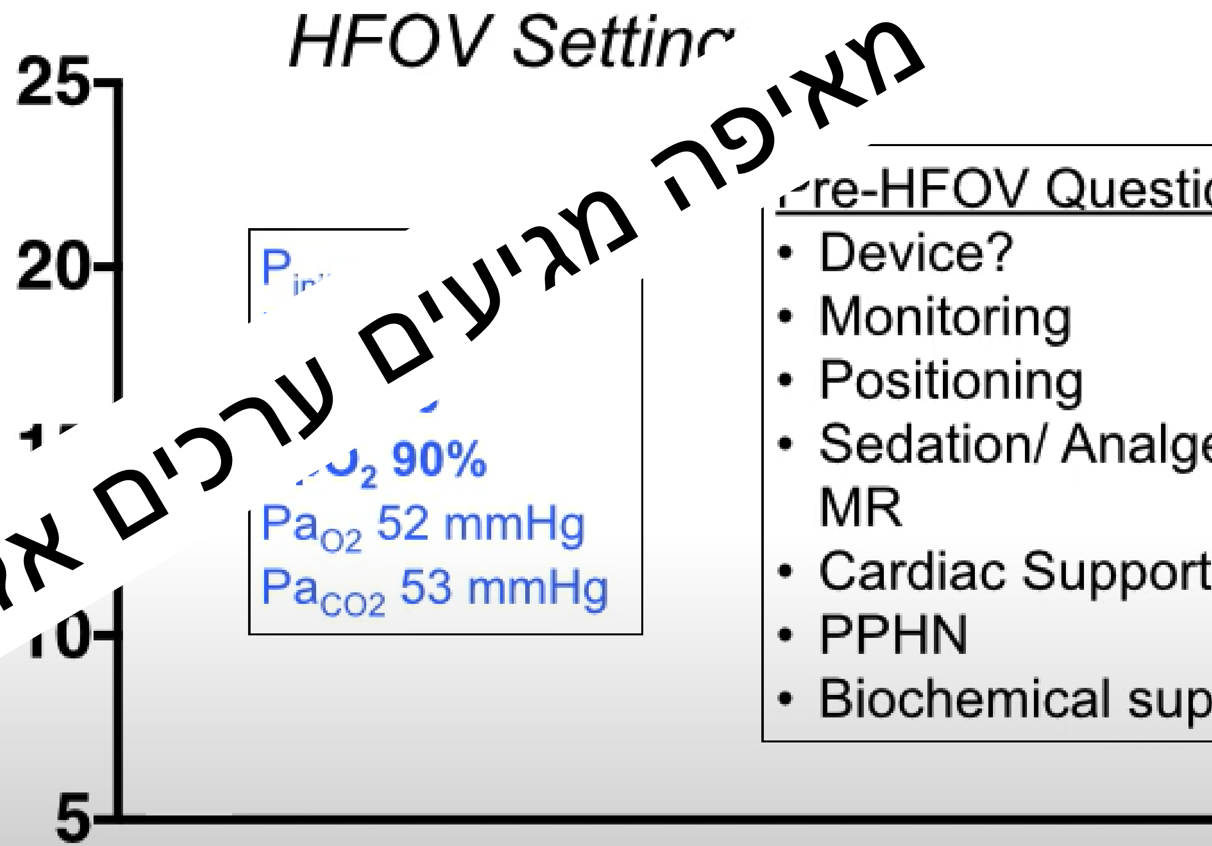
- 28/40 GA
- BW 1 kg
- Intubated at 1 hr
- **P_{aw} 12 cmH_2O**
- **FiO_2 1.0**
- **SpO_2 86%**
- Pa_{O2} 45 mmHg
- Pa_{CO2} 55 mmHg



Initiating HFOV

Preterm Infant

- 28/40 GA
- BW 1 kg
- Intubated at 1 hr
- **P_{aw} 12 cmH_2O**
- **FiO_2 1.0**
- **SpO_2 86%**
- Pa_{O2} 45 mmH
- Pa_{CO2} 55 mmH



Pre-HFOV Questions

- Device?
- Monitoring
- Positioning
- Sedation/ Analgesia/ MR
- Cardiac Support
- PPHN
- Biochemical support

מאיפה מגיעים ערכים אלה?

High Frequency Ventilation

The term high frequency ventilation describes a group of technologies that, when appropriately used, can accomplish adequate alveolar ventilation using low tidal volumes (smaller than the dead space) and supraphysiologic ventilator frequencies (>150).

The term ***high frequency ventilation*** describes a **group** of technologies that, when appropriately used, can accomplish adequate alveolar ventilation using **low-tidal volumes** (smaller than the dead space) and **supraphysiologic ventilatory frequencies** (>150)**.**

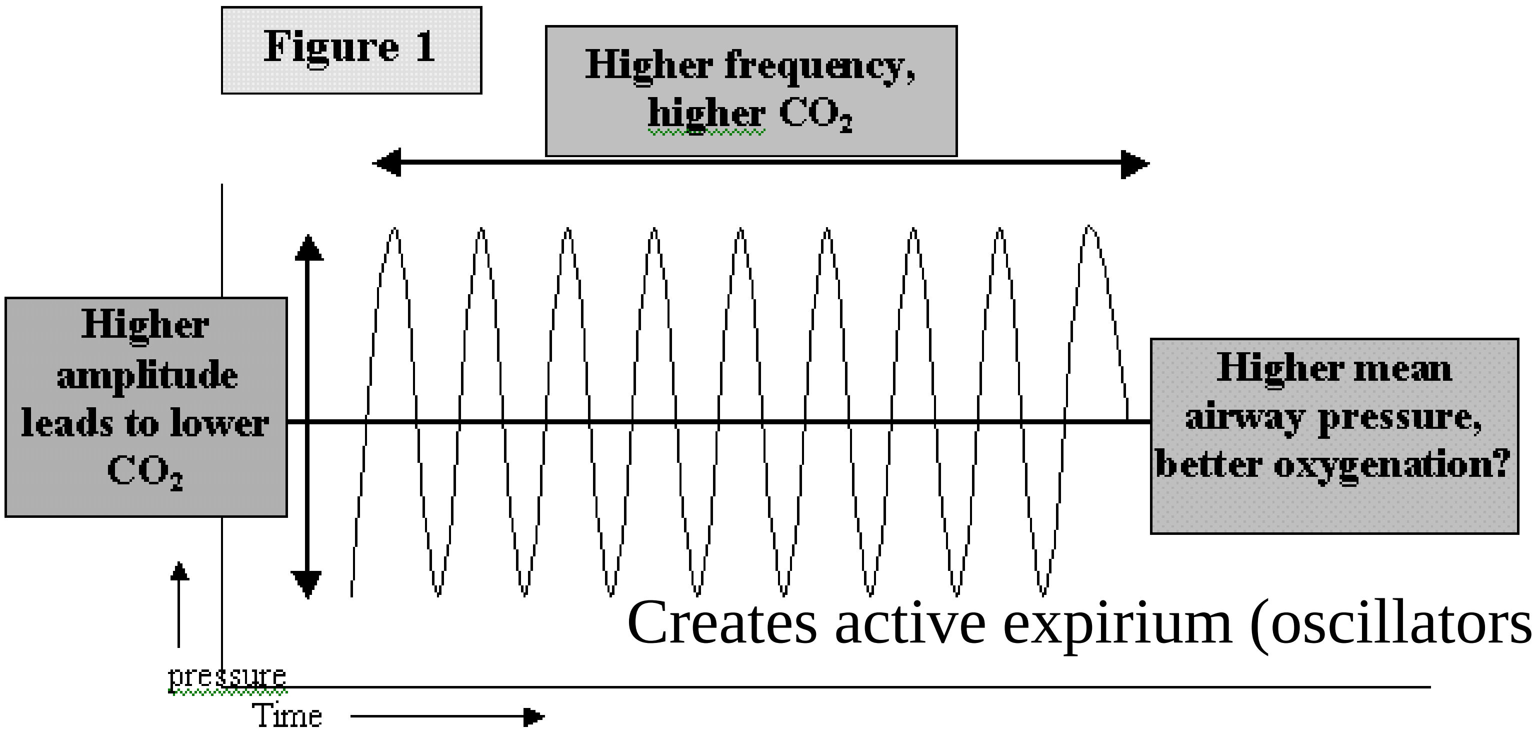
Hertz = 1 cycle per second

10 Hz is 10 cycles / second

= 600 cycles / minute

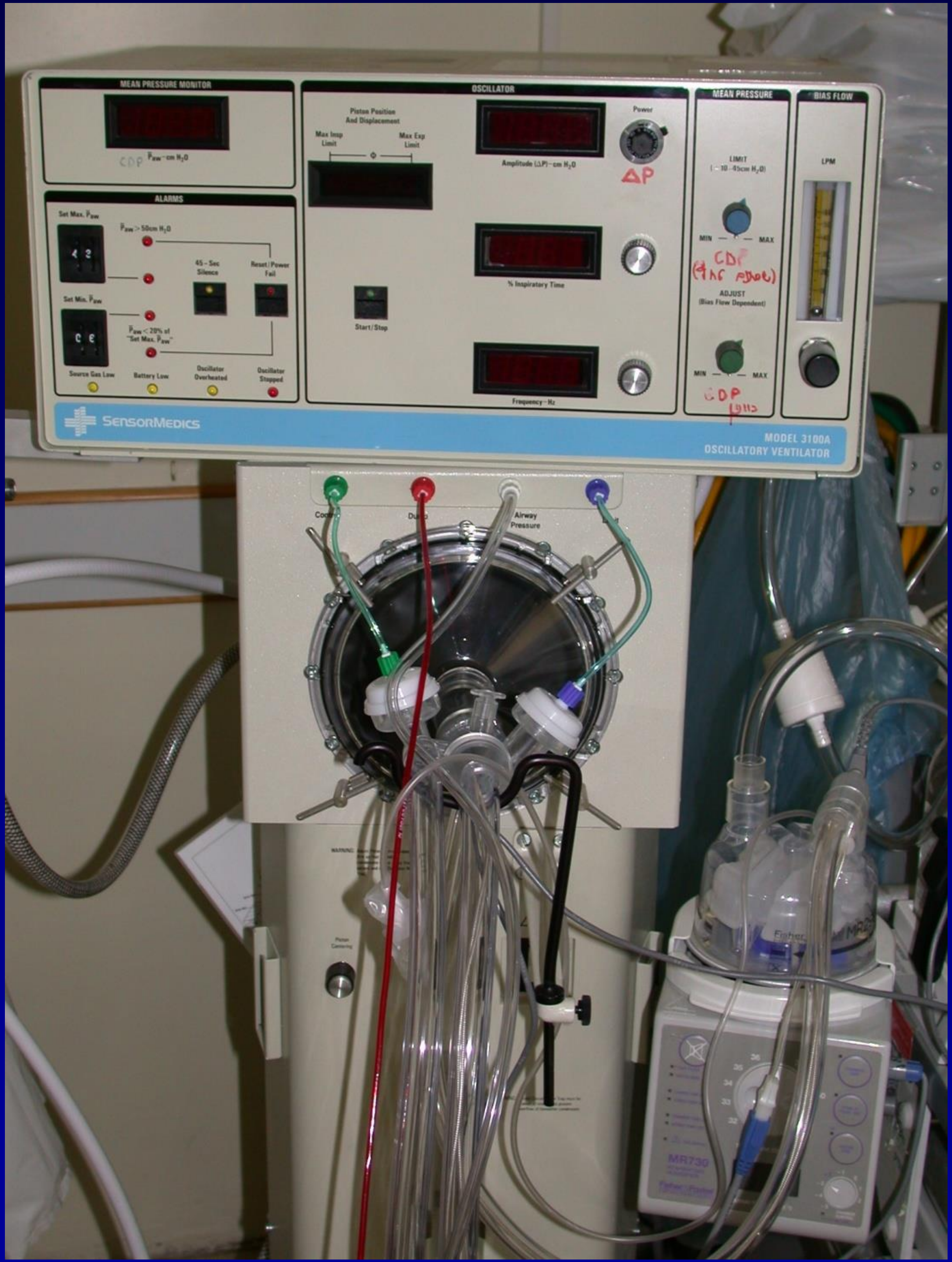
Active expiration in oscillators

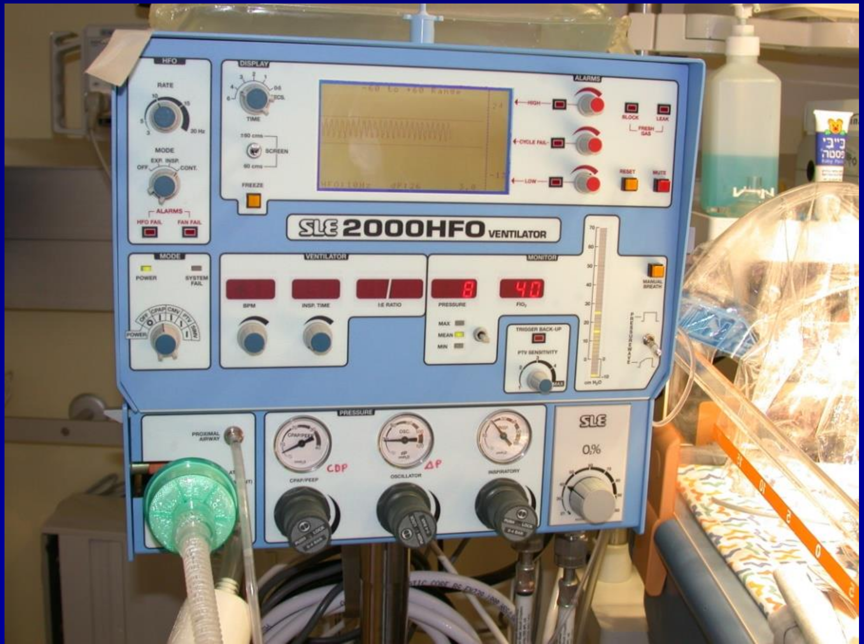
HFOV



Creates active expirium (oscillators only)

Can generate negative airway pressures


MEAN PRESSURE MONITOR
OSCILLATOR
ALARMS
MEAN PRESSURE
BIAS FLOW
CDP
ΔP
SensorMedics
MODEL 3100A
OSCILLATORY VENTILATOR


SLE 2000HFO VENTILATOR
CDP
ΔP
SLE

History of High Frequency Ventilation

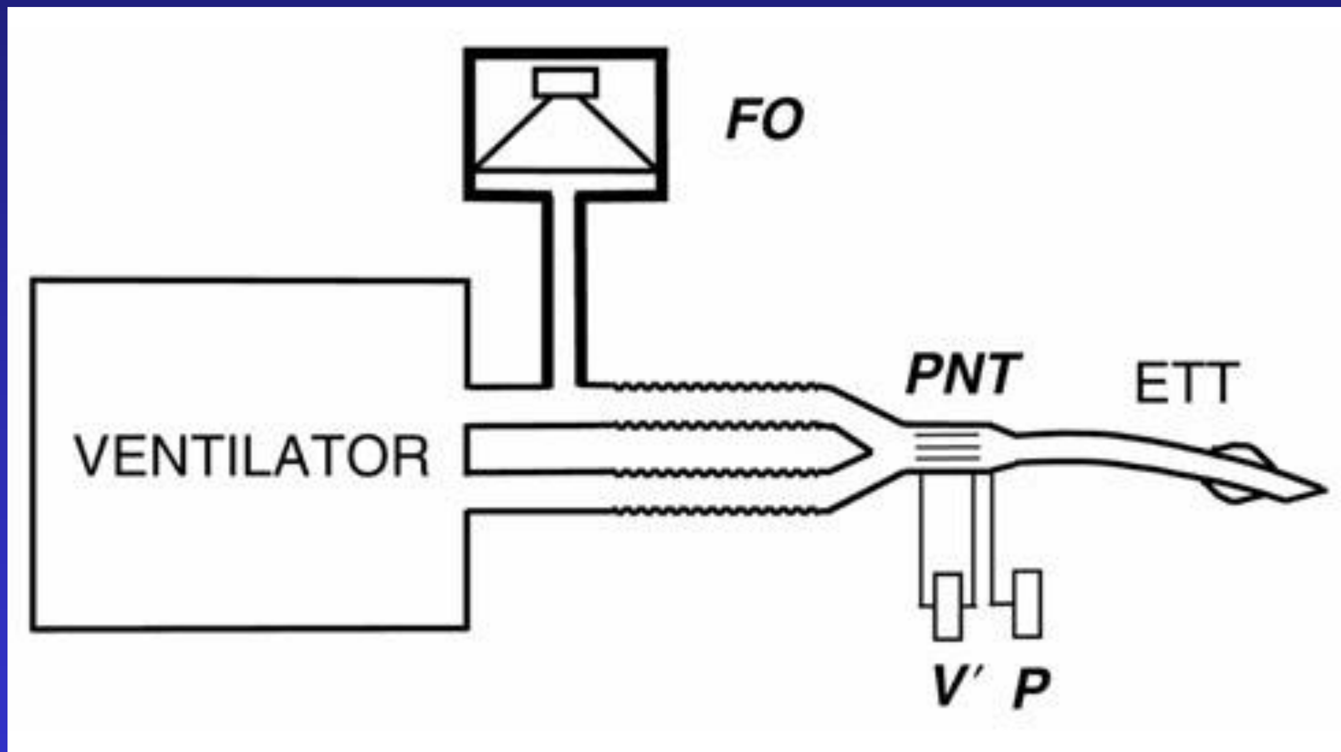
- 1952: Emerson - engineering HFO
- 1967: Sanders - jet ventilation during bronchoscopy
- 1968: Sjostrand - ventilatory efficiency 2.5Hz
- 1974: Klain-Smith - clinical introduction of the jet ventilation .
- 1972: Lukenheimer - High Frequency Oscillatory ventilation

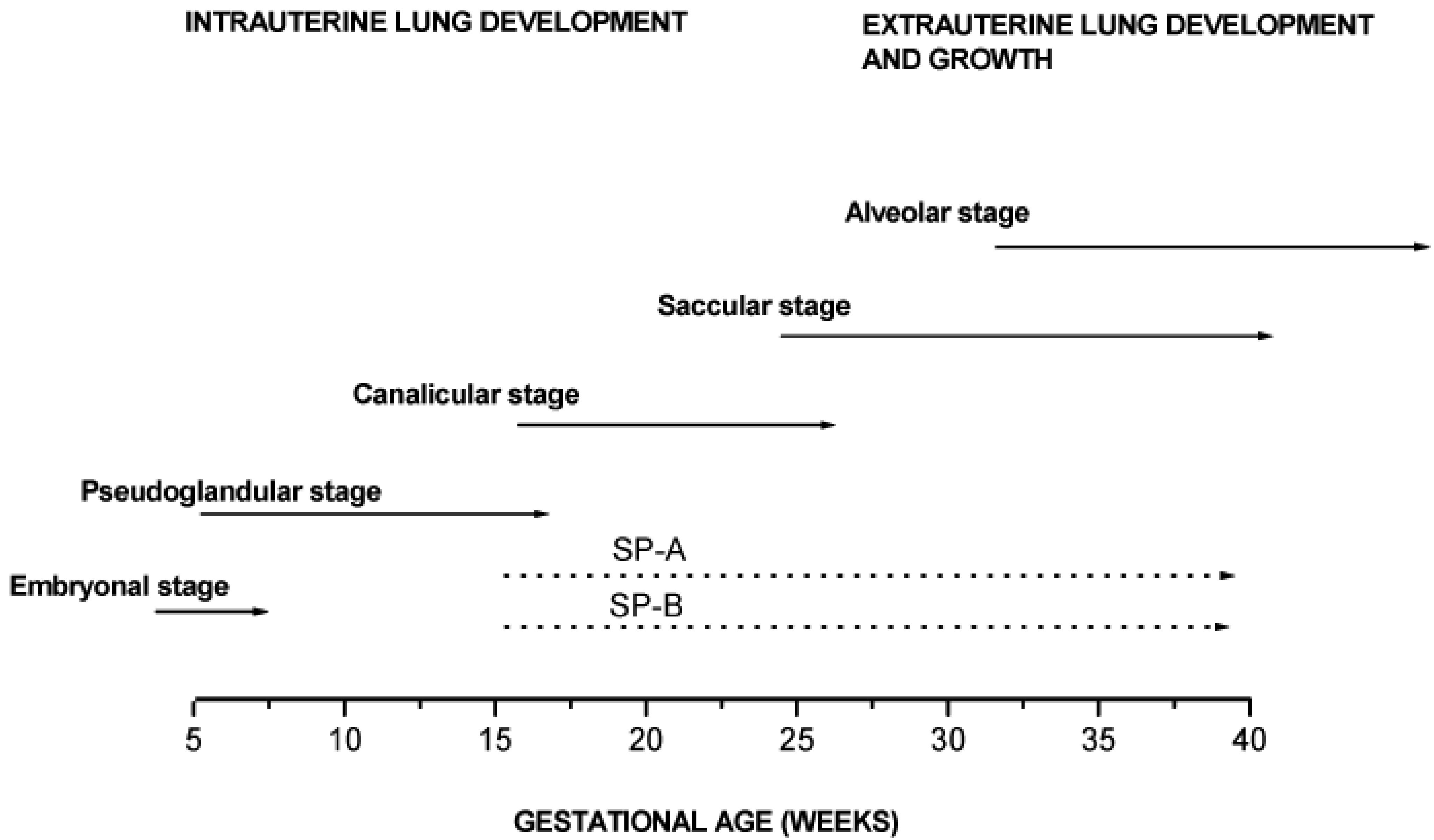
Types of high-frequency ventilators

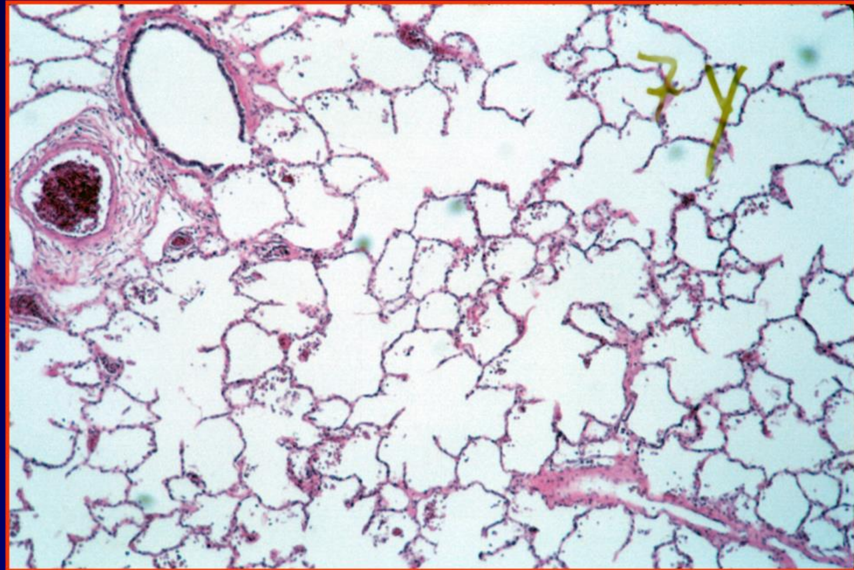
HFPPV- high frequency positive-pressure ventilation – flow interrupter (60-150 BPM)

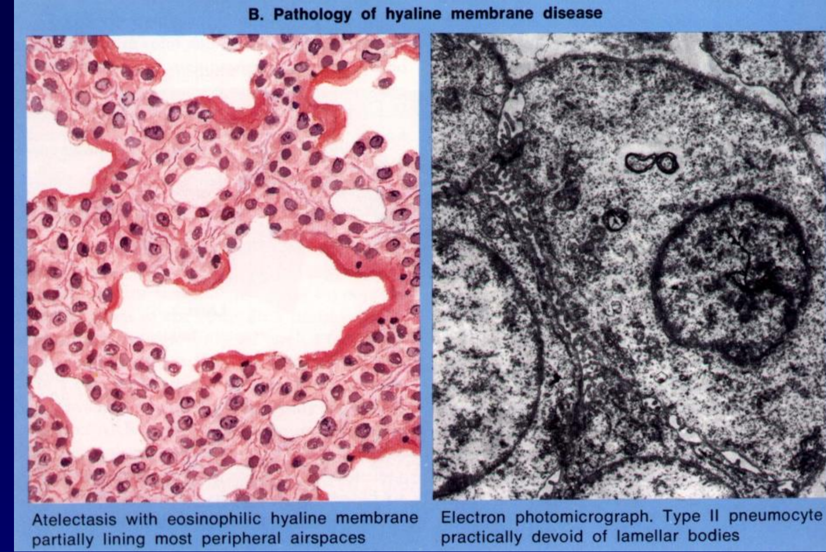
HFJV - high frequency jet ventilation (100-600 BPM)

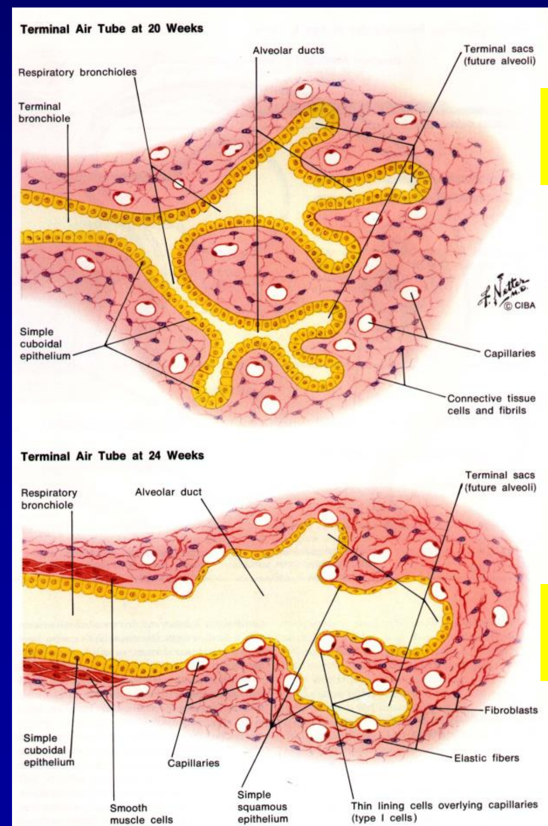
HFO - high frequency oscillation (180-1500 BPM // 3-25 Hz)


FO
VENTILATOR
PNT
ETT
V′
P


INTRAUTERINE LUNG DEVELOPMENT
EXTRAUTERINE LUNG DEVELOPMENT AND GROWTH
Alveolar stage
Saccular stage
Canalicular stage
Pseudoglandular stage
SP-A
Embryonal stage
SP-B
5
10
15
20
25
30
35
40
GESTATIONAL AGE (WEEKS)







20 weeks

Low compliance
Normal Resistance

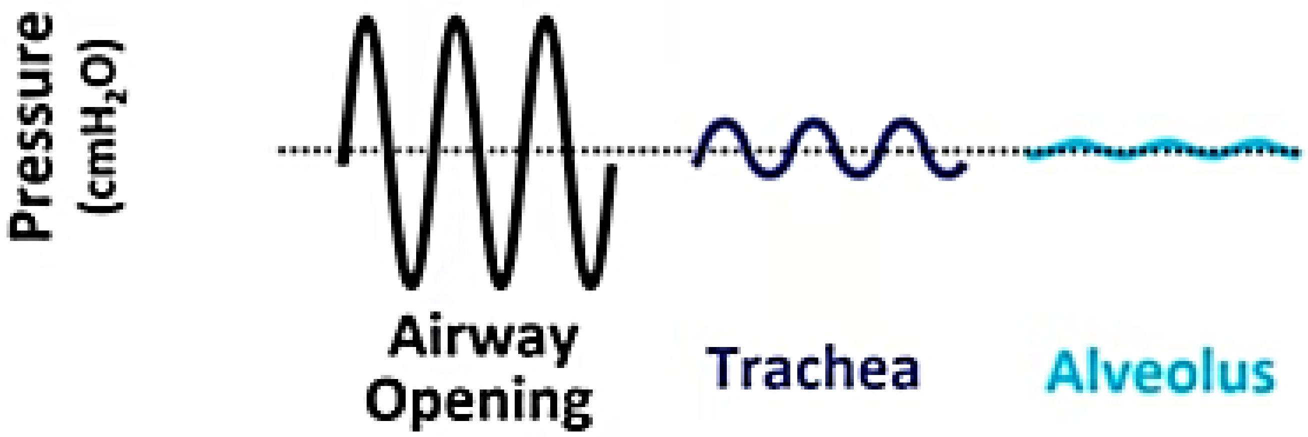
24 weeks

High Frequency Oscillatory Ventilation (HFOV)

- 10 - 15 Hz (600 - 900 breaths/min)

1 Hz = 1 cycle/second

- Active Expiration
- Low V_T (1.5-2.5 mL/Kg)
- Small ΔP_A (1-2 cmH_2O)



High frequency ventilation

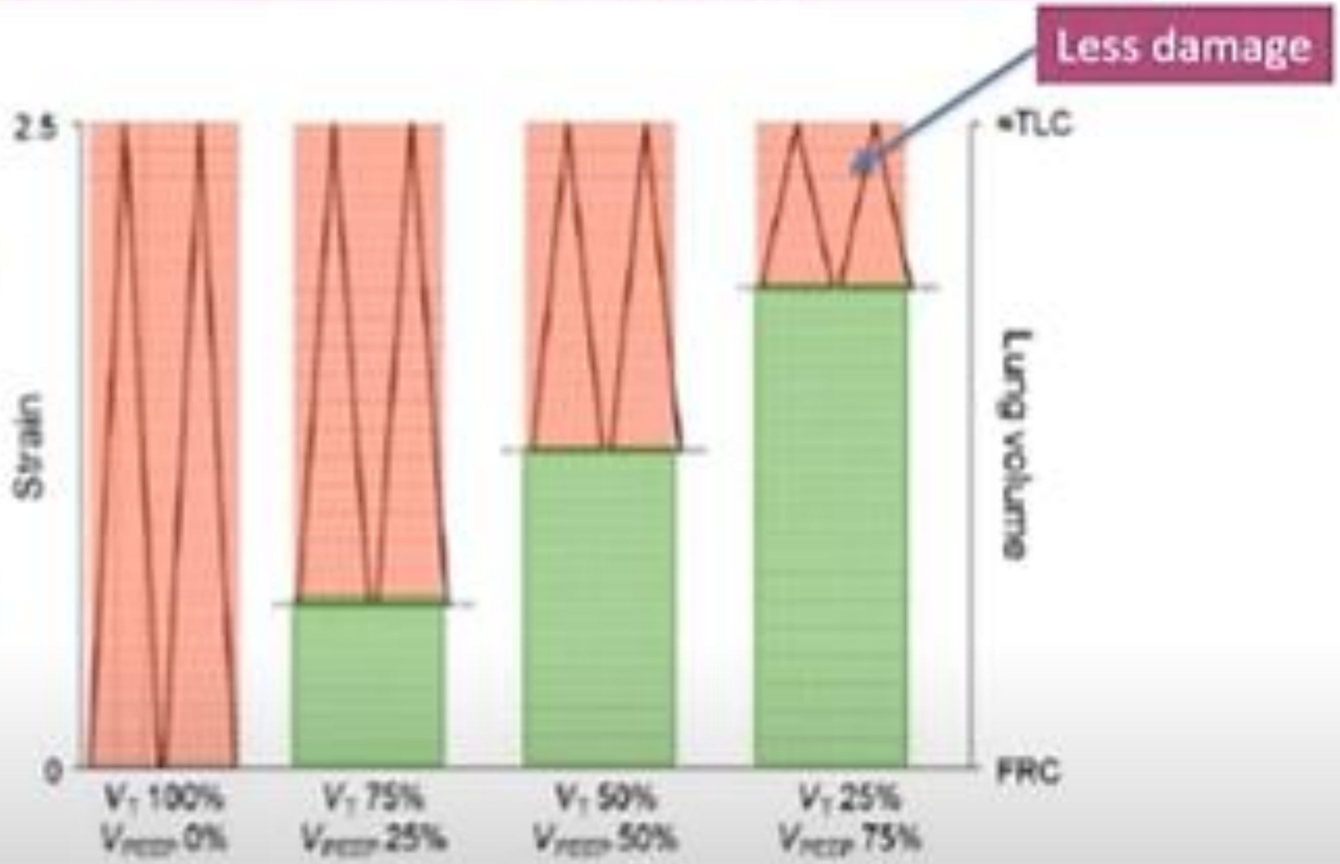
GUIDING PRINCIPLES OF LUNG PROTECTIVE VENTILATION WITH HFV

- Lung volume is maintained constantly above FRC by the use of a constant distending pressure (MAP or CDP)
- HFOV uses tidal volumes smaller than anatomical deadspace ($V_{d,an}$), approx. 2 ml/kg BW
  - prevents over-distention of more compliant lung units
  - improves V/Q
- In theory, separates oxygenation and ventilation to manipulate them independently

Ventilation = Deformation (STRAIN)
ΔV/V= Volume Variation respect to Starting Volume
↑ DV/V-> Ventilation Induced Lung Injury

Strain=V_T/V_{PEEP}

Dynamic Strain
Static Strain



Lung Stress and Strain During Mechanical Ventilation: Any Difference Between Statics and Dynamics?* Crit Care Med 2013; 41:1046–1055

Dynamic alveolar mechanics and ventilator-induced lung injury

David Carney, MD; Joseph DiRocco, MD; Gary Nieman, BA

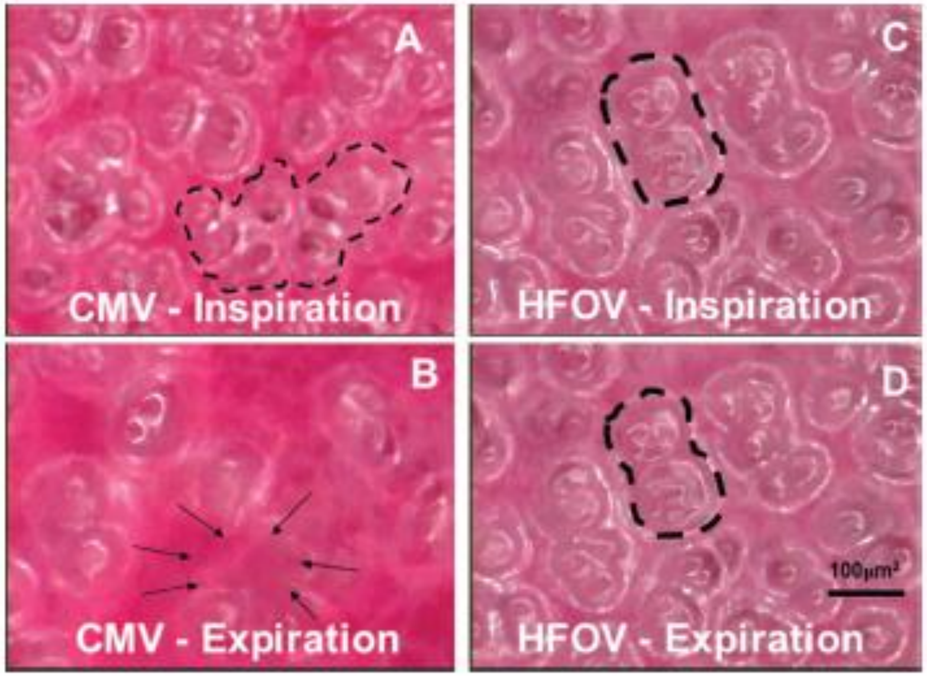
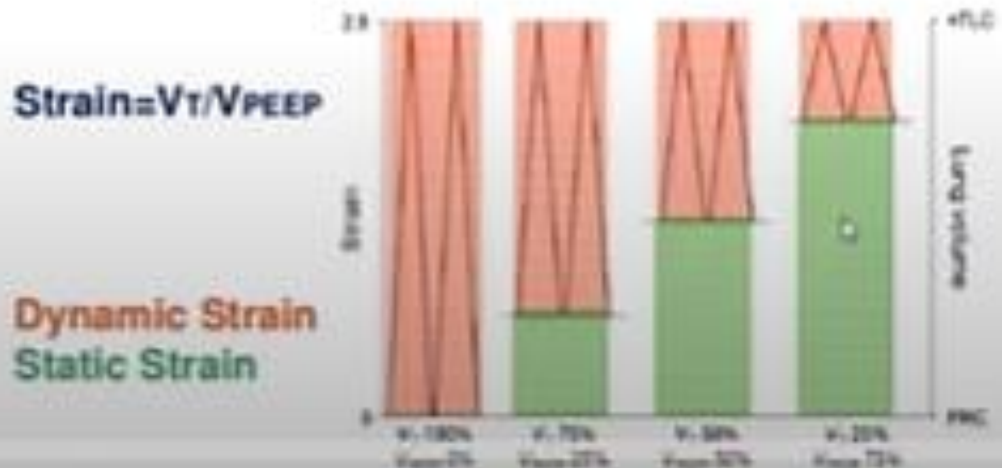


Figure 8. *In vivo* photomicrographs of subpleural alveoli in the rat after lung injury by saline lavage ventilated with either conventional mechanical ventilation (*CMV*) or high-frequency oscillatory ventilation (*HFOV*) using a 2.5-internal diameter tracheal tube. With CMV, a group of alveoli are seen inflated during inspiration (*dots*) but collapse with expiration (*arrows*). Alveoli are very stable with HFOV during ventilation. The same alveolus is seen with HFOV at inflation and exhalation (*dots*).

Crit Care Med 2005 Vol. 33, No. 3 (Suppl.)

HFOV = Protective ventilation
Why?

- **Lung Volume(V_L)** is mantained above the FRC by a constant distending pressure (MAP or CDP) (↑ Static Strain)
- **Tidal volume** (TV_{HF}) is very small, less than anatomical dead space (↓ Dynamic Strain)



How to remove CO_2 ?

Conventional Ventilation (< 3 Hz):

Minute Ventilation : $\mathbf{MV = V_T \cdot f}$

High-Frequency Ventilation (> 3 Hz):

Minute Ventilation in HFO: $\mathbf{MV_{HF} = ?}$

HFOV: Gas transport coefficient DCO_2

$$D_{CO2} = V_{THf}^{2} \cdot f$$

In HFOV the V_T has a major effect than the frequency on the gas exchange

Kamitsuka et al. Ped. Research (1990) Vol 27, No1, 64 -69
Chang. J Appl. Physiol (1984) 56(3): 553-563

מקדם הדיפוזיה של ה- CO_2: ערך מחושב שנותן אינדיקציה טובה לניטור שינוים באוורור הריאתי

HFOV: Gas transport coefficient DCO_2

$$D_{CO2} = V_{THf}^{2} \cdot f$$

In HFOV the V_T has a major effect than the frequency on the gas exchange

Kamitsuka et al. Ped. Research (1990) Vol 27, No1, 64 -69
Chang. J Appl. Physiol (1984) 56(3): 553-563

THE COEFFICIENT OF GAS TRANSPORT

- DCO_2 is the critical determinant of the effciency of gas mixing.
- The removal of carbon dioxide in HFOV is approximately $f * V_T^2$.
- DCO_2 is an absolute value and depends on the tidal volume.
- CO_2 removal is most efficiently achieved by increasing the tidal volume.

$*DCO_2: f * V_T^2/kg^2$

FUTURE (HFOV + VG)?

$$cD_{CO2} = V_{THf}^{1.78} \cdot f^{1.15}$$

Pressure damping during HFOV

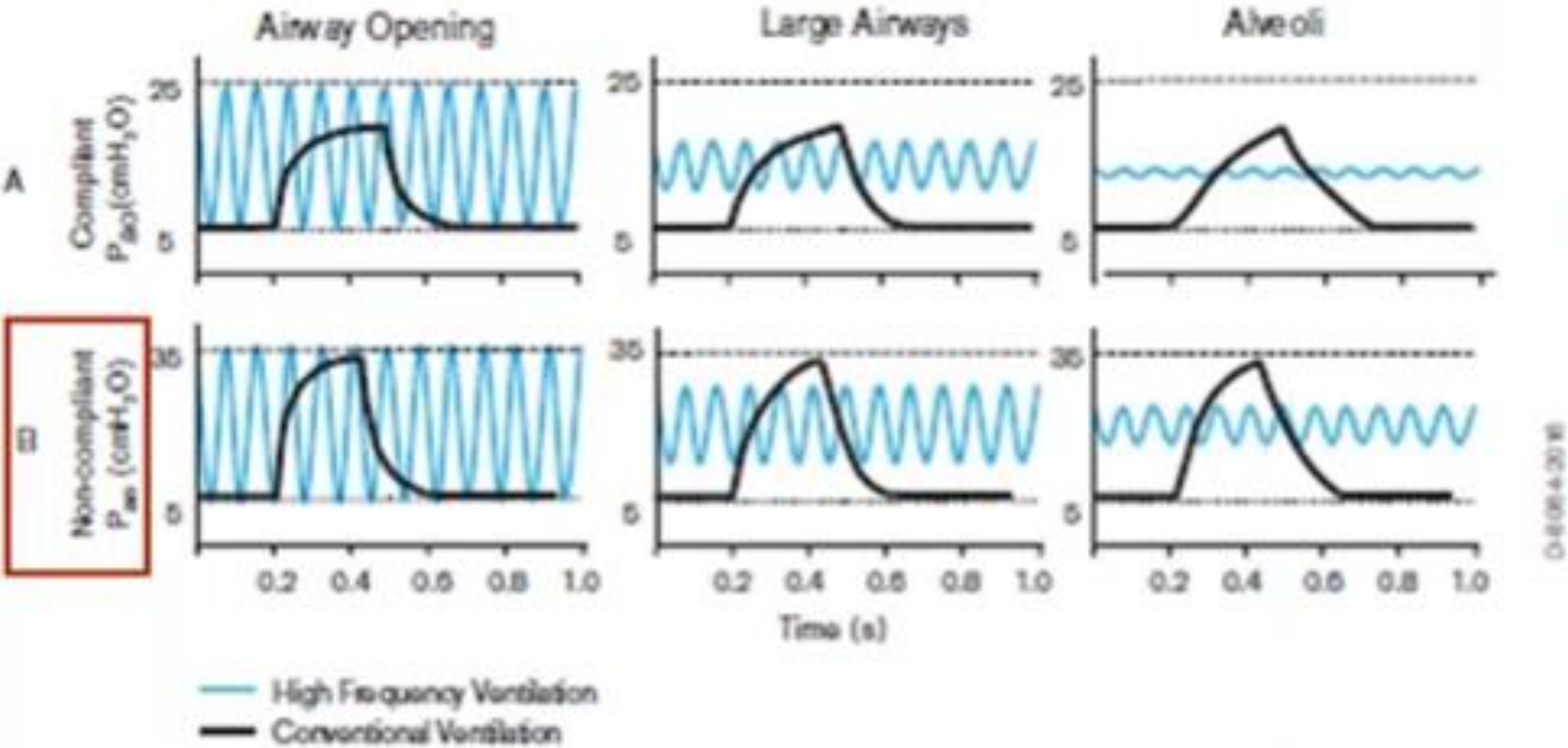


FIG. A

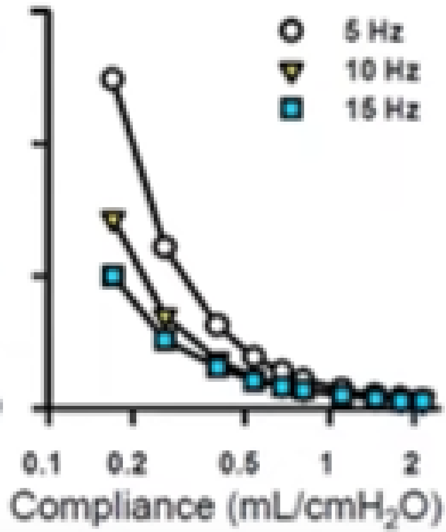
- **At physiological breathing ra** time for the pressure wavef transmitted from the airway o
- **During HFOV** the very short insufficient to fully transmit t waveform → progressive dar waveform from the airway o compartment .

FIG. B

- **In the presence of low compliance** the inspiratory and expiratory time constants are **peak inspiratory pressures (or ΔP)** needs to be delivered to the airway opening **to ach volume**.
- **For HFOV**, not only **are higher ΔP** required at the airway opening, but the extent of **p reduced →** higher percentage transmission of pressure from the airway opening to the

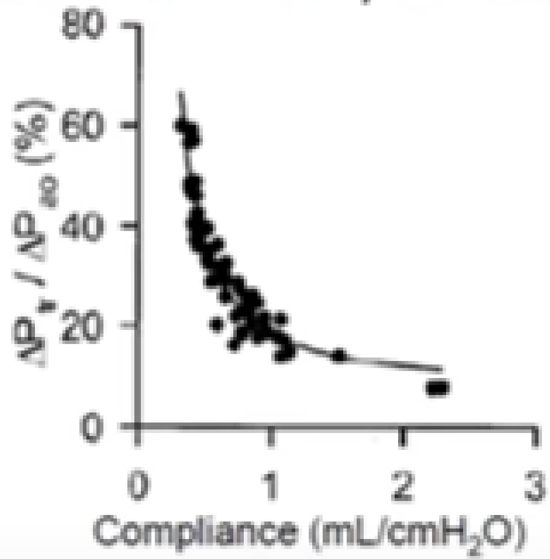
Damping: Compliance and Frequency

In Vitro



AJRCCM. 2001;164,1019-24

Lambs: Volume Optimisation



Pillow et al Pediatr Crit Care Med. 2004;5:172-80

In the compliant lung th
is marked damping of th
pressure waveform in H

Pressure amplitude transmission decreases with:

- Increasing complianc
- Increasing frequency
- decreasing inner TT diameter

RESTRICTIVE RESPIRATORY DISEASES OF THE NEWBORN
(homogeneous lung diseases)

A) RDS
B) Pulmonary Hypoplasia
C) Pneumonia

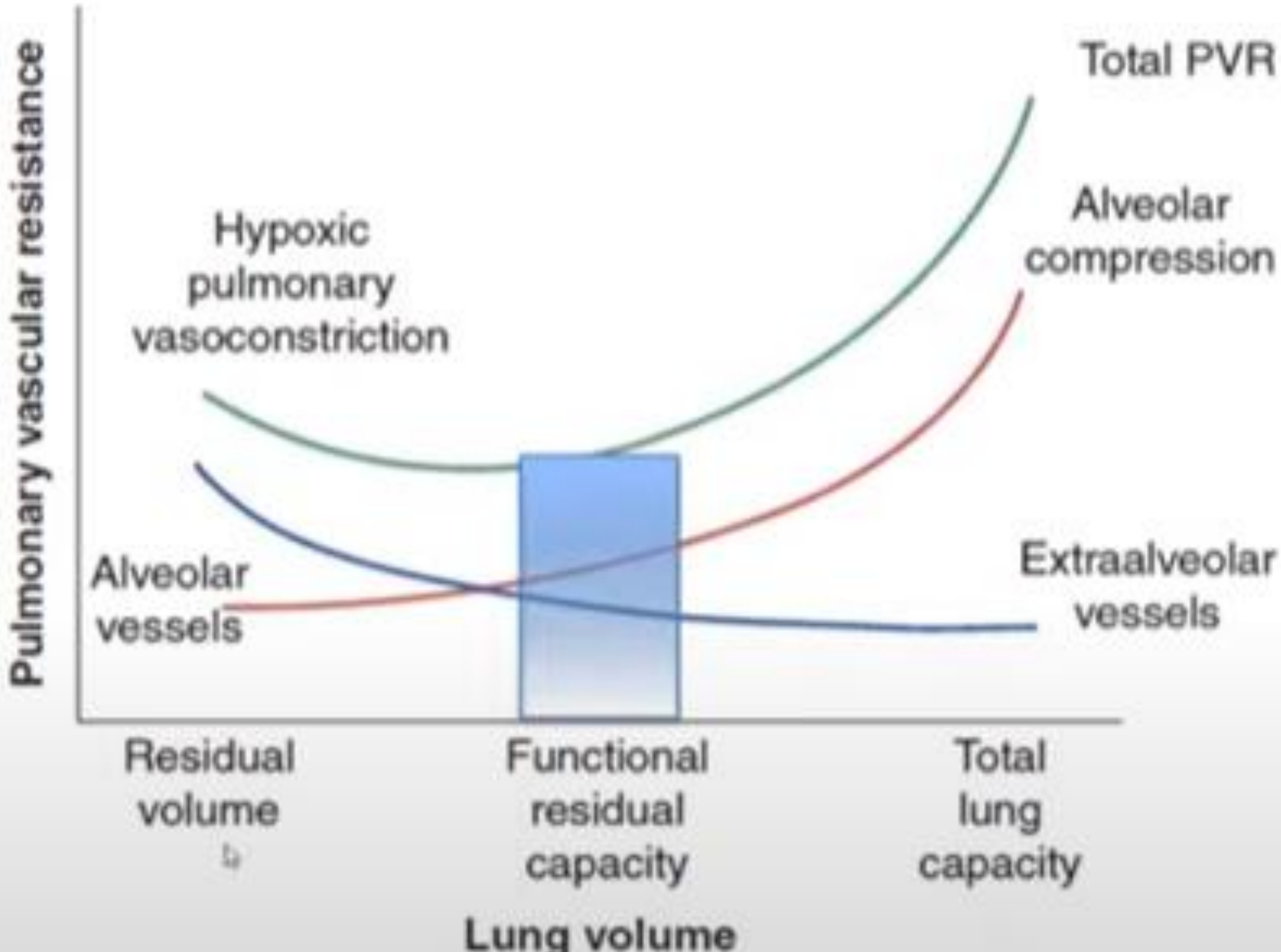
↓ Compliance

OBSTRUCTIVE RESPIRATORY DISEASES OF THE NEWBORN
(in*homogeneous lung diseases)*

A) BPD
B) MAS
C) AIR-LEAK
D) PULMONARY HEMORRHAGE (?)

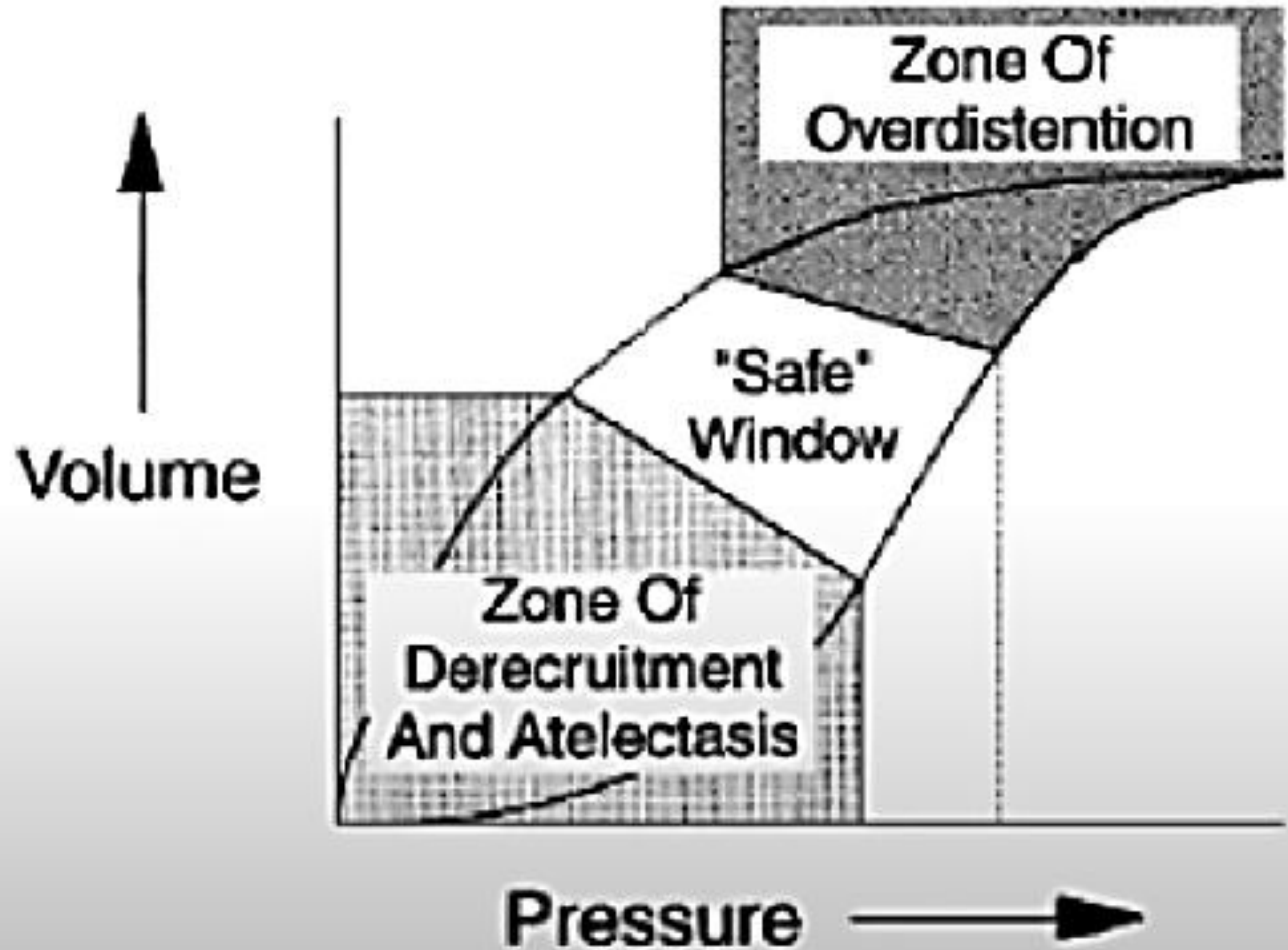
↑ Resistance

Relationship between changes in lung volume and PVR (Right Ventricular Afterload)



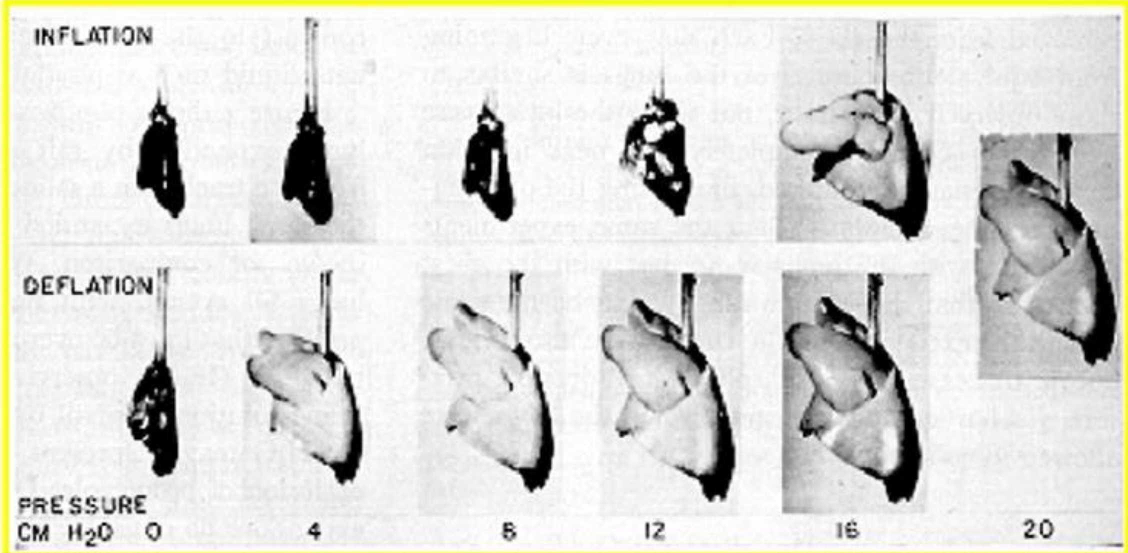
Gomez H, Pinsky MR

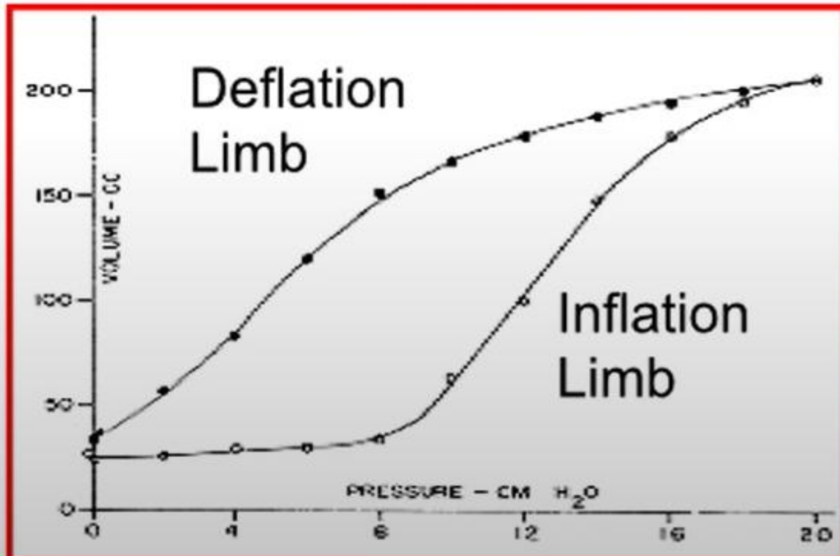
How do you know that you are in the Safe Window?



Pressure – Volume Relationship

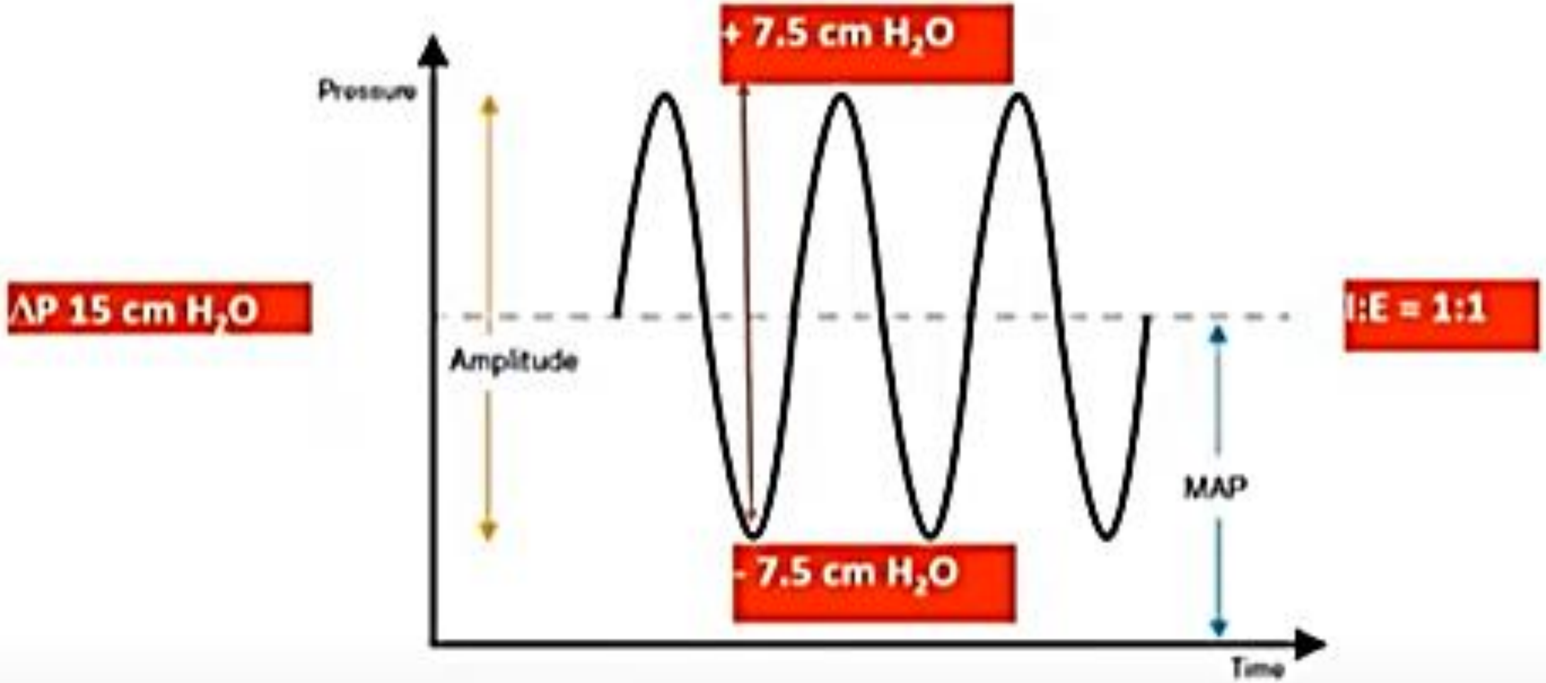
Hysteresis





J Clin Invest 1959. 38:2168

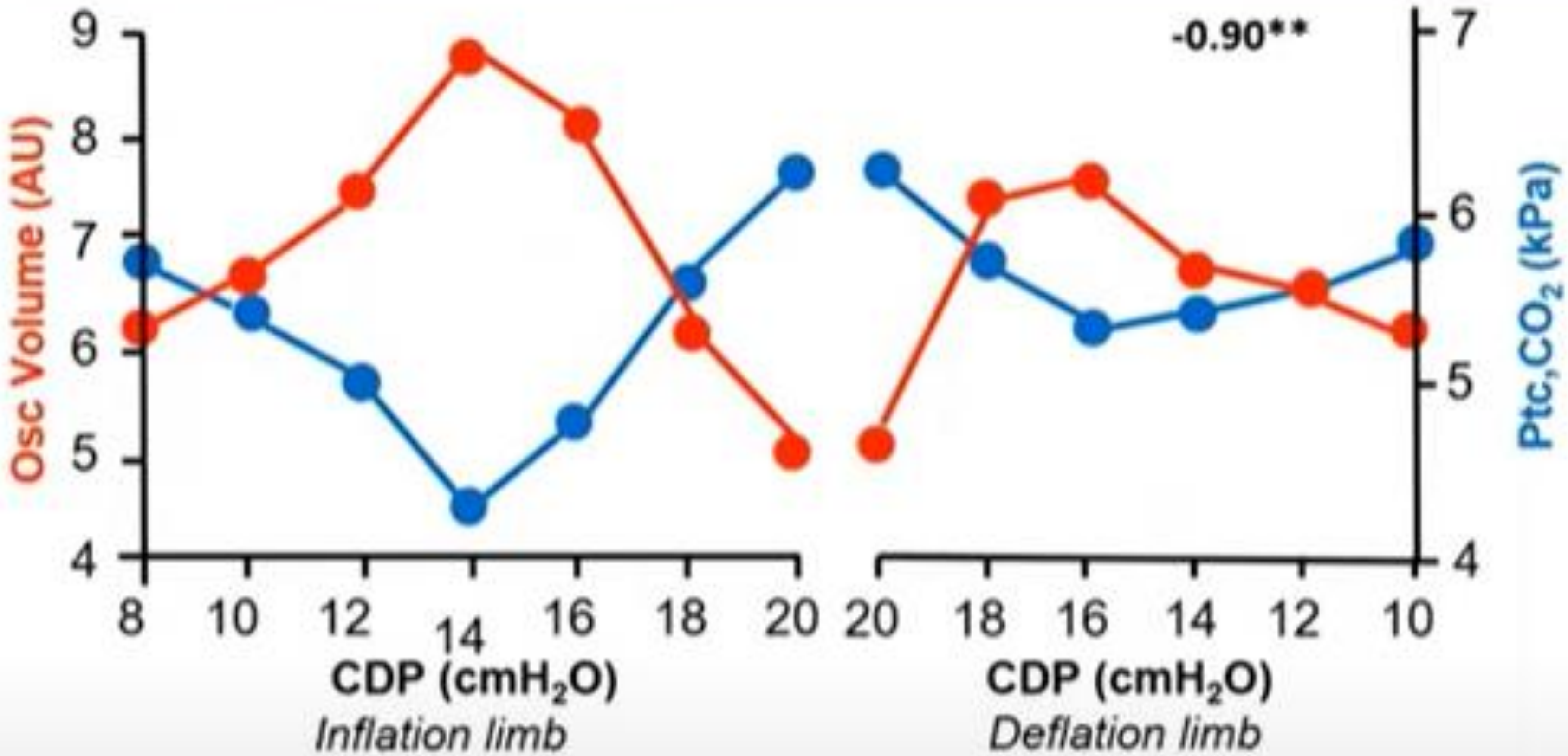
Delta Pressure ΔP



Pressure amplitude is the principal modifiable parameter that influence the oscillatory volume, that is the ultimate key determinant of the CO_2 removal.

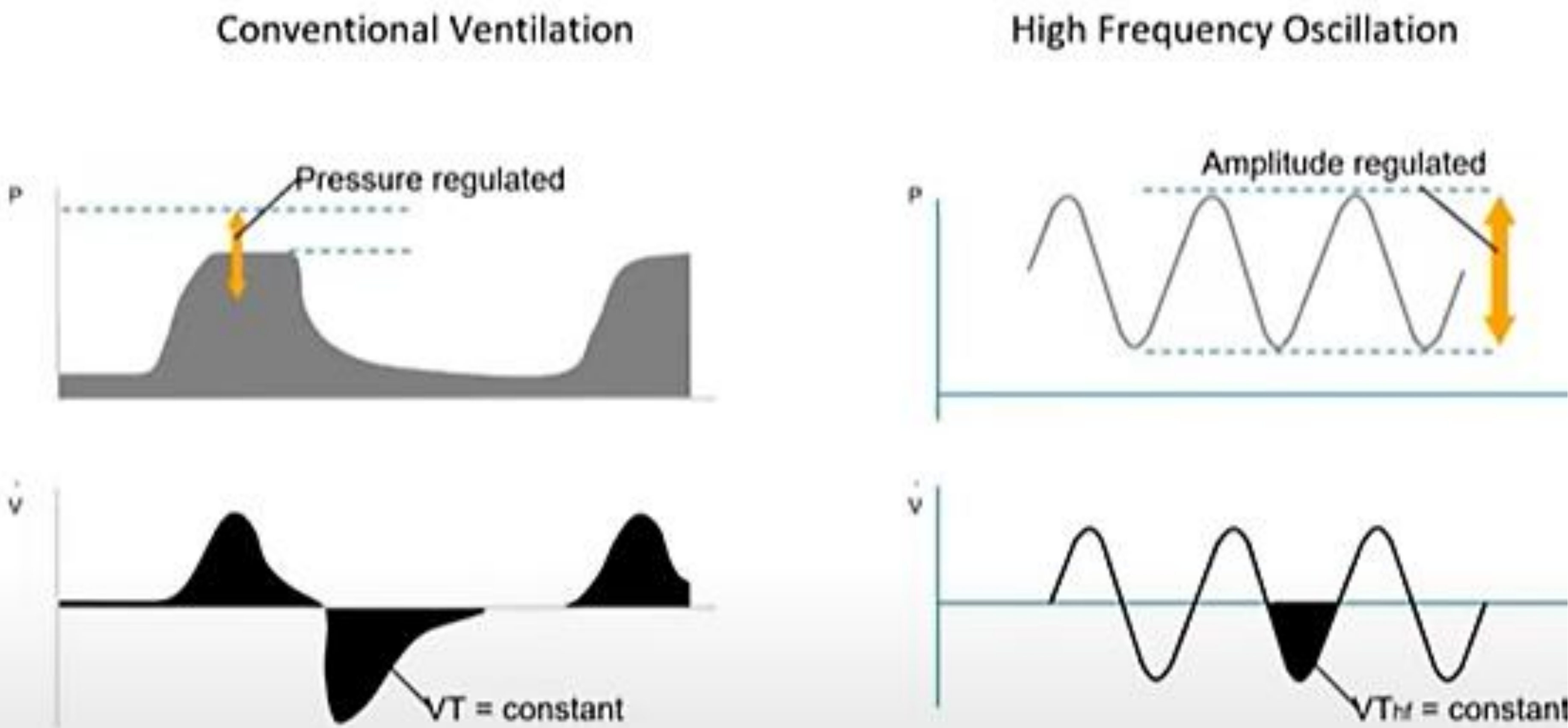
Changes in V_T and $PaCO_2$ with volume recruitment at constant ΔP

Miedema et al, Eur Resp J 2012



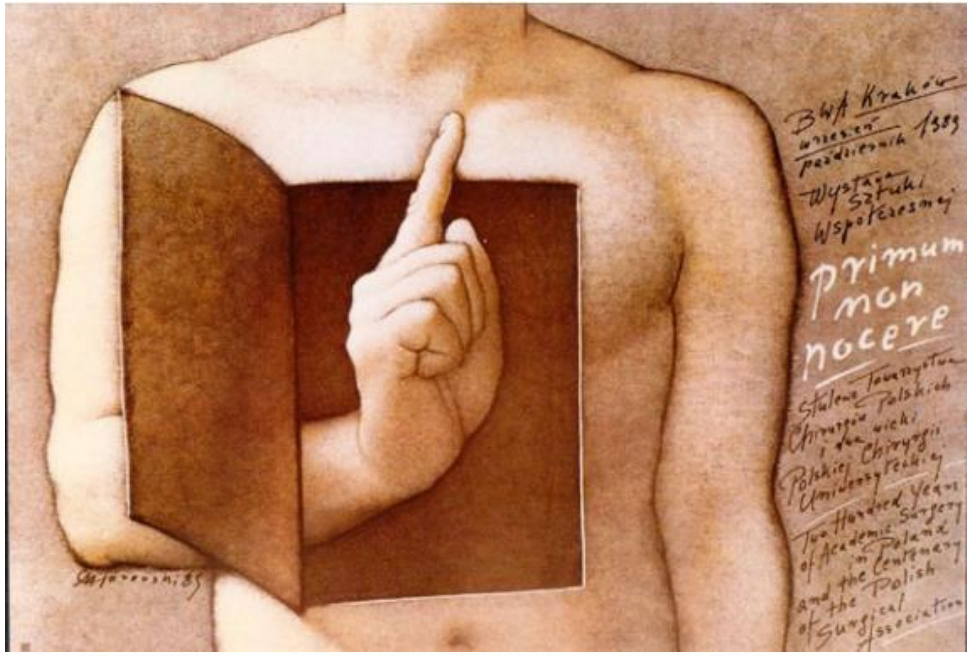
- Changes in V_T due to ↑ C_{rs} may result in marked change in $PaCO_2$ if no adjustment of ΔP

HFOV with Volume Guarantee

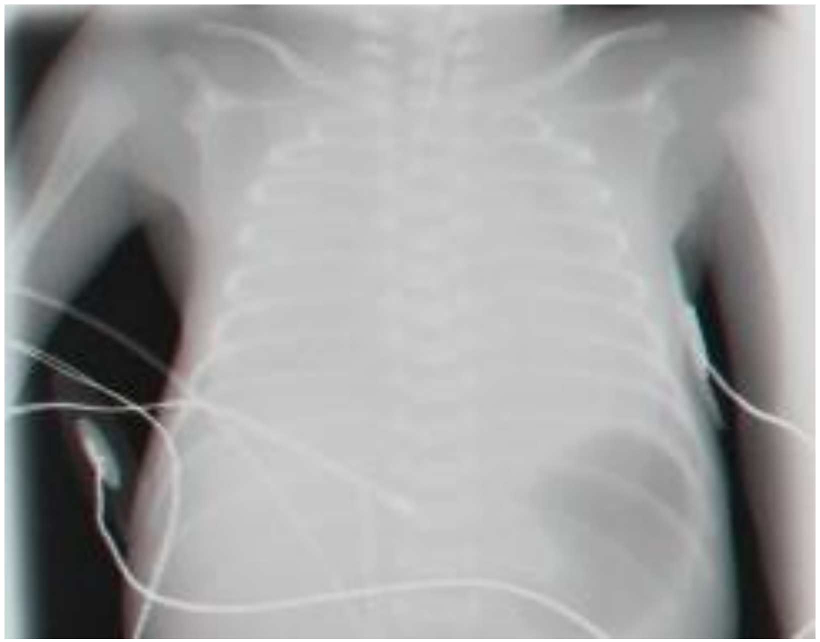


One of the key messages

Primum non nocere



RDS and surfactant administration



Before

After

The changes in lung compliance need an appropriate adaptive changes in the mechanical support settings. If no automatic mechanism as in VG, need to prevent overventilation while improving compliance.

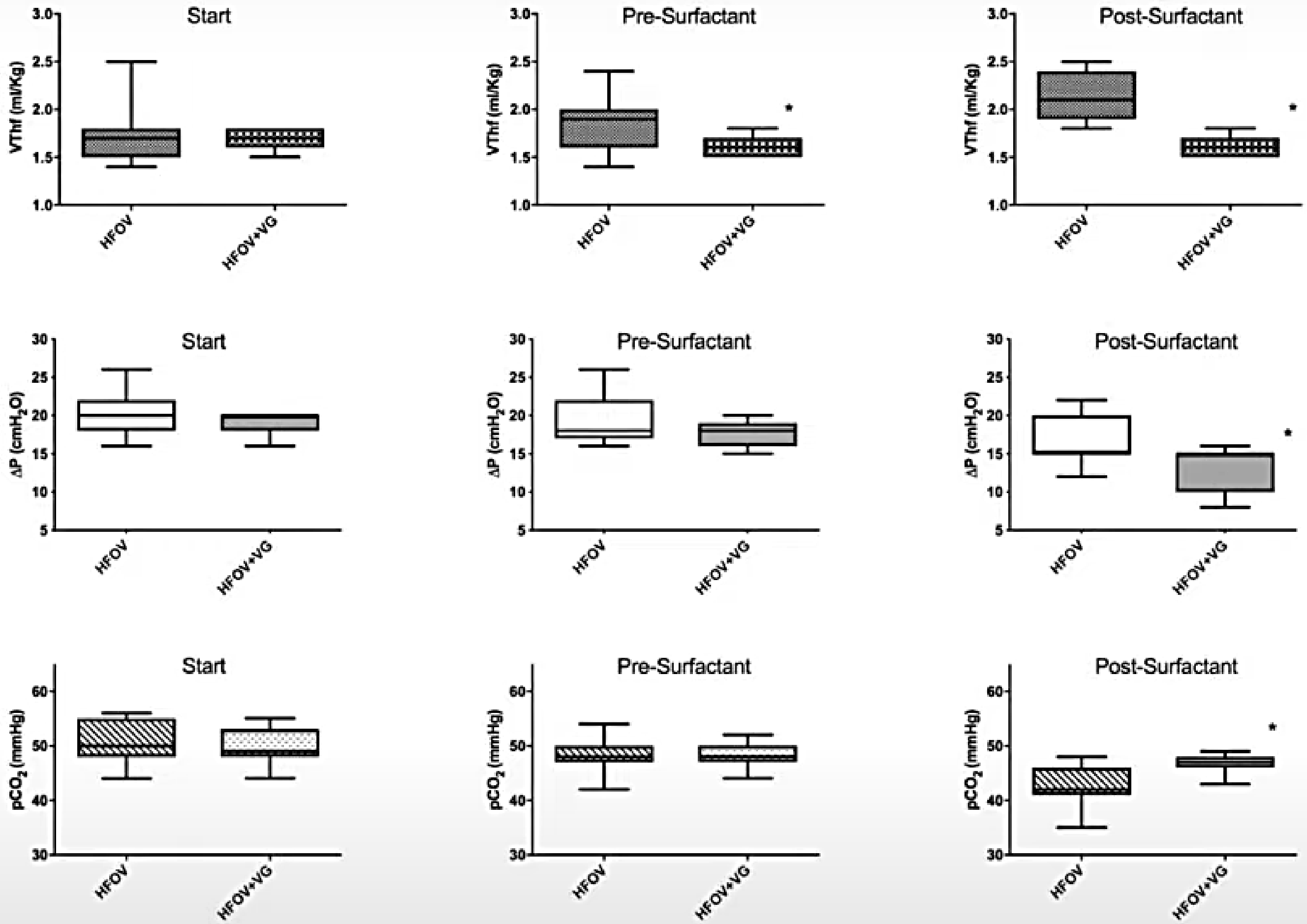
Effects of HFOV with VG during surfactant treatment in Extremely Low Gestational Age Newborns with RDS: an observational study

Ventilator settings, ventilation at baseline, pre-surfactant and post surfactant time.

	HFOV n 11	HFOV+VG n 11	p
Gestational Age, weeks	25.8 ± 1.0	25.2 ± 1.2	0.20
Birth Weight, g	754 ± 74	688 ± 141	0.20
Complete course of Antenatal Steroids*	5 (45)	8 (44)	1
5-min Apgar Score	7 [7-9]	7 [4-9]	0.50
SGA	2 (18)	2 (18)	1
Male	5 (45)	6 (54)	1
Premature Rupture of Membranes >12 h	4 (36)	5 (45)	1
Delivery by caesarean section	9 (82)	10 (91)	1
Surfactant, hours of life	2.6 ± 1.7	2.7 ± 1.8	0.86

Vento et al

Fig. 2. Evaluation of VThf, pCO_2 and amplitude levels in the HFOV and HFOV + VG groups



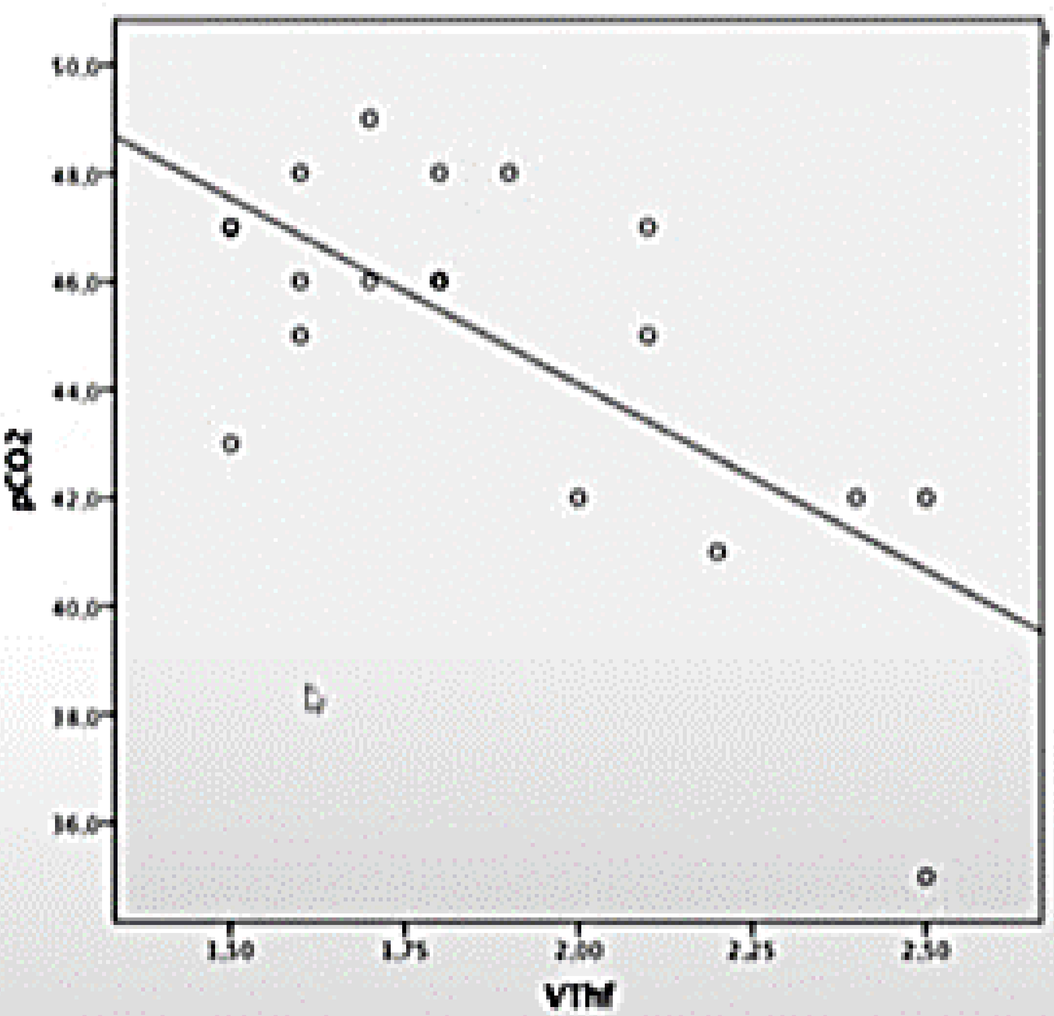
a **b** **c**

a There are no significant differences between the two groups.

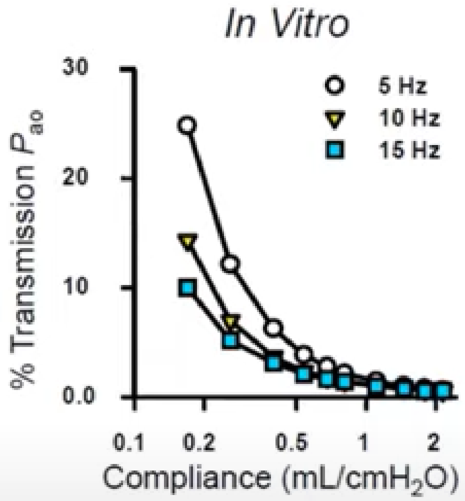
b Significant difference between the two groups in terms of VThf values ($p = 0.03$).

c Statistically significant difference between the two groups regarding all the parameters: VThf ml/kg (p:<0.0001), ΔP cmH_2O (p.0.005), pCO2 mmHg (p: 0.006)

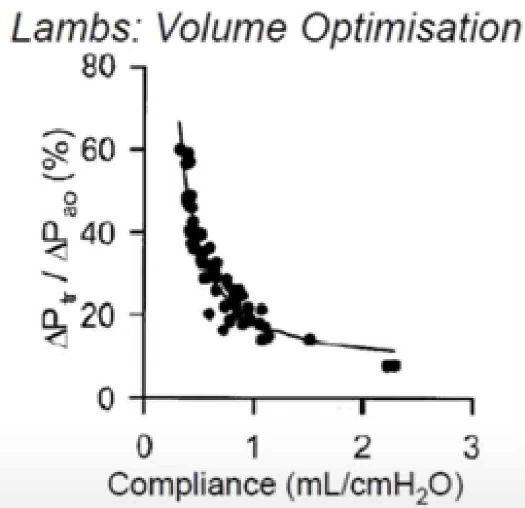
Significant correlation between VThf and PCO2 levels. (Pearson correlation coefficient: $r=0.69$, $p<0.0001$)



Damping: Compliance and Frequency



Pillow et al AJRCCM. 2001;164,1019-24



Pillow et al Pediatr Crit Care Med. 2004;5:172-80

In the compliant lung there is marked damping of the pressure waveform in HFOV

Pressure amplitude transmission decreases with:

- Increasing compliance
- Increasing frequency
- decreasing inner TT diameter

Frequency: number of oscillations per minute

PRACTICAL TIPS

HFOV FREQUENCY

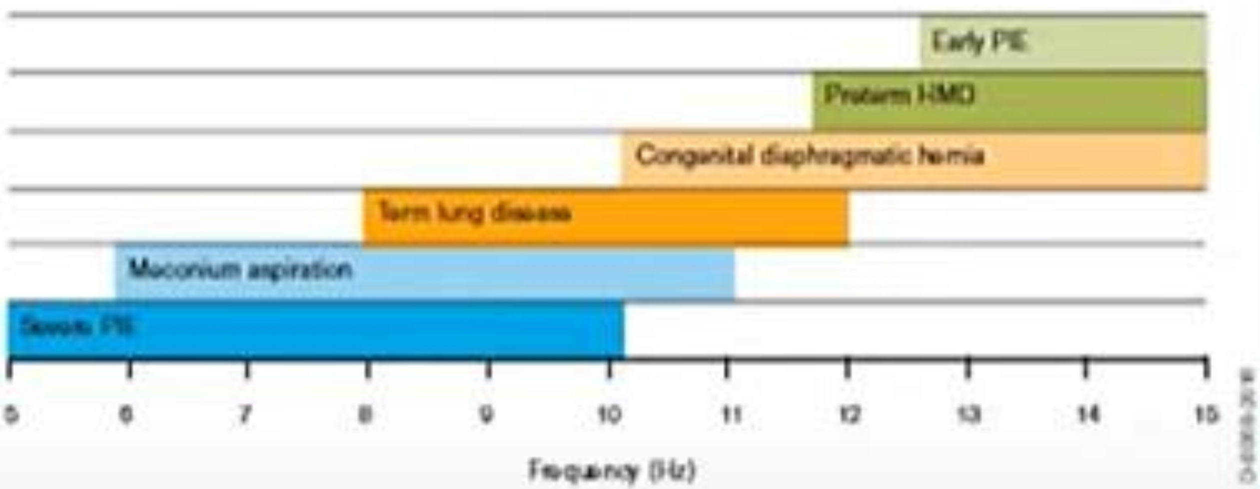


Figure 12-1: Suggested HFOV frequency ranges for common neonatal conditions.

The used frequency should be adjusted according to the underlying mechanical properties of the airways and the lung:

- Lower frequencies in high resistance and/or high compliant lungs.
- Higher frequencies in low compliant lungs with normal resistance.

I : E ratio

The ins

oscillat

pressur

and tro

directio

duration

from th

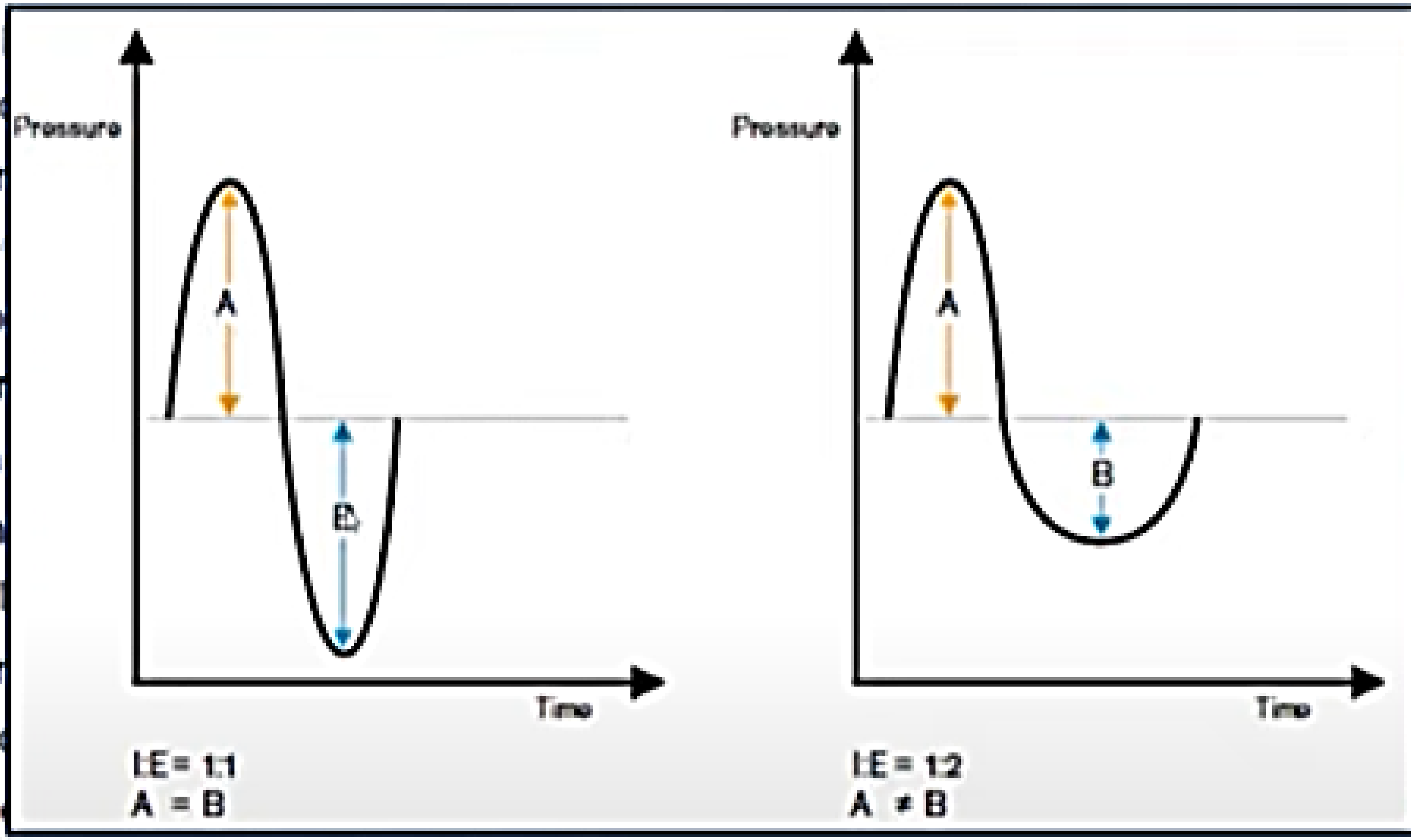
area un

removal

pressur

oscillat

negativ



he spent when

mean airway

low. The peak

(in opposing

xpiratory cycle

e peak/trough

nsure that the

and complete

the oscillatory

peak of the

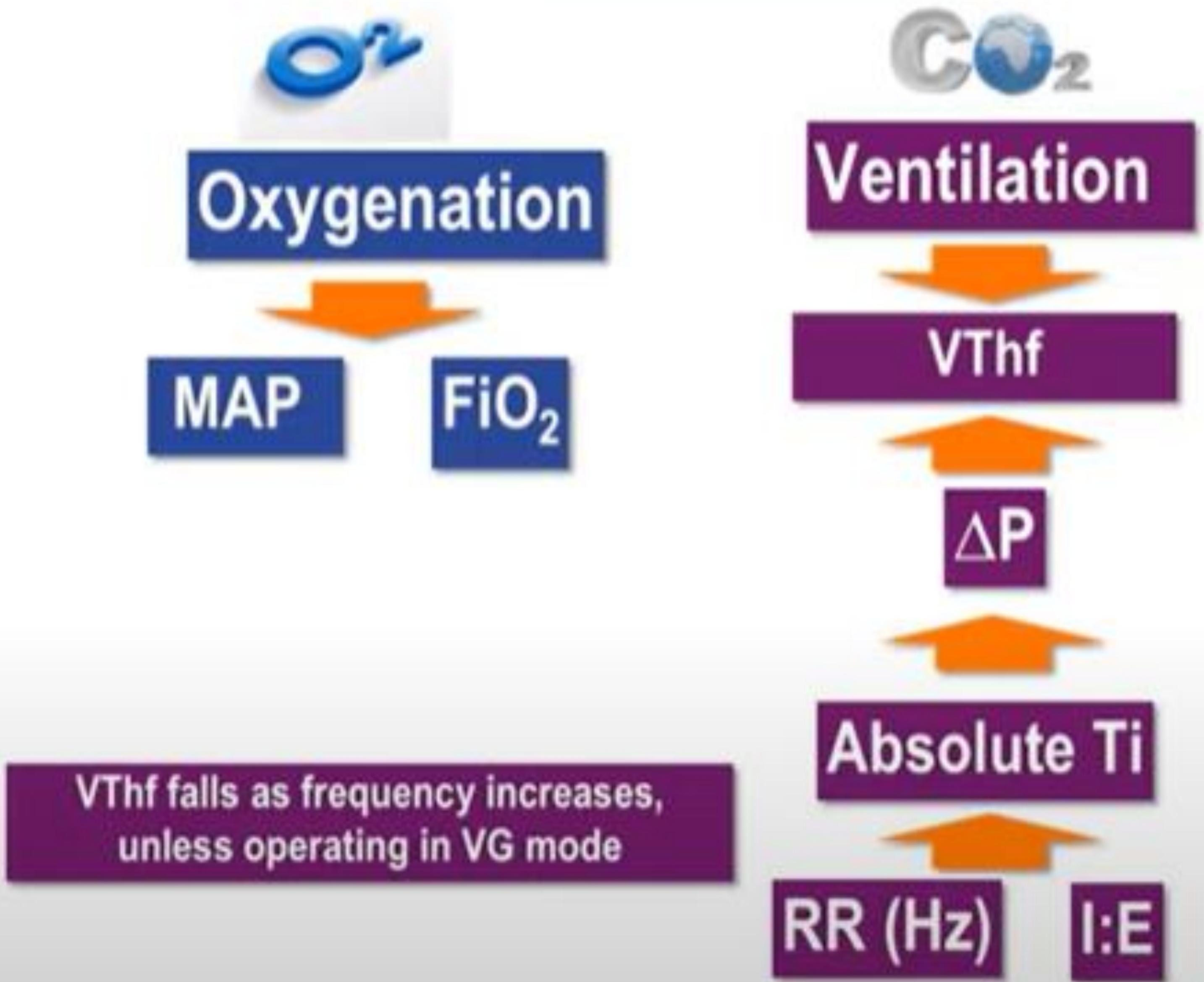
out the relative

2).

Mean intrapulmonary pressure (IPP) and I:E ratio

- The mean IPP is the effective pressure distending the lungs.
- It cannot be measured directly.
- The mean IPP is closest to the set MAP at an I:E ratio of 1:1.
- At I:E ratios if 1:2 or 1:3, the mean IPP will be lower than the set MAP.

HFOV Strategy



PAST

I:E=1:2

≠

PRESENT

I:E= 1:1

«Optimum» lung volume strategy during HFOV in babies with GA ≤ 27 wks and/or BW ≤ 1 kg

Starting Phase

Baby-Log VN-500

MAP: 8-10 cmH_2O

Respiratory rate: 15 Hz

VG: 1.5-1.7 ml/kg

I:E : 1:1

FiO_2: to achieve SpO_2 90-94%

Optimum = high volume strategy

«Optimum» lung volume strategy during HFOV in babies with GA ≤ 27 wks and/or BW ≤ 1 kg

- Verify ASAP the goodness of the V_T chosen by $TcCO_2$ monitoring and/or BGA
- Use a recruitment strategy (set a new VG if necessary on the basis of $TcCO_2$ monitoring)
- Use the lowest level of MAP guaranteeing optimal oxygenation with FiO_2 target (0.25)
- Continue to monitor $TcCO_2$
- Look at V_T set and delivered, ΔP delivered and DCO_2

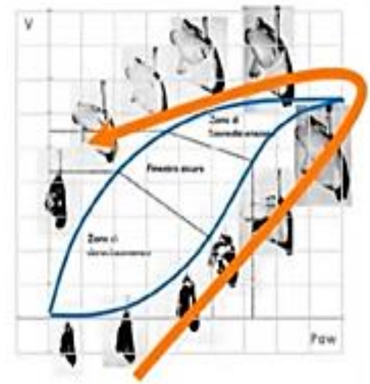
Weaning from HFOV

As with any ventilatory modality, the goal of weaning during HFOV is to gradually withdraw support and encourage spontaneous breathing. Although many clinicians still wean from high-frequency back to conventional ventilation (possibly due to relative availability of different ventilators), weaning from HFOV directly to a non-invasive mode of respiratory support is possible, and often the preferred mode.

Suggested pre-extubation parameters in HFOV:

MAP 6-7 cmH_2O
↓FiO2 ≤0,25
ΔP 15-20 cm H_2O *(ampiezza 10-30%)* con $PaCO_2$ 45-55 mmHg

HFOV Recruitment Maneuver



Phase 1: Start

MAP 8 cm H_2O
FiO_2 for SpO_2 87-94%

↓

Phase 2: Recruitment

MAP increase by 1-2 cm H_2O (every 2’-3’) until:
1) **$FiO_2 \leq 0.25$**
2) No further improvement of oxygenation

Opening Pressure (MAP_O)

↓

Phase 3: De-Recruitment

MAP decrease by 1-2 cm H_2O (every 2’-3’) until oxygenation deteriorates

Closing Pressure (MAP_C)

↓

Recruit the lung once more with the known MAP_O for 2 minutes and set the MAP 2 cm H_2O above MAP_C for at least 3 minutes

Optimal Pressure (MAP_{OPT})

↓

De Jagere A. et al . Am J Respir Crit Care Med. 2006

Lung recruitment before surfactant administration in extremely preterm neonates with respiratory distress syndrome (IN-REC-SUR-E): a randomised, unblinded, controlled trial

Duration of the HFOV recruitment maneuver: 30 [IQR 20-45] min

	INSURE Group	INRECSURE Group	
Hours of life at surfactant administration	3 [2-5]	4 [3-9]	$p=0.0012$
MAP_O ($cm\ H_2O$)	T-piece device PIP:20-22 cmH_2O PEEP:5-6 cmH_2O RR:30-40 apm MAP: 8.8-10.2 cmH_2O	14.6 ± 3.2	
MAP_C ($cm\ H_2O$)		10.8 ± 3.0	
MAP_{OPT} ($cm\ H_2O$)		12.6 ± 3.0	
FiO_2 at MAP_{OPT}		0.28 ± 0.09	
FiO_2 pre-surfactant	0.42± 0.09	0.28 ± 0.09	$p<0.0001$

High Frequency Ventilation
Principles of gas exchange

- Facilitated or enhanced diffusion because of increased turbulence.
- Convective dispersion due to asymmetric velocity profiles.
- Direct alveolar ventilation.
- Axial distribution of transit times.

High-frequency oscillatory ventilation: Mechanisms of gas exchange and lung mechanics

J. Jane Pillow, MBBS, FRACP, PhD

Crit Care Med 2005 Vol. 33, No. 3 (Suppl.)

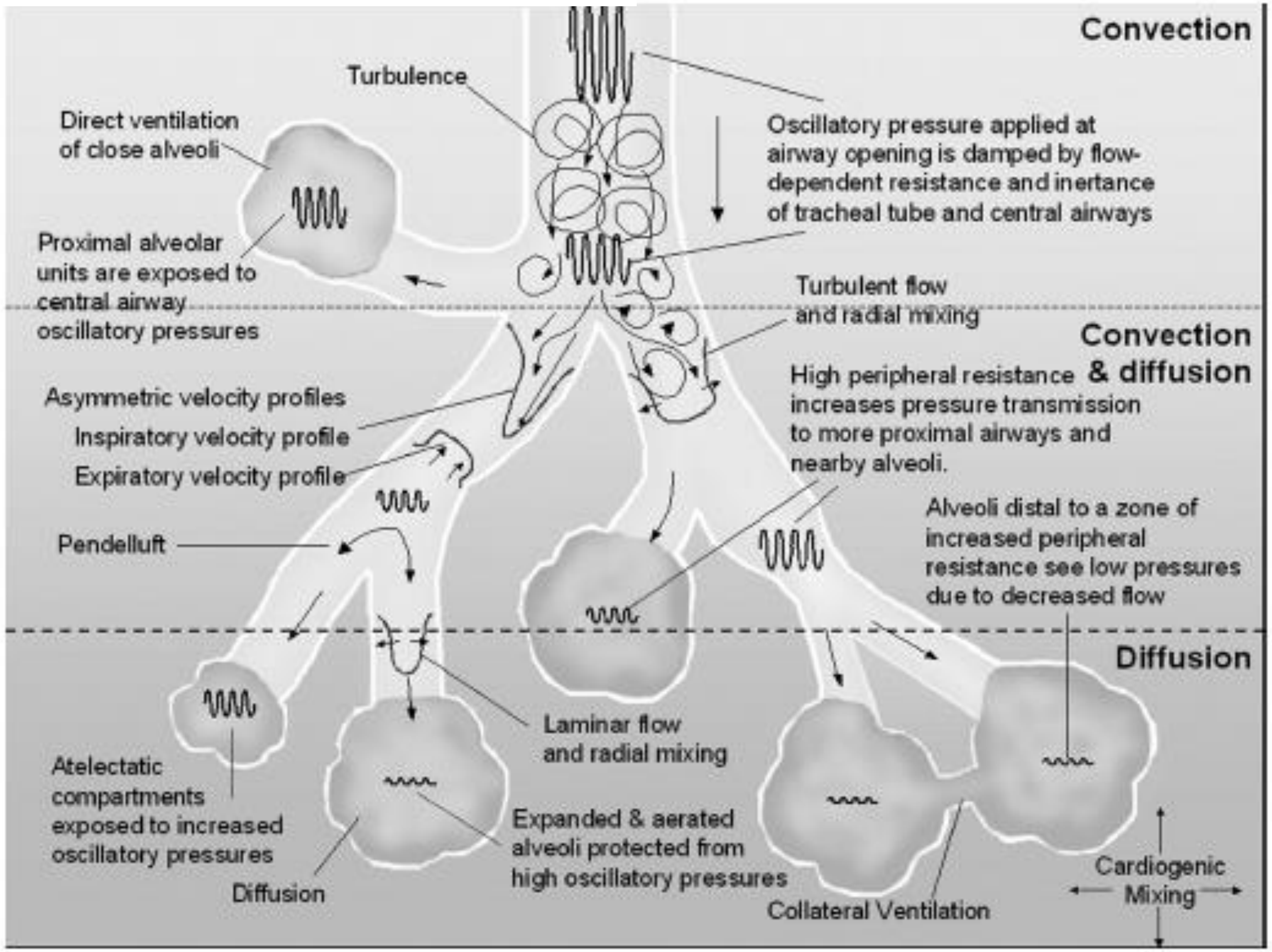


Figure 1. Gas transport mechanisms and pressure damping during high-frequency oscillatory ventilation (HFOV). The major gas-transport mechanisms operating during HFOV in convection, convection–diffusion, and diffusion zones include: turbulence, bulk convection (direct ventilation of close alveoli), asymmetric inspiratory and expiratory velocity profiles, pendelluft, cardiogenic mixing, laminar flow with Taylor dispersion, collateral ventilation between neighboring alveoli, and molecular diffusion (see text for details). The extent to which the oscillatory pressure waveform is damped is influenced by the mechanical characteristics of the respiratory system. Atelectatic alveoli will experience higher oscillatory pressures than normally aerated alveoli, whereas increased peripheral resistance increases the oscillatory pressures transmitted to proximal airways and neighboring alveolar units (adapted with permission (2), © 2005 Massachusetts Medical Society).

Entry #: 83928

Flow visualization inside a Ranque-Hilsch tube

Porta Zepeda David, Echeverría Arjonilla Carlos, Stern Forgach Elizabeth Catalina

Taller de Hidrodinámica y Turbulencia
Facultad de Ciencias. UNAM

HFV - Operational principles and individual technical capabilities (I)

- **Maximum Mean Airway Pressure -** Oxygenation capabilities
- **Maximum Delta-P (Amplitude) -** Ventilation capabilities
- **Percent I- time range -** increase or decrease delivered volume - minimize gas trapping in high frequencies
- **Frequency range -** low freq important in large patients or in obstructive lung diseases

HFV - Operational principles and individual technical capabilities (II)

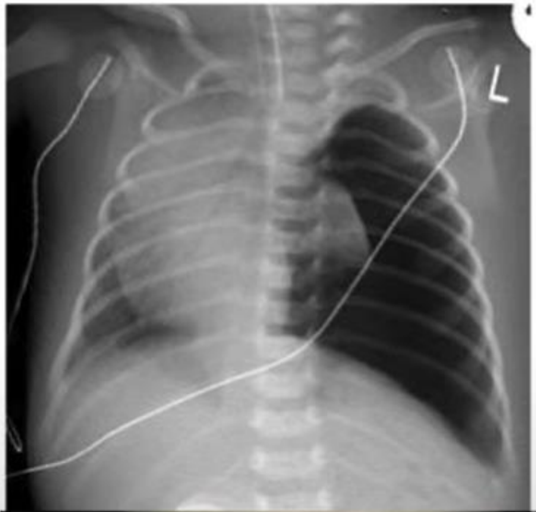
- True oscillation :Active exhalation - without it limits use of high power and high frequencies
- Inclusion of conventional breaths - SI capabilities - Increase in barotrauma/volutrauma - affects ability to evaluate lung volume in x-ray
- Patient circuit - important simplicity
- Indications and Approvals (FDA, other org.)
- Patient weight range
- Published Randomized Trials
- Formal training programs

High Frequency Ventilation Complications

- Mucus impaction
- Lung overinflation / suspected clapping effect
- Decreased cardiac output
- Increase incidence of IVH (in initial HiFi study)
- Necrotizing tracheobronchitis (HFJV)

When not to use a HLVS

- Lung recruitment manoeuvres are only indicated in diseases that will need recruitment (atelectasis)
- Recruitment manouevres in other lung states/diseases may be harmful
  - Pulmonary hypoplasia
  - CDH
  - Primary PHT
- Understand the disease and physiology
- Individualise your strategy
- *When in doubt decrease* P_{aw}*!*



Protocols for HFOV management, initial settings, maintenance and weaning

- Recommendations are different for each ventilator type
- Nursing issues: patient positioning, noise control, suctioning (NICU and PICU protocols), sedation (NICU and PICU protocols).
- Initial settings different for each pathology
- Guidelines for gas and x-rays checks
- Weaning strategies (to CMV, CPAP, or Vapotherm)
- Circuit changes

Clinical monitoring

- Chest wall bouncing: a change in chest wall "bouncing", that is controlled by the amplitude, without a change in the oscillatory settings is "incorrect" and should be immediately investigated.
  - ETT dislodgment.
  - Mucus plug.
- Blood gas - O_2 saturation - TCM.
- Consider transillumination and/or chest x-ray in any suspicion.

No value to $EtCO_2$ and to auscultation (????).

PEDIATRICS

Letter to the editor

High-Frequency Oscillatory Ventilation: "Please do not forget me," said the stethoscope.

Dan Waisman, Zalman Weintraub, Avi Rotschild, Olga Davkin, Irena Kessel and Yoram Bental

Pediatrics 2001;108;819-
DOI: 10.1542/peds.108.3.819

Nursing an infant on HFO

- Maintenance of lung volume is critical.
- Discouraged disconnections.
- Suction when necessary.
- Suction with closed circuit. < 30 seconds and increase MAP by 20% for 1-2 minutes.
- No physiotherapy.
- Plan the change in position (Sensormedics).
- Humidification is vital.
- Sedation Vs. paralysis: consider hypoxia first.

Summary

- Need a good understanding of respiratory physiology
- In the atelectatic lung, lung recruitment can be individualized using an open lung strategy (high or optimal lung volumes)
- Look at patient’s clues and adapt
- Need to know the devices in use
- Too little and too much – is not good (volumes, O_2, pressures…)


נו כבר! זה
משעמם עם כל
הדיבורים!
זה הסוף להיום...

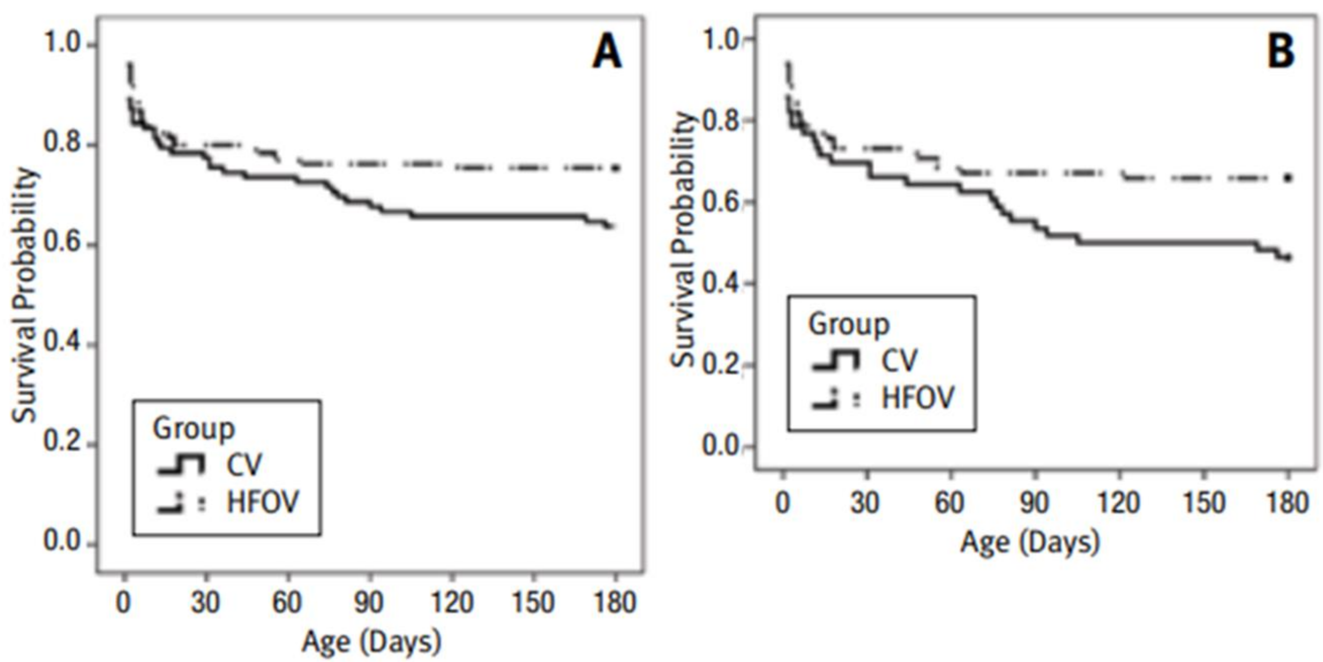
Benefits of High Frequency Oscillatory Ventilation for Premature Infants

Irena Kessel MD[1], Dan Waisman MD[1], Ofra Barnet-Grinnes PhD[2], Tali Zim Ben Ari RN MA[1] and Avi Rotschild MD[1]

Departments of [1]Neonatology and [2]Community Medicine and Epidemiology, Carmel Medical Center and Rappaport Faculty of Medicine, Technion-Israel Institute of Technology, Haifa, Israel

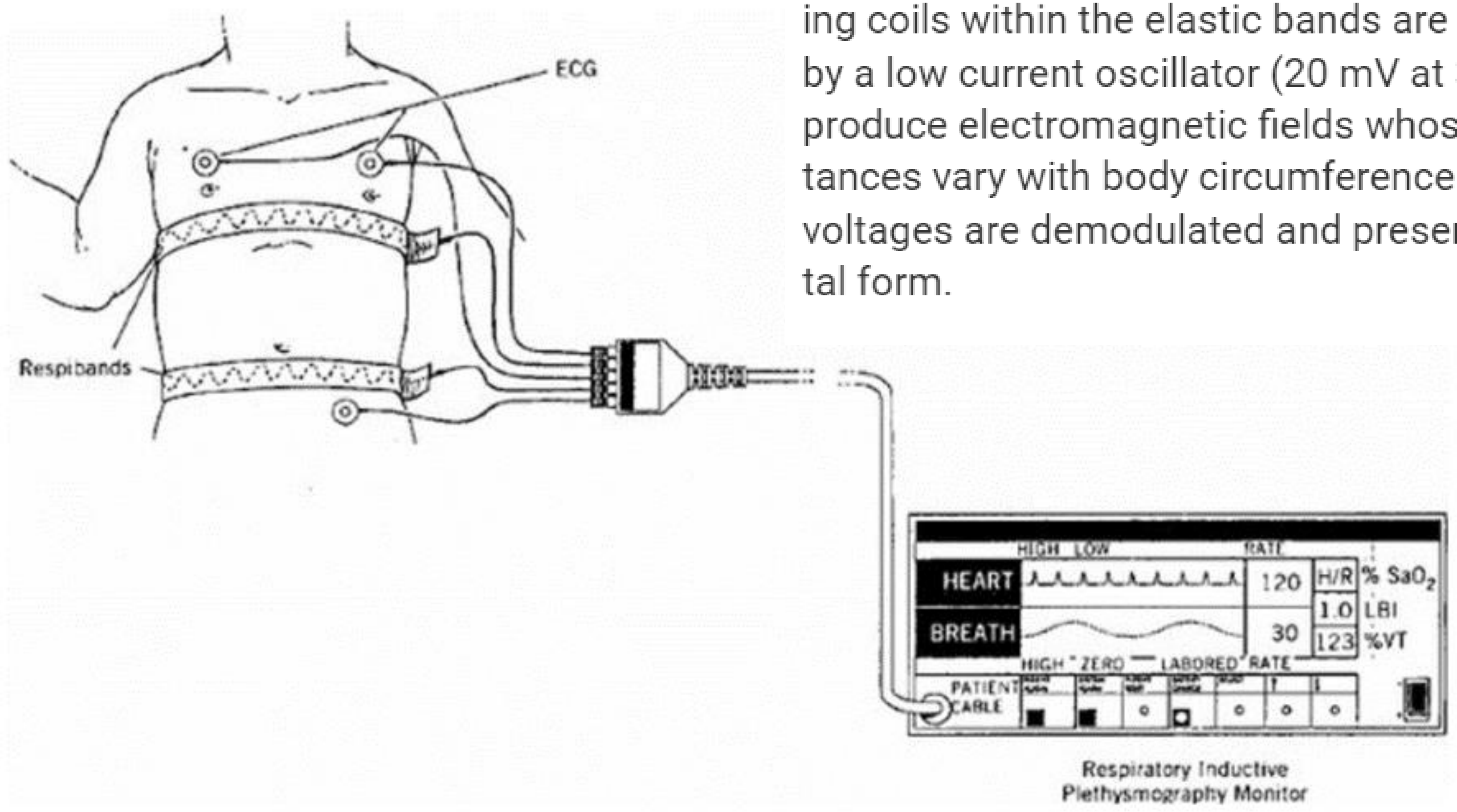
Figure 1. [A] Kaplan-Meier overall survival curves. In both sub-samples of body weight, ‹ 1000 g and ≥ 1000 g, no differences are demonstrated between the ventilation groups in the incidence of both early neonatal deaths and neonatal deaths. The differences appeared after the 30th day of an infant's life, with higher although not statistically significant survival rates in the HFOV group.

[B] Kaplan-Meier survival curves for infants with BW ‹ 1000 g. After the 30th day of an infant's life, higher and statistically significant survival rates are demonstrated in the HFOV group.



Relative Inductive Plethysmography

Respiratory Inductive Plethysmograpy (Respitrace®)



Respiratory Inductive Plethysmography Monitor

Figure 1. The Respitrace system. The two winding coils within the elastic bands are activated by a low current oscillator (20 mV at 300 kHz) to produce electromagnetic fields whose inductances vary with body circumference. Output voltages are demodulated and presented in digital form.

Monitoring the breathing frequency and respiratory regional lung function based on chest and abdominal wall dynamics

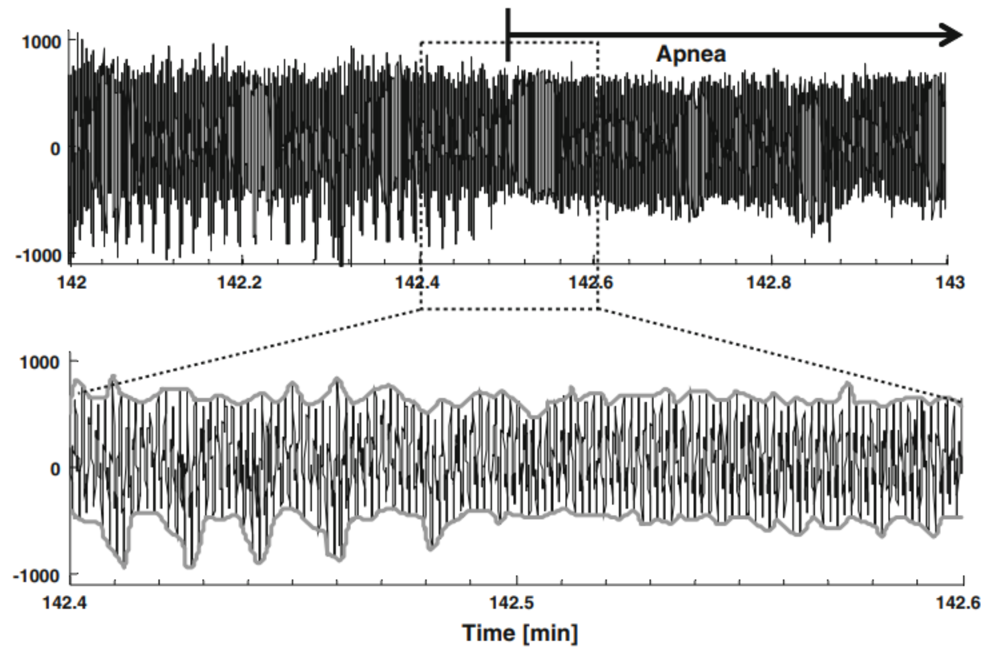
Intensive Care Med
DOI 10.1007/s00134-011-2228-y

PEDIATRIC ORIGINAL

A new method for continuous monitoring of chest wall movement to characterize hypoxemic episodes during HFOV

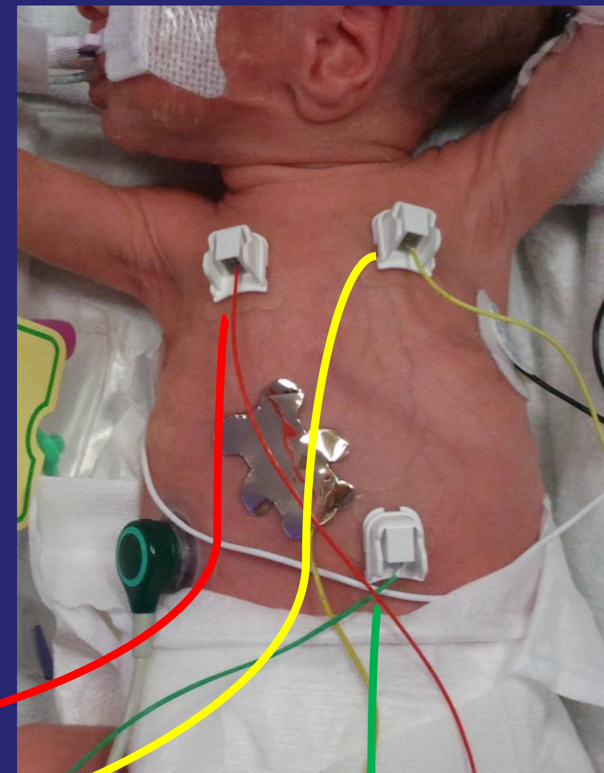
Dan Waisman
Carmit Levy
Anna Faingersh
Fatmi Ifat Colman Klotzman
Eugene Konyukhov
Irena Kessel
Avi Rotschild
Amir Landesberg

Fig. 5 Detection of an apneic episode during HFOV, by monitoring chest movement. The spontaneous breathing pattern (74 breaths/min) that modulated the 10-Hz ventilator signals disappeared (142.5 min), and only the oscillations of HFOV remained

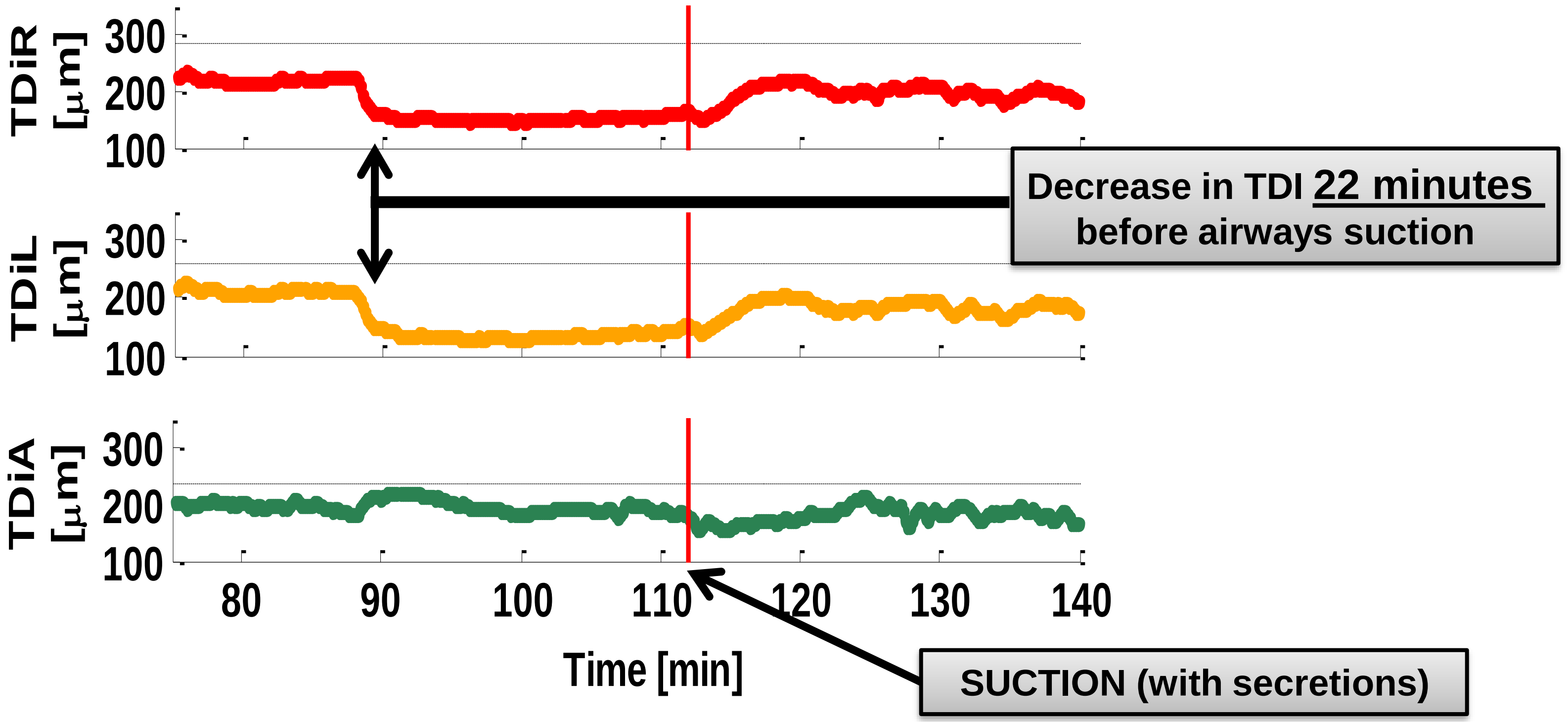


Monitoring the chest wall dynamics with motion sensors: regionalization of lung function monitoring.

A new index was applied: tidal displacement index, showing the trend of the amplitude of the chest wall displacement during normal breathing, conventional ventilation, and HFV.

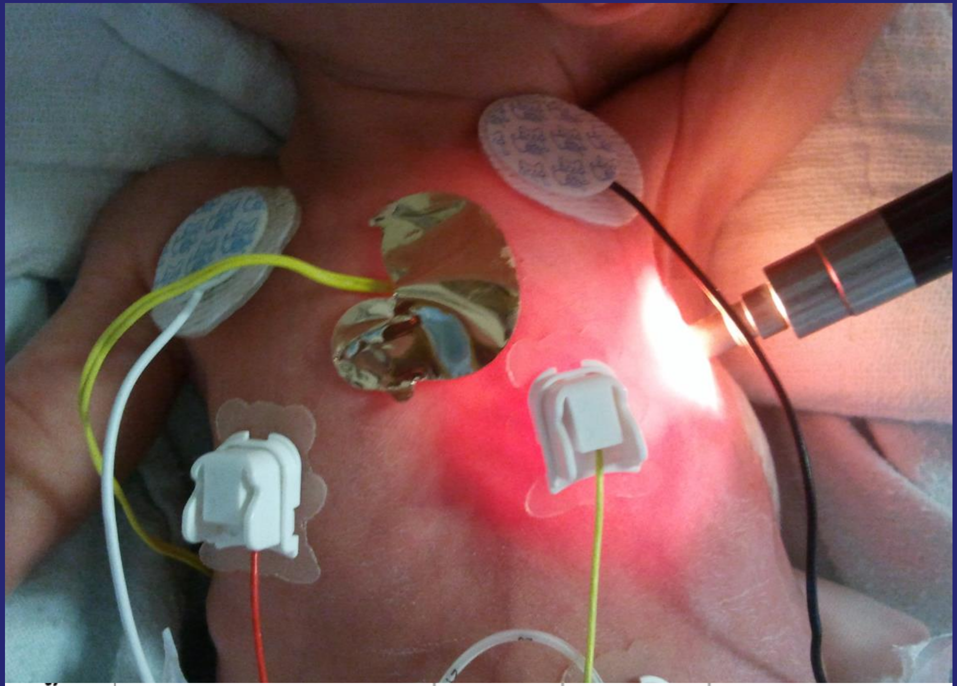


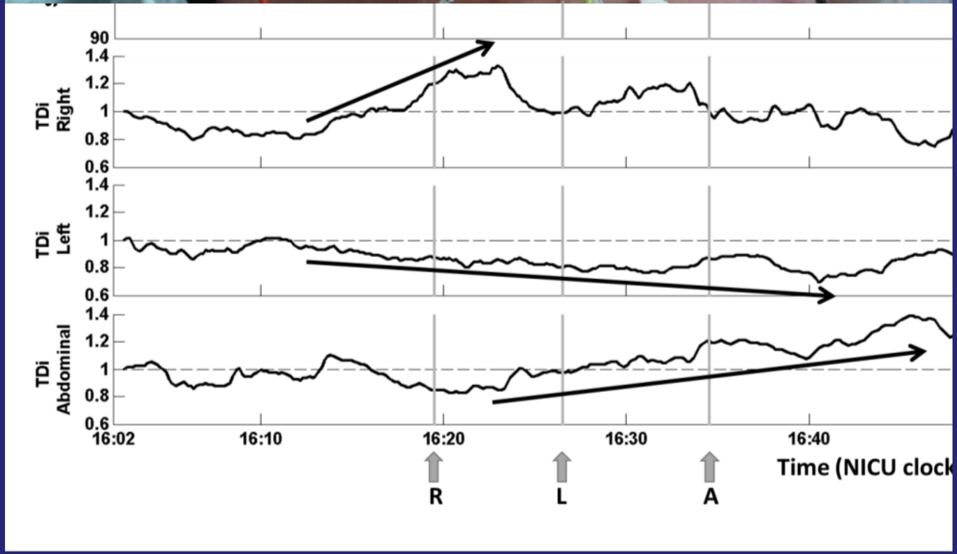
Earlier detection of ventilatory deterioration and characterization of the episode. Regionalization.



Case 010-1: Supported by High Frequency Oscillatory Ventilation.

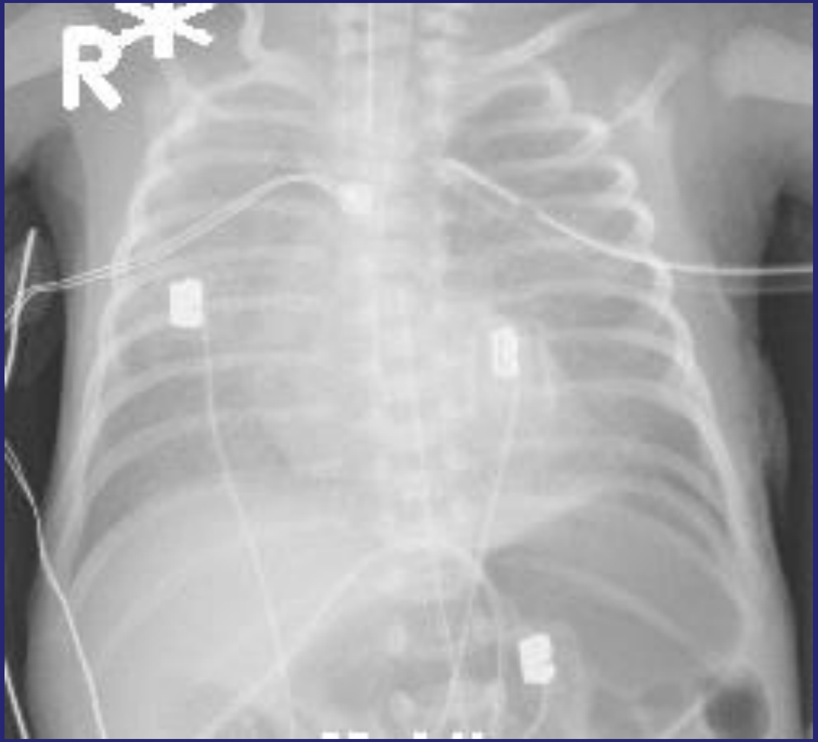
Bilateral, simmetrical decrease in TDi





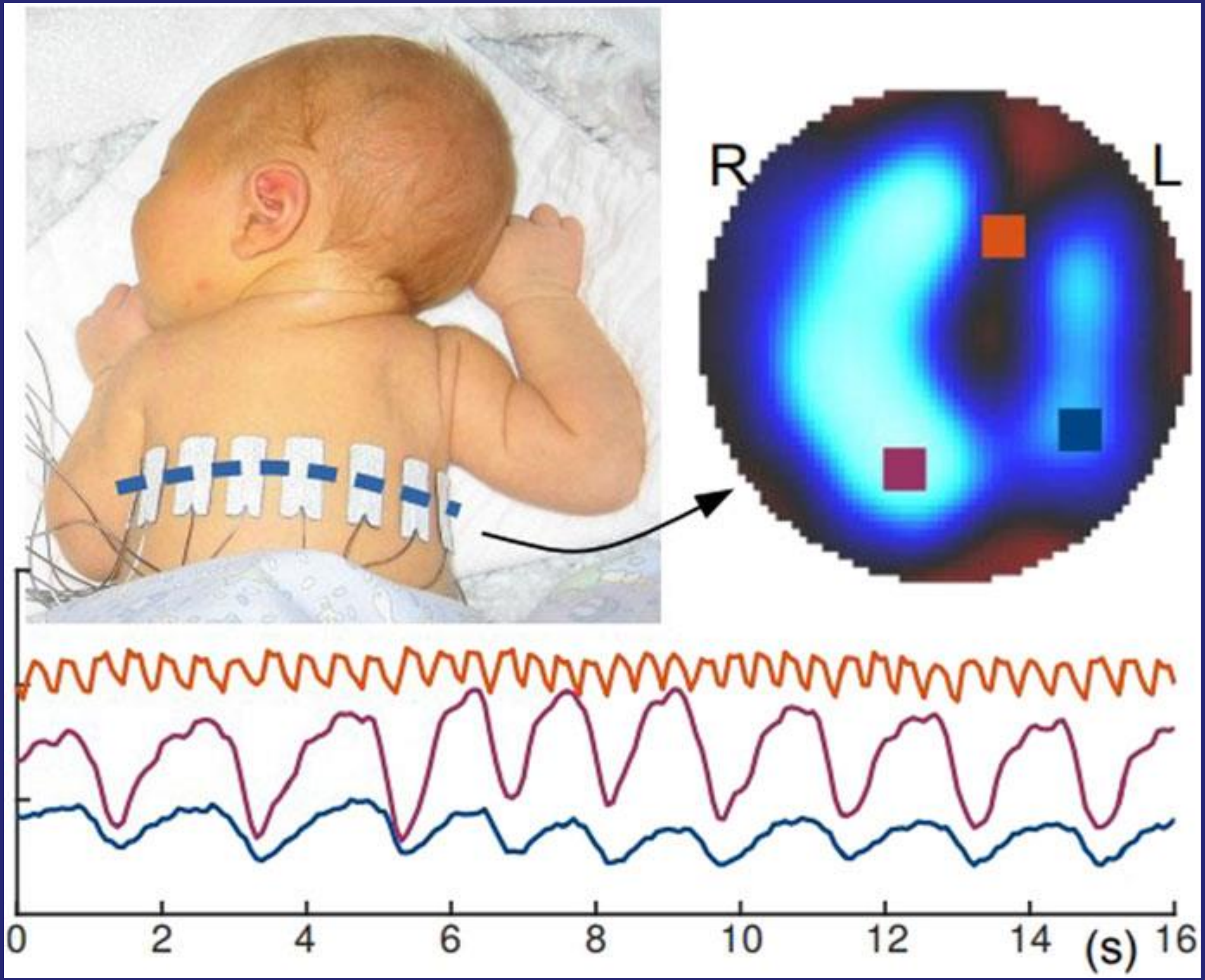
Early detection of asymmetric deterioration in ventilation (38 min)

Left pneumothorax in a premature male newborn, 32 weeks, 1369 grams birth weight, ventilated with High Frequency Oscillatory Ventilation



Successful drainage of the pneumothorax

Electrical Impedance tomography




Dräger
36 - 44 cm
14.2 - 17.3"
16
1
2
3
Ref

Respiratory Inductive Plethysmograpy (Respitrace®)

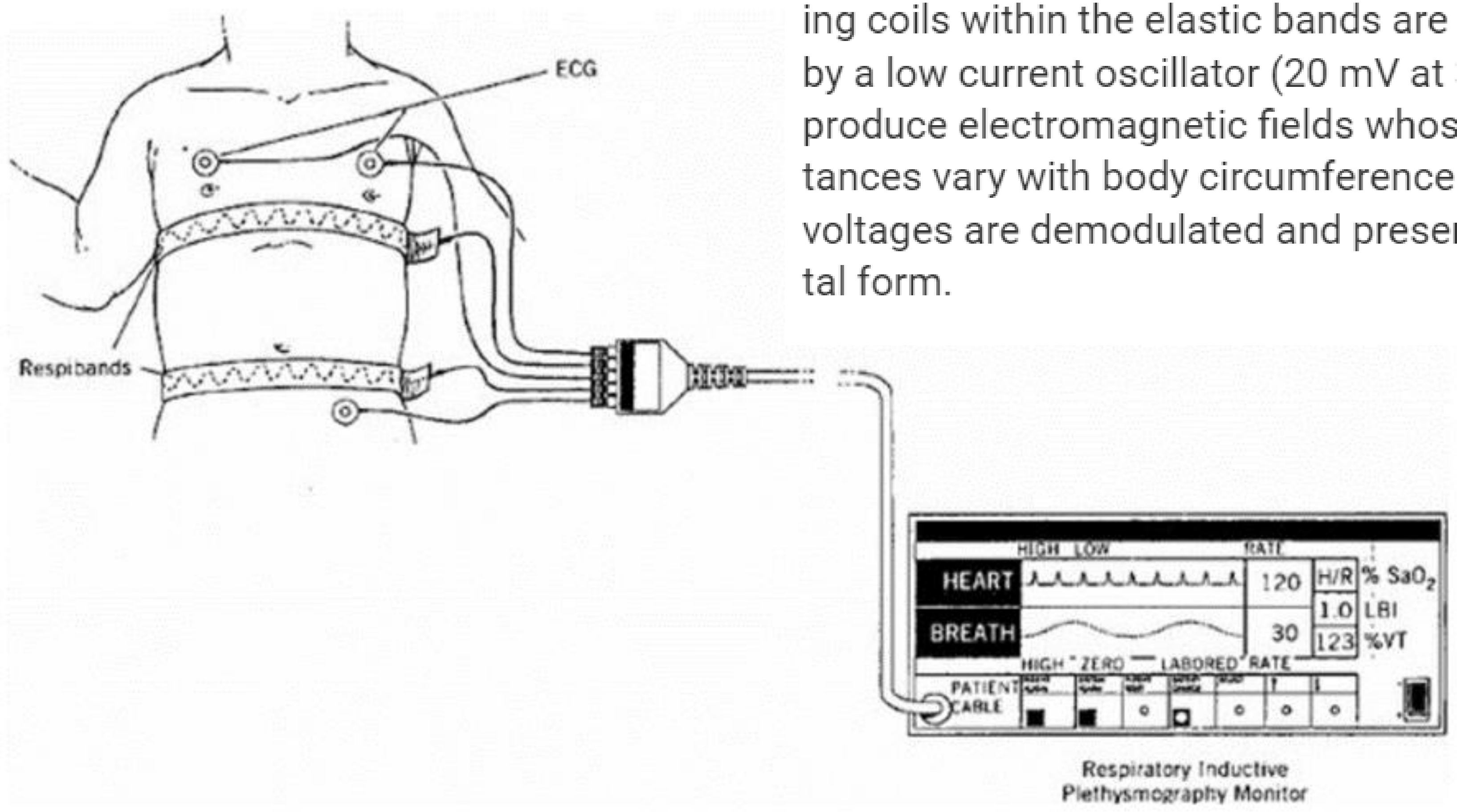


Figure 1. The Respitrace system. The two winding coils within the elastic bands are activated by a low current oscillator (20 mV at 300 kHz) to produce electromagnetic fields whose inductances vary with body circumference. Output voltages are demodulated and presented in digital form.