High Frequency Ventilation

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High frequency ventilation

- Concept of ventilator induced lung injury and lung protective ventilatory strategies
- Why HFOV may be an important lung protective strategy:
  - Gas transport mechanisms
  - Airway (and alveolar) pressure profiles
- Outcome data

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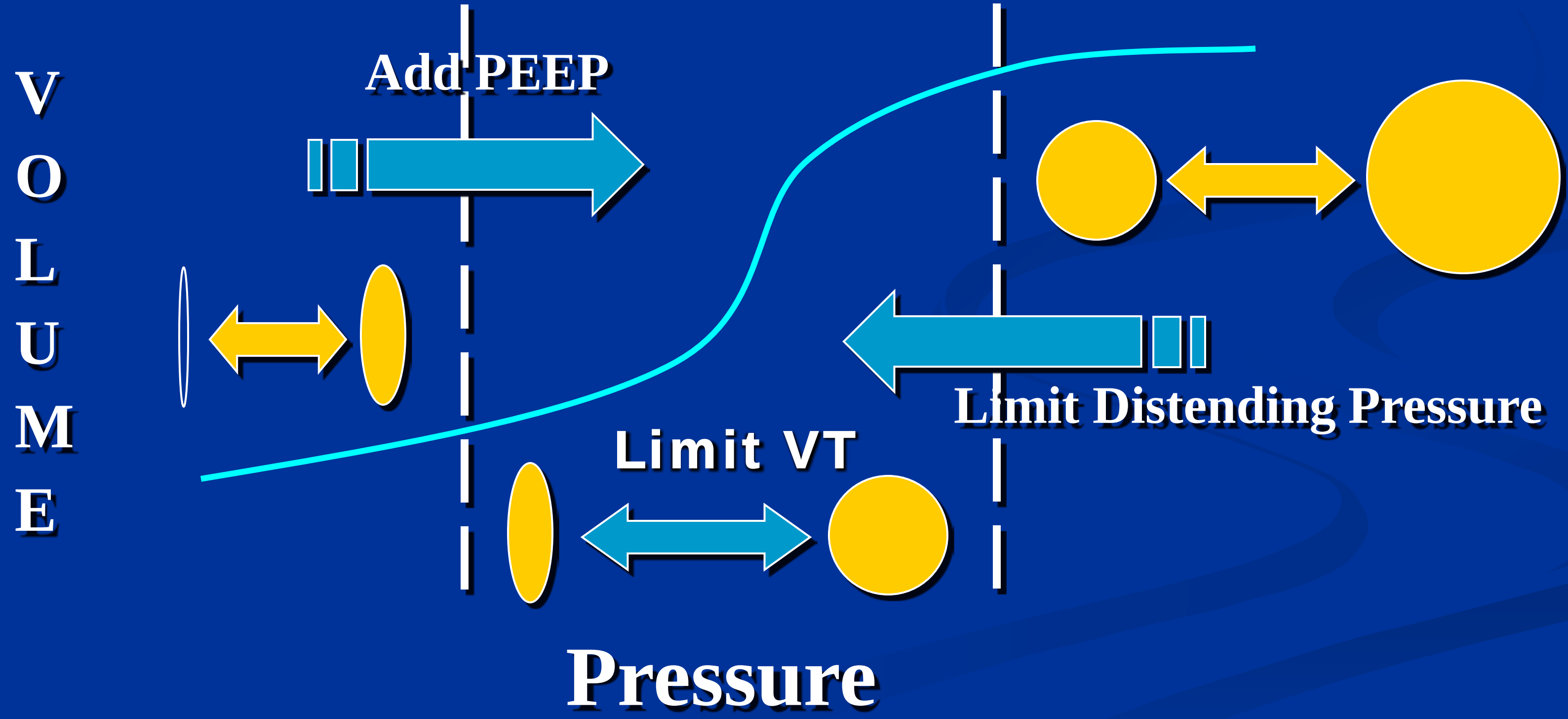
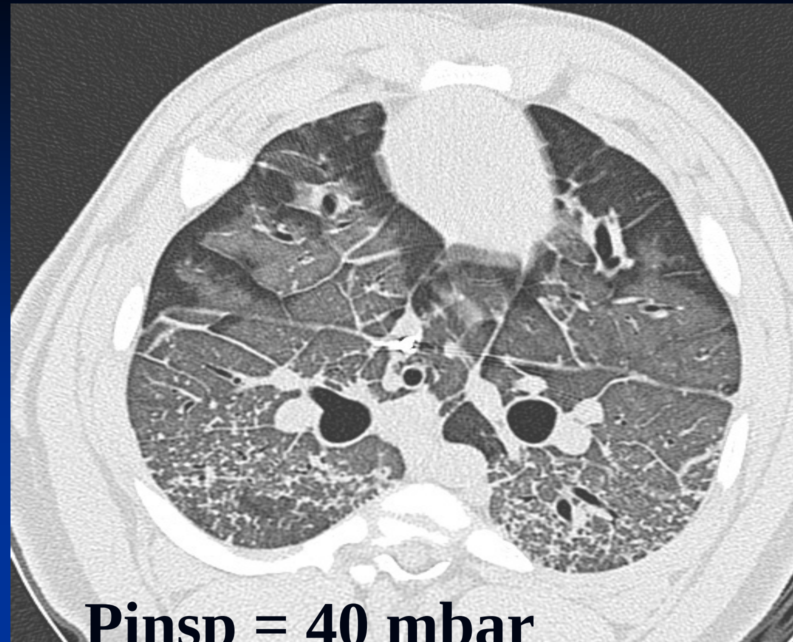
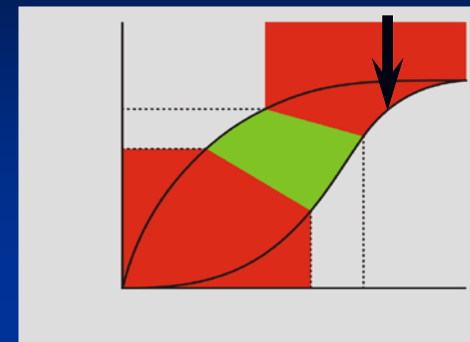
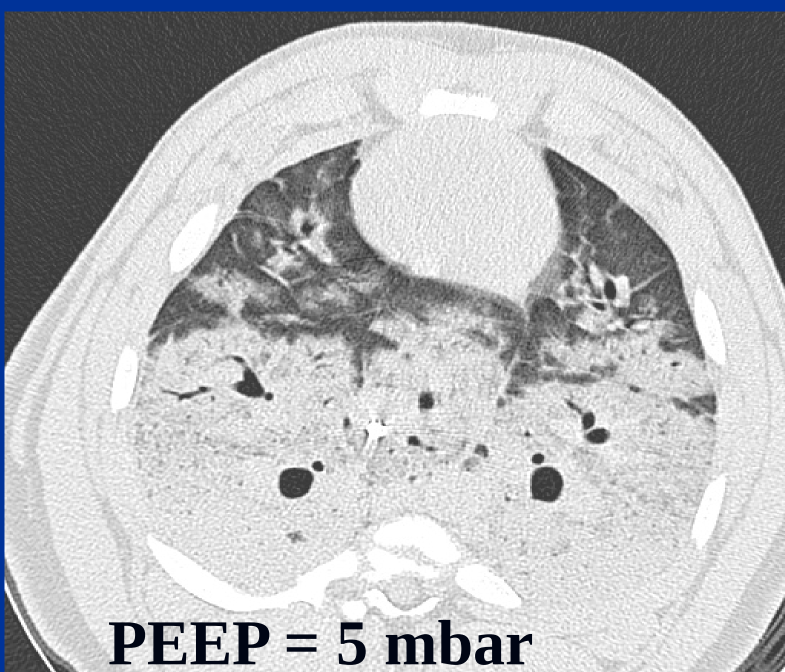
Preventing Overdistention and Under-Recruitment Injury

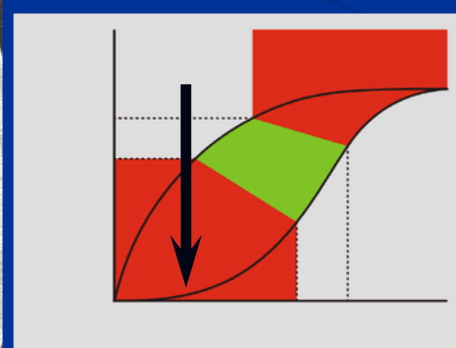
"Lung Protective" Ventilation



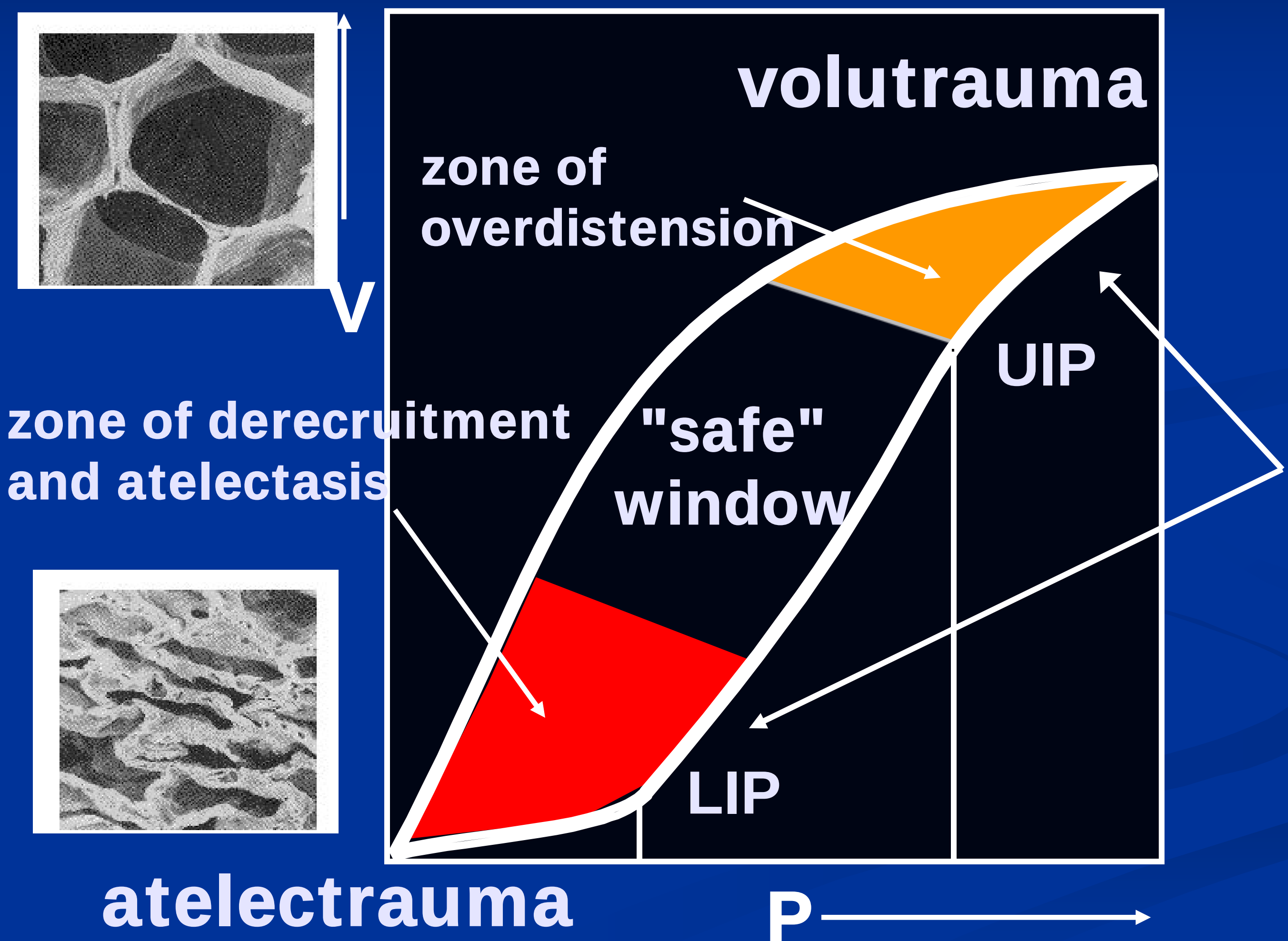

Pinsp = 40 mbar




PEEP = 5 mbar



Lung Protective Ventilator Strategies



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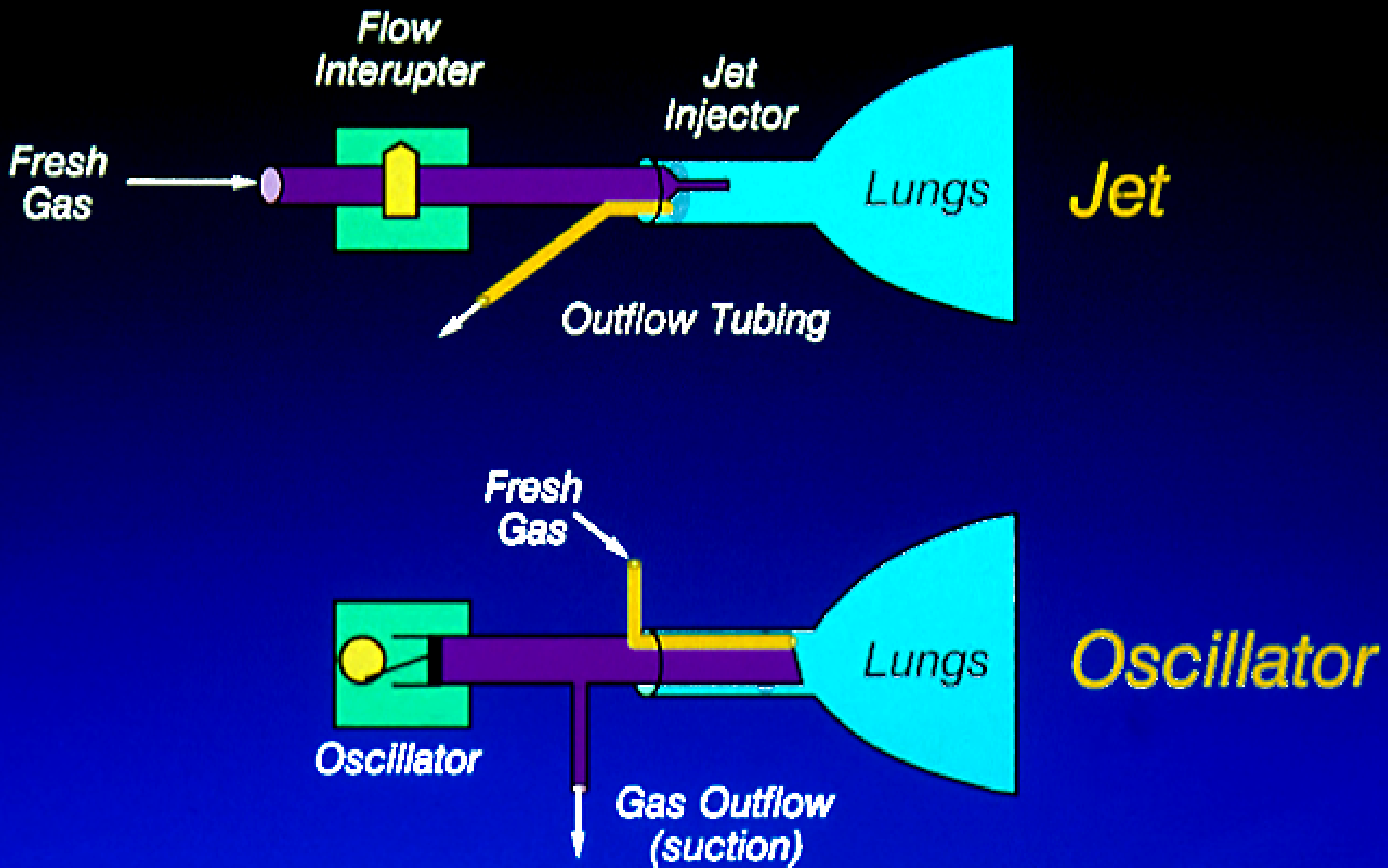
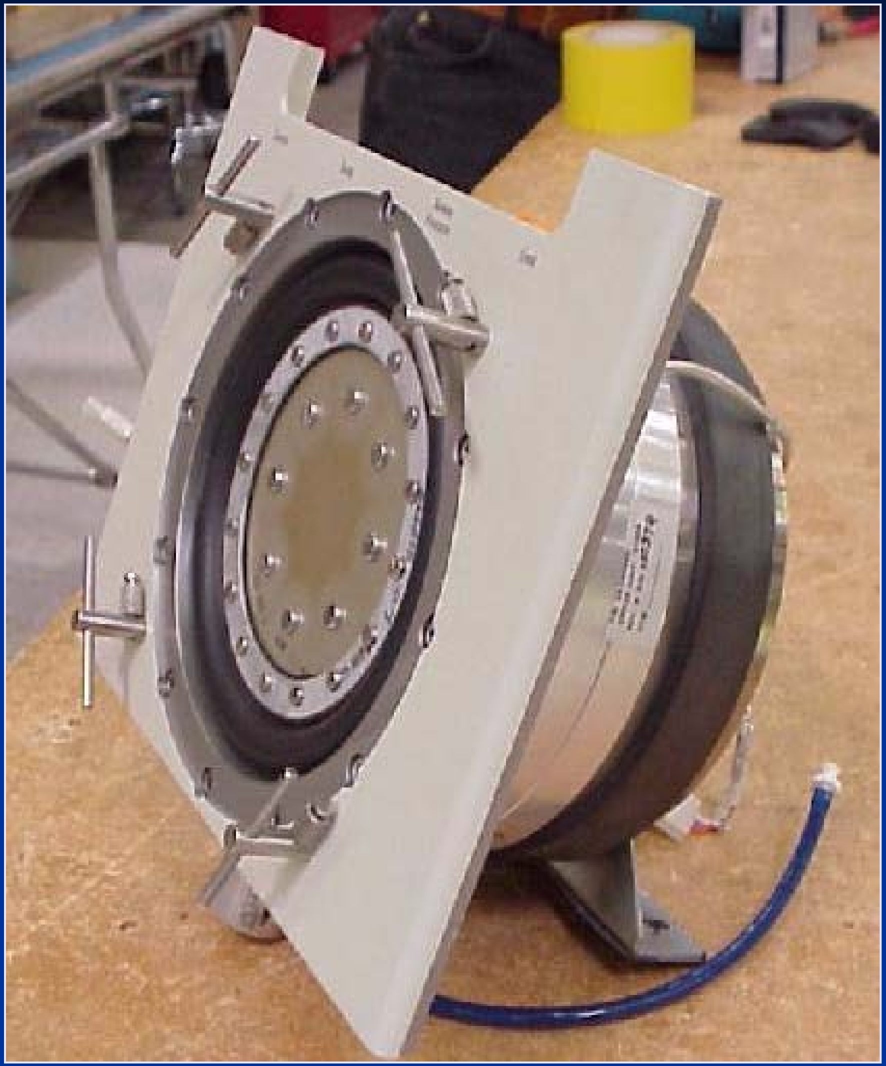
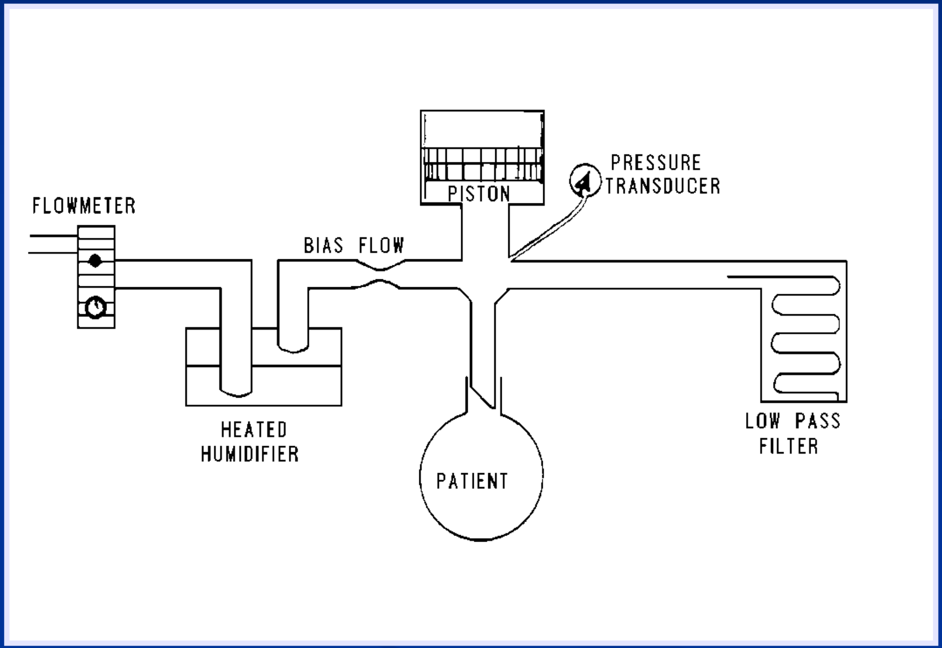
High frequency ventilation

- Breathing frequencies > “normal”. In adult 120-300 bpm. Need special devices:
  - Jets
  - Oscillators
- Small tidal volumes (usually smaller than anatomic dead space)
  - Gas transport by non-convective mechanisms

Devices for Delivering HFV

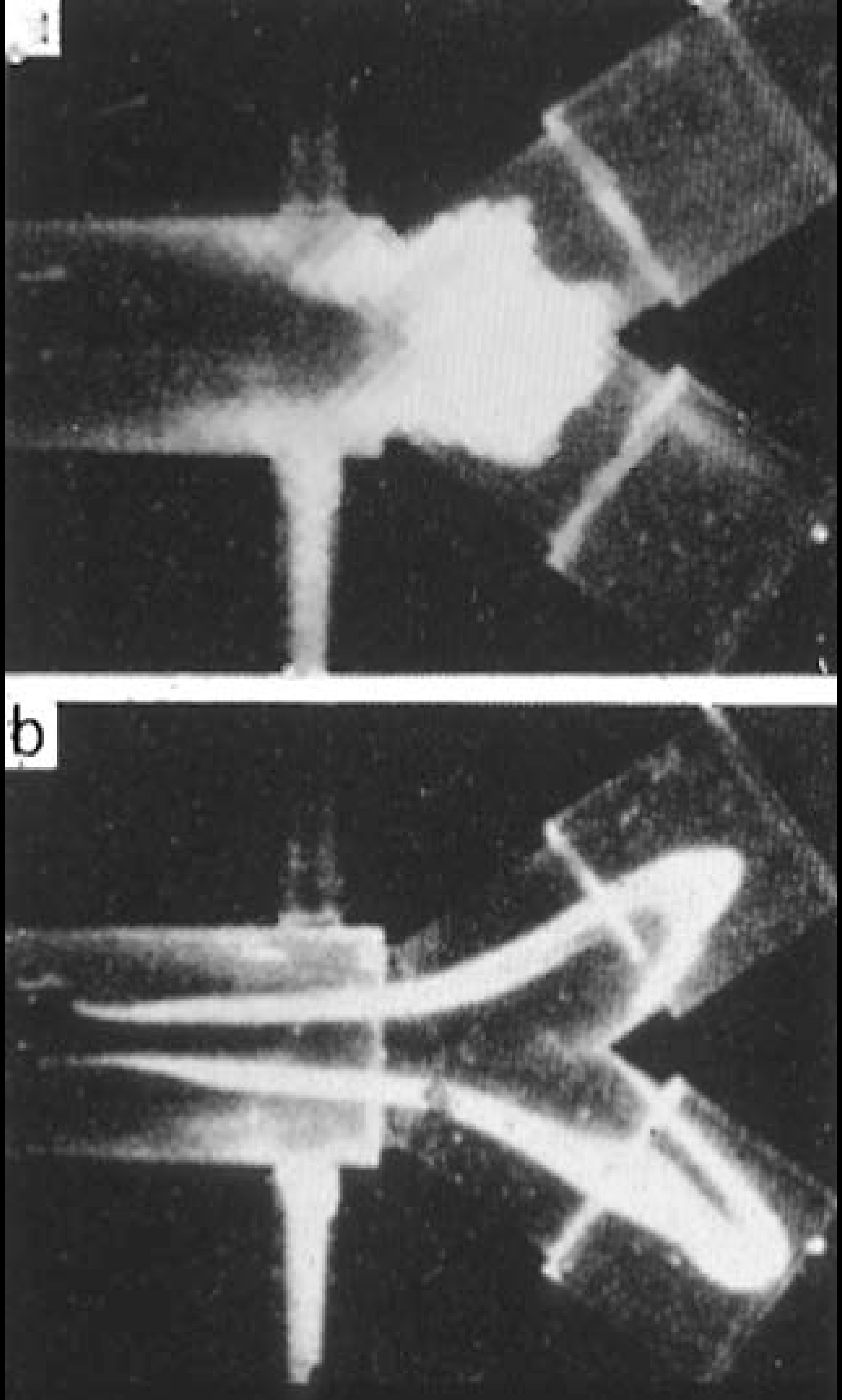




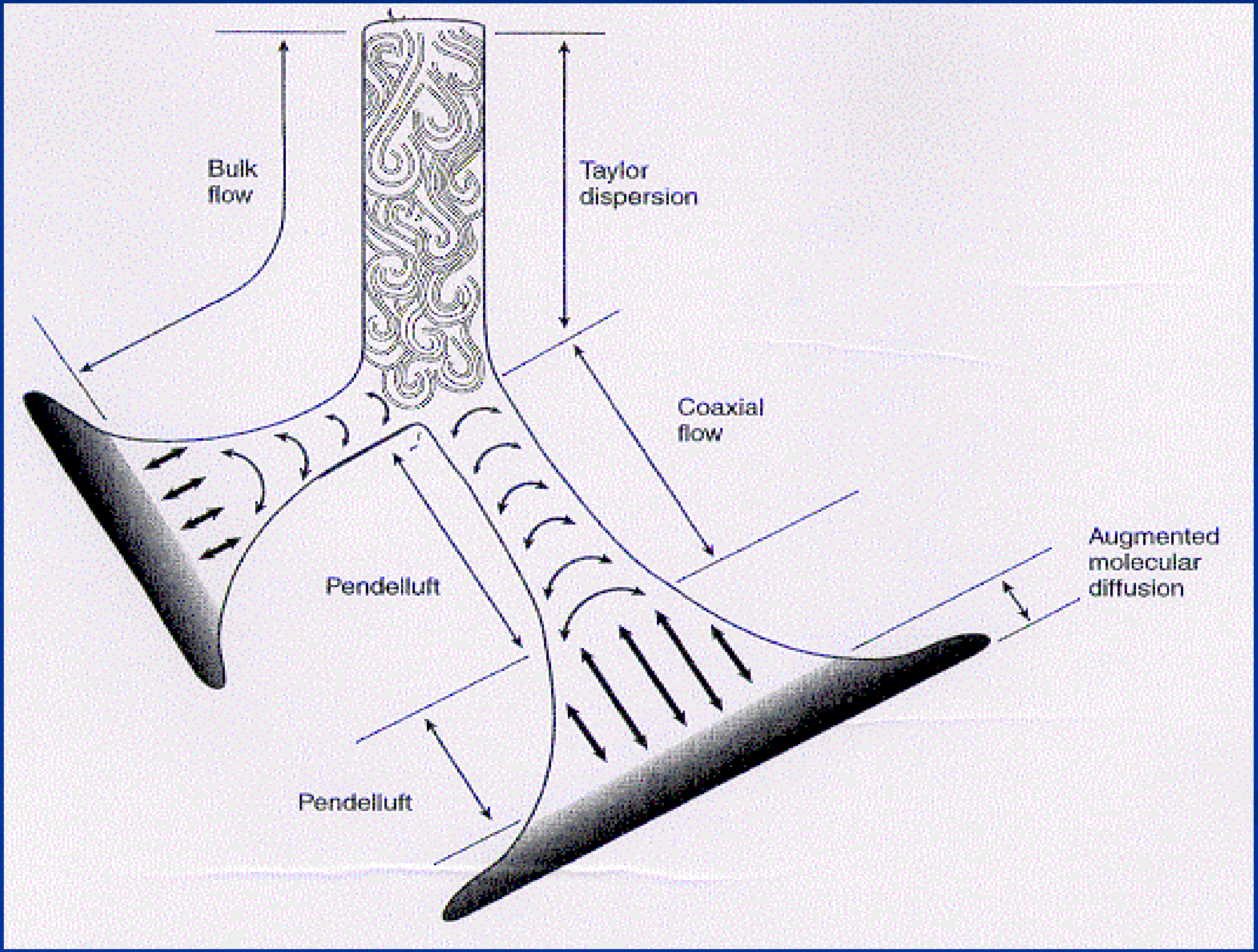

FLOWMETER
BIAS FLOW
PISTON
PRESSURE
TRANSDUCER
HEATED
HUMIDIFIER
PATIENT
LOW PASS
FILTER

Mechanisms of gas transport when Vt << Vd

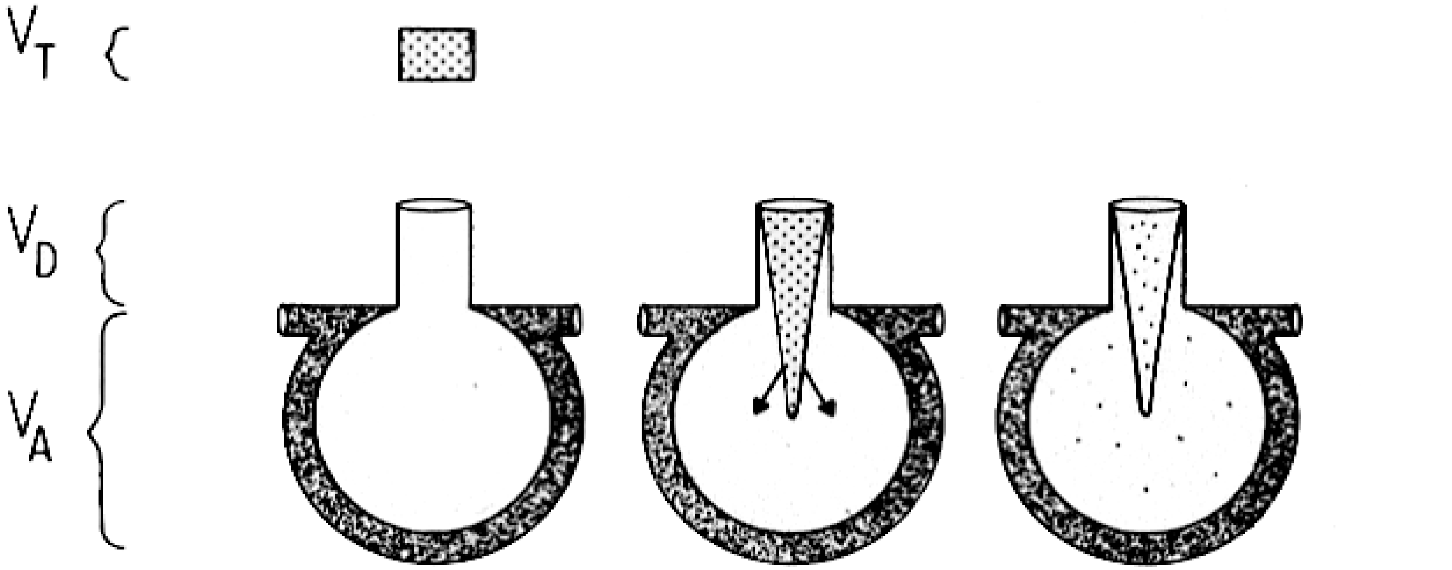
- A turbulent gas wavefront will "disperse" forward (Taylor dispersion).
- An oscillating column of gas in a branched system will have the center move distal and the periphery move proximal ("coaxial flow")
- In distal lung regions, "vibrating gas" will facilitate molecular diffusion
- Pendelluft action


b

HFV gas transport mechanisms



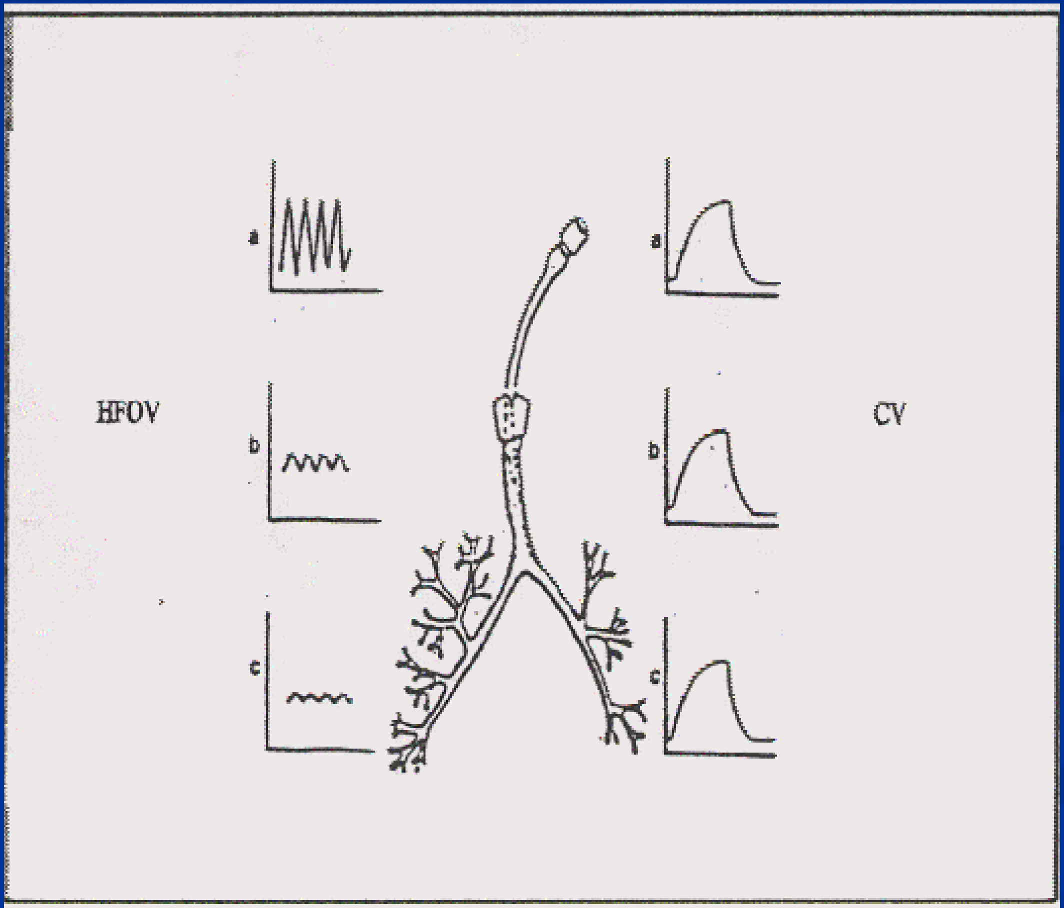
When Vt << Vd, the conventional $V_A = f \times (Vt - Vd)$ makes no sense. An alternate formula is thus necessary:



$$\dot{V}_A = f \times V_T \times \frac{V_T}{V_D} \times K$$

(K = .01–.20)

Airway pressures damped with HFOV

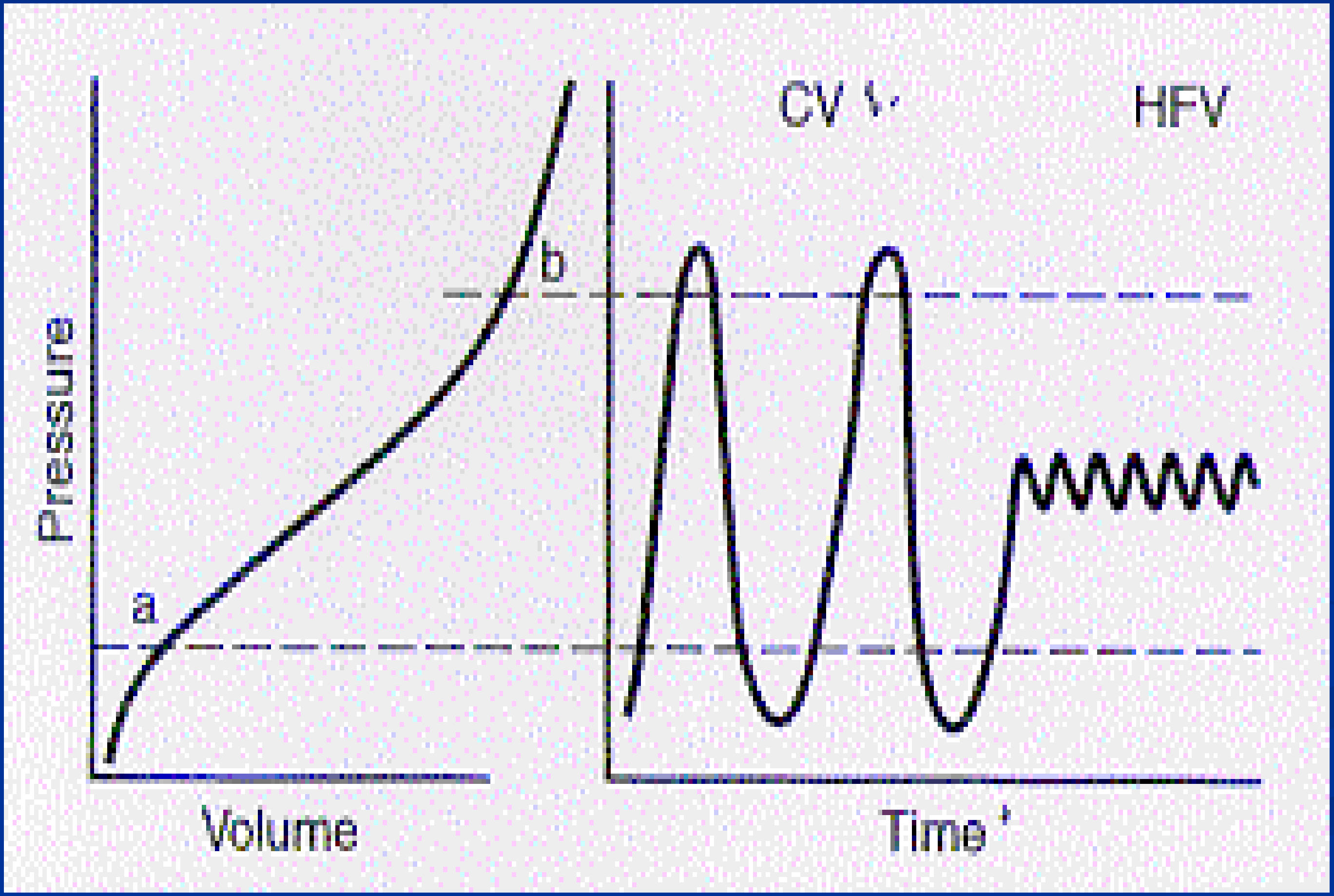


Inside machine

Endotracheal tube

Alveolar regions

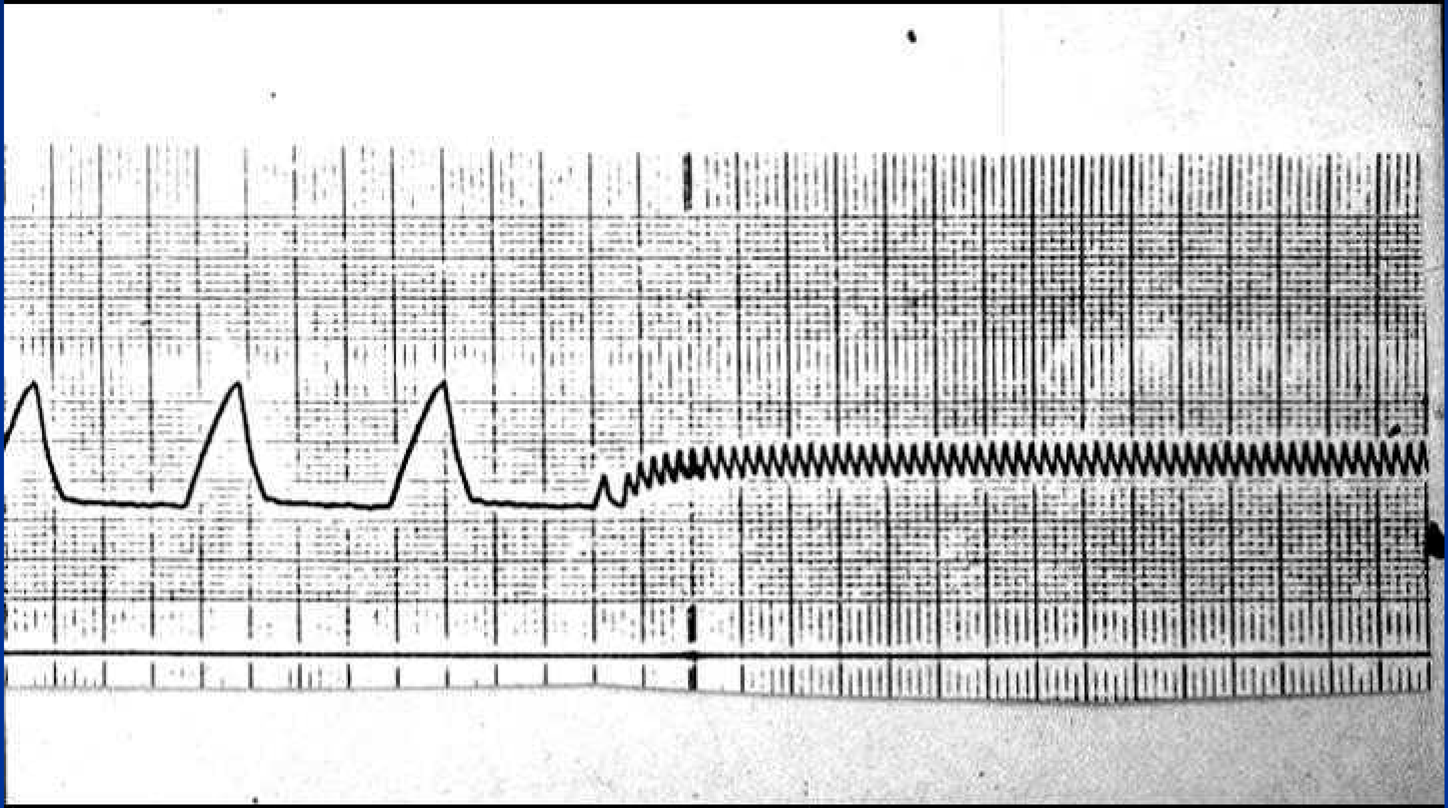
HFV – CPAP with a "wiggle"



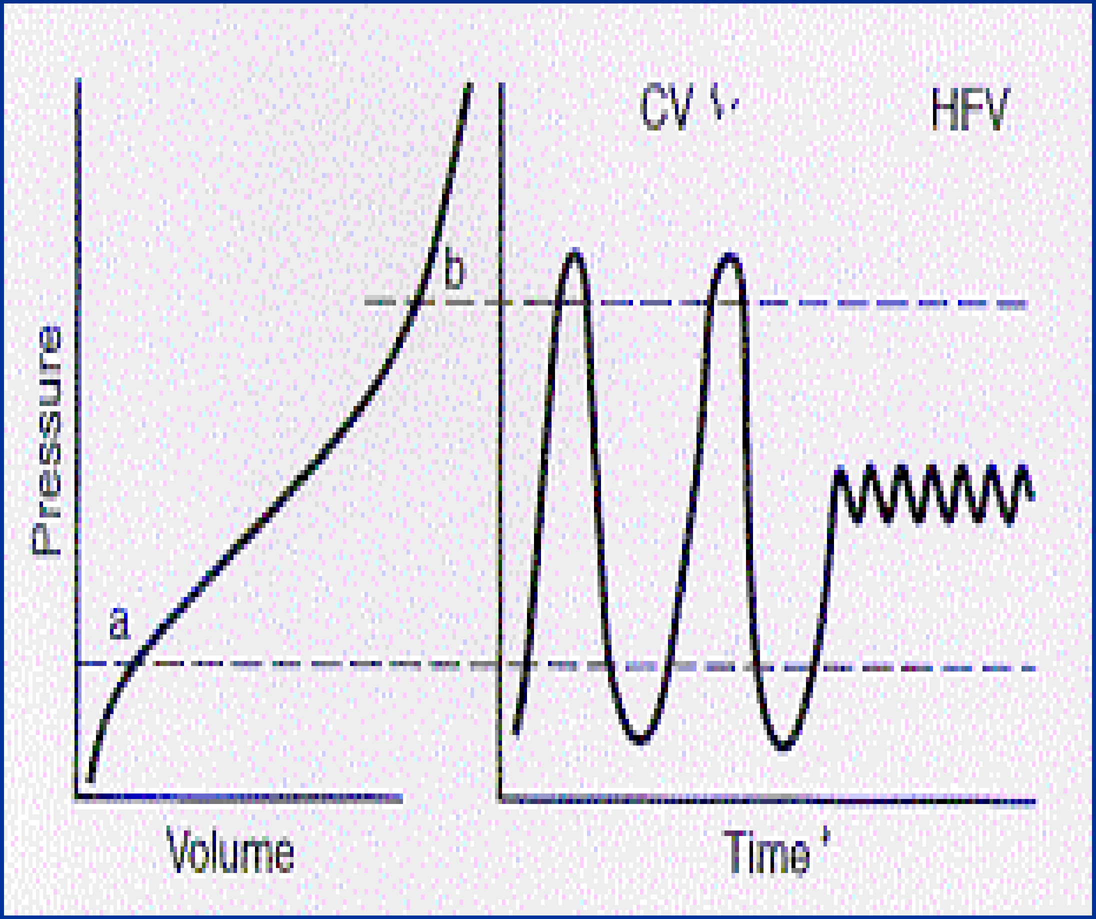
Overdistend

Protected

Under-recruit



HFV – CPAP with a "wiggle"



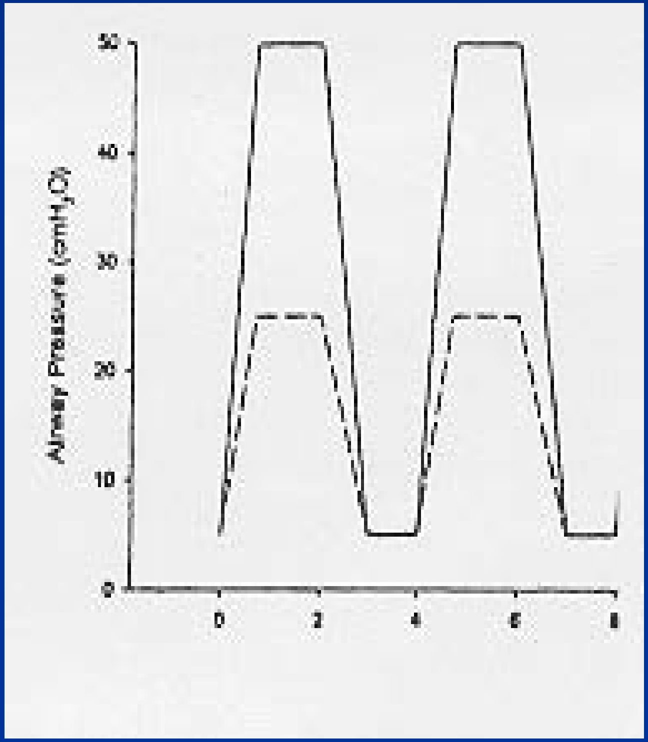
Overdistend

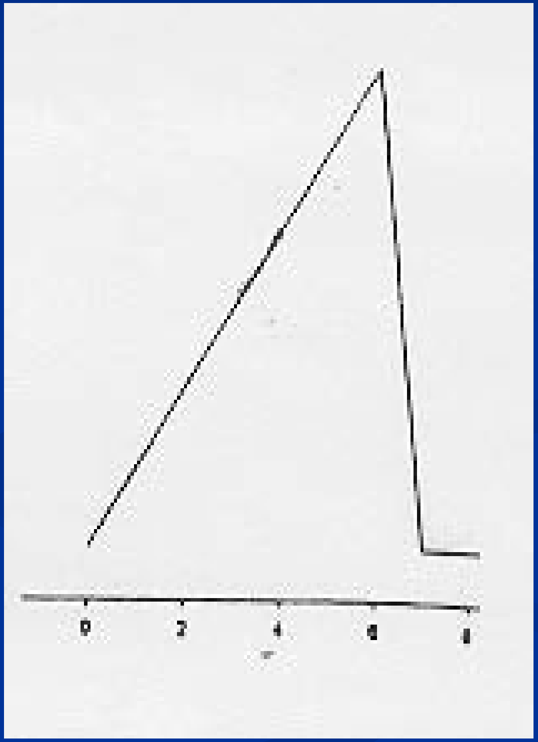
CAN HFV RAISE THIS?

Protected

Under-recruit

Can the injury threshold of 30-35 cm H2O be raised if applied slowly enough?

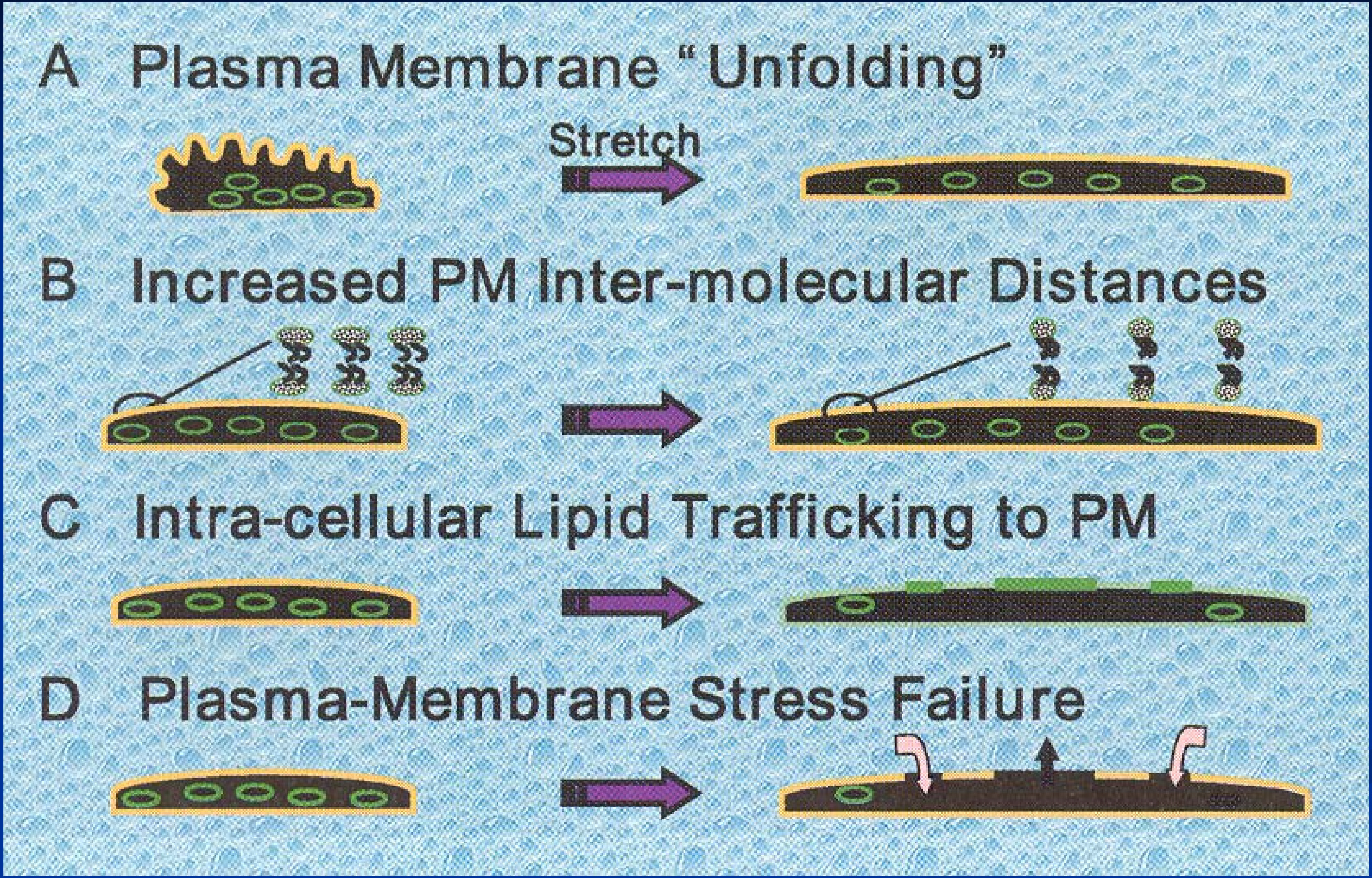




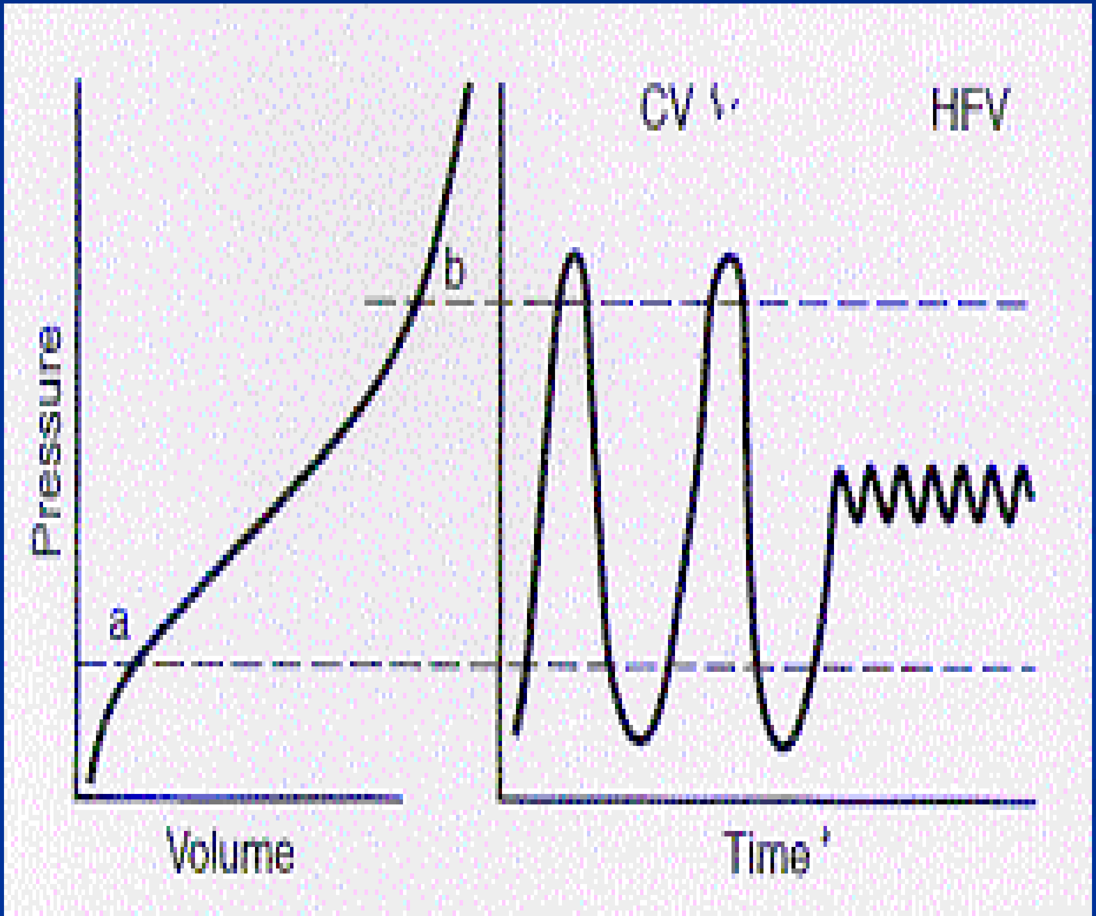
Injury Scores:

Hi = 12.5, Low = 2.1

Slo flow = 1.9


A Plasma Membrane "Unfolding"
Stretch
B Increased PM Inter-molecular Distances
C Intra-cellular Lipid Trafficking to PM
D Plasma-Membrane Stress Failure

HFV – CPAP with a "wiggle"



Overdistend

CAN HFV RAISE THIS?

Protected

Under-recruit

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RCTs: HFV vs CV in pediatric/neonatal patients

Author	Device	Patients	Main outcomes (HFV vs CV)
Kinsella	HFO	205 PPHN	Improved PO2 (with NO)
Gerstman	HFO	125 RDS	Improved PO2, lower chronic dz
Clark	HFO	79 RDS	Fewer treatment failures with HFO
Clark	HFO	83 RDS	Less chronic dz
Carlo	HFJV	42 RDS	No difference
Keszler	HFJV	130 RDS	Less chronic dz
Keszler	HFO	144 PIE	Faster PIE resolution, better survival
HIFI	HFO	673 RDS	More IVH with HFO
Johnson	HFO	400 RDS	No difference
Courtney	HFO	500 RDS	Less chronic dz

HFV vs CV: Adults

Author	Device	Patients	Design	Main outcomes (HFV vs CV)
Carlon	HFJV	300 ARF	RCT	Lower PeakP, same survival
MacIntyre	HFJV	58 ARF	Xover	Lower PeakP, same PO2
Gluck	HFJV	90 ARDS	Xover	Lower PeakP, better PO2
Forte	HFO	18 ARDS	Xover	Same gas exchange
Mehta	HFO	24 ARDS	Xover	Better PO2, higher meanP

HFV: CPAP with a "wiggle"

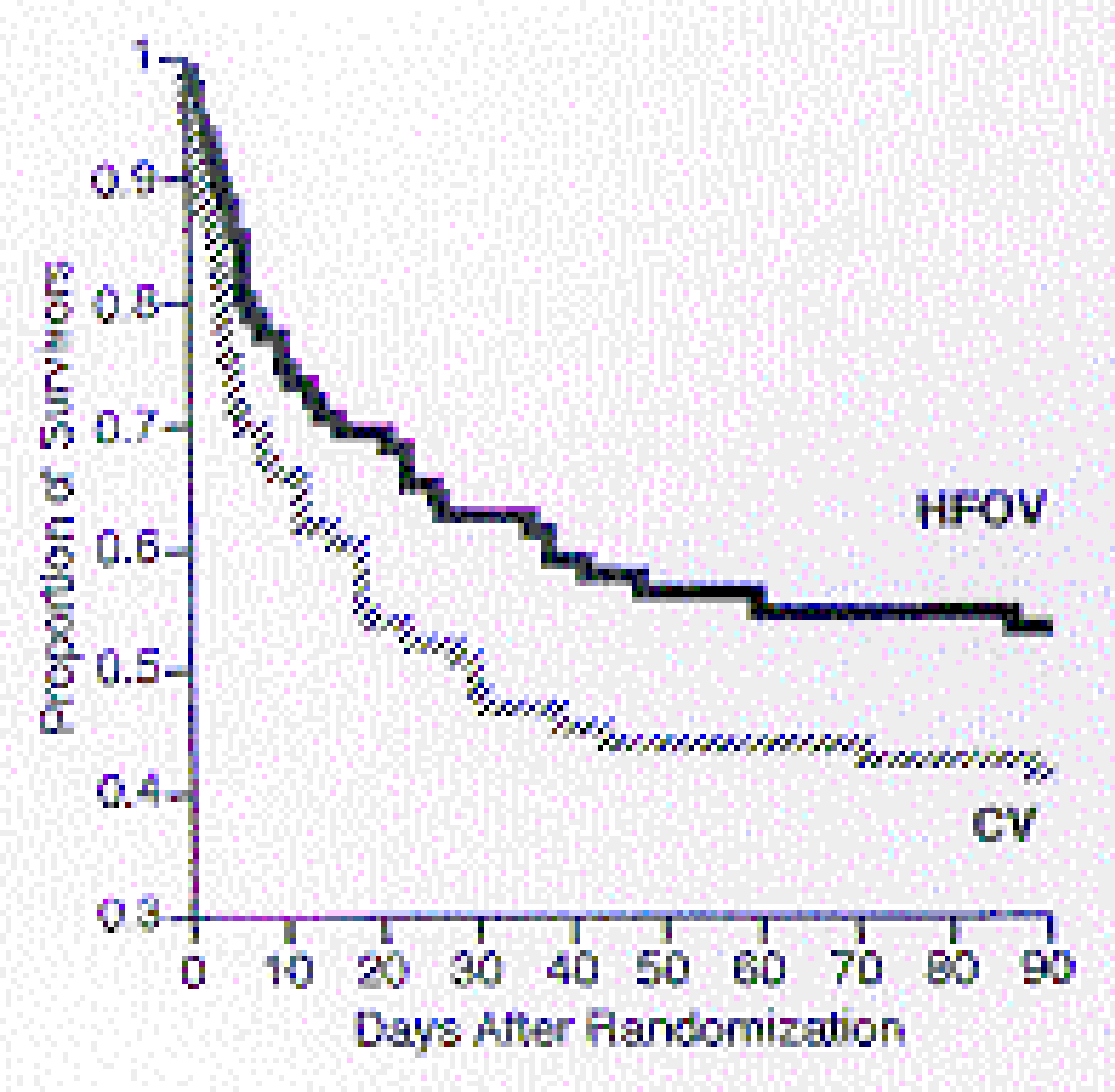
MOAT Trial*:

- 143 pts ARDS
- RCT - HFO v CV
- HFO mean P +5

  Rate 300 bpm

  I:E 1:3
- CV Vt 10/kg IBW

*Derdak. AJRCCM 2002


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
Proportion of Survivors
0
10
20
30
40
50
60
70
80
90
Days After Randomization
HFOV
CV

P = 0.057

HFV in ALI/ARDS:
2010 Meta-analysis

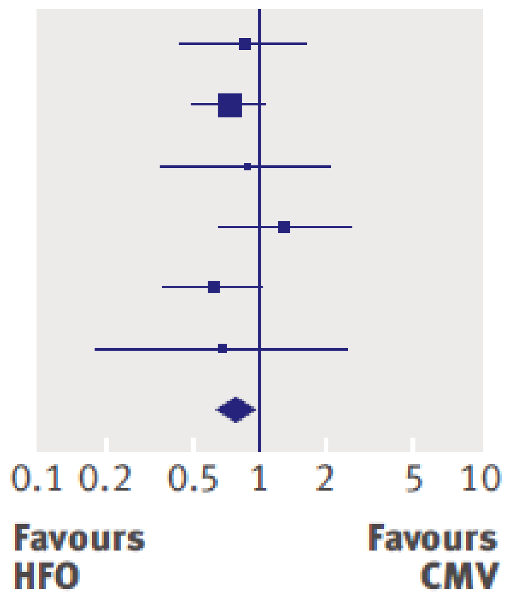
- From the Canadian EBM group
- 8 RCTs (6 more since meta-analysis of 2004)
  - 419 pediatric and adult patients (n= 16-148)
  - 6/8 <48hrs of ARDS
  - Initial settings: 4-10Hz, 3-5 cm H2O mean P above conventional
  - Control: 5/8 ARDSnet

BMJ 2010; 340:2327

Mortality

	High frequency oscillation	Conventional mechanical ventilation	Weight (%)	Risk ratio (95% CI)
Arnold 1994	10/29	12/29	13.0	0.83 (0.43 to 1.62)
Derdak 2002	28/75	38/73	42.6	0.72 (0.50 to 1.03)
Shah 2004	6/15	6/13	7.9	0.87 (0.37 to 20.4)
Bollen 2005	16/37	8/24	12.5	1.30 (0.66 to 2.55)
Mentzelopoulus 2007	11/27	18/27	20.6	0.61 (0.36 to 1.04)
Samransamruajkit 2005	2/6	5/10	3.4	0.67 (0.18 to 2.42)
Total (95% CI)	73/189	87/176	100.0	0.77 (0.61 to 0.98)

Risk ratio (95% CI)



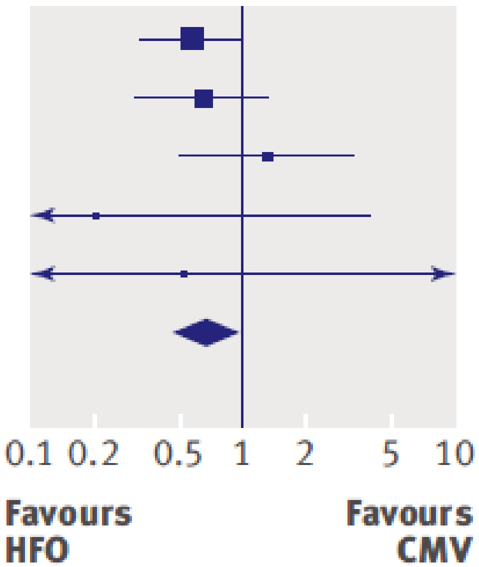
Test for heterogeneity: $\tau^2=0.00$, $\chi^2=3.36$, df=5, P=0.64, $I^2=0\%$

Test for overall effect: z=2.12, P=0.03

BMJ 2010; 340:2327

Treatment Failure

	High frequency oscillation	Conventional mechanical ventilation	Risk ratio (95% CI)	Weight (%)	Risk ratio (95% CI)
Arnold 1994	11/29	19/29		52.1	0.58 (0.34 to 0.99)
Derdak 2002	10/75	15/73		27.8	0.65 (0.31 to 1.35)
Bollen 2005	10/37	5/24		16.8	1.30 (0.51 to 3.33)
Mentzelopoulus 2007	0/27	2/27		1.7	0.20 (0.01 to 3.98)
Samransamruajkit 2005	0/6	1/10		1.6	0.52 (0.02 to 11.14)
Total (95% CI)	31/174	42/163		100.0	0.67 (0.46 to 0.99)

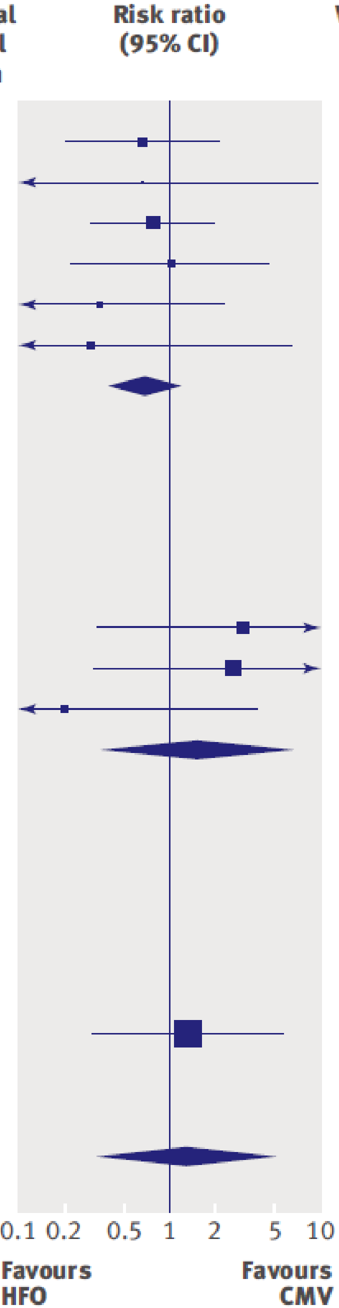


Test for heterogeneity: τ^2=0.00, χ^2=2.84, df=4, P=0.59, I^2=0%

Test for overall effect: z=2.02, P=0.04

BMJ 2010; 340:2327

	High frequency oscillation	Conventional mechanical ventilation	Weight (%)	Risk ratio (95% CI)
Barotrauma				
Arnold 1994	4/29	6/29	26.3	0.67 (0.21 to 2.12)
Bollen 2005	1/37	1/24	4.7	0.65 (0.04 to 9.88)
Derdak 2002	7/75	9/73	40.2	0.76 (0.30 to 1.93)
Mentzelopoulus 2007	3/27	3/27	15.4	1.00 (0.22 to 4.52)
Samransamruajkit 2005	1/6	5/10	9.8	0.33 (0.05 to 2.21)
Shah 2004	0/51	1/13	3.6	0.29 (0.01 to 6.60)
Subtotal	16/189	25/176	100.0	0.68 (0.37 to 1.22)
Test for heterogeneity: τ^2=0.00, χ^2=1.13, df=5, P=0.95, I^2=0%				
Test for overall effect: z=1.29, P=0.20				
Hypotension				
Arnold 1994	3/29	1/29	37.8	3.00 (0.33 to 27.18)
Bollen 2005	4/37	1/24	39.9	2.59 (0.31 to 21.84)
Derdak 2002	0/75	2/73	22.2	0.19 (0.01 to 3.99)
Subtotal	7/141	4/126	100.0	1.54 (0.34 to 7.02)
Test for heterogeneity: τ^2=0.32, χ^2=2.42, df=2, P=0.30, I^2=17%				
Test for overall effect: z=0.56, P=0.58				
Endotracheal tube obstruction				
Demory 2007	0/13	0/15	—	—
Derdak 2002	4/75	3/73	100.0	1.30 (0.30 to 5.60)
Mentzelopoulus 2007	0/27	0/27	—	—
Samransamruajkit 2005	0/6	0/10	—	—
Subtotal (95% CI)	4/121	3/125	100.0	1.30 (0.30 to 5.60)
Test for heterogeneity: not applicable				
Test for overall effect: z=0.35, P=0.73				



HFV in ALI/ARDS:
2010 Meta-analysis

- Key results from 6 peer reviewed studies:
  - Mortality reduced (RR 0.77, P=0.03), 5/6 trials +
  - Treatment failures (RR 0.67, P=0.04), 5/6 trials +
  - Barotrauma (RR 0.68, P=0.2)
- Physiology:
  - Consistently better PaO_2/FiO_2

BMJ 2010; 340:2327

OSCAR

- 29 hospitals, 20 with no HFO experience
- 795 pts meeting ARDS criteria
- Novalung R100 (Metran) – never used before
- Initial: 10 Hz, mean P = plateau + 5
- Control "encouraged" to use ARDSnet
- 30 day mortality 41.7% (HFO) vs 41.1% (CV)

NEJM 2013

OSCILLATE

- 41 hospitals, many with no HFO experience
- 548 pts meeting ARDS criteria (75 already on HFO and excluded)
- Sensormedics 3100b (CareFusion)
- Initial: RM, then 30; Up to 10Hz
- Control: Protocolized LOVS/ARDSnet
- In hospital mortality: 47% (HFO) vs 35% (CV)

NEJM 2013

Comparing Trials

	Meta Analysis	OSCAR	OSCILLATE
Age	41	55	55
Baseline P/F	101	113	121
Initial HFO P	5+CVm (25)	5+CVm (27)	31
Vasoactive needs	7	44	67
HFO mortality	39*	41	41
CV mortality	49	41	35*

Note: Mortality in 4188 ventilated ARDS patients with new Berlin criteria:

Mild (P/F 200-300) 24-32%;
Moderate (P/F 100-200) 29-34%
Severe (P/F <100) 42-48%

JAMA 2012;307:2526

OSCAR and OSCILLATE Trials

- 2 large RCTs – OSCAR equivalent, OSCILLATE suggested harm
- Concerns (both):
  - HFO expertise low (majority had never used HFO)
  - Best candidates excluded (75 subjects in OSCILLATE on HFO)
- Concerns (OSCILLATE)
  - High Paw protocol in setting of high vasopressor use
- My take:
  - Should not expose pts with adequate lung protection on CV to risks of HFO (fluid balance, NMBs)
  - Clinician skill important – especially with high mean P and hemodynamic compromise
  - Still a reasonable rescue strategy

HFV in the adult -when to use?

- Suggested criteria - when “lung protection” cannot be provided with conventional strategies:
  - Pplat (corrected for Ccw) > 30
  - FiO_2 > 0.5-0.6
- Earlier rather than later

MAP/FiO_2 Scale for HFOV

Adjust FiO_2 or MAP according to the scale
to maintain oxygenation in target range

(for patients without circulatory failure)

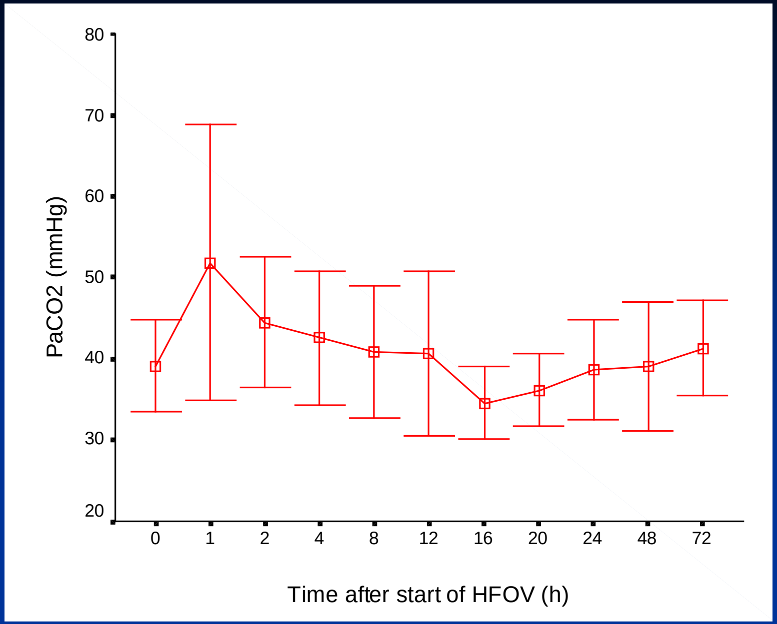
FiO_2	**.40**	**.40**	**.50**	**.50**	**.60**	**.70**	**.80**	**.90**	**.90**	**.90**	**1.0**	**1.0**
MAP	**20**	**25**	**25**	**30**	**30**	**30**	**30**	**30**	**35**	**40**	**40**	**45**

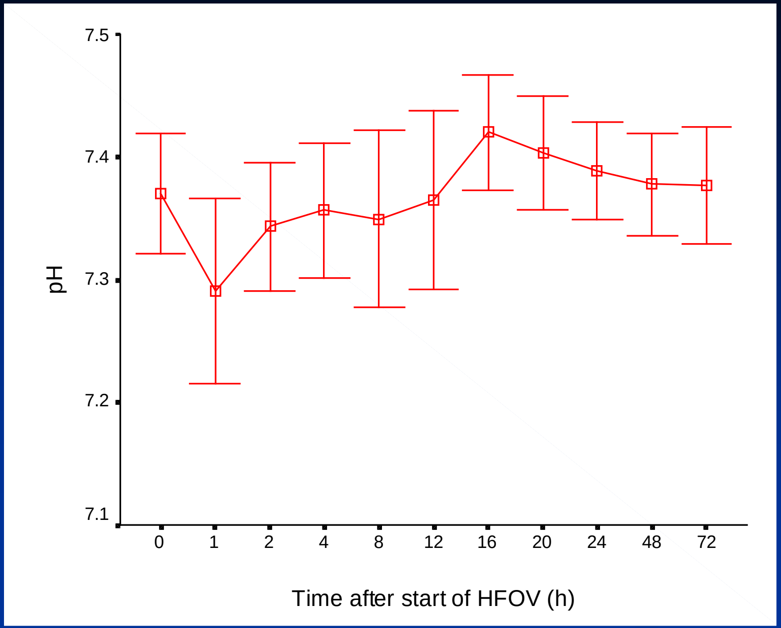
(for patients with circulatory failure)

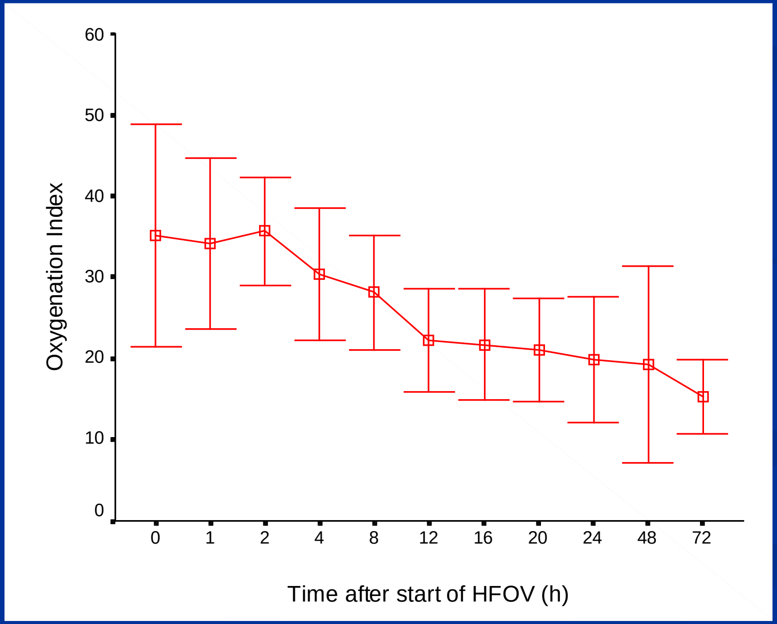
FiO_2	**.40**	**.50**	**.60**	**.60**	**.70**	**.80**	**.80**	**.90**	**.90**	**1.0**	**1.0**	**1.0**
MAP	**20**	**20**	**20**	**25**	**25**	**25**	**30**	**30**	**35**	**35**	**40**	**45**

Worsening Arterial Oxygenation →
← Improving Arterial Oxygenation

- Oxygenation Goals: Oxygen Saturation 88-95% or PaO_2 55-80 mmHg
- Circulatory failure = mean arterial pressure < 60 mmHg or vasopressors; note that CVP 15-20 mmHg may be needed to achieve adequate RV filling.


80
70
60
50
40
30
20
PaCO2 (mmHg)
0
1
2
4
8
12
16
20
24
48
72
Time after start of HFOV (h)


7.5
7.4
7.3
7.2
7.1
pH
0
1
2
4
8
12
16
20
24
48
72
Time after start of HFOV (h)


60
50
40
30
20
10
0
Oxygenation Index
0
1
2
4
8
12
16
20
24
48
72
Time after start of HFOV (h)

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