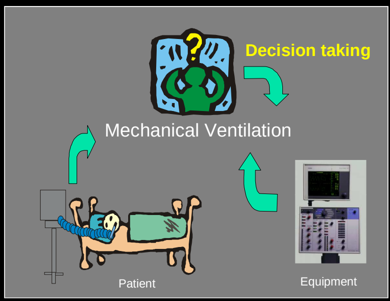
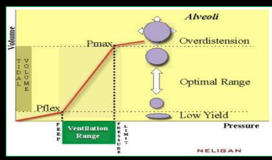
Hot to choose optimal seetings



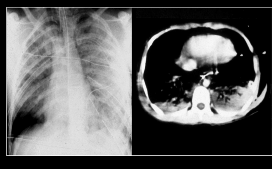
Peter C. Rimensberger
Pediatric and Neonatal ICU
Department of Pediatrics
University Hospital of Geneva
Geneva, Switzerland

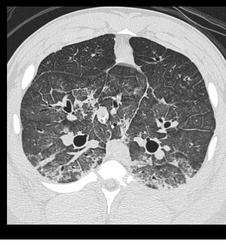
Defined Clinical Targets and Goals

1) Achieve good oxygenation and acceptable CO2
2) reduce WOB in spontaneous breathing patients

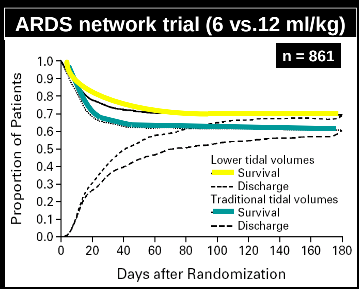


3) Try to protect the lung
- limit peak pressure
- use lower Vt
- use higher PEEP





Small Vt ventilation



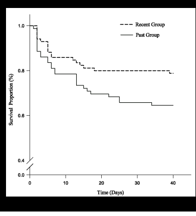
Mortality: 31 vs. 38 (p < 0.007)

PIP: 32 vs. 39 cmH2O
Pplat: 25 vs. 33 cmH2O

NEJM 2000;342:1301-1308

Have changes in ventilation practice improved outcomes ?

	Past (1988–1992) (n = 79)	Recent (2000–2004) (n = 85)	p^a Value
VT, mL·kg^{-1}	10.2 ± 1.7 (211)	8.1 ± 1.4 (233)	<.001
PIP, cm H_2O	31.5 ± 7.3 (223)	27.8 ± 4.2 (233)	<.001
PEEP, cm H_2O	6.1 ± 2.7 (223)	7.1 ± 2.4 (232)	.007
$Paco_2$, mm Hg	37.0 ± 5.0 (225)	47.2 ± 11.8 (231)	<.001
Pao_2, mm Hg	84.4 ± 14.4 (225)	78.9 ± 14.9 (245)	.017
OI	14.7 ± 5.0 (223)	17.7 ± 5.3 (232)	<.001
Pao_2/Fio_2	153.0 ± 59.9 (225)	139.2 ± 53.1 (239)	.12
VI	28.4 ± 13.6 (225)	28.6 ± 15.6 (235)	.94
PC, %	52 (225)	55 (245)	.99
VC, %	47 (225)	37 (245)	.02
HFOV, %	1 (225)	8 (245)	<.001

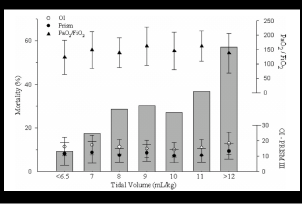


Albuali WH Pediatr Crit Care Med 2007; 8:324 –330

Clinical variables associated with mortality

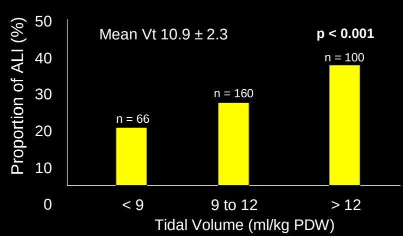
Multivariate analysis

		Mortality		Ventilation-Free Days	
Variable	Odds Ratio	95% CI	p Value	95% CI	p Value
PRISM III	1.35	1.21, 1.50	<.001	−1.20, −0.66	<.001
Group (recent vs. past group)	0.86	−0.82, 0.99	.23	−6.21, 0.06	.06
Tidal volume[b]	1.59	1.20, 2.10	<.001	−1.99, −0.43	.003
PEEP[b]	1.08	0.83, 1.41	.56	−0.84, 0.46	.56
PIP[b]	0.95	0.88, 1.02	.15	−0.06, 0.50	.13
Pao_2/Fio_2 <200	3.58	0.45, 28.34	.23	−5.38, 1.44	.25
Immunodeficiency	3.58	1.09, 11.76	.04	−7.41, −0.32	.03
Male gender	0.44	0.17, 1.15	.09	0.44, 5.29	.02
Sepsis	1.75	0.49, 6.23	.39	−4.99, 1.25	.24
Pneumonia	1.64	0.50, 5.38	.42	−4.42, 1.60	.36
Prone position	3.14	0.67, 14.67	.15	−9.58, −0.17	.04
HFOV	0.65	0.13, 3.36	.61	−3.30, 5.49	.62



Albuali WH
PCCM 2007; 8:324 –330

Max. used V_t and effect on the developpment of ALI in ICU patients without lung injury

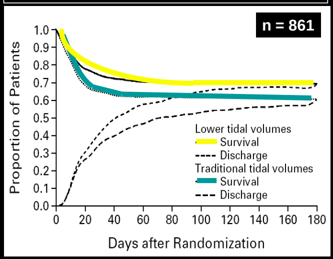


Gajic O et al. Crit Care Med 2004; 32:1817-1824

Physiologic Vt (normal lungs with spont. breathing) : 6 to 7 ml/kg

The concept of small Vt ventilation is a concept of "physiologic Vt ventilation"

ARDS network trial (Vt 6 vs. 12 ml/kg)

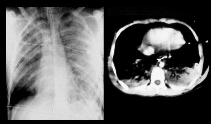


Mortality: 31 vs. 38 ($p < 0.007$)

NEJM 2000;342:1301-1308

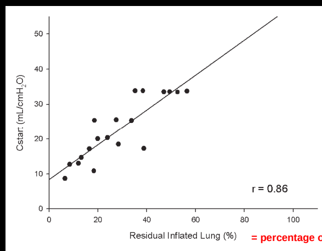
Physiologic Vt (normal lungs with spont. breathing) : 6 to 7 ml/kg

The baby lung



The ARDS lung is small, with a normal aerated portion having the dimension of the lung of a 5- to 6- year old child (200 – 300 g of lung tissue as compared to 700 g)

Gattinoni L Intensive Care Crit Dig 1987; 6:1-4

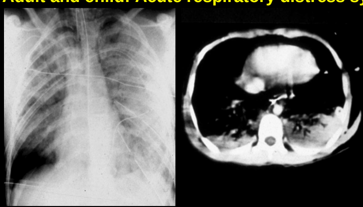


= percentage of the expected normal lung volume

The ARDS lung is rather small than stiff

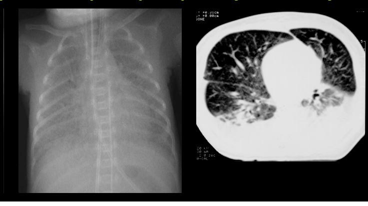
Gattinoni L et al. J Thorac Imaging 1988; 3:59-64

1) Adult and child: Acute respiratory distress syndrome (ARDS)



ARDS is a heterogeneous lung disease

2) Neonate: (Infant) Respiratory distress syndrome (iRDS)

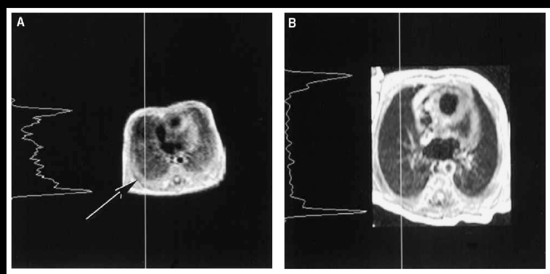


iRDS is a heterogeneous lung disease

MRI signal intensity from non-dependent to dependent regions

The water burden of the lung makes the lung of the preterm infant, despite surfactant treatment, vulnerable to VILI

4-day-old, 26-week gestation infant — 2-day-old, 38-week gestation infant



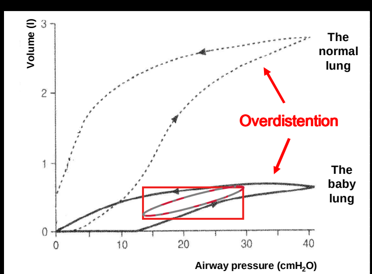
Adams EW AJRCCM 2002; 166:397–402

The baby lung

The ARDS lung is small, with a normal portion having the dimension of the lung of a 5- to 6- year old child

(200 – 300 g of lung tissue as compared to 700 g)

Gattinoni L, Pesenti A Intensive Care Crit Dig 1987; 6:1-4

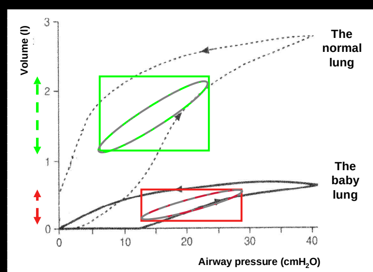


~~Vt / kg ratio~~

↓

Vt / "baby lung" ratio

Allowable V_t depends on pathology and disease severity



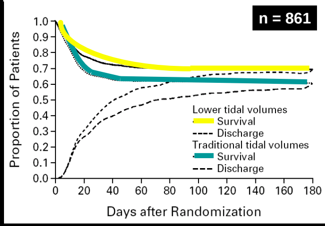
or pathologies with reduced TLC:
- **Lung hypoplasia**
- **CDH**
- **iRDS**
- **Lobar Collapse**
- **Lobar Pneumonia**

Vt of 6 ml/kg bw in a patient with a by 50% reduced TLC corresponds to at Vt of 12 "ml/kg", he should therefore receive only 3 ml/kg bw !

→ "permissive hypercapnia", HFOV, ECMO or ECCO2-R

Higher PEEP
during small Vt ventilation or peak pressure limitation

ARDS network trial (6 vs.12 ml/kg)



Mortality: 31 vs. 38 (p < 0.007)

PIP: 32 vs. 39 cmH2O
Pplat: 25 vs. 33 cmH2O

NEJM 2000;342:1301-1308

FiO_2	.30	.40	.40	.50	.50	.60	.70	.70	.70	.80	.90	.90	.90	1.0
PEEP	5	5	8	8	10	10	10	12	14	14	14	16	18	18-24

Oxygenation target

PEEP and FiO2 allowances in PEEP studies

FiO_2	.30	.40	.40	.50	.50	.60	.70	.70	.70	.80	.90	.90	.90	1.0
PEEP	5	5	8	8	10	10	10	12	14	14	14	16	18	18-24

ARDS Network 6 versus 12 ml/kg: NEJM 2000;342:1301-1308

Lo-PEEP/Hi-FiO_2 Treatment Group FiO_2

FiO_2	.30	.40	.40	.50	.50	.60	.70	.70	.70	.80	.90	.90	.90	1.0
PEEP	5	5	8	8	10	10	10	12	14	14	14	16	18	18-24

Hi-PEEP/Lo-FiO_2 Study Group FiO_2

FiO_2	.30	.30	.30	.30	.30	.40	.40	.50	.50	.50-.80	.80	.90	1.0	1.0
PEEP	5	8	10	12	14	14	16	16	18	20	22	22	22	24

ALVEOLI: NEJM 2004;351:327-336

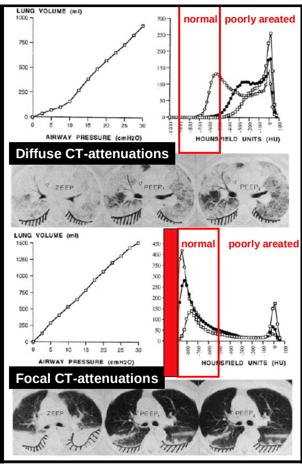
	Fraction of Inspired Oxygen (FiO_2)							
	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Control PEEP ranges, cm H_2O	5	5-8	8-10	10	10-14	14	14-18	18-24
Lung open ventilation PEEP ranges, cm H_2O								
Before protocol change	5-10	10-14	14-20	20	20	20	20	20-24
After protocol change	5-10	10-18	18-20	20	20	20-22	22	22-24

LOVES: Meade MO 2008;299(6):637-645

CT-aeration

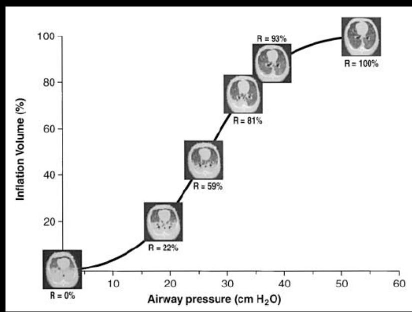
At ZEEP and 2 PEEP levels

= turning up the PEEP approach



Rouby JJ AJRCCM 2002;165:1182-6

"Anatomical" Recruitment



Recruit to TLC (?)

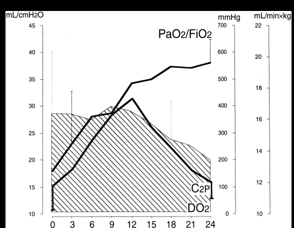
Gattinoni L
AJRCCM 2001; 164:1701

Focus is on "opening" (re-aerating) previously collapsed lung units

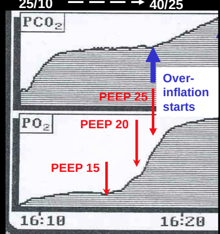
The PEEP step approach: "Functional" Recruitment

Focus is on "opening",
but certainly on avoiding overdistending lung units

P/F-ratio, oxygen delivery and quasi-static Crs during PEEP steps



Pressure control ventilation
25/10 — — — → 40/25

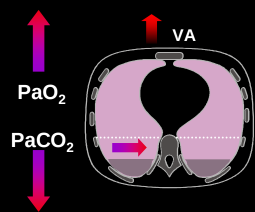


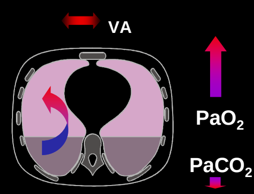
Lichtwarck-Aschoff M AJRCCM 2000; 182:2125-32

Rimensberger 2000 (unpublished)

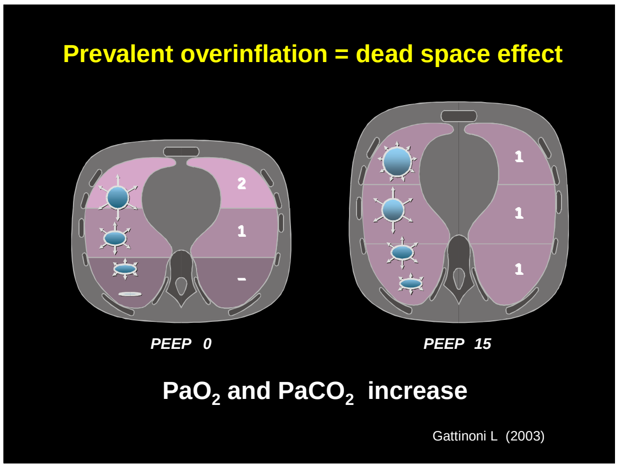
O_2-improvement = Shunt improvement =

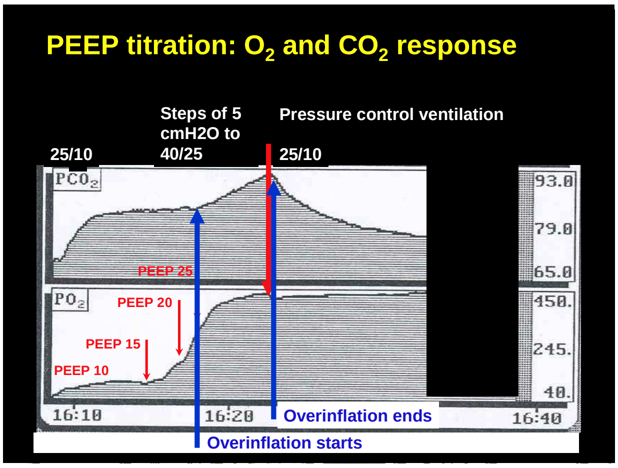
a) recruitment **b) flow diversion**

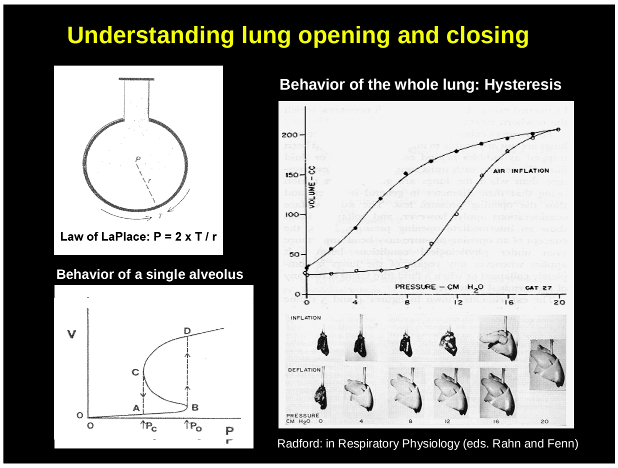


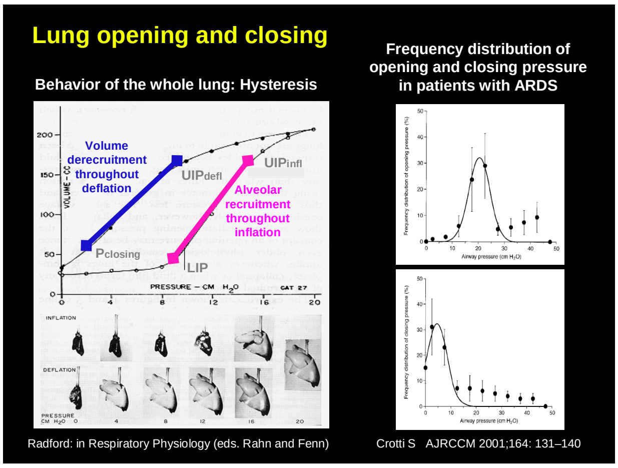


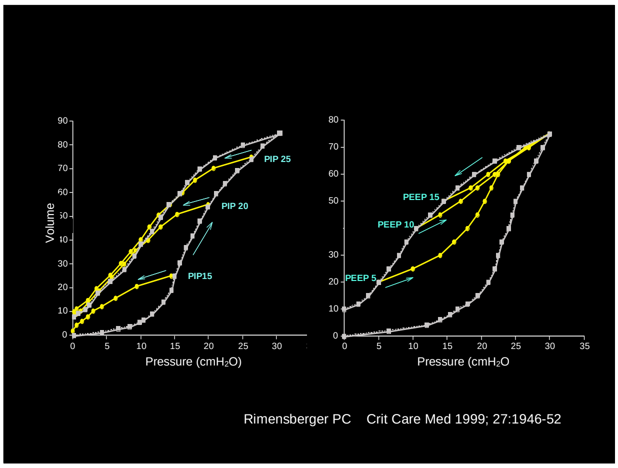
Gattinoni L (2003)

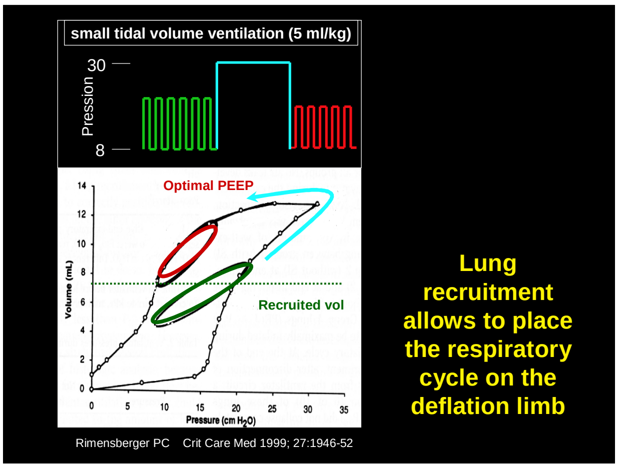

Prevalent overinflation = dead space effect
PEEP 0
PEEP 15
PaO2 and PaCO2 increase
Gattinoni L (2003)

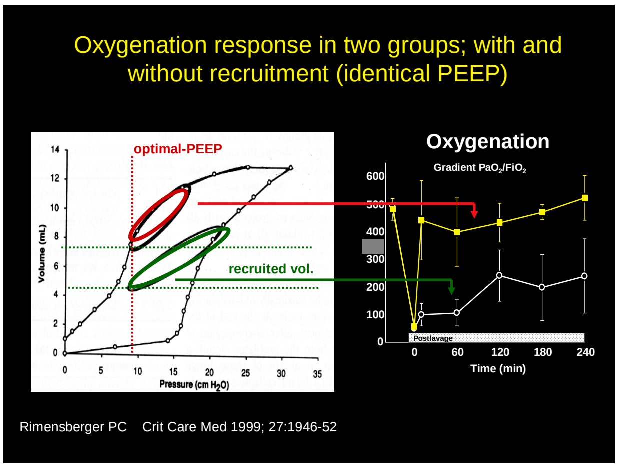

PEEP titration: O2 and CO2 response
Steps of 5 cmH2O to 40/25
Pressure control ventilation
25/10
25/10
PCO2
PO2
PEEP 25
PEEP 20
PEEP 15
PEEP 10
93.0
79.0
65.0
450.
245.
40.
16:10
16:20
16:40
Overinflation ends
Overinflation starts

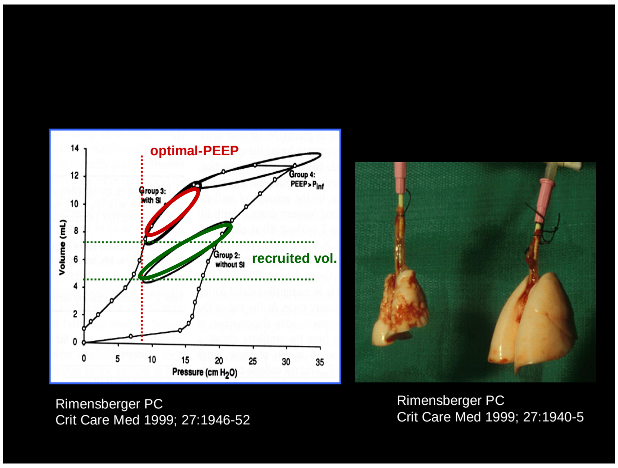

Understanding lung opening and closing
Law of LaPlace: P = 2 x T / r
Behavior of a single alveolus
Behavior of the whole lung: Hysteresis
AIR INFLATION
PRESSURE – CM H2O
INFLATION
DEFLATION
Radford: in Respiratory Physiology (eds. Rahn and Fenn)

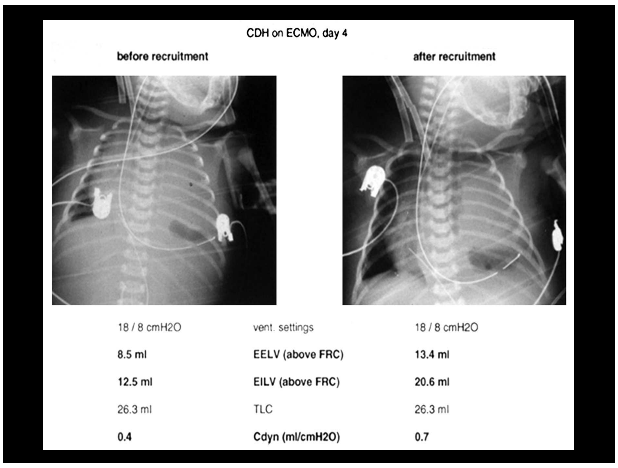

Lung opening and closing
Behavior of the whole lung: Hysteresis
Volume derecruitment throughout deflation
UIPdefl
UIPinfl
Alveolar recruitment throughout inflation
Pclosing
LIP
PRESSURE – CM H2O
Frequency distribution of opening and closing pressure in patients with ARDS
Radford: in Respiratory Physiology (eds. Rahn and Fenn)
Crotti S AJRCCM 2001;164: 131–140

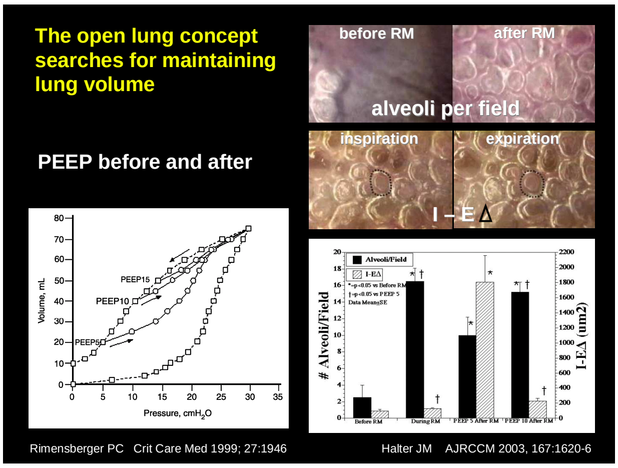

Volume
PIP 25
PIP 20
PIP15
Pressure (cmH2O)
PEEP 15
PEEP 10
PEEP 5
Pressure (cmH2O)
Rimensberger PC Crit Care Med 1999; 27:1946-52

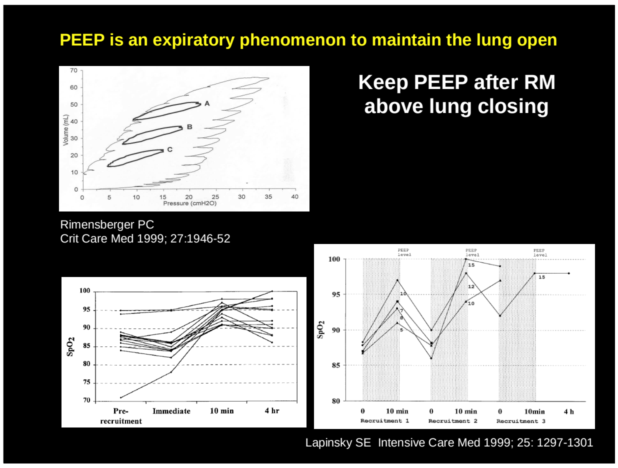

small tidal volume ventilation (5 ml/kg)
30
Pression
8
Optimal PEEP
Volume (mL)
Recruited vol
Pressure (cm H2O)
Lung recruitment allows to place the respiratory cycle on the deflation limb
Rimensberger PC Crit Care Med 1999; 27:1946-52

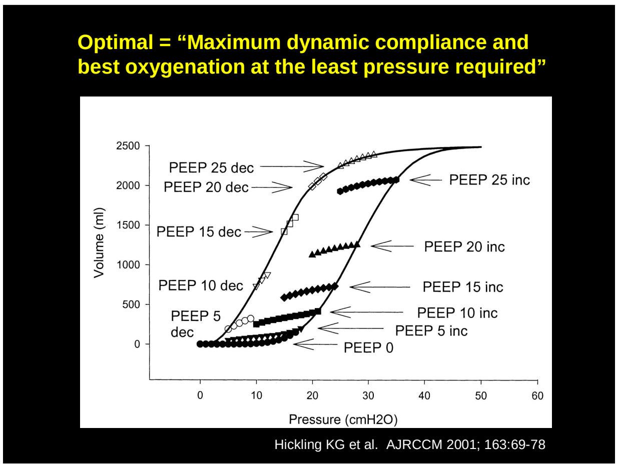

Oxygenation response in two groups; with and without recruitment (identical PEEP)
optimal-PEEP
recruited vol.
Volume (mL)
Pressure (cm H2O)
Oxygenation
Gradient PaO2/FiO2
Postlavage
Time (min)
Rimensberger PC Crit Care Med 1999; 27:1946-52

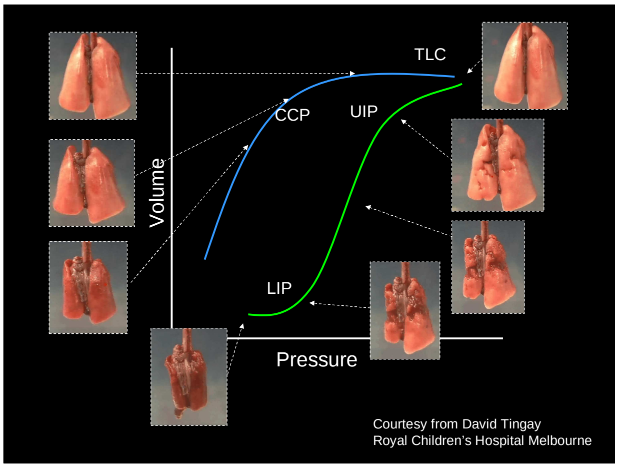

optimal-PEEP
Group 3: with SI
Group 4: PEEP > Pinf
Group 2: without SI
recruited vol.
Volume (mL)
Pressure (cm H2O)
Rimensberger PC
Crit Care Med 1999; 27:1946-52
Rimensberger PC
Crit Care Med 1999; 27:1940-5

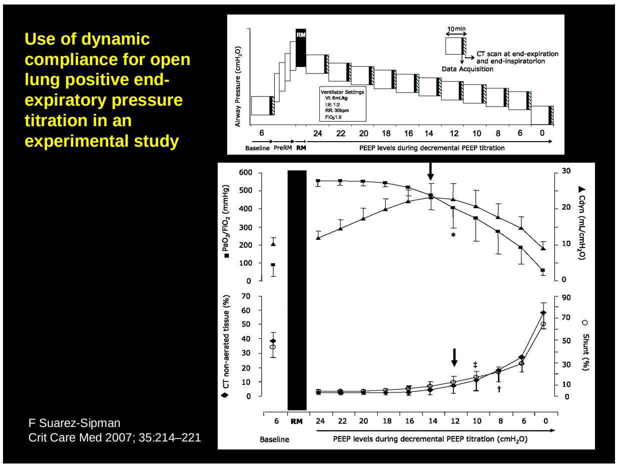

CDH on ECMO, day 4
before recruitment
after recruitment
18 / 8 cmH2O | vent. settings | 18 / 8 cmH2O
8.5 ml | EELV (above FRC) | 13.4 ml
12.5 ml | EILV (above FRC) | 20.6 ml
26.3 ml | TLC | 26.3 ml
0.4 | Cdyn (ml/cmH2O) | 0.7

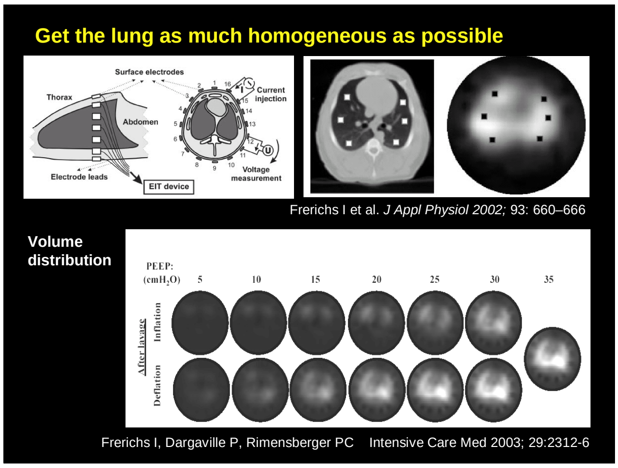

The open lung concept searches for maintaining lung volume
before RM
after RM
alveoli per field
inspiration
expiration
I – E Δ
PEEP before and after
PEEP15
PEEP10
PEEP5
Volume, mL
Pressure, cmH2O
Alveoli/Field
I-EΔ (um2)
Rimensberger PC Crit Care Med 1999; 27:1946
Halter JM AJRCCM 2003, 167:1620-6

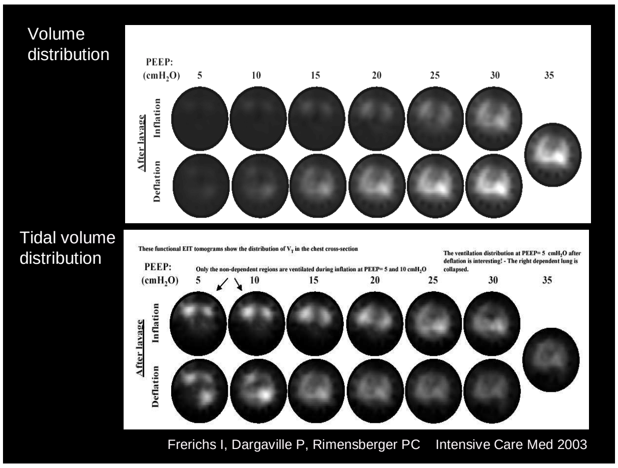

PEEP is an expiratory phenomenon to maintain the lung open
Keep PEEP after RM above lung closing
Rimensberger PC
Crit Care Med 1999; 27:1946-52
Pre-recruitment
Immediate
10 min
4 hr
Recruitment 1
Recruitment 2
Recruitment 3
Lapinsky SE Intensive Care Med 1999; 25: 1297-1301

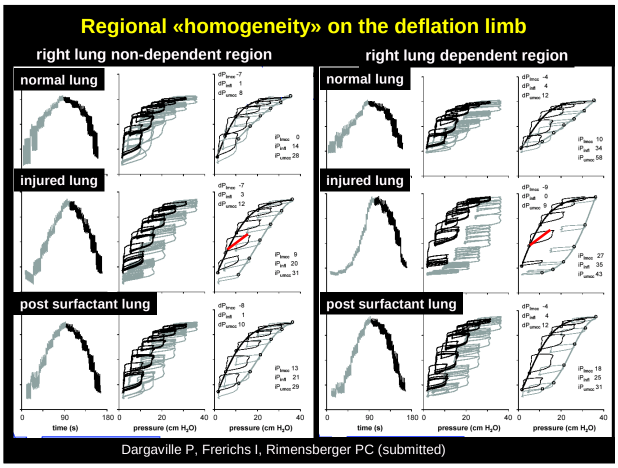

Optimal = "Maximum dynamic compliance and best oxygenation at the least pressure required"
PEEP 25 dec
PEEP 20 dec
PEEP 15 dec
PEEP 10 dec
PEEP 5 dec
PEEP 25 inc
PEEP 20 inc
PEEP 15 inc
PEEP 10 inc
PEEP 5 inc
PEEP 0
Volume (ml)
Pressure (cmH2O)
Hickling KG et al. AJRCCM 2001; 163:69-78

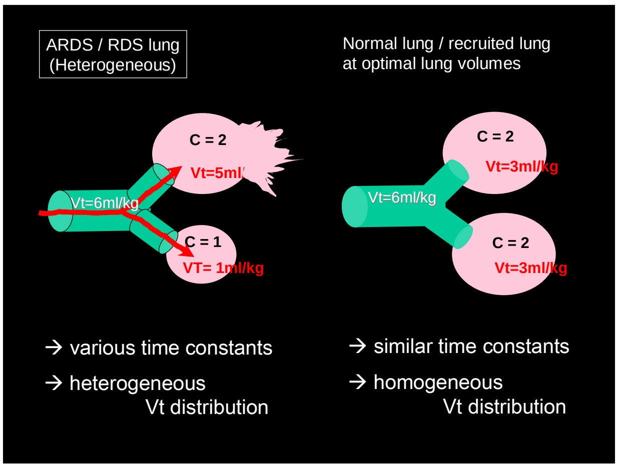

TLC
CCP
UIP
Volume
LIP
Pressure
Courtesy from David Tingay
Royal Children's Hospital Melbourne


Use of dynamic compliance for open lung positive end-expiratory pressure titration in an experimental study
F Suarez-Sipman
Crit Care Med 2007; 35:214–221
PEEP levels during decremental PEEP titration
Baseline
PEEP levels during decremental PEEP titration (cmH2O)

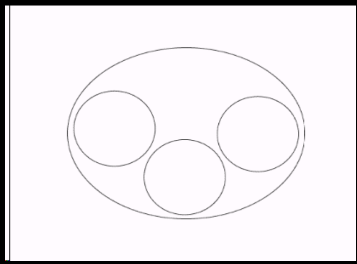

Get the lung as much homogeneous as possible
Surface electrodes
Thorax
Abdomen
Current injection
Electrode leads
EIT device
Voltage measurement
Frerichs I et al. J Appl Physiol 2002; 93: 660–666
Volume distribution
PEEP: (cmH2O) 5 10 15 20 25 30 35
After lavage
Inflation
Deflation
Frerichs I, Dargaville P, Rimensberger PC Intensive Care Med 2003; 29:2312-6


Volume distribution
PEEP: (cmH2O) 5 10 15 20 25 30 35
After lavage
Inflation
Deflation
Tidal volume distribution
Frerichs I, Dargaville P, Rimensberger PC Intensive Care Med 2003


Regional «homogeneity» on the deflation limb
right lung non-dependent region
right lung dependent region
normal lung
injured lung
post surfactant lung
time (s)
pressure (cm H2O)
Dargaville P, Frerichs I, Rimensberger PC (submitted)

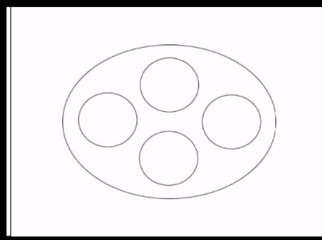

ARDS / RDS lung
(Heterogeneous)
Normal lung / recruited lung
at optimal lung volumes
C = 2
Vt=5ml
Vt=6ml/kg
C = 1
VT= 1ml/kg
C = 2
Vt=3ml/kg
Vt=6ml/kg
C = 2
Vt=3ml/kg
→ various time constants
→ heterogeneous Vt distribution
→ similar time constants
→ homogeneous Vt distribution

Heterogeneous: Injured Lung



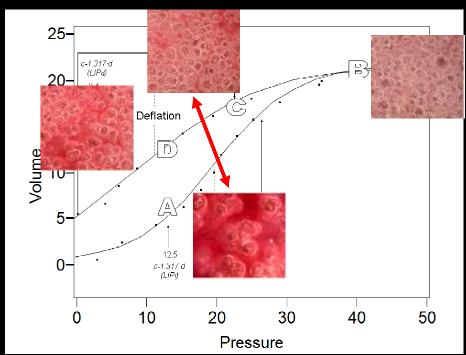
Alveolar Overdistension into the Area of the Collapsed Alveoli

Homogeneous: Normal Lung



Minimal Change in Alveolar Size with Ventilation

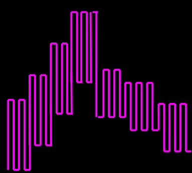
Correlation of Inflection Points with Individual Alveolar R/D

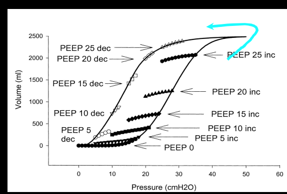


DiRocco et al. *Intensive Care Med*

Best approach to recruitment: «Open the lung and keep it open»

Use the smallest Vt you can afford (you deal with a baby lung !)





then you have to work you through to find the optimal <u>least</u> PEEP approach = “Functional Approach to Recruitment”

Your tools at bedside: P/F ratio, PaCO2 and Cdyn

There is no sound rational for fixed PEEP and FiO2 schemes as used in PEEP studies !

FiO_2	.30	.40	.40	.50	.50	.60	.70	.70	.70	.80	.90	.90	.90	1.0
PEEP	5	5	8	8	10	10	10	12	14	14	14	16	18	18-24

ARDS Network 6 versus 12 ml/kg: NEJM 2000;342:1301-1308

Lo-PEEP/Hi-FiO_2 Treatment Group FiO_2

FiO_2	.30	.40	.40	.50	.50	.60	.70	.70	.70	.80	.90	.90	.90	1.0
PEEP	5	5	8	8	10	10	10	12	14	14	14	16	18	18-24

Hi-PEEP/Lo-FiO_2 Study Group FiO_2

FiO_2	.30	.30	.30	.30	.30	.40	.40	.50	.50	.50-.80	.80	.90	1.0	1.0
PEEP	5	8	10	12	14	14	16	16	18	20	22	22	22	24

ALVEOLI: NEJM 2004;351:327-336

	Fraction of Inspired Oxygen (FiO_2)							
	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Control PEEP ranges, cm H_2O	5	5-8	8-10	10	10-14	14	14-18	18-24
Lung open ventilation PEEP ranges, cm H_2O								
Before protocol change	5-10	10-14	14-20	20	20	20	20	20-24
After protocol change	5-10	10-18	18-20	20	20	20-22	22	22-24

LOVES: Meade MO 2008;299(6):637-645

But there is a significant risk of overdistending many patients