
Basic respiratory mechanics
relevant for mechanical vnetilation
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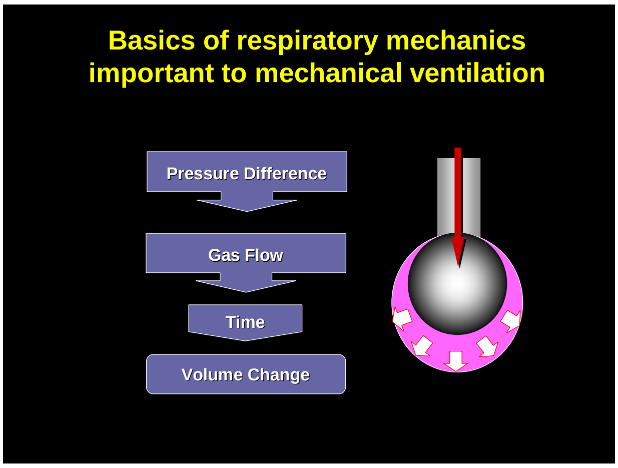
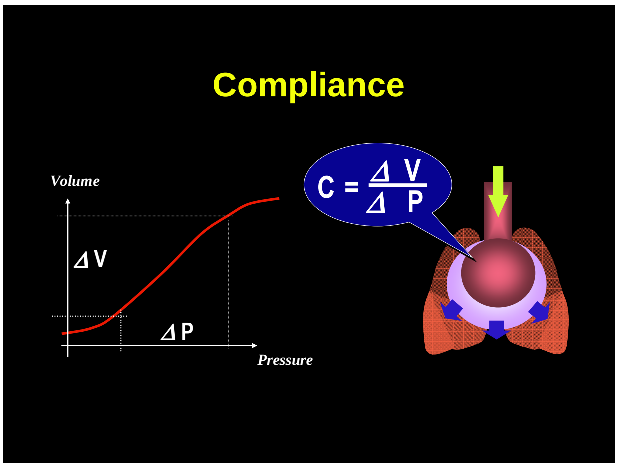
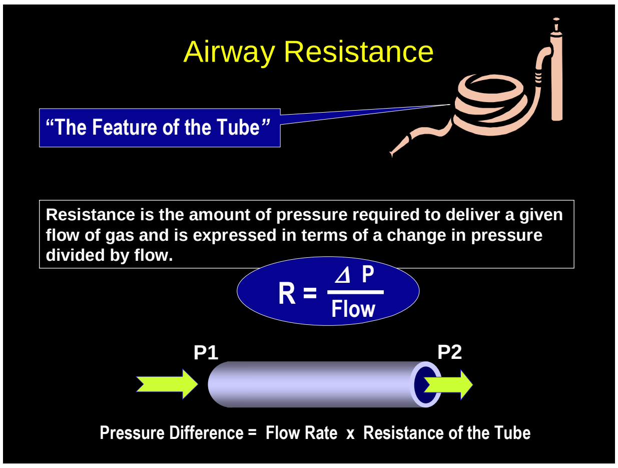
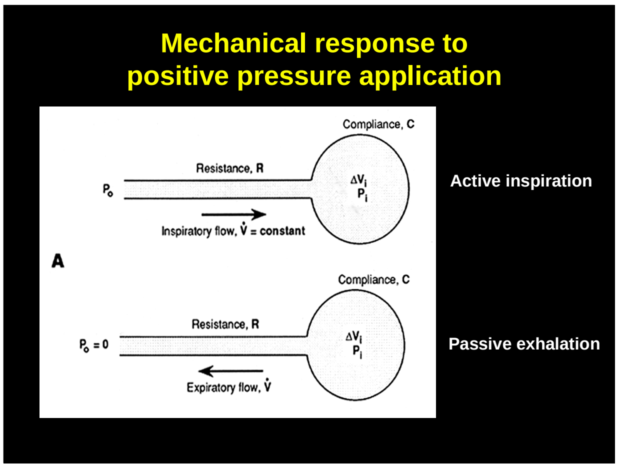
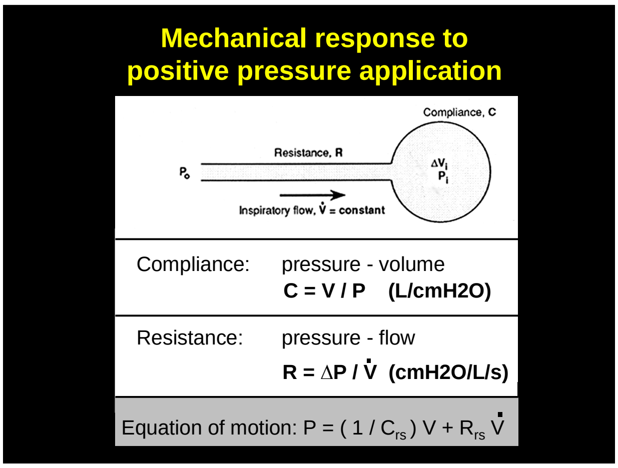

Basics of respiratory mechanics
important to mechanical ventilation
Pressure Difference
Gas Flow
Time
Volume Change


Compliance
Volume
ΔV
ΔP
Pressure
C = ΔV / ΔP


Airway Resistance
"The Feature of the Tube"
Resistance is the amount of pressure required to deliver a given flow of gas and is expressed in terms of a change in pressure divided by flow.
R = ΔP / Flow
P1
P2
Pressure Difference = Flow Rate x Resistance of the Tube

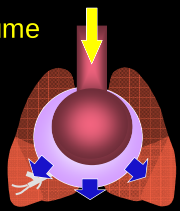

Mechanical response to
positive pressure application
Compliance, C
Resistance, R
Po
ΔVi
Pi
Inspiratory flow, V̇ = constant
Active inspiration
A
Compliance, C
Resistance, R
Po = 0
ΔVi
Pi
Expiratory flow, V̇
Passive exhalation


Mechanical response to
positive pressure application
Compliance, C
Resistance, R
Po
ΔVi
Pi
Inspiratory flow, V̇ = constant
Compliance: pressure - volume
C = V / P (L/cmH2O)
Resistance: pressure - flow
R = ΔP / V̇ (cmH2O/L/s)
Equation of motion: P = (1 / Crs) V + Rrs V̇

Pressure – Flow – Time - Volume

P = (1 / Crs) x V + ~~Rrs x V̇~~

ΔVol,max = ΔP x Crs



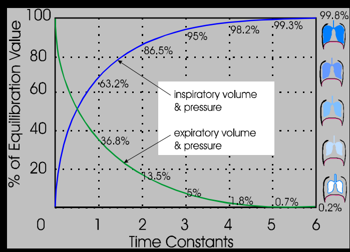
Volume change requires time to take place.

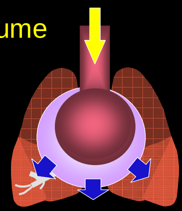
When a step change in pressure is applied, the instantaneous change in volume follows an exponential curve, which means that, formerly faster, it slows down progressively while it approaches the new equilibrium.

Time constant: T = Crs x Rrs

Pressure – Flow – Time - Volume

Time constant: T = Crs x Rrs

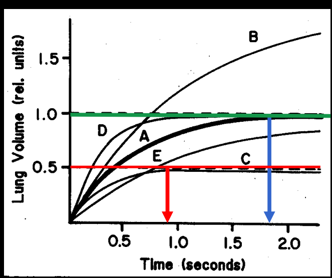




Will pressure equilibrium be reached in the lungs?

Effect of varying time constants on the change in lung volume over time

(with constant inflating pressure at the airway opening)



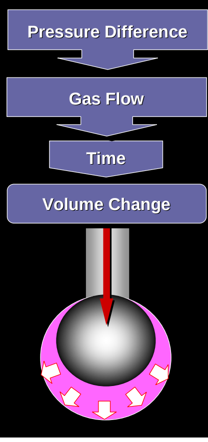
A: Crs = 1, R = 1

B: Crs = 2 (T = R x 2C)

C: Crs = 0.5 (T = R x 1/2C) (reduced inspiratory capacity to 0.5)

D: R = 0.5 (T = 1/2R x C)

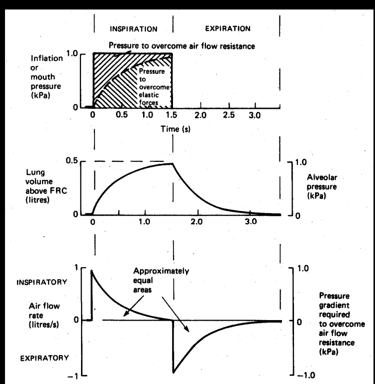
E: R = 2 (T = 2R x C)



Ventilators deliver gas to the lungs using positive pressure at a certain *rate*.

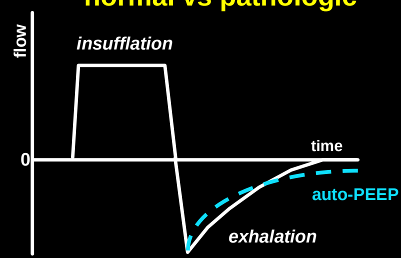
The amount of gas delivered can be *limited* by time, pressure or volume.

The duration can be *cycled* by time, pressure or flow.

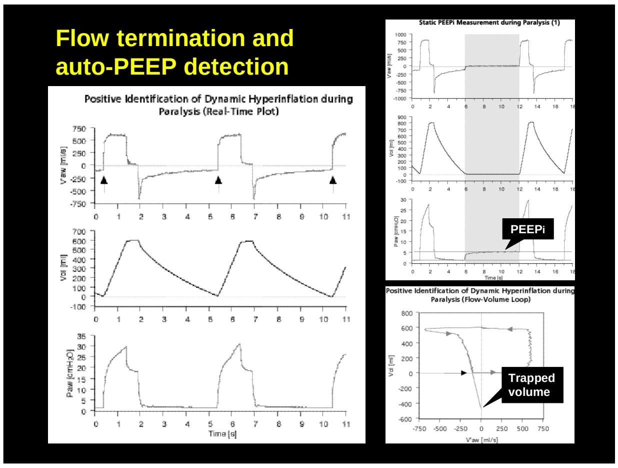


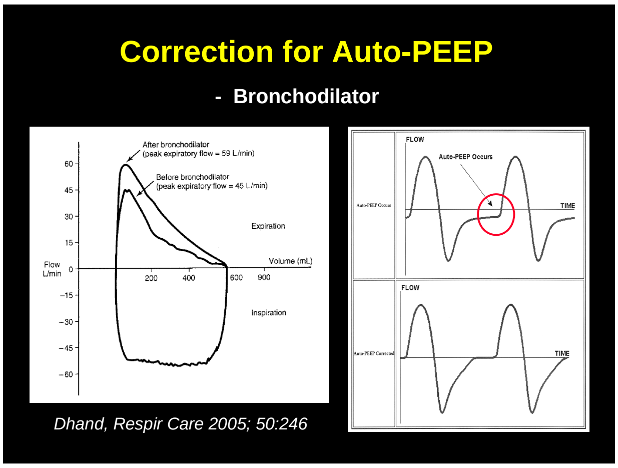
Nunn JF Applied respiratory physiology 1987:397

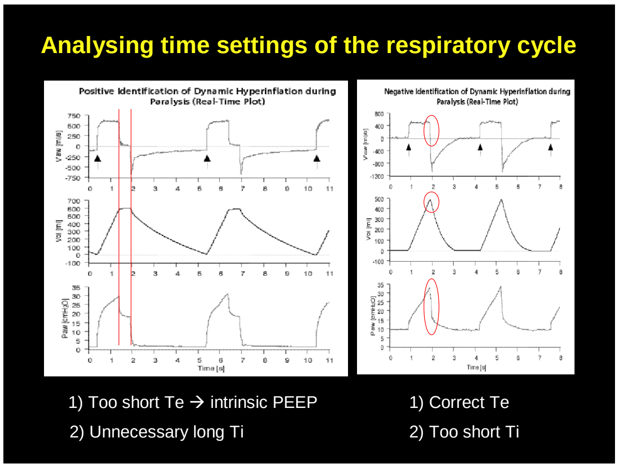
Expiratory flow waveform: normal vs pathologic

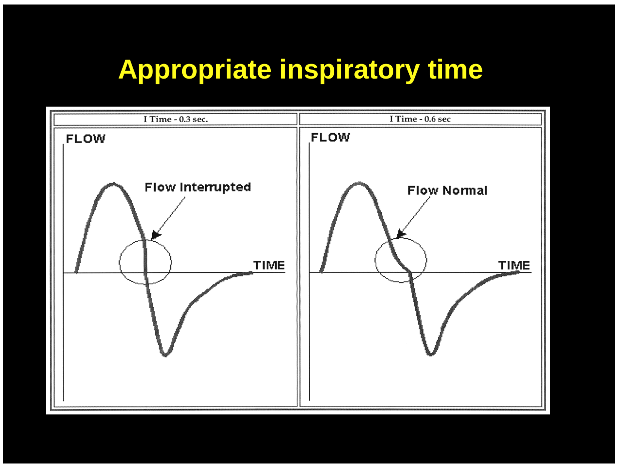


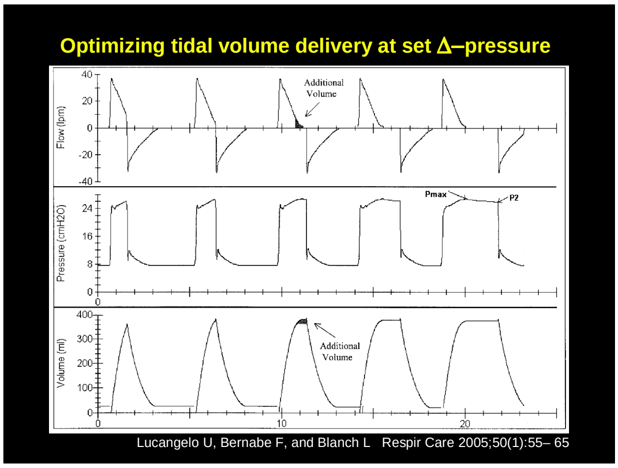
Premature flow termination during expiration = "gas trapping" = deadspace (Vd/Vt) will increase

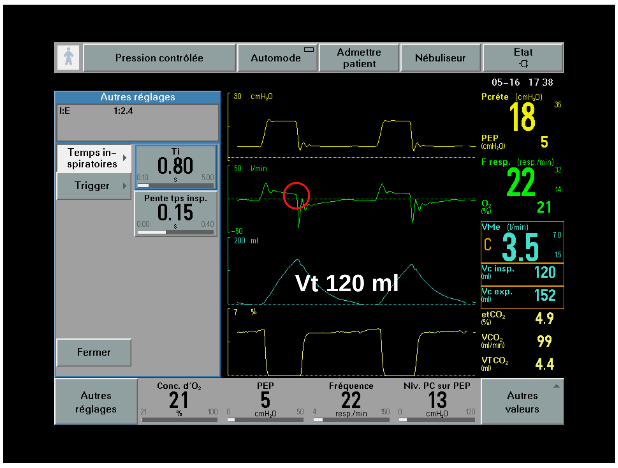

Flow termination and
auto-PEEP detection
Positive Identification of Dynamic Hyperinflation during Paralysis (Real-Time Plot)
Static PEEPi Measurement during Paralysis (1)
PEEPi
Positive Identification of Dynamic Hyperinflation during Paralysis (Flow-Volume Loop)
Trapped volume
Time [s]

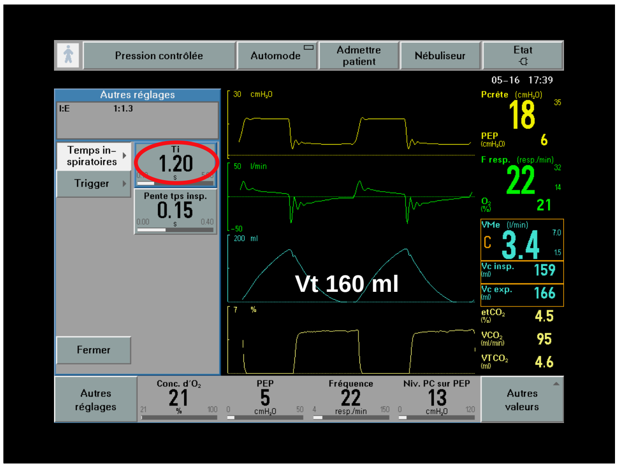

Correction for Auto-PEEP
- Bronchodilator
After bronchodilator
(peak expiratory flow = 59 L/min)
Before bronchodilator
(peak expiratory flow = 45 L/min)
Expiration
Volume (mL)
Inspiration
Flow
L/min
FLOW
Auto-PEEP Occurs
TIME
FLOW
TIME
Dhand, Respir Care 2005; 50:246

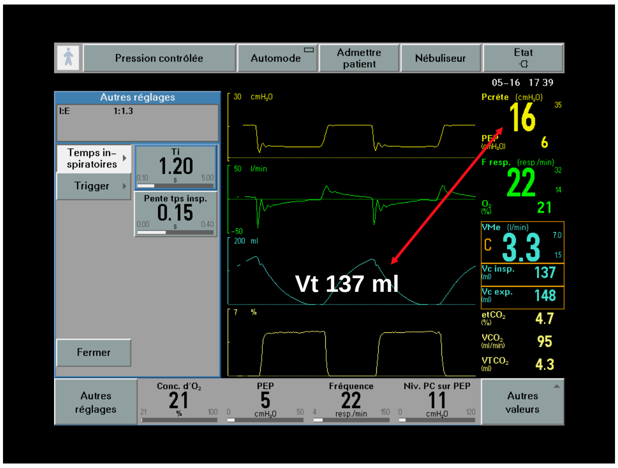

Analysing time settings of the respiratory cycle
Positive Identification of Dynamic Hyperinflation during Paralysis (Real-Time Plot)
Negative Identification of Dynamic Hyperinflation during Paralysis (Real-Time Plot)
1) Too short Te → intrinsic PEEP
2) Unnecessary long Ti
1) Correct Te
2) Too short Ti

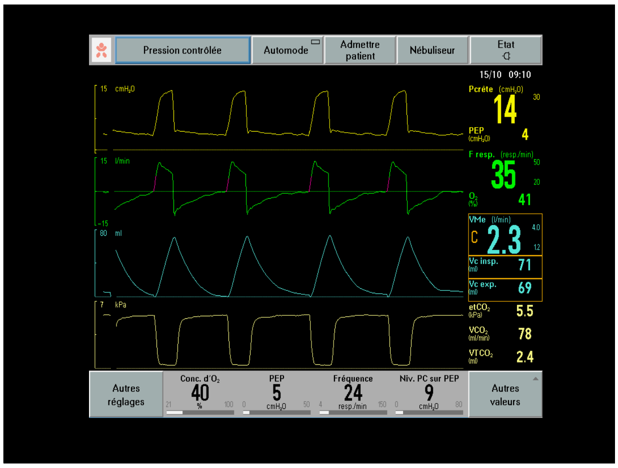

Appropriate inspiratory time
I Time - 0.3 sec.
I Time - 0.6 sec
FLOW
Flow Interrupted
TIME
FLOW
Flow Normal
TIME

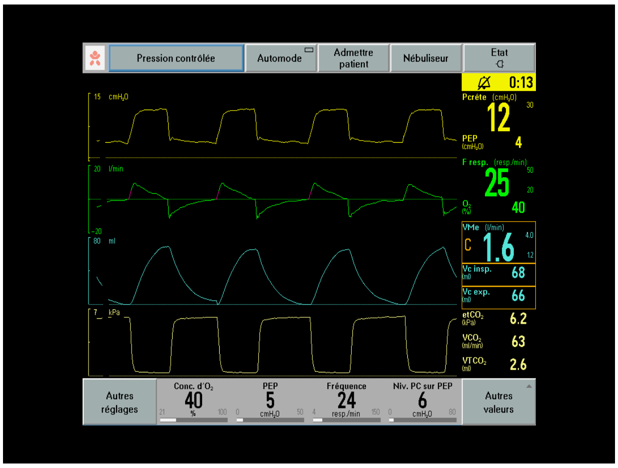

Optimizing tidal volume delivery at set Δ–pressure
Flow (lpm)
Additional Volume
Pressure (cmH2O)
Pmax
P2
Volume (ml)
Additional Volume
Lucangelo U, Bernabe F, and Blanch L Respir Care 2005;50(1):55– 65

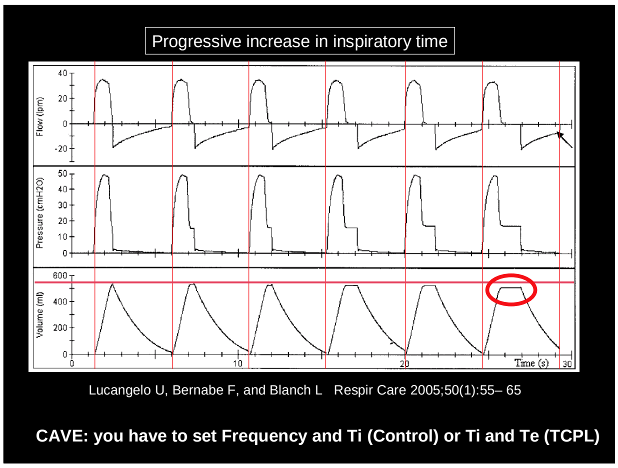

Pression contrôlée
Automode
Admettre patient
Nébuliseur
Etat
Autres réglages
I:E
1:2.4
Temps in-spiratoires
Ti
0.80
Trigger
Pente tps insp.
0.15
Fermer
Vt 120 ml
Pcrête
18
PEP
5
F resp.
22
21
VMe
3.5
Vc insp.
120
Vc exp.
152
etCO2
4.9
VCO2
99
VTCO2
4.4
Conc. d'O2
21
PEP
5
Fréquence
22
Niv. PC sur PEP
13
Autres valeurs

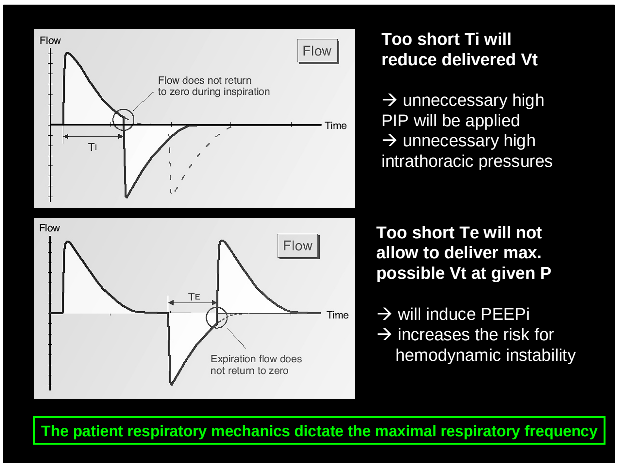

Pression contrôlée
Automode
Admettre patient
Nébuliseur
Etat
Autres réglages
Temps in-spiratoires
Ti
1.20
Trigger
Pente tps insp.
0.15
Fermer
Vt 160 ml
Autres réglages
Conc. d'O2
21
PEP
5
Fréquence
22
Niv. PC sur PEP
13
Autres valeurs

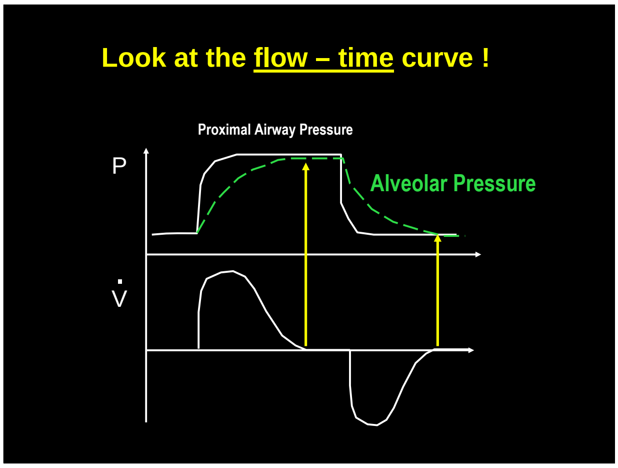

Pression contrôlée
Automode
Admettre patient
Nébuliseur
Etat
Autres réglages
Temps in-spiratoires
Ti
1.20
Trigger
Pente tps insp.
0.15
Fermer
Vt 137 ml
Autres réglages
Conc. d'O2
21
PEP
5
Fréquence
22
Niv. PC sur PEP
11
Autres valeurs

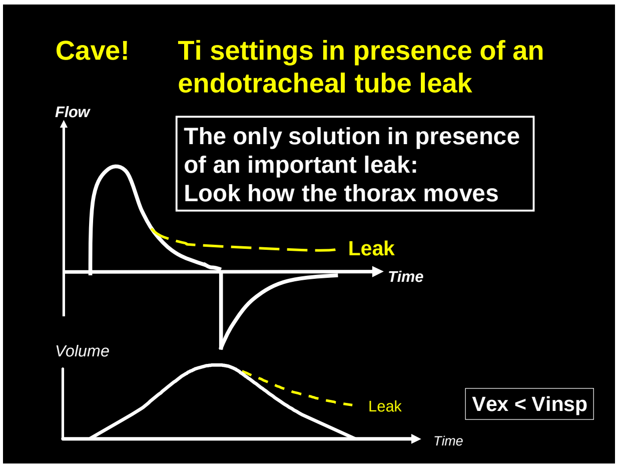

Pression contrôlée
Automode
Admettre patient
Nébuliseur
Etat
Autres réglages
Conc. d'O2
40
PEP
5
Fréquence
24
Niv. PC sur PEP
9
Autres valeurs

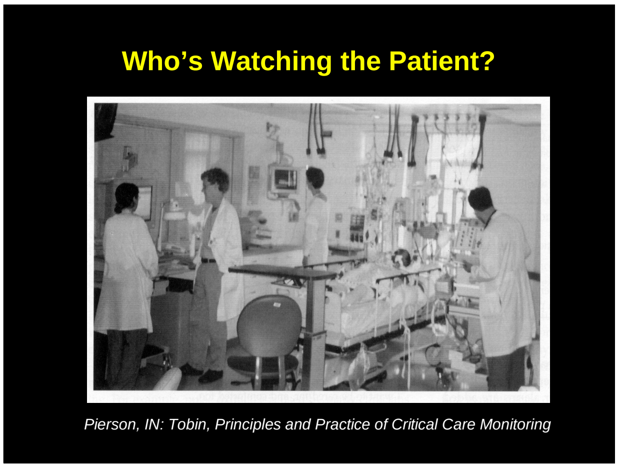

Pression contrôlée
Automode
Admettre patient
Nébuliseur
Etat
Autres réglages
Conc. d'O2
40
PEP
5
Fréquence
24
Niv. PC sur PEP
6
Autres valeurs

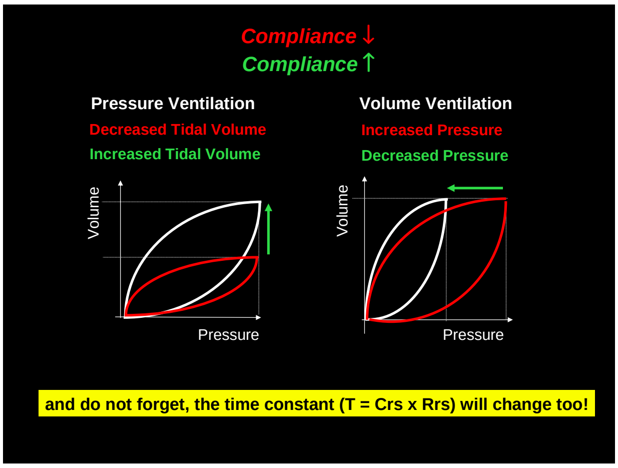

Progressive increase in inspiratory time
Flow (lpm)
Pressure (cmH2O)
Volume (ml)
Time (s)
Lucangelo U, Bernabe F, and Blanch L Respir Care 2005;50(1):55– 65
CAVE: you have to set Frequency and Ti (Control) or Ti and Te (TCPL)

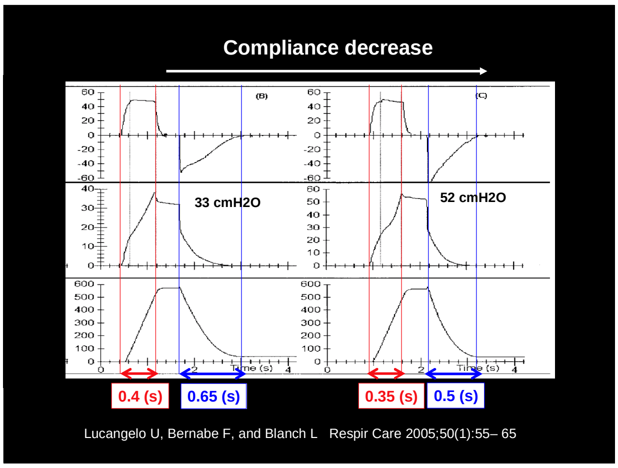

Flow
Flow does not return to zero during inspiration
Time
Ti
Too short Ti will reduce delivered Vt
→ unneccessary high PIP will be applied
→ unnecessary high intrathoracic pressures
Te
Expiration flow does not return to zero
Too short Te will not allow to deliver max. possible Vt at given P
→ will induce PEEPi
→ increases the risk for hemodynamic instability
The patient respiratory mechanics dictate the maximal respiratory frequency

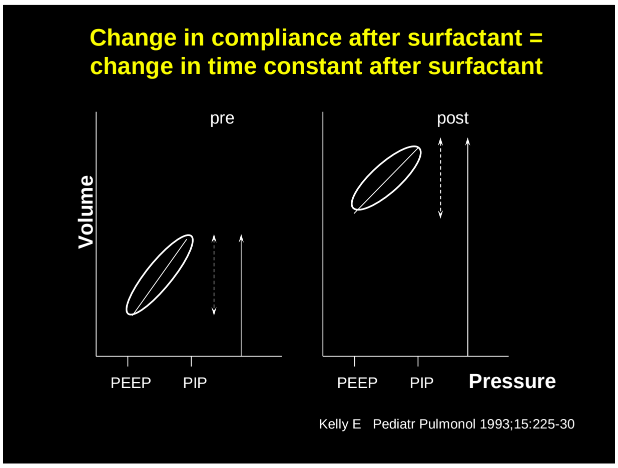

Look at the flow – time curve !
Proximal Airway Pressure
P
Alveolar Pressure
V̇

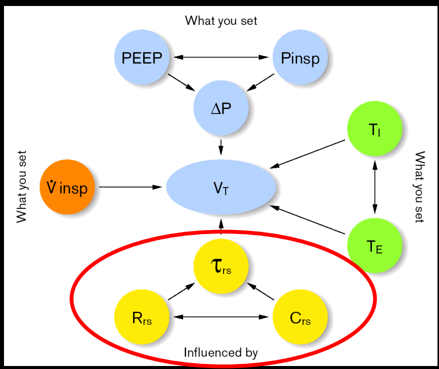

Cave!
Ti settings in presence of an endotracheal tube leak
Flow
The only solution in presence of an important leak:
Look how the thorax moves
Leak
Time
Volume
Leak
Vex < Vinsp
Time


Who's Watching the Patient?
Pierson, IN: Tobin, Principles and Practice of Critical Care Monitoring


Compliance ↓
Compliance ↑
Pressure Ventilation
Decreased Tidal Volume
Increased Tidal Volume
Volume Ventilation
Increased Pressure
Decreased Pressure
Volume
Pressure
Volume
Pressure
and do not forget, the time constant (T = Crs x Rrs) will change too!

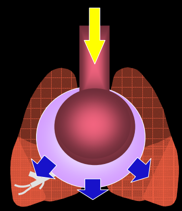

Compliance decrease
33 cmH2O
52 cmH2O
0.4 (s)
0.65 (s)
0.35 (s)
0.5 (s)
Lucangelo U, Bernabe F, and Blanch L Respir Care 2005;50(1):55– 65


Change in compliance after surfactant = change in time constant after surfactant
pre
post
Volume
PEEP
PIP
PEEP
PIP
Pressure
Kelly E Pediatr Pulmonol 1993;15:225-30



Volume Guarantee: New Approaches in Volume Controlled Ventilation for Neonates.
Ahluwalia J, Morley C, Wahle G. Dräger Medizintechnik GmbH. ISBN 3-926762-42-X

To measure compliance and resistance - is it in the clinical setting important ?

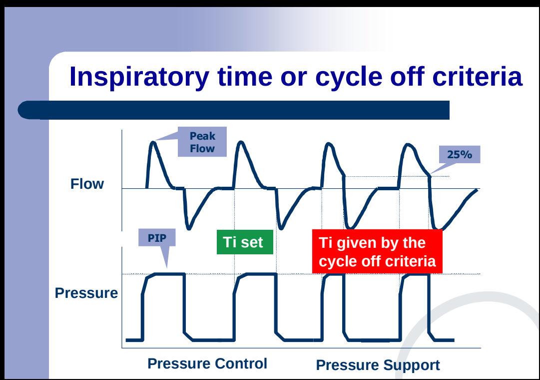


Time constant: τ = Crs x Rrs

Use the flow curve for decision making about the settings for respiratory rate and duty cycle in the mechanical ventilator

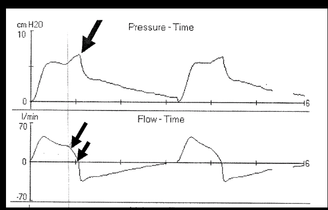
The saying "we ventilate at 40/min" or "with a Ti of 0.3" is a testimony of no understanding !

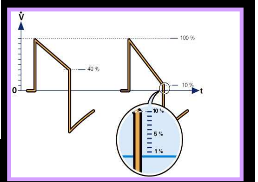
Pressure Control versus Pressure Support



Pressure-Support and flow termination criteria

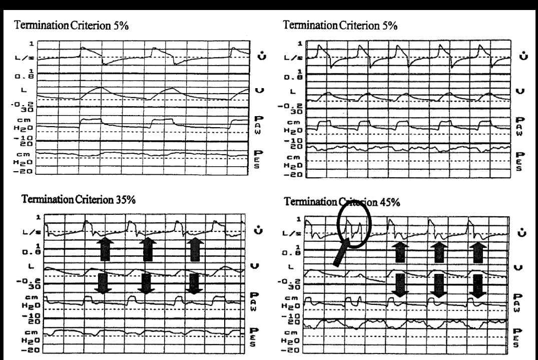
The non synchronized patient during Pressure-Support (inappropriate end-inspiratory flow termination criteria)





Nilsestuen J Respir Care 2005;50:202–232.

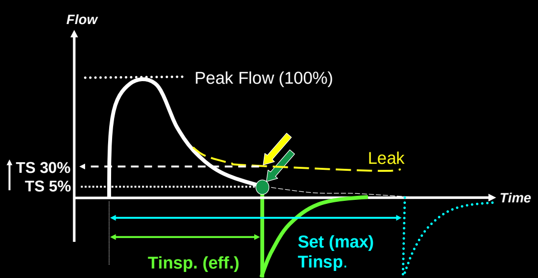
Pressure-Support and flow termination criteria

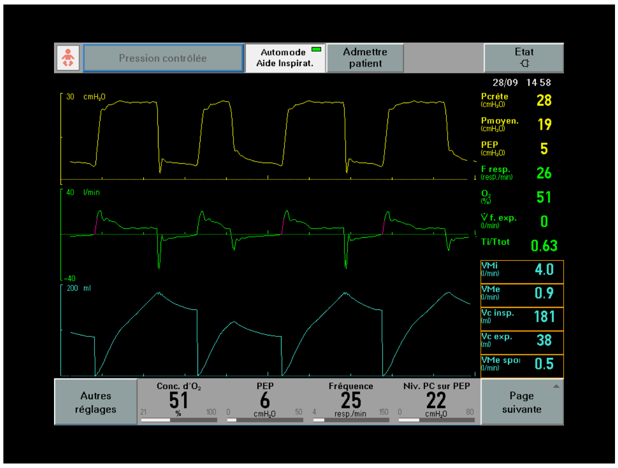


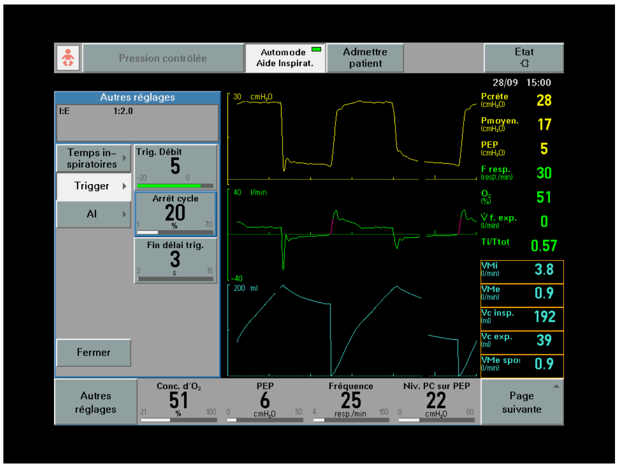
Increase in RR, reduction in VT, increase in WOB

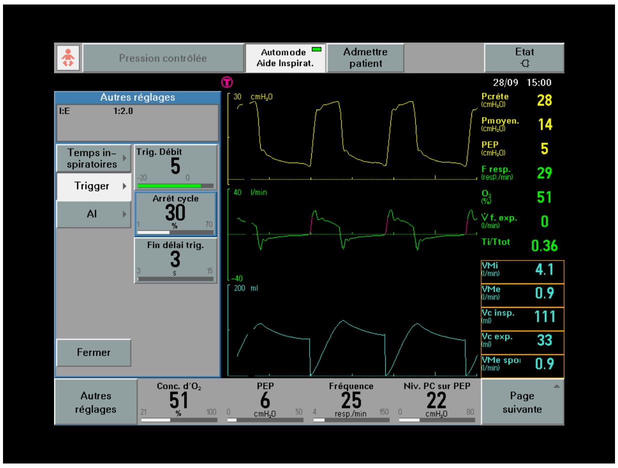
Nilsestuen J
Respir Care 2005

Termination Sensitivity = Cycle-off Criteria

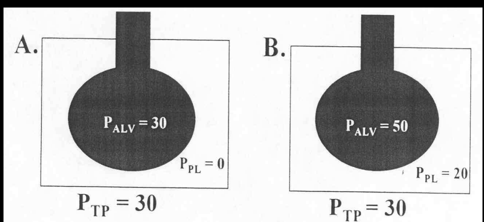








What do airway pressures mean?



Palv = Ppl + Ptp

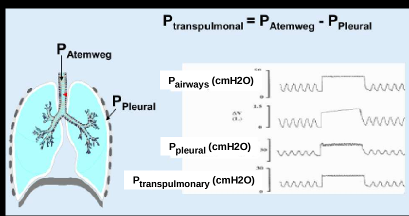
↓

Ptp = Palv - Ppl

Where Ptp is transpulmonary pressure, Palv is alveolar pressure, and Ppl is pleural pressure

Palv = Ppl + Ptp **Etot = EL + Ecw**

when airway resistance is nil (static condition)

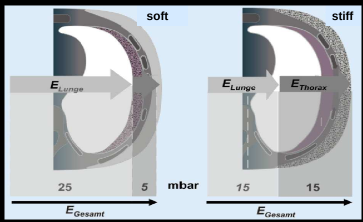


Ppl = Paw x [E cw / (E L + E cw)]

Ptp = Paw x [E L / (E L + E cw)]

Paw = PPl + Ptp

when airway resistance is nil (static condition)



Gattinoni L *Critical Care* 2004, **8**:350-355

Etot = EL + Ecw

Ptp = Paw x [E L / (E L + E cw)]

PPl = Paw x [E cw / (E L + E cw)]

Ptp = Paw x [E L / (E L + E cw)]

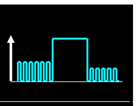
In normal condition: EL = Ecw
Ecw/ Etot = 0.5 and EL/ Etot = 0.5
PTP ~ 50% of Paw applied

In ARDS: PTP ~ 20 to 80% of Paw applied

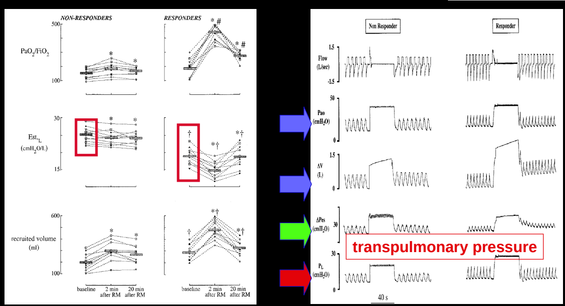
In primary ARDS: EL > Ecw (EL / Etot > 0.5)
Stiff lung, soft thorax — PTP > 50 % of Paw applied

In secondary ARDS: EL < Ecw (EL / Etot < 0.5)
Soft lung, stiff thorax — PTP < 50 % of Paw applied

Respiratory mechanics influence the efficiency of RM



22 ARDS-patients: Vt 6 ml/kg, PEEP and FiO2 to obtain SO2 90–95%
RM: CPAP to 40 cm H2O for 40 s



Grasso S Anesthesiology 2002; 96:795–802

Elastic properties, compliance and FRC in neonates

Neonate chest wall compliance, C_W = 3-6 x C_L, lung compliance tending to decrease FRC, functional residual capacity

By 9-12 months $C_W = C_L$

In infant RDS (HMD): EL >>> Ecw (EL / Etot >>> 0.5)
Stiff lung, very soft thorax — PTP >>> 50 % of Paw applied

Elastic properties, compliance and FRC in neonates

Neonate chest wall compliance, C_W = 3-6 x C_L, lung compliance tending to decrease FRC, functional residual capacity

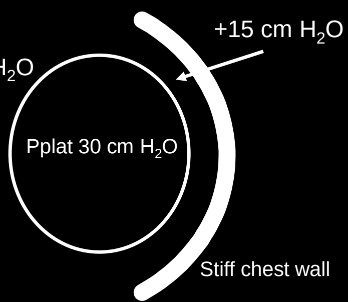
By 9-12 months $C_W = C_L$

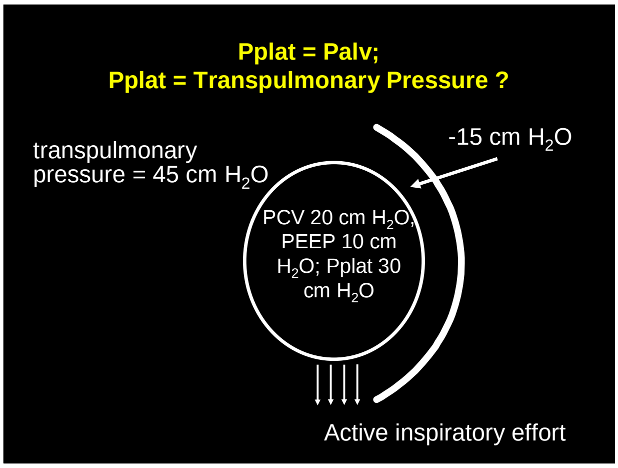
Dynamic FRC in awake, spontaneously ventilating infants is maintained near values seen in older children and adults because of

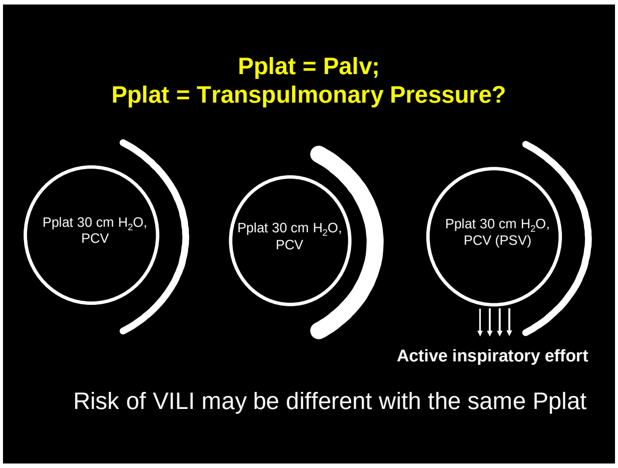
1. continued diaphragmatic activity in early expiratory phase
2. intrinsic PEEP (relative tachypnea with start of inspiration before end of preceding expiration)
3. sustained tonic activity of inspiratory muscles (incl. diaphragma) (probably most important)

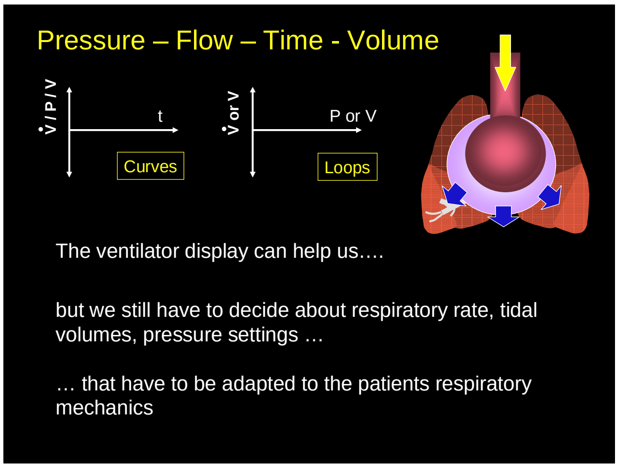
By 1 year of age, relaxed end-expiratory volume predominates

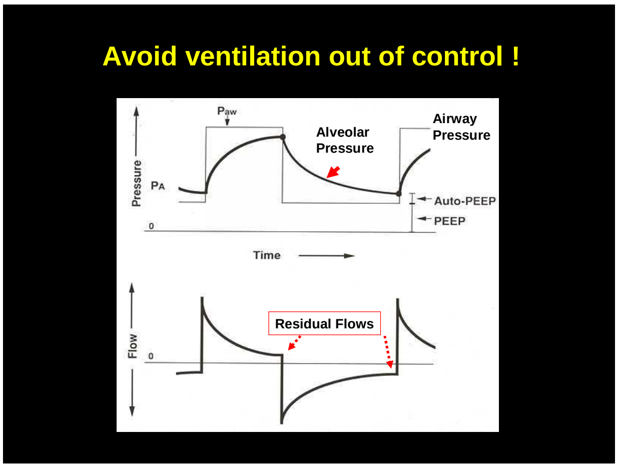
Pplat = Palv;
Pplat = Transpulmonary Pressure ?




Pplat = Palv;
Pplat = Transpulmonary Pressure ?
transpulmonary pressure = 45 cm H_2O
-15 cm H_2O
PCV 20 cm H_2O; PEEP 10 cm H_2O; Pplat 30 cm H_2O
Active inspiratory effort


Pplat = Palv;
Pplat = Transpulmonary Pressure?
Pplat 30 cm H_2O, PCV
Pplat 30 cm H_2O, PCV
Pplat 30 cm H_2O, PCV (PSV)
Active inspiratory effort
Risk of VILI may be different with the same Pplat


Pressure – Flow – Time - Volume
V̇ / P / V
t
Curves
V̇ or V
P or V
Loops
The ventilator display can help us….
but we still have to decide about respiratory rate, tidal volumes, pressure settings …
… that have to be adapted to the patients respiratory mechanics


Avoid ventilation out of control !
Paw
Alveolar Pressure
Airway Pressure
Pressure
PA
Auto-PEEP
PEEP
0
Time
Flow
0
Residual Flows