Minimally invasive ventilation – the principles

Dietmar Enk

University Hospital Münster (UKM)
Department of Anesthesiology and Intensive Care Medicine
D - 48149 Münster (Germany)

Conflict of interest declaration

VENTINOVA — royalties, consultation fees

COOK MEDICAL — royalties

Tritube (Ventinova): Three in one

three lumens:

- ventilation lumen ~ 2.3 mm
- pressure measurement lumen
- cuff lumen

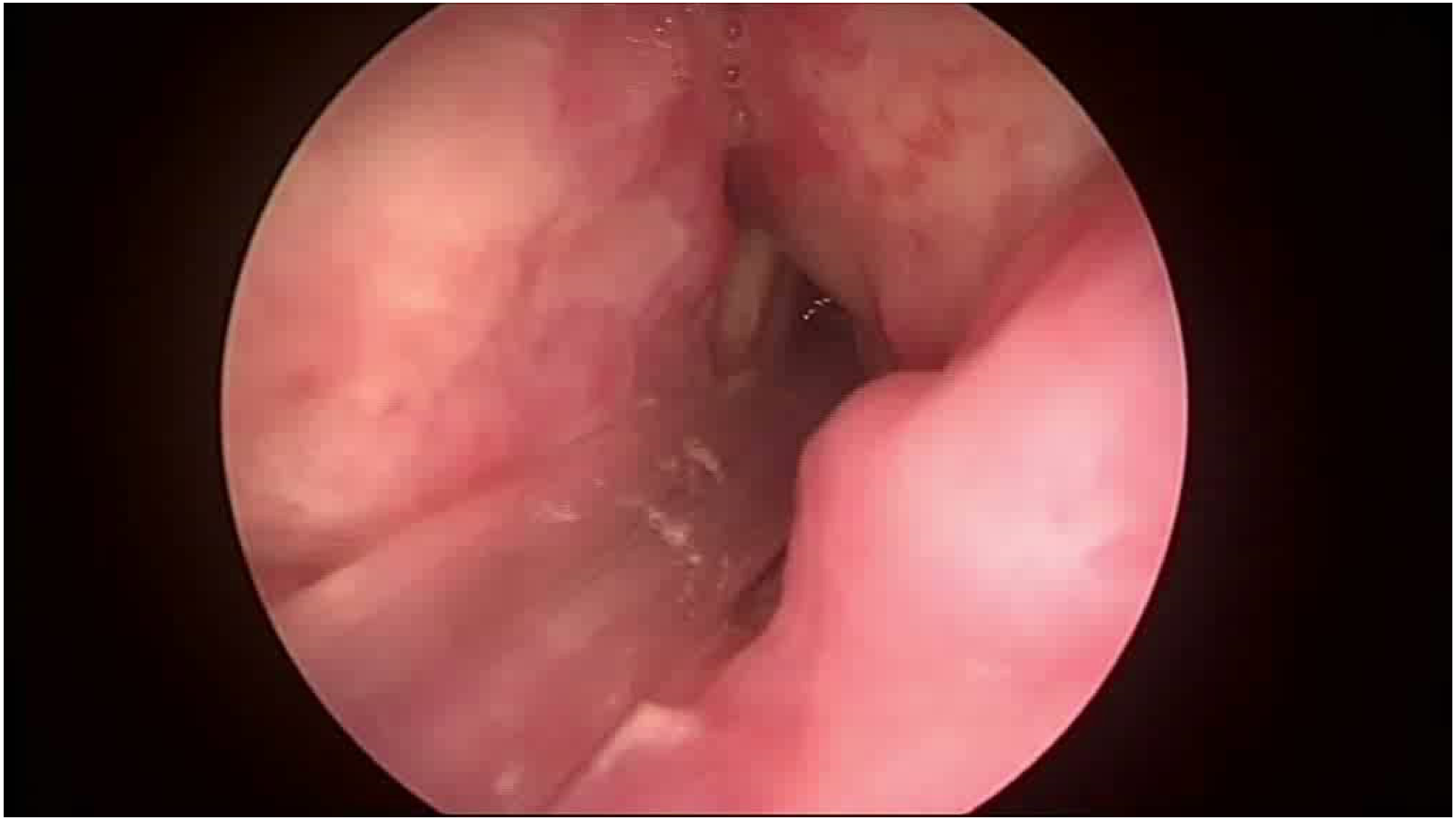
Enk D: patent application 10 2009 013 205.8, DPMA, 17.3.2009
Enk D: patent 5655219, JPO, 21.1.2015

Tritube (Ventinova): Three in one

three functions:
- intubating catheter / stylet
- definitive airway
- extubating catheter / O_2-probe

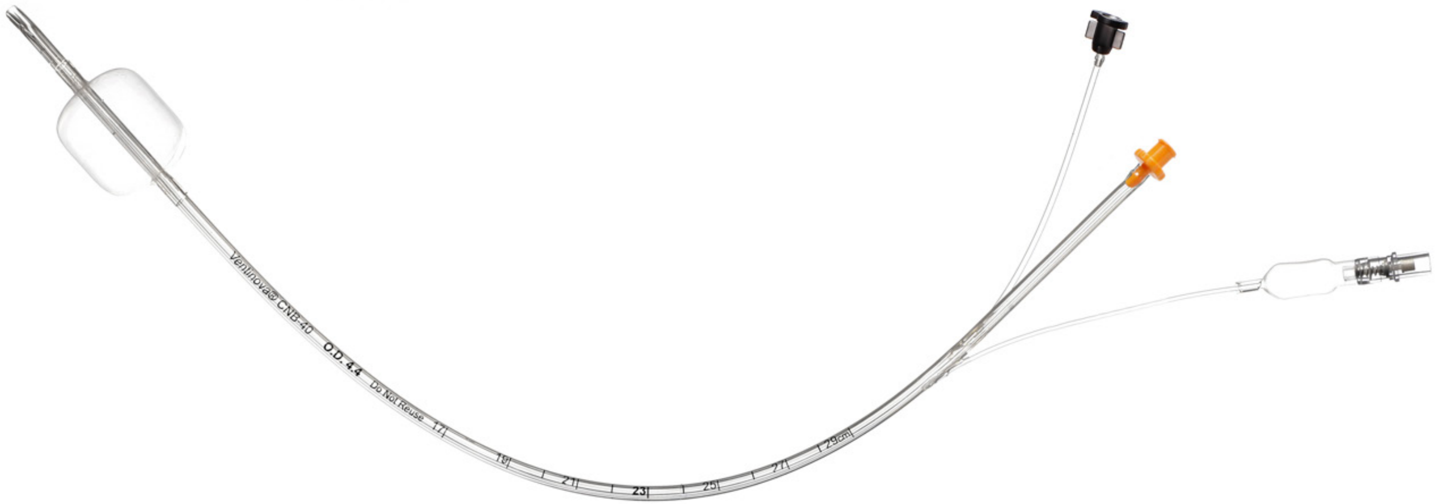
Kristensen MS et al.: Acta Anaesthesiol Scand 61 (2017) 580-589

Tritube (Ventinova): Three in one



courtesy of M. Lacko (MUMC, Maastricht, The Netherlands)

Tritube (Ventinova): Three in one



three benefits:
- less obstruction of the airway
- (elective) seal of the lung
- full control on the lung

Enk D: patent 102355920, SIPO, 22.7.2015
Enk D: patent 2560506, Rospatent, 20.8.2015

Ventilation: Relying on passive expiration

Is today‘s ventilation really controlled ?

Controlling inspiration and expiration

Euroanaesthesia, Berlin, industrial exhibition, Ventinova Medical, 31.5.2015

Lung injury: The „driving pressure“ concept *

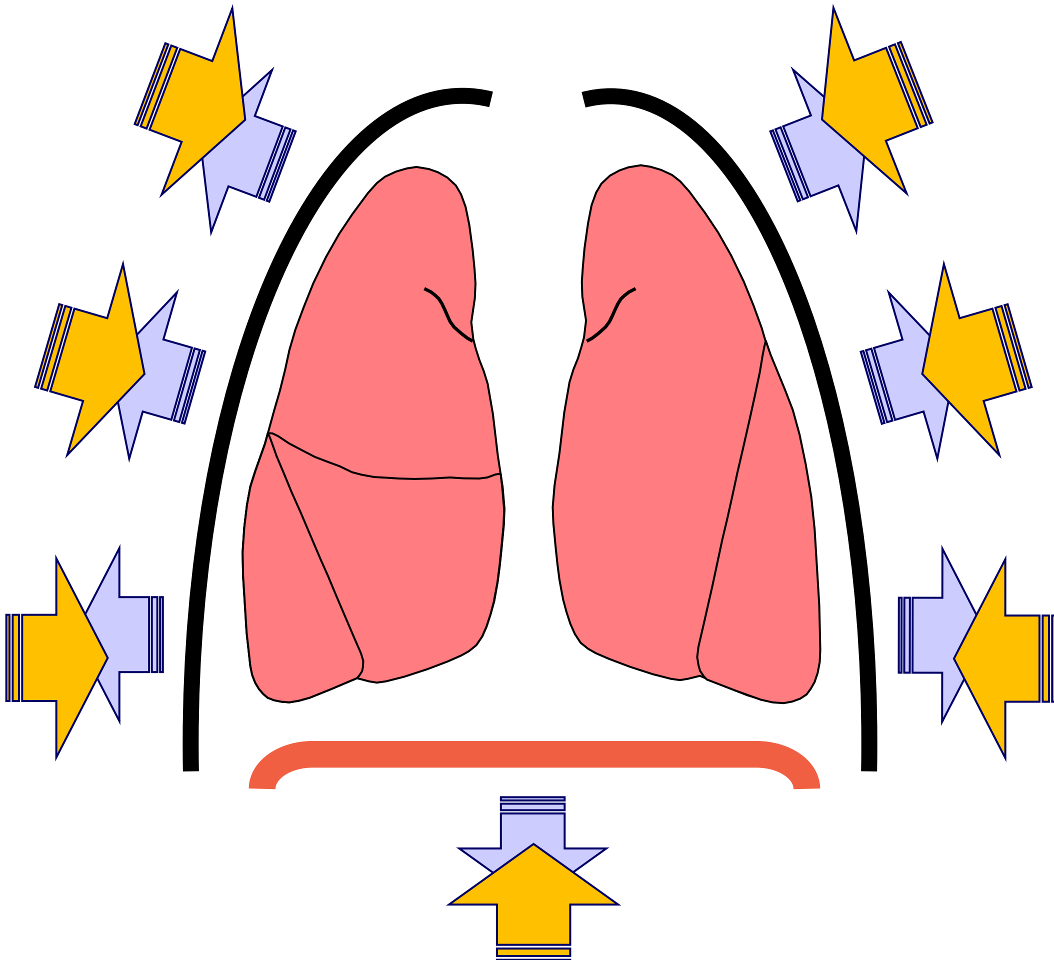
But how to go from PEEP
to PIP / inspiratory plateau
pressure and back to PEEP ?

* Amato MB et al.: N Engl J Med 372 (2015) 747-755

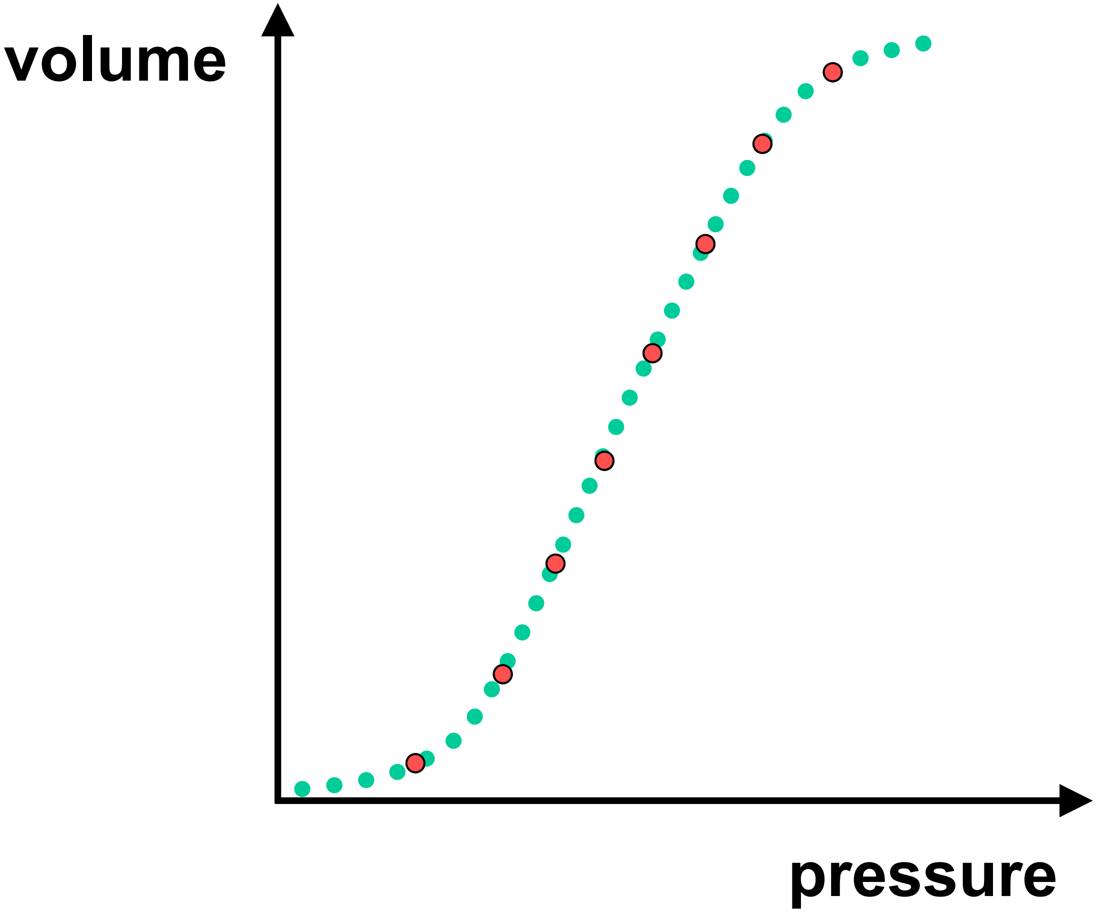
Lung injury: „Driving pressure“ and time

$$\frac{\Delta \text{ pressure}}{\text{time}}$$

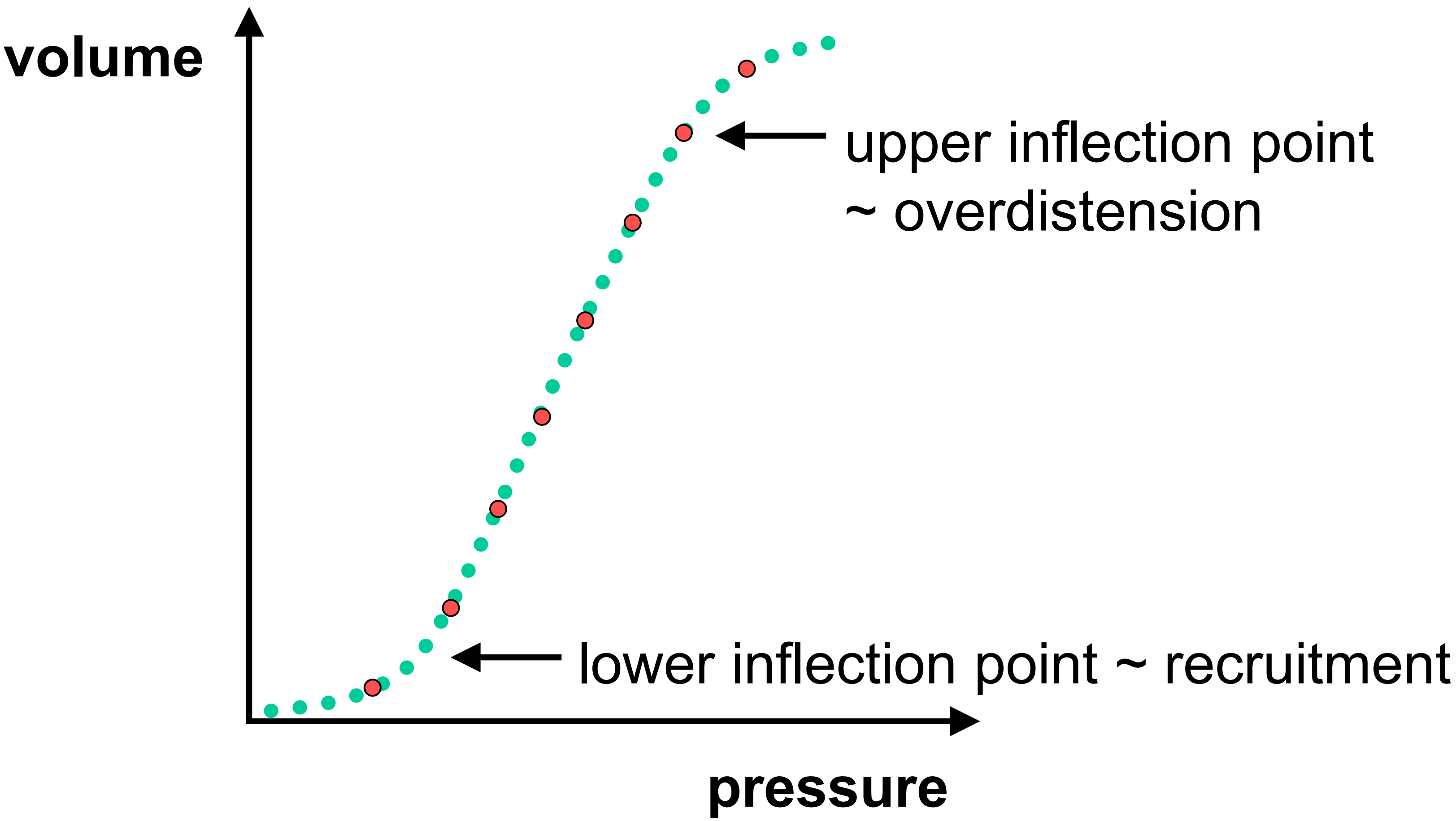
Ventilation as a matter of energy exposure



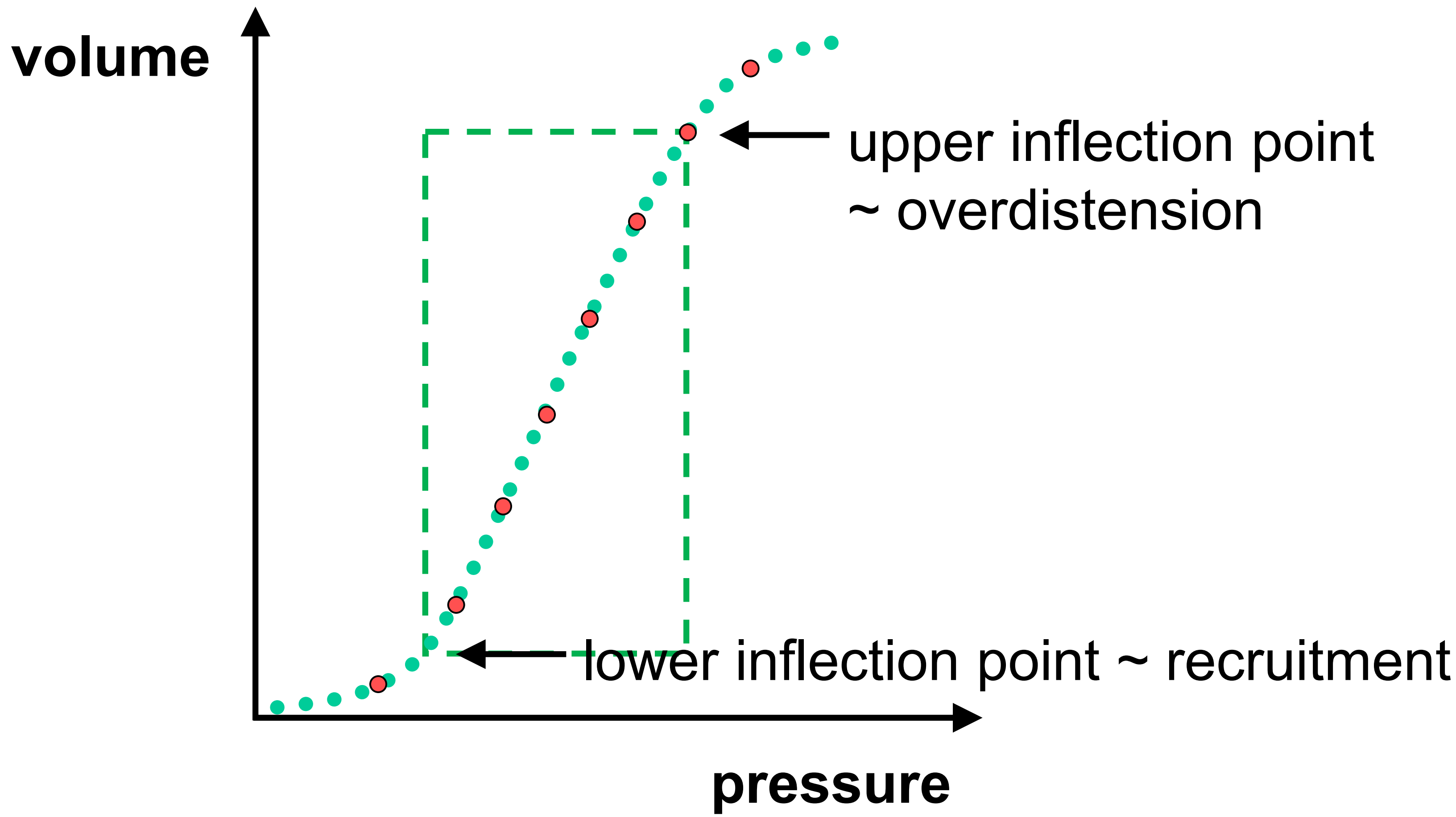
Static compliance curve
(„super syringe method“)



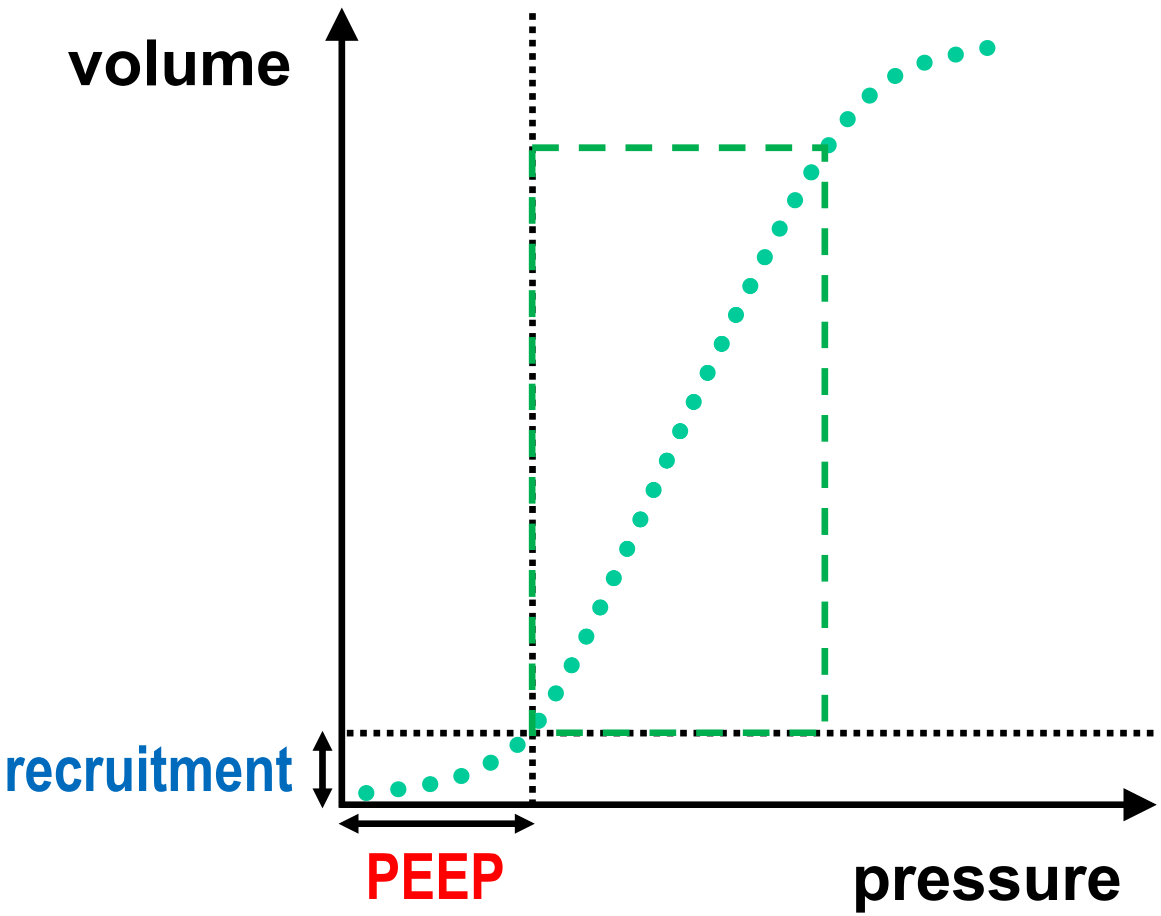
Static compliance curve: LIP and UIP



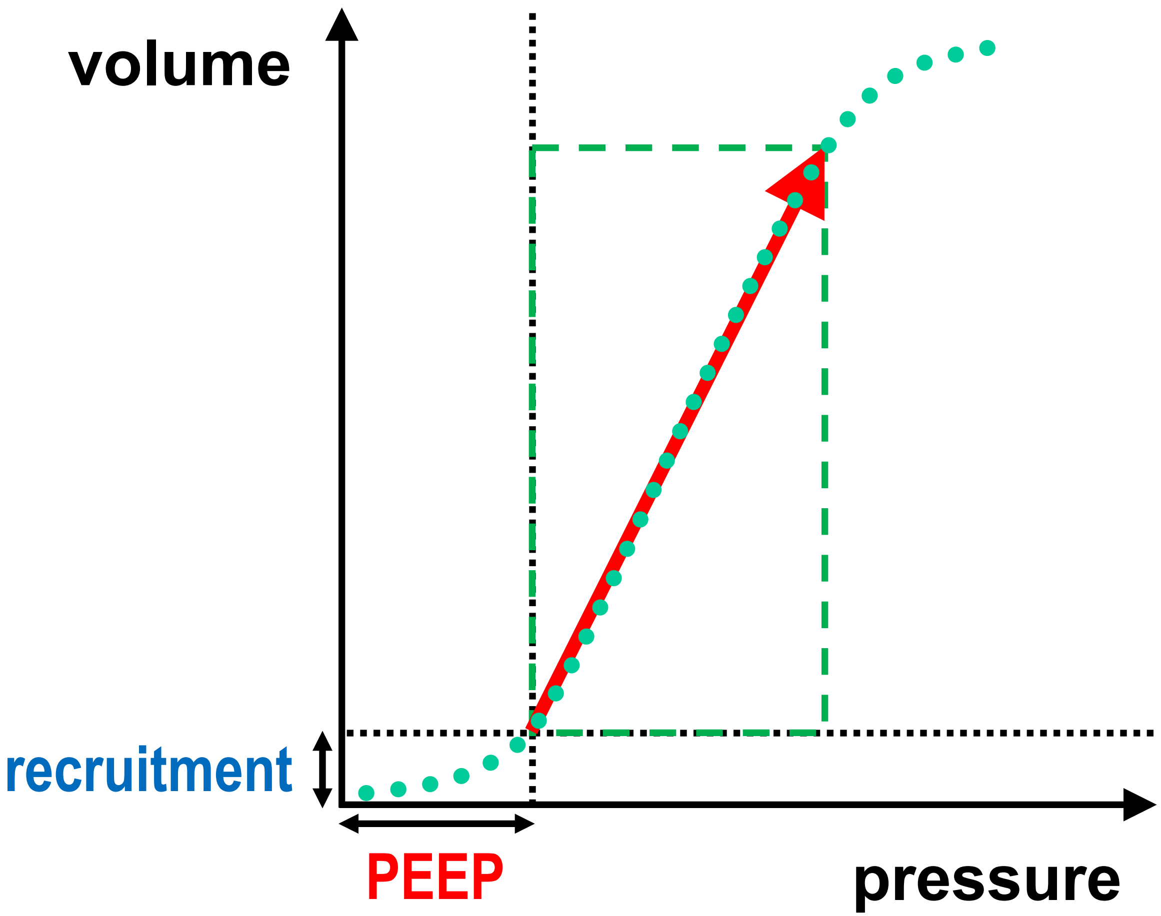
Static compliance curve: LIP and UIP



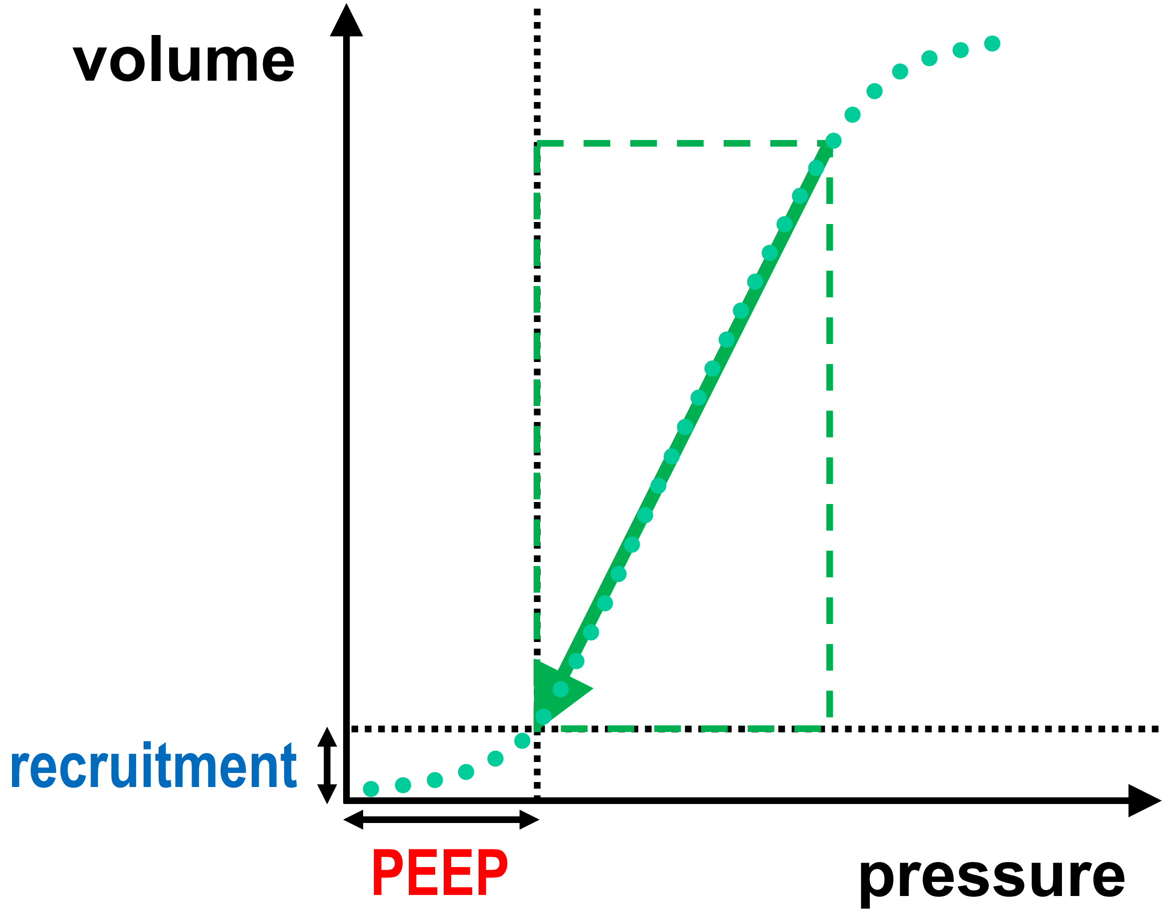
Static compliance curve: PEEP



Static compliance curve: Ideal inspiration



Static compliance curve: Ideal expiration



Pressure, flow, energy and power

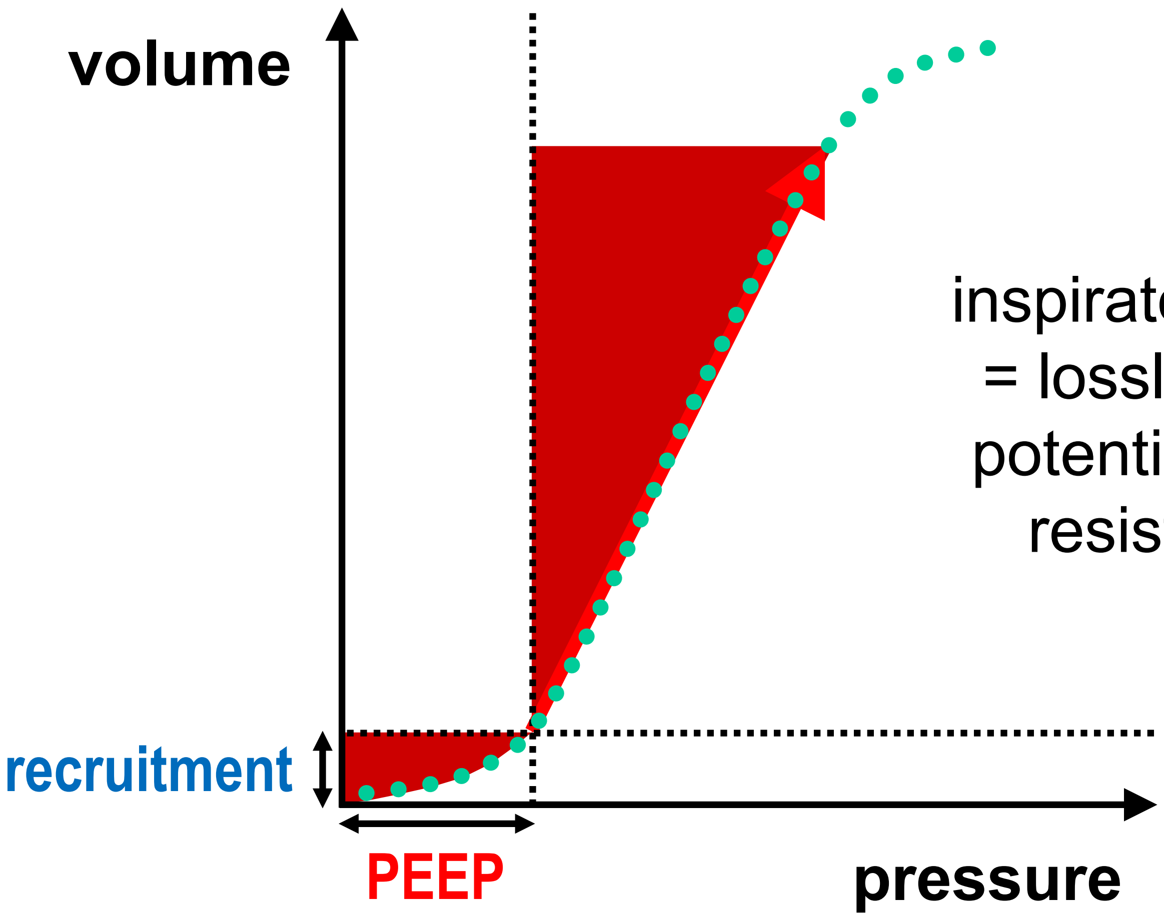
$$\Delta \text{ pressure} \cdot \text{flow} =$$

$$\Delta \text{ pressure} \cdot \frac{\Delta \text{ volume}}{\text{time}} =$$

$$\frac{\Delta \text{ (pressure} \cdot \text{volume)}}{\text{time}} =$$

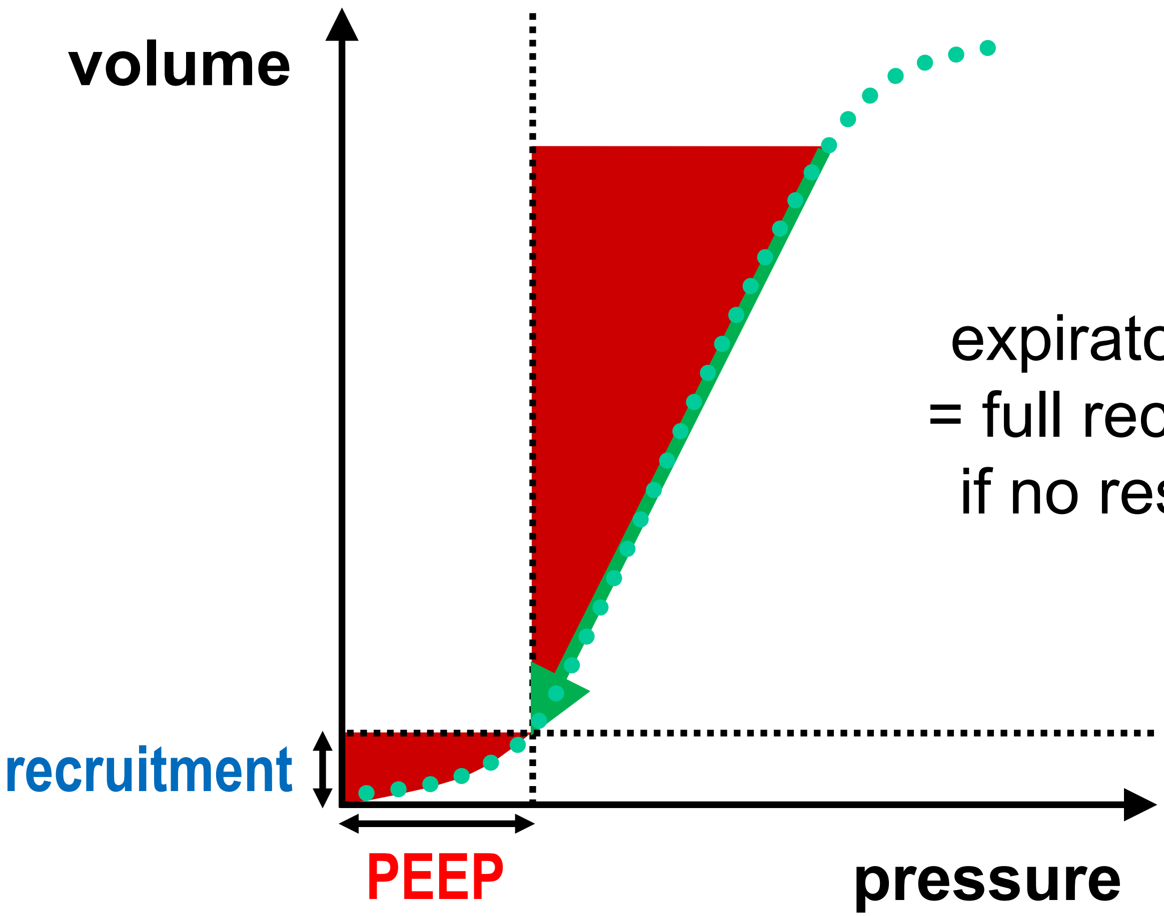
$$\frac{\Delta \text{ energy}}{\text{time}} = \text{power}$$

Ideal inspiration and storage of energy



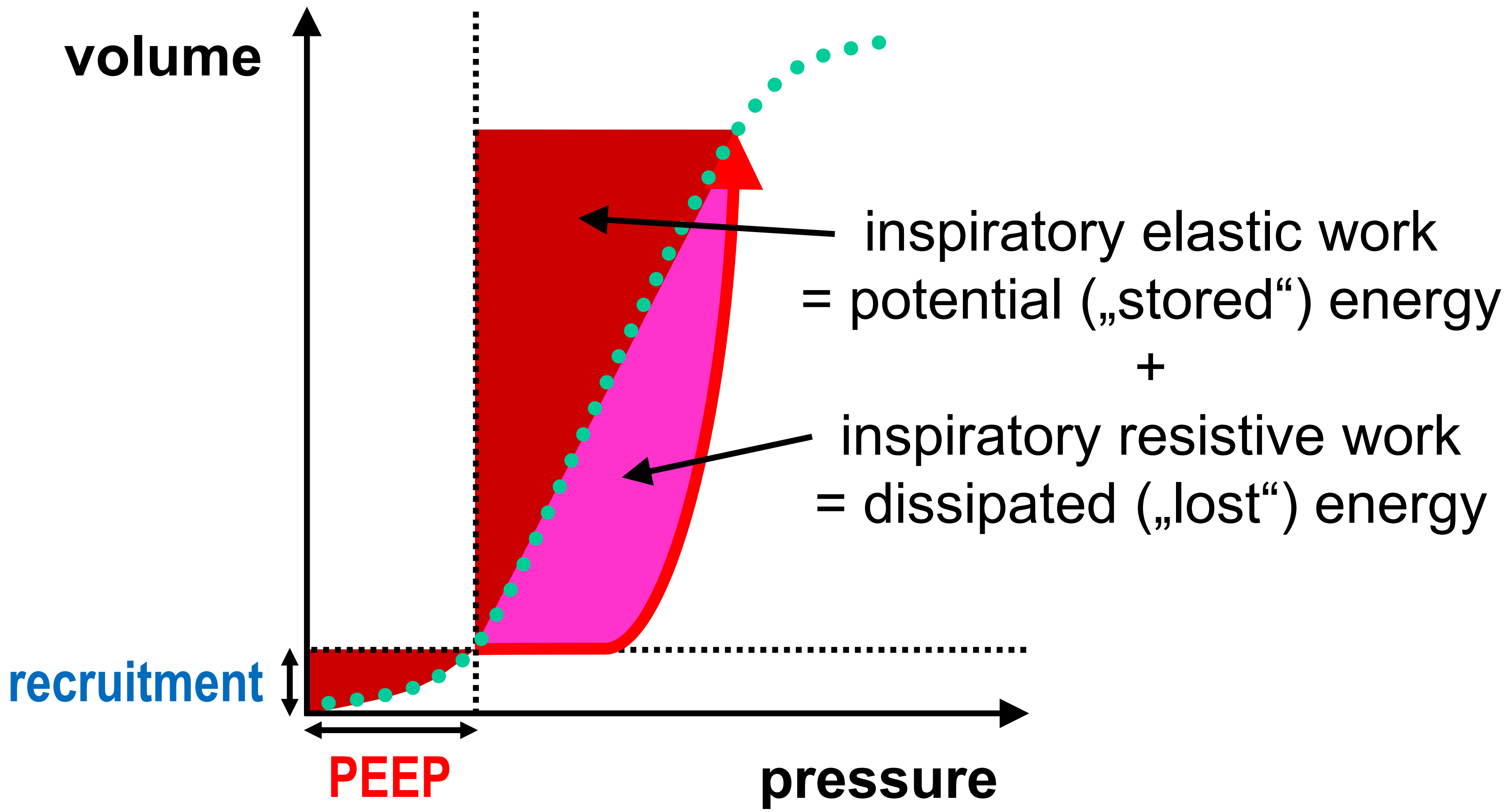
inspiratory elastic work = lossless storage of potential energy, if no resistance to flow

Ideal expiration and recovery of energy

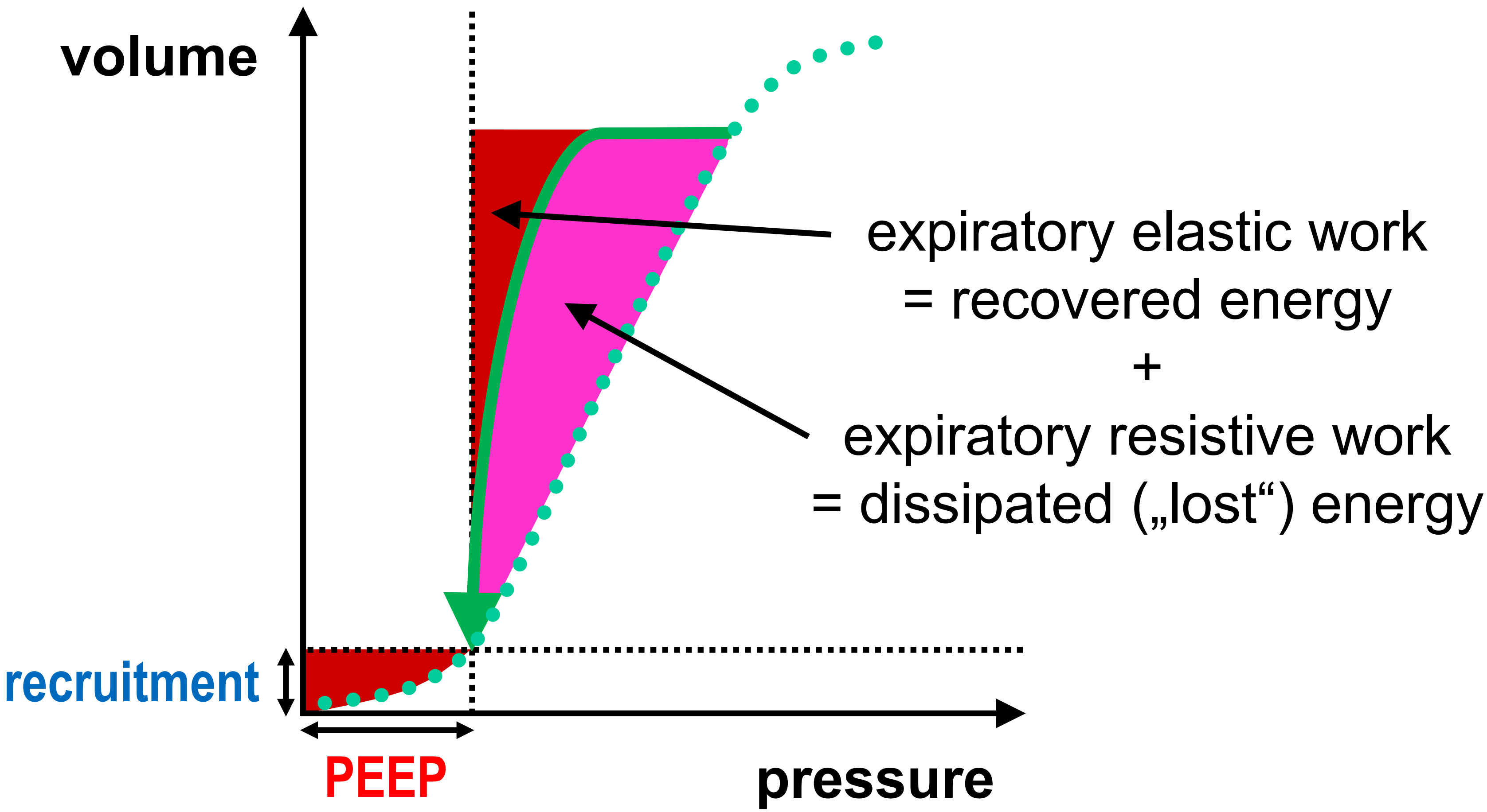


expiratory elastic recoil
= full recovery of energy,
if no resistance to flow

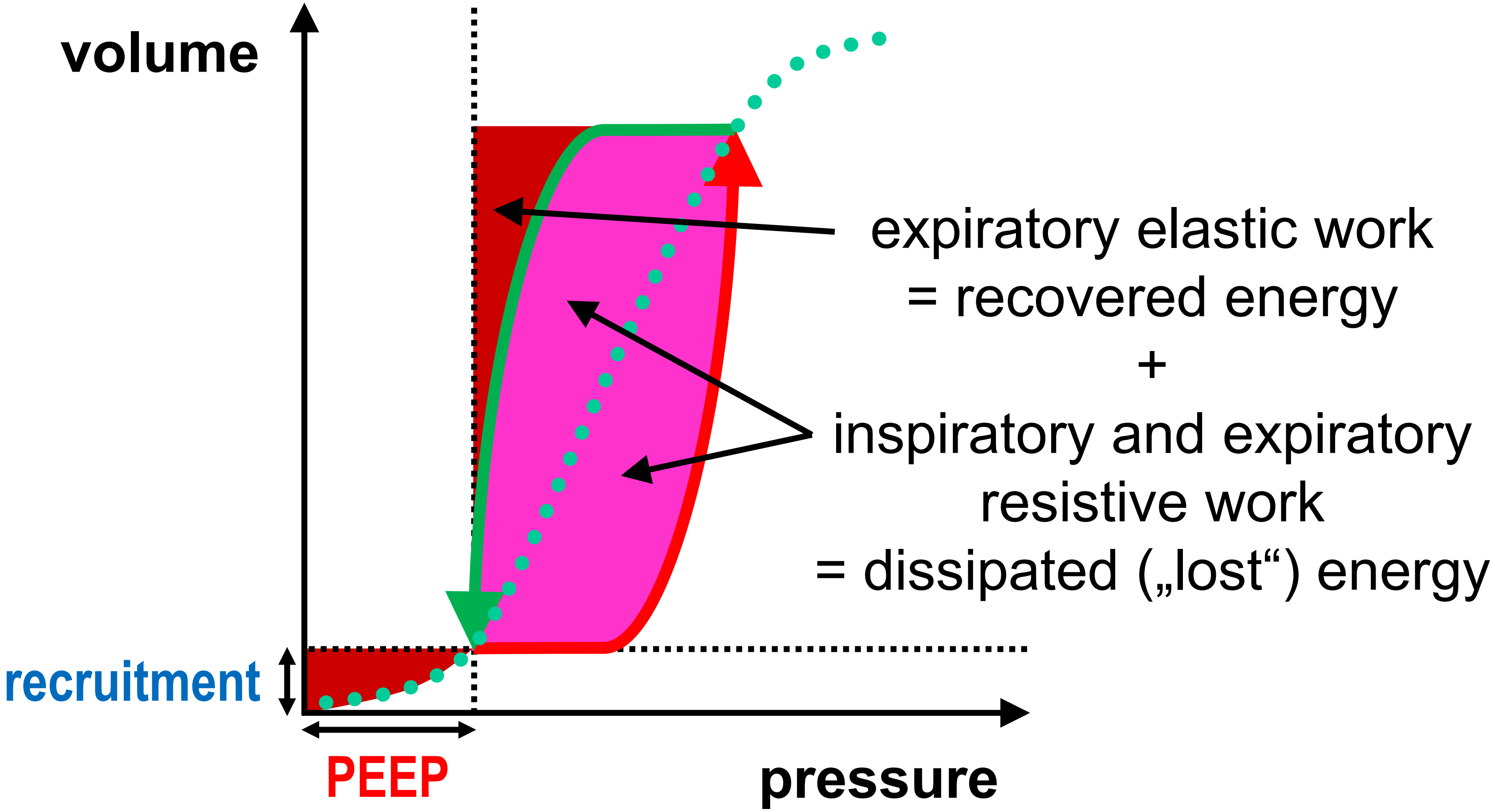
Real inspiration and energy



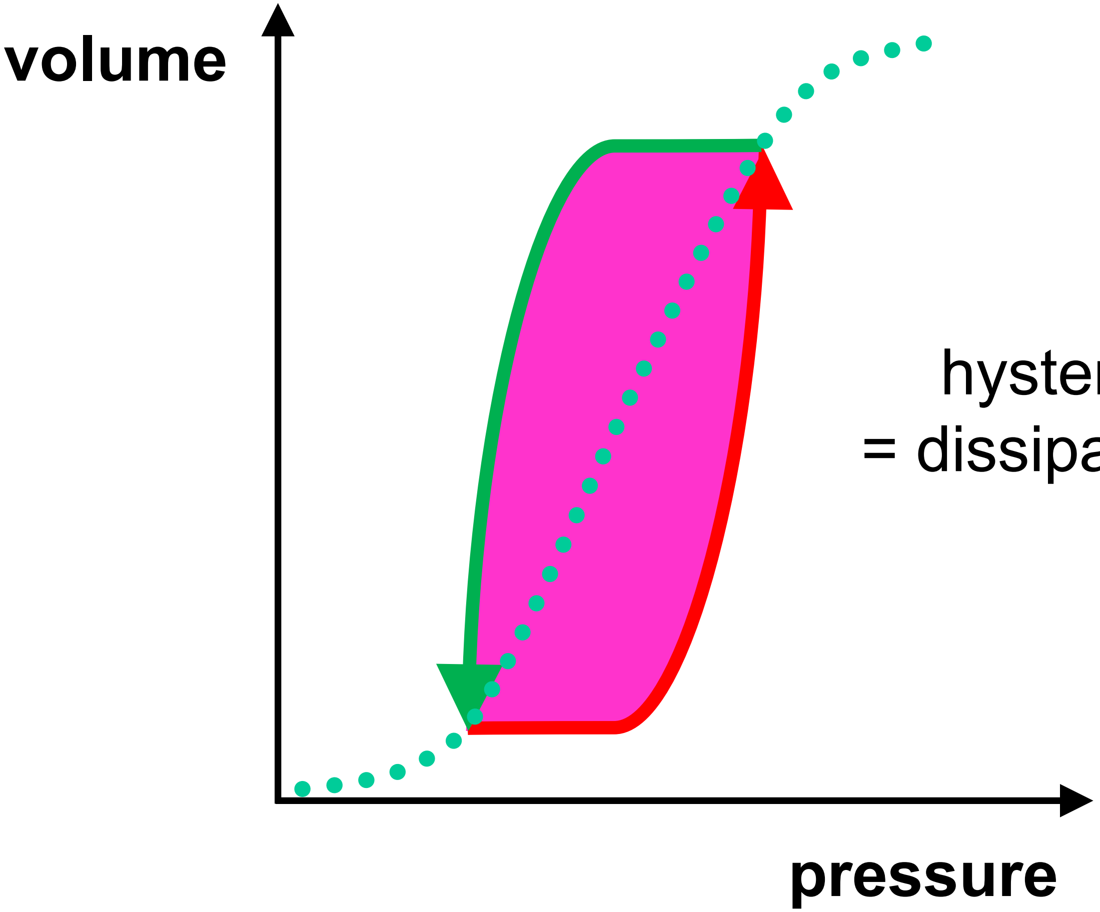
Real expiration and energy



Ventilation cycle and energy



Ventilation cycle and energy



hysteresis of PV loop
= dissipated („lost“) energy

Lung injury and dissipated („lost") energy

Only dissipated („lost"), but not recovered energy is the „bad guy", which can harm the lungs.

Lung injury and mechanical power

CRITICAL CARE MEDICINE

Mechanical Power and Development of Ventilator-induced Lung Injury

Massimo Cressoni, M.D., Miriam Gotti, M.D., Chiara Chiurazzi, M.D., Dario Massari, M.D., Ilaria Algieri, M.D., Martina Amini, M.D., Antonio Cammaroto, M.D., Matteo Brioni, M.D., Claudia Montaruli, M.D., Klodiana Nikolla, M.D., Mariateresa Guanziroli, M.D., Daniele Dondossola, M.D., Stefano Gatti, M.D., Vincenza Valerio, Ph.D., Giordano Luca Vergani, M.D., Paola Pugni, M.D., Paolo Cadringher, M.Sc., Nicoletta Gagliano, Ph.D., Luciano Gattinoni, M.D., F.R.C.P.

Cressoni M et al.: Anesthesiology 124 (2016) 1100-1108

Lung injury and mechanical power

ABSTRACT

Background: The ventilator works mechanically on the lung parenchyma. The authors set out to obtain the proof of concept that ventilator-induced lung injury (VILI) depends on the mechanical power applied to the lung.

Methods: Mechanical power was defined as the function of transpulmonary pressure, tidal volume (TV), and respiratory rate. Three piglets were ventilated with a mechanical power known to be lethal (TV, 38 ml/kg; plateau pressure, 27 cm H_2O; and respiratory rate, 15 breaths/min). Other groups (three piglets each) were ventilated with the same TV per kilogram and transpulmonary pressure but at the respiratory rates of 12, 9, 6, and 3 breaths/min. The authors identified a mechanical power threshold for VILI and did nine additional experiments at the respiratory rate of 35 breaths/min and mechanical power below (TV 11 ml/kg) and above (TV 22 ml/kg) the threshold.

Results: In the 15 experiments to detect the threshold for VILI, up to a mechanical power of approximately 12 J/min (respiratory rate, 9 breaths/min), the computed tomography scans showed mostly isolated densities, whereas at the mechanical power above approximately 12 J/min, all piglets developed whole-lung edema. In the nine confirmatory experiments, the five piglets ventilated above the power threshold developed VILI, but the four piglets ventilated below did not. By grouping all 24 piglets, the authors found a significant relationship between the mechanical power applied to the lung and the increase in lung weight ($r^2 = 0.41$, $P = 0.001$) and lung elastance ($r^2 = 0.33$, $P < 0.01$) and decrease in Pa_{O_2}/F_{IO_2} ($r^2 = 0.40$, $P < 0.001$) at the end of the study.

Conclusion: In piglets, VILI develops if a mechanical power threshold is exceeded.

Cressoni M et al.: Anesthesiology 124 (2016) 1100-1108

The threshold value: An analogy

12 J / min is about three calories / min.
This is the amount of energy
required to warm up one ml of water
in one minute by three degrees.

Lung injury and mechanical power

the energy threshold for VILI. Therefore, in our opinion, paying attention to mechanical power might help extending our focus on VILI, taking into account not only the TV and driving pressure, as recently suggested,[39] but also the flows and the respiratory rate and—maybe more important—their combination. Thus, any reduction in any component of the cyclic mechanical power should lower the risk of VILI.

Cressoni M et al.: Anesthesiology 124 (2016) 1100-1108

(Peak) flow and dissipated („lost“) energy

$$\frac{\Delta \text{ pressure}}{\text{time}}$$

high (peak) flow *versus* low (peak) flow

(Dissipated) energy and power peaks

Snickers (US bar = 57 g)

dynamite (stick = 190 g)

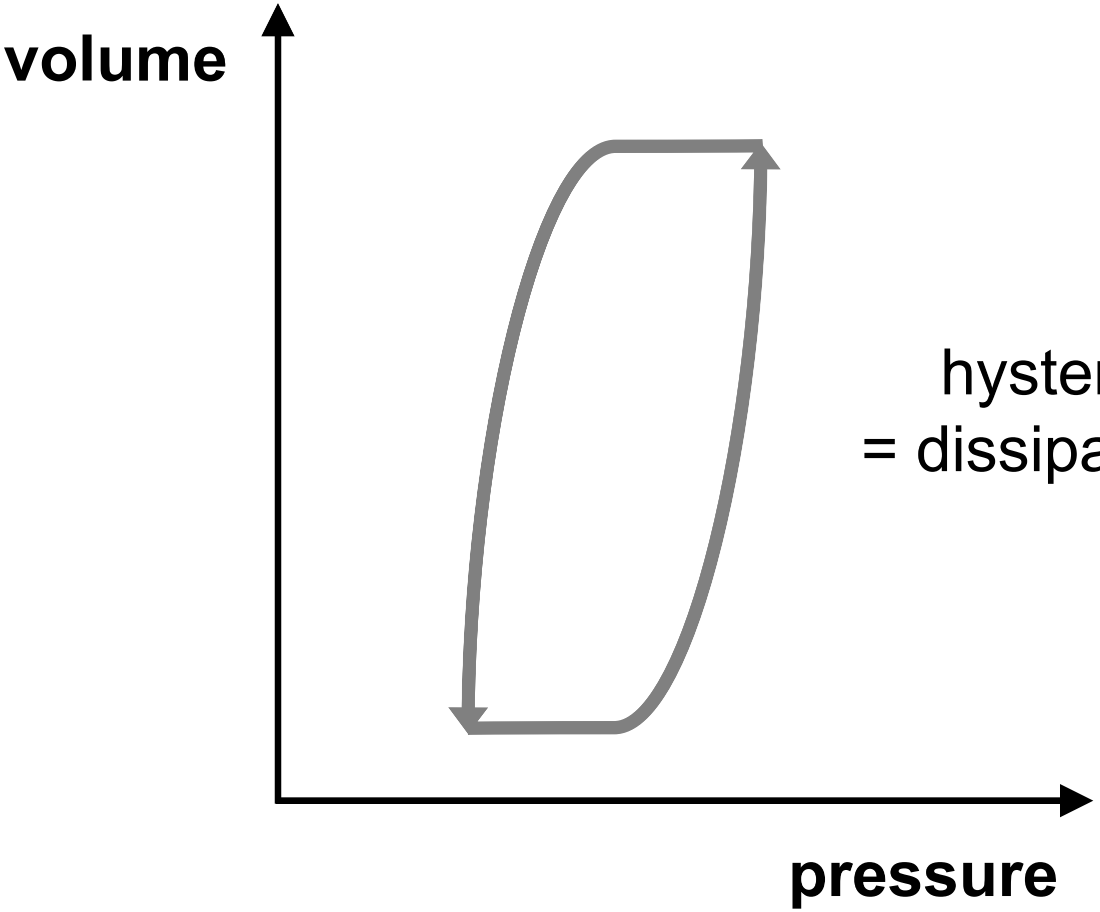
(Dissipated) energy and power peaks

Snickers (US bar = 57 g):
280 kcal / 57 g =
1.17 MJ / 57 g =
20.5 MJ / kg

dynamite (stick = 190 g):
1 MJ / 190 g =
5.26 MJ / kg

https://ndb.nal.usda.gov/ndb/foods/show/6186?manu=&fgcd=&ds=
http://www.chemistryviews.org/details/ezine/3622371/145_Years_of_Dynamite.html

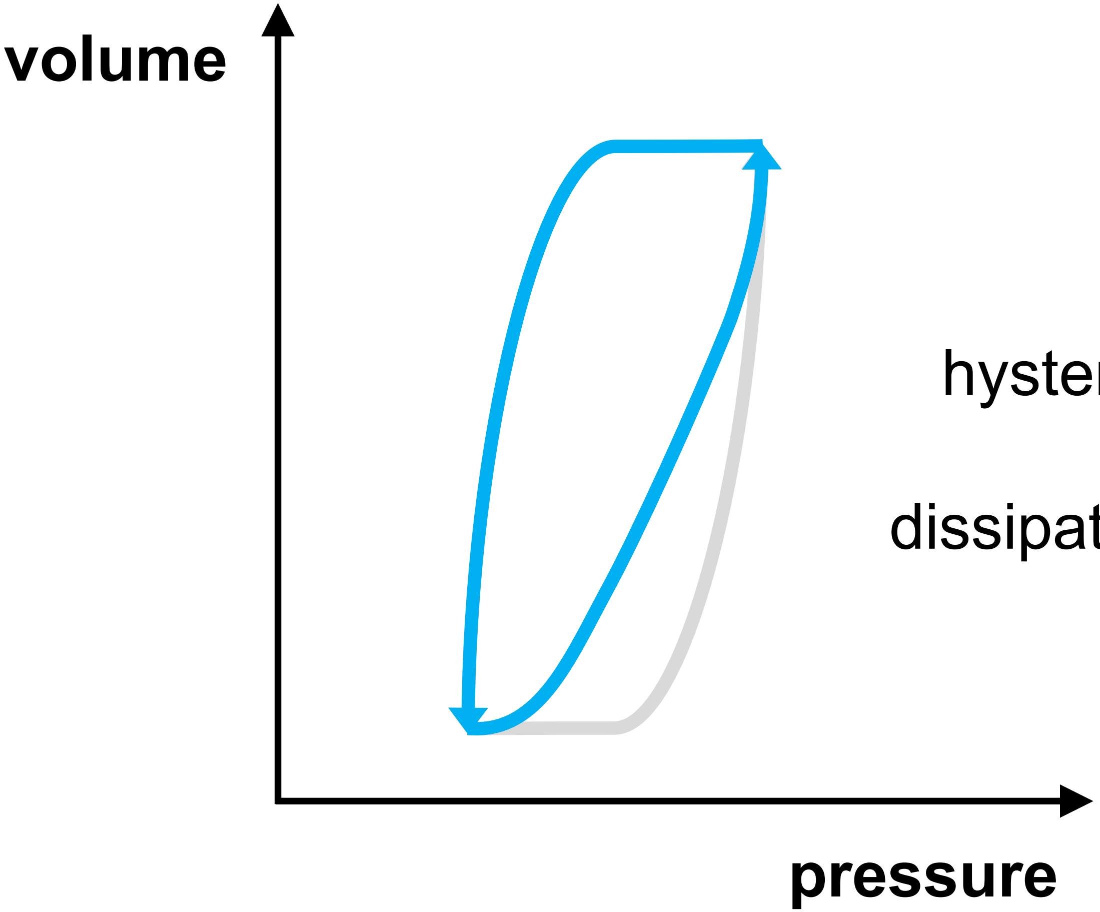
Pressure Controlled Ventilation
(= highly dynamic inspiratory and expiratory flow)



hysteresis of PV loop
= dissipated („lost“) energy

Volume Controlled Ventilation

(= stable inspiratory, highly dynamic expiratory flow)



smaller

hysteresis of PV loop

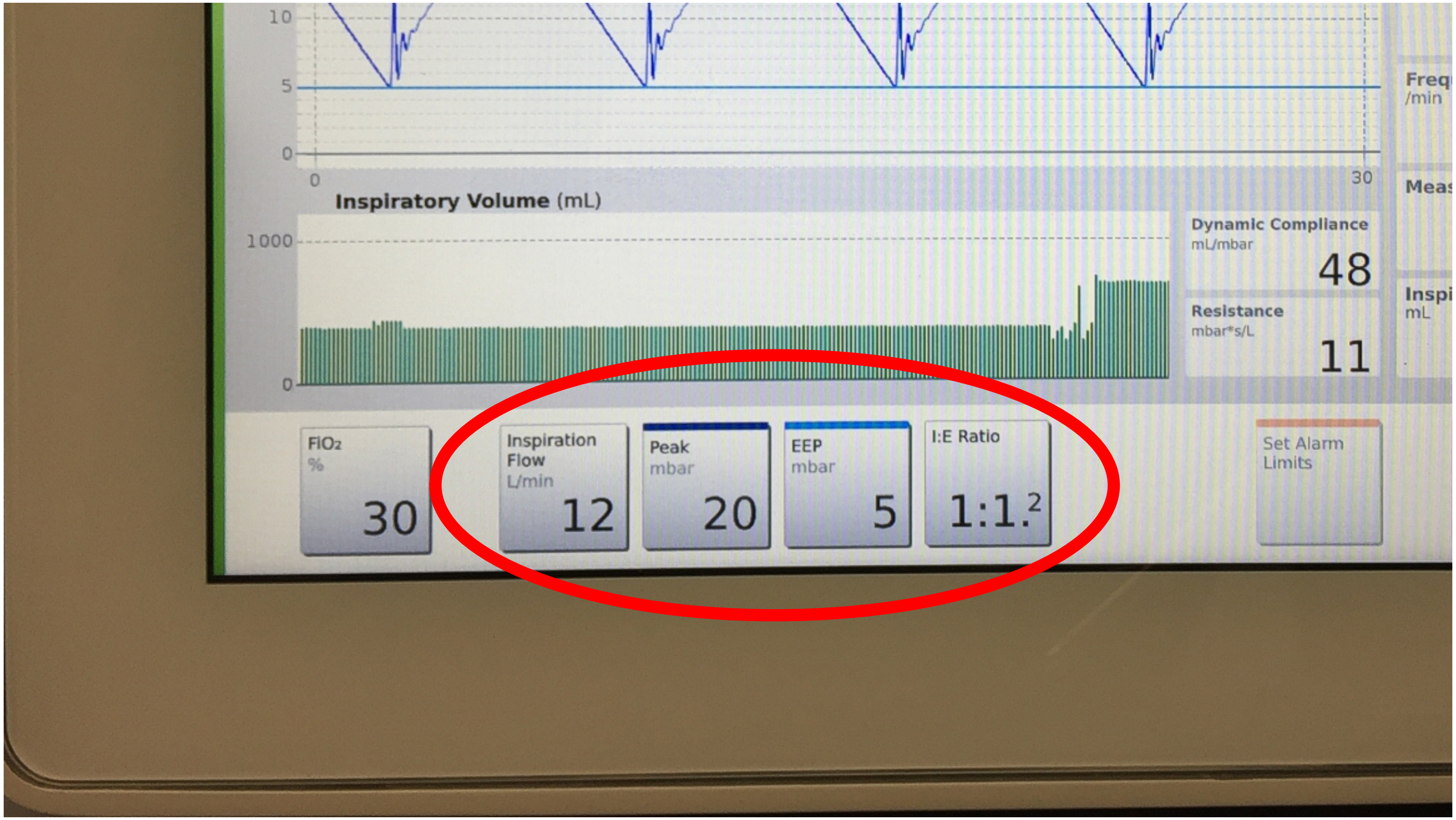
= **less**

dissipated („lost“) energy

Prototype Evone (Ventinova)

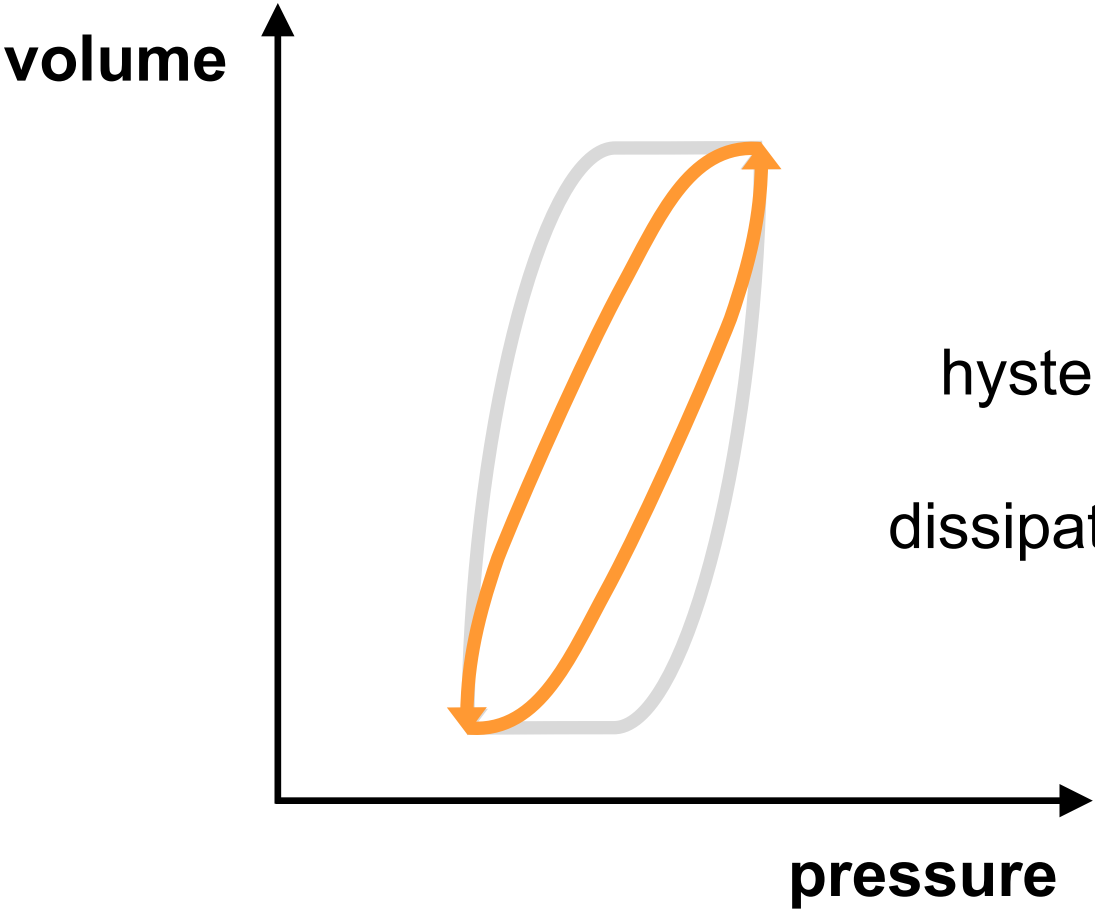
University Hospital Freiburg, ventilation laboratory (Prof. S. Schumann), 26.2.2016

Prototype Evone: Energy controls



University Hospital Freiburg, ventilation laboratory (Prof. S. Schumann), 26.2.2016

Flow Controlled Ventilation with Evone
(= continuous, stable inspiratory and expiratory flow)



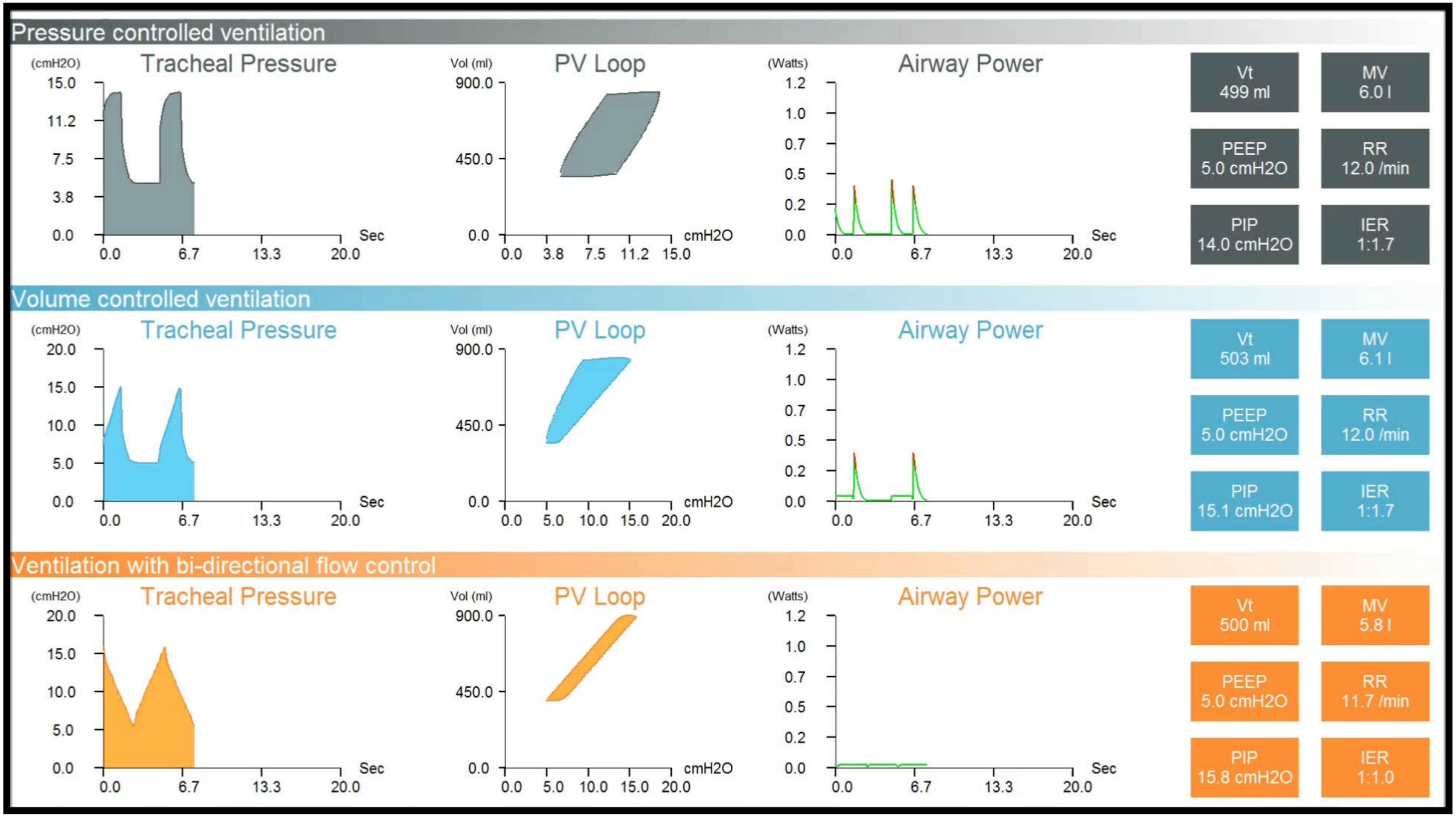
minimal
hysteresis of PV loop
= **minimal**
dissipated („lost“) energy

Lung injury and (peak) flow

Higher flow and flow peaks result in …

- more resistive work
- more dissipated („lost“) energy
- intratidal power peaks

Ventilation and intratidal power profile



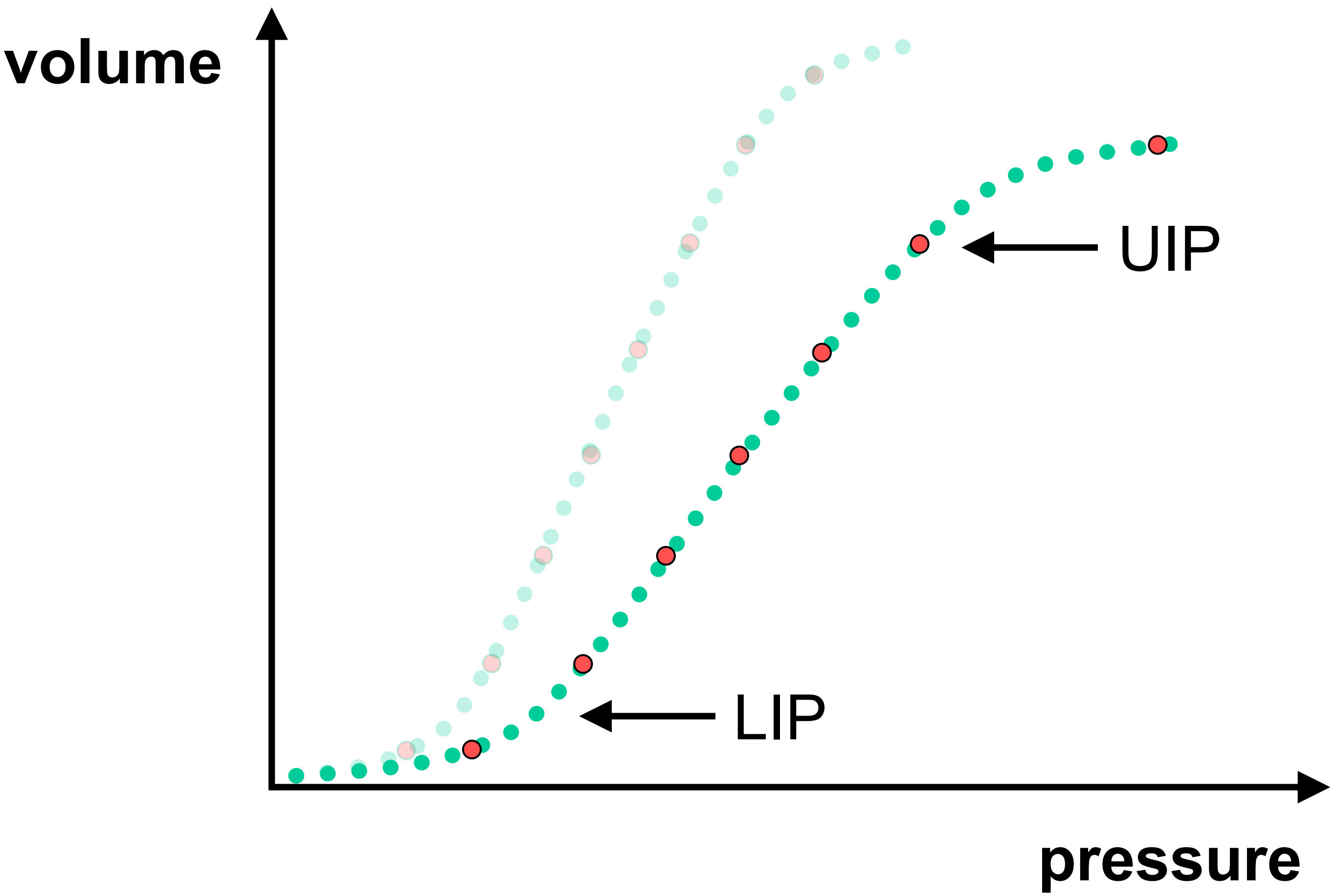
courtesy of T. Barnes (STS Ltd., Warlingham, Great Britain)

Lung injury, pressure and flow

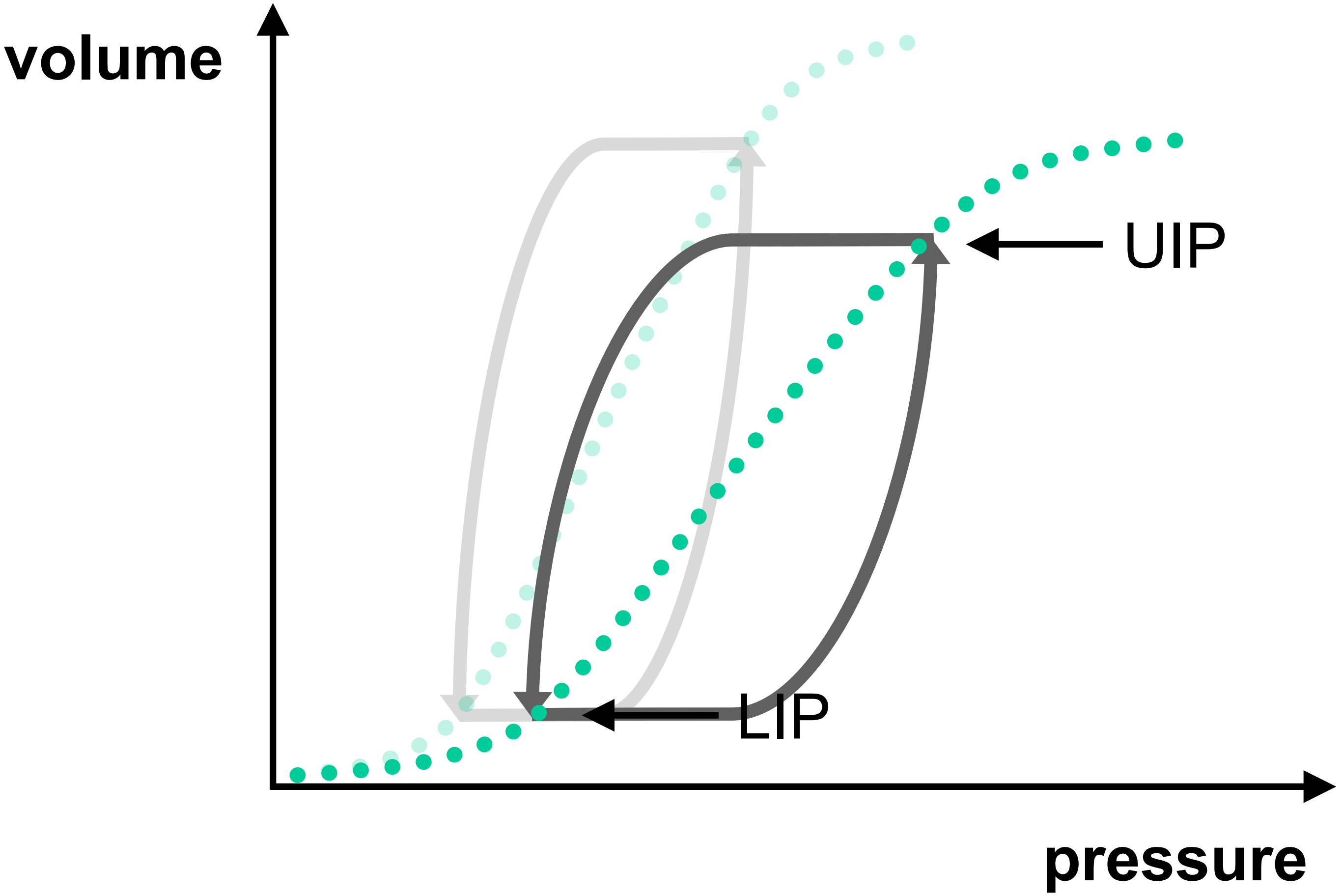
Minimal exposure of the lung tissue to energy over time (i.e. avoidance of power peaks) demands slow and continuous pressure changes at optimal compliance by a continuous, stable flow (without relevant pause phases) during inspiration and also (an equally long) expiration.

Enk D: patent application 10 2016 109 528.1, DPMA, 24.5.2016

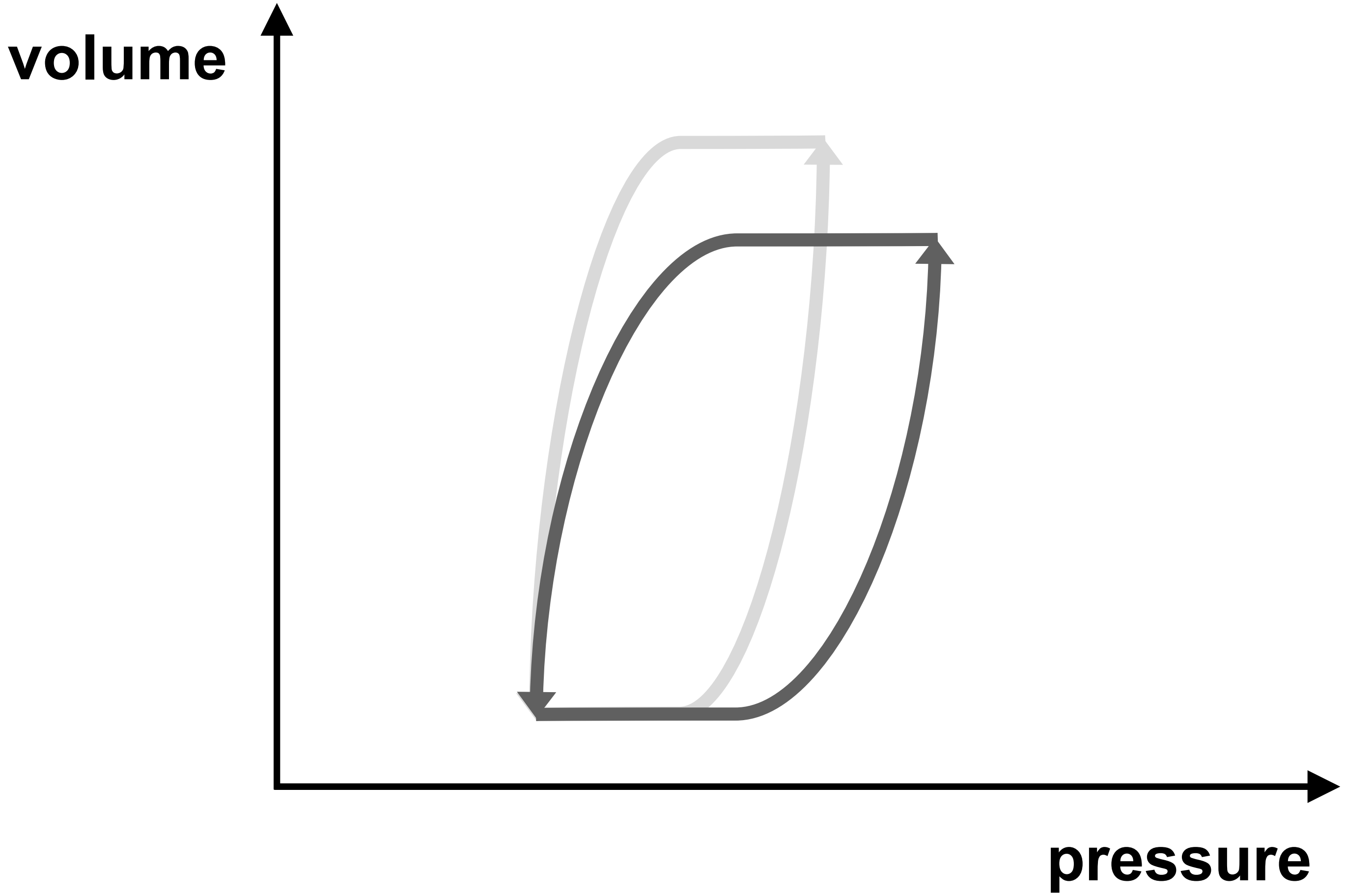
Static compliance curve in ARDS
(„super syringe method“)



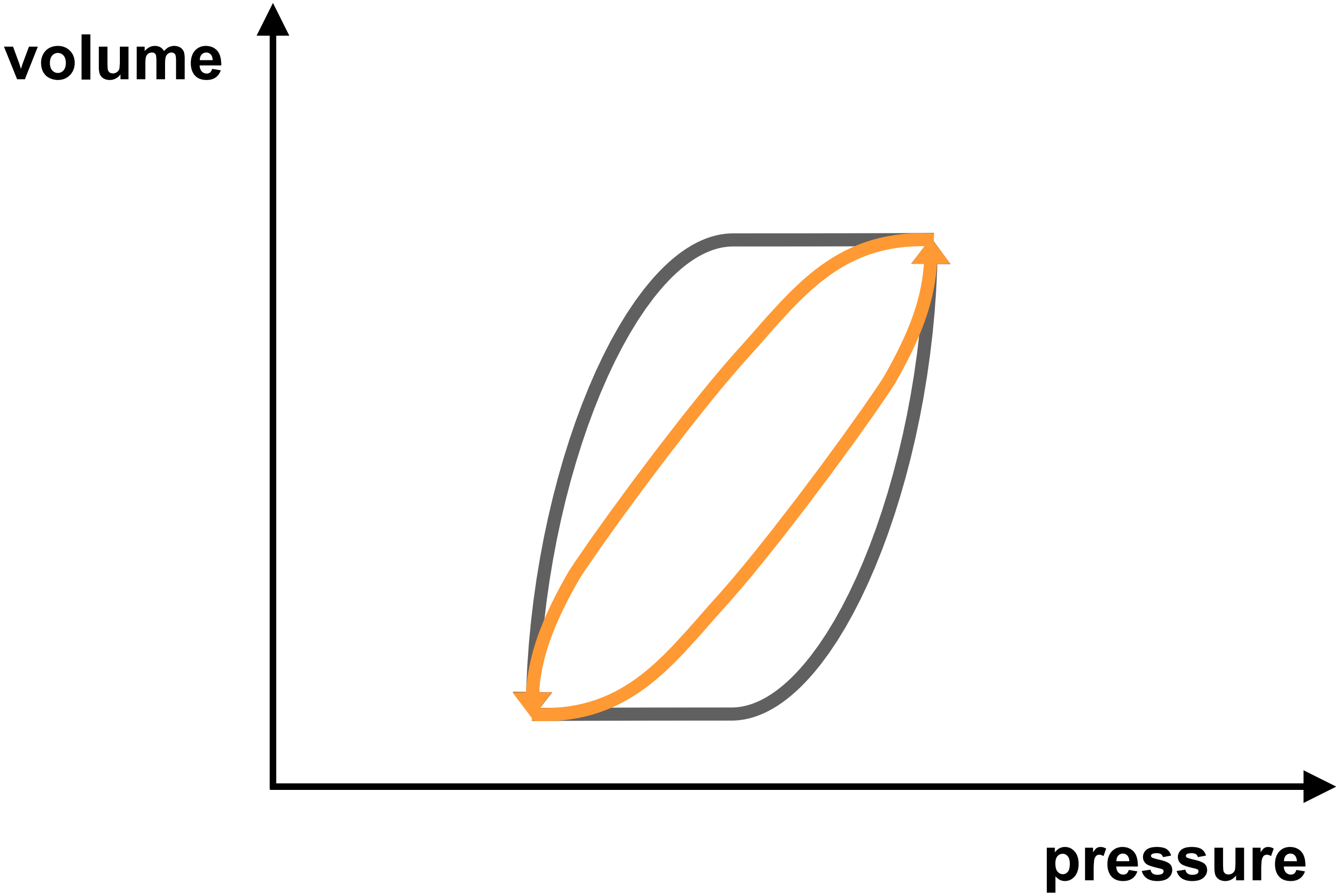
PCV in ARDS



PCV in ARDS: Too much dissipated energy !



PCV *versus* FCV in ARDS



Lung injury and HFOV

HFOV = knight in shining armor ?

Ferguson ND et al.: N Engl J Med 368 (2013) 795-805
Young D et al.: N Engl J Med 368 (2013) 806-813
Fan E et al.: Am J Respir Crit Care Med 195 (2017) 1253-1263

Lung injury and mechanical power

WHAT'S NEW IN INTENSIVE CARE

CrossMark

Intensive care medicine in 2050: ventilator-induced lung injury

Luciano Gattinoni*, Tommaso Tonetti and Michael Quintel

Gattinoni L et al.: Intensive Care Med, 22.3.2017 (doi: 10.1007/s00134-017-4770-8)

Lung injury and mechanical power

Table 1 "Representative" ventilatory set applied in ARDS worldwide in 2002 and 2016

	2002	2016				
	ARDS all ($n = 231$)	ARDS all ($n = 2377$)	Mild ($n = 714$)	Moderate ($n = 1106$)	Severe ($n = 557$)	P value
Vt/PBW (ml/kg)	8.7 (2.0)	7.6 [7.5–7.7]	7.8 [7.6–7.9]	7.6 [7.5–7.7]	7.5 [7.3–7.6]	0.02
RR (bpm)	20 (6)	20.8 [21.5–21.2]	19.5 [19.0–19.9]	20.7 [20.3–21.1]	22.7 [21.5–23.8]	<0.001
Peak (cmH_2O)	34 (9)	27 [26.7–27.4]	24.7 [24.1–25.4]	26.9 [26.5–27.4]	30.3 [29.6–30.9]	<0.001
Plat (cmH_2O)	28 (7)	23.2 [22.6–23.7]	20.5 [19.8–21.3]	23.1 [21.6–23.7]	26.2 [25.2–27.1]	<0.001
PEEP (cmH_2O)	8 (4)	8.4 [8.3–8.6]	7.4 [7.2–7.6]	8.3 [8.1–8.5]	10.1 [9.8–10.4]	<0.001
$Power_{rs}$ estimated (J/min)[a]	31.9	23.7	21.1	23.5	29.0	–
ICU mortality (%)	52 [46–59]	35.3 [33.3–37.2]	29.7 [26.4–33.2]	35.0 [32.2–37.9]	42.9 [38.8–47.1]	<0.001

2002 data are taken from Esteban et al. [5], while 2016 data are taken from Bellani et al. [4]. Values are expressed as mean ± standard deviation (round brackets) or 95% confidence interval (square brackets)

P values refer only to the 2016 data [4]

[a] Mechanical power to the respiratory system was calculated with a simplified formula: $Power_{rs} = 0.098 \cdot RR \cdot \Delta V \cdot \left(P_{peak} - \frac{1}{2} \cdot \Delta P_{aw}\right)$ (see supplemental content of [13]) in which the tidal volume was calculated considering a body weight of 78 kg (which is the average patient weight of the cohort in the study by Bellani and colleagues [4])

Gattinoni L et al.: Intensive Care Med, 22.3.2017 (doi: 10.1007/s00134-017-4770-8)

Evone (Ventinova): Not just one premiere

Evone is the world‘s first commercially available ventilator capable to provide

- ventilation through a „straw“
- fully controlled ventilation
- energetically optimized ventilation

The future is now …

Cliniques universitaires Saint-Luc, Brussels, OR (Prof. M. Van Boven), 22.9.2017