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Flór Ferenc Kórház

UNIVERSITAS BUDAPESTINENSIS DE SEMMELWEIS NOMINATA 1769

Personalized mechanical ventilation: tools and goals

Zoltán Ruszkai MD, PhD

24/01/2023

Flór Ferenc Hospital Kistarcsa, Hungary

Colours of Sepsis 2023, Ostrava

Declarations

Affiliations

- Flór Ferenc Hospital Kistarcsa, Hungary
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Disclosure

- None to declare

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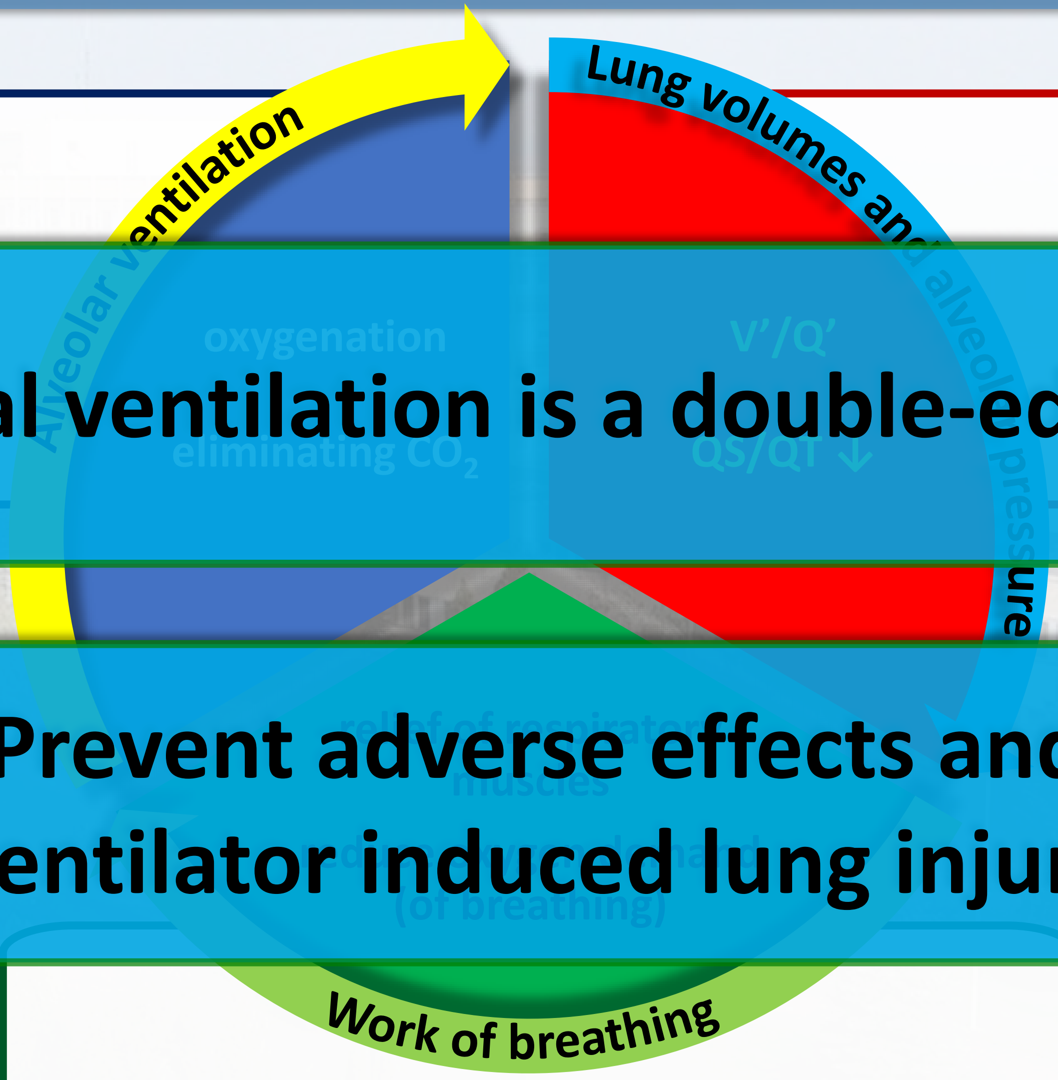
Main goals of mechanical ventilation

FiO_2
Respiratory rate
I:E ratio

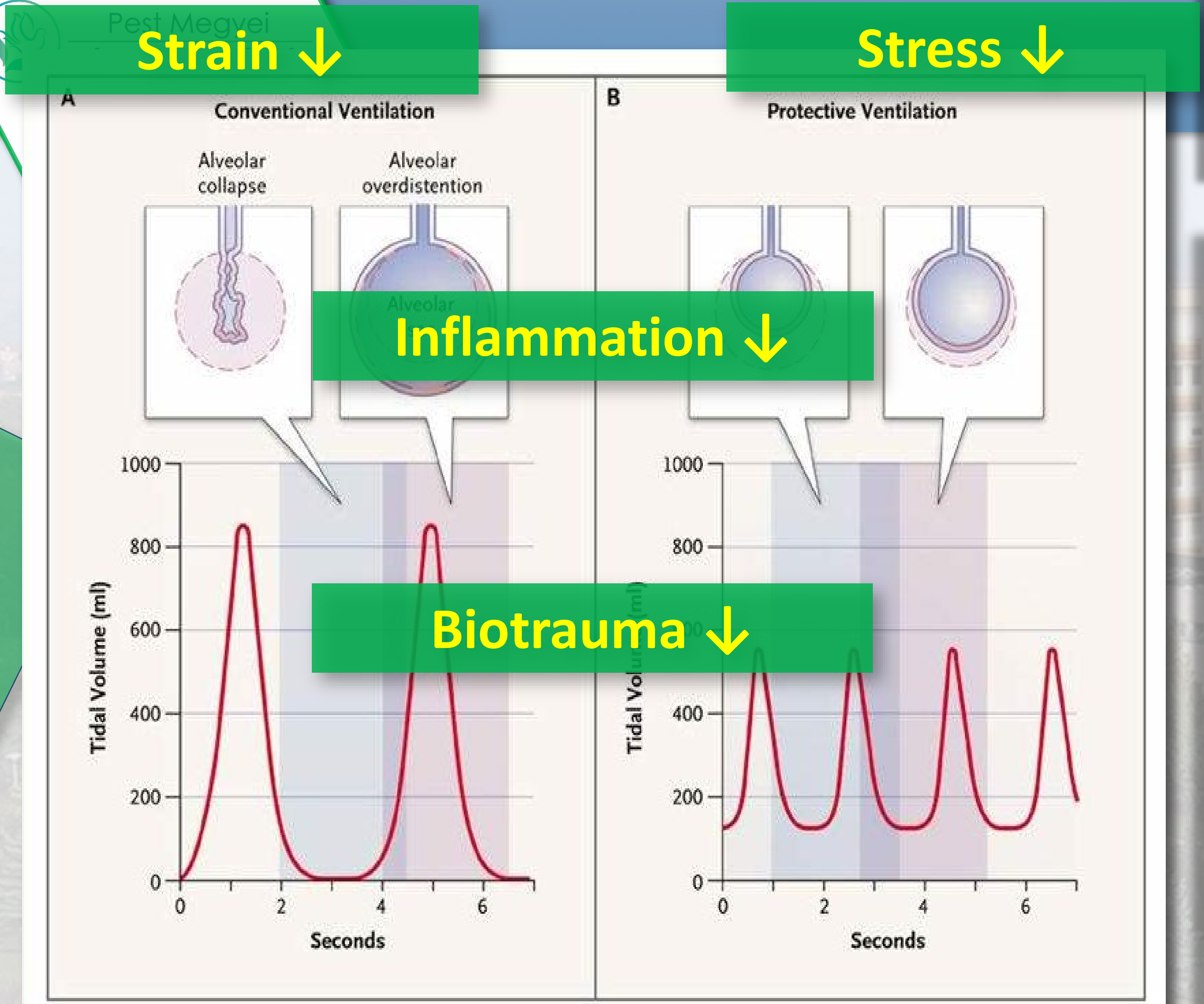
Tidal volume
PEEP
ARM



Mechanical ventilation is a double-edged sword

Prevent adverse effects and ventilator induced lung injury

Ventilation modalities, Analgesia, Sedation



Low-Tidal-Volume Ventilation in the Acute Respiratory Distress Syndrome

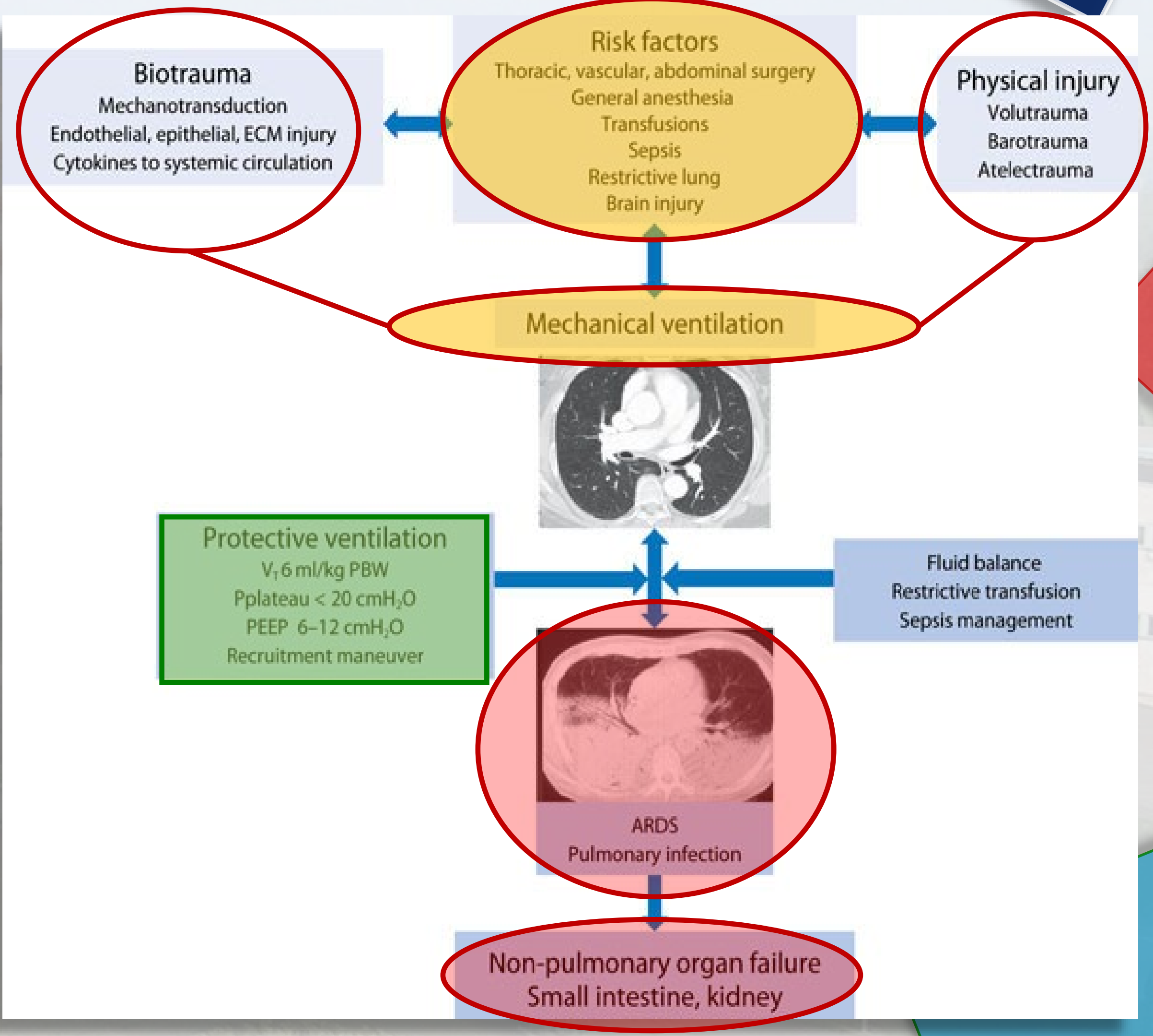
Atul Malhotra, M.D.

N Engl J Med. 2007 September 13; 357(11): 1113–1120.

Sutherasan *et al. Critical Care* 2014, 18:211
http://ccforum.com/content/18/2/211
CRITICAL CARE
REVIEW

Protective mechanical ventilation in the non-injured lung: review and meta-analysis

Yuda Sutherasan[1], Maria Vargas[2], Paolo Pelosi[3]*



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Low Tidal Volumes

VT ≤ 8mL/kg PBW

„Open the lungs and keep them open”

Alveolar recruitment manoeuvres

Optimal airway pressures

Optimal PEEP and $P_{plat} < 30\ cmH_2O$

Lung protective mechanical ventilation

Pathophysiology, RCTs, Meta-analyses, Systematic reviews

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Lung protective mechanical ventilation

Low Tidal Volumes

VT ≤ 8mL/kg PBW

The NEW ENGLAND JOURNAL of MEDICINE

ORIGINAL ARTICLE

The NEW ENGLAND JOURNAL of MEDICINE

ORIGINAL ARTICLE

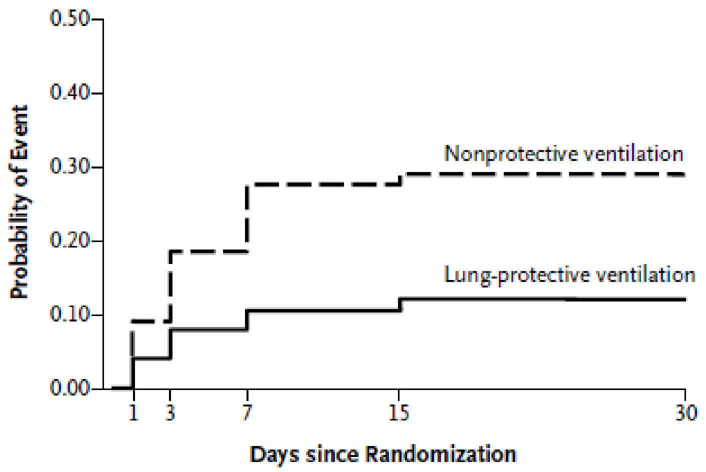
A Trial of Intraoperative Low-Tidal-Volume Ventilation in Abdominal Surgery

CONCLUSIONS

As compared with a practice of nonprotective mechanical ventilation, the use of a lung-protective ventilation strategy in intermediate-risk and high-risk patients undergoing major abdominal surgery was associated with improved clinical outcomes and reduced health care utilization. (IMPROVE ClinicalTrials.gov number, NCT01282996.)

Days after Randomization

No. at Risk				
Protective	29	25	20	18
Conventional	24	11	9	7



No. at Risk						
Nonprotective ventilation	200	182	163	145	142	142
Lung-protective ventilation	200	192	184	179	176	175

Figure 2. Kaplan–Meier Estimates of the Probability of the Composite Primary Outcome.

Data for the Kaplan–Meier estimates of the probability of the composite primary outcome of major pulmonary or extrapulmonary complications were censored at 30 days after surgery. Major pulmonary complications included pneumonia or the need for invasive or noninvasive ventilation for acute respiratory failure. Major extrapulmonary complications were sepsis, severe sepsis, septic shock, and death. P<0.001 by the log-rank test for the between-group difference in the probability of the primary outcome.

Pathophysiology, RCTs, Meta-analyses, Systematic reviews

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Lung protective mechanical ventilation

Lancet. 2014 Aug 9;384(9942):495-503. doi: 10.1016/S0140-6736(14)60416-5. Epub 2014 Jun 2.

High versus low positive end-expiratory pressure during general anaesthesia for open abdominal surgery (PROVHILO trial): a multicentre randomised controlled trial.

FINDINGS: From February, 2011, to January, 2013, 447 patients were randomly allocated to the higher PEEP group and 453 to the lower PEEP group. Six patients were excluded from the analysis, four because they withdrew consent and two for violation of inclusion criteria. Median levels of positive end-expiratory pressure were 12 cm H2O (IQR 12-12) in the higher PEEP group and 2 cm H2O (0-2) in the lower PEEP group. Postoperative pulmonary complications were reported in 174 (40%) of 445 patients in the higher PEEP group versus 172 (39%) of 449 patients in the lower PEEP group (relative risk 1·01; 95% CI 0·86-1·20; p=0·86). Compared with patients in the lower PEEP group, those in the higher PEEP group developed intraoperative hypotension and needed more vasoactive drugs.

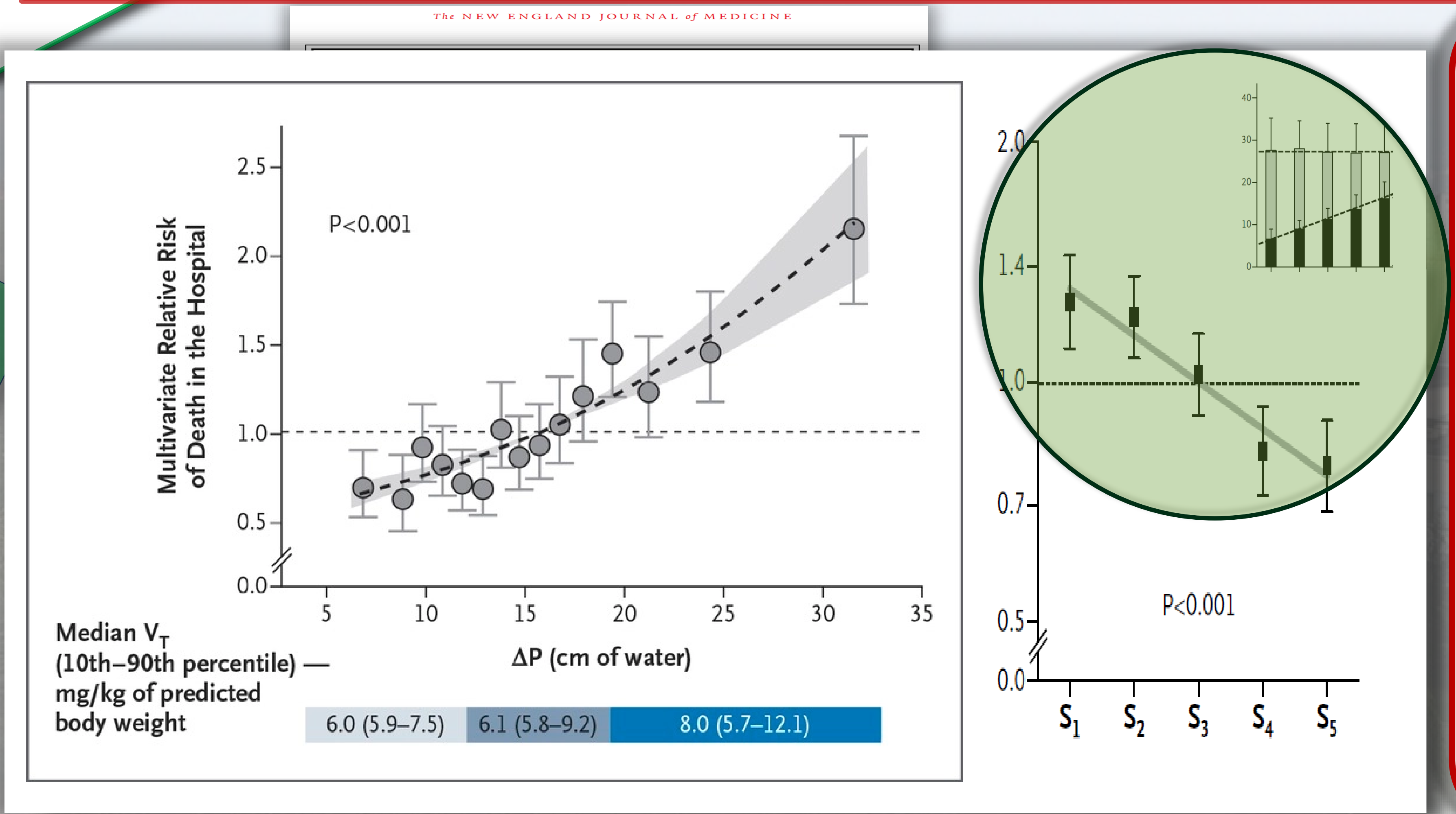
INTERPRETATION: A strategy with a high level of positive end-expiratory pressure and recruitment manoeuvres during open abdominal surgery does not protect against postoperative pulmonary complications. An intraoperative protective ventilation strategy should include a low tidal volume and low positive end-expiratory pressure, without recruitment manoeuvres.

Optimal airway pressures

Optimal PEEP and $P_{plat} < 30\ cmH_2O$

Pathophysiology, RCTs, Meta-analyses, Systematic reviews

Lung protective mechanical ventilation



Optimal airway pressures

Optimal PEEP

and

$P_{plat} < 30\ cmH_2O$

and

$dP < 15\ cmH_2O$

Pathophysiology, RCTs, Meta-analyses, Systematic reviews

Lung protective mechanical ventilation

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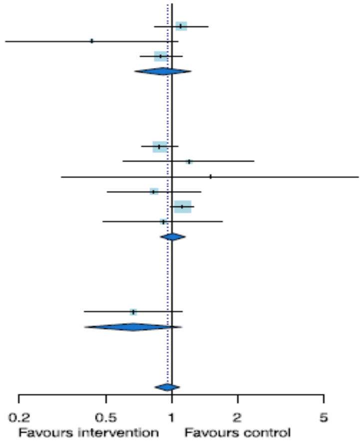
Darren Markland
https://youtu.be/BYH6sldk3zU

Effects of higher PEEP and recruitment manoeuvres on mortality in patients with ARDS: a systematic review, meta-analysis, meta-regression and trial sequential analysis of randomized controlled trials

Lorenzo Ball[1,2,3*], Ary Serpa Neto[3,4], Valeria Trifiletti[1], Maura Mandelli[1], Iacopo Firpo[1], Chiara Robba[2], Marcelo Gama de Abreu[5], Marcus J. Schultz[3,6,7], Nicolò Patroniti[1,2], Patricia R. M. Rocco[8], Paolo Pelosi[1,2] and For the PROVE Network: PROtective Ventilation Network

Ball *et al. Intensive Care Medicine Experimental* 2020, **8**(Suppl 1):39
https://doi.org/10.1186/s40635-020-00322-2



Study	Intervention Events	Intervention Total	Control Events	Control Total	RR	95%–CI	Weight
Higher PEEP alone							
Brower 2004	76	276	68	273	1.11	[0.83; 1.46]	13.4%
Talmor 2008	5	30	12	31	0.43	[0.17; 1.07]	1.9%
Mercat 2008	107	385	119	382	0.89	[0.72; 1.11]	17.7%
Subgroup	**188**	**691**	**199**	**686**	**0.91**	**[0.68; 1.23]**	**33.1%**
Heterogeneity: $I^2 = 53\%$, $\tau^2 = 0.03$, $p = 0.12$							
Test for effect in subgroup: $z = -0.60$ ($p = 0.55$)							
Higher PEEP and recruitment manoeuvres							
Meade 2008	135	475	164	508	0.88	[0.73; 1.06]	20.2%
Huh 2009	12	30	9	27	1.20	[0.60; 2.39]	3.3%
Hodgson 2011	3	10	2	10	1.50	[0.32; 7.14]	0.7%
Kacmarek 2016	22	99	27	101	0.83	[0.51; 1.36]	5.9%
Cavalcanti 2017	277	501	251	509	1.12	[1.00; 1.26]	27.5%
Hodgson 2019	14	57	15	56	0.92	[0.49; 1.72]	3.9%
Subgroup	**463**	**1172**	**468**	**1211**	**1.01**	**[0.89; 1.16]**	**61.4%**
Heterogeneity: $I^2 = 17\%$, $\tau^2 = < 0.01$, $p = 0.30$							
Test for effect in subgroup: $z = 0.20$ ($p = 0.84$)							
Recruitment manoeuvres alone							
Xi 2010	16	55	24	55	0.67	[0.40; 1.11]	5.5%
Subgroup	**16**	**55**	**24**	**55**	**0.67**	**[0.40; 1.11]**	**5.5%**
Heterogeneity: not applicable							
Test for effect in subgroup: $z = -1.56$ ($p = 0.12$)							
Random effects model	**667**	**1918**	**691**	**1952**	**0.96**	**[0.84; 1.09]**	**100.0%**
Heterogeneity: $I^2 = 35\%$, $\tau^2 = 0.01$, $p = 0.12$							
Test for overall effect: $z = -0.68$ ($p = 0.50$)							
Test for subgroup differences: $\chi^2_2 = 2.65$, df = 2 ($p = 0.27$)							

Fig. 2 Forest plot for mortality (collapsed at 28 days, ICU discharge, hospital discharge or 60–days). Studies are stratified according to whether higher PEEP and recruitment manoeuvres were used separately or as a bundle of interventions. ICU, intensive care unit; PEEP, positive end-expiratory pressure

„Open the ngs and keep them open”

Alveolar recruitment manoeuvres

Optimal airway pressures

Optimal PEEP and P_{plat} < 30 cmH_2O and dP < 15 cmH_2O

Pathophysiology, RCTs, Meta-analyses, Systematic reviews

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Surviving Sepsis Campaign: International Guidelines for Management of Sepsis and Septic Shock 2021

Critical Care Medicine 49(11):p e1063-e1143, November 2021.
DOI: 10.1097/CCM.0000000000005337

49. For adults with sepsis-induced ARDS, we recommend using a low tidal volume ventilation strategy (6 mL/kg), over a high tidal volume strategy (> 10 mL/kg).	***Strong**, high-quality evidence*
50. For adults with sepsis-induced severe ARDS, we recommend using an upper limit goal for plateau pressures of 30 cm H_2O, over higher plateau pressures.	***Strong,** moderate-quality evidence*
51. For adults with moderate to severe sepsis-induced ARDS, we suggest using higher PEEP over lower PEEP.	***Weak,** moderate-quality evidence*
52. For adults with sepsis-induced respiratory failure (without ARDS), we suggest using low tidal volume as compared with high tidal volume ventilation.	***Weak,** low quality of evidence*
53. For adults with sepsis-induced moderate-severe ARDS, we suggest using traditional recruitment maneuvers.	***Weak,** moderate-quality evidence*
54. When using recruitment maneuvers, we recommend against using incremental PEEP titration/strategy.	***Strong,** moderate-quality evidence*

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Lung-protective ventilation for the surgical patient: international expert panel-based consensus recommendations

Christopher C. Young[1,2,*], Erica M. Harris[2], Charles Vacchiano[1,3], Stephan Bodnar[3], Brooks Bukowy[3], R. Ryland D. Elliott[2], Jaclyn Migliarese[3], Chad Ragains[2], Brittany Trethewey[3], Amanda Woodward[4], Marcelo Gama de Abreu[5], Martin Girard[6], Emmanuel Futier[7], Jan P. Mulier[8], Paolo Pelosi[9,10] and Juraj Sprung[11]

British Journal of Anaesthesia, 123 (6): 898–913 (2019)
doi: 10.1016/j.bja.2019.08.017

ARDS-related mortality is still high

Table 1 Recommendations and statements concerning pulmonary risk assessment, case set-up, and ventilation management during anaesthesia induction. CPAP, continuous positive airway pressure; F_IO_2, fraction of inspired oxygen; HOB, head of bed; I:E, inspiratory:expiratory; NIPPV, ... predicted body weight; PPC, postoperative pulmonary complication; P_{plat}, plateau pressure; SpO_2, peripheral oxygen saturation; V_T, tidal volume; ZEEP, zero end-expiratory pressure.

Postoperative pulmonary complications are also common

Question	Statement/recommendation	Consensus (%)	Quality of evidence	Strength of recommendation
1.1	A de... The greatest risk factors for PPCs include age >50 yr, BMI >40 kg m^{-2}, ASA >2, OSA, preoperative anaemia, preoperative hypoxaemia, emergency or ur... duration >2 h, and intraoperative factors (such as haemodynamic impairment and low oxyhaemoglobin saturation).	100 100	☒☒☐☐	Strong Statement
1.2	Use a low-tidal-volume protective-ventilation strategy (6–8 ml kg^{-1} PBW). ZEEP is not recommended. Appropriate PEEP and recruitment manoeuvres may improve intraoperative respiratory function and prevent PPCs.	86	☒☒☒☐	Strong

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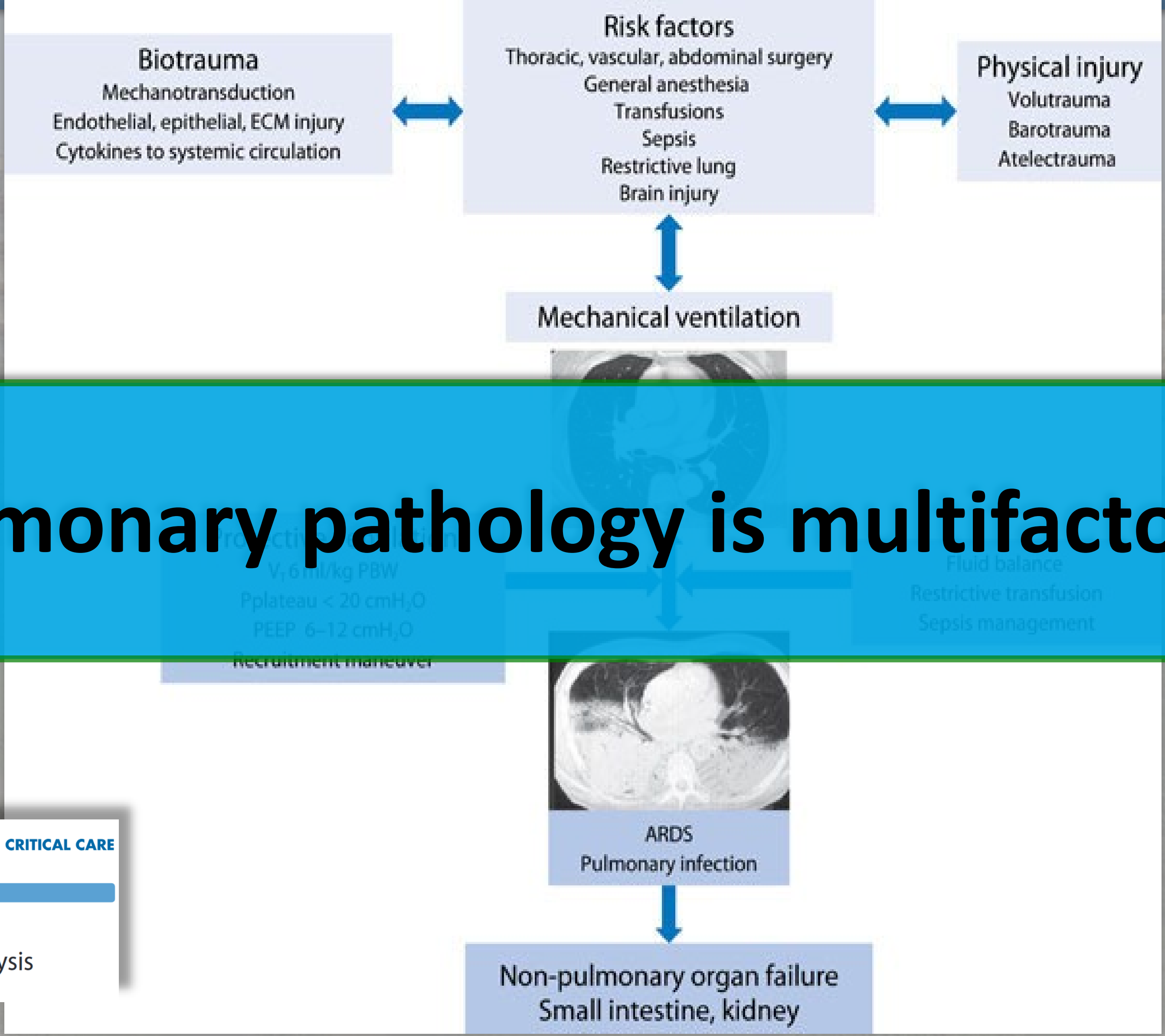
But why?



Pulmonary pathology is multifactorial

Sutherasan *et al. Critical Care* 2014, 18:211
http://ccforum.com/content/18/2/211
CRITICAL CARE
REVIEW

Protective mechanical ventilation in the non-injured lung: review and meta-analysis

Yuda Sutherasan[1], Maria Vargas[2], Paolo Pelosi[3]*

ARDS is a clinical diagnosis rather than a definitive disease

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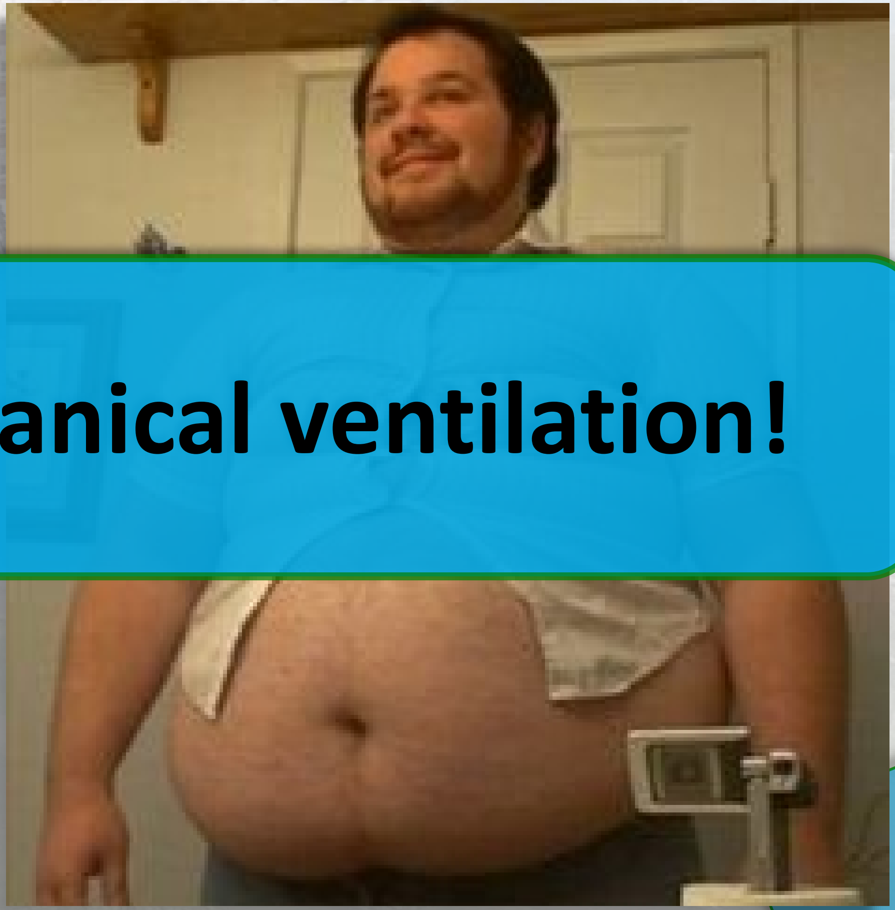
… and because one size does not fit for all



We should personalize mechanical ventilation!

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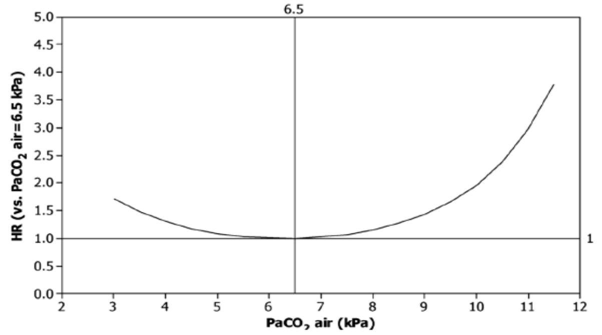
Main goals of personalized venti

Journal of Cardiothoracic and Vascular Anesthesia
Volume 31, Issue 1, February 2017, Pages 61-68

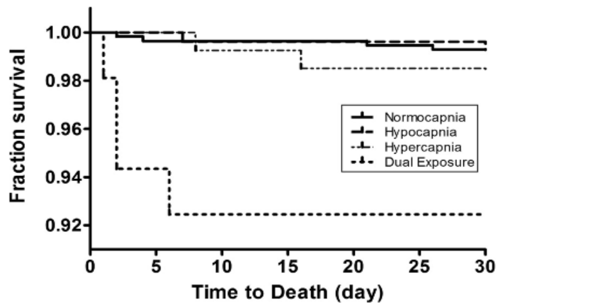
Association Between Arterial Carbon Dioxide Tension and Outcome in Patients Admitted to the Intensive Care Unit After Coronary Artery Bypass Surgery

Jeong-Hyun Choi MD *, Eun-Ho Lee MD †, Myung-Soo Jang MD *, Dae-Hee Jeong MD *, Mi Kyeong Kim MD *

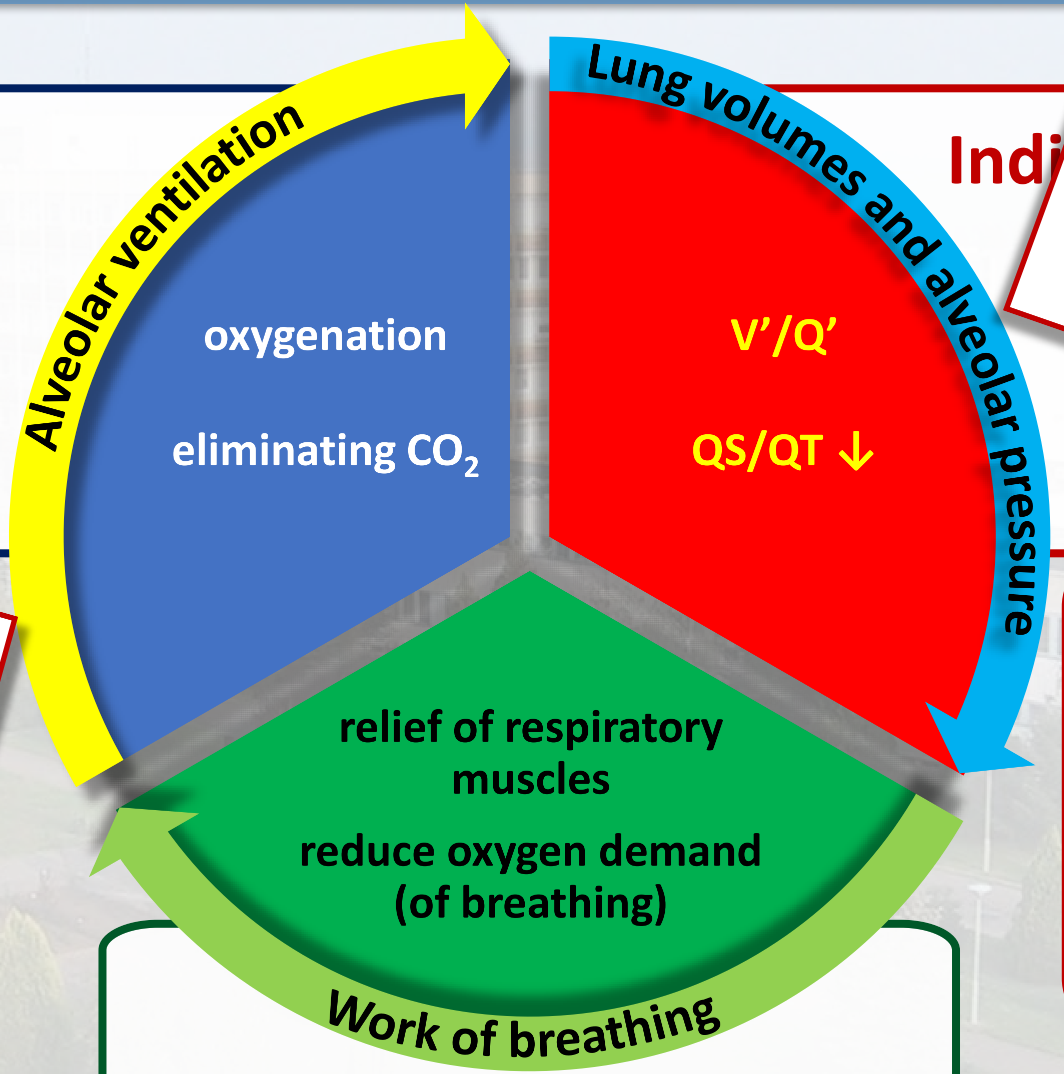
https://doi.org/10.1053/j.jvca.2016.05.003



Ahmadi *et al. Respiratory Research* 2014, 15:30
http://respiratory-research.com/content/15/1/30

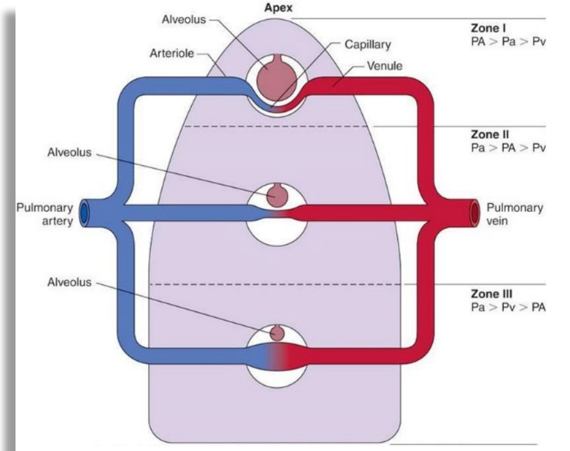


J.-H. Choi et al. / Journal of Cardiothoracic and Vascular Anesthesia 31 (2017) 61–68

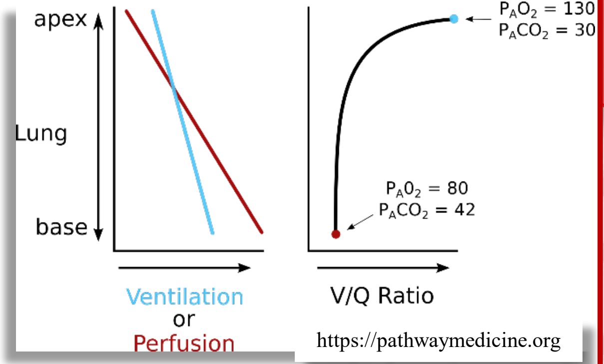


Ventilation modalities, Analgesia, Sedation

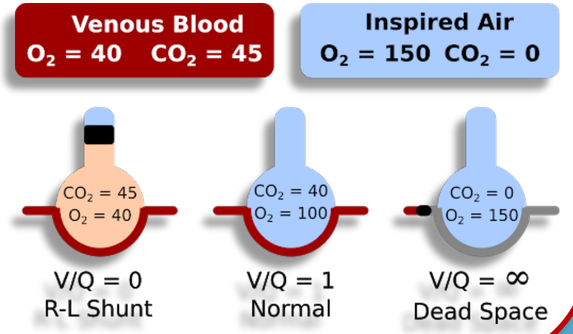
Indi



McCance KL, Huether SE, editors: Pathophysiology: the biologic basis for disease in adults and children, ed 4, St. Louis, 2020, Mosby



https://pathwaymedicine.org



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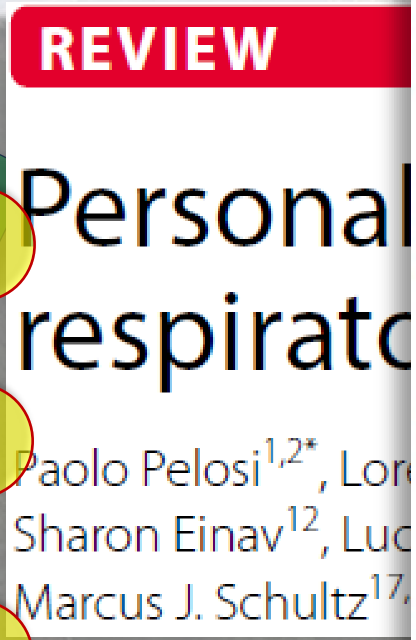
Let’s see our tools and goals!


REVIEW

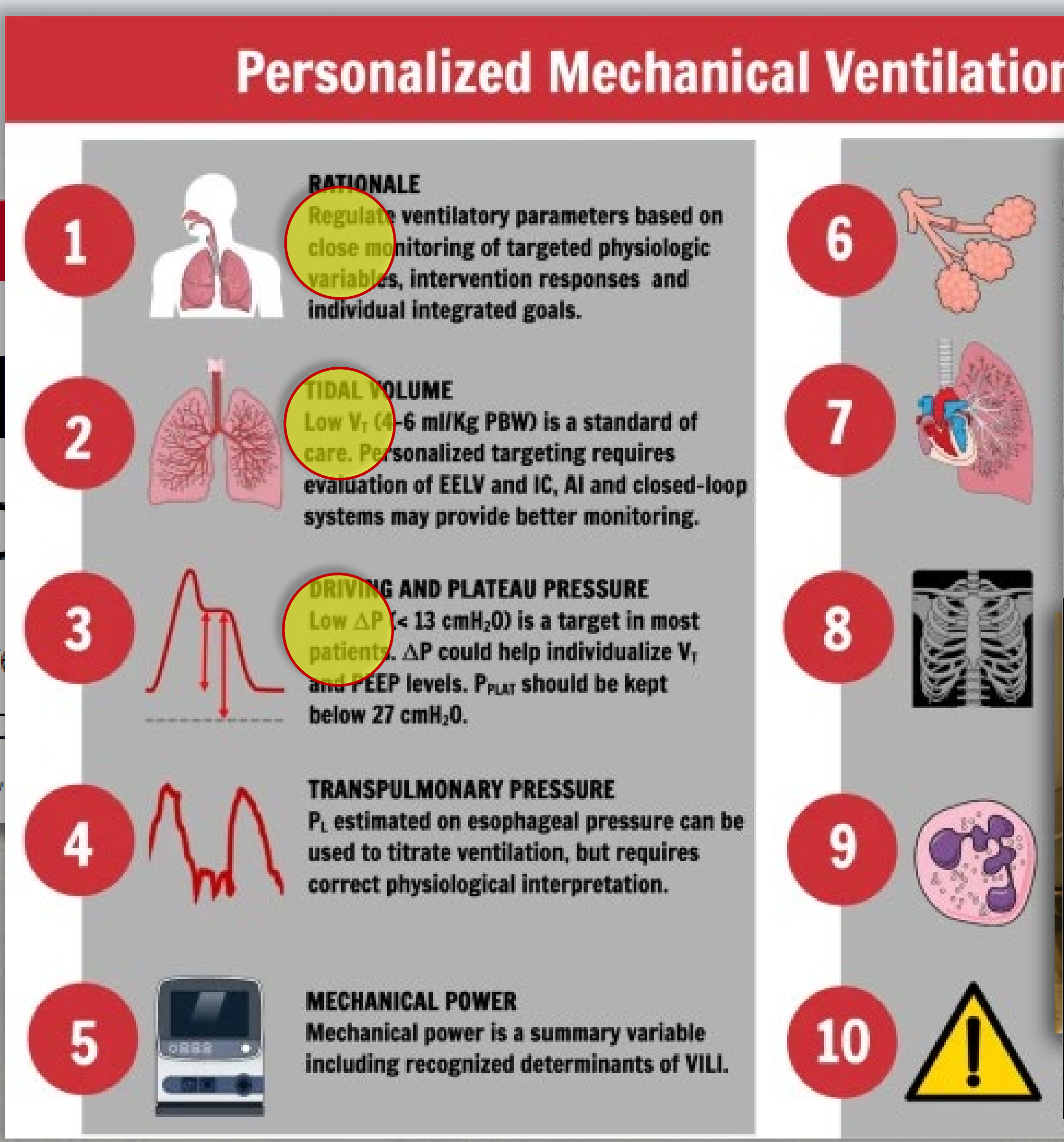
Personal

respirato

Paolo Pelosi[1,2*], Lor

Sharon Einav[12], Luc

Marcus J. Schultz[17,



Personalized mechanical ventilation

Individually optimal PEEP	Individually optimal Tidal Volume	Assess recruitability
PEEP titration	**VT titration**	**Lung imaging**
Highest Cstat / Cdyn	P_{plat} < 25-30 cmH_2O	Hysteresis
Lowest Vds/VT	dP < 15 cmH_2O	Lung US
P_{Lexpi} ≈ 0-5 cmH_2O	P_{Linsp} < 20-25 cmH_2O	EIT
Highest EELV	Alveolar ODCL	X-ray / CT scan

Gas exchange parameters, recovery, weaning

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PEEP titration based on FiO_2

FiO_2/PEEP index: a simple tool for opitimizing ventilator settings

D Trasy, M Nemeth, K Kiss, Z Till, Z Molnar
University of Szeged, Hungary

Critical Care 2013, **17(Suppl 2)**:P90 (doi: 10.1186/cc12028)

Lower PEEP/higher FiO2

[illegible]	[illegible]	[illegible]	[illegible]	0.5	0.5	0.6	0.7	0.7
[illegible]	[illegible]	[illegible]	[illegible]	8	10	10	10	12

[illegible]	0.9	0.9	1.0
[illegible]	16	18	18-24

Introduction During mechanical ventilation, oxygenation can be influenced by adjusting FiO_2 and positive end-expiratory pressure (PEEP). There have been recommendations for how the FiO_2 and PEEP should be set [1]. However, in a recent audit we found that the compliance of doctors of these recommendations is very low [2]. Therefore we invented a simple parameter called the FiO_2/PEEP index (FPi) of which the physiologic value is ≤7 (that is, FiO_2 = 21%/PEEP = 3 cmH_2O), which corresponds to the ARDSNet trial's minimum FiO_2/PEEP settings: 35%/5 cmH_2O [2]. The aim of this case–control study was to investigate the impact of an FPi ≤7 targeted protocol on clinical practice.

NIH N[illegible]
Mechanical Ventilation Protocol Summary

[illegible]	0.3	0.3	0.4	0.4	0.5
[illegible]	12	14	14	16	16

FiO_2	0.5	0.5-0.8	0.8	0.9	1.0	1.0
PEEP	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Conclusion Implementing an FPi ≤7-based algorithm significantly reduced the FiO_2 and increased the PEEP applied in mechanically ventilated within the first 24 hours. Whether this has any impact on earlier weaning due to reaching the weaning criteria of FiO_2 sooner, and as a result shortening the duration of mechanical ventilation, has to be investigated in the future.

PEEP titration based on respiratory mechanics

Pulmonary compliance (C_{stat} / C_{dyn})

- **Target:**
  - highest compliance
- **Method:**
  - decremental PEEP titration
- **Measurements:**
  - C_{stat} = VT / (Pplat-PEEP)
  - C_{dyn} = VT / (PIP-PEEP)

Dead space ratio (Vds/VT)

- **Target:**
  - lowest dead space (Vds/VT)
- **Method:**
  - decremental PEEP titration
- **Measurements:**
  - Advanced spirometry
  - (a-Et)PCO_2
    - Vds/VT = (a-Et)PCO_2 / $PaCO_2$
  - EIT

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Effects of intraoperative positive end-expiratory pressure optimization on respiratory mechanics and the inflammatory response: a randomized controlled trial

Zoltán Ruszkai[1] · Erika Kiss[2] · Ildikó László[2] · Gergely Péter Bokrétás[3] · Dóra Vizserálek[3] · Ildikó Vámossy[3] · Erika Surány[3] · István Buzogány[4] · Zoltán Bajory[5] · Zsolt Molnár[6]

Journal of Clinical Monitoring and Computing
https://doi.org/10.1007/s10877-020-00519-6

	CG (n = 15)	SG (n = 15)	*P* value
PaO_2/FiO_2 (mmHg)	404.15 (115.87)	451.24 (121.78)	0.005
Cstat (ml cmH_2O^{-1})	45.22 (9.13)	52.54 (13.59)	< 0.0001
Vds/Vt (%)	23.05 [20.05–25.50]	21.14 [17.94–24.93]	0.001
Raw (cmH_2O L^{-1} s^{-1})	6.84 (2.39)	5.86 (1.31)	< 0.0001
P (cmH_2O)	9.73 (4.02)	8.26 (1.74)	< 0.0001
Respiratory rate (min^{-1})	16.04 [14.04–16.75]	17.07 [15.01–18.87]	0.0001
$EtCO_2$ (mmHg)	37.63 [36.23–38.16]	38.00 [36.96–39.52]	0.017
(a-Et)PCO_2 (mmHg)	7.25 (0.92)	5.76 (1.39)	0.007

Data are expressed as mean (SD) or median [IQR]

Cstat static pulmonary compliance; *Vds/Vt* dead space fraction; *Raw* airway resistance; ΔP driving pressure; *$EtCO_2$* end-tidal carbon dioxide tension; *(a-Et)PCO_2* arterial to end-tidal carbon dioxide difference; *PaO_2/FiO_2* ratio of arterial oxygen partial pressure to fraction of inspired oxygen; *SD* standard deviation; *IQR* interquartile range

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Individualised … in abdominal surgery: a sys… s

Andres Zorrilla-Vac… Gyorgy Frendl[1]

British Journal of Anaesthesi…

doi: 10.1016/j.bja.2022.07.009

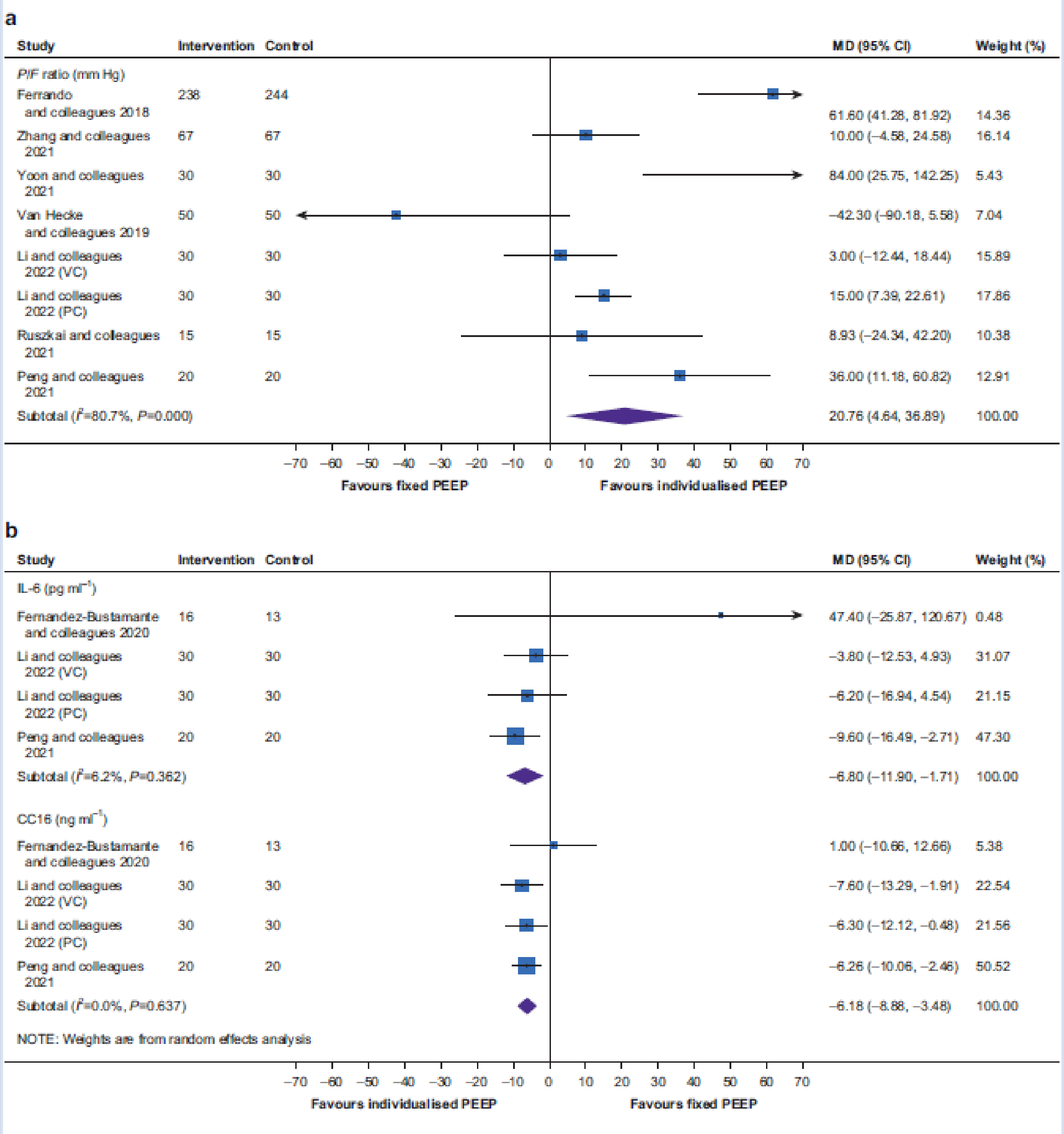

Fig 4. Secondary outcomes: Forest plots for oxygenation and systemic inflammation in patients receiving individualised PEEP vs fixed PEEP in abdominal surgery. (a) Oxygenation, (b) Systemic inflammation: CC16, club cell protein-16; IL-6, interleukin-6. CI, confidence interval

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Anesthesiology

Individualized Positive End-Expiratory Pressure Settings Reduce the Incidence of Postoperative Pulmonary Complications: A Systematic Review and Meta-Analysis of Randomized Controlled Trials

--Manuscript Draft--

Manuscript Number:	
Full Title:	Individualized Positive End-Expiratory Pressure Settings Reduce the Incidence of Postoperative Pulmonary Complications: A Systematic Review and Meta-Analysis of Randomized Controlled Trials
Short Title:	Effects of titrated PEEP setting, a meta-analysis
Article Type:	Original Investigation: Perioperative Medicine
Section/Category:	
Corresponding Author:	Zsolt Molnár, MD, Ph.D Pecsi Tudomanyegyetem Altalanos Orvostudomanyi Kar Pécs, HUNGARY
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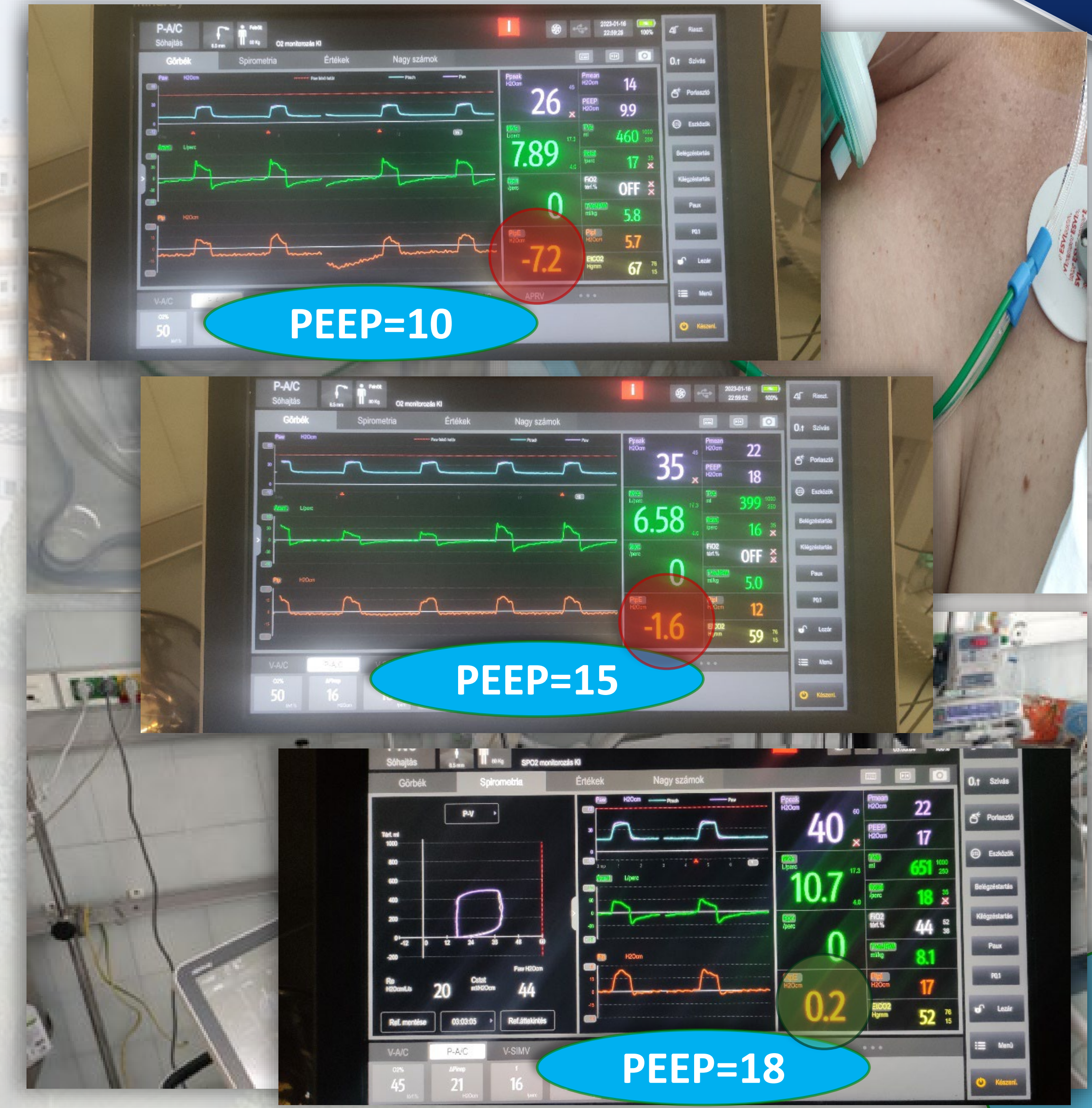
	Zoltán Ruszkai, MD, Ph.D
	Zsolt Molnár, MD, Ph.D

PEEP titration based on transpulmonary pressure

Basic principles

- Transpulmonary pressure (P_L) is responsible for maintaining alveolar inflation
- $P_L < 0$ cmH2O → alveolar collapse
- $P_L = P_{ao} - P_{pl}$ while $P_{pl} \approx P_{ES}$
- Adjusting PEEP to achieve positive end-expiratory transpulmonary pressures (P_{Lexpi} = 0-5 cmH2O) prevents collapse



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Mechanical Ventilation Guided by Esophageal Pressure in Acute Lung Injury

Daniel Talmor, M.D., M.P.H., Todd Sarge, M.D., Atul Malhotra, M.D., Carl R. O'Donnell, Sc.D., M.P. ... d Stephen H. Loring,

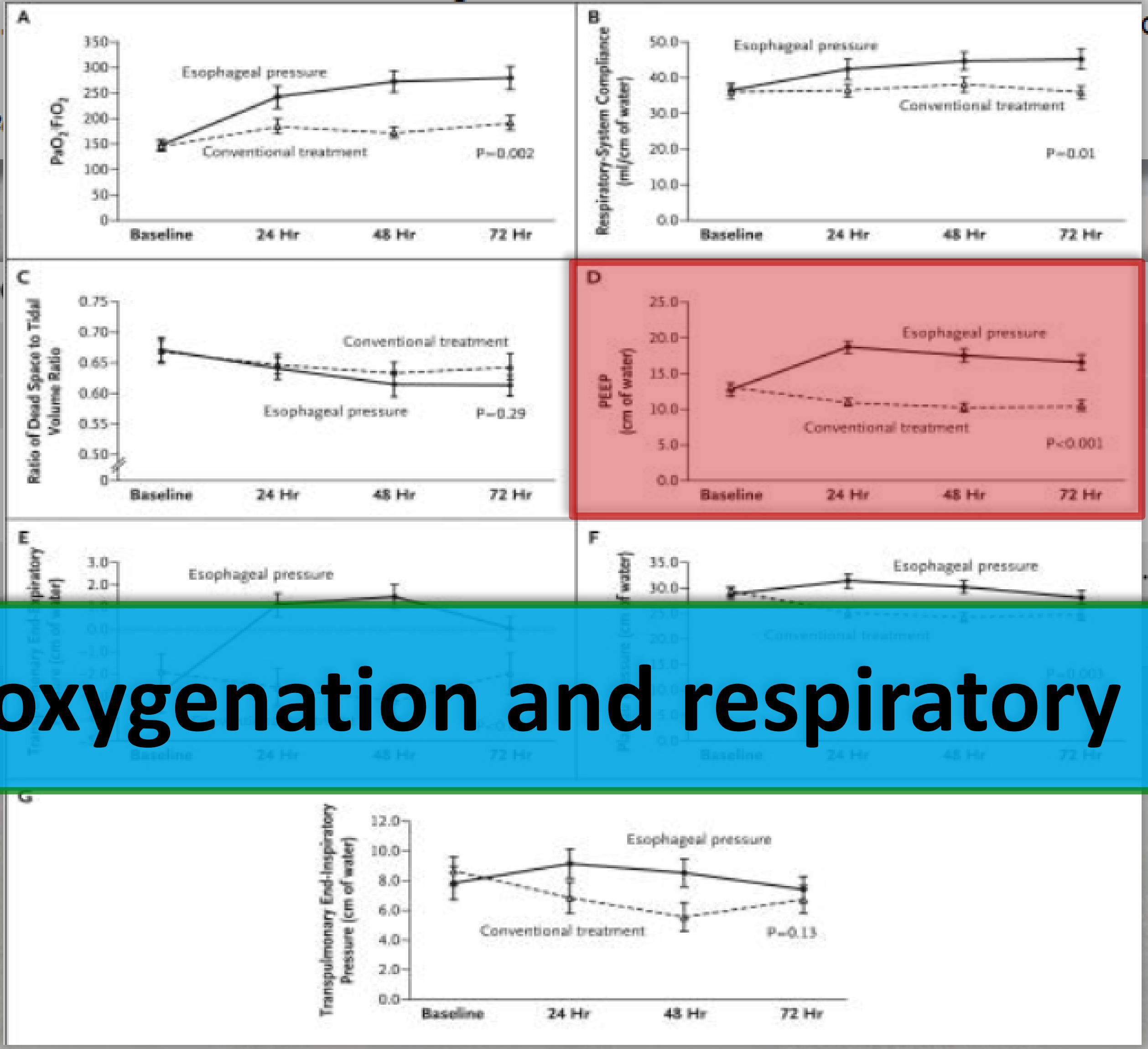
N Engl J Me

Esophageal-Pressure–Guide

F_IO_2	0.4	0.5	0.9	1.0
P_{Lexp}	0	0	10	10

Control Group

F_IO_2	0.3	0.4	.9	0.9	0.9	1.0
PEEP	5	5		16	18	20–24



Improved oxygenation and respiratory mechanics

Esophageal Pressure Versus Gas Exchange to Set PEEP During Intraoperative Ventilation

Gianmaria Cammarota, Gianluigi Lauro, Ilaria Sguazzotti, Iolanda Mariano, Raffaella Perucca, Antonio Messina, Marta Zanoni, Eugenio Garofalo, Andrea Bruni, Francesco Della Corte, Paolo Navalesi, Elena Bignami, Rosanna Vaschetto, and Francesco Mojoli

Respir Care 2020;65(5):625–635.

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There was a higher risk of overdistension in the SG

Patients in the SG required more vasopressors

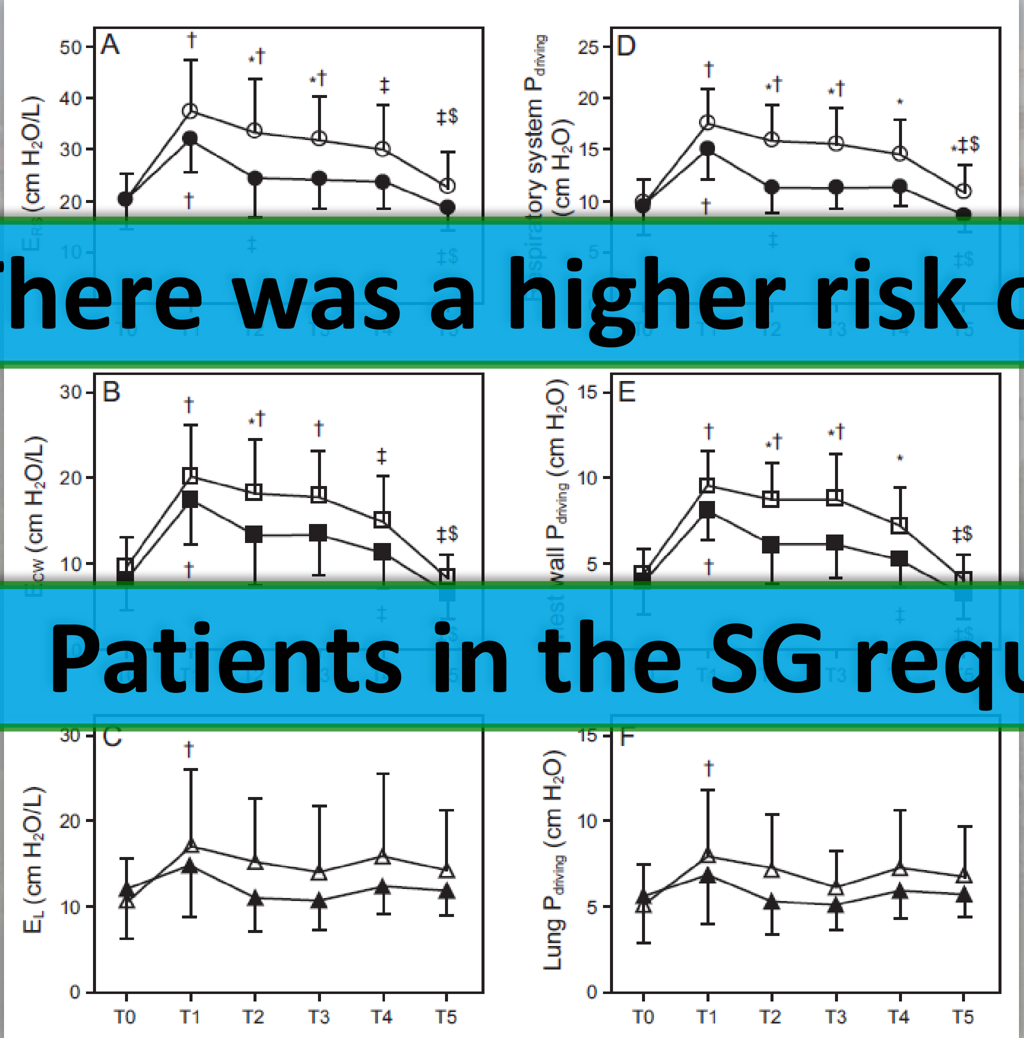

Table 3. Arterial Blood Gases

Parameters	Randomization	At 60 Min	At 120 Min	At End of Surgery
P_{aO_2}/F_{IO_2}, mm Hg				
$V_{Gas\text{-}guided}$	[illegible]	[illegible]	[illegible]	[illegible]
$V_{Pes\text{-}guided}$	307 ± 102	388 ± 90†	400 ± 90†	402 ± 95†
F_{IO_2}				
$V_{Gas\text{-}guided}$	0.50 ± 0.06	0.47 ± 0.06	0.48 ± 0.07	0.48 ± 0.08
$V_{Pes\text{-}guided}$	0.47 ± 0.05	0.42 ± 0.07	0.41 ± 0.07	0.41 ± 0.07
P_{aCO_2}, mm Hg				
$V_{Gas\text{-}guided}$	47.1 ± 4.6	44.0 ± 2.9	42.3 ± 2.9†	42.0 ± 3.2
$V_{Pes\text{-}guided}$	44.5 ± 6.1	42.7 ± 5.1	41.1 ± 3.9	40.6 ± 3.7
pH				
$V_{Gas\text{-}guided}$	7.33 ± 0.04	7.33 ± 0.03	7.33 ± 0.03	7.32 ± 0.02
$V_{Pes\text{-}guided}$	7.33 ± 0.05	7.34 ± 0.04	7.35 ± 0.03	7.35 ± 0.04
[illegible]				
$V_{Gas\text{-}guided}$	[illegible]	[illegible]	[illegible]	[illegible]
$V_{Pes\text{-}guided}$	0.49 ± 0.12	0.55 ± 0.19	0.60 ± 0.21	0.64 ± 0.22†

Data are presented as mean ± SD.

* $V_{Gas\text{-}guided}$ vs $V_{Pes\text{-}guided}$ ($P < .05$).

† vs randomization ($P < .05$).

$V_{Gas\text{-}guided}$ = conventional low-tidal ventilation with PEEP set according to gas exchange

$V_{Pes\text{-}guided}$ = low-tidal ventilation tailoring PEEP according to esophageal pressure

P_{aO_2}/F_{IO_2} = ratio of arterial partial pressure of oxygen to the fraction of inspired oxygen

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PEEP titration in moderate to severe ARDS: plateau versus transpulmonary pressure

Marie Bergez[1], Nicolas Fritsch[1], David Tran-Van[1], Tahar Saghi[2], Tan Bounkim[3], Ariane Gentile[1], Philippe Labadie[1], Bruno Fontaine[1], Alexandre Ouattara[4,5] and Hadrien Rozé[4*]

Bergez et al. Ann. Intensive Care (2019) 9:81
https://doi.org/10.1186/s13613-019-0554-3

Table 2 Measurements of respiratory function and hemodynamics ($n=19$)

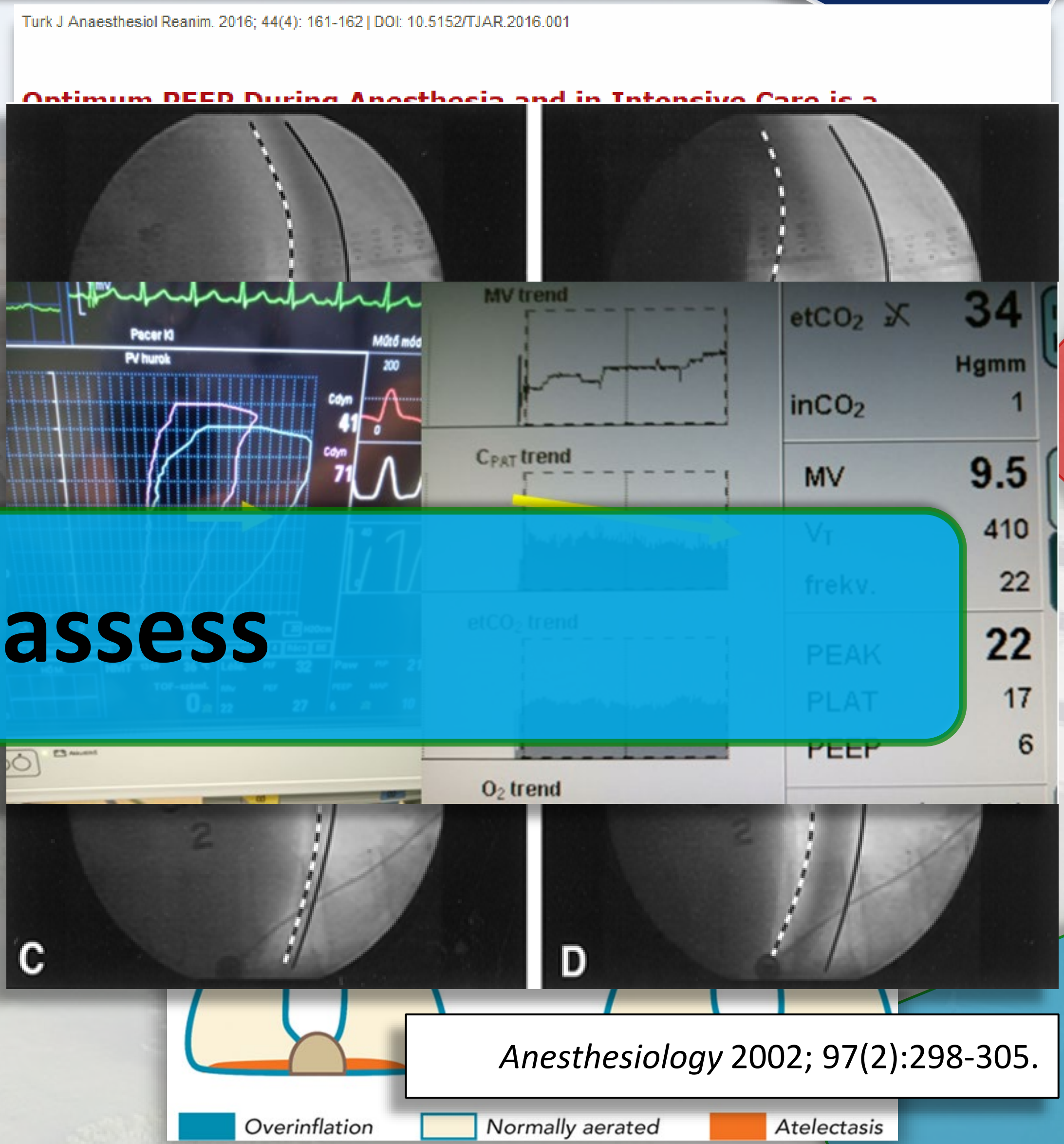
Protocols	$PEEP_{baseline}$	Express protocol	P_{Lexpi}	p value
PEEP (cmH_2O)	7.0 ± 1.8	14.2 ± 3.6*	16.7 (5.9)*	< 0.0001
P_{plat} (cmH_2O)	20.8 ± 4.0	28.8 ± 2.0 *	33.9 ± 10.6*	< 0.0001
$P_{L,es}$ (cmH_2O)	7.0 ± 5.9	11.9 ± 6.2*	15.5 ± 8.5*	0.0013
$P_{L,EL}$ (cmH_2O)	15.3 ± 4.9)	20.5 ± 4.7*	24.3 ± 11.4*	0.0025
P_{Lexpi} (cmH_2O)	− 2.6 ± 5.2	1.4 ± 5.1*	3.3 ± 1.6*	< 0.0001
EELV (ml)	1546 ± 634	2067 ± 924*	2287 ± 945*	0.001
DP_{aw} (cmH_2O)	13.0 ± 3.9	14.2 ± 5.0	16.4 ± 7.8	0.17
DP_L (cmH_2O)	9.9 ± 4.4	10.6 ± 5.6	12.3 ± 8.3	0.20
$DP_{L,EL}$ (cmH_2O)	7.5 ± 4.3	8.1 ± 5.6	9.5 ± 8.1	0.30
Crs (ml/cmH_2O)	33.3 ± 15.8	30.0 ± 10.7	28.3 ± 13.2	0.17
E_{cw} (cmH_2O/l)	8.7 ± 2.7	9.6 ± 3.4*	10.9 ± 4.3*	0.03
E_L (cmH_2O/l)	26.0 ± 11.9	28.0 ± 15.9	33.2 ± 25.1	0.25
FiO_2 (%)	80.0 ± 21.1	80.6 ± 21.2	81.1 ± 21.6	0.46
PaO_2/FiO_2	91.2 ± 31.2	134.0 ± 67.2*	152.7 ± 80.1*	0.01
pH	7.31 ± 0.11	7.30 ± 0.11	7.31 ± 0.12	0.08
$PaCO_2$ (mmHg)	45.2 ± 10.4	46.5 ± 9.6	45.3 ± 11.0	0.26
MAP (mmHg)	82.0 ± 13.4	74.7 ± 12.9	75.7 ± 12.0	0.06
Heart rate (beats/min)	99 ± 27	102 ± 26	107 ± 28	0.19
Lactates (mmol/l)	1.6 ± 0.9	1.5 ± 0.8	1.5 ± 0.8	0.27

Results are expressed as mean ± standard deviation

P_{plat}: plateau pressure; P_{Lexpi}: end-expiratory transpulmonary pressure; DP_L: transpulmonary driving pressure; $P_{L,EL}$: relative end-expiratory pressure; $P_{L,es}$: absolute inspiratory transpulmonary pressure; DP_{aw}: airway driving pressure; DP_L: transpulmonary driving pressure, $DP_{L,EL}$: transpulmonary elastance-related driving pressure; E_L: lung elastance; EELV: end-expiratory lung volume; E_{cw}: elastance chest wall; Crs: compliance respiratory system; MAP: mean arterial pressure. p value refers to repeated measures ANOVA. *$p < 0.05$ of Express and P_{Lexpi} groups versus baseline group. §$p < 0.05$ of Express versus P_{Lexpi} groups

Limitations

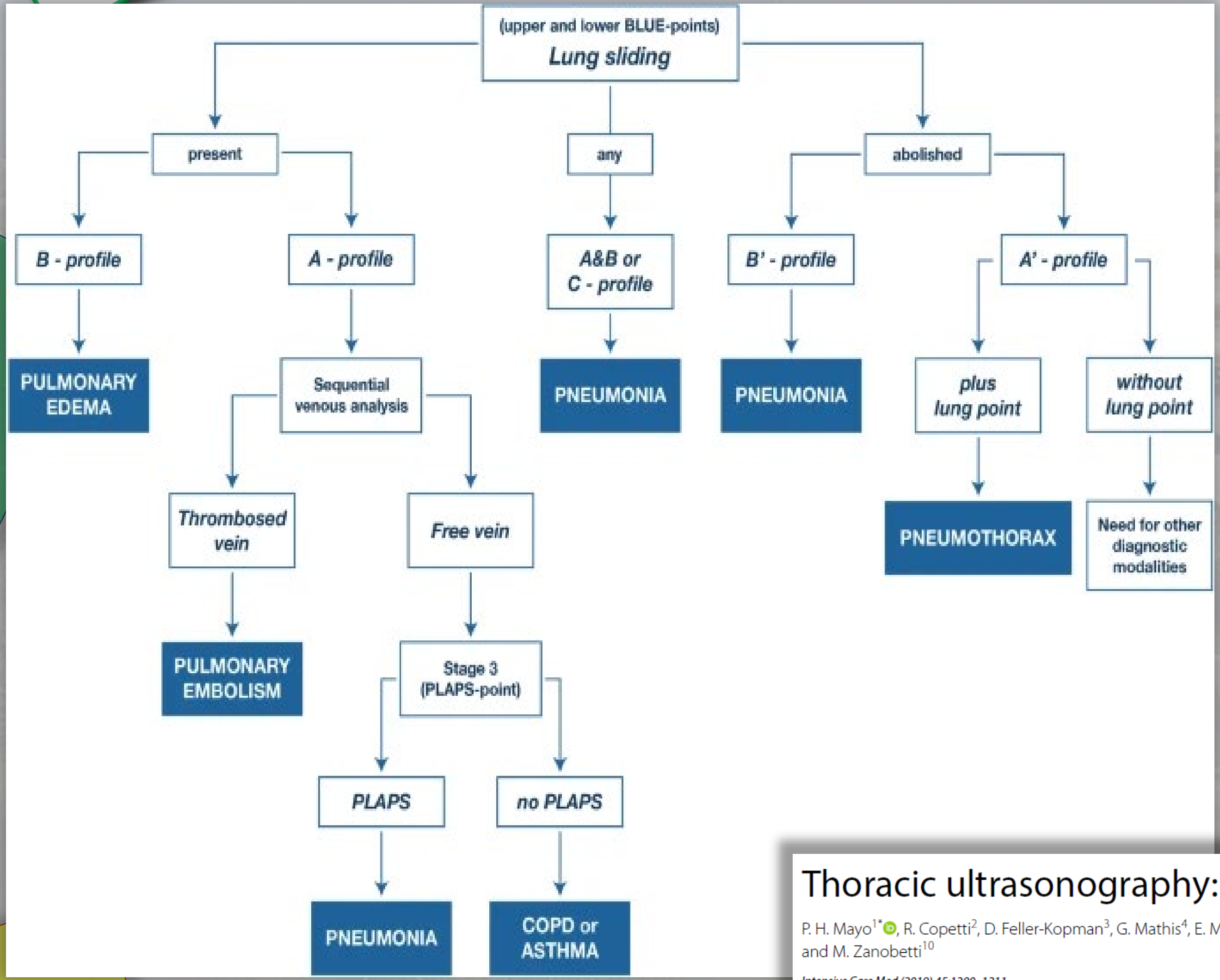
- Distribution of ventilation is heterogenous
  - elastic properties of the lungs
  - vertical gradient of transpulmonary pressure
- Excurison of the diaphragm changes during mechanical ventilation
  - ventral redistribution of ventilation to the nondependent and less perfused anterior regions of the lungs
  - V/Q mismatch
  - extent atelectasis in the dependent lung regions
- Optimal PEEP changes during time



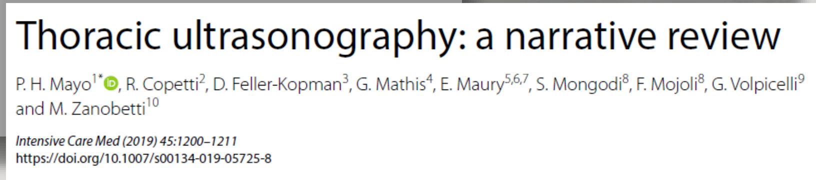
Anesthesiology 2002; 97(2):298-305.

Assess and Reassess

Titrating PEEP and assessing recruitability applying LUS



- Non-invasive
- Radiation-free
- Reproducible
- Rapid and real-time assessment
  - Etiology
  - Result of interventions
    - PEEP titration
    - Alveolar recruitment
- Intermittent


Thoracic ultrasonography: a narrative review

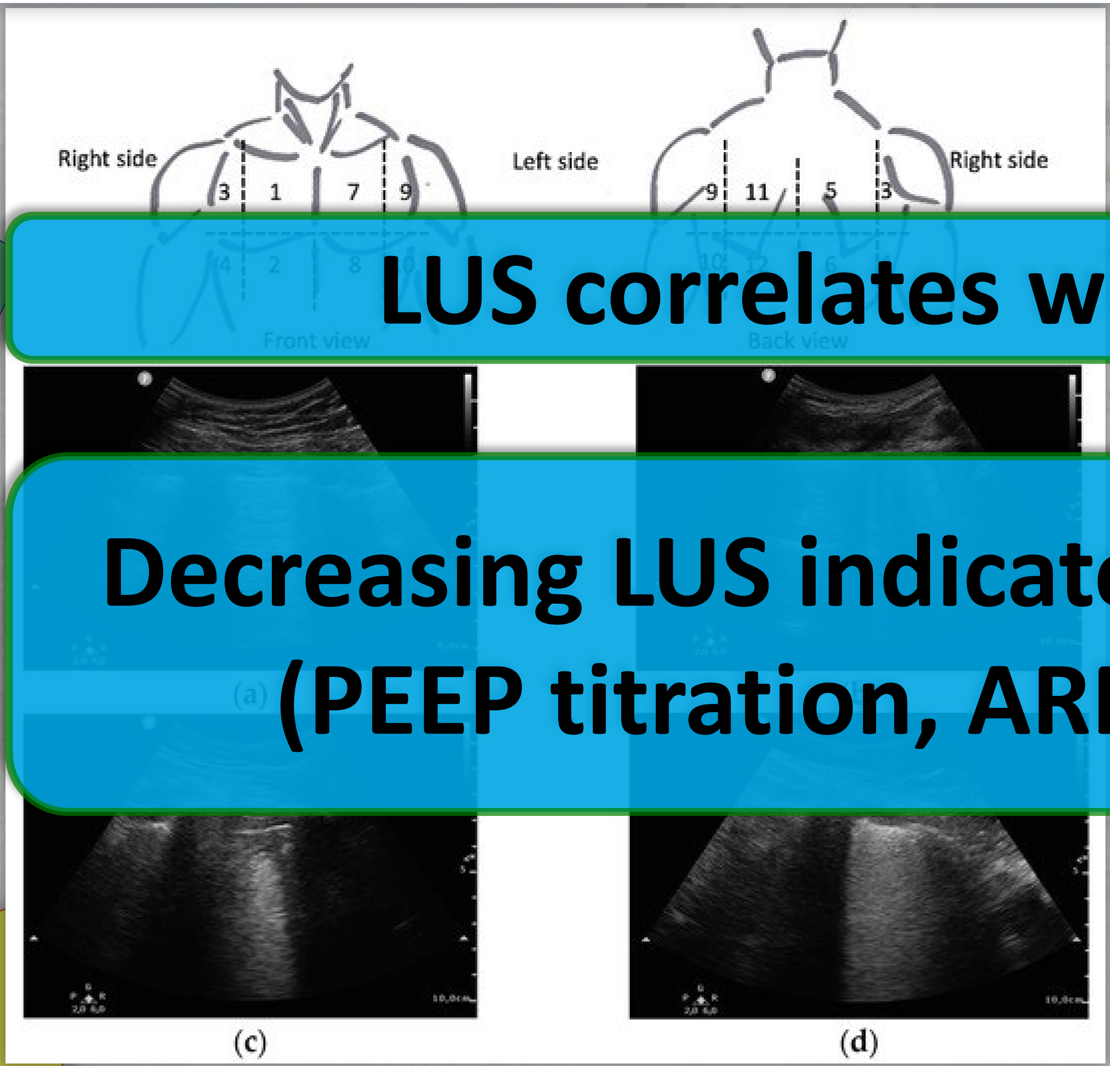
P. H. Mayo[1*], R. Copetti[2], D. Feller-Kopman[3], G. Mathis[4], E. Maury[5,6,7], S. Mongodi[8], F. Mojoli[8], G. Volpicelli[9] and M. Zanobetti[10]

Intensive Care Med (2019) 45:1200–1211
https://doi.org/10.1007/s00134-019-05725-8

Lung Ultrasound Score (LUS)

Lung Ultrasound, Clinical and Analytic Scoring Systems as Prognostic Tools in SARS-CoV-2 Pneumonia: A Validating Cohort

Diagnostics **2021**, *11*(12), 2211; https://doi.org/10.3390/diagnostics11122211



Finding	POINT
normal aeration	0
moderate loss of aeration • multiple spaced B lines • localized pulmonary edema B lines in less ... intercostal space	1
severe loss of aeration (alveolar edema) • ... whole intercostal space	2
complete loss of lung aeration • lung consolidation defined as a tissue pattern with or without air bronchogram	3

LUS correlates with disease severity

Decreasing LUS indicates succesful interventions (PEEP titration, ARM, AMBs) or recovery

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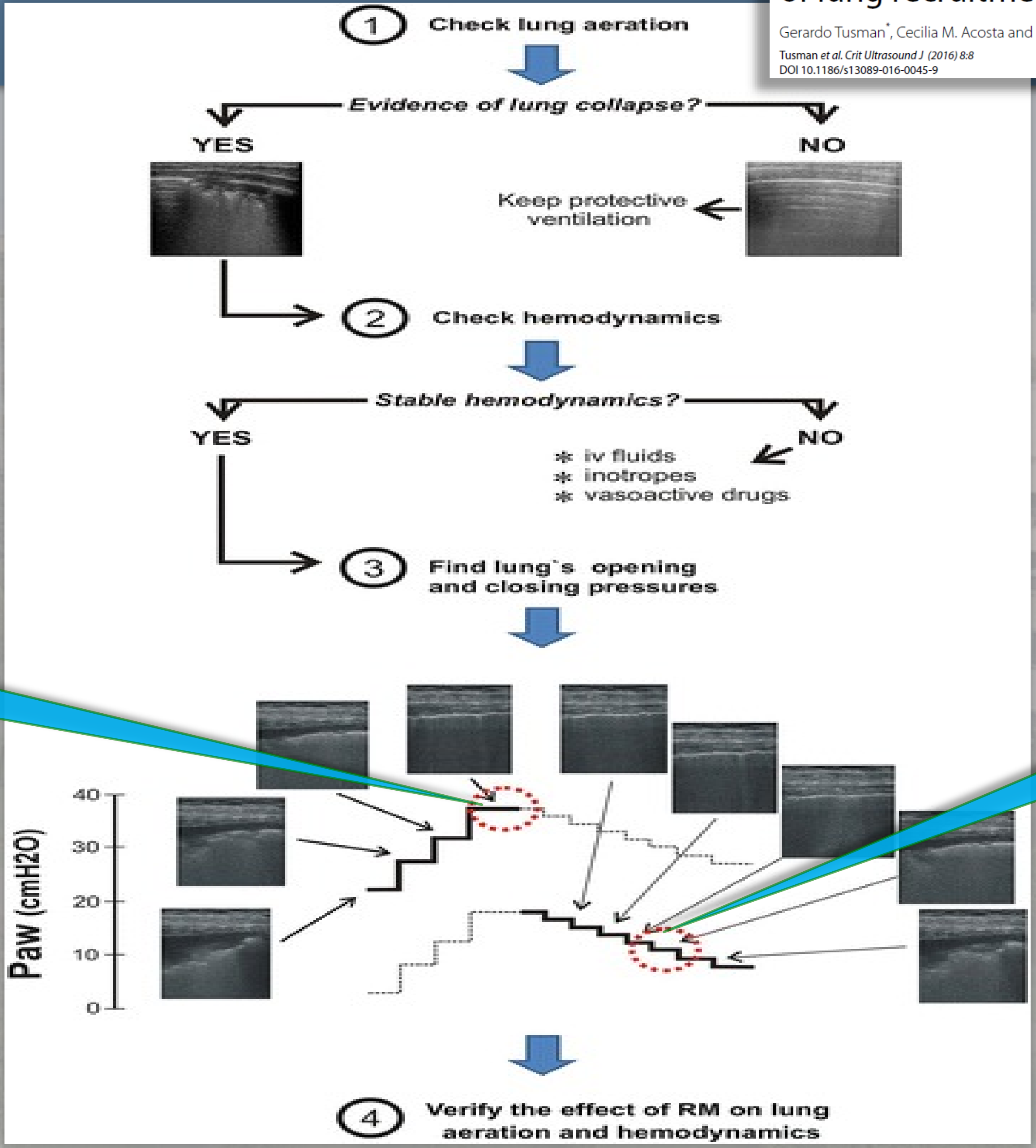
Ultrasonography for the assessment of lung recruitment maneuvers

Gerardo Tusman*, Cecilia M. Acosta and Mauro Costantini

Tusman et al. Crit Ultrasound J (2016) 8:8
DOI 10.1186/s13089-016-0045-9



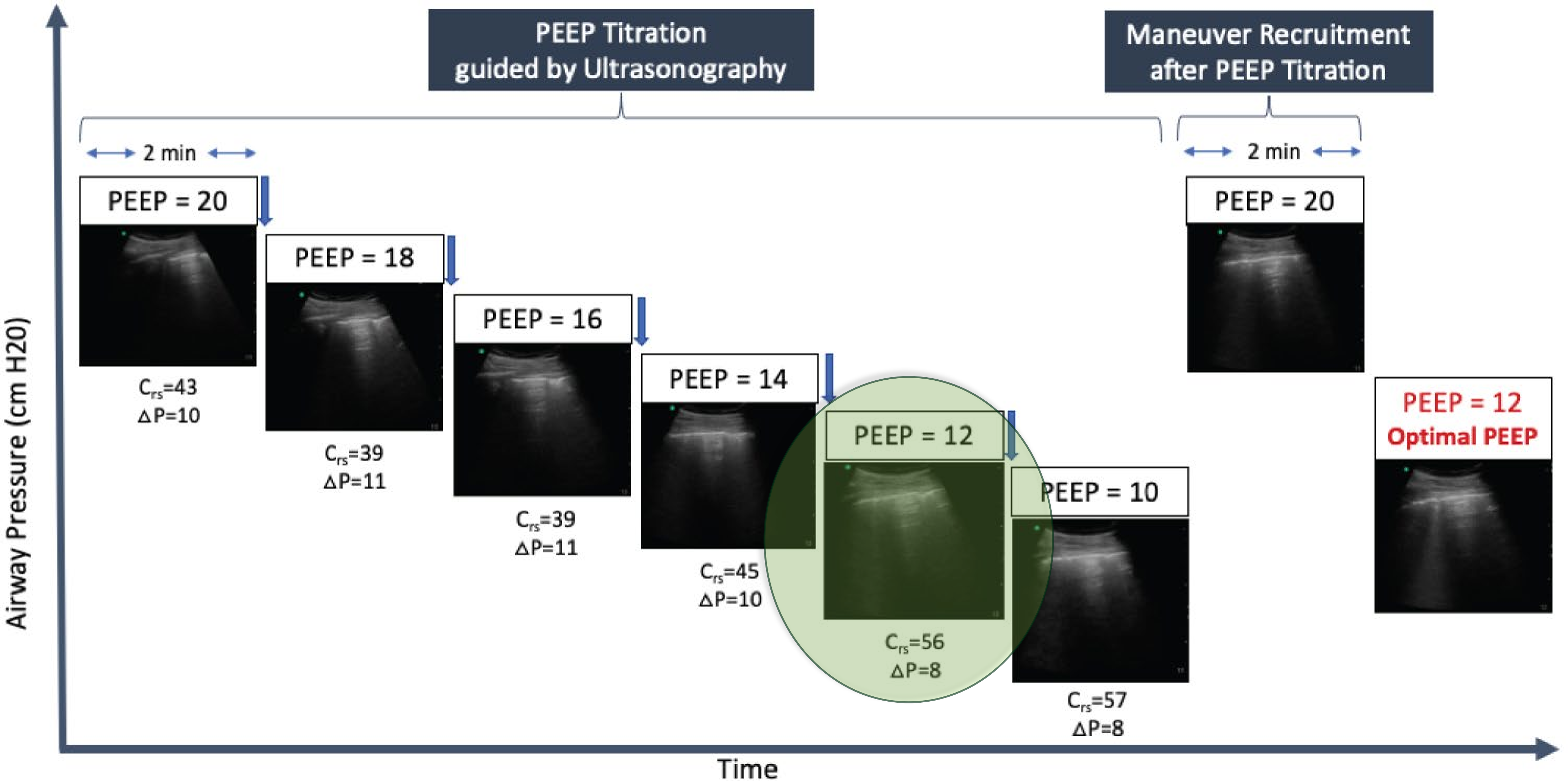
Opening Pplat

Closing PEEP

CASE REPORT | OPEN ACCESS DOI: 10.23937/2474-3674/1510132

Lung Recruitment Guided by Ultrasonography in Unilateral Lung Injury

Roosevelt Santos Nunes*, Larissa Christina Pires Barrientto, Viviane Barbosa Silva, Kamila da Grazia Iazzetta, Taiana Bertacini Almas de Jesus and Gil Cezar Teixeira Alkmin



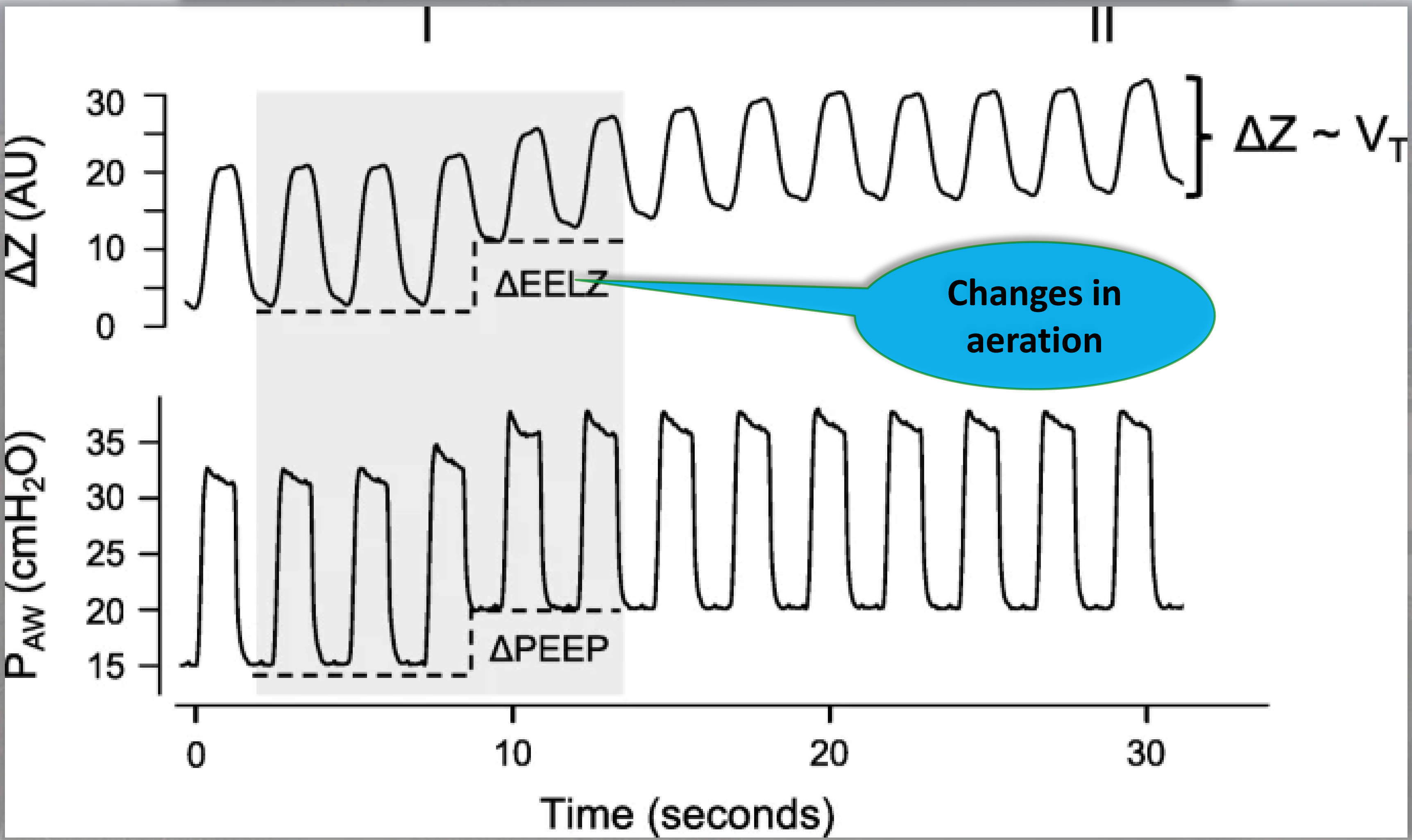
Titrating PEEP and assessing recruitability applying EIT

- Non-invasive
- Radiation-free
- Continuous, real-time assessment of distribution of ventilation
- Etiology
- Result of interventions
  - PEEP titration
  - Alveolar recruitment / Pendelluft
- EIT can also track the distribution of pulmonary blood flow

Electrical impedance tomography in acute respiratory distress syndrome

M Consuelo Bachmann[1,2], Caio Morais[4], Guillermo Bugedo[1,2], Alejandro Bruhn[1,2], Arturo Morales[3], João B Borges[4,5], Eduardo Costa[4] and Jaime Retamal[1,2*]

Bachmann *et al. Critical Care* (2018) 22:263
https://doi.org/10.1186/s13054-018-2195-6



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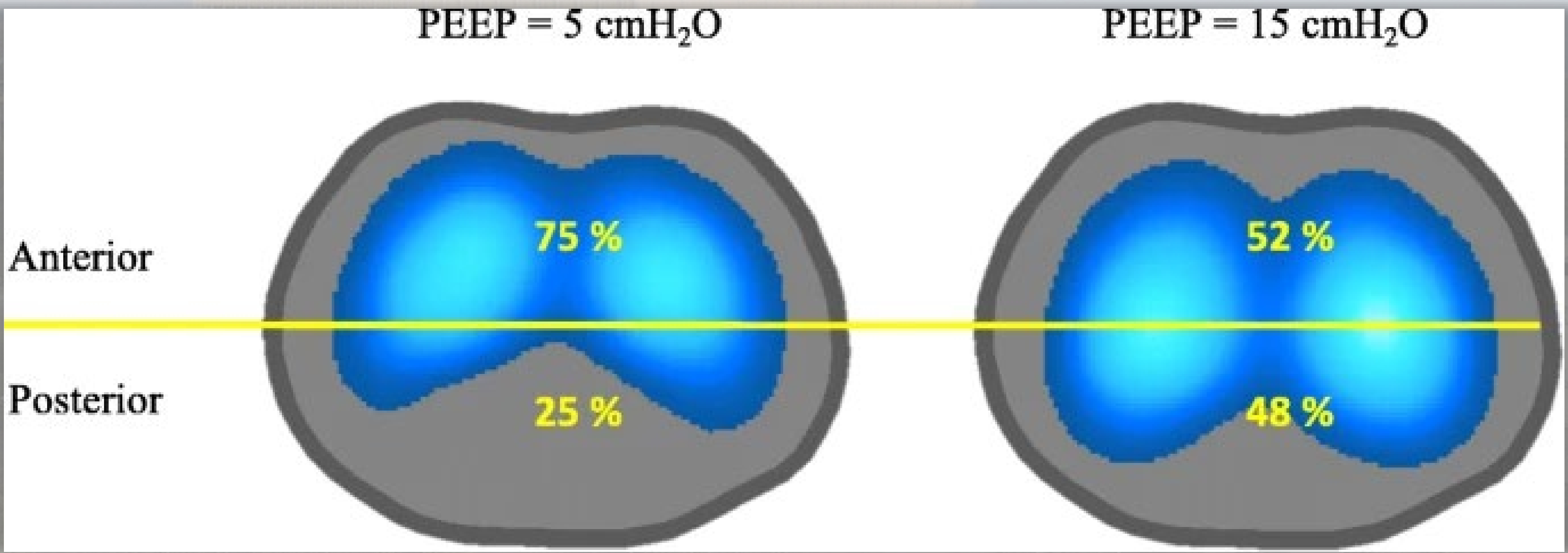

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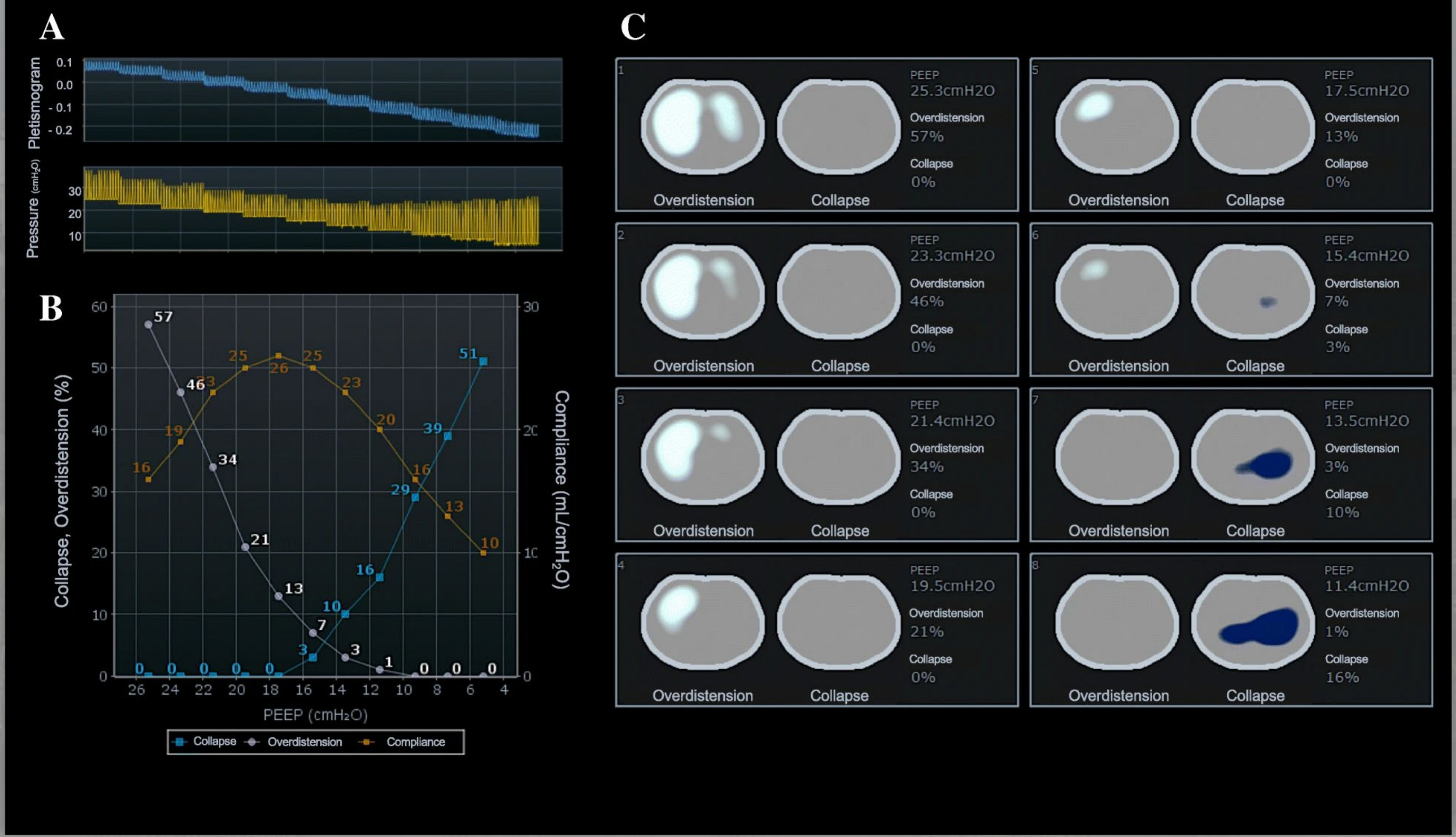

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Electric impedance tomography-guided PEEP titration reduces mechanical power in ARDS: a randomized crossover pilot trial

Jose Victor Jimenez[1], Elizabeth Munroe[1], Andrew J. Weirauch[2], Kelly Fiorino[2], Christopher A. Culter[2], Kristine Nelson[1], Wassim W. Labaki[1], Philip J. Choi[1,2], Ivan Co[1], Theodore J. Standiford[1], Hallie C. Prescott[1,3] and Robert C. Hyzy[1*]

Jimenez et al. Critical Care (2023) 27:21
https://doi.org/10.1186/s13054-023-04315-x

Table 2 Comparison of changes in ventilator parameters with EIT vs tables, for all participants, *n* = 12

	Change with EIT*	Change with tables**		95% CI of mean difference	*p* value
Mechanical Power[1], J/min	− 2.50 ± 3.70	1.87 ± 1.61	− 4.36	(− 6.77, − 1.95)	0.002
4ΔP + RR Index, J/min	− 6.80 ± 9.36	4.62 ± 6.25	− 11.42	(− 19.01, − 3.82)	0.007
Elastic–static power[2], J/min	− 1.37 ± 2.11	0.19 ± 2.28	− 1.56	(− 3.71, 0.58)	0.138
Elastic–dynamic power[3], J/min	− 1.13 ± 1.66	0.48 ± 0.88	− 1.61	(− 2.99, − 0.22)	0.027
Resistive power[4], J/min	0.01 ± 3.30	1.15 ± 2.48	− 1.14	(− 4.59, 2.30)	0.48
Driving Pressure, cmH_2O	− 1.58 ± 2.32	1.34 ± 1.31	− 2.92	(− 4.59, − 1.24)	0.003
PEEP (set), cmH_2O	− 1.17 ± 1.80	0.83 ± 1.80	− 2	(− 3.95, − 0.05)	0.046
Ppeak, cmH_2O	− 2.75 ± 3.55	3.5 ± 2.78	− 6.25	(− 9.79, − 2.71)	0.003
Pplat, cmH_2O	− 2.48 ± 3.22	2.06 ± 1.88	− 4.53	(− 7.45, − 1.62)	0.006
RR, breaths/min	− 0.5 ± 2.35	− 0.75 ± 2.73	0.25	(− 2.71, 3.21)	0.856
Cstat, ml/cmH_2O	3.24 ± 9.85	− 4.6 ± 5.26	7.93	(2.54, 13.32)	0.008
PaO2/FiO2 ratio	25.14 ± 27.11	− 0.89 ± 60.05	26.03	(− 16.01, 68.06)	0.2

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Assessing recruitability

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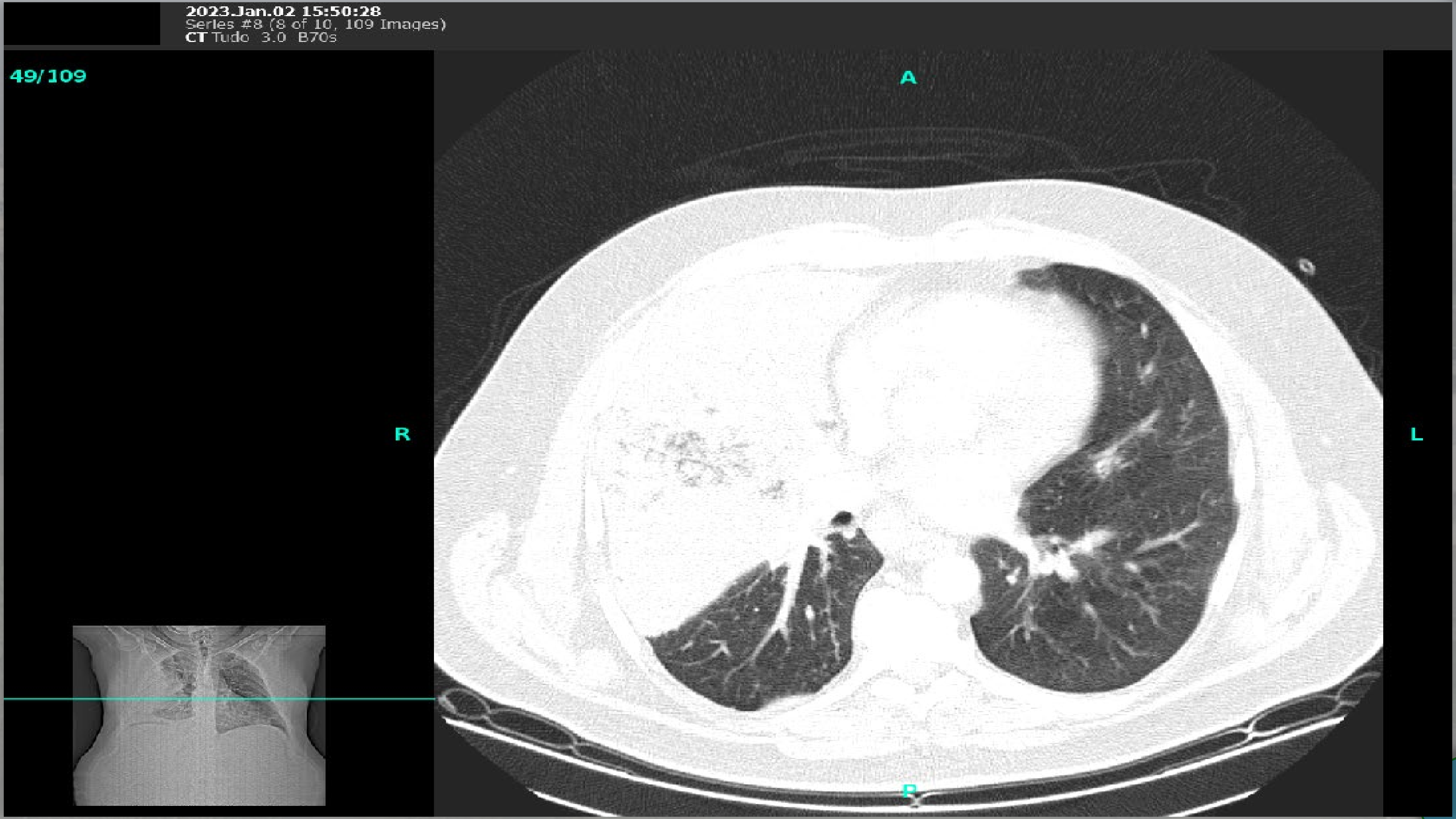
A non-recruitable lung



Weaning

CPAP + PSV (6+8)	HFTO 30 L/min	HFTO 40 L/min	HFTO 50 L/min

Titrating Tidal Volume

- In ARDS patients, lung volumes do not correlate closely with PBW due to heterogeneous distribution of lung disease
- Measuring EELV or IC is not so simple at the bedside and requires special equipment / CT scan

- Safety limits of mechanical ventilation
  - Driving pressure < 15 cmH_2O
  - Plateau pressure < 30 (25) cmH_2O
  - P_{Linsp} < 20 (25) cmH_2O

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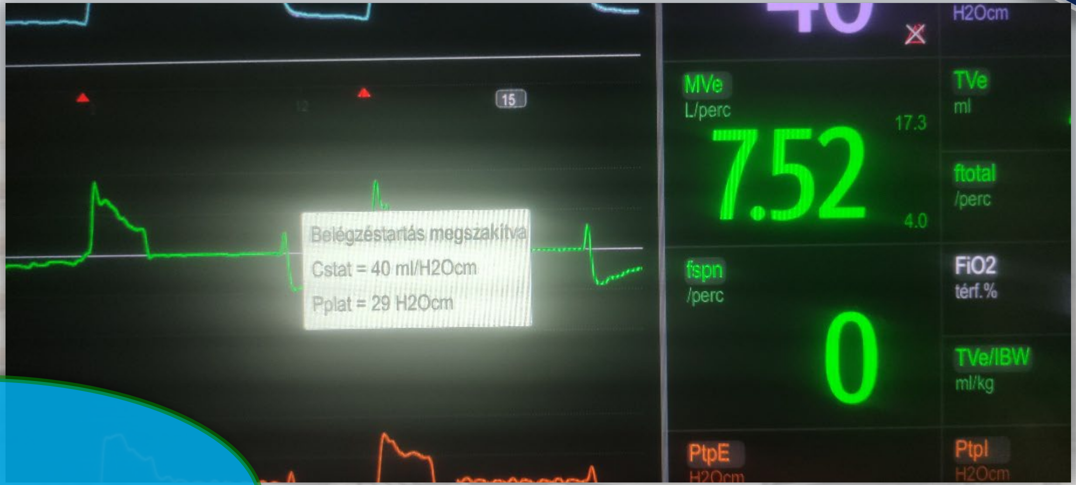
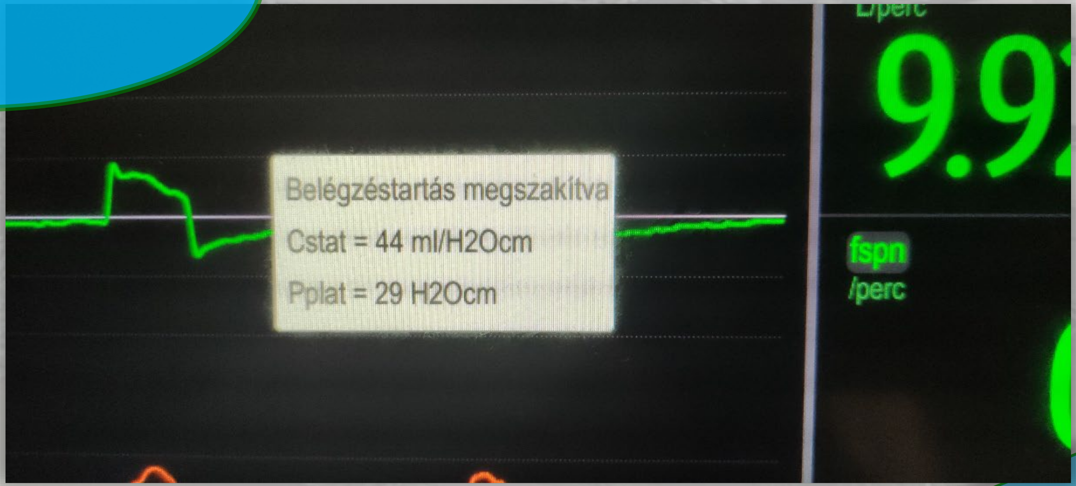
Titrating Tidal Volume



dP = 10 cmH2O



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Future aspects

REVIEW — Open Access

Personalized mechanical ventilation in acute respiratory distress syndrome

Paolo Pelosi[1,2*], Lorenzo Ball[1,2], Carmen S. V. Barbas[3,4], Rinaldo Bellomo[5,6,7,8,9], Karen E. A. Burns[10,11], Sharon Einav[12], Luciano Gattinoni[13], John G. Laffey[14], John J. Marini[15], Sheila N. Myatra[16], Marcus J. Schultz[17,20,21], Jean Louis Teboul[18] and Patricia R. M. Rocco[19]

Personalized Mechanical Ventilation in ARDS

1. **RATIONALE**
Regulate ventilatory parameters based on close monitoring of targeted physiologic variables, intervention responses and individual integrated goals.

2. **TIDAL VOLUME**
Low V_T (4-6 ml/Kg PBW) is a standard of care. Personalized targeting requires evaluation of EELV and IC, AI and closed-loop systems may provide better monitoring.

3. **DRIVING AND PLATEAU PRESSURE**
Low ΔP (< 13 cmH_2O) is a target in most patients. ΔP could help individualize V_T and PEEP levels. P_{PLAT} should be kept below 27 cmH_2O.

4. **TRANSPULMONARY PRESSURE**
P_L estimated on esophageal pressure can be used to titrate ventilation, but requires correct physiological interpretation.

5. **MECHANICAL POWER**
Mechanical power is a summary variable including recognized determinants of VILI.

6. **ALVEOLAR RECRUITMENT**
The identification of recruitable patients and estimation of recruitment are essential to individualize recruitment strategies.

7. **GAS-EXCHANGE**
Gas-exchange including oxygenation is commonly targeted to set ventilation. However, dead space, ventilatory ratio and oxygen transport should be considered.

8. **LUNG IMAGING**
Computed tomography remains the gold standard. Lung ultrasound and electrical impedance tomography are promising bedside tools.

9. **PHENOTYPES**
Patient stratification according to biological phenotypes is promising, but translation into clinical practice requires further research.

10. **LIMITS OF PHYSIOLOGICAL GAIN**
When applying physiological manipulations, clinicians should consider the uncertainty surrounding their effect on patient-centered outcomes

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Central and Eastern European Sepsis Forum

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Thank you for your attention!