November 12, 2016

Minnesota Society of Anesthesiologists

Mechanical Ventilation in the Operating Room

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Outline

- Ventilator induced lung injury
- Postoperative pulmonary complications
- Mechanical ventilation in the operating room – challenges and strategies available
- Conclusions

Andrea Vesalio

De humani corporis fabrica

1543

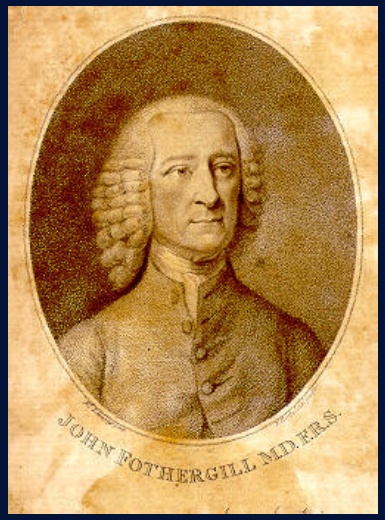
But that life may in a manner of speaking be restored to the animal, an opening must be attempted in the trunk of the trachea, into which a tube of reed or cane should be put; you will then blow into this, so that the lung may rise again and the animal take in air. Indeed, with a slight breath in the case of this living animal the lung will swell to the full extent of the thoracic cavity, and the heart become strong and exhibit a wondrous variety of motions. So, with the lung inflated once and a second time, you examine the motion of the heart by sight and touch as much as you wish.[9]

ARTIFICIAL RESPIRATION,
THE HISTORY OF AN IDEA

by

A. BARRINGTON BAKER

Med Hist 1971; 15; 336-51



In 1744, John Fothergill discussed a case of a patient who was "dead in appearance" after exposure to coal fumes and who was successfully treated by mouth-to-mouth resuscitation.

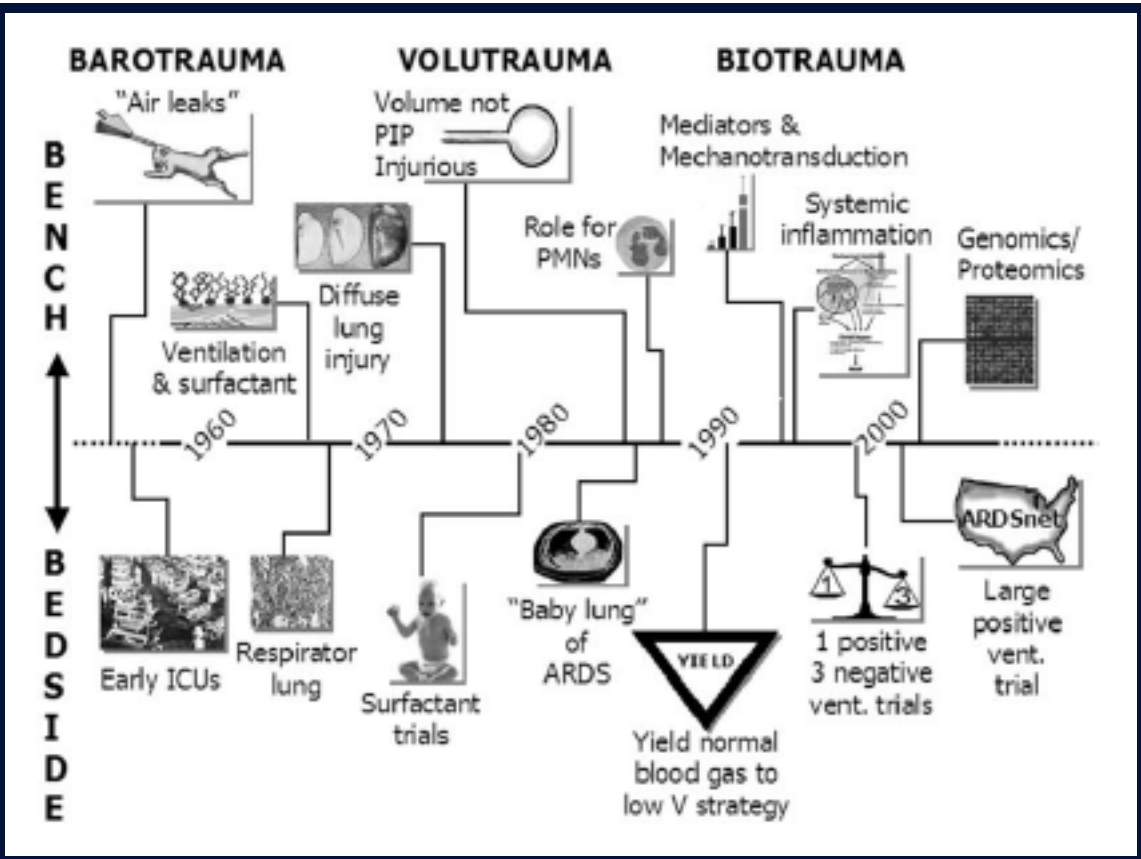
Fothergill noted that mouth-to-mouth resuscitation was preferable to using bellows because "the lungs of one man may bear, without injury, as great a force as those of another man can exert; which by the bellows cannot always be determin'd."

Intensive Care Med (2006) 32:24–33
DOI 10.1007/s00134-005-2817-8

SEMINAL STUDY

Lorraine N. Tremblay
Arthur S. Slutsky

Ventilator-induced lung injury: from the bench to the bedside



Ventilator induced lung injury

Barotrauma

- excessive pressure in the airways ➔ “air leaks”

Volutrauma

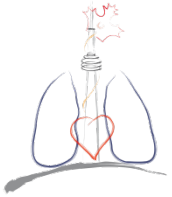
- cyclic overstretching of aerated alveolar areas with high VT

Atelectrauma

- from repeated closing (at end expiration) and opening (at the next inspiration) of lung units

Biotrauma

- inflammatory processes involving both epithelium and endothelium ➔ local and systemic



Ventilator induced lung injury

…the concept that mechanical ventilation can have a significant influence on the inflammatory/anti-inflammatory milieu of the lung, and thus may play a role in initiating or propagating a local, and possibly systemic inflammatory response…

Tremblay L, Valenza F, Ribeiro SP, Li J, Slutsky AS. 1997. Injurious ventilatory strategies increase cytokines and c-fos m-RNA expression in an isolated rat lung model.

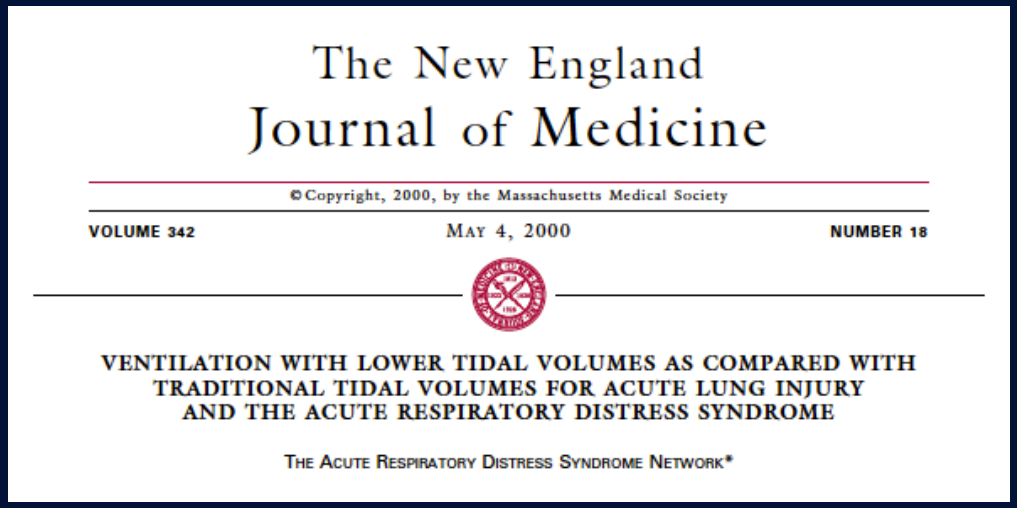
J Clin Invest 99:944-952.

Effect of Mechanical Ventilation on Inflammatory Mediators in Patients With Acute Respiratory Distress Syndrome: A Randomized Controlled Trial

V. Marco Ranieri; Peter M. Suter; Cosimo Tortorella; et al.

JAMA. 1999;282(1):54-61 (doi:10.1001/jama.282.1.54)

The concentration of the inflammatory mediators in bronchoalveolar lavage fluid and plasma 36 hours after randomization was significantly lower in the lung-protective strategy group than in the control group



The New England
Journal of Medicine

VOLUME 342 MAY 4, 2000 NUMBER 18

VENTILATION WITH LOWER TIDAL VOLUMES AS COMPARED WITH TRADITIONAL TIDAL VOLUMES FOR ACUTE LUNG INJURY AND THE ACUTE RESPIRATORY DISTRESS SYNDROME

THE ACUTE RESPIRATORY DISTRESS SYNDROME NETWORK*

In patients with ARDS, mechanical ventilation with a lower tidal volume than is traditionally used results in decreased mortality (31% vs 40%) and increases the number of days without ventilator use

The New England
Journal of Medicine

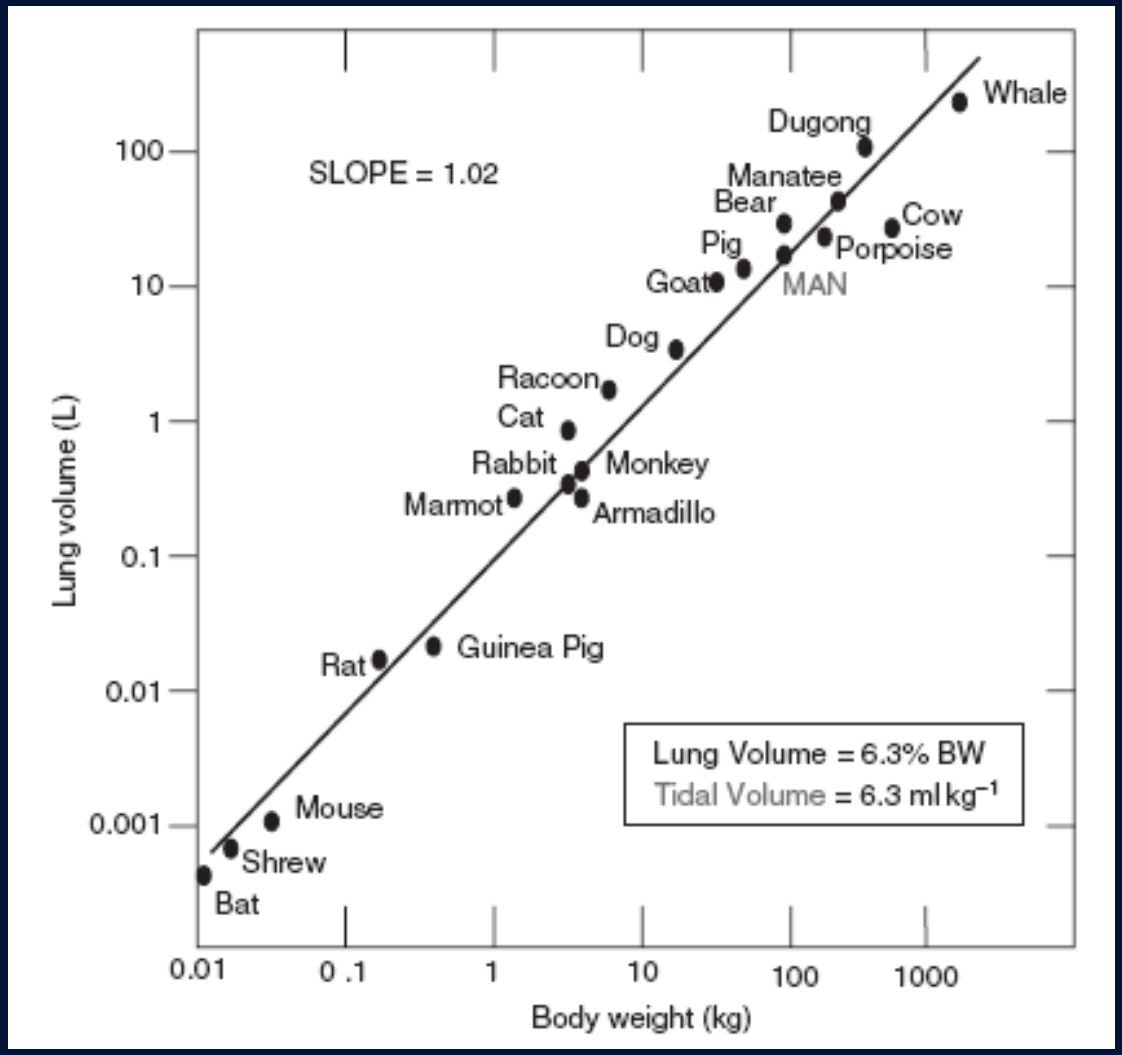
VOLUME 342 MAY 4, 2000 NUMBER 18

VENTILATION WITH LOWER TIDAL VOLUMES AS COMPARED WITH TRADITIONAL TIDAL VOLUMES FOR ACUTE LUNG INJURY AND THE ACUTE RESPIRATORY DISTRESS SYNDROME

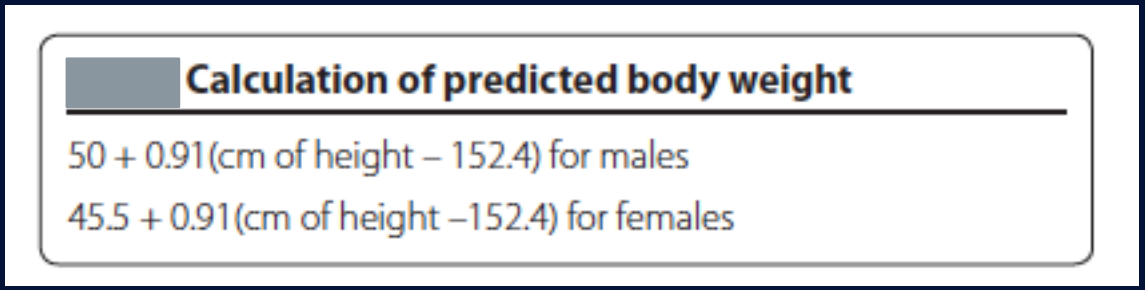
THE ACUTE RESPIRATORY DISTRESS SYNDROME NETWORK*

TABLE 4. MAIN OUTCOME VARIABLES.*

VARIABLE	GROUP RECEIVING LOWER TIDAL VOLUMES	GROUP RECEIVING TRADITIONAL TIDAL VOLUMES	P VALUE
Death before discharge home and breathing without assistance (%)	31.0	39.8	0.007
Breathing without assistance by day 28 (%)	65.7	55.0	<0.001
No. of ventilator-free days, days 1 to 28	12±11	10±11	0.007
Barotrauma, days 1 to 28 (%)	10	11	0.43
No. of days without failure of nonpulmonary organs or systems, days 1 to 28	15±11	12±11	0.006


SLOPE = 1.02
Whale
Dugong
Manatee
Bear
Cow
Pig
Porpoise
Goat
MAN
Dog
Racoon
Cat
Rabbit
Monkey
Marmot
Armadillo
Rat
Guinea Pig
Mouse
Shrew
Bat
Lung Volume = 6.3% BW
Tidal Volume = 6.3 ml kg⁻¹
Lung volume (L)
100
10
1
0.1
0.01
0.001
0.01
0 .1
1
10
100
1000
Body weight (kg)

Predicted Body Weight



Calculation of predicted body weight

50 + 0.91(cm of height – 152.4) for males

45.5 + 0.91(cm of height –152.4) for females

ORIGINAL ARTICLE ARCHIVE

Impaired Oxygenation in Surgical Patients during General Anesthesia with Controlled Ventilation — A Concept of Atelectasis

H. H. Bendixen, M.D.[†], Hedley Whyte, M.B., B.Chir.[‡], and M. B. Laver, M.D.[§]

N Engl J Med 1963; 269:991-996 | November 7, 1963 | DOI: 10.1056/NEJM196311072691901

The use of high VT (usually defined as a VT between 10 and 15 ml/kg) during mechanical ventilation has been historically encouraged to prevent hypoxemia and gradual loss of lung volume (i.e. , atelectasis formation)

WHAT OF NORMAL LUNGS IN THE OPERATING ROOM?

Why bother?

- More than 200 million major surgical procedures are performed annually worldwide
- 5 to 10% of all surgical patients and up to 30 to 40% of those undergoing thoracic or abdominal surgery develop postoperative pulmonary complications (PPCs)

Futier E, Marrat E, Jaber S. Anesthesiology 2014;121:400-8

Postoperative pulmonary complications

- Account for a substantial proportion of **risks** related to the surgical procedure and general anesthesia
- Are a **major** cause of postoperative morbidity and mortality
- Are associated with considerable **costs** in hospital care (In the US, approximately $3.42 billion/year (USD)

Futier E, Marrat E, Jaber S. Anesthesiology 2014;121:400-8

Postoperative pulmonary complications

- Striking evidence of the harmful effect of PPCs
- Unplanned reintubation within the first 3 days after surgery was associated with a 72-fold increased risk of in-hospital mortality

Brueckmann B, Villa-Uribe JL, Bateman BT, et al. Anesthesiology 2013; 118:1276–85

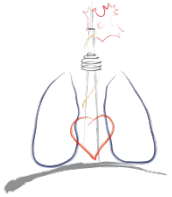


Table 1. Risk Factors for Postoperative Pulmonary Complications

Patient Characteristics	Preoperative Testing	Surgery	Anesthetic Management
Age	Low albumin	Open thoracic surgery	General anesthesia
Male sex	Low SpO_2 (≤95%)	Cardiac surgery	High respiratory driving pressure (≥13 cm H_2O)
ASA class ≥3	Anemia (Hb <10 g/dl)	Open upper abdominal surgery	High inspiratory oxygen fraction
Previous respiratory infection		Major vascular surgery	High volume of crystalloid administration
Functional dependency		Neurosurgery	Erythrocyte transfusion
Congestive heart failure		Urology	Residual neuromuscular blockade
COPD		Duration of surgery >2 h	Nasogastric tube use
Smoking		Emergent surgery	
Renal failure			
Gastroesophageal reflux disease			
Weight loss			

Respiratory driving pressure is defined as inspiratory plateau airway pressure *minus* positive end-expiratory pressure.

ASA = American Society of Anesthesiologists; COPD = chronic obstructive pulmonary disease; Hb = hemoglobin concentration; SpO_2 = oxygen saturation as measured by pulse oximetry.

Guldner A, Kiss T, Serpa Neto A, et al. Anesthesiology 2015;123:692-713

- Recent anesthesia observational studies reported that a significant number of surgical patients (25-30% of patients in the two studies, respectively) continue to receive non-protective mechanical ventilation with VT more than 10 ml/kg of PBW or more

- Likewise, a retrospective analysis of prospectively collected data recently found no difference in intraoperative VT between patients with and without acute lung injury, suggesting that low VT ventilation may not be widely applied in operating room, even in patients who could benefit the most

Jaber S, Coisel Y, Chanques G, et al. Anaesthesia 2012; 67:999–1008

Hess DR, Kondili D, Burns E, et al. J Crit Care 2013; 28:533.e9–15

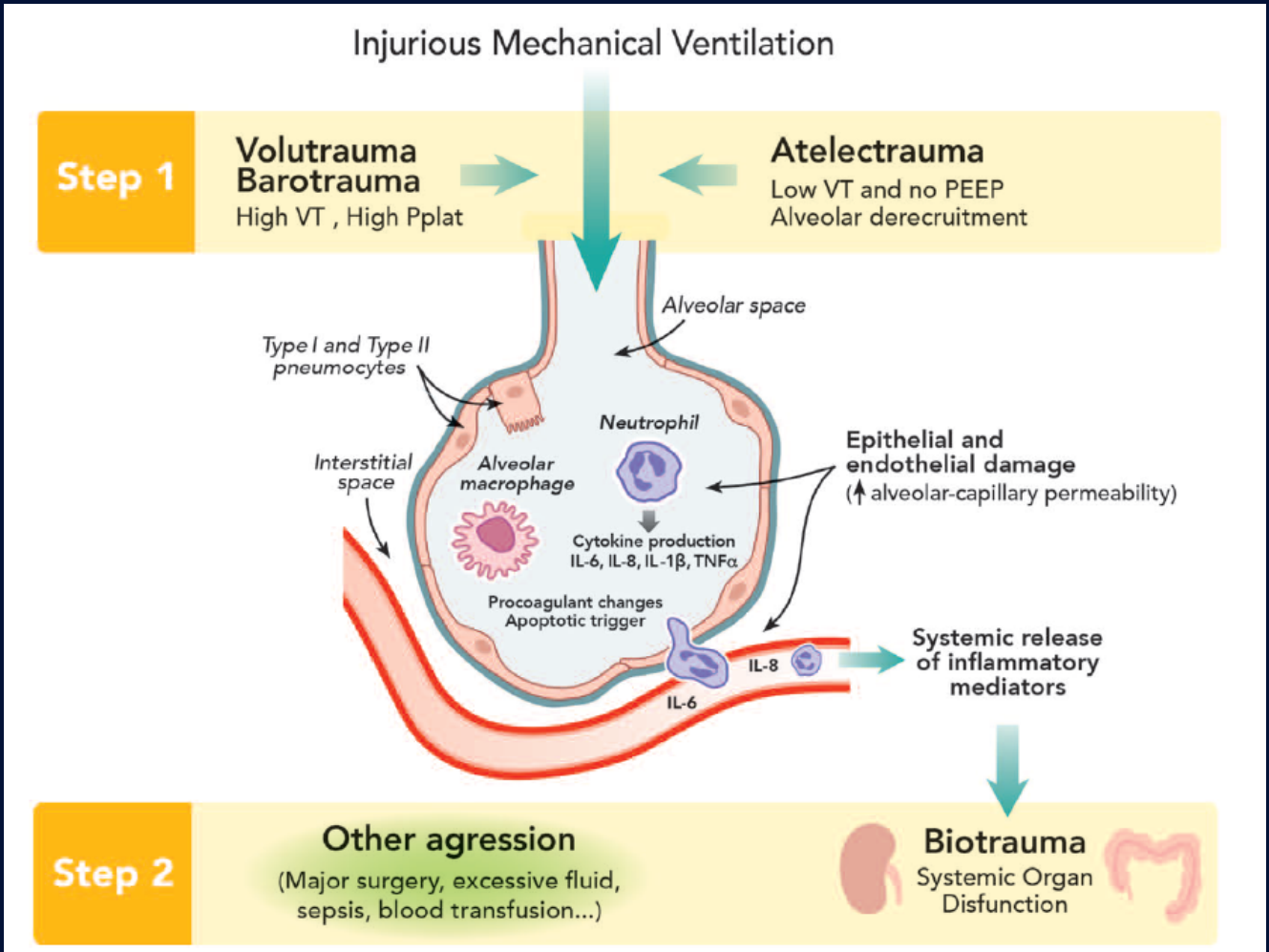
- PEEP is surprisingly not commonly applied in the operating room

- an observational study including 2,960 patients from 49 university and nonuniversity hospitals recently reported
  - more than 80% of patients received mechanical ventilation without PEEP
  - 90% of patients received only very low levels of PEEP (<4 cm H_2O)

- another observational study involving 45,550 patients between 2006 and 2011 found that approximately 30% of patients still received nonprotective ventilation

Jaber S, Coisel Y, Chanques G, et al. Anaesthesia 2012; 67:999–1008

Hess DR, Kondili D, Burns E, et al. J Crit Care 2013; 28:533.e9–15



Futier E, Marrat E, Jaber S. Anesthesiology 2014;121:400-8

British Journal of Anaesthesia **109** (2): 263–71 (2012)
Advance Access publication 1 June 2012 · doi:10.1093/bja/aes140

BJA

RESPIRATION AND THE AIRWAY

Ventilation with low tidal volumes during upper abdominal surgery does not improve postoperative lung function

T. A. Treschan[1*], W. Kaisers[1], M. S. Schaefer[1], B. Bastin[1], U. Schmalz[1], V. Wania[1], C. F. Eisenberger[2], A. Saleh[3], M. Weiss[1], A. Schmitz[1], P. Kienbaum[1], D. I. Sessler[4,5], B. Pannen[1] and M. Beiderlinden[1,6]

- Prospective, randomized, controlled trial
- 101 patients with low-to-intermediate preoperative risk during upper abdominal surgery
- Low vs High VT intraoperatively

Treschan TA, Kaisers W, Schaefer MS. Br J Anaesth 2012;109:263–71

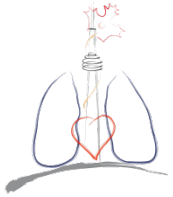
- No significant benefit in the postoperative lung function testing during the first 5 postoperative days
- Gas exchange was better with high VT

Treschan TA, Kaisers W, Schaefer MS. Br J Anaesth 2012;109:263–71

- Use of relatively low PEEP levels in both groups
- Absence of alveolar recruitment maneuver (RM) in the low VT group

Treschan TA, Kaisers W, Schaefer MS. Br J Anaesth 2012;109:263–71

Lung-protective ventilation is not straightforward and should therefore not be confined only to lowering VT

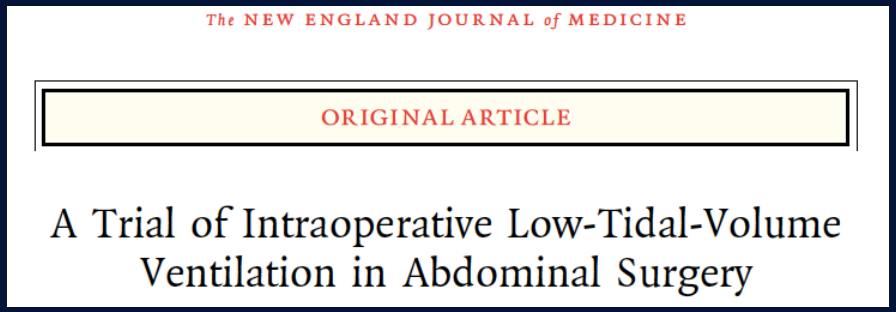


The NEW ENGLAND JOURNAL of MEDICINE

ORIGINAL ARTICLE

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

Emmanuel Futier, M.D., Jean-Michel Constantin, M.D., Ph.D., Catherine Paugam-Burtz, M.D., Ph.D., Julien Pascal, M.D., Mathilde Eurin, M.D., Arthur Neuschwander, M.D., Emmanuel Marret, M.D., Marc Beaussier, M.D., Ph.D., Christophe Gutton, M.D., Jean-Yves Lefrant, M.D., Ph.D., Bernard Allaouchiche, M.D., Ph.D., Daniel Verzilli, M.D., Marc Leone, M.D., Ph.D., Audrey De Jong, M.D., Jean-Etienne Bazin, M.D., Ph.D., Bruno Pereira, Ph.D., and Samir Jaber, M.D., Ph.D., for the IMPROVE Study Group*


The NEW ENGLAND JOURNAL of MEDICINE

ORIGINAL ARTICLE

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

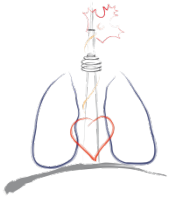
- Multicenter, double-blind, stratified, parallel-group, randomized clinical trial
- 400 undergoing laparoscopic or nonlaparoscopic elective major abdominal surgery (duration > 2 hours)
- Lung protective (low TV, PEEP, RM) vs traditional MV intraoperatively

Table 2. Intraoperative Procedures.*

Variable	Nonprotective Ventilation (N=200)	Lung-Protective Ventilation (N=200)	P Value
Tidal volume — ml	719.0±127.8	406.7±75.6	<0.001
Tidal volume — ml/kg of predicted body weight	11.1±1.1	6.4±0.8	<0.001
PEEP — cm of water			
Baseline			<0.001
Median	0	6	
Interquartile range	0–0	6–8	
End of surgery			<0.001
Median	0	6	
Interquartile range	0–0	6–8	
No. of recruitment maneuvers			<0.001
Median	0	9	
Interquartile range	0–0	6–12	
Peak pressure — cm of water			
Baseline	20.1±4.9	18.9±3.6	0.04
End of surgery	20.6±4.4	20.0±4.0	0.15
Plateau pressure — cm of water			
Baseline	16.1±4.3	15.2±3.0	0.02
End of surgery	16.6±3.5	15.2±2.6	<0.001
Respiratory system compliance — ml/cm of water			
Baseline	48.4±17.8	55.2±26.6	0.06
End of surgery	45.1±12.9	55.2±26.7	<0.001
F_{IO_2} — %	47.2±7.6	46.4±7.3	0.27
Volume of fluids administered — liters			
Crystalloid			0.47
Median	2.0	1.5	
Interquartile range	1.5–3.5	2.0–3.0	
Colloid			0.97
Median	0.5	0.5	
Interquartile range	0.25–1.0	0.50–1.0	
Duration of surgery — no./total no. (%)†			0.95
2–4 hr	76/192 (39.6)	75/195 (38.5)	
>4–6 hr	75/192 (39.1)	76/195 (39.0)	
>6 hr	41/192 (21.4)	44/195 (22.6)	
Duration of mechanical ventilation — min	344±127.9	319±139.4	0.84
Epidural analgesia — no. (%)	77 (38.5)	83 (41.5)	0.61

Table 3. Results of Unadjusted and Adjusted Outcome Analyses.*

Variable	Nonprotective Ventilation (N=200)	Lung-Protective Ventilation (N=200)	Unadjusted Relative Risk or Between-Group Difference (95% CI)	P Value†	Adjusted Relative Risk or Between-Group Difference (95% CI)‡	P Value
Primary composite outcome — no. (%)						
Within 7 days§	55 (27.5)	21 (10.5)	0.38 (0.24–0.61)	<0.001	0.40 (0.24–0.68)	0.001
Within 30 days	58 (29.0)	25 (12.5)	0.43 (0.28–0.66)	<0.001	0.45 (0.28–0.73)	<0.001
Secondary outcomes — no. (%)						
Pulmonary complication within 7 days¶						
Grade 1 or 2	30 (15.0)	25 (12.5)	0.69 (0.42–1.13)	0.14	0.67 (0.39–1.16)	0.16
Grade ≥3	42 (21.0)	10 (5.0)	0.24 (0.12–0.46)	<0.001	0.23 (0.11–0.49)	<0.001
Atelectasis within 7 days‖	34 (17.0)	13 (6.5)	0.38 (0.21–0.70)	0.001	0.37 (0.19–0.73)	0.004
Pneumonia within 7 days	16 (8.0)	3 (1.5)	0.19 (0.05–0.63)	0.01	0.19 (0.05–0.66)	0.009
Acute lung injury or ARDS within 7 days	6 (3.0)	1 (0.5)	0.17 (0.02–1.37)	0.12	0.21 (0.02–1.71)	0.14
Need for ventilation within 7 days						
Invasive	7 (3.5)	2 (1.0)	0.29 (0.06–1.36)	0.51	0.40 (0.08–1.97)	0.26
Noninvasive	29 (14.5)	9 (4.5)	0.31 (0.15–0.64)	0.006	0.29 (0.13–0.65)	0.002
Extrapulmonary complication within 7 days						
SIRS	100 (50.0)	86 (43.0)	0.86 (0.70–1.06)	0.16	0.87 (0.65–1.17)	0.37
Sepsis	29 (14.5)	13 (6.5)	0.45 (0.24–0.84)	0.04	0.48 (0.25–0.93)	0.03
Severe sepsis or septic shock	9 (4.5)	8 (4.0)	0.89 (0.35–2.26)	0.80	1.48 (0.51–4.32)	0.47
Death within 30 days	7 (3.5)	6 (3.0)	0.86 (0.29–2.51)	0.80	1.13 (0.36–3.61)	0.83
Duration of stay in hospital and ICU — days						
Hospital				0.02		0.006
Median	13	11	−2.25 (−4.04 to −0.47)		−2.45 (−4.17 to −0.72)	
Interquartile range	8–20	8–15				
ICU				0.58		0.69
Median	7	6	−1.48 (−6.87 to 3.91)		−1.21 (−4.98 to 7.40)	
Interquartile range	4–9	4–8				

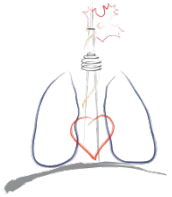


Atelectasis

- occurs in the most dependent parts of the lungs of 90% or more of anesthetized patients from the first minutes of anesthesia induction
- atelectasis that develops during general anesthesia remains in the postoperative period
- low VT ventilation promotes atelectasis formation

Bendixen HH , Hedley-Whyte J, Laver MB. NEJM 1963;269:991–6

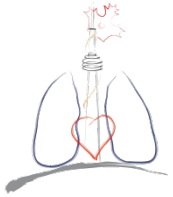
Futier E, Marrat E, Jaber S. Anesthesiology 2014;121:400-8



Importance of Recruitment Maneuvers…

- Consist of a ventilatory strategy that increases the transpulmonary pressure transiently to reopen the recruitable lung units

Guerin C, Debord S, Leray V, et al. Annals of Intensive Care 2011;1:9



- There are different methods to perform RM – the three that are mostly used are:

  - sighs (increasing tidal volume or level of PEEP, for one or several breaths)
  - sustained inflation (pressurizing the airways at a specific level and maintaining it for a given duration – i.e. 40 cmH_2O airway pressure for 40 seconds)
  - extended sigh (combines lower pressure level, progressive rising of airway pressurization, and longer time of application)

Guerin C, Debord S, Leray V, et al. Annals of Intensive Care 2011;1:9

Hemodynamic effects of recruitment

PEEP and/or RM may compromise hemodynamic function by

- impeding venous return with an increase in right atrial pressure

- likely promoting a decrease in cardiac output and arterial pressure

- increase in the need of fluid and vasopressors

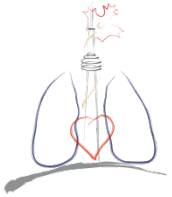
Hemodynamic effects of recruitment

The hemodynamic effects of RM are widely influenced by

- the method of recruitment (e.g. , sustained insufflation or progressive increment in PEEP level)

- the applied level of alveolar pressure

- the properties of the underlying cardiovascular system, and the lung and chest wall mechanics

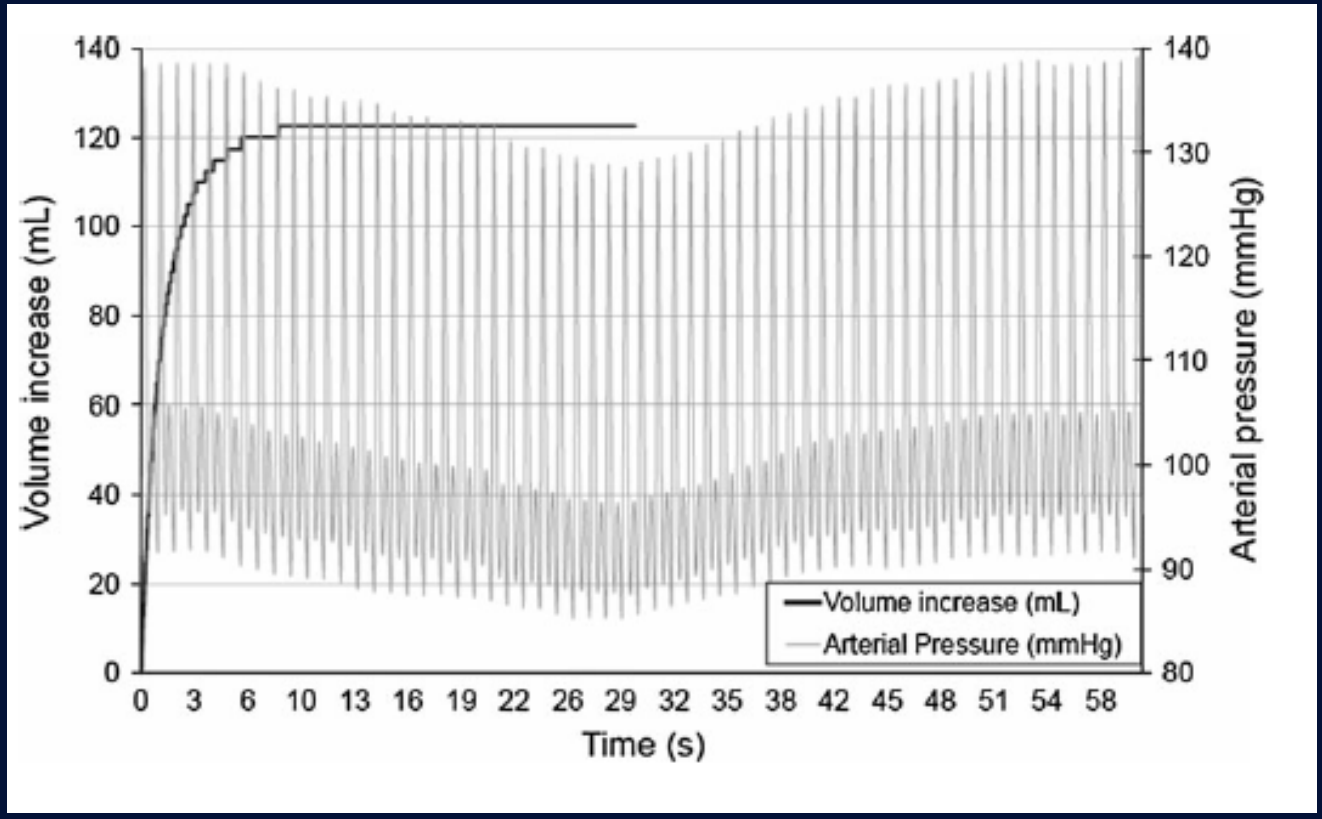


Intensive Care Med (2011) 37:1588–1594
DOI 10.1007/s00134-011-2323-0

ORIGINAL

Jean-Michel Arnal
Jérémie Paquet
Marc Wysocki
Didier Demory
Stéphane Donati
Isabelle Granier
Gaëlle Corno
Jacques Durand-Gasselin

Optimal duration of a sustained inflation recruitment maneuver in ARDS patients



What about PEEP?

Lancet 2014; 384: 495–503

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

The PROVE Network Investigators for the Clinical Trial Network of the European Society of Anaesthesiology*

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

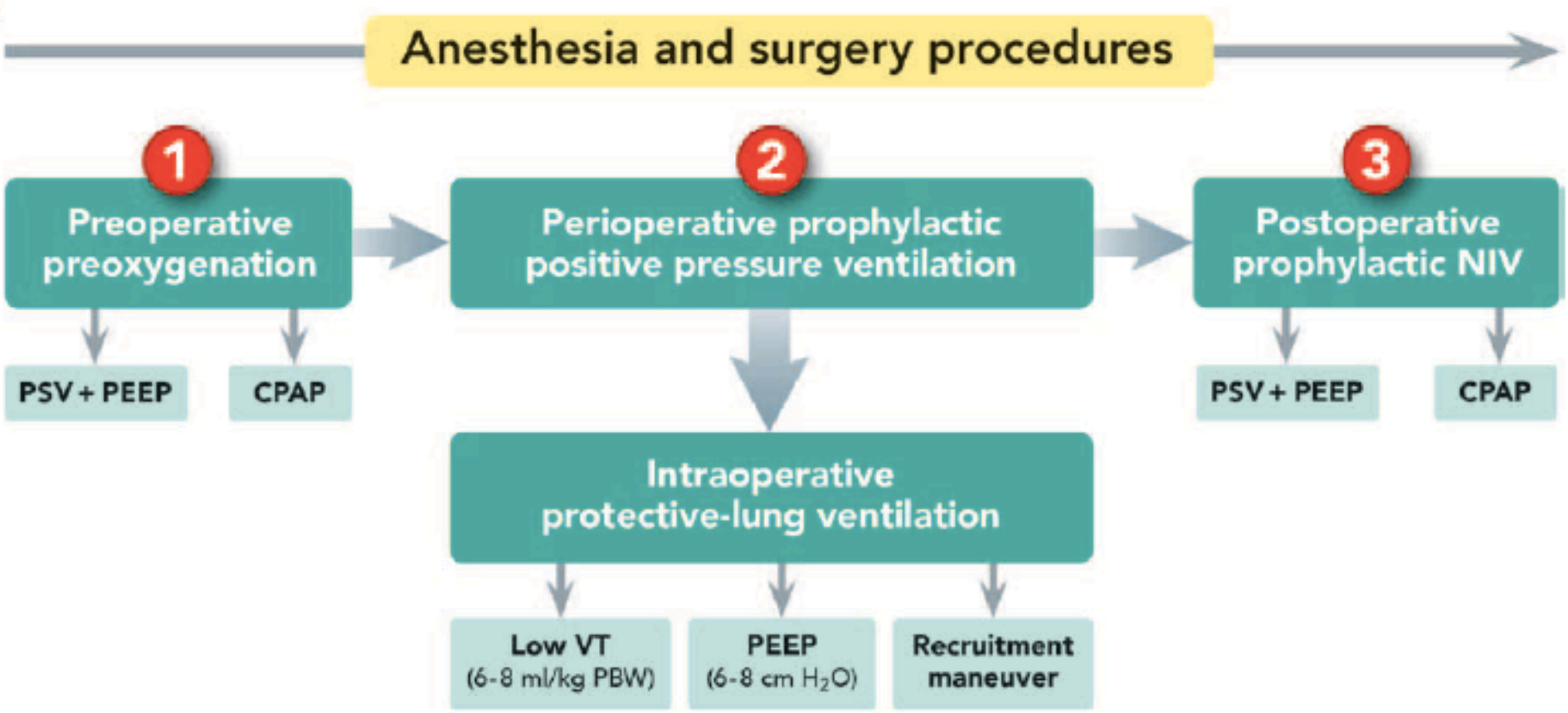
The PROVE Network Investigators for the Clinical Trial Network of the European Society of Anaesthesiology*

- randomized controlled trial at 30 centres in Europe and North and South America
- 900 patients scheduled for open abdominal surgery
- TV 8ml/kg
- Low (< 2 cmH_2O) vs high (12 cmH_2O) PEEP with RM

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

The PROVE Network Investigators for the Clinical Trial Network of the European Society of Anaesthesiology*

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


Anesthesia and surgery procedures
1
Preoperative preoxygenation
PSV + PEEP
CPAP
2
Perioperative prophylactic positive pressure ventilation
Intraoperative protective-lung ventilation
Low VT (6-8 ml/kg PBW)
PEEP (6-8 cm H_2O)
Recruitment maneuver
3
Postoperative prophylactic NIV
PSV + PEEP
CPAP

What about FiO_2?

Small Tidal Volumes, Positive End-expiratory Pressure, and Lung Recruitment Maneuvers during Anesthesia

Good or Bad?

Göran Hedenstierna, M.D., Ph.D.

What about FiO_2?

- There is no discussion regarding the inspired oxygen concentration in any of the larger multicenter studies

- An alveolus full of oxygen behind a closed airway, for example, after induction of anesthesia or after a recruitment maneuver, will not stay open for more than 4 to 5 min

Hedenstierna G. Anesthesiology 2015;123:501-3

What about FiO_2?

If the same recruitment maneuver is performed with lower oxygen concentration (e.g. , 40%) in nitrogen, the alveolus will stay open for half an hour or longer, nitrogen being slowly absorbed and acting as a scaffold

Hedenstierna G. Anesthesiology 2015;123:501-3

What about FiO_2?

If the patient is "postoxygenated," possibly together with airway suctioning minutes before extubation of the trachea, atelectasis is most likely produced. A patient with no atelectasis during anesthesia may then be delivered to the postoperative ward with collapsed lungs.[18]

Hedenstierna G. Anesthesiology 2015;123:501-3

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Intraoperative mechanical ventilation strategies for one-lung ventilation

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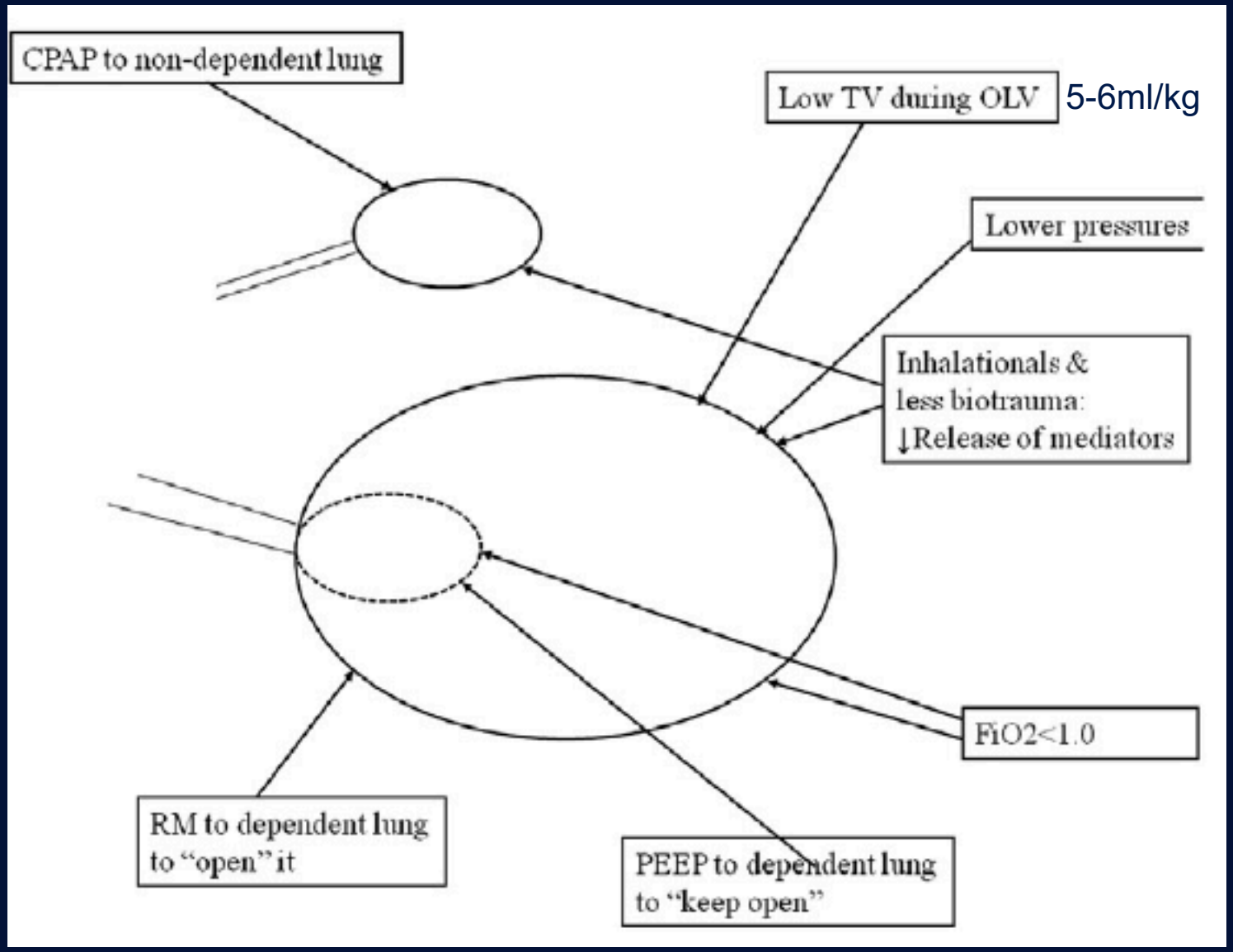
CPAP to non-dependent lung
Low TV during OLV
5-6ml/kg
Lower pressures
Inhalationals &
less biotrauma:
↓Release of mediators
FiO2<1.0
RM to dependent lung
to "open" it
PEEP to dependent lung
to "keep open"

Conclusions

- Mechanical ventilation in the operating room has the potential to affect patients outcomes

- Protective strategies that include low TV, PEEP, RM should be applied

Conclusions

- Further studies will inform optimal PEEP settings, RM timing and methods, perioperative care, role of additional factors such as volatile anesthetics, and strategies in special circumstances

Questions

Thank You

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