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APRV:
Moving beyond ARDSnet

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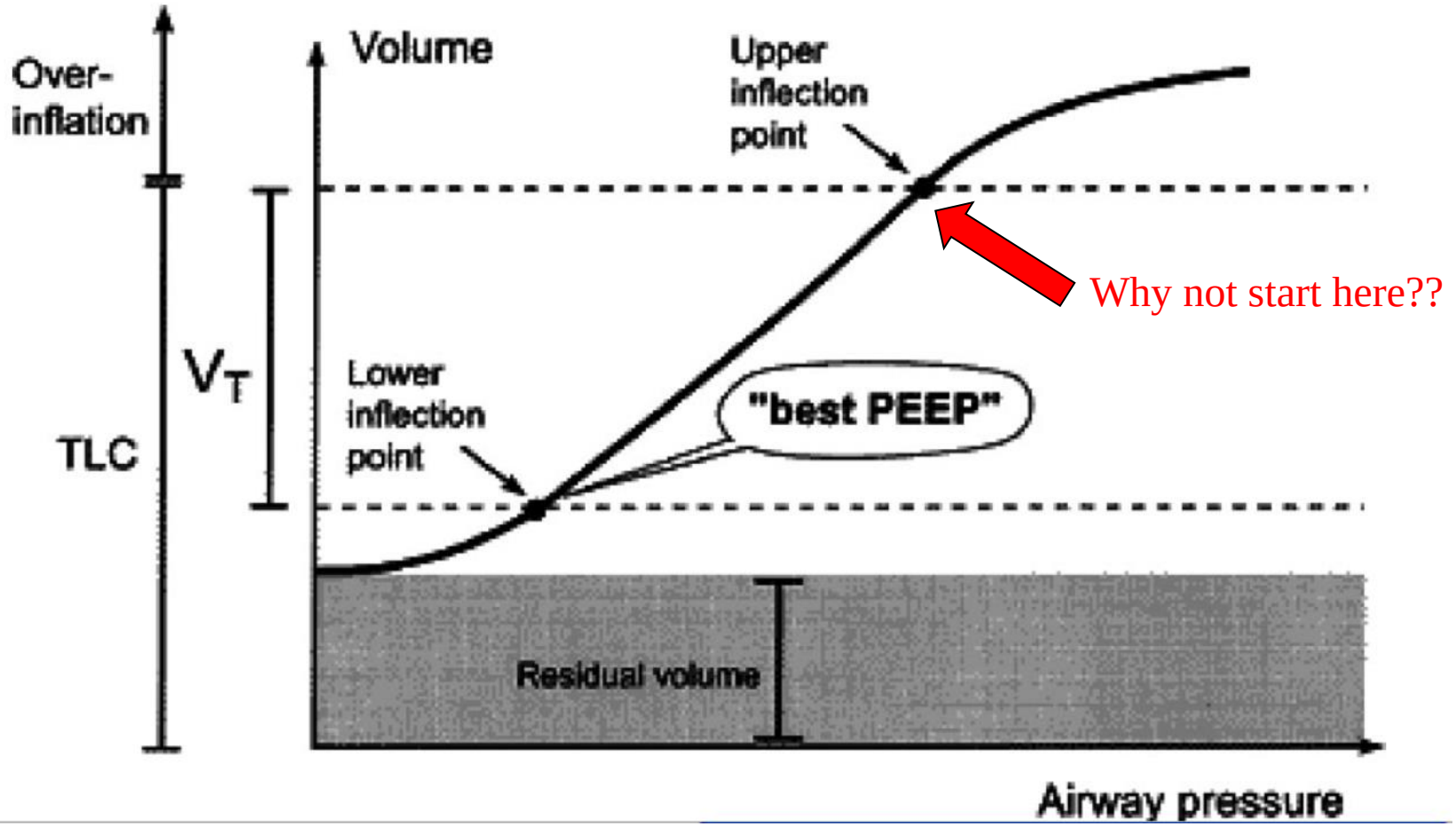
What is APRV?

- APRV is different from conventional mechanical ventilation
  - Conventional: Peep maintains recruitment, and volumes are delivered on top of peep. Peep should be above the lower inflection point of the volume/pressure curve. Volumes should be minimized (ARDSnet)
  - APRV: Pressure limited, time-cycled, time-initiated, volume-variable mode which limits peak airway pressure and allows spontaneous breathing to occur at a higher FRC throughout the entire ventilator cycle

APRV

- Maintains continuous high-pressure which overcomes tendency to atalectasis
- Increases FRC (to baseline)
- It allows spontaneous breathing throughout the respiratory cycle
- As opposed to conventional ventilation, maximal inspiratory pressure is at inspiration and occurs of 80 – 95% of the respiratory cycle, and alveolar collapse is limited by timing the release to the time-constant of the expiratory flow

Lower inflection point and peep



What are the arguments against APRV?

- Too high a pressure…this must be bad for the lungs
- Auto peep…you are not measuring it!
- We already have perfection in ARDSnet..it is the only mode that reduces mortality in ARDS in the literature!
- People stay on the vent too long
- Too complex

- Before we get to how to use it, lets address these

It's bad for the lungs…too much pressure

- Actually the opposite…if P_{high} is too high, yup you are going to have trouble. With appropriate P_{high} the lung is stented open at its normal volume.
  - Less alveolar collapse and re-recruitment which decreases lung injury!
  - More to come on this
    - Am J Respir Crit Care Med 1999;160(6):2118-2124

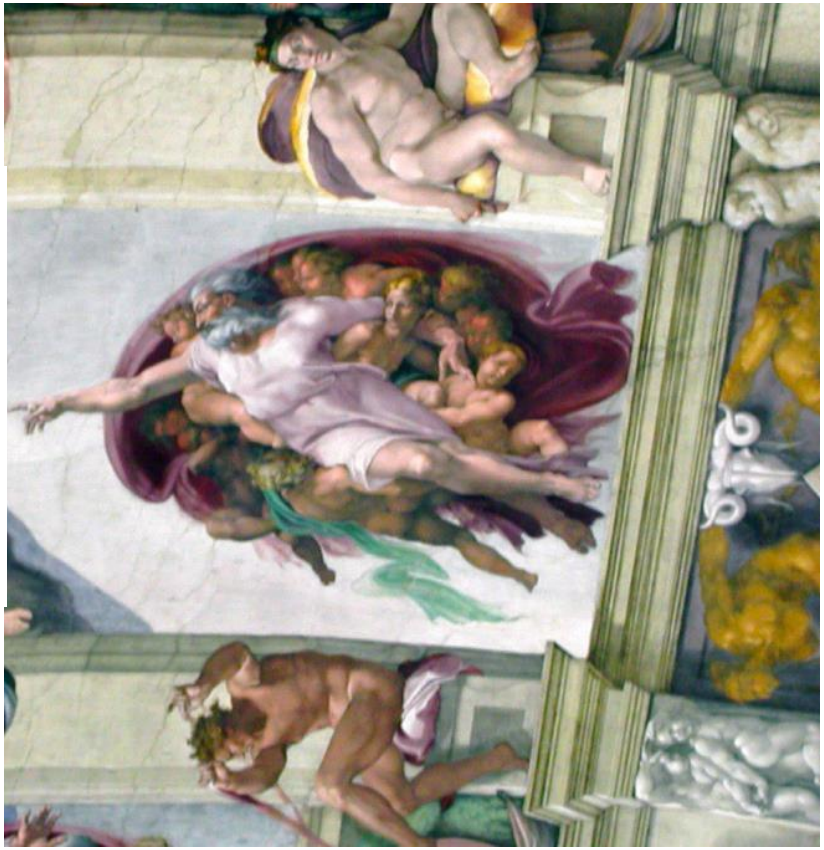
Autopeep = bad you are not measuring it!

- No, you are not measuring the exact pressure of the autopeep, but that does not matter!
  - It is less than the P_{high}
  - It is titrated by the T_{low}
  - It should be based on the time constant (t) of expiratory flow
    - t = C X R where C = compliance and R = resistance of the airway circuit
    - 4 time constants equal full deflation of the lung (think of it like a half-life)
    - 1 time constant is needed to empty the lung to 63% of total lung volume at Phigh
    - At this level alveoli stay open, but ventilation occurs
    - It represents a reduction in peak expiratory flow (which is a product of compliance and resistance….aha!) to somewhere around 2/3 peak flow

But ARDSnet is already proven to reduce mortality!

- Really? Mortality still 30+% in the experimental group

NIH NHLBI ARDS Clinical Network
Mechanical Ventilation Protocol Summary



Too complex and people stay on the vent too long

- This may be a legitimate critique…

Lets delve into all of these a little deeper

- First…the pressures are too high! Too much intrathoracic pressure will decrease preload then decrease cardiac index and be bad for the patient

- Improved cardiac index
- Improved O_2 Delivery
- Improved shunt
- Improved compliance
- Reduced sedation requirements
- Reduced vasopressors and inotropes
- (Compared to paralyzed patients)
  - Putensen et al. Am J Respir Crit Care Med 2001; 164:43
- Increased lung compliance, and more open alveoli reduces pulmonary vascular resistance and allows for increased flow and therefore filling of the L heart!

But auto-peep….you have auto-peep you are not measuring!

Again, we are using a p_{low} of zero and titrating the auto-peep via limiting the time of expiration. There are a bunch of gory details we need to delve into to understand this process

- Using P_{low} of zero restricts the variable needed to control end-expiratory volume to a single easily measurable variable: time
- The artificial airway itself is a resistor in the circuit limiting expiratory flow
- By limiting the time of expiration against this resistor, peep/auto-peep is maintained.
- IT IS ALWAYS LESS THAN P_{high}!
  - Am Rev Respir Dis 1989; 140:10 –16
  - *Crit Care Med* 1989; 17:671– 677

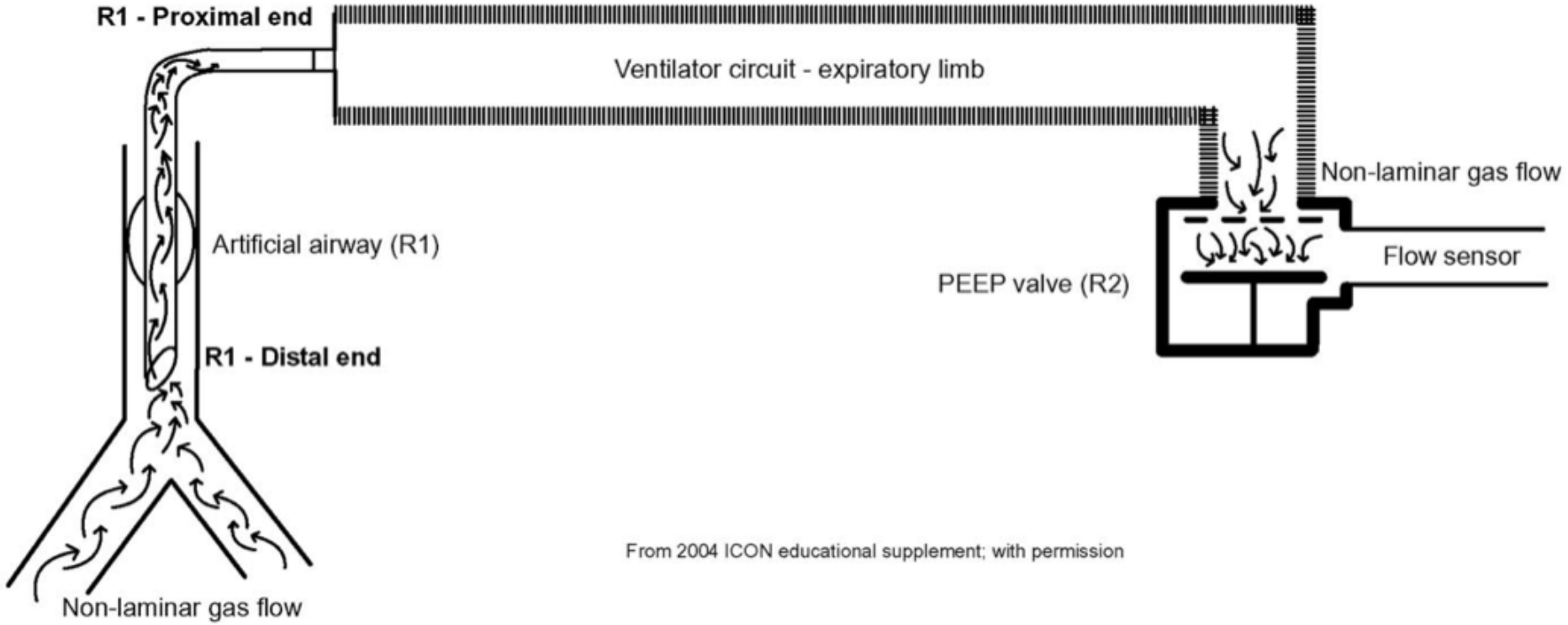


Figure 5. Patient interface to mechanical ventilator circuit and inherent resistance to expiratory flow from artificial airway (R1) and positive end-expiratory pressure (*PEEP*) valve (R2). Because the release occurs from a high lung volume during airway pressure release ventilation, flow resistance develops at the distal end of R1 and R2. The proximal end of R1 decompresses more rapidly than the distal end. Despite zero end-expiratory pressure (ZEEP), flow resistance at R2 (typically measured approximately 8 ft away) contributes to tracheal pressure elevation above end-expiratory pressure. Flow resistance is highest at the onset of the release (>0.2 L/sec) and decreases as expiratory flow rate declines. Release time is terminated after a brief duration before flow resistance dissipates to maintain end-expiratory lung volume (67–69). Reprinted from ICON educational supplement 2004 with permission.

Crit Care Med 2005 Vol. 33, No. 3 (Suppl.): S228

- The final result is when applied correctly, the lung will move from a full but not over-distended FRC to about 2/3rds FRC.
- In a lung that is fully recruited, this may mean the release volumes are up to a liter, but each alveoli is only shrinking by a 1/3 and is maintained in an open manner….more on this later

OK, I am beginning to get it now….but ARDSnet actually improves outcomes right?

- Randomized controlled trial
- Volume assist/control
- High tidal volume group: 12 cc/kg predicted body weight or decreased to keep plateau pressure $\leq$ 50 cm H_20
- Low tidal volume group 6 cc/kg, could be increased to 7 or 8 cc/kg if plateau $\leq$ 30 cm H_20

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

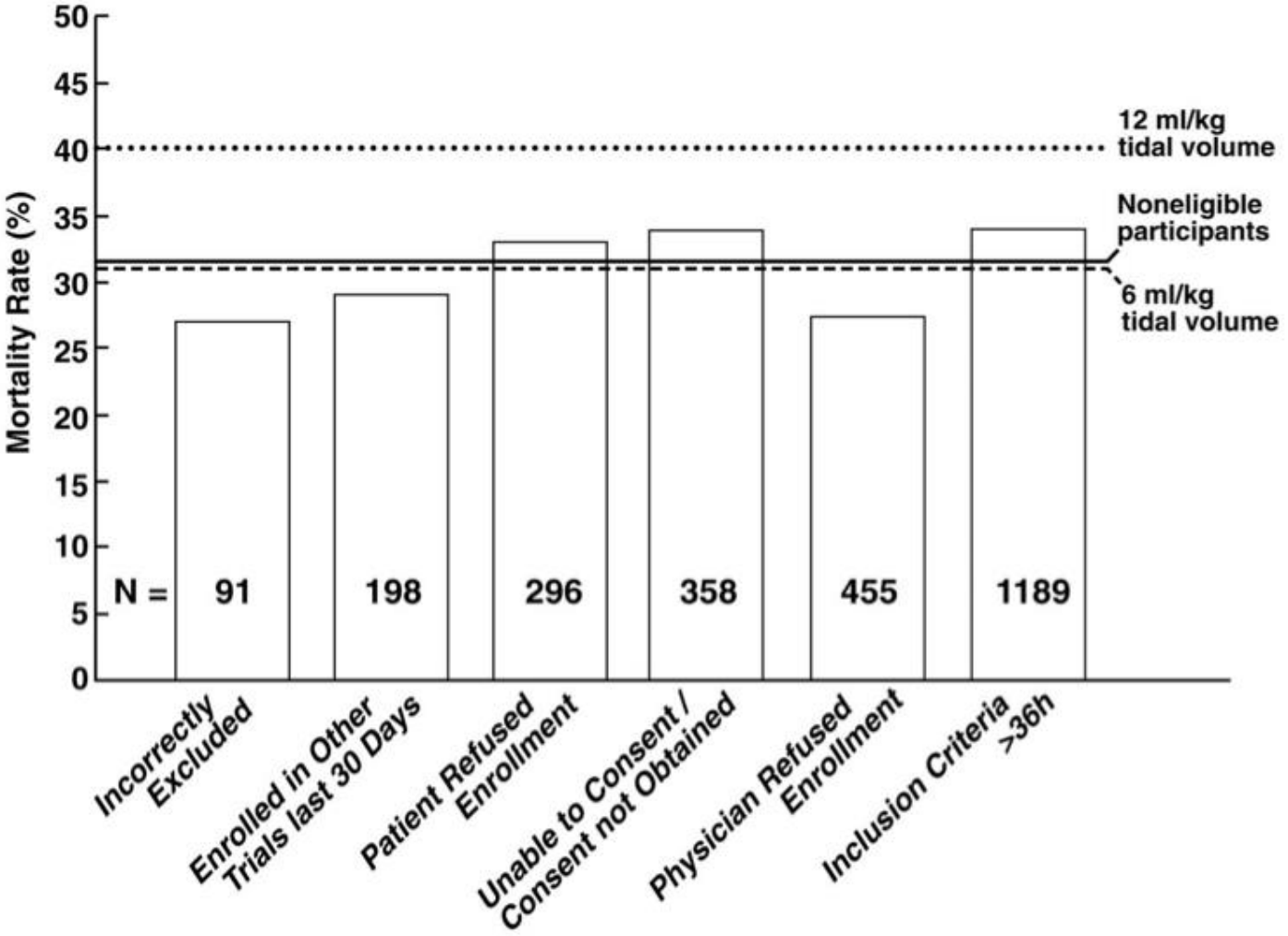
*Plus–minus values are means ±SD. The number of ventilator-free days is the mean number of days from day 1 to day 28 on which the patient had been breathing without assistance for at least 48 consecutive hours. Barotrauma was defined as any new pneumothorax, pneumomediastinum, or subcutaneous emphysema, or a pneumatocele that was more than 2 cm in diameter. Organ and system failures were defined as described in the Methods section.

Sounds great

- But 12 cc/kg
  - This was not standard of care at the time
    - 8 – 10 cc/kg more common
  - How does ARDSnet compare to standard of care at the time?
  - Still was a 30% mortality!
    - Can we be any more specific?

Yes we can!

Crit Care Med 2005 Vol. 33(5): 1141



So we can use APRV safely but how?

- Start with P_{high}…generally set at desired plateau pressure, or alternatively 2 – 4 cm H2O above mean pressure if on conventional mode
- Adjust to optimize FRC (This cannot be taught easily and is the toughest variable to account for.)
  - Product of lung compliance, chest wall observation, mechanics and flow.
- Usually 20 – 35 cm H2O, though if significant extrinsic compliance exists, maybe higher
  - My record is 89/0….patient did not die from their lung disease!
- Set P_{low} at zero ALWAYS!

- T_{high} can usually be set from 4 – 6 seconds.
  - With a very high P_{high}, may need to drop to 3
- T_{low} is the most "complex" but the most easy
  - Usually start around .3 - .6 seconds
    - (higher in patients with obstructive disease)
  - Titrate rapidly for T-PEFR of 50 – 75% with a good goal being 66% (2/3 PEFR)

I still don't see how the lung doesn't overdistend?

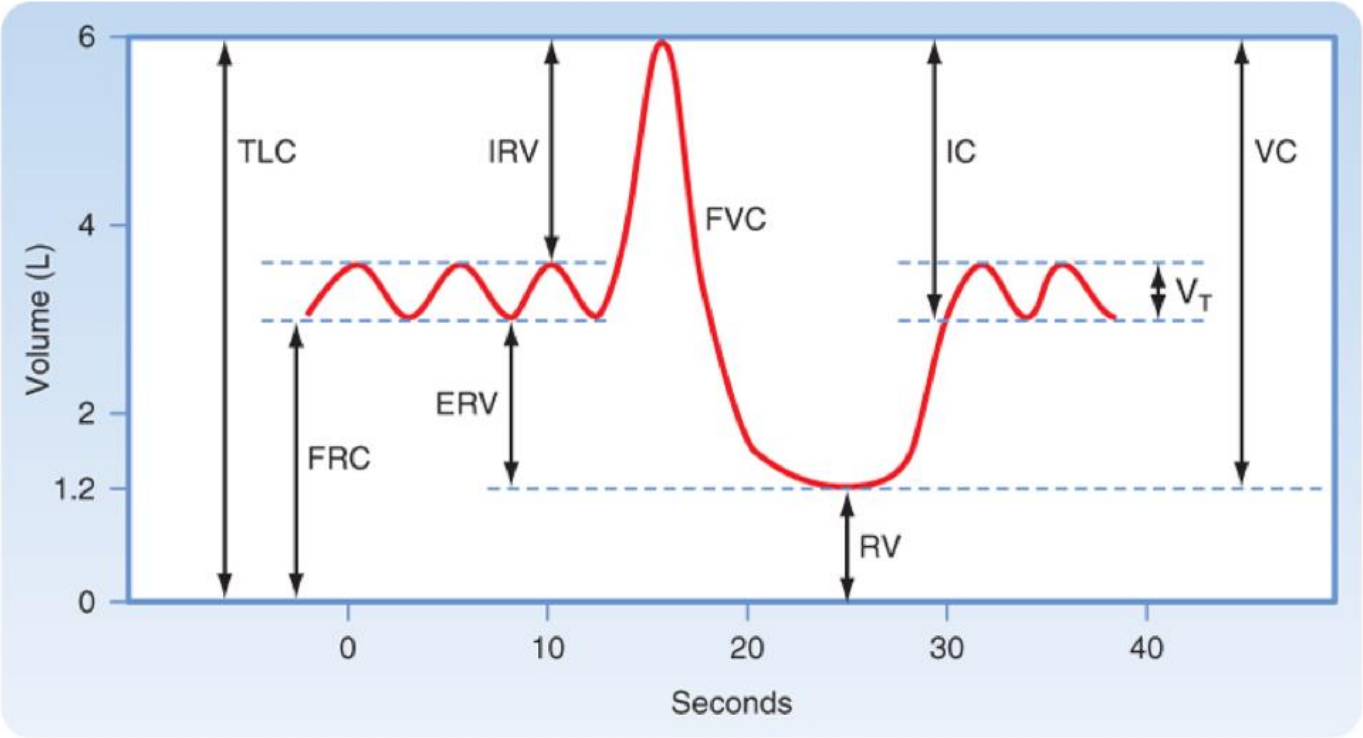
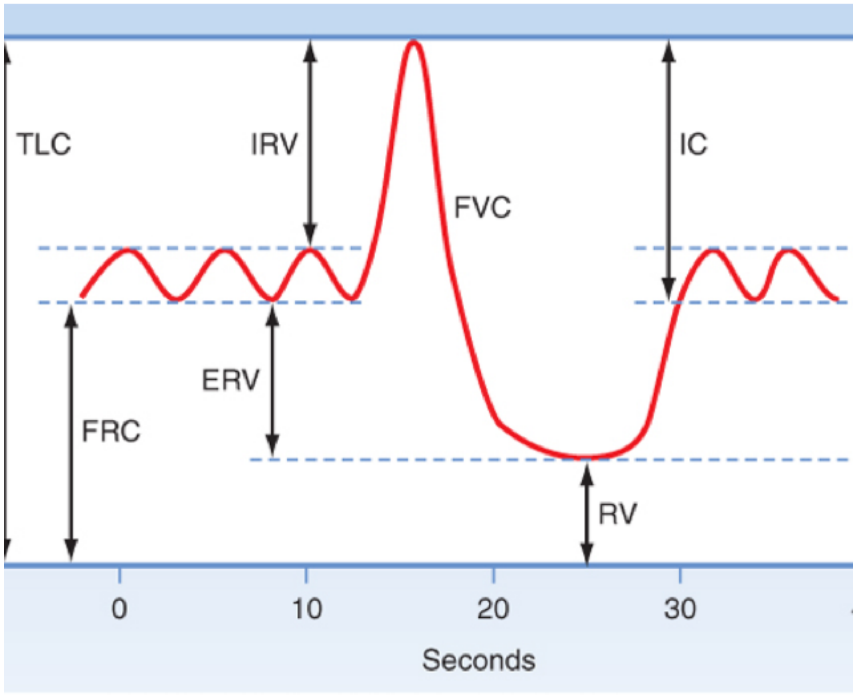


Figure 21-1 The various lung volumes and capacities. ERV, expiratory reserve volume; FRC, functional residual capacity; FVC, forced vital capacity; IC, inspiratory capacity; IRV, inspiratory reserve volume; RV, residual volume; TLC, total lung capacity; VC, vital capacity; V_T, tidal volume.

What happens on the vent?

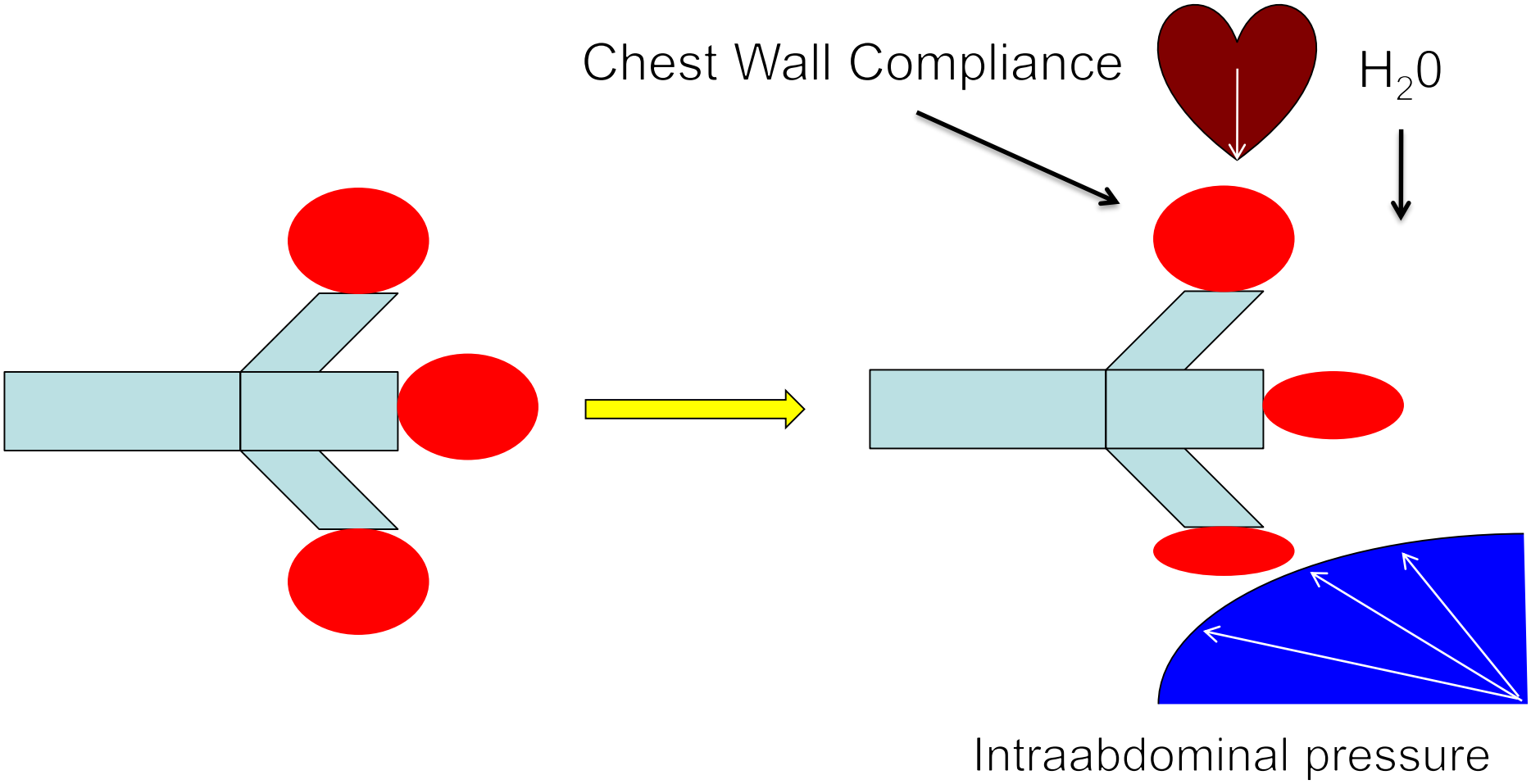


Koeppen & Stanton: Berne and Levy Physiology, 6th Edition.

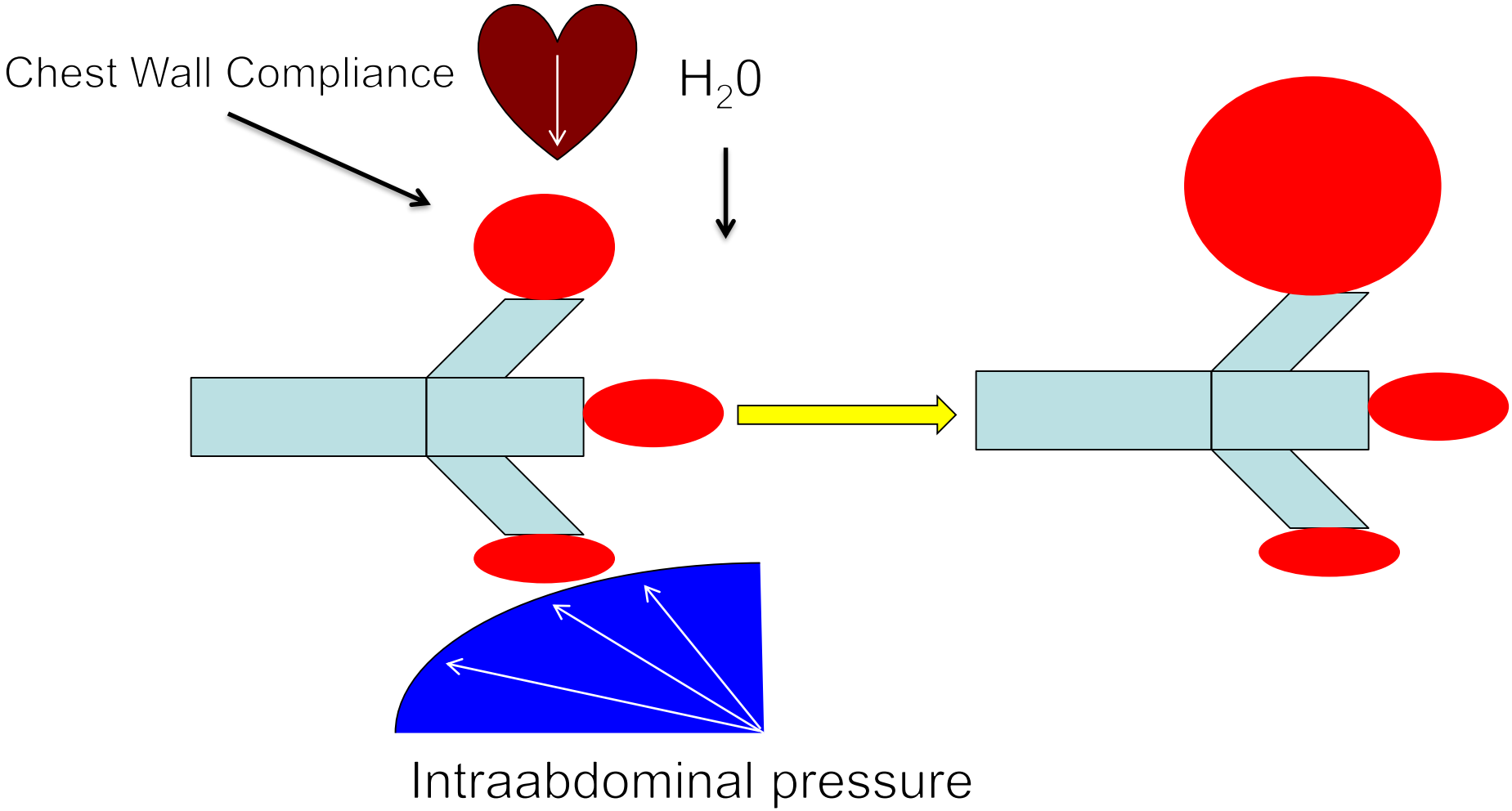
, expiratory reserve volume; FRC, functional residual capacity; FVC, forced vital capacity; IC, inspiratory capacity; total lung capacity; VC, vital capacity; V_T, tidal volume.

Compliance worsens

- Lung elasticity increases
- Chest wall recoil and ability to fight the lung decreases
- Edema and swollen abdomens push in
- FRC drops, RV drops
- P_{high} "stents" the lung at normal FRC and allows easier spontaneous breathing!


Chest Wall Compliance
H_20
Intraabdominal pressure

Simply adding a tidal volume overdistends anterior and apical alveoli!



Stress index

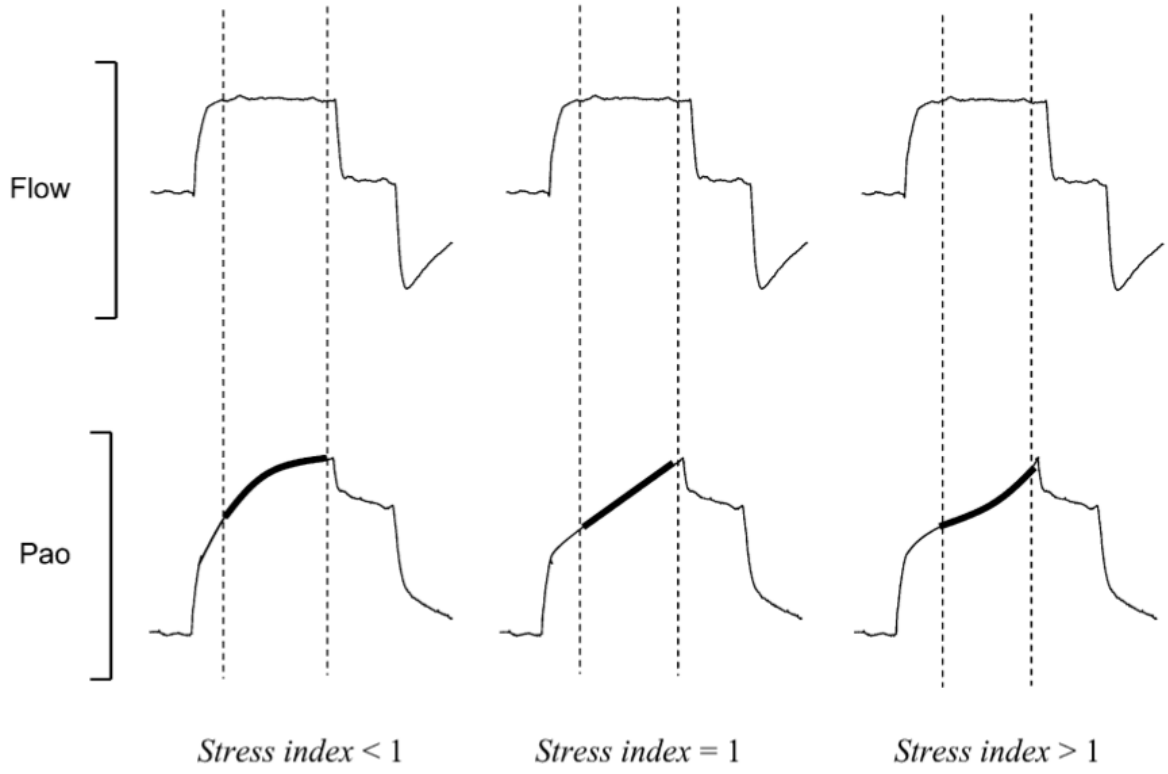
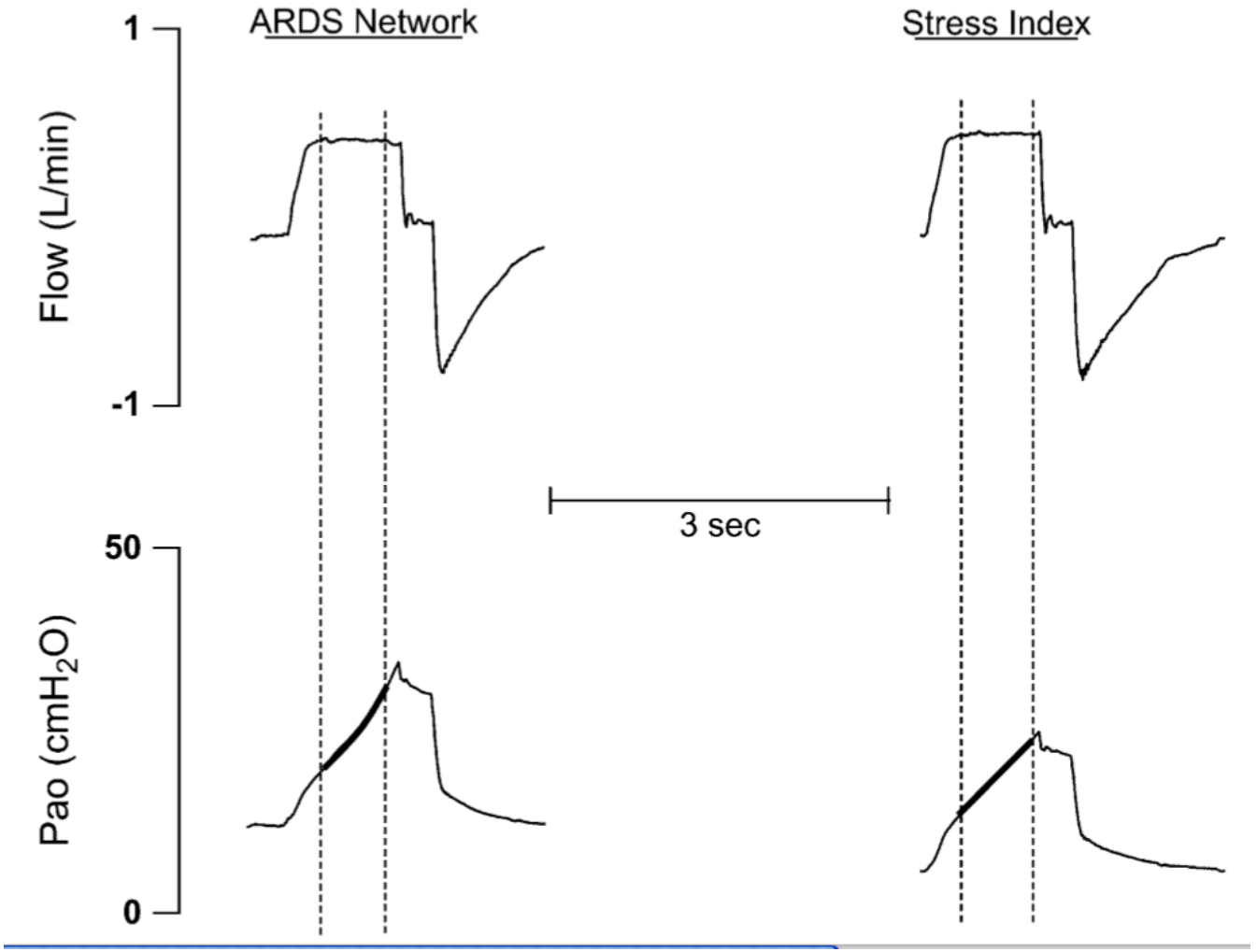


Figure 1. Graphic representation of the stress index concept. The stress index is the coefficient *b* of a power equation (airway pressure = $a \cdot$ inspiratory time^b + *c*), fitted on the airway opening pressure (Pao) segment (*bold lines*) corresponding to the period of constant-flow inflation (*dotted lines*), during constant-flow, volume-cycled mechanical ventilation. For stress index values of less than 1, the Pao curve presents a downward concavity, suggesting a continuous decrease in elastance during constant-flow inflation. For stress index values higher than 1, the curve presents an upward concavity suggesting a continuous increase in elastance. Finally, for a stress index value equal to 1, the curve is straight, suggesting the absence of tidal variations in elastance.

Am J Respir Crit Care Med 2007; 176:761

Stress index



Am J Respir Crit Care Med 2007; 176:761

What about real world data…what you have shown me is great, but……I need data!

ORIGINAL ARTICLE

Early application of airway pressure release ventilation may reduce mortality in high-risk trauma patients: A systematic review of observational trauma ARDS literature

Penny L. Andrews, RN, BSN, Joseph R. Shiber, MD, Ewa Jaruga-Killeen, PhD, Shreyas Roy, MD, CM, Benjamin Sadowitz, MD, Robert V. O'Toole, Louis A. Gatto, PhD, Gary F. Nieman, BA, Thomas Scalea, MD, *and* **Nader M. Habashi, MD,** *Baltimore, Maryland*

J Trauma Acute Care Surg. 2013; 75(4):635

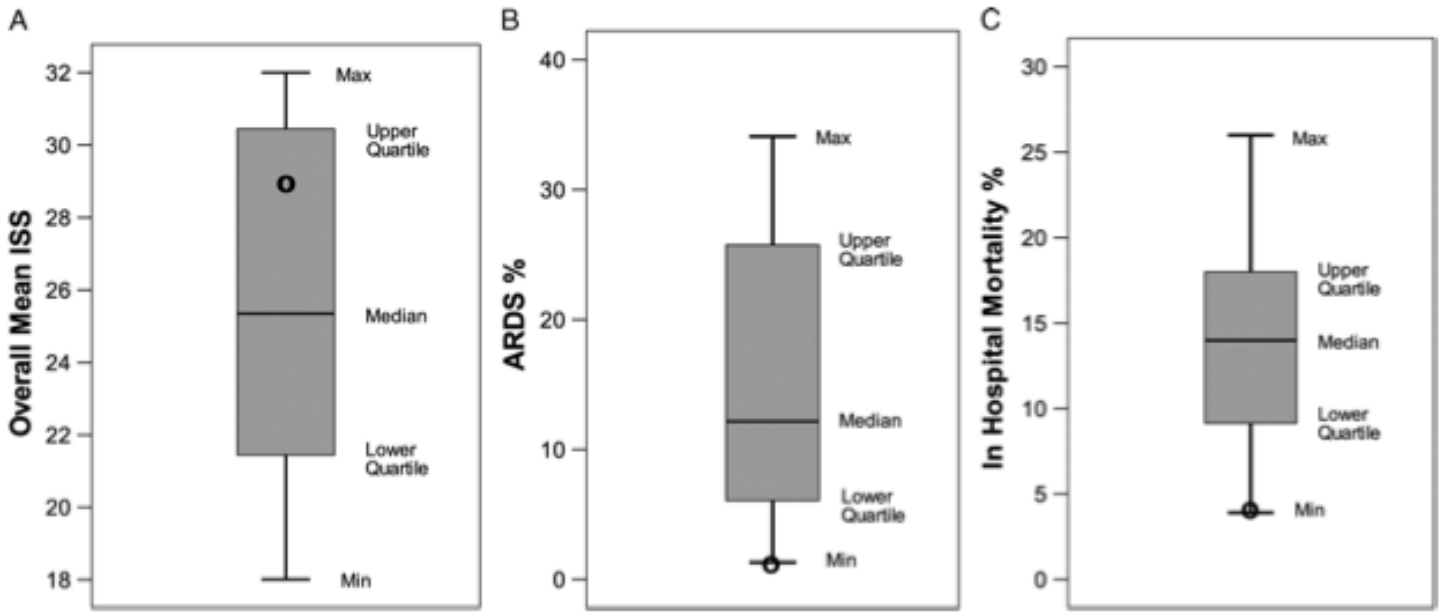


Figure 1. Boxplots for mean ISS (*A*), ARDS % (*B*), and in-hospital mortality % (*C*). Mean ISS shows the range and distribution of ISS scores reported by 16 authors; 50% of them reported ISS between 30.5 and 23.2, with the middle score of 25.4 (median). The maximum ISS was reported by Dicker at 32. *O*, The mean ISS of 29 for the preemptive APRV group belonged to the upper quartile of the boxplot. ARDS incidence % shows the range and distribution of scores reported by 16 authors; 50% of them reported ARDS incidence between 22.5% and 6%, with the middle score of 11.95% (median). The maximum incidence of ARDS was reported by Shah et al. at 34.1%. *O*, The incidence of ARDS in the preemptive APRV group represented the minimum score at 1.3%. Mortality % shows the range and distribution of mortality scores reported by 16 authors; 50% of them reported mortality between 18.2% and 9.2%, with the middle score of 13.9% (median). The maximum mortality was reported by Salim et al. at 25.3%. *O*, The preemptive APRV group scored the minimum mortality rate of 3.9%.

J Trauma Acute Care Surg. 2013; 75(4):635

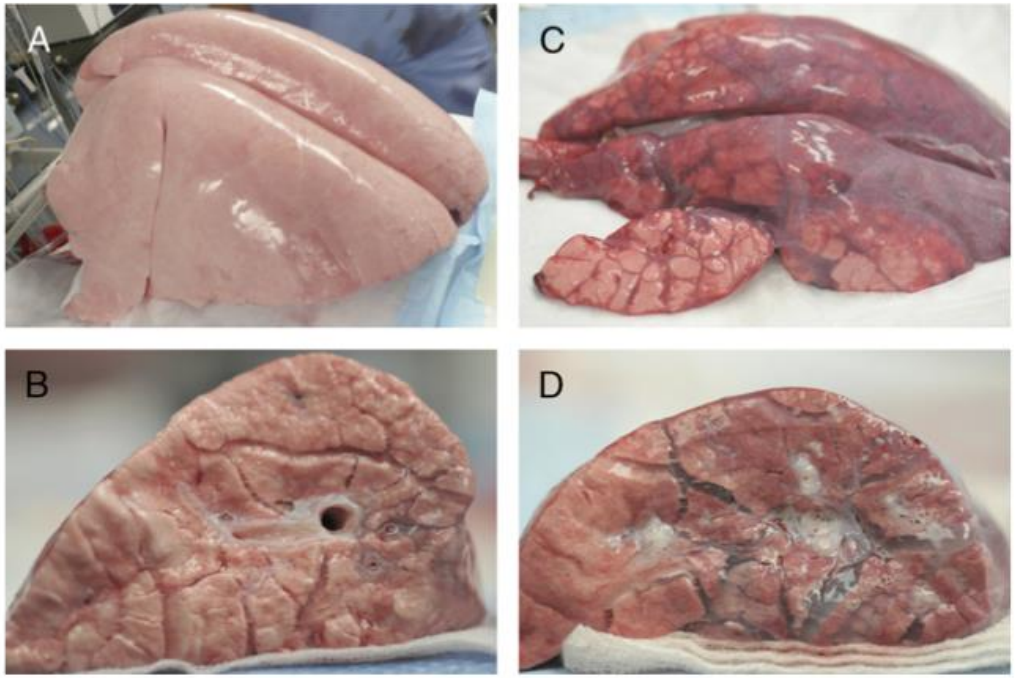


FIG. 2. **Gross pathology: Representative specimens of gross lungs from LTV ventilation and APRV groups are shown**. A, Airway pressure release ventilation whole lung: animals exhibited normal, pink, homogenously well-inflated lung tissue with no evidence of inflammation and no evidence of atelectasis and appeared to be inflated nearly to TLC. B, Airway pressure release ventilation cut surface: the cut surface of the representative APRV lung specimen shows neither bronchial nor septal edema. C, Low tidal volume ventilation whole lung: the lungs were predominantly atelectatic with heterogeneous parenchymal inflammation. D, Low tidal volume ventilation cut surface: the cut surface shows gel-like edema filling the interlobular septae of the lung in the LTV ventilation group and airway edema in the bronchial openings.

Shock. 2013; 39(1):28

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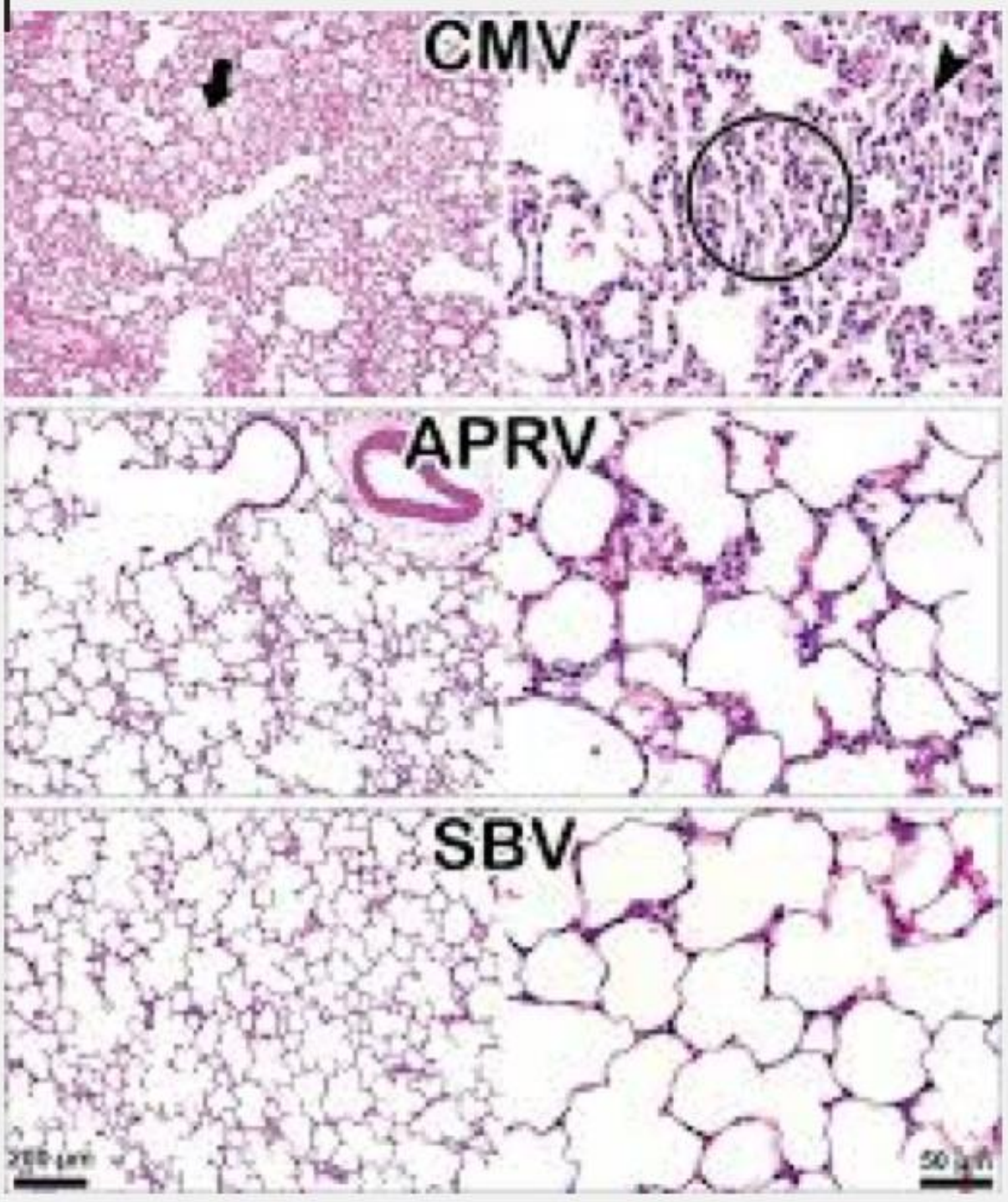

JAMA Surg. 2013;148(11):1005

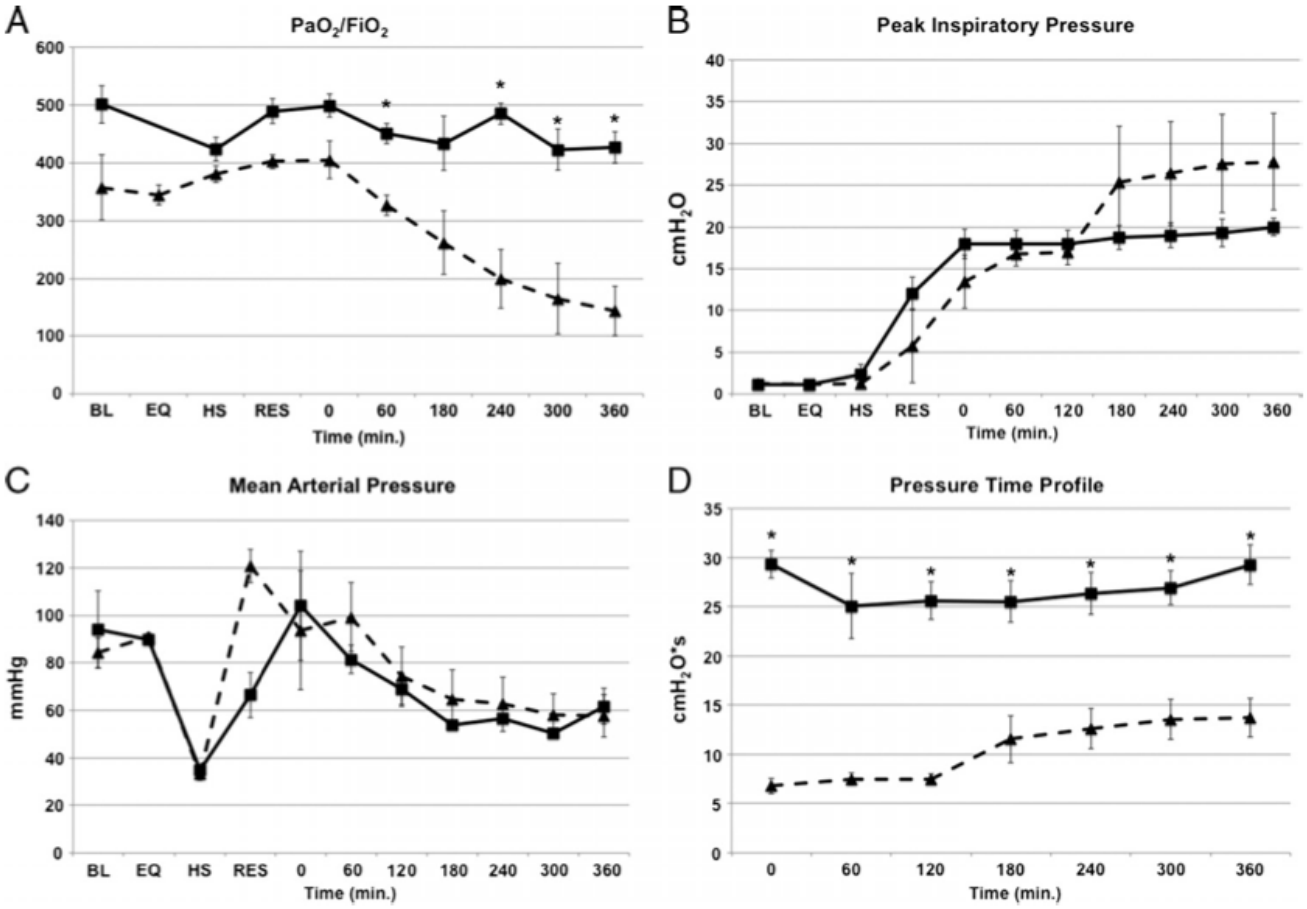

FIG. 2. **A, Pao_2/Fio_2 ratio (P/F) over time in the VC (Δ) and APRV (□) groups.** There was a significant fall in P/F in the VC as compared with APRV group, with the P/F falling below 200 at T_{300} indicating the development of ARDS. B, Peak airway pressure over time in the VC (Δ) and APRV (□) groups. C, Mean arterial blood pressure over time in the VC (Δ) and APRV (□) groups. D, P/T_P over time in the VC (Δ) and APRV (□) groups. P/T_P was significantly elevated in the APRV as compared with VC group throughout the entire experiment. BL indicates baseline; EQ, equilibrium; HS, hemorrhagic shock; RES, resuscitation. Data ± SEM. $*P < 0.05$ vs. VC group.

Shock 2013; 40(3):210

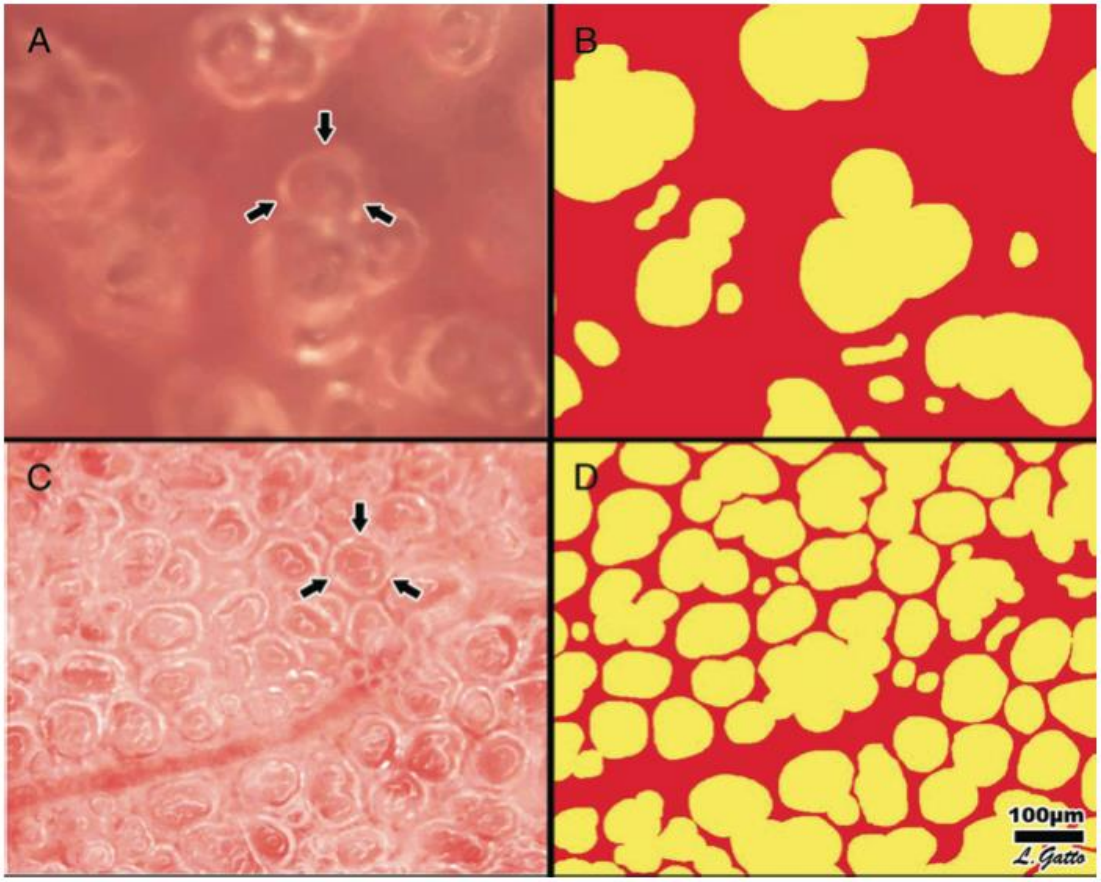

FIG. 3. ***In vivo* photomicrographs and image analysis of inflated subpleural alveoli in the VC (A, B) and APRV (C, D) groups.** Measurement of the percent air space was accomplished by circling the inflated alveoli using computer image analysis. All inflated alveoli were then assigned the color yellow, and noninflated areas were assigned the color red, generating a sharp contrast for the image analysis software to identify and measure the percentage of inflated alveoli/microscopic field. Arrows (A, C) identify a single alveolus.

Shock 2013; 40(3):210

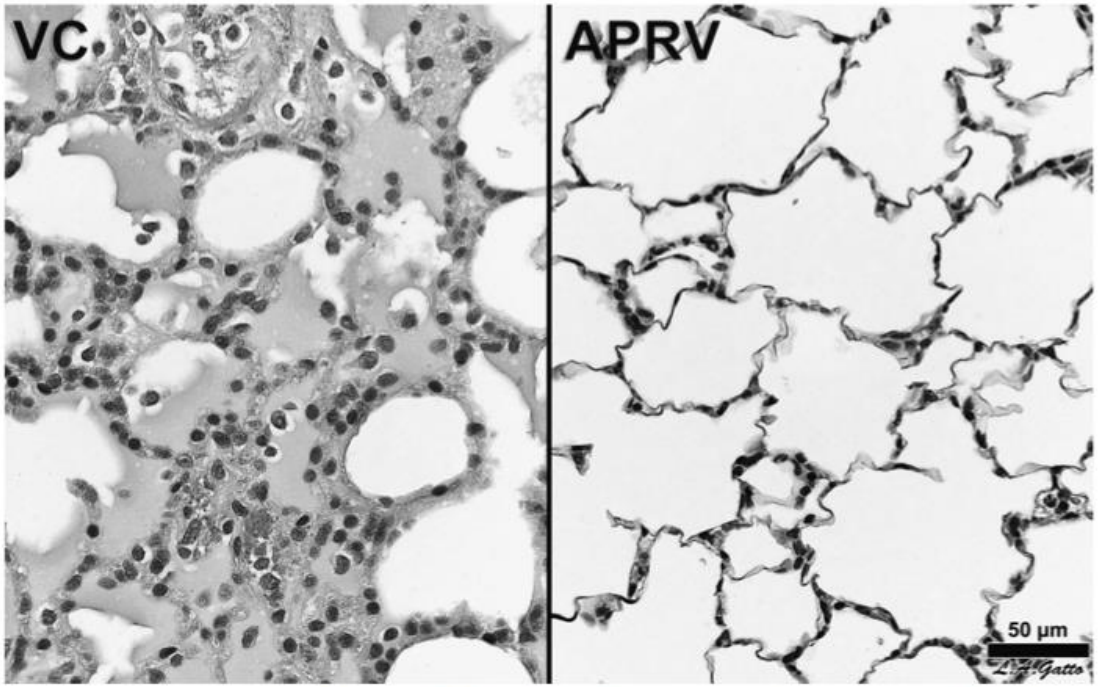

FIG. 4. **Histologic comparison of a rats receiving VC versus APRV**. The VC animal exhibits hallmarks of ARDS, including alveolar flooding (stars), fibrinous deposits in the air compartment (arrowheads), and high cellularity (between arrows). The APRV animal shows patent alveoli with notable preservation of nearly normal histology.

Shock 2013; 40(3):210

Final word

- It may not be the tidal pressure, volume delivered, nor what we are measuring at the vent that counts in regards to ventilator induced lung injury
- It may be the actual pressure and flows at the alveolar level
- “low tidal volume” may not be so low at the alveolar level in certain instances
  - If only ¼ of the alveoli in the anterior apical spaces are receiving the majority of the LTV, they may overdistend

- In a fully recruited lung, large release volumes may still result in less distension and gas movement over individual alveoli
- Maybe ARDS is a preventable disease?

Thank you