Mechanical ventilation: a physiological approach

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Chairman of Anaesthesia and Critical Care Service
Puerta de Hierro University Hospital
Associate Professor. Medical School. UAM
CV and Conflict of interest

• Chairman of Anaesthesia, Critical Care and Pain Department. Puerta de Hierro Univ. Hospital. Madrid
• Ph.D. UCM. Madrid
• MBA. UCM. Madrid
• Expertise: Pediatric Anaesthesia and critical care, mechanical ventilation.

SCIENTIFIC ACTIVITY
• Patents: 1
• Oral presentations: 85
• Lectures: 152
• Book Editor: 3 ; Book Chapters: 33
• Director of Ph.D.: 3
• Grants and Prizes: 12
• Director of training courses: 14
• Journal associated editor: 4
• Journals Referee: 4
• Indexed publications (Medline): 55; F.I. 45,99

• I have received research grants from: Maquet, GE, Dräger, Spacelab, Masimo, Covidine, Abbot and Baxter

• I have been invited to form part of the advisory board of several of those companies but I prefer to keep independent and open to what new technologies are offering to us

• I don´t have any conflict of interest for this lecture but ..I don´t want you to go sleep so I am going to provoke you…
What is your story?

Once upon a time...
Clinical actions of subarachnoid sevoflurane administration
in vivo: a study in dogs

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R. Cediel³ and F. Gilsanz²,⁵

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This study presents a novel in vivo experimental model in dogs that has not been used before. Sevoflurane is directly administered to the spine instead of through the more traditional route of systemic inhalation. The main objective of our study with this model was to characterize the effects of sevoflurane, administered directly to the spine in pure liquid form for the first time, and to study the clinical effects of
6 months all patient; 6 Kg
Dx: hiatus hernia
Qx: laparoscopic Nissen.

Before
PNEUMOPERITONEUM

After
PNEUMOPERITONEUM
University of Michigan Medical Center, review of all operations performed between 2005-2009, using a general anesthetic which at least 1 arterial blood gas determination was made.

- 83,866 ABGs were obtained in 27,101 patients
- Excluding cardiac and thoracic procedures
- Four cohorts of arterial blood gases were identified with P/F > 300, P/F= 300-201, P/F = 200-101, P/F ≤ 100.
- Positive end-expiratory pressure (PEEP), peak inspiratory pressures (PIPs), FIO2, oxygen saturation (SaO2), and tidal volume in mL/kg PBW were compared
A Description of Intraoperative Ventilator Management and Ventilation Strategies in Hypoxic Patients

James M. Blum, MD,* Douglas M. Fetterman, MD,* Pauline K. Park, MD,† Michelle Morris, MS,* and Andrew L. Rosenberg, MD*

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Table 4. Changes in Ventilation by Calendar Year

<table>
<thead>
<tr>
<th>Year</th>
<th>Normal</th>
<th>Mild hypoxia</th>
<th>Moderate hypoxia</th>
<th>Severe hypoxia</th>
<th>Total</th>
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<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
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<tr>
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<td>9.35</td>
<td>1.98</td>
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<td>2007</td>
<td>9.06*</td>
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<td>9.13*</td>
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<td>2008</td>
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<td>9.16</td>
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</table>

Average tidal volumes by hypoxia group in mL/kg pbw

<table>
<thead>
<tr>
<th>Year</th>
<th>Normal</th>
<th>Mild hypoxia</th>
<th>Moderate hypoxia</th>
<th>Severe hypoxia</th>
<th>Total</th>
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<td>2005</td>
<td>25.38</td>
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<td>27.52</td>
<td>5.70</td>
<td>28.91</td>
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<td>2006</td>
<td>25.61</td>
<td>5.02</td>
<td>27.78</td>
<td>5.49</td>
<td>29.31</td>
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<td>2007</td>
<td>21.28*</td>
<td>5.32</td>
<td>23.69*</td>
<td>5.91</td>
<td>25.52*</td>
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<td>2008</td>
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<td>4.80</td>
<td>22.35*</td>
<td>5.55</td>
<td>24.00*</td>
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<td>2009</td>
<td>19.99*</td>
<td>4.73</td>
<td>22.50*</td>
<td>5.21</td>
<td>24.27*</td>
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<tr>
<td>Total</td>
<td>22.18</td>
<td>5.54</td>
<td>24.41</td>
<td>6.04</td>
<td>26.08</td>
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Average peak inspiratory pressures by hypoxia group in cm H₂O

<table>
<thead>
<tr>
<th>Year</th>
<th>Normal</th>
<th>Mild hypoxia</th>
<th>Moderate hypoxia</th>
<th>Severe hypoxia</th>
<th>Total</th>
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<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>2005</td>
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<td>1.37</td>
<td>2.43</td>
<td>1.73</td>
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<td>2.12</td>
<td>1.34</td>
<td>2.52</td>
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<tr>
<td>2007</td>
<td>2.38*</td>
<td>2.59</td>
<td>2.99*</td>
<td>2.85</td>
<td>3.99*</td>
</tr>
<tr>
<td>2008</td>
<td>3.42*</td>
<td>2.54</td>
<td>4.03*</td>
<td>2.74</td>
<td>4.64*</td>
</tr>
<tr>
<td>2009</td>
<td>4.06*</td>
<td>2.25</td>
<td>4.57*</td>
<td>2.41</td>
<td>5.14*</td>
</tr>
<tr>
<td>Total</td>
<td>2.86</td>
<td>2.30</td>
<td>3.40</td>
<td>2.96</td>
<td>3.98</td>
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</tbody>
</table>

Average PEEP by hypoxia group in cm H₂O

PBW = predicted body weight.
* P ≤ 0.05, † P ≤ 0.001 when compared with the 2005 group using ANOVA with the Bonferroni correction.
Conclusions

- Similar ventilation strategies in mL/kg PBW and PEEP were used among patients regardless of P/F ratio.

- The results of this study suggest that anesthesiologists, in general, are treating hypoxemia with higher FIO2 and letting increase the PIP, but never use low Vt, high levels of PEEP and recruitment maneuvers as in intensive care units are starting to do for improving oxygenation.
“To keep learning, sometimes, it is crucial to unlearn, what you have studied before...”

Aristotle
1. Pulmonary physiology and Physics never lies

2. Never louse the clinical common sense

3. Training mechanical ventilation in a total completely different way: simple and visual
Protective ventilation and ARDS
EFFECT OF A PROTECTIVE-VENTILATION STRATEGY ON MORTALITY IN THE ACUTE RESPIRATORY DISTRESS SYNDROME

MARCELO BRITO PASSOS AMATO, M.D., CARMEN SILVIA VALENTA BARBAS, M.D., DENOISE MACHADO MEDEIROS, M.D., RICARDO BORGES MAGALDI, M.D., GUILHERME DE PAULA PINTO SCHETTINO, M.D., GERALDO LORENZI-FILHO, M.D., RONALDO ADIB KAIRALLA, M.D., DANIEL DEHEINZELIN, M.D., CARLOS MUÑOZ, M.D., ROSELAIM OLIVEIRA, M.D., TERESA YAE TAKAGAKI, M.D., AND CARLOS ROBERTO RIBEIRO CARVALHO, M.D.

ABSTRACT

Background In patients with the acute respiratory distress syndrome, massive alveolar collapse and cyclic lung reopening and overdistention during mechanical ventilation may perpetuate alveolar injury. We determined whether a ventilatory strategy designed to minimize such lung injuries could reduce not only pulmonary complications but also mortality at 28 days in patients with the acute respiratory distress syndrome.

Methods We randomly assigned 53 patients with early acute respiratory distress syndrome (including 28 described previously), all of whom were receiving identical hemodynamic and general support, to conventional or protective mechanical ventilation. Conventional ventilation was based on the strategy of recruiting alveolar expansion with positive end-expiratory pressure (PEEP) that results in acceptable oxygenation.1

Mechanical ventilation can damage the lungs.2,3 Lesions at the alveolar-capillary interface,2,3 alterations in permeability,4 and edema5-7 have repeatedly been shown to occur in animals subjected to adverse patterns of mechanical ventilation.

In clinical practice, however, the “mechanical stretch” caused by conventional ventilation has been found to be detrimental in only a few uncontrolled studies.8-11 Large variations in the susceptibility of individual animal species12 and the apparent success of mechanical ventilation based on a strategy of using the lowest positive end-expiratory pressure (PEEP) that results in acceptable oxygenation13,14 suggest that the devastating effects observed in animal models do not necessarily apply to patients.
Survival function - Amato et al.

- Time after Entry (days)
- N = 53

Cumulative Survival

- Protective
- Control

P < 0.001
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*


• N = 466

• 6 ml/kg

• 12 ml/kg
Evolution of Mortality in ARDS


Permissive Hypercapnia

• AECC
  • 44% observational
  • 36% in RCT
Lung protective ventilation strategy for the acute respiratory distress syndrome (Review)

Petrucci N, De Feo C

Outcome: Hospital Mortality

<table>
<thead>
<tr>
<th>Study or subgroup</th>
<th>Treatment n/N</th>
<th>Control n/N</th>
<th>Risk Ratio M-H.Fixed, 95% CI</th>
<th>Weight</th>
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</thead>
<tbody>
<tr>
<td>Amato 1998</td>
<td>13/29</td>
<td>17/24</td>
<td>0.63 [0.39, 1.02]</td>
<td>7.3 %</td>
</tr>
<tr>
<td>ARDS Network 2000</td>
<td>133/432</td>
<td>170/429</td>
<td>0.78 [0.65, 0.93]</td>
<td>66.8 %</td>
</tr>
<tr>
<td>Brower 1999</td>
<td>13/26</td>
<td>12/26</td>
<td>1.08 [0.62, 1.91]</td>
<td>4.7 %</td>
</tr>
<tr>
<td>Stewart 1998</td>
<td>30/60</td>
<td>28/60</td>
<td>1.07 [0.74, 1.55]</td>
<td>11.0 %</td>
</tr>
<tr>
<td>Villar 2006</td>
<td>17/50</td>
<td>25/45</td>
<td>0.61 [0.38, 0.98]</td>
<td>10.3 %</td>
</tr>
<tr>
<td><strong>Total (95% CI)</strong></td>
<td><strong>597</strong></td>
<td><strong>584</strong></td>
<td><strong>0.80 [0.69, 0.92]</strong></td>
<td>100.0 %</td>
</tr>
</tbody>
</table>

Total events: 206 (Treatment), 252 (Control)
Heterogeneity: Chi² = 5.78, df = 4 (P = 0.22); I² = 31%
Test for overall effect: Z = 3.12 (P = 0.0018)
Test for subgroup differences: Not applicable

Authors’ conclusions
Mortality was significantly reduced at day 28 and at the end of the hospital stay. **Ventilation with lower tidal volumes is becoming a routine strategy of treatment** in patients with ARDS and ALI.

Cochrane Database Syst Rev. 2013
Protective ventilation and Anaesthesia
Mechanical ventilation and healthy lungs

¿What is low or high Vt in thoracic surgery for you?

- **Unit of measurement : (ml)**

- **Know the minimum and maximum valor used:**
  - Minimum: 2-3 ml/kg HFOV
  - Maximum: 32 ml/kg


- **Media: 15 ml/kg**

- **ASA guidelines 2004 recommended the use Vt 15 ml/kg for avoiding hypoxemia in one-lung ventilation in thoracic surgery**
Mechanical ventilation and healthy lungs

Incidence of mortality and morbidity related to postoperative lung injury in patients who have undergone abdominal or thoracic surgery: a systematic review and meta-analysis

Ary Serpa Neto, Sabrine NT Hemmes, Carmen SV Barbas, Martin Beiderlinden, Ana Fernandez-Bustamante, Emmanuel Futier, Markus WHollmann, Samir Jaber, Alf Koziar, Marc Licker, Wen Qian Lin, Pierre Moine, Federica Scavonetto, Thomas Schilling, Gabriele Selmo, Paolo Severgnini, Juraj Sprung, Tanja Treschan, Carmen Unzueta, Toby NWeingarten, Esther K Wolthuis, Hermann Wrigge, Marcelo Gama de Abreu, Paolo Pelosi, Marcus J Schultz, for the the PROVE Network investigators

Individual data analysis of 3365 patients from 12 observational and RCTs
Postoperative lung injury: 3.65%

Figure 3: Timing of PLI during hospital stay

Mean time to onset of PLI: 2.9 (2.2) days

Figure 4: Kaplan-Meier estimates of overall survival in patients with and without PLI

In-hospital mortality: 1.4% vs 20.3%
(HR 9.58, CI95% 5.32–17.34)
Incidence of mortality and morbidity related to postoperative lung injury in patients who have undergone abdominal or thoracic surgery: a systematic review and meta-analysis

Ary Serpa Neto, Sabrine NT Hemmes, Carmen SV Barbas, Martin Beiderlinden, Ana Fernandez-Bustamante, Emmanuel Futier, Markus W Hollmann, Samir Jaber, Alf Kozian, Marc Licker, Wen-Qian Lin, Pierre Moine, Federica Scavonetto, Thomas Schilling, Gabriele Selmo, Paolo Severgnini, Juraj Sprung, Tanja Treschan, Carmen Unzueta, Toby N Weingarten, Esther K Wolthuis, Hermann Wrigge, Marcelo Gama de Abreu, Paolo Pelosi, Marcus J Schultz, for the the PROVE Network investigators

Individual data analysis of 3365 patients from 12 observational and RCTs
Postoperative lung injury: 3.65%

Mortality
1.4%
25.2%
35.9%
EDITORIAL: “Mechanical ventilation is a massive destructive weapon or a powerful tool of freedom…”

What is “optimal ventilation” or “protective ventilation”? In what parameters is it based on?

- **Optimal ventilation**: MV using the less pressure possible to obtain the minimum minute volume to cover the oxygen-demand and CO₂ removal required for the body for this patient in this specific moment.

- **Protective ventilation**: Mechanical ventilation avoiding VILI.
Mechanical Ventilation objectives

- Oxygenation:
  - Do you intubate a patient with $\text{Sat O}_2$ 80%?
  - Acute/chronic

- Ventilation:
  - EtCO$_2$ of 30 mmHg is the ideal ventilatory objective?
  - COPD patients the pH is giving you the answer

Please always set your oxygenation and ventilation objective individually for each patient you ventilate (in critical patients can change every day).
Why would an adult anesthetist who is never going to anesthetize children be interested in mechanical ventilation for pediatric anesthesia?
Because the healthy lungs of neonates and of infants under 5 kg in weight, are a good physiological model for altered pulmonary states in adults.
Neonatal lungs are perfect model for ARDS states in adults:

- Neonatal lungs have:
  - Low FRC / high closure volume very prone to have atelectasis during any disconnection
  - Low pulmonary compliance (dynamic and static)
  - Low inspiratory and expiratory times
  - High rate of oxygen consumption (double than adult).
  - High airway resistances
Compliance dyn (cmH₂O/l/s) vs weight (kg)

Airway resistance (cmH$_2$O/l/s) vs age (years)

Inspiratory airway resistance is 7-10 times higher in newborns than in adults (>75 cmH2O/l/s vs. 10-15 cmH2O/l/s). In premature babies, inspiratory airway resistance can exceed 150 cmH2O/l/s

J. Garcia-Fernandez et al. Current Anaesthesia & Critical Care 21 (2010); 262-268
Glottic Closure Reflex:
Glottic closure stops expiration before lung volume decreases below the pulmonary closing volume. (This can be called the physiological “AUTOPEEP” we are all born with and it is about 2-3 cm H₂O)

Diaphragm function to keep FRC above closing volume

spontaneous ventilation

IPPV with diaphragm relaxation
Lung compliance: (elastic recoil) adult versus neonate

Reclutamiento pulmonar comparación adulto y neonato
Curva P-V
Descenso por rama espiratoria

Curva P-V de reclutamiento pulmonar comparando adulto y neonato (15-20 cm H₂O)
Non-anaesthesiated healthy rabbit

Anaesthesiated rabbit after induction

Effects of anaesthesia on ventilation/perfusion matching

Göran Hedenstierna

Fig. 2. Three-dimensional reconstruction of atelectasis in an anesthetized subject. The chest wall is shown in light grey and the atelectasis in dark grey. Note the rather uneven distribution in the dependent regions of the atelectasis that is larger to the left (near the diaphragm) and decreases in the right towards the apex.

Fig. 4. CT in an anesthetized obese patient with the cut 1 cm above the diaphragm. A recruitment maneuver (RM) (airway pressure of 55 cm H₂O for 10 seconds) + PEEP of 10 cm H₂O reduced atelectasis and this effect was sustained for 20 minutes. RM + ZEEP caused a reduction of atelectasis, but this effect could not be seen after 20 minutes. PEEP had no effect on the amount of atelectasis.

* p < 0.05 vs anesthesia, † p < 0.05 vs PEEP and RM + ZEEP. PEEP = positive end expiratory pressure, RM = recruitment maneuver, ZEEP = zero end expiratory pressure. From ref 25, with permission by the editor of Anesthesiology.
Why and when do atelectasis form?

FRC / EELV

Open lung

Closing volume

Atelectasis
Apneic oxygenation time: Directly proportional to FRC
1. PEEP must be programmed individually and after obtaining an open lung (after Recruitment maneuvers).

2. Protocol of no disconnection no suction.

3. Vt of 6 ml/kg doesn't guarantee to avoid VILI. Watch out DRIVING PRESSURE and the role is "the less the better".

4. No fix and constant I:E relation and better high respiratory rate than high driving pressure (Physiological programming).
5. Individualize the oxygenation and hypercapnia level in each patient each day (Permissive or adaptive hypercapnia for pH > 7.2)

6. FiO₂ < 0.7

**TIMING IS CRUTIAL (THERAPEUTIC WINDOW)** (MOST OF THIS ACTIONS WORK WELL IF YOU APPLY THEM WITHIN THE FIRST 2-3 DAYS OF THE ONSET OF ARDS)

ventilator situations

10. Mechanical assistant devices: CO₂ removal systems or respiratory ECMO
Lessons from pulmonary physiology....

This must be apply to any ventilator...
This advanced mechanical ventilation course is designed for experienced hospital staff with at least four years' experience in ventilation techniques and is especially appropriate for professionals such as Chiefs of Department, Unit Coordinators or Resident Tutors, who are responsible for training other professionals. There are only 15 places per course.
Thank you!!!

¿Questions?

ventilacionanestesia@gmail.com