MAJOR ADVANCES IN MECHANICAL VENTILATION – A 40 YEAR PERSPECTIVE

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Disclosures

• Financial
  • Investor, advisor – InVent Respiratory
  • Speaker bureau – La Jolla Pharmaceutical
  • Investor, advisor – Connected Rock Ventures
  • Investor, board member – Octet Medical Inc

• Non-financial
  • The contents largely reflect my opinions and experience, as opposed to proven theses
Today’s Objectives

• Review some of the most important developments in mechanical ventilation over the past 4 decades

• Stimulate discussion and pondering of your own opinions

• Celebrate some of the meaningful progress made in the field of mechanical ventilatory support
Some Important Developments in Mechanical Ventilation

1. Recognition of the role and effects of autoPEEP
2. Discovery that ‘assist-control’ ventilation may not reduce W.O.B.
3. Pulse Oximetry in ventilated patients
4. Graphic waveforms, and how they can help you...
5. Pressure-limited forms of mechanical ventilation
6. The incredible impact of NIPPV
7. Evolution and clinical importance of the VILI concept
8. The migration from ‘weaning’ to ‘liberation’
9. The attention to positioning the patient during M.V.
10. High-flow heated humidified nasal therapy (HFNC)

1. Development and Detection of Occult PEEP

- Intrinsic PEEP
- Dynamic airflow obstruction
- AutoPEEP

Clinical Commentary

Occult Positive End-Expiratory Pressure in Mechanically Ventilated Patients with Airflow Obstruction

The Auto-PEEP Effect

Paul Pepe
John Marini
Cardiovascular Consequences of Overdistention

Ventilator delivers a breath before the patient has completely exhaled the previous breath

- increased intrathoracic pressure
- hyperinflation adjacent to heart
- dynamic airway collapse

\[ \rightarrow \text{venous return} \]
\[ \downarrow \text{stroke volume} \]
\[ \downarrow \text{hypotension} \]

Fig. 1. Effect of temporary discontinuation of intermittent positive pressure ventilation (IPPV) or cardiac output (QT), systemic blood pressure (BP), wedge and esophageal (ESOPH) pressures in a patient with severe airflow obstruction (Patient 1).
Severe Inadvertent PEEP in COPD with Mechanical Ventilation

PS 10, PEEPset 5
IMV 12, VT 450, PEEPset 5

Effect of Decreasing Rate

FLOW
mL/s
2000
200
A
TIME
200
mL/s
2000
200

Respir Care Clin N Am 2000;6(1):171
Potential Consequences of AutoPEEP

- Hemodynamic instability
- Barotrauma or lung injury
- V/Q mismatch and hypoxemia
- Difficulty triggering the ventilator
- Need for additional sedation
- Impair weaning

2. Inspiratory Work of Breathing Continues during Assisted Ventilation

*These observations contradict the common clinical belief that assisted mechanical ventilation spares patient exertion and call attention to the possibility that inappropriate selection of ventilator mode or machine settings may cause or contribute to respiratory muscle fatigue or dyspnea*
3. Pulse Oximetry in Mechanical Ventilation

- 1980 - Biox introduces first commercially distributed oximeters for clinical use
- 1986 - “the most significant technologic advance ever made in monitoring the well-being and safety of patients during anesthesia, recovery and critical care” *
- October 1989 - ASA delegates voted oximetry a mandatory monitoring standard of care in all anesthetic cases (USA)
- “Despite its widespread use, the value of oximetry has been poorly studied with no trials showing a convincing benefit on clinically meaningful outcome (e.g., mortality, myocardial infarction, resource allocation)” UpToDate

4. Use of Graphic Waveforms
Uses of Graphic Waveforms

- Is the patient being ventilated?
- Detection of secretions
- Response to bronchodilators
- Shows air trapping
- Autocycling
- Excessive triggering effort
- Recognizing flow starvation
- Evaluation of patient-ventilator dyssynchrony
- Detection of lower inflection point to help set PEEP
5. Pressure Targeted Ventilation

- Pressure support ventilation
- Pressure control (can be IMV, CMV, AC)
- ‘Dual modes’ (e.g. PRVC, APV)
- Adaptive support

- Touted benefits include patient-ventilator synchrony, V/Q matching, sedation reduction, possible weaning aid
- Positive impact on important outcomes of interest generally not proven in well-done trials
- Definitely another modal option when attempting to resolve dyssynchrony

6. Non-invasive Mechanical Ventilation

Photo Courtesy Stanley B. Burns, MD
6. Non-invasive *Positive Pressure* Ventilation

Non-invasive Ventilation Comes Back

- Acute hypercapnic states, COPD
- Cardiogenic pulmonary edema
- Immunocompromised patients
- Facilitating discontinuation of ventilation in borderline cases

- For this, there is robust scientific data supporting clinical benefit in several important outcomes in respiratory failure
NIV for COPD: Risk of Treatment Failure: (Death, ETT, Intolerance)

<table>
<thead>
<tr>
<th>Study</th>
<th>NPPV</th>
<th>Usual medical care</th>
<th>Risk ratio (fixed 95% CI)</th>
<th>Weight (%)</th>
<th>Risk ratio (fixed 95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avdotiev et al 1998</td>
<td>7/20</td>
<td>12/29</td>
<td>11.2</td>
<td>0.58</td>
<td>0.27 to 1.27</td>
</tr>
<tr>
<td>Barba et al 1998</td>
<td>4/14</td>
<td>0/10</td>
<td>0.5</td>
<td>6.60</td>
<td>0.30 to 11.03</td>
</tr>
<tr>
<td>Bott et al 1986</td>
<td>5/30</td>
<td>13/30</td>
<td>7.38</td>
<td>0.07</td>
<td>0.01</td>
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<tr>
<td>Brochard et al 1995</td>
<td>12/43</td>
<td>32/42</td>
<td>12.1</td>
<td>0.38</td>
<td>0.16 to 0.94</td>
</tr>
<tr>
<td>Collkel et al 1994</td>
<td>1/15</td>
<td>6/15</td>
<td>31.1</td>
<td>0.36</td>
<td>0.21 to 0.59</td>
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<tr>
<td>Dreseney et al 2002</td>
<td>4/19</td>
<td>7/17</td>
<td>5.6</td>
<td>0.17</td>
<td>0.02 to 1.22</td>
</tr>
<tr>
<td>Plant et al 2000</td>
<td>22/118</td>
<td>35/118</td>
<td>6.9</td>
<td>0.51</td>
<td>0.18 to 1.45</td>
</tr>
<tr>
<td>Total (95% CI)</td>
<td>50/268</td>
<td>106/261</td>
<td>32.6</td>
<td>0.63</td>
<td>0.39 to 1.00</td>
</tr>
</tbody>
</table>

Test for heterogeneity: $\chi^2=7.59, df=6, P=0.27$
Test for overall effect: $Z=4.82, P<0.001$

### 7. The Ventilator-Induced Lung Injury Concept, and its Effect on Clinical Practice

- **1974 Webb & Tierney**
  - Demonstrated that ventilation of rats at high airway pressures could cause lung damage similar to ARDS, partially mitigated by application of PEEP

- **1980s Kolobow, and others**
  - Various animal models (sheep, others) demonstrated ARDS pattern could be induced by ventilation at high PIPs (and thus Vt)

- **1980s Gattinoni, and others**
  - Showed that by CT imaging the lungs of ARDS patients, the pattern of injury was heterogeneous, including areas of normal appearing lung (‘baby lung’ concept)

- **1990 Hickling**
  - Higher than expected survival in ARDS patients treated with very low tidal volumes, and consequent hypercapnia. "Permissive hypercapnia"

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### Overt Barotrauma

![Overt Barotrauma Image](image-url)
The Ventilator-Induced Lung Injury Concept, and its Effect on Clinical Practice

Rat lungs ventilated for 1 hr at:
- 14 cmH2O
- 45 + 10 PEEP
- 45 + Zero PEEP


Pig Ventilated for 42 h at High Peak Inspiratory Pressure

Tsuno *Am Rev Resp Dis* 1991;143:1115
VILI - Animal Studies

Severe Impairment in Lung Function Induced by High Peak Airway Pressure during Mechanical Ventilation
An Experimental Study

Lung Edema Caused by High Peak Inspiratory Pressures in Dogs

Adverse Effects of Large Tidal Volume and Low PEEP in Canine Acid Aspiration

The Ventilator-Induced Lung Injury Concept, and its Effect on Clinical Practice

Morphological response to positive end expiratory pressure in acute respiratory failure. Computerized tomography study

ARDS is Heterogeneous Process

Gattinoni's “baby lung” concept emerges

Permissive Hypercapnia in ARDS


Originals

Low mortality associated with low volume pressure limited ventilation with permissive hypercapnia in severe adult respiratory distress syndrome

K.G. Hickling, S.J. Henderson and R. Jackson

Departments of Intensive Care and Radiology, Christchurch Hospital, Christchurch, New Zealand

Received: 28 September 1989; accepted: 16 February 1990
The Ventilator-Induced Lung Injury Concept, and its Effect on Clinical Practice

ARDSNet Trial of Low Tidal Volume in ARDS

ARDSNet Study-- Daily PaO$_2$ / FiO$_2$ Trend

8. ‘Weaning’ Put to Rest - Mostly
Weaning Time vs Total Ventilator Time

Prospective Weaning Trials
Re: Esteban

“…an alternative explanation is that a once-daily trial of unassisted breathing is not intrinsically superior in facilitating weaning, but rather that daily testing allows earlier recognition of the patient’s ability to breathe without assistance…”

Weinberger and Weiss NEJM 1995; 332:388

Protocol-Directed Weaning vs Ad Lib

Figure 1. Kaplan–Meier Analysis of the Duration of Mechanical Ventilation after a Successful Screening Test.

Ely et al NEJM 1996; 335:1864
Protocol vs Control Weaning


Protocol vs Control Weaning

9. Position of Patient During Mechanical Ventilation

Pulmonary Aspiration of Gastric Contents in Patients Receiving Mechanical Ventilation: The Effect of Body Position
Antoni Torres, MD; Joan Serra-Batiles, MD; Emilio Ros, MD; Carles Piera, MD; Jorge Puig de la Bellacasa, MD; Albert Cobos, MD; Francisco Lomelía, MD; and Robert Rodríguez-Roisín, MD


Prone Positioning – Finally Proven to Help
Prone Positioning – Finally Proven to Help

Prone Positioning in Severe Acute Respiratory Distress Syndrome

Claude Guérin, M. D., Ph. D., Jean-Regis M. D., Ph. D., Jean-Charles Richard, M. D., Ph. D., Pascal Brunt, M. D., Arnaud Gosselin, M. D., Thierry Dodin, M. D., Céline Leconte, M. D., Michel Bade, M. D., Alain Meurice, M. D., Jean-Pierre Tron, M. D., Norbert Garel, M. D., Ph. D., Sylvestre Boussard, M. D., Jérôme Marcellin, M. D., Ph. D., Michel Savola, M. D., Gilles Lefebvre, M. D., Ph. D., Christian Angelier, M. D., Jean-Edouard M. D., Jean-Claude Gilard, M. D., Ph. D., Ambroise Leclercq, M. D., Card Bouchut, M. D., Henriques Leme, M. D., Kyprianou Gouris, W. D., Somarem Babu, Ph. D., and Louis Arroyo, M. D., for the PROSEA Study Group

10. High-Flow Heated Humidified Nasal Therapy (HFNC)

ERS clinical practice guidelines: high-flow nasal cannula in acute respiratory failure

Sinisa Ockanikova,1,2,3, Regina Eige,2,3,4, Linusse Bux,5,6, Michelle Cluyma,4, Miguel Ferrer,4, Cesare Greczeni,7, Leo Hurdoll,7, Jean-Pierre Fedra,7, Theodore Longhi,7, Stefano Navara,7, Pedro Navazol,8,9, Attila Szendro,8,9, Laura Povone,9,10,11, Tomasz Poreba,9,10,11,23,24, Arnaud D. Thiba,9,10,11,23,24, Julio Cables Urtiga,9,10,11,23,24,25,26,27, Thierry Tonkis,9,10,11,23,24,25,26,27, José Huyse,9,10,11,23,24,25,26,27, Giovanni Sbigio,9,10,11,23,24, and Raffaele Scalza9,10,11,23,24,25,26,27

Note: The information provided is a summary of the content of the entire page. For full context and details, please refer to the original document.
Honorable Mention?

- PC-IRV
- Capnography
- APRV
- ECMO
- HFO
- ASV
- More rational sedation management

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What developments do YOU find most important in your experience?