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

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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

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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)

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1. Development and Detection of Occult PEEP

- Intrinsic PEEP
- Dynamic airflow obstruction
- AutoPEEP

Paul Pepe
John Marini

Clinical Commentary

Occult Positive End-Expiratory Pressure in Mechanically Ventilated Patients with Airflow Obstruction[1–2]

The Auto-PEEP Effect

Mechanically-assisted ventilation with intermittent positive pressure (IPPV) increases intrathoracic pressure and can depress cardiac output ($\dot{Q}T$) by diminishing preload (1, 2). Reduction in $\dot{Q}T$ occurs most predictably in patients depleted of intravascular volume and in those ventilated with positive end-expiratory pressure (PEEP) (1, 3, 4). However, patients with chronic obstructive pulmonary disease (COPD)

SUMMARY Alveolar pressure can remain positive throughout the ventilatory cycle of mechanically-ventilated patients with airflow obstruction, even when positive end-expiratory pressure (PEEP) is not applied intentionally. The increase of intrathoracic pressure associated with this "auto-PEEP" phenomenon can severely depress cardiac output as well as elevate the end-expiratory pulmonary artery wedge pressure. Such effects may be exaggerated in patients with chronic obstructive pulmonary disease because abnormally compliant lungs transmit a high fraction of alveolar pressure to intrathoracic vessels. Failure to recognize the hemodynamic consequences of auto-PEEP may lead to inappropriate fluid restriction or unnecessary vasopressor therapy. Although not apparent during normal ventilator operation, the auto-PEEP effect can be detected and quantified by a simple bedside maneuver: expiratory port occlusion at the end of the set exhalation period.

AM REV RESPIR DIS 1982; 126:166-170

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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

↓venous return
↓ stroke volume
hypotension

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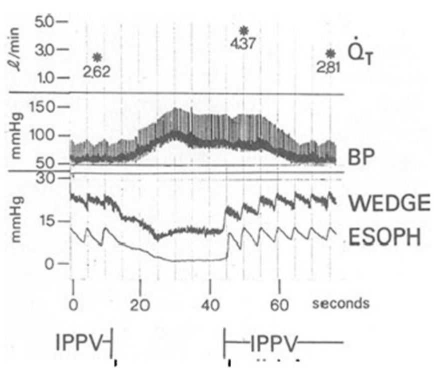
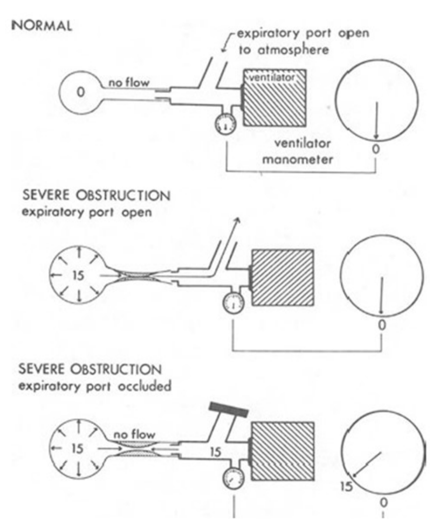


Fig. 1. Effect of temporary discontinuation of intermittent positive pressure ventilation (IPPV) on cardiac output (Q̇T), systemic blood pressure (BP) wedge and esophageal (ESOPH) pressures in a patient with severe airflow obstruction (Patient 1).



Pepe *Am Rev Respir Dis* 1982; 126:166

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Severe Inadvertent PEEP in COPD with Mechanical Ventilation

PS 10, PEEPset 5

IMV 12, V_T 450, PEEPset 5

Deliganis ***Am J Rad*** 2000;174:1339

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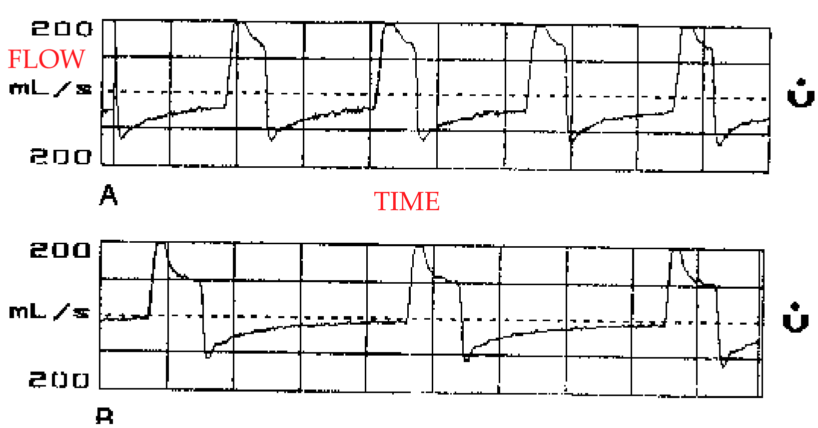
Effect of Decreasing Rate



Respir Care Clin N Am 2000;6(1):171

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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

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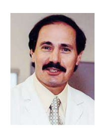
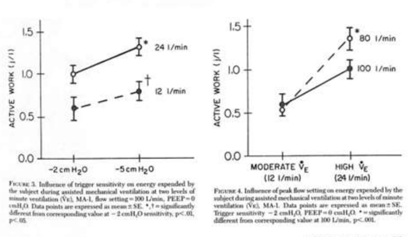
2. Inspiratory Work of Breathing Continues during Assisted Ventilation

The Inspiratory Work of Breathing during Assisted Mechanical Ventilation*

John J. Marini, M.D., F.C.C.P.; John S. Capps, R.R.T.; and Bruce H. Culver, M.D.





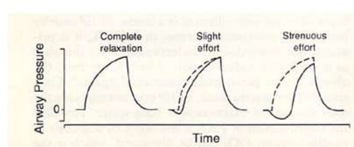


Figure 1. Airway-Pressure Wave Forms Recorded during Assist-Control Ventilation.
The tracings represent changes in airway pressure during inspiration in a completely relaxed patient and in patients making a slight effort and a strenuous effort to breathe. The distance between the dashed line (representing controlled ventilation) and the solid line (representing spontaneous breathing) is proportional to the patient's work in breathing.

"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"

Marini et al ***Chest*** 1985; 87:612

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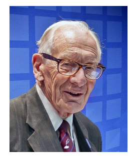
3. Pulse Oximetry in Mechanical Ventilation

- 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*

*Severinghaus et al ***J Clin Monit*** 1986; 2:270



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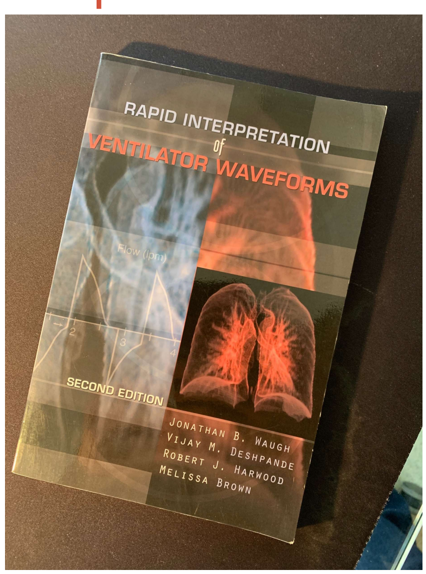
4. Use of Graphic Waveforms



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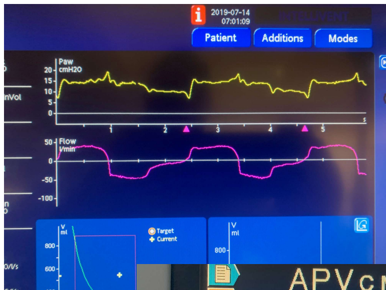
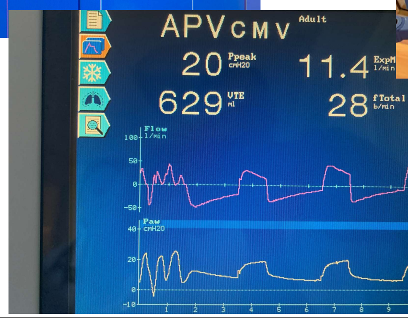
Graphic Waveforms





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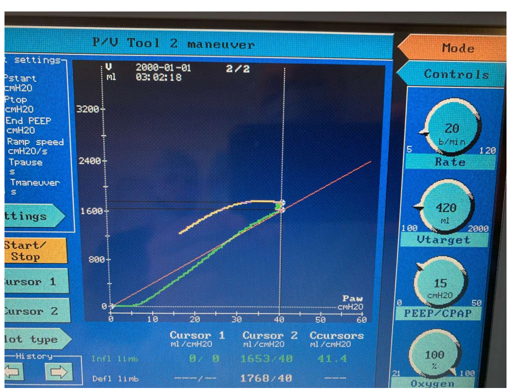
Graphic Waveforms



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Graphic Waveforms - Secretions

Use of Flow-Volume Curves in Detecting Secretions in Ventilator-dependent Patients

AMAL JUBRAN and MARTIN J. TOBIN

Division of Pulmonary and Critical Care Medicine, Edward Hines Jr. Veterans Administration Hospital, Loyola University of Chicago Stritch School Medicine, Hines, Illinois

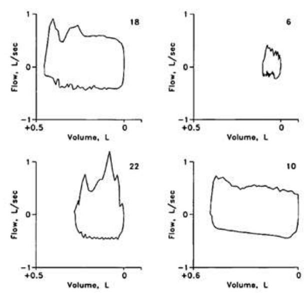

Figure 1. Flow-volume curves obtained in four patients with secretions. Note the presence of a sawtooth pattern on both the inspiratory and expiratory flow-volume curves. The numbers on the right side of each grid represent the patient number.

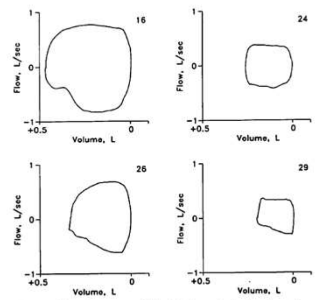

Figure 2. Flow-volume curves obtained in four patients without secretions. Note the smooth contour on the flow-volume curves. The numbers on the right side of each grid represent the patient number.

Am J Respir Crit Care Med 1994;150:766

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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

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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

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6. Non-invasive Mechanical Ventilation

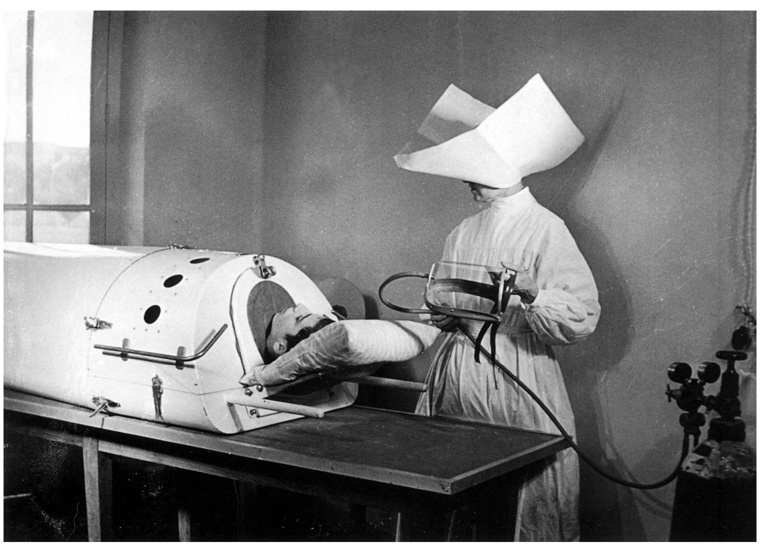

Photo Courtesy Stanley B Burns, MD

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6. Non-invasive *Positive Pressure* Ventilation

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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

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Vol. 323 No. 22 REVERSAL OF EXACERBATIONS OF COPD BY FACE MASK — BROCHARD ET AL. 1523

REVERSAL OF ACUTE EXACERBATIONS OF CHRONIC OBSTRUCTIVE LUNG DISEASE BY INSPIRATORY ASSISTANCE WITH A FACE MASK

LAURENT BROCHARD, DANIEL ISABEY, JACQUES PIQUET, PIEDADE AMARO, JORGE MANCEBO, AMEN-ALLAH MESSADI, CHRISTIAN BRUN-BUISSON, ALAIN RAUSS, FRANÇOIS LEMAIRE, AND ALAIN HARF

Abstract *Background.* Patients with acute exacerbations of chronic obstructive pulmonary disease may require endotracheal intubation with mechanical ventilation. We designed, and here report on the efficacy of, a noninvasive ventilatory-assistance apparatus to provide inspiratory-pressure support by means of a face mask.

Methods. We assessed the short-term (45-minute) physiologic effects of the apparatus in 11 patients with acute exacerbations of chronic obstructive pulmonary disease and evaluated its therapeutic efficacy in 13 such patients (including 3 of the 11 in the physiologic study) who were treated for several days and compared with 13 matched historical-control patients.

Results. In the physiologic study, after 45 minutes of inspiratory positive airway pressure by face mask, the mean (±SD) arterial pH rose from 7.31±0.08 to 7.38±0.07 (P<0.01), the partial pressure of carbon dioxide fell from 68±17 mm Hg to 55±15 mm Hg (P<0.01), and the partial pressure of oxygen rose from 52±12 mm Hg to 69±16 mm Hg (P<0.05). These changes were accompanied by marked reductions in respiratory rate (from 31±7 to 21±9 breaths per minute, P<0.01).

Only 1 of the 13 patients treated with inspiratory positive airway pressure needed tracheal intubation and mechanical ventilation, as compared with 11 of the 13 historical controls (P<0.001). Two patients in each group died. As compared with the controls, the treated patients had a more transient need for ventilatory assistance (3±1 vs. 12±11 days, P<0.01) and a shorter stay in the intensive care unit (7±3 vs. 19±13 days, P<0.01).

Conclusions. Inspiratory positive airway pressure delivered by a face mask can obviate the need for conventional mechanical ventilation in patients with acute exacerbations of chronic obstructive pulmonary disease. (N Engl J Med 1990; 323:1523-30.)

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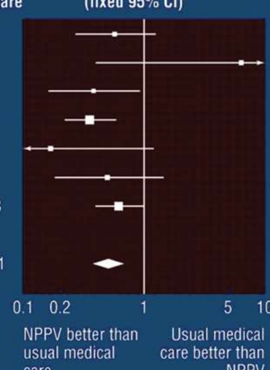
NIV for COPD: Risk of Treatment Failure: (Death, ETT, Intolerance)

Study	NPPV	Usual medical care	Risk ratio (fixed 95% CI)	Weight (%)	Risk ratio (fixed 95% CI)
Avdeev et al 1998[19]	7/29	12/29		11.2	0.58 (0.27 to 1.27)
Barbe et al 1996[16]	4/14	0/10		0.5	6.60 (0.39 to 110.32)
Bott et al 1993[2]	5/30	13/30		12.1	0.38 (0.16 to 0.94)
Brochard et al 1995[3]	12/43	33/42		31.1	0.36 (0.21 to 0.59)
Celikel et al 1998[14]	1/15	6/15		5.6	0.17 (0.02 to 1.22)
Dikensoy et al 2002[20]	4/19	7/17		6.9	0.51 (0.18 to 1.45)
Plant et al 2000[15]	22/118	35/118		32.6	0.63 (0.39 to 1.00)
Total (95% CI)	55/268	106/261		100	0.51 (0.38 to 0.67)



Test for heterogeneity: χ^2=7.59, df=6, P=0.27
Test for overall effect: Z=-4.82, P<0.0001

Lightowler JV, et.al: BMJ 326:185, 2003

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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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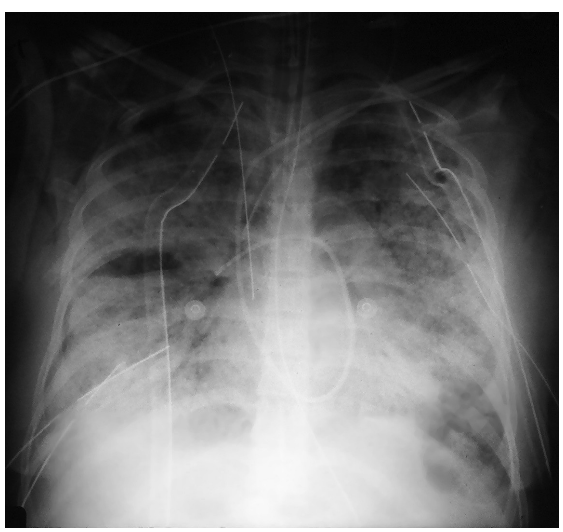
Overt Barotrauma



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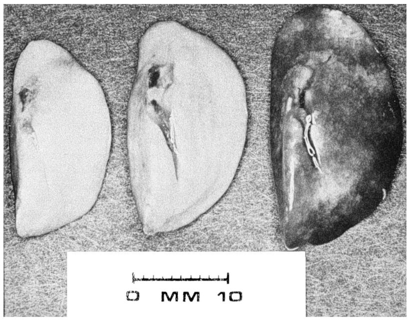
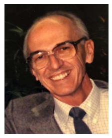
The Ventilator-Induced Lung Injury Concept, and its Effect on Clinical Practice



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



Webb, Tierney ***Am Rev Resp Dis*** 1974;110:556

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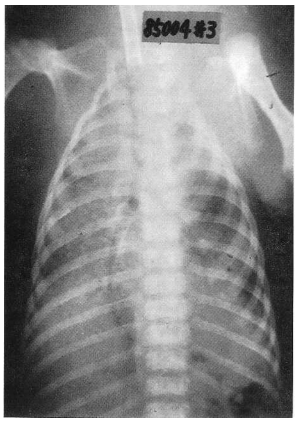
Pig Ventilated for 42 h at High Peak Inspiratory Pressure



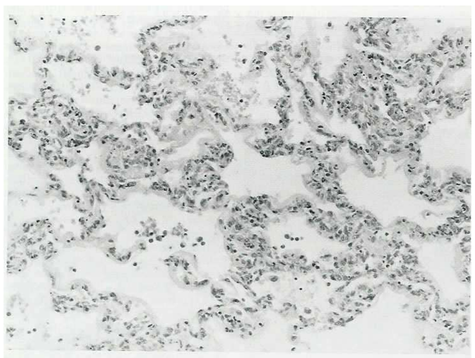


Fig. 4. Lung of a pig of group B-1, mechanically ventilated at a PIP of 40 cm H_2O and an FI_{O_2} of 0.4 for 42 h. Severe lesions consisted of disruption of epithelial lining, hyaline membrane formation, alveolar hemorrhage, alveolar neutrophil infiltration, alveolar macrophage and type II pneumocyte proliferation, interstitial thickening and fibrosis, and endothelial swelling.

Tsuno ***Am Rev Resp Dis*** 1991;143:1115

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VILI - Animal Studies

High Inflation Pressure Pulmonary Edema

Respective Effects of High Airway Pressure, High Tidal Volume, and Positive End-expiratory Pressure[1-3]

DIDIER DREYFUSS, PAUL SOLER, GUY BASSET, and GEORGES SAUMON

Intermittent Positive-Pressure Hyperventilation with High Inflation Pressures Produces Pulmonary Microvascular Injury in Rats[1-3]

DIDIER DREYFUSS, GUY BASSET, PAUL SOLER, and GEORGES SAUMON

Lung Edema Caused by High Peak Inspiratory Pressures in Dogs

Role of Increased Microvascular Filtration Pressure and Permeability[1-3]

JAMES C. PARKER, LUCRECIA A. HERNANDEZ, GESINA L. LONGENECKER, KEITH PEEVY, and WALTER JOHNSON

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

An Experimental Study[1]

Summarize for slide

THEODOR KOLOBOW, MARIA P. MORETTI, ROBERTO FUMAGALLI, DANIELE MASCHERONI, PAOLO PRATO, VICTOR CHEN, and MARC JORIS

Adverse Effects of Large Tidal Volume and Low PEEP in Canine Acid Aspiration[1-3]

THOMAS C. CORBRIDGE, LAWRENCE D. H. WOOD, GREGORY P. CRAWFORD, MARIA J. CHUDOBA, JOHN YANOS, and J. IASHA SZNAJDER

0090-3493/89/1709-0908$02.00/0
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High tidal volume ventilation produces increased lung water in oleic acid-injured rabbit lungs

DAVID L. BOWTON, MD; DAN L. KONG, MS

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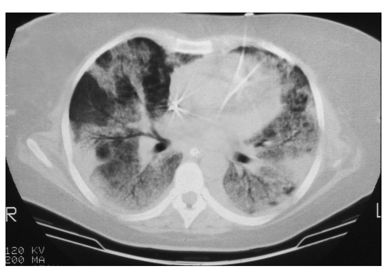
The Ventilator-Induced Lung Injury Concept, and its Effect on Clinical Practice

Intensive Care Medicine
May 1986, Volume 12, Issue 3, pp 137–142 | Cite as

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

Authors | Authors and affiliations

L. Gattinoni, D. Mascheroni, A. Torresin, R. Marcolin, R. Fumagalli, S. Vesconi, G. P. Rossi, F. Rossi, S. Baglioni, F. Bassi, G. Nastri, A. Pesenti



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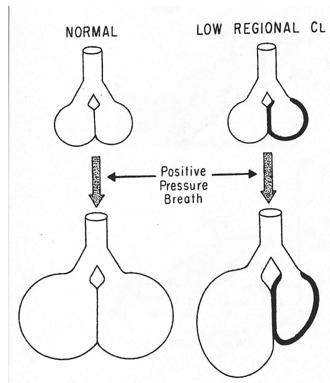
ARDS is Heterogeneous Process



Gattinoni's "baby lung" concept emerges

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Permissive Hypercapnia in ARDS

Intensive Care Med (1990) 16:372–377

Intensive Care Medicine

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

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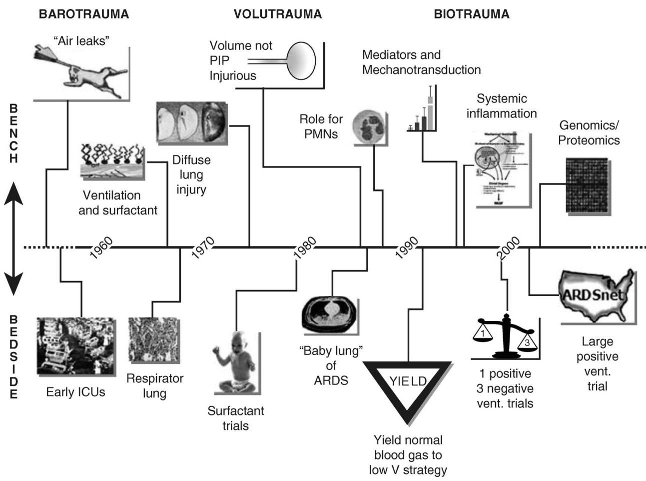
The Ventilator-Induced Lung Injury Concept, and its Effect on Clinical Practice



Slutsky *Am J Respir Crit Care Med* 2015;191:1106

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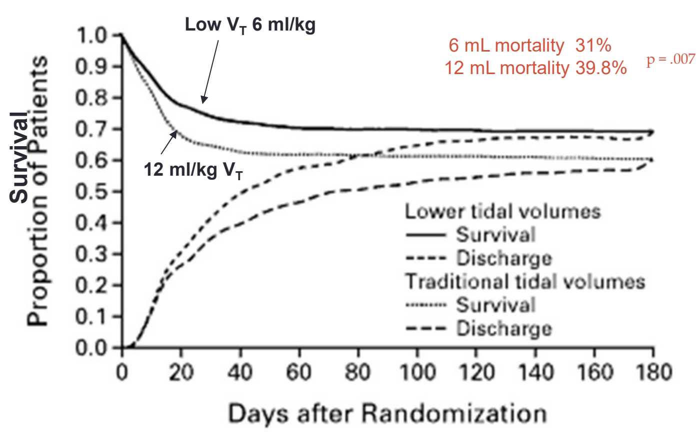
ARDSNet Trial of Low Tidal Volume in ARDS



ARDS Network *N Engl J Med* 2000;342:1301

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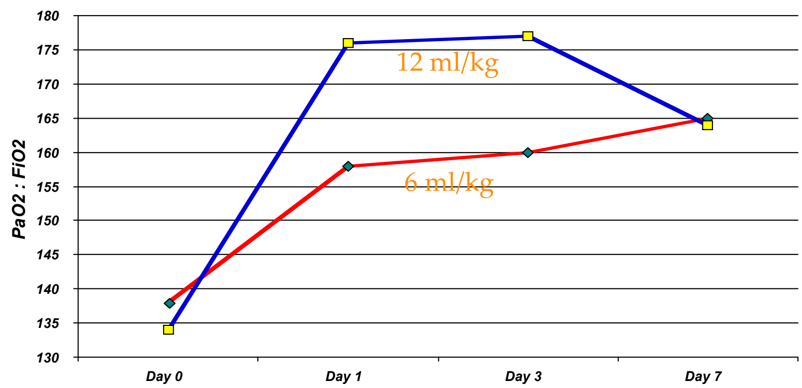
ARDSNet Study-- Daily PaO_2 / FiO_2 Trend



ARDS Network ***N Engl J Med*** 2000;342:1301

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8. 'Weaning' Put to Rest - Mostly

The New England
Journal of Medicine

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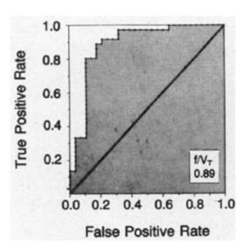
Volume 324 MAY 23, 1991 Number 21

A PROSPECTIVE STUDY OF INDEXES PREDICTING THE OUTCOME OF TRIALS OF WEANING FROM MECHANICAL VENTILATION

Karl L. Yang, M.D., and Martin J. Tobin, M.D.

f/Vt > 100



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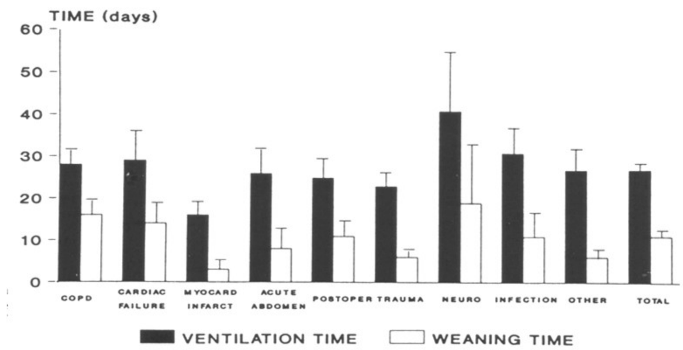
Weaning Time vs Total Ventilator Time



Esteban et al ***Chest*** 1994; 106:1188

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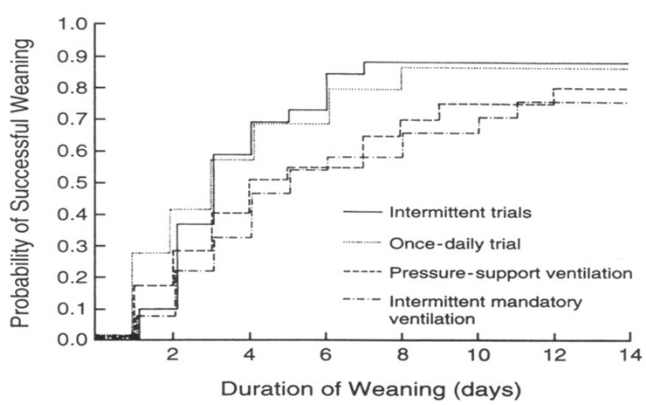
Prospective Weaning Trials



Esteban et al ***NEJM*** 1995; 332:345

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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

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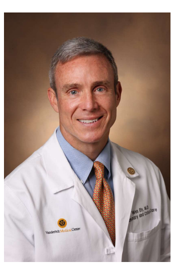
Protocol-Directed Weaning vs Ad Lib



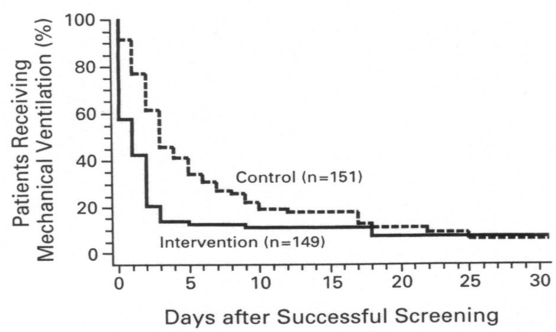


Figure 1. Kaplan–Meier Analysis of the Duration of Mechanical Ventilation after a Successful Screening Test.

Ely et al ***NEJM*** 1996; 335:1864

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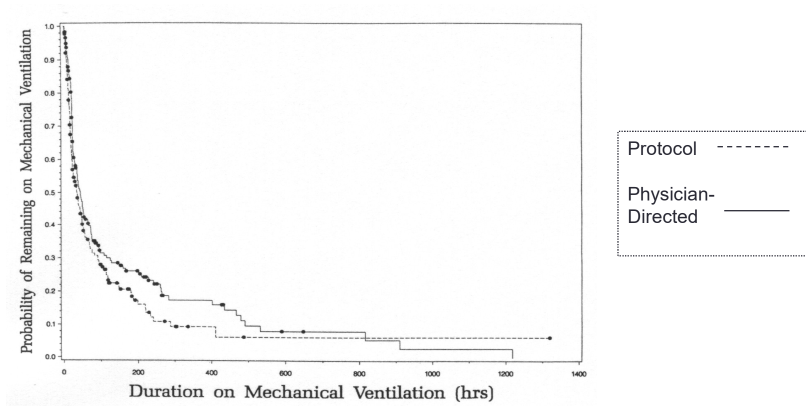
Protocol vs Control Weaning



Koleff et al *Crit Care Med* 1997; 25:567

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Protocol vs Control Weaning

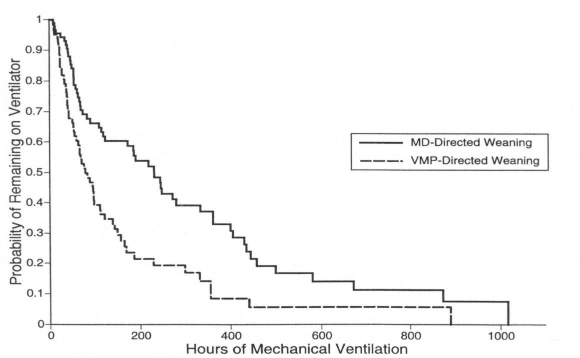

FIGURE 3. Probability of continued ventilatory support in MICU patients.

Marelich et al *Chest* 2000; 118:459

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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-Batlles, MD; Emilio Ros, MD; Carles Piera, MD; Jorge Puig de la Bellacasa, MD; Albert Cobos, MD; Francisco Lomeña, MD; and Robert Rodríguez-Roisin, MD

Ann Intern Med 1992; 116:540

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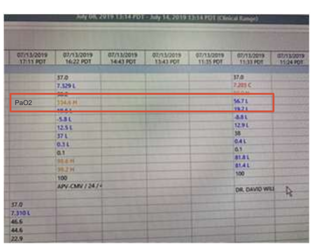
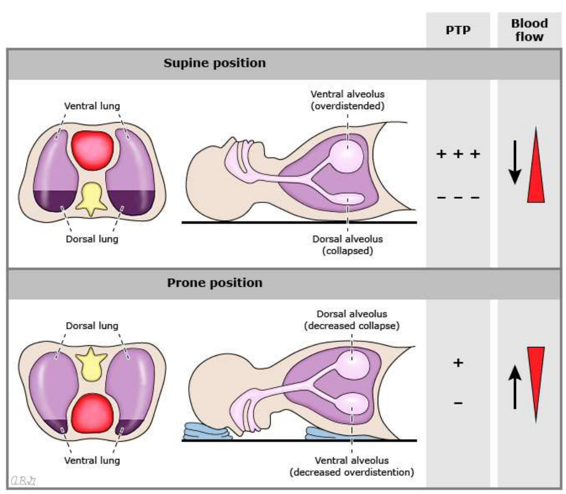
Prone Positioning – Finally Proven to Help





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Prone Positioning – Finally Proven to Help

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Prone Positioning in Severe Acute Respiratory Distress Syndrome

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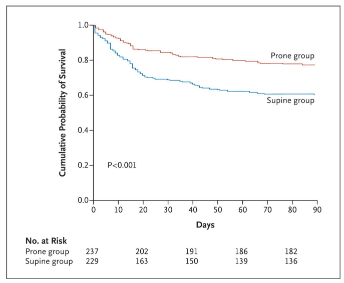

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10. High-Flow Heated Humidified Nasal Therapy (HFNC)

EUROPEAN RESPIRATORY JOURNAL
ERS OFFICIAL DOCUMENTS
S. OCZKOWSKI ET AL.

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

Simon Oczkowski[1,2,26], Begüm Ergan[3,26], Lieuwe Bos[4,5], Michelle Chatwin[6], Miguel Ferrer[7], Cesare Gregoretti[8,9], Leo Heunks[10], Jean-Pierre Frat[11,12], Federico Longhini[13], Stefano Nava[14,15], Paolo Navalesi[16,17], Aylin Ozsancak Uğurlu[18], Lara Pisani[14,15], Teresa Renda[19], Arnaud W. Thille[11,12], João Carlos Winck[20], Wolfram Windisch[21], Thomy Tonia[22], Jeanette Boyd[23], Giovanni Sotgiu[24] and Raffaele Scala[25]

TABLE 2 Population, intervention, comparison, outcomes (PICO) questions and recommendations

1. Should HFNC or COT be used in patients with acute hypoxaemic respiratory failure?	The ERS task force suggests the use of HFNC over COT in patients with acute hypoxaemic respiratory failure (conditional recommendation, moderate certainty of evidence)
2. Should HFNC or NIV be used in patients with acute hypoxaemic respiratory failure?	The ERS task force suggests the use of HFNC over NIV in acute hypoxaemic respiratory failure (conditional recommendation, very low certainty of evidence)
3. Should HFNC or COT be used during breaks from NIV in patients with acute hypoxaemic respiratory failure?	The ERS task force suggests the use of HFNC over COT during breaks from NIV in patients with acute hypoxaemic respiratory failure (conditional recommendation, low certainty of evidence)
4. Should HFNC or COT be used in post-operative patients after extubation?	The ERS task force suggests the use of either COT or HFNC in post-operative patients at low risk of respiratory complications (conditional recommendation, low certainty of evidence)
5. Should HFNC or NIV be used in post-operative patients after extubation?	The ERS task force suggests the use of either HFNC or NIV in post-operative patients at high risk of respiratory complications (conditional recommendation, low certainty of evidence)
6. Should HFNC or COT be used in nonsurgical patients after extubation?	The ERS task force suggests the use of HFNC over COT in nonsurgical patients after extubation (conditional recommendation, low certainty of evidence)
7. Should HFNC or NIV be used in nonsurgical patients after extubation?	The ERS task force suggests the use of NIV over HFNC for patients at high risk of extubation failure, unless there are absolute or relative contraindications to NIV (conditional recommendation, moderate certainty of evidence)
8. Should HFNC or NIV be used in patients with acute hypercapnic respiratory failure?	The ERS task force suggests a trial of NIV prior to use of HFNC in patients with COPD and acute hypercapnic respiratory failure (conditional recommendation, low certainty of evidence)

HFNC: high-flow nasal cannula; COT: conventional oxygen therapy; NIV: noninvasive ventilation; ERS: European Respiratory Society.

Eur Respir J 2022;59:2101574

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Honorable Mention?

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

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Some Important Developments in Mechanical Ventilation

1. Recognition of the role and effects of autoPEEP
2. Discovery that ‘controlled’ 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)

What developments do YOU find most important in your experience?

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