History of Mechanical Ventilation Technology

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Disclaimer

- All views expressed are my own opinion and not necessarily those of the Cleveland Clinic.

Disclosure

- I have affiliations with, special interests, or have conducted business with the following companies that in context with this presentation might possibly constitute a real or perceived conflict of interest: 
  - IngMar Medical
  - DeVilbiss
History of Resuscitation
Origin of the term “blowing smoke”???
Original Bible of Mechanical Ventilation

Automatic Ventilation of the Lungs

William W. Mushin
L. Rendell-Baker
Peter W. Thompson
W. W. Mapleson

Third Edition

Blackwell Scientific Publications

London 1959

All Anesthesiologists

Detailed descriptions of 74 ventilators!
Woillez’s Spirophore (1876)
Fell-O'Dwyer Apparatus (1888)
Cleveland Respirator

photo courtesy of Rich Branson
Early Operating Room Ventilator

photo courtesy of Rich Branson
Dräger Pulmotor (Germany 1907)

Heinreich Dräger

photo courtesy of Rich Branson
Janeway-Green
Rhythmic Inflation Apparatus (1909)
Läwan - Sievers
Anesthesia Apparatus (1910)
Wilhelm Schwake Germany (1926)

- Designed to improve synchrony
- “Negative pressure on the skin pulls out gaseous by-products”
Drinker-Shaw
New Mechanical Respirator (USA 1929)
First mass produced Iron Lung
Dräger (1950)
Polio Epidemics

Pioneer of tank and piston ventilators
A Good Idea Never Dies

George Emerson

His mom
Mörch III Piston Ventilator (1954)

photo courtesy of Rich Branson
Blease Pulmoflator, London (1955)

photo courtesy of Rich Branson
Ray Bennett, USAF (1970)

Flow control valve (1947)
PR Series Ventilators (1948-1990s)
Dr. Forest Bird (1958)

Magnets and clutch plates

photo courtesy of Rich Branson
Bird Prototype Mark 7 (1951)

(1951) The original Mark 7, built inside a coffee can. This was the first Bird breathing device to use magnets for the control of gas movement.

photo courtesy of Rich Branson
Bird Prototype IPPB (1949)

(1949) Initial prototype of the hand-operated IPPB device. Note the silver doorknob on top for actuation of the unit. There are two sets of springs, one in the center over the diaphragm and one on the right-hand side. Depressing the doorknob straight down activated the positive pressure (by depressing the diaphragm) and flow for nebulization of medications (by depressing the spring on the right-hand side). This allowed the patient to have nebulization, positive pressure, or both — depending upon the angle of force directed on the doorknob.

- positive pressure
- nebulization
- both

photo courtesy of Rich Branson
Bird “Respirators” (1959 to present)
Henri Coanda (1933)
Father of fluidic control devices

• Designer of early jet planes
• Discovered “wall attachment effect” – later named “Coanda Effect”

In his first and last jet test flight, the plane emerged from a sheet of flame and smoke. Coanda said “Apparently I had given it too much fuel. When I looked over the side I saw flames shooting out, and that should not be. I ducked inside to adjust matters. A moment later things felt very differently. I looked outside again to find myself many feet in the air. Straight ahead of me was the Paris wall. I didn’t know what to do. I pulled on the control wheels, the machine went up on one wing and I was thrown out. The plane crashed at the foot of the wall”
Fluidic Logic Control Circuits

(A) FLIP-FLOP
(B) OR/NOR GATE
(C) BACK PRESSURE SWITCH
(D) AND/NAND GATE
(E) PROPORTIONAL AMPLIFIER
(F) SCHMITT TRIGGER
Corning Fluidikit Ventilator Circuit (1980s)
Dr. Jere Mead (1920–2009)

He established a whole new field of research. Respiratory Mechanics was his invention. Was the first to use the term “compliance” in medicine an idea he borrowed from electronics (capacitance).

Journal of Applied Physiology;107(6):1679
Mushin “Butterfly Diagram”
Constant Flow – Pressure Cycled
Simulator-Based Waveforms

- **V**: 1/min
- **P_{Mo}**: cm H_2O
- **P_A**: cm H_2O
- **V**: ml

(a) Standard conditions
(b) Compliance halved
(c) Resistance doubled
1977 Textbook on Mechanical Ventilation
Described 10 ventilators

Anesthesiologist

Resp Therapist
CHAPTER 2 WHAT
THE DESIGN, FUNCTION AND CARE OF RESPIRATORY THERAPY EQUIPMENT

“As he picks up his beautiful new tool, however it is well for the modern biologist to remind himself how subtly and completely a fascination for gadgets can betray sound sense.”

William T. Salter (1901-1952)

THE VENTILATOR

A. Classification

The most commonly employed ventilators today are those that exert a positive pressure at the upper airway to effect the
Pressure Control Waveforms
Bennett MA-1 (USA)
Emerson Post-Op and 3-PV (USA)
Engström (Denmark)
Servo 900 series Sweden (1970s)
Bird Mark V11

[Diagram of Bird Mark V11 with labels for sensitivity adjustment, ambient chamber, venturi air diluter, flow control, pressure gauge, air mix, expiratory time (pressure bleed off), 50 psi source gas, center body, ceramic valve, metal disc, pressure magnet, pressure adjustment, spring loaded timing mechanism, and pressure chamber.]
Gill 1
The First RT Equipment Book (1977)

Respiratory therapy equipment
STEVEN P. McPHERSON

Respiratory therapist author

Detailed descriptions of 31 ventilators

Only mentions 3 modes!
Fluidic Logic Control Circuits (again)
Emerson Cuirass
Bird Mark 14-6

1980s philosophy:
Normalize blood gases no matter what the inspiratory pressure
Monaghan 225
Bourns BEAR Series (1980s 1990s)

Bear 1  Bear 5  Bear 1000
The First Infant Ventilators
Bourns LS104-150 US (1960s)
First ventilator with mode selection?

Assist
Control
Assist/Control

Set slide so that ventilator tidal volume is directly above breathing rate reading.

Read I/E ratio directly below flow rate.
Babybird Ventilator US (late 1970s)
Bourns BP200 (late 1970s)
The First Mean Airway Pressure Device

Modification of a Ventilator Pressure Monitoring Circuit To Permit Display of Mean Airway Pressure

Robert L Chatburn RRT, Marvin Lough RRT, and Frank P Primiano Jr PhD
Bear Cubs (1990s)

Bear Cub

Bear Cub 750
Bird Corporation Ventilators (1990s)

Bird 840 ST

Bird V.I.P infant ventilator
Infrasonics Ventilators (1990s)

Adult Star

Infant Star
Sechrist ventilators (1990s)

IV-100B  SAVI
Healthdyne (1990s)

105 Infant Ventilator
Plexiglas Modification of Respiratory Therapy Equipment for Teaching Purposes

Baby Bird

MA-1

PR-2
The origin of IMV – first used in pediatrics

Continuous-Flow Ventilation as an Alternative to Assisted or Controlled Ventilation in Infants

ROBERT KIRBY, LT. COL., USAF (MC)*
ELMO ROBISON, MAJOR, USAF (MC)†
JIMMY SCHULZ, A.A.I.T.†
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☆ Robert R. Kirby, Lt. Colonel, USAF, MC graduated from the School of Medicine of the University of California in San Francisco and served as a Resident in Anesthesiology at Wilford Hall USAF Medical Center, San Antonio, Texas. He is currently Chief of the Anesthesiology Service at the USAF Medical Center, Keesler AFB, Mississippi.

Intermittent Mandatory Ventilation: A New Approach to Weaning Patients from Mechanical Ventilators

Intermittent Demand Ventilation (IDV): A New Technique for Supporting Ventilation in Critically Ill Patients

Barry A Shapiro MD, Ronald A Harrison MD, John R Walton BS CRTT ARRT, and Richard Davison MD

The origin of VC-SIMV using the Searle Ventilator
1976: Ads in Respiratory Care Journal
1976: Ads in Respiratory Care Journal

The CV 2000 provides optimum patient care with every significant ventilatory technique.

If the ventilator you're considering doesn't offer all these features, consider the one that does: the CV 2000.

- Synchronized IMV prevents asynchronous mandatory breaths.
- Demand Valve eliminates cumbersome reservoir system.
- Tr and Tc Independently Controllable, providing precise calibrated control over the components of ventilation.
- Uninterrupted Continuous Flow (CPAP) Mode with rapid switch-over to control modes when necessary.
- Custom-Calibrated Controls for wide and accurate ranges.
- All Pneumatic for extended life and reliability.
- A Price Well Below that of other ventilators with fewer capabilities.

Don't settle on any ventilator until you judge the CV 2000 for yourself. Simply write or call for a trial evaluation.

The IMV Machine
EMERSON IMV Ventilator

Designed specifically for IMV, to gain the maximum benefit from this new concept.

Air fully humidified flows continuously to a reservoir bag, and is available for unobstructed inspiration by the patient. PEEP may be added to keep the lungs expanded. At intervals the ventilator delivers a "mandatory" breath, which supplements the patient's own breathing and increases minute volume. The patient maintains his own homeostasis, without interference from drugs or hyperventilation.

At first the ventilator is generally set to supply mandatory breaths at a normal controlled rate. This is then gradually changed, by lengthening the interval between breaths as the patient's condition improves. Eventually mandatory breaths are spaced so far apart that the patient scarcely relies on them at all — and "weaning" is completed.

J. H. EMERSON COMPANY
22 COTTAGE PARK AVENUE, CAMBRIDGE, MASSACHUSETTS 02140
1976: Ads in Respiratory Care Journal

**Intermittent Demand Ventilation**

*IDV is a ventilation mode in which the mandatory (or forced) breath is given in response to patient demand.*

The Searle VMC® Ventilation Mode Controller also features:
- STANDARD
- CPAP
- Apnea Warning in all modes

Contact your Searle Cardio-Pulmonary Systems representative or write for complete details.

Searle Cardio-Pulmonary Systems Inc.
Subsidiary of G. D. Searle & Co.
Box 8308
Emeryville, California 94607
1976: Ads in Respiratory Care Journal

The Ventilator that won't be outmoded

Now you have some choices: the versatile Searle VIVA III Ventilation Mode Controller which provides Intermitent Demand Ventilation, CPAP (or "blow by"), selectable control back-up and safety alarms in all modes; the AUTOWEDGE™5i ventilator for breath by breath monitoring, the unique TIDAL™ Humidifier; the Power Pack for patient transport. The VWA/VV/C. It won't be outmoded. Call or write.

Searle Cardio-Pulmonary Systems Inc.
213 Diary of O. D. Searle & Co.
Box 6106
Eureka, Califormia 94610
(415) 523-2100
1976: Ads in Respiratory Care Journal

dependable
...anywhere

MONAGHAN
225/SIMV*
Volume Ventilator

Trouble-free fluidic principle operates on 50 psig from wall outlet, tank, or compressor...in room, ambulance, plane.

- higher flow, volume and pressure capabilities
- synchronized intermittent mandatory ventilation
- completely portable
- lighter, more compact
- fewer moving parts
- costs substantially less

Evaluate Monaghan 225/SIMV...
Call Donald Burgett collect.
(303) 770-2700

MONAGHAN
A DIVISION OF SANDOZ, INC.
4100 East Dry Creek Road,
Littleton, Colorado 80122
1976: Ads in Respiratory Care Journal
1976: Ads in Respiratory Care Journal

The FOREGGER 210 Volume Ventilator.

1. IMV: IMV lets you remove a patient from the ventilator through a gradual weaning process. With most ventilators, you must add extra equipment to attain this benefit. But with the new FOREGGER 210 Volume Ventilator, IMV is built-in, not added on. So you can administer IMV without taping or untangling wires.


3. Alarm System: The FOREGGER 210 Volume Ventilator has an alarm for all anticipated clinical contingencies. THESE ALARMS INCLUDE HIGH AIRWAY PRESSURE, HIGH SIGH PRESSURE, APNEA, INTERNAL FAILURE, POWER FAILURE, LOW GAS PRESSURE, AND HIGH AND LOW MINUTE VOLUMES. Alarms are both audible and visual so the operator can ascertain ventilator status from a distance and react quickly if a change occurs. In addition, press-to-test and audio-off controls are included.

4. Multiple Function: We provide the latest state of the art versatility. This includes Manual Start, IMV, I:E Ratio, Sigh, Multiple Sigh, Manual Sigh, Assist, Inspiratory Pause and PEEP.

5. Service: Because of all-electronic circuitry, most factory servicing can be done right in the hospital. And, emergency response can be provided within 48 hours on a regional level by specialized technicians. So you get fast, expert service.

6. In-Service Training: To help you become more familiar with our new Volume Ventilator, we've put together
1976: Ads in Respiratory Care Journal

**BIO-MED IC-2 VENTILATOR.** The IC-2 Adult Intensive Care/Transport Ventilator is said by the...

**BOURNS BP200 VENTILATOR.** An electronically controlled and pneumatically operated time-cycled device, the Bourns Model BP200 Infant Pressure Ventilator is a continuous flow generator that serves as a controller. It provides ZEEP, PEEP, CPAP, IMV, or inspiratory pause. Pressure limit may be controlled in any mode. Rate is adjustable from 1 to 60/min, I/E from 4/1 to 1/10, flow from zero to 20 l/min, CPAP/PEEP from zero to 20 cm H₂O, pressure limit from 10 to 80 cm H₂O. The ventilator has a heated humidifier, integral oxygen blender, manual breath capability, and audible alarms for gas supply pressure failure and power failure. It weighs 35 lbs, measures 9” high by 9” wide by 13” deep, and can be placed on a table or counter or mounted on a castered stand. 

**IMVbird.** The IMVbird is pneumatically powered, time cycled, and offers tidal volume determination by inspiratory time and flow-rate, pressure limiting, CPAP, PEEP, IMV, demand acceleration and flow acceleration, with a minimum of controls and absence of gadgetry. *bird Corporation.*
1976: Ads in Respiratory Care Journal

Over-engineered at Case Western Reserve University
1976: Ads in Respiratory Care Journal

Bennett AP-5 . . . A Standard of Excellence

The Bennett AP-5 is a portable electric IPPB therapy Unit expressly designed and manufactured to give you years of trouble-free service. The AP-5 features:

- Long life motor/compressor
- Flow Sensitive Bennett Valve
- Full line of optional accessories
- Full two year warranty

When you buy Puritan-Bennett products, you buy reliability, craftsmanship, service and concern for quality unequalled in the industry.

Puritan Bennett Corporation
General Offices
Oak At Thirteenth Streets
Kansas City, Missouri 64106
High Frequency Ventilators
First High Frequency Oscillator (1950s)

Jack Emerson

photo courtesy of Rich Branson
Rainbow Jet Makes the News

Niles Man’s Respirator Device Hailed by Medical Society

EMILY WEBSTER
Vindicator Trumbull County Staff

NILES — A city resident is receiving credit for developing a new respirator for use on premature and newborn babies.

Rob Chatburn’s “high-frequency jet ventilation” device has already been credited with saving the life of at least one baby. It has been the subject of articles in several professional journals and has generated an expanding lecture tour for the Niles McKinley High School graduate.

He is currently director of clinical research in the respiratory department at Rainbow Babies and Children’s Hospital in Cleveland.

Put in simple terms, the HFJV device warms and humidifies air and then delivers it to the patient with great success,” he says, and uses the case of an 8-month-old patient as illustration.

The child was hospitalized with bronchitis and placed on a respirator. The respirator was, however, not working well because of the cold air. Chatburn modified the device to deliver warm, humidified air, which helped the child recover.

Fluidic logic control circuit
Rainbow Jet Ventilator 1980s

United States Patent

Patent Number: 4,589,409
Date of Patent: May 20, 1986

Chafburn et al.

Diagram of Rainbow Jet Ventilator
First Commercial Jet Ventilator (1980s)
Second Commercial Jet Ventilator (1980s)

Bunnell LifePulse Infant Jet Ventilator
First Commercial Oscillator (1980s)
Dr. Bird - Sinusoidal Percussionator
The Leading Equipment Book of 1990s

Respiratory Care Equipment

Richard D. Branson
Dean R. Hess
Robert L. Chatburn
Branson Book Innovations

Volume Control

Pressure Control

\[ P_{vent} + P_{mus} = E \times V + R \times \dot{V} \]
First Generation Ventilators (early 1900s)
Growth in Ventilator Complexity
Growing Knowledge Gap

- Technology: 3 modes
- Education: 300 modes
Like Driving a Sports Car in 1\textsuperscript{st} Gear Only
Most Recent RC Equipment Book (2016)

35 ventilators
300 modes
No More Schematics!
1. Memorize Key Terminology (Standardized Vocabulary)

2. Know Ten Maxims of Ventilator Technology

3. Taxonomy to Classify Modes

4. Compare Modes

5. Use Modes
Ventilator Mode Taxonomy

• **Mode**: predetermined pattern of patient-ventilator interaction
  
  – Mode name: arbitrary name coined by vendor
  
  – Mode tag: classification of mode using a taxonomy
Targeting Schemes

Manual
- setpoint (PC-IMV)
- dual (Pmax, Flow Adapt)
  operator-selected, static setpoints

Semi-Automatic
- servo (proportional assist)
- bio-variabole
- adaptive (CMV+AutoFlow)
- optimal (ASV)
  ventilator-selected, dynamic setpoints
  static model

Advanced Total Automatic
- intelligent (SmartCare, IntelliVent)
  ventilator-selected, dynamic setpoints
  dynamic model
The Ultimate in Targeting Schemes
The Future is Now

Riemannian Geometry Applied to Detection of Respiratory States from EEG Signals: the Basis for a Brain-Ventilator Interface


*IEEE transactions on bio-medical engineering* (2016)

**Significance:** The proposed framework opens the door to brain-ventilator interfaces for monitoring patients’ breathing comfort and adapting ventilator parameters to patient respiratory needs.
Rewriting the Books

Image of various books on respiratory care.
The Challenge of Total Computer Control
The Ventilator of the Future (black box)
Ventilator AI Becomes Self-Aware

Termilator
The Newest Kid on the Block

Ventilation Oxygenation Cough-assist Suction Nebulization
Rainbow B&C Legacy

Marvin Lough
Father of pediatric and neonatal respiratory care

Robert L. Chatburn
Your Humble Narrator

Tom Kallstrom
CEO of AARC

Tim Myers
CBO of AARC

Terry Volsko
Director Respiratory Care, Transport Com Cntr Akron Children’s Hospital