The Evolution of Mechanical Ventilation

- Historical Review of Mechanical Ventilation: A Journey in Innovation

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Lehigh Valley Health Network

And the many great RRTs I have been privileged to work with

Conflict of Interest

I have no real or perceived conflict of interest that relates to this presentation. Any use of brand names is not in any way meant to be an endorsement of a specific product, but to merely illustrate a point of emphasis and educational learning.

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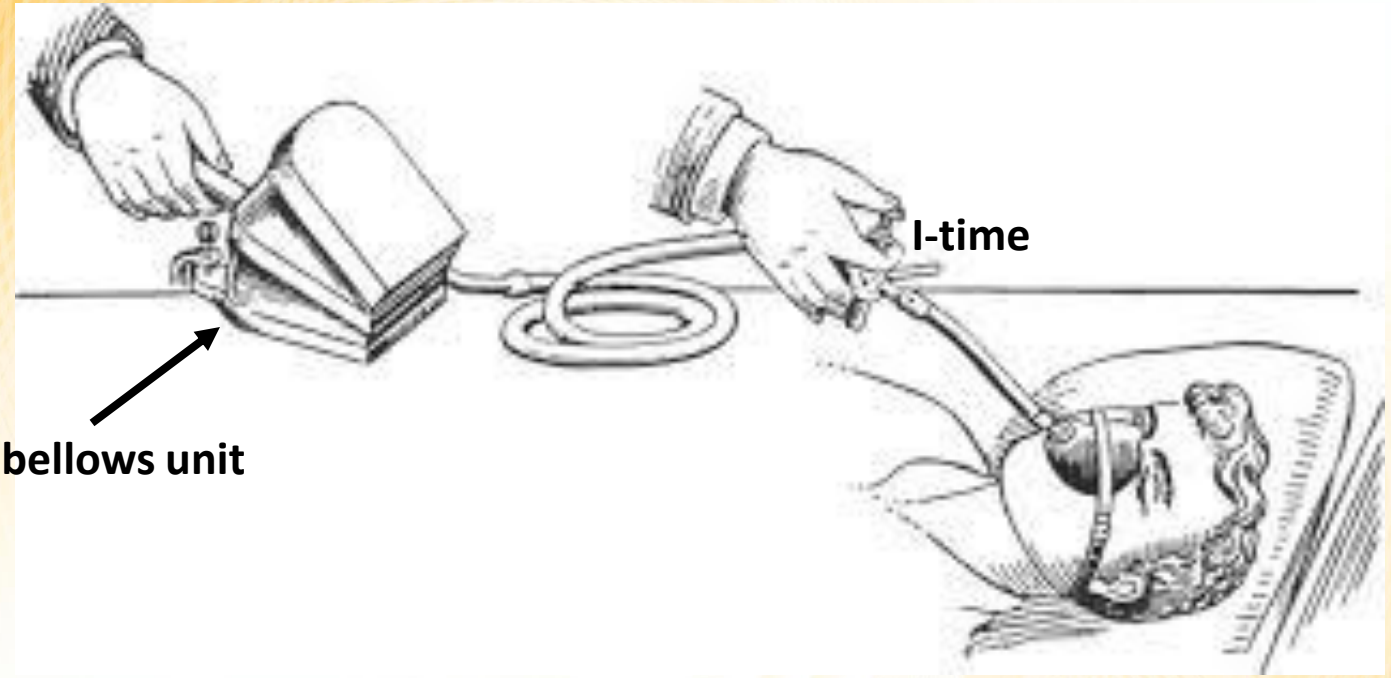
Learning Objectives

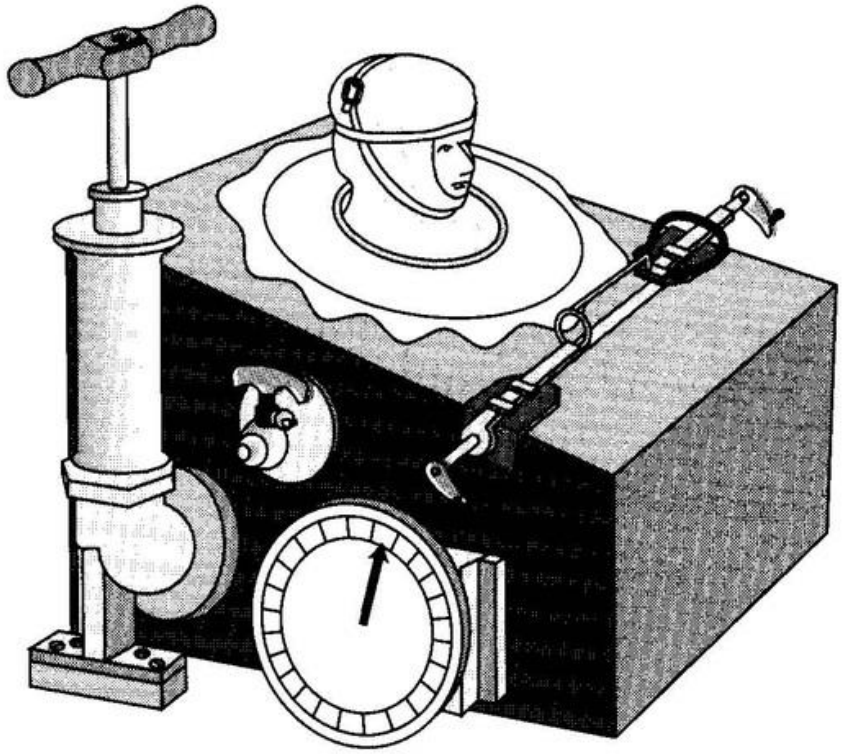
1. Describe the historical development of negative and positive pressure ventilators
2. Review the progressive generations of modern-day positive pressure ventilators
3. Describe the technological capacity of today's ICU ventilators
4. Predict the future direction of mechanical ventilation

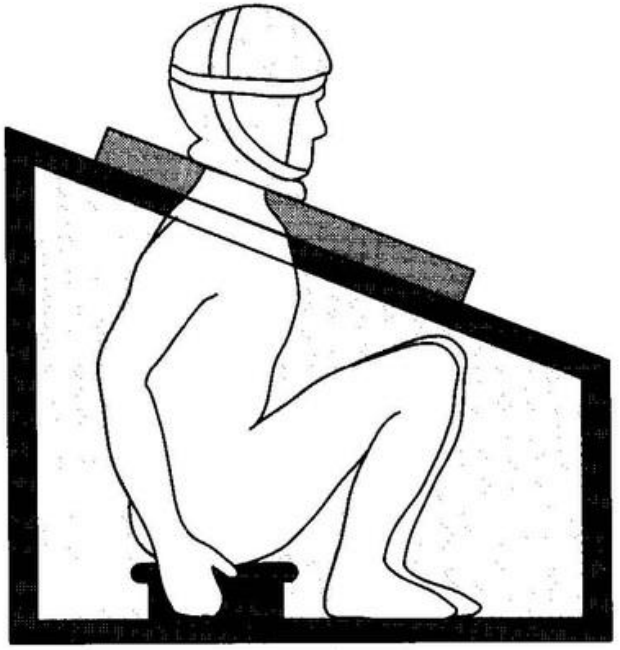
Early Attempts At Mechanical Ventilation

First know manual resuscitator: 1740



First Negative Pressure Ventilators Mid/Late 1800s
Negative pressure was manually pumped in and out of the box





Pressure gauge

Robert M Kacmarek
Respiratory Care August 2011, 56 (8) 1170-1180; DOI: https://doi.org/10.4187/respcare.01420

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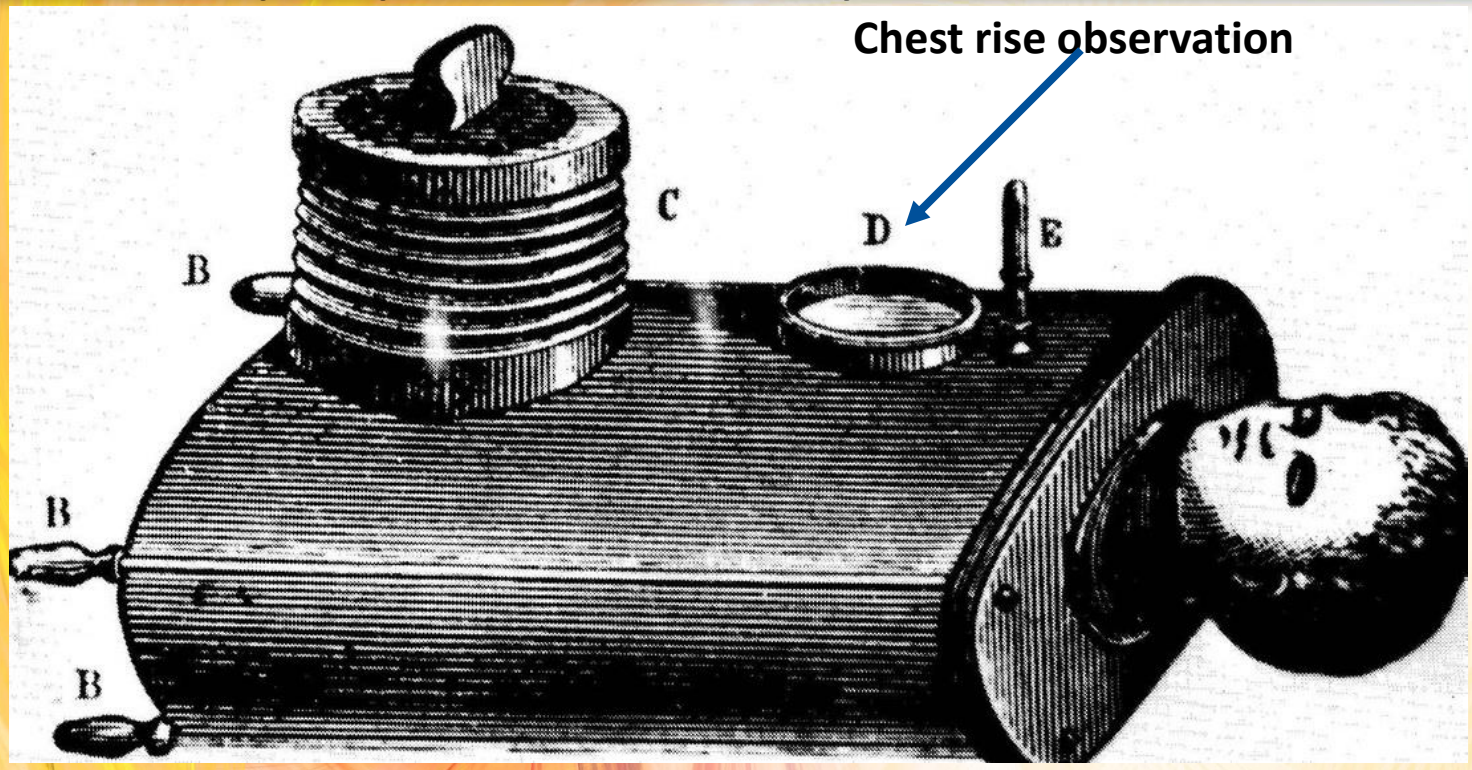
Woillez's Spirophone(Germany) 1876



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Grumman First successful ventilation of anesthetized rabbit 1910

AARC Gallery

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Drager's Pulmotor, 1911

First resuscitation ventilator: Used for near drowning, CO poisoning, high altitude sickness

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Hamilton T-1 Transport Ventilator

Drinker and Shaw Iron Lung:1929

Permission Felix Kudshid RRT

Last of the Iron Lung:☹

Major inventions late 1920s

Advertisement for an early General Electric refrigerator

Mechanical Ventilation 1920-1950

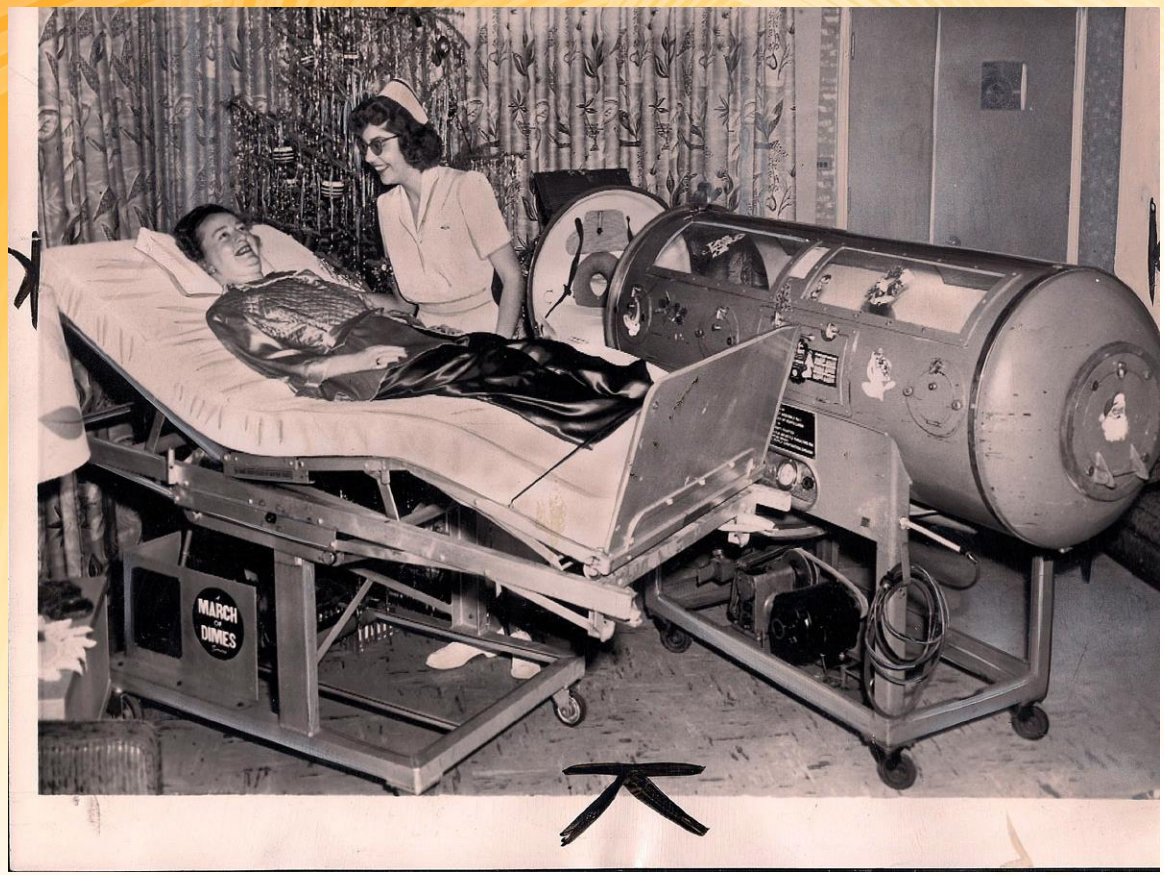
- Confined to the OR suite
- Anesthesia
  - Rubber self-inflating bags
  - Flow inflating bags

1953 Polio Epidemic: Changed the Trajectory of Mechanical Ventilation

Multi-person Negative Pressure Ventilator
Boston Children's Hospital

Robert M Kaczmarek
Respiratory Care August 2011, 56 (8) 1170-1180; DOI: https://doi.org/10.4187/respcare.01420

Rocking Bed Ventilation

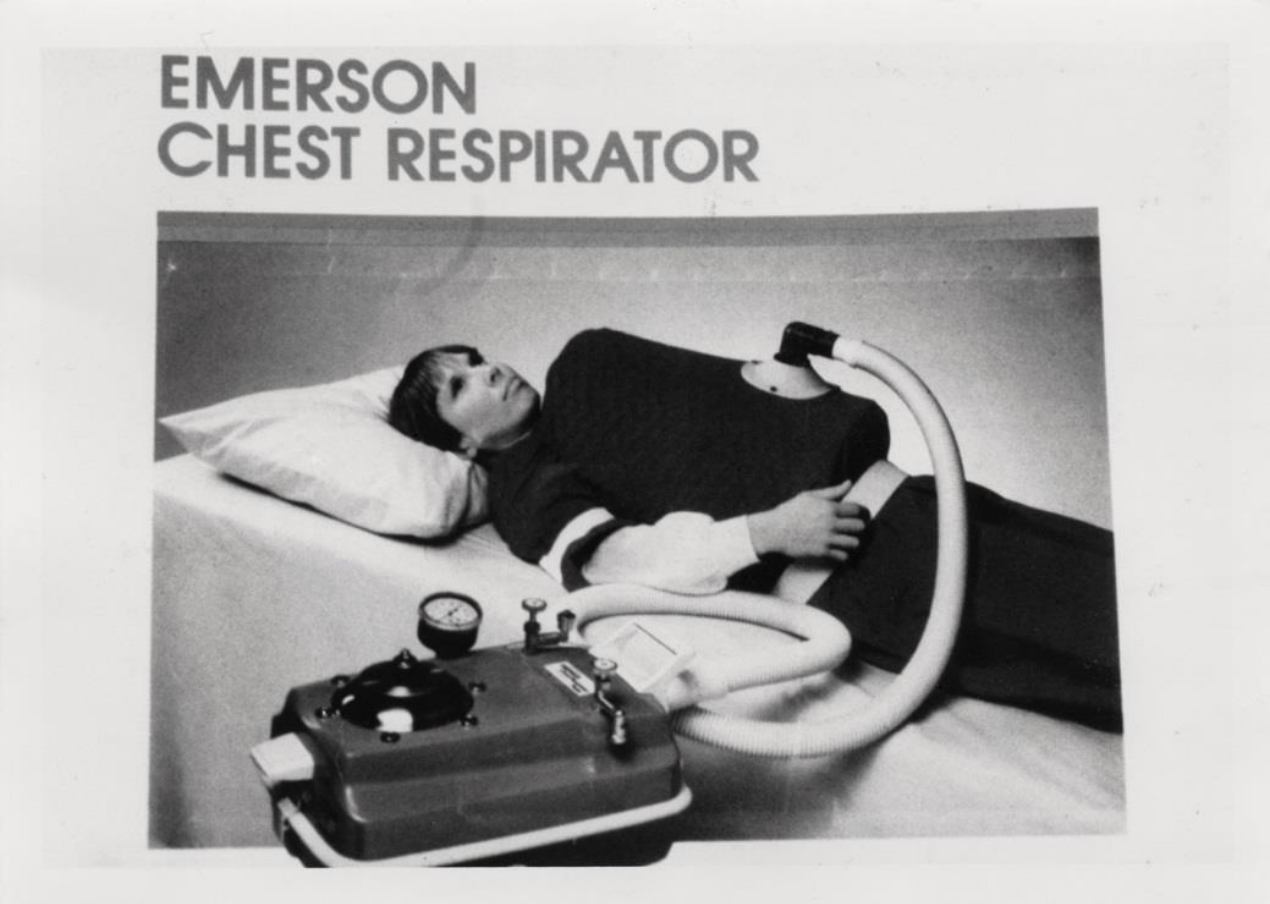


1957
Christmas Card

Rocking bed:
Speed of bed movement =rate
Angle of bed movement =tidal volume

Permission: Felix KHUSID RRT

Pneumomotor Chest Cuirass with Rocking Bed



Doubled as a canister vacuum cleaner

Permission Dr. Jack Emerson

Clinical Endpoint/Ventilatory Parameters via Negative Pressure Ventilators

- Clinical endpoint
  - Survival!!
- Ventilator parameters
  - Supplemental oxygen via cannula/tubing
  - Negative pressure adjusted via chest rise
  - No ABGs/tidal volume measurement/artificial airway avaiable

Demise of Negative Pressure Ventilation

- Problems with negative pressure exceeded benefits: Outcome poor compared to positive pressure ventilators utilized in Sweden and other parts of Europe: 73% to 17% survival!!
- Large, cumbersome
- Difficult to avoid leakage
- Cooling of body surface
- Difficult to maintain consistent ventilation
- Generally unable to consistently generate high pressure and maintain PEEP
- Limited assess to patients
- Pooling of blood in the thoracic/abdominal cavities

Kenny in 1st grade:☺

Mechanical Ventilators

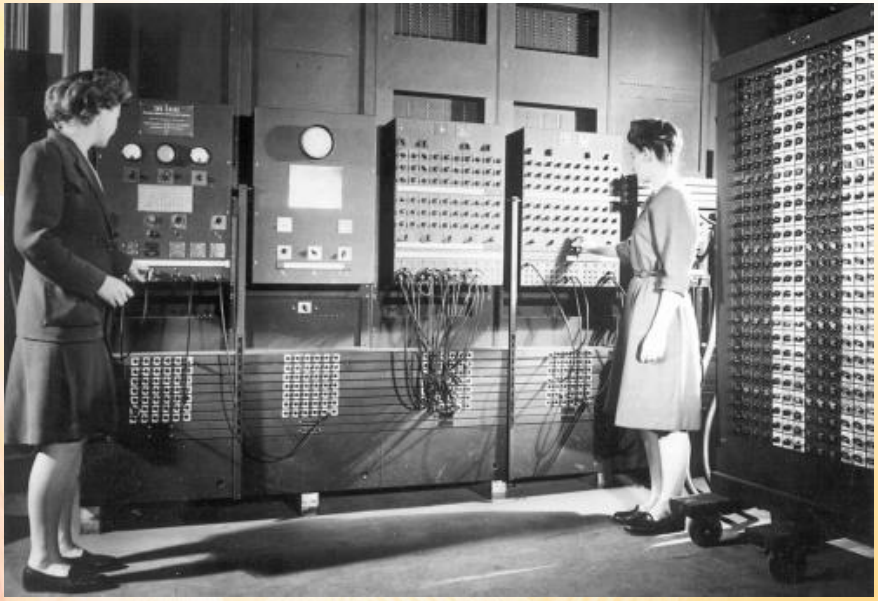
- 1st Generation – Early 1960's thru mid 1970's
- 2nd Generation – Mid 1970's thru early 1980's
- 3rd Generation – Early 1980's thru mid 1990's
- 4th Generation – Mid 1990's thru 2010
- 5th Generation-current

First Generation

- Controlled Mechanical Ventilation **ONLY**
- Limited monitoring
- No alarms
- All simple mechanical devices (pistons, rods, sednoids)
- First application of PEEP
- Machine variables(rate) had to be counted – could not be set
- I/E ratio fixed @ 1:2

Engstrom Ventilator-Weight 500 lbs!!!

Wheeled in via a cart



First computers

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The Bird Mark 7 being used as a pressure ventilator
Set I-time for rate and flow for pressure.

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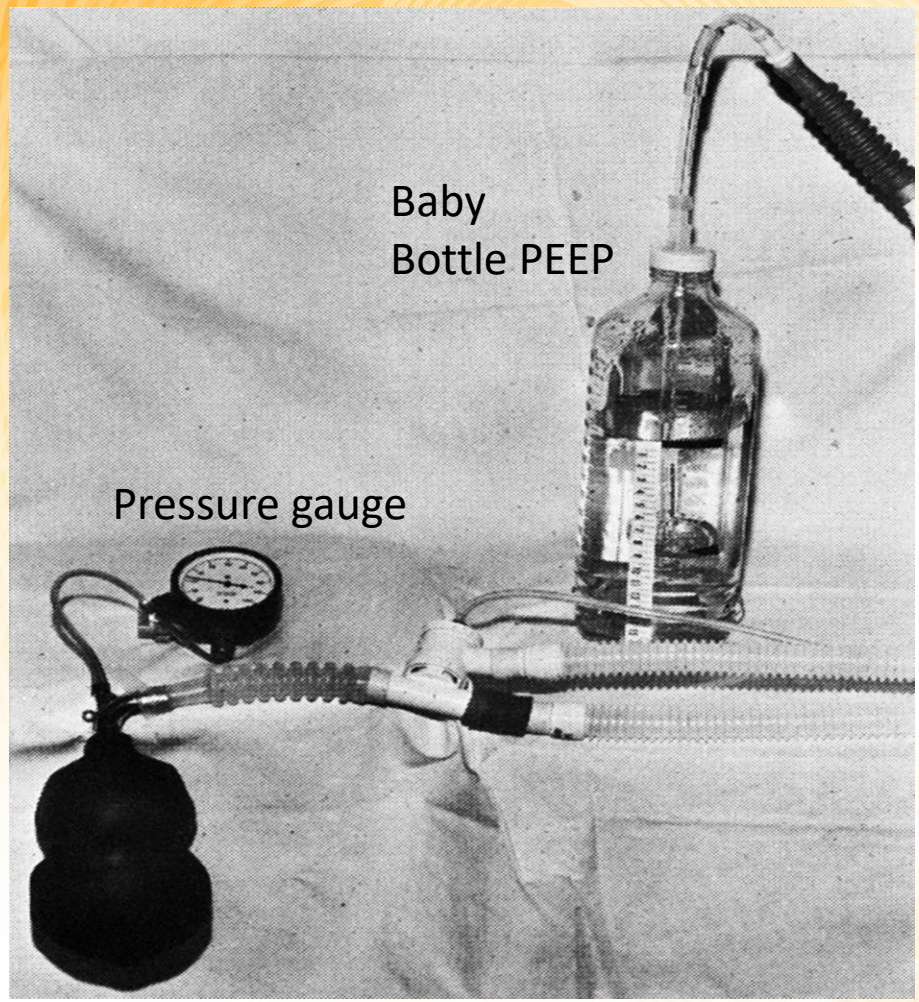
Vietnam Conflict



Application of PEEP -
Ashbaugh, Petty 1967
During Vietnam Conflict
Improved survival rate of injured combinations

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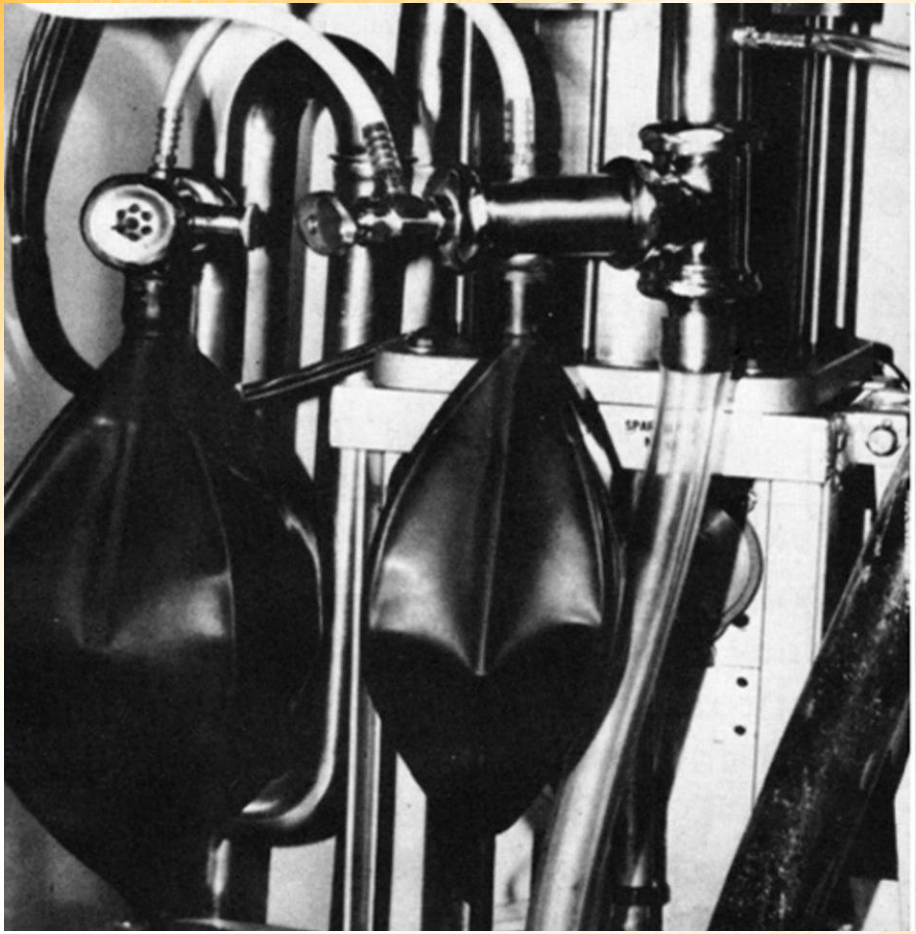
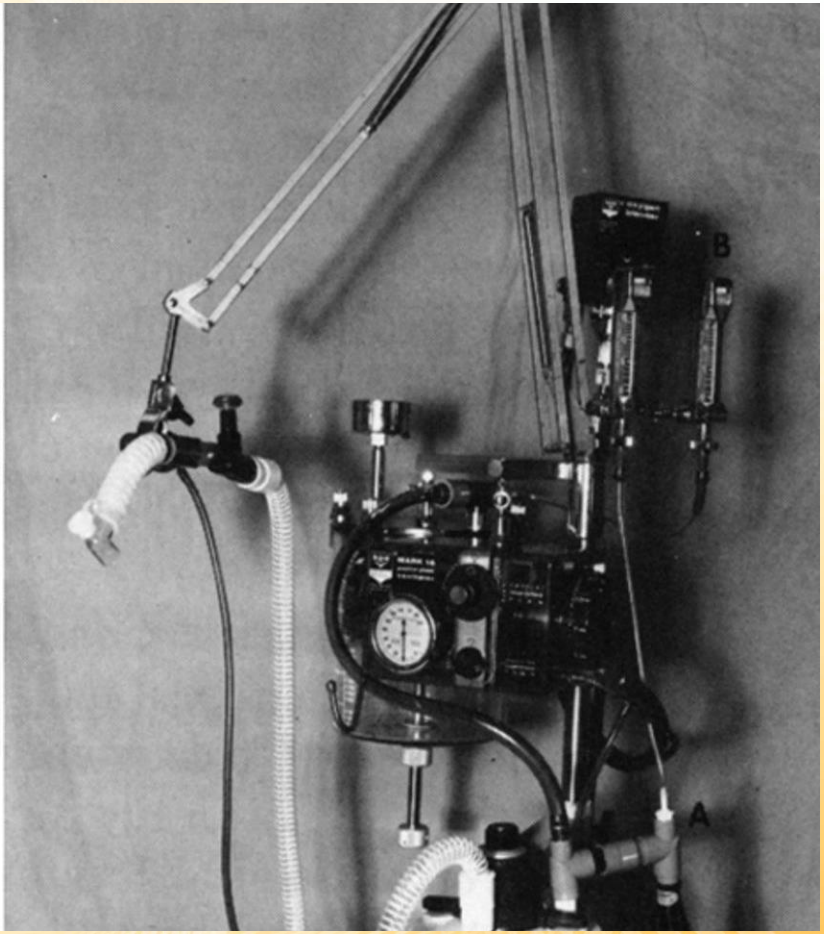
Common Vietnam Conflict Ventilators

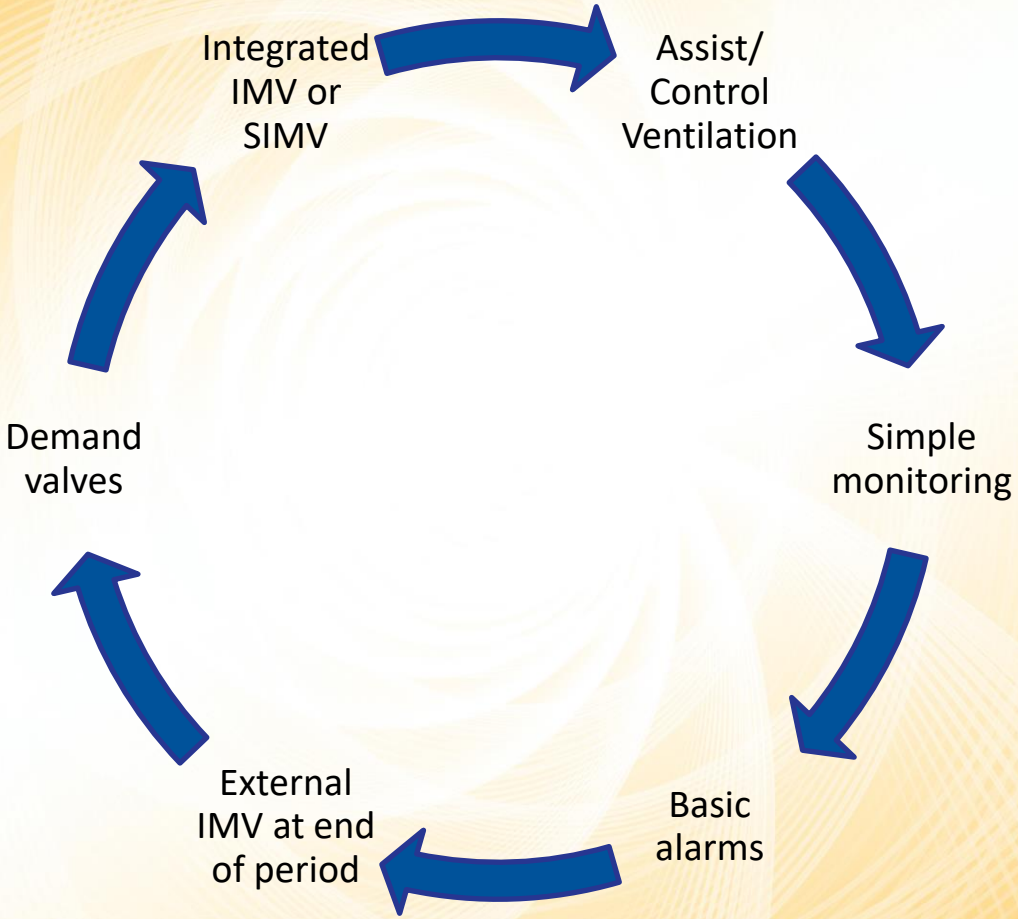


Volume target

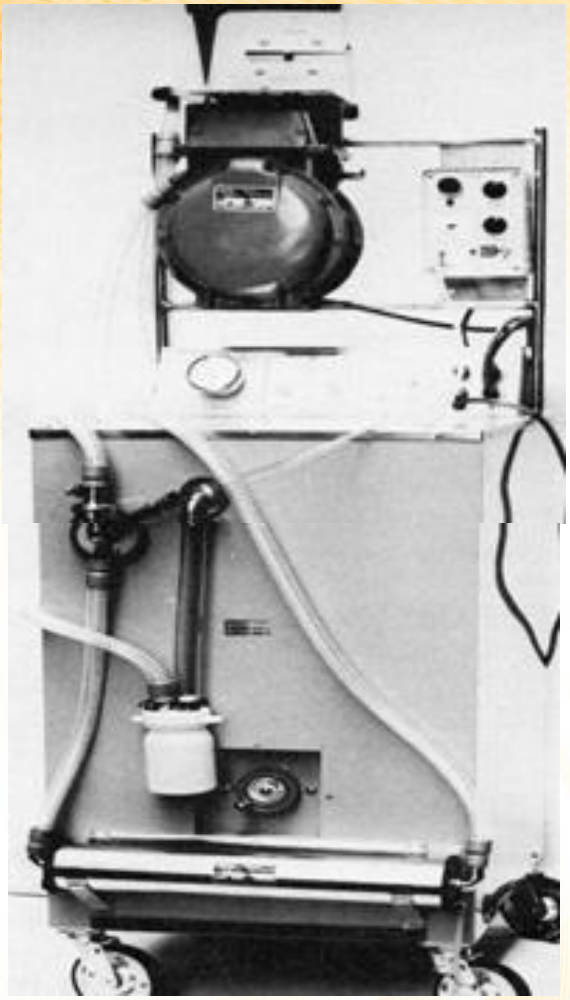


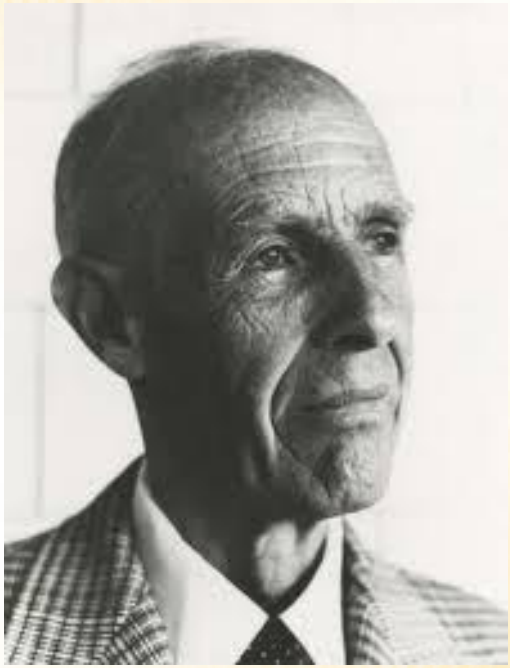
Pressure target

Second Generation 1970-1980



Emerson
Post-op
Ventilator





Dr. Jack Emerson

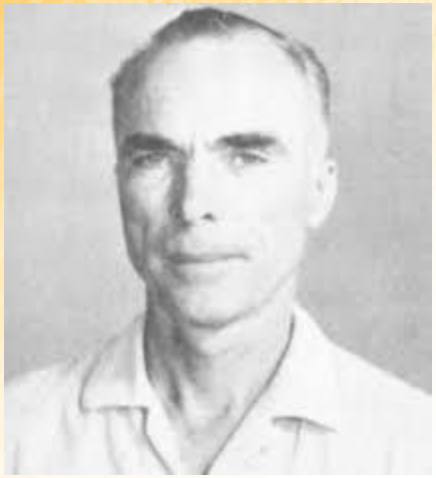
Rate controller

Spirometer

Baby Bird-developed by Dr. Bird was responsible for saving >10,000 babies its first year

Personal Library

Puritan Bennett MA-1



Personal Library

Clinical Endpoints/Ventilatory Parameters

- Normal ABGs
- No concern of airway pressure or VILI
- Minimal use of PEEP 5-8cm (external)
- No waveforms
- Only A/C mode
- Minimal patient triggered breaths
- Minimal alarms
  - High pressure alarm
  - Disconnect alarm

Typical Ventilator Settings

- CMV 10-15cc/kg/IBW x 10-20 3-5cm PEEP
  - 500-1000cc x 15-30 100% 5cm

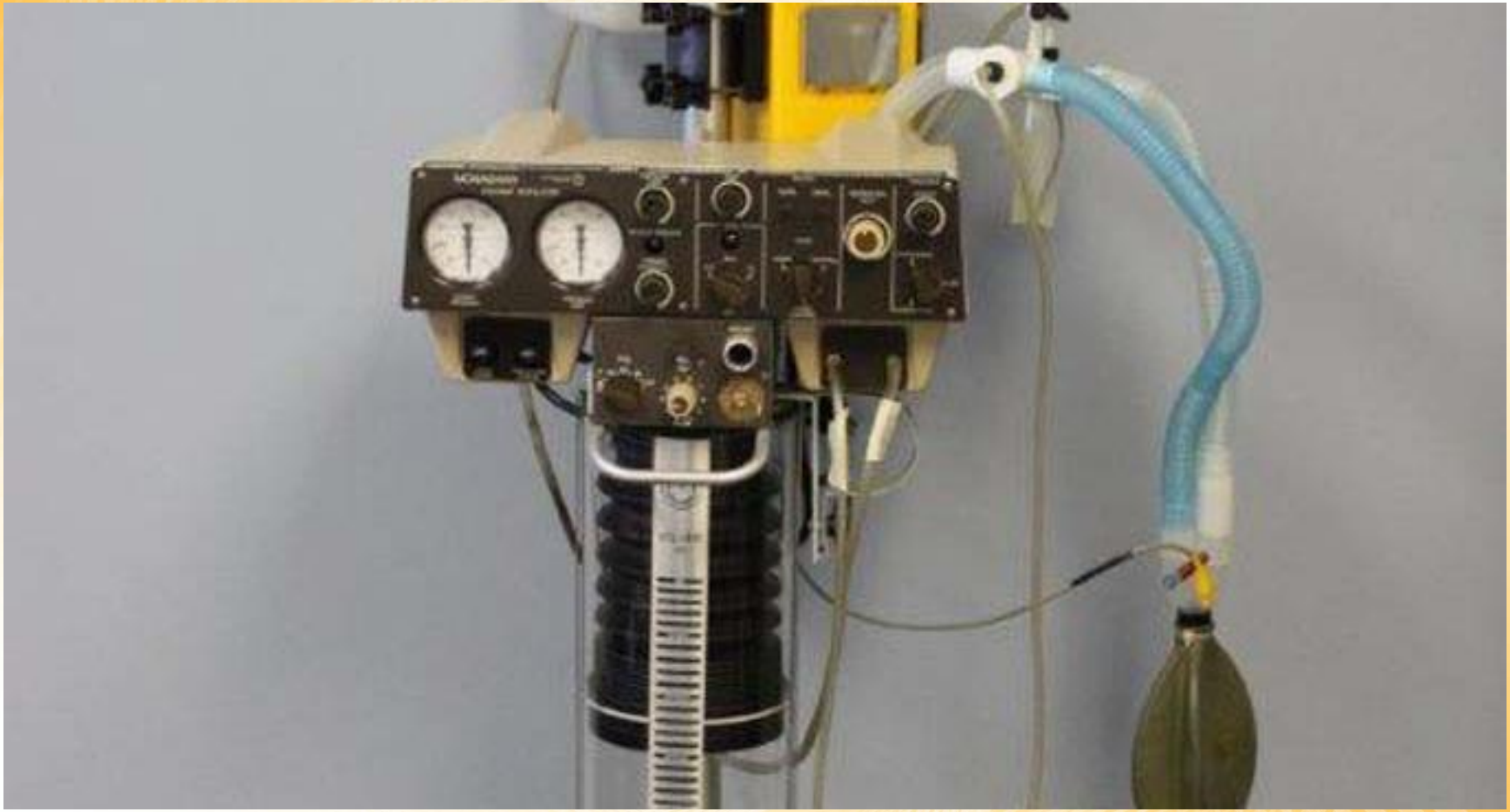
Third Generations Ventilators

- More complex
  - Diverse way to delivery gas
- Addition alarms
- Ability to perform pressure and target ventilation with a single device
- Development of IMV
- Implementation of ICU rounds
- Beginning to understand ventilator induced injury

Gill Ventilator utilized magnetic weights

Personal Library

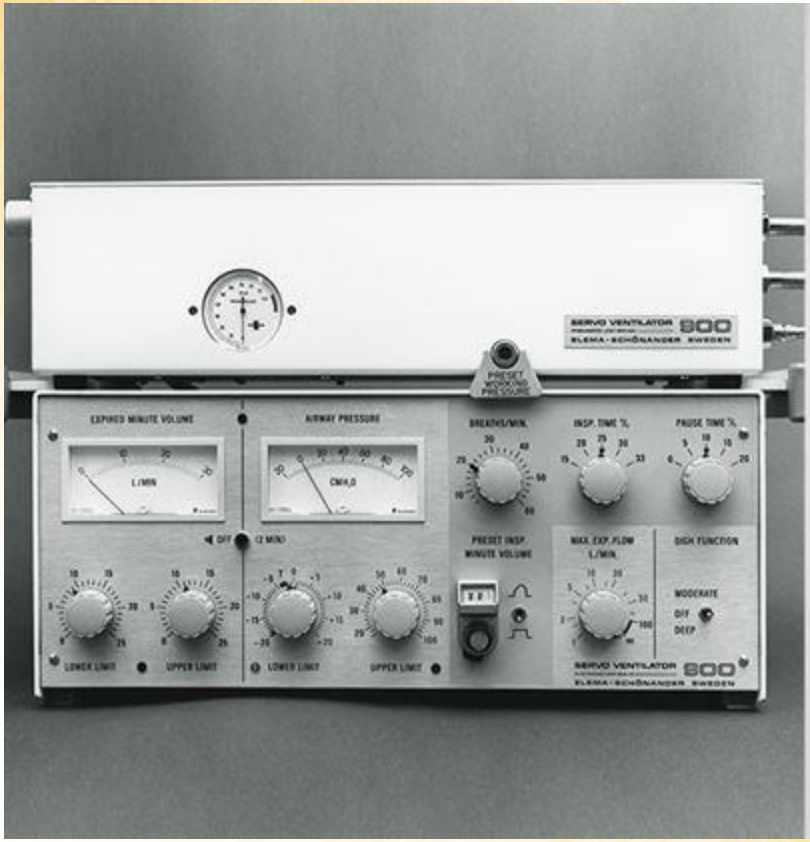
Mohaghan225 Ventilator:

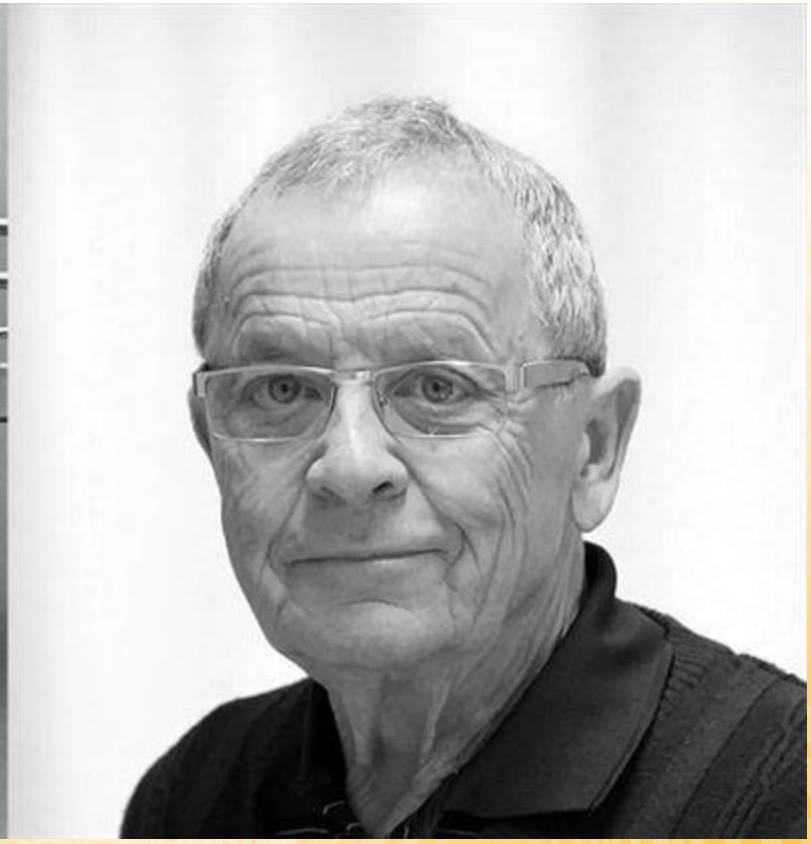


Servo 900 B-first volume ventilator that could provide PCV and measure exhaled tidal volume

- Personal Library

Professor Björn Jonson





IMV

Revisor bag for patient
To obtain gas

Origin of ICU rounds

Clinical Endpoints/Ventilatory Parameters

- Normalization of ABGs (COPD)
- Understanding of patient's work of breathing on mechanical ventilation
  - Development of IMV and SIMV
- Utilization of super PEEP(20-30cm)
- Manuel maneuvers to determine lung compliance and auto-PEEP

Ventilator Settings

- CMV
  - 800 x 20 8-12 PEEP (rare cases 30-35 PEEP)
- IMV 500 x 10

Developments in 1980s

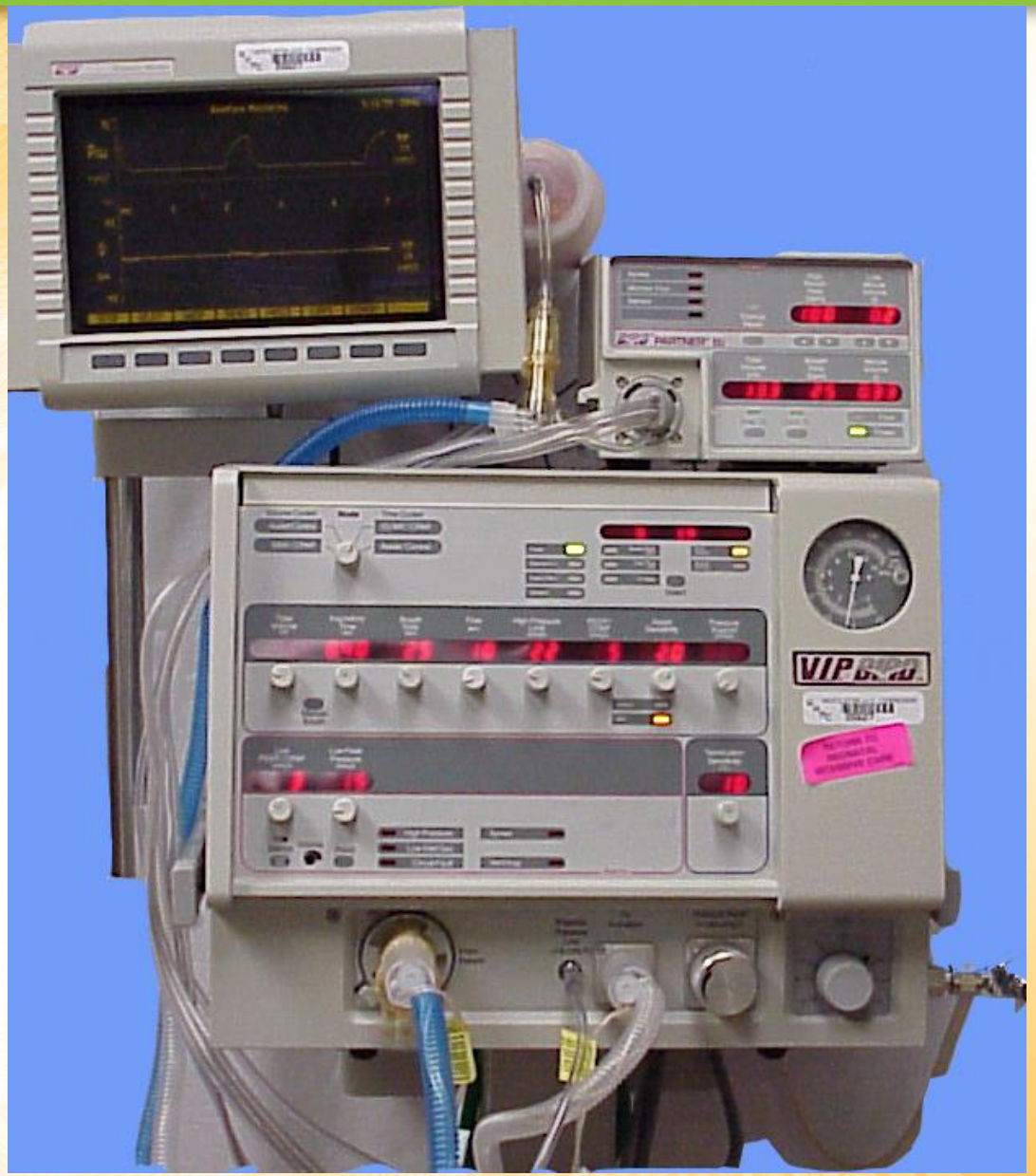
Fourth Generation 1980-2000

- **Microprocessor Controlled**
- Increased responsiveness
- Addition of SIMV/PSV
- Triggering effort improved
- Widespread Introduction of pressure ventilation on ICU ventilators
- Extensive alarms
- Expanded monitoring and waveforms

Puritan Bennett 7200 AE

Evita E-4

Bird ST 8400



Development of Non-Conventional Ventilators

HFJV

HFPV

HFO

Personal Library

Non-Convention Ventilators

- Often utilized as rescue therapy
- Few outcome-based studies
- Confusion when on how to set and adjust, when to implement
- Minimal textbook education devoted to these devices
- Few “experts” in RRT departments or driver physicians

Clinical Endpoints/Ventilator Parameters

- Understanding of VILI
  - ARDSnet
  - Best PEEP
  - Plateau pressure
- Maximizing ventilator-patient synchrony
- Utilization of Pressure target ventilation
- Novel modes
  - ASV
  - APRV

Developments in 1990s

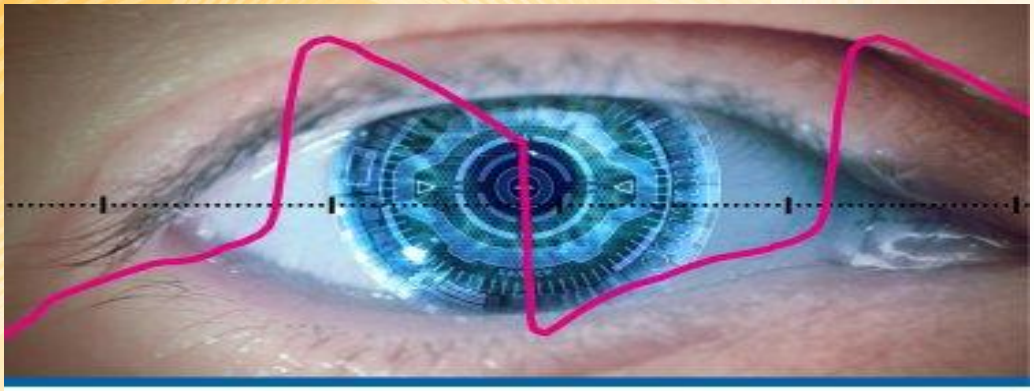
Current Generation

- Cradle-Grave ventilators
- Introduction of non-invasive ventilation modes
- Introduction of new modes
- Waveforms enhanced
- Extensive monitoring data provided
- Software upgrade ability
- Management/Assessment packages
  - P-V curves
  - Open lung Tool
  - Weaning tools
  - Closed Loop Ventilation

AVEA-Cradle to Grave Ventilator Concept

Hamilton G-5

Intelligent ventilation: proactive ventilation



IntelliSync+

Keeping an eye on patient-ventilator synchrony

Significant patient-ventilator asynchronies occur in more than 25% of all mechanically ventilated patients[1], and are associated with increased work of breathing[2], prolonged ventilation time[3], and higher mortality[4].

The well-trained eye of a ventilation expert is capable of detecting asynchronies by analyzing the waveform shapes of either the flow or the pressure waveforms. However, the expert cannot always be at the bedside, and the patient condition can change from breath to breath.

That is where IntelliSync+ takes over. This new technology mimics the expert's eye to identify signs of patient effort (trigger) or relaxation (cycling), thus replacing conventional trigger settings for inspiration and expiration.

Intellisync +

- Changes ETS%
- Changes triggering sensitivity

Fig.5: Flow curve with conventional trigger settings

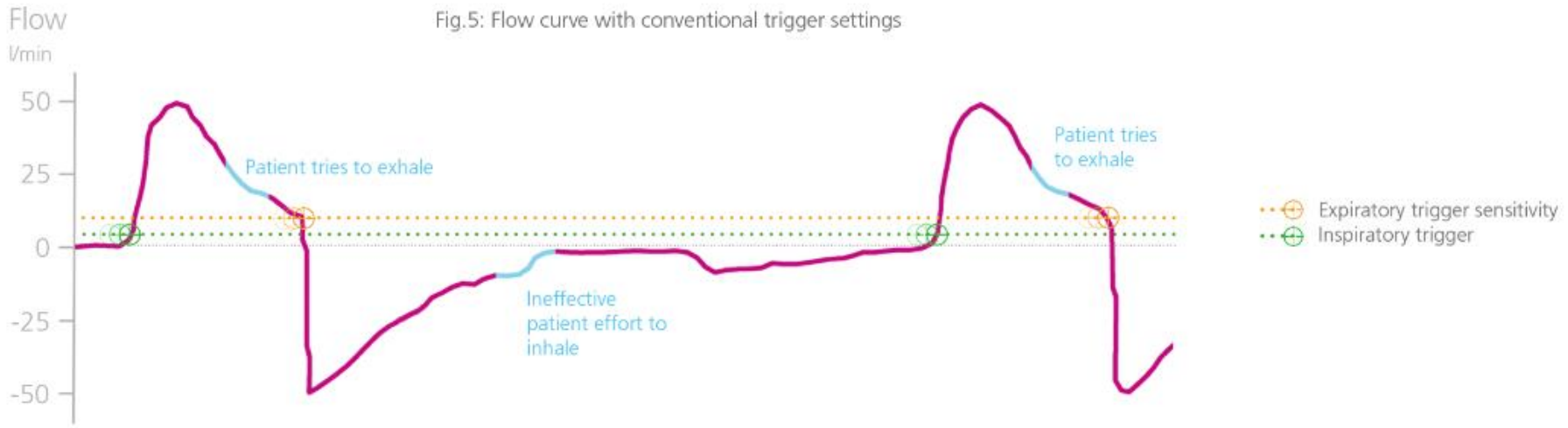
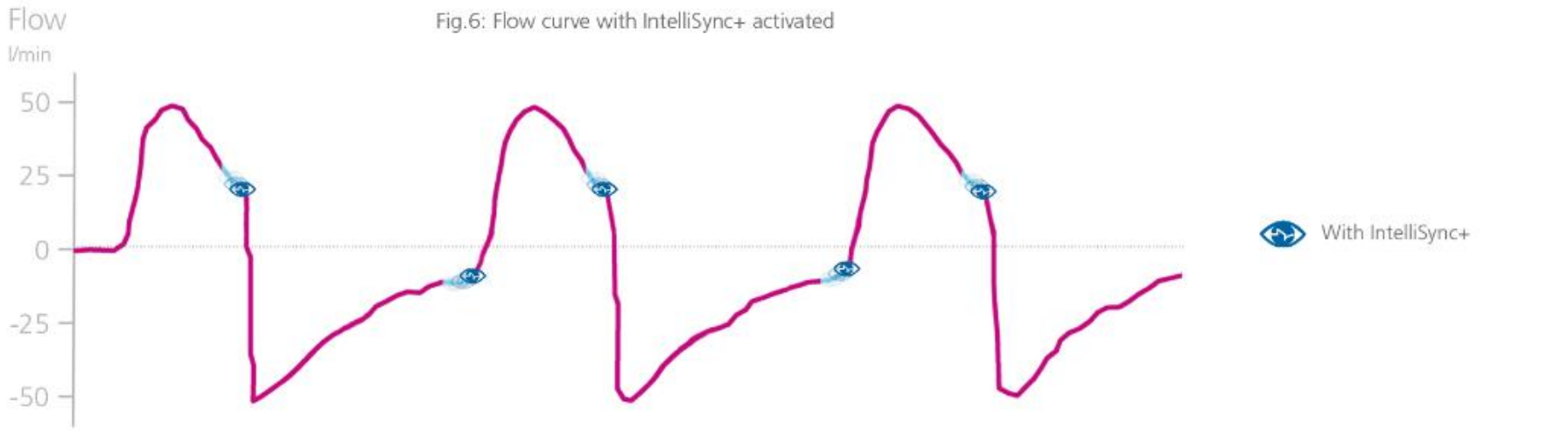
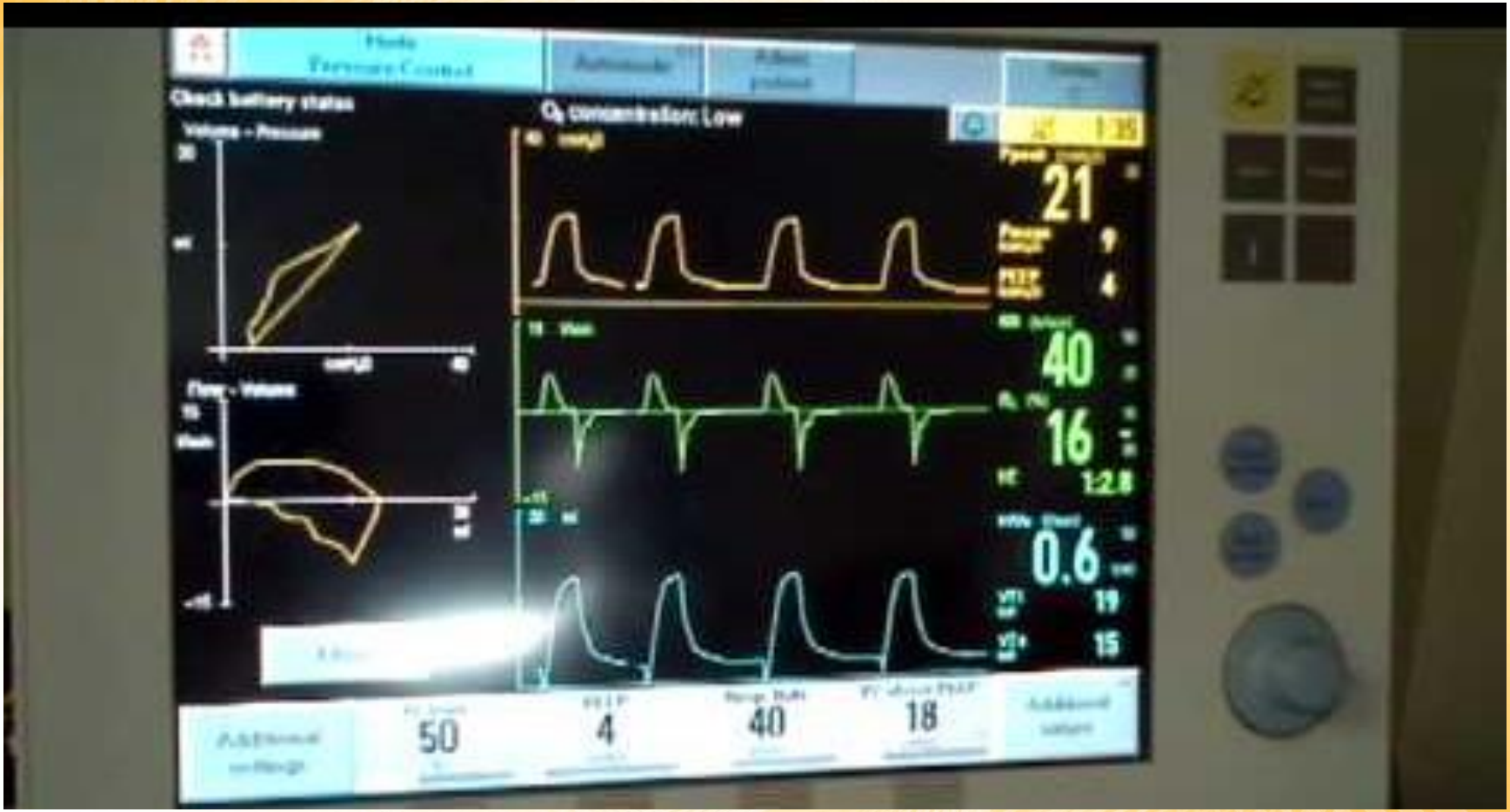


Fig.6: Flow curve with IntelliSync+ activated




1:50
Low tidal volume
2023-04-03
10:24:34
INTELLiVENT
SPONT
Adult
Backup
Patient
Additions
Modes
Trend
IntelliCuff
40
29 Ppeak cmH2O
13 Pmean cmH2O
750
250
228 VTE ml
10.0
4.0
4.5 ExpMinVol l/min
23
21 fTotal
Paw cmH2O
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 s
Flow l/min
100
50
0
-50
-100
16 cmH2O
Psupport
10 cmH2O
PEEP/CPAP
35 %
Oxygen
1
2
SpO2raw
Paw/Paux
92 RSB 1/(l*min)
0.00 WOBimp j/l
--- Ptrans I cmH2O
--- Ptrans E cmH2O
8.1 Pminimum cmH2O
85 VDaw ml
36.6 slopeCO2 %CO2/l
143 Vtalv ml
2.6 V'alv l/min
37 VDaw/VTE %
47 PetCO2 mmHg
6.6 FetCO2 %
5 VeCO2 ml
1 ViCO2 ml
83 V'CO2 ml/min
Controls
Alarms
Monitoring
Graphics
Tools
Events
System
INT
AC

Servo I



Hayek Negative Pressure Ventilator

Typical Ventilator Settings

- 4-8cc/kg/IBW
- Maintain driving pressure<15cm
- Optimize PEEP
- Maintain SpO2>88%-92%
- Attempt spontaneous breathing ASAP

Future of Mechanical Ventilation?

Questions $$$$$

- Does it make safer?
- Does it decrease the incidence of VILI?
- Does it more effectively ventilate or oxygenate the patient?
- Does it wean the patient faster?
- Does it improve patient-ventilator synchrony?

Continuing Challenges Relative to Ventilator Management

- Address and minimize heterogeneity of mechanics
- Facilitate ventilatory demands
- Optimize sedation and comfort
- Minimize ventilatory duration
- Automated ventilator adjustments for changing patient requirements and mechanics
- Prevent infection and ARDS

Emerging Economic Realities Related to Critical Care

- Less staff per patient
  - Assessment
  - Interventions
- Faster patient discharge/liberation
- Increased needs:
  - Safety
  - Timely interventions
  - Quicker assessment of interventions
  - Decision support

Shifting Paradigm

- Give ventilation control to patient?
- Revise clinical targets
- Adapt to abnormal physiology
- Gas exchange without ventilators
- Multisystem integrated monitoring

Future Innovations in Mechanical Ventilation

- Goal-directed self adaptation
- Reduction of ventilatory demand
- Remote reporting and ventilatory parameter adjustments
- Patient-guided control
- Improved secretion removal
- Bedside lung imaging

Question to Ask Regarding The Development of New Ventilators

- Does it make ventilation safer?
- Does it reduce the chance of VILI?
- Can it effectively ventilate or oxygenate the patient adequately?
- Does it help wean patients faster?
- Does it improve patient-ventilator synchrony?

Can The Ventilator Determine the Significance of a High-Pressure Alarm?

- Secretions
- Reduction in pulmonary mechanics
- Tension pneumothorax
- Ventilator asynchrony
- Biting on the tube

Features of Future Ventilators

- Integration with other bedside technology
- Ability to ventilate all patients in all settings
- Ventilator protocols incorporated in ventilator
- Tidal volume set based on input IBW
- Smart alarms systems
- Close-loop ventilation
- Decision support

Why Closed Loop Ventilation?

- Less likelihood of ventilator associated lung injury
- Less hemodynamic compromise
- More effectively ventilate/oxygenate!
- More rapid weaning!
- Improve patient - ventilator synchrony!

Decision Support - Smart Alarms

- The ventilator should be able to distinguish between a high-pressure alarm as a result of :
  - Acute partial airway obstruction
  - Gradual change in resistance or compliance over time
  - A pneumothorax
- The ventilator should be able to provide the clinician with a list of potential causes of the problems and potential solutions

Decision Support – Data Presentation

- Future ventilators will provide information as

opposed to lines and lines of generally useless unrelated data!

-Peak and plateau pressure change over time (Volume)

-Tidal volume, rate and MV change over time (Pressure)

-Relationship between tidal volume and plateau pressure

over time

- Relationship between FIO2, PEEP and plateau pressure

over time.

- The number of missed triggers, double triggers, prolonged inspirations, short inspirations, dis-synchrony index

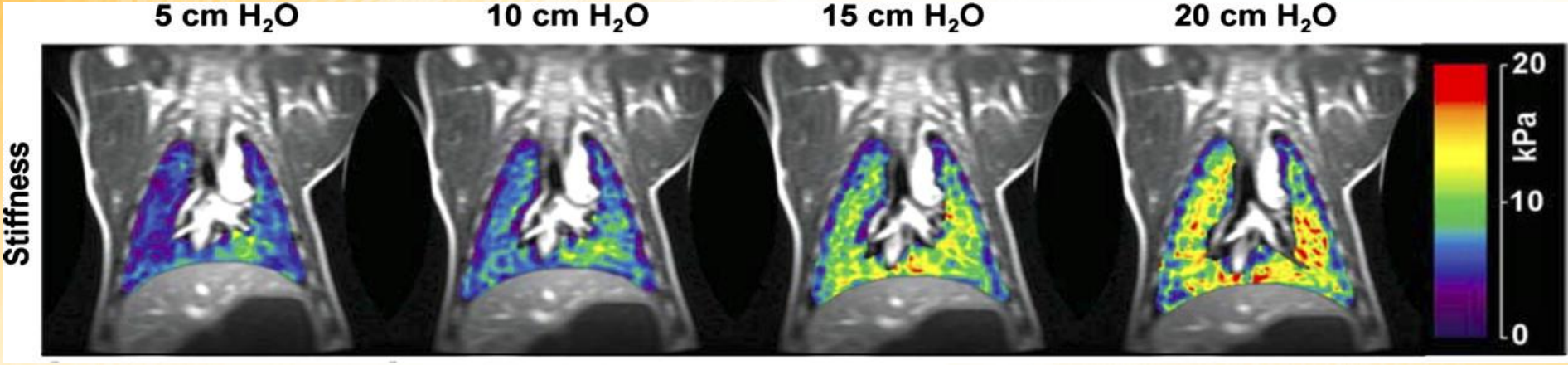
Patient – Ventilator Synchrony

- Future ventilators will be able to interpret waveforms and adjust gas delivery based on recognition of asynchrony
- Clinicians will find that asynchrony has a marked affect on patient outcome!!

GE Care Station: Includes all patient vital sign assessments in one machine

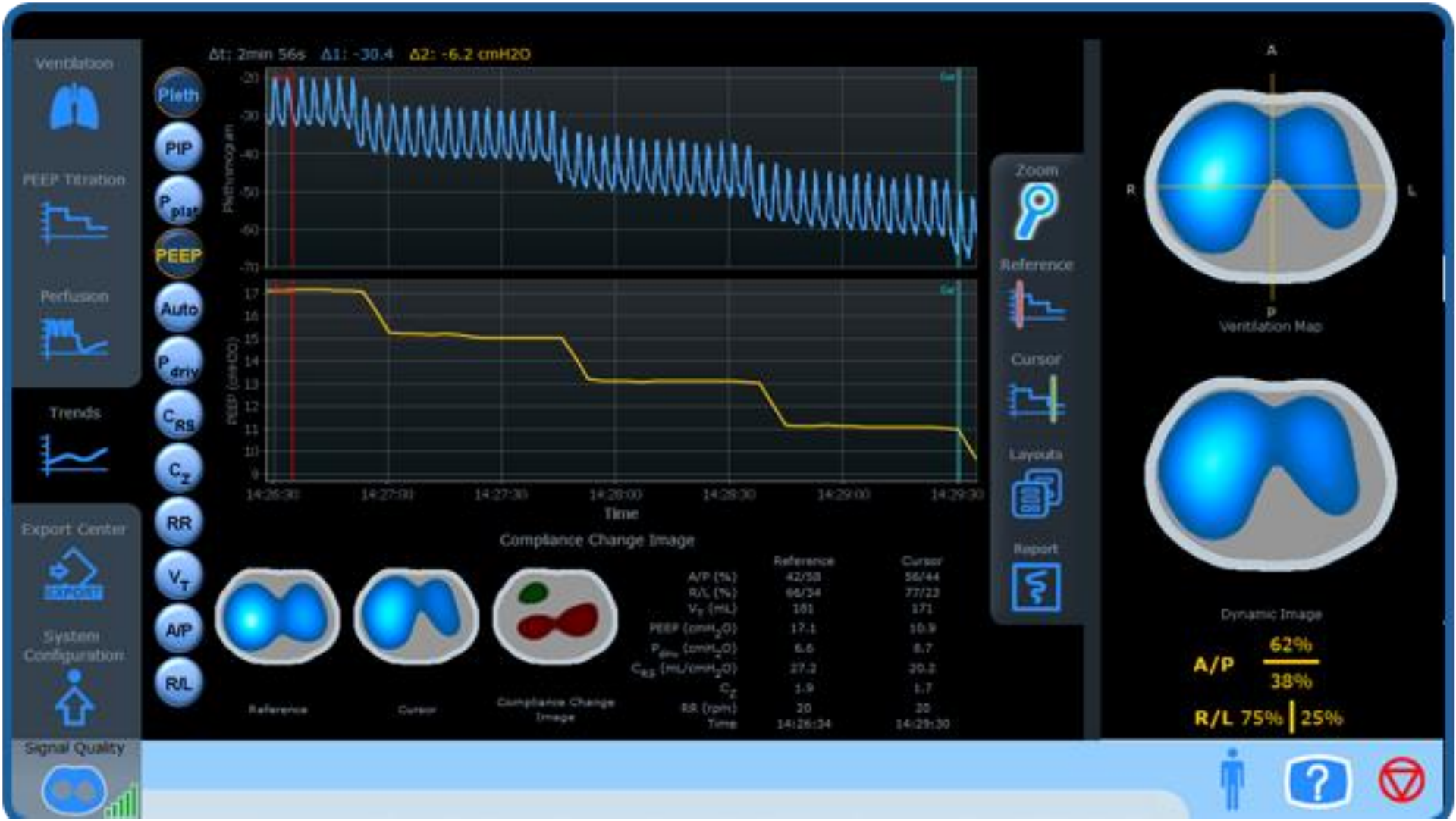
Servo Q Ventilator

Electrical Impedance Tomography

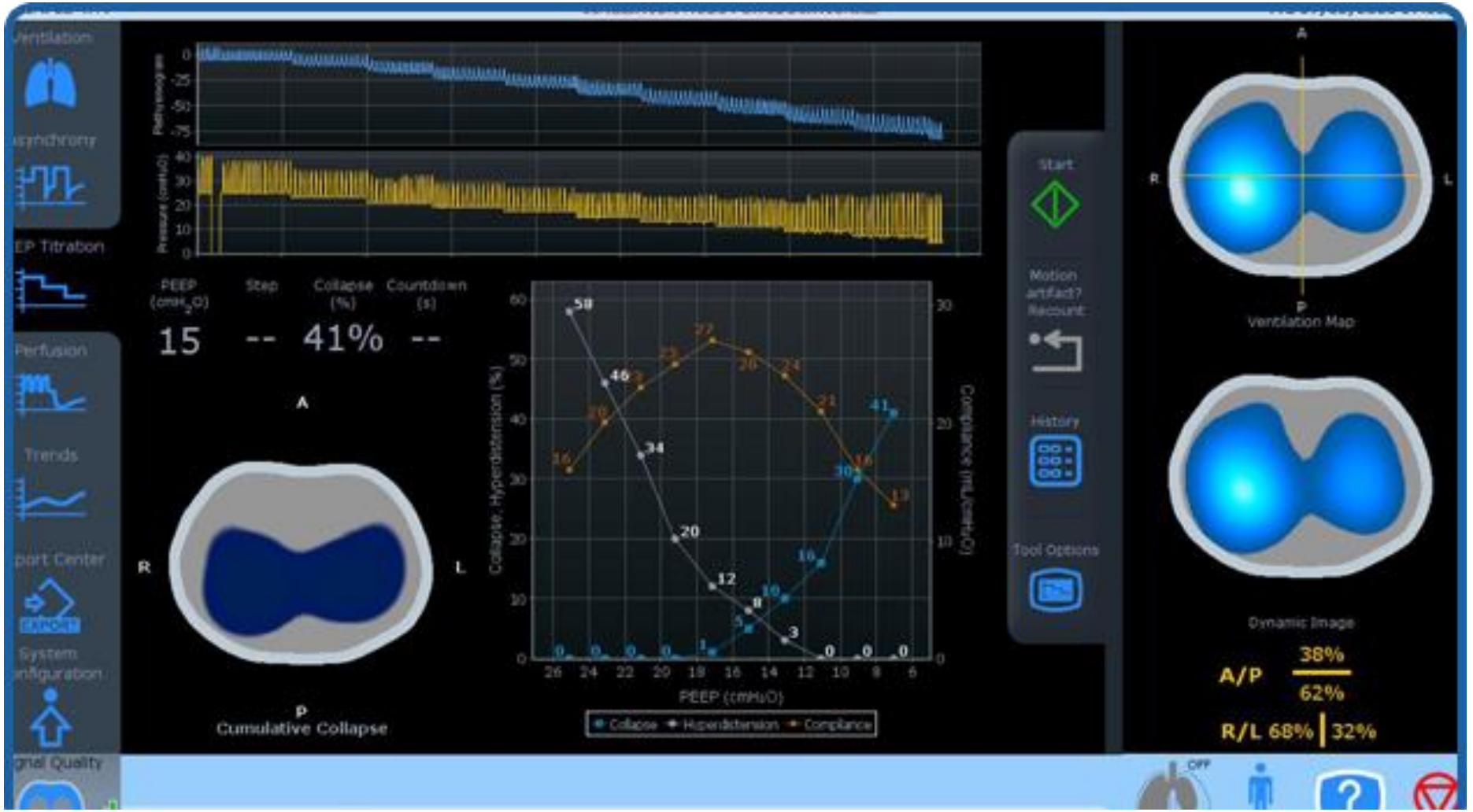


Incremental PEEP titration

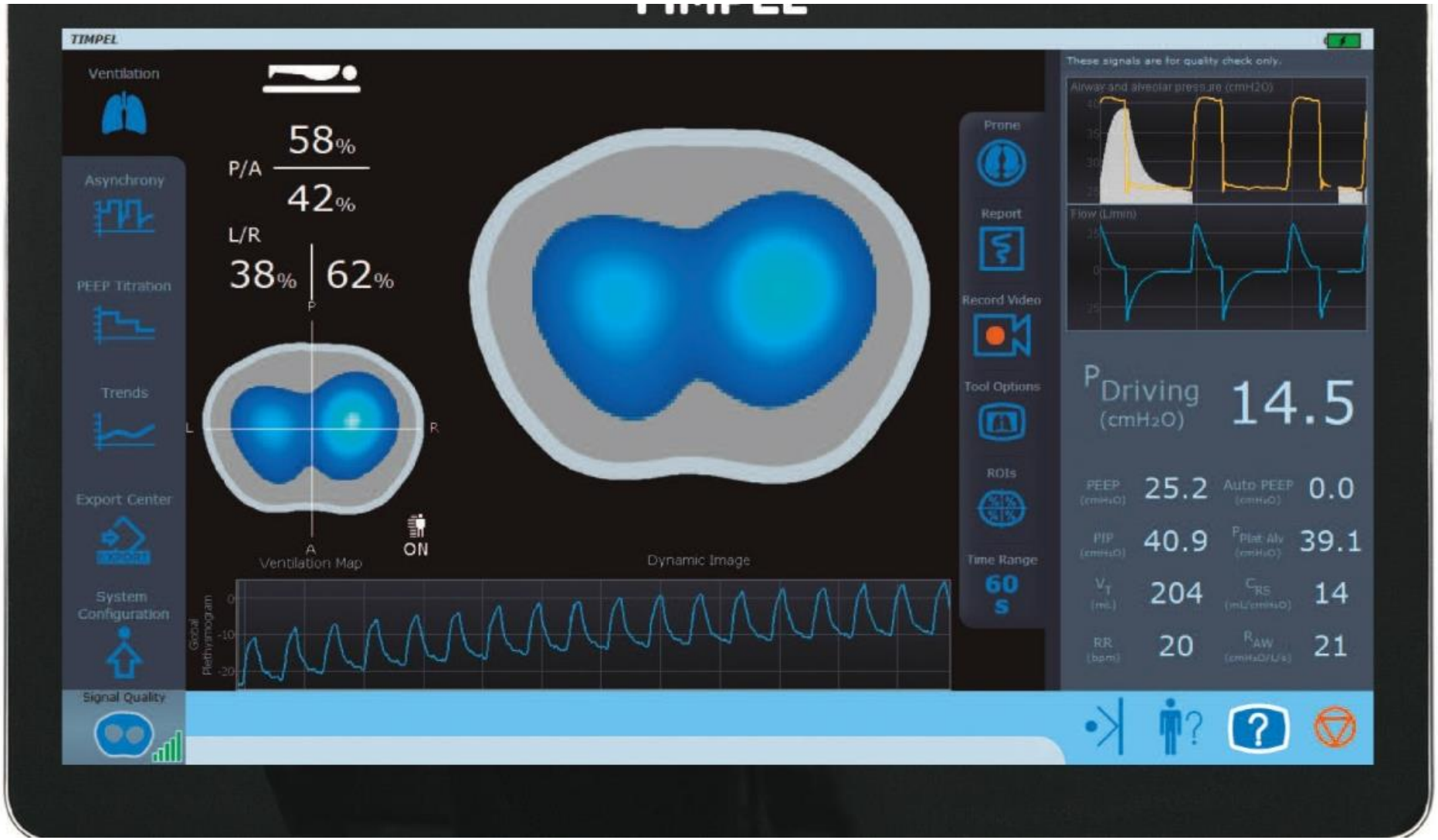
Trimpel-Enlight



Provides lung inflation images



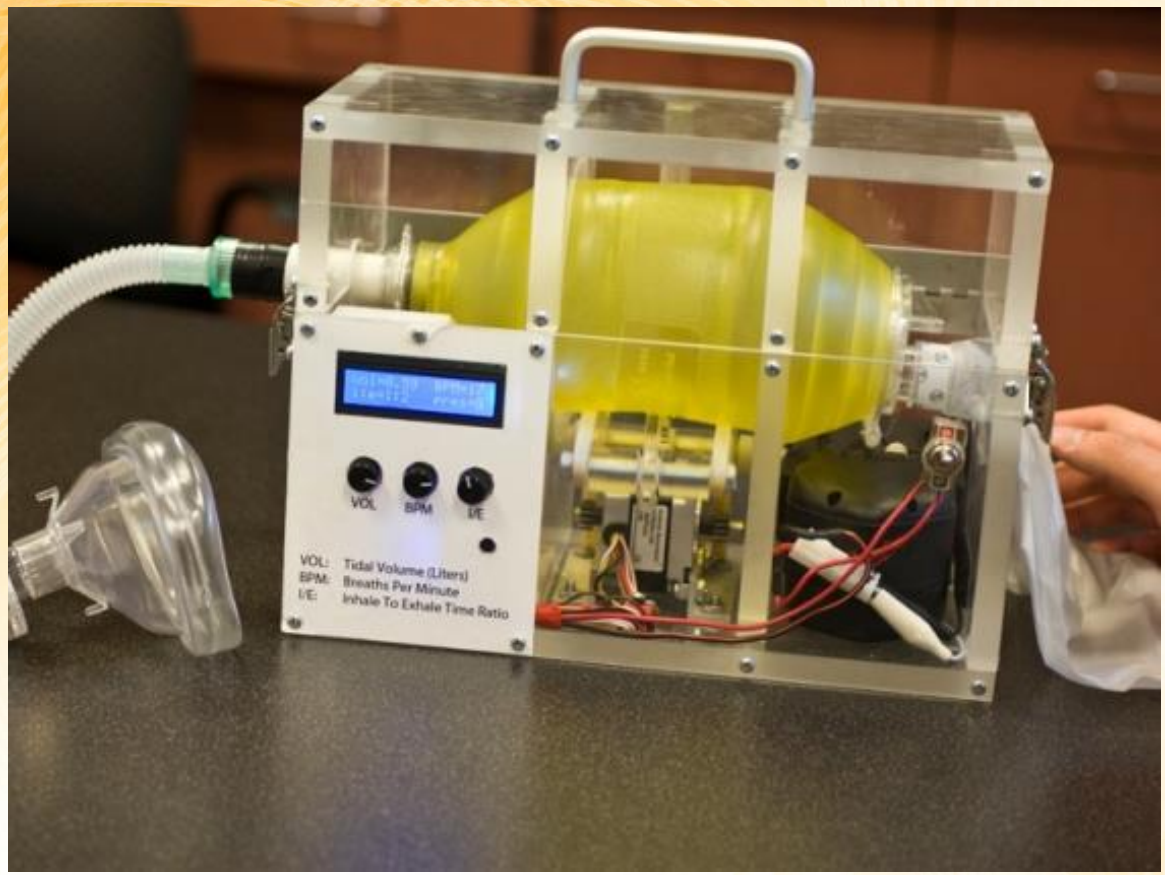
Helps in assessing optimal ventilator pressures



Visualization of lung inflation

Decremental PEEP trial


TIMPEL
PEEP Titration
Loose Electrode, check Signal Quality
OFF
Dynamic



Permission Felix Kushid RRT

Automatic Hand-bag Respirator

Small Compact Ventilators

Personal Library

Novalung: CO2 removal, oxygenation, cardiac support

Permission Gerry Broniec RRT

Permission Gerry Broniec RRT

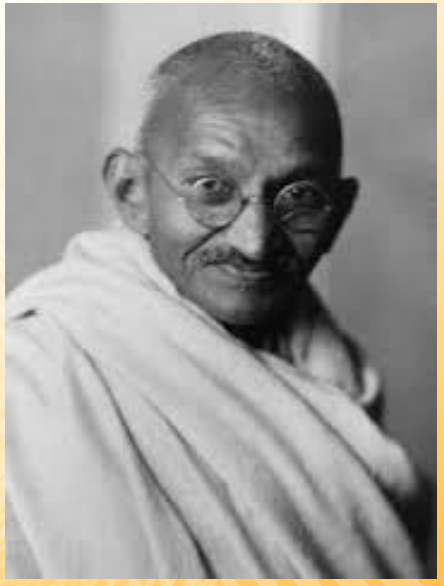
Conclusion

- THE Mechanical Ventilator :
  - The growth and development of the mechanical ventilator has been remarkable!
  - The refinement of the MV has been one of primary factors contributing to the development of the Critical ICU Care!
  - The single word that will best describe the MV of the future is **SMART Clinicians**!!!!

"What we Learn from Academic Studies is Knowledge"

"What we Learn from Experience is Wisdom"

Mohandas Gandhi



Past

During COVID

Current

More PEEP!

Future???

Questions/Thoughts?