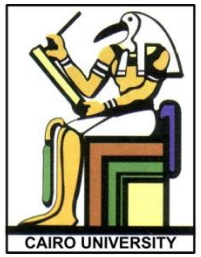
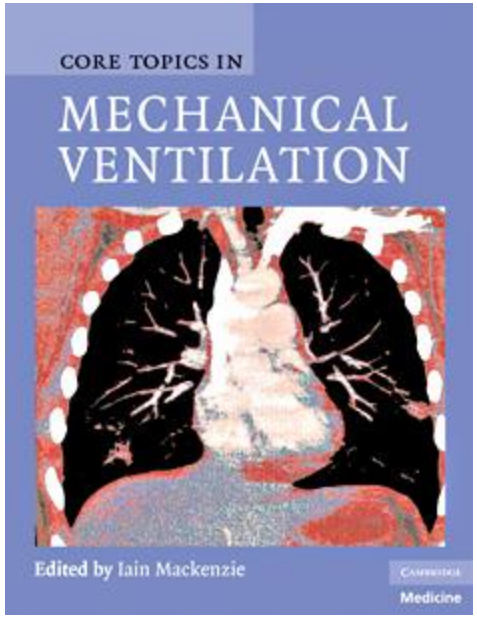


MEDICAL EQUIPMENT: MECHANICAL VENTILATORS

Prof. Yasser Mostafa Kadah – www.k-space.org

Recommended Textbook

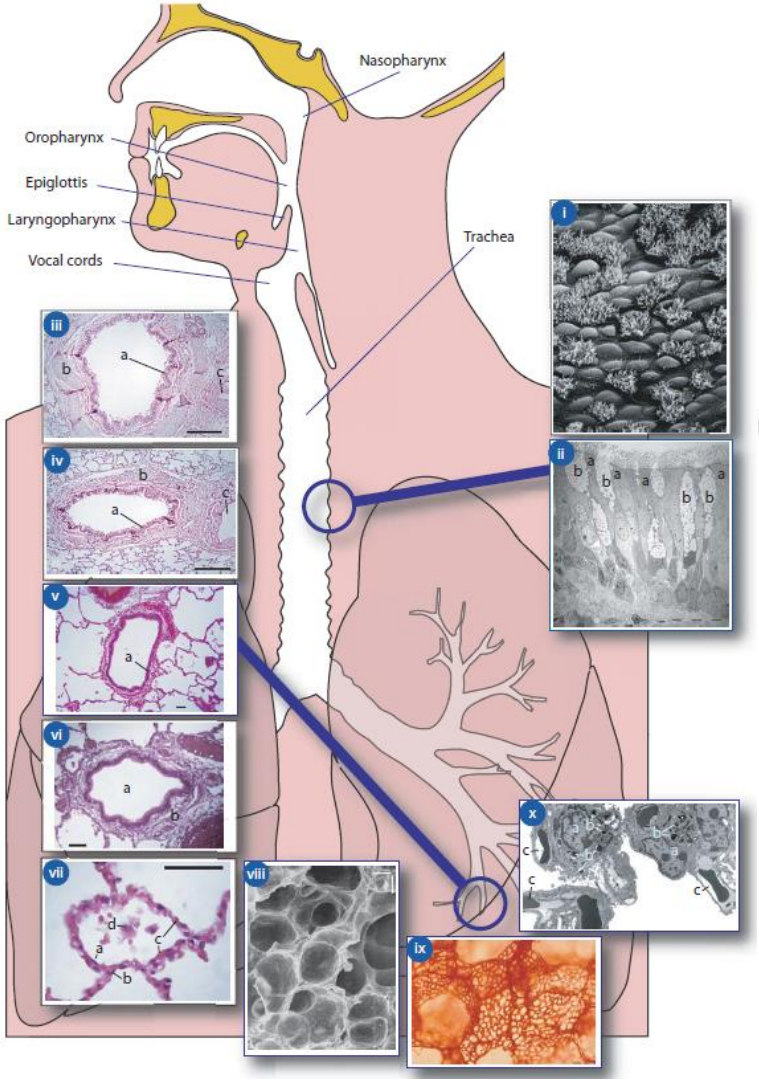
- *Core Topics in Mechanical Ventilation*, edited by IAIN MACKENZIE, Cambridge University Press, 2008.

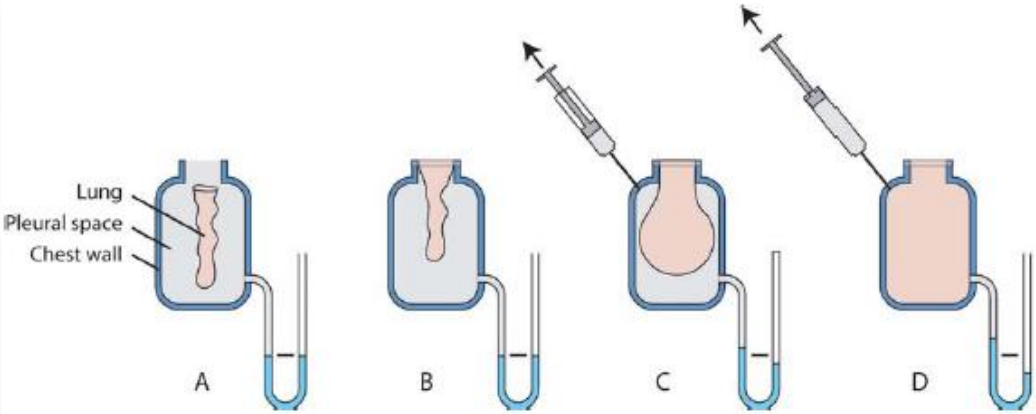


Mechanical Ventilator

- A ventilator is a machine, a system of related elements designed to alter, transmit, and direct energy in a predetermined manner to augment or replace patient's muscles in performing the work of breathing
  - Energy in: electricity or compressed air

Anatomy of Respiratory Tract

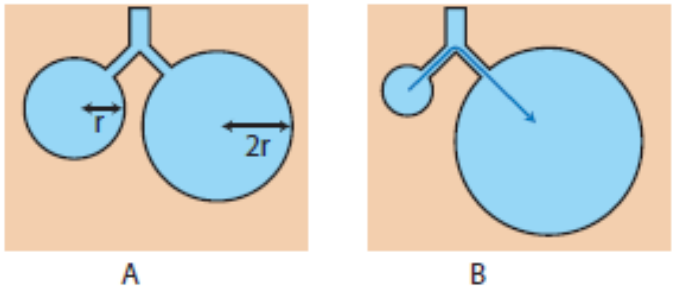




Surface Tension Forces within the Lung

- The pressure within a truly spherical alveolus (Pa) would normally be calculated as twice the surface tension (*Ts*) divided by the alveolar radius (r):

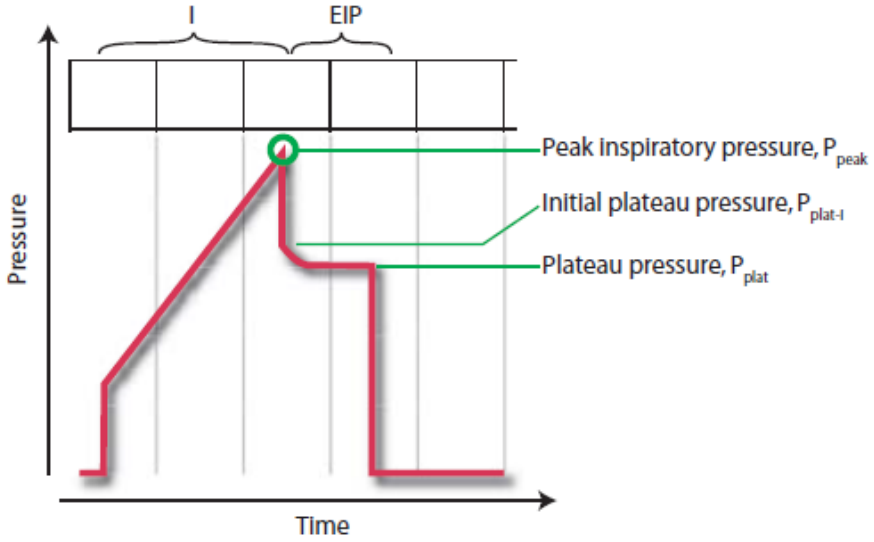
$$P_A = \frac{2 \times T_s}{r}.$$

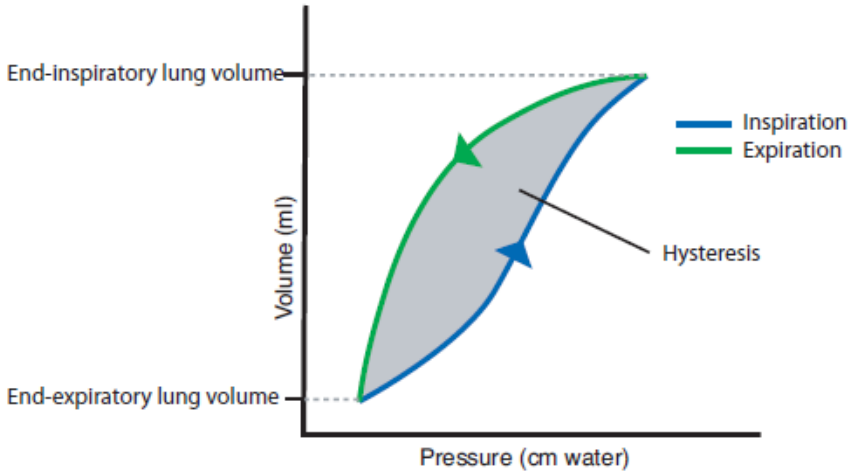


  - If *Ts* is constant, all of the alveoli in a lung would empty into one huge alveolus!
  - Fortunately, surface tension is *not* constant: surfactant reduces the surface tension in proportion to the change in the surface area
    - The smaller the surface area of the alveolus, the greater the reduction in surface tension
    - Gas flows from larger to smaller alveoli

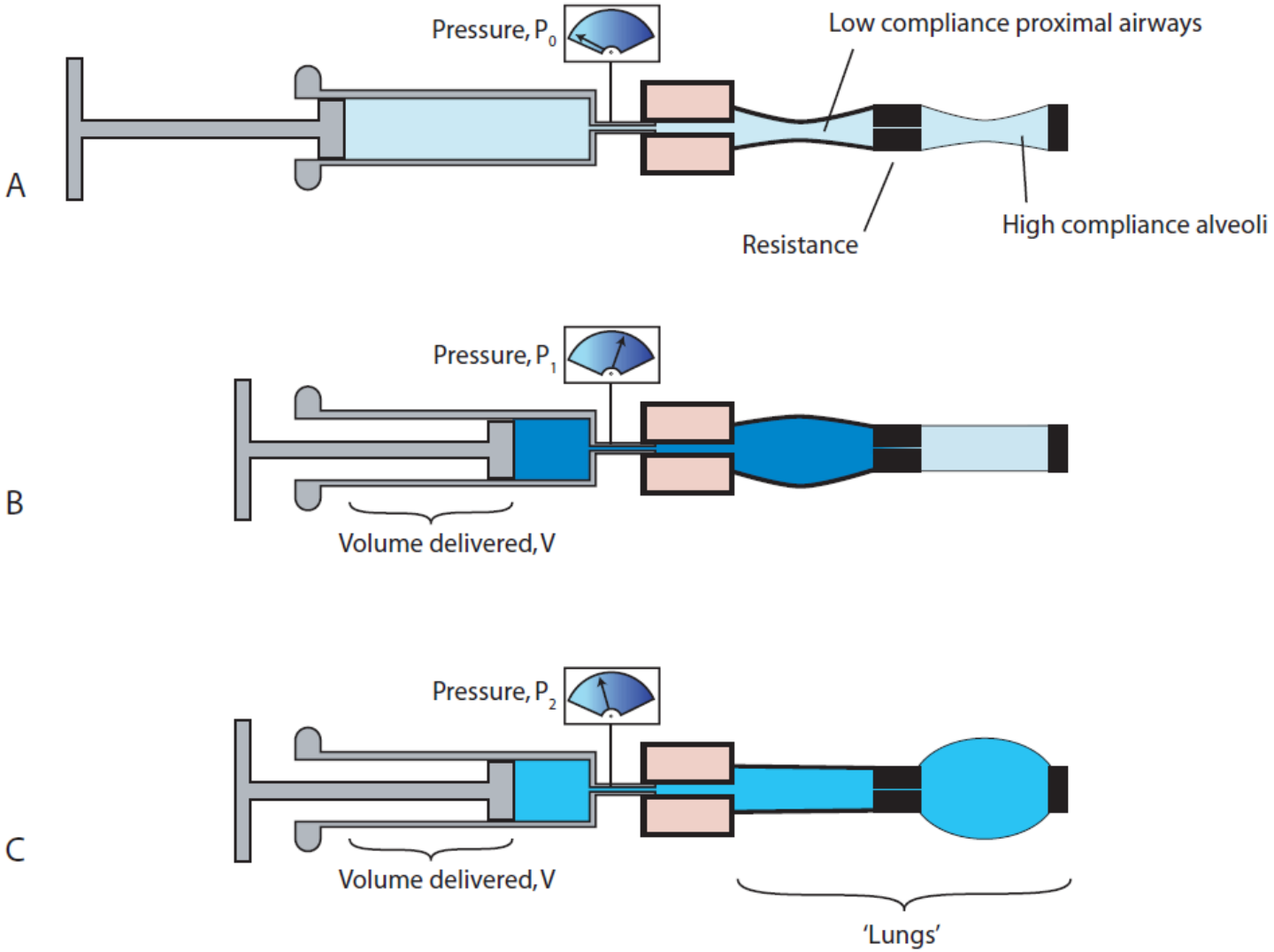
Lung Compliance

- The 'expandability' of the lung is known as its compliance.
  - A high compliance means that the lung expands easily
  - Compliance is generally given by Volume/Pressure
- For a delivered tidal volume of V mL:
  - Dynamic compliance is given by V/P_{peak}
  - Static compliance is given by V/P_{plat}



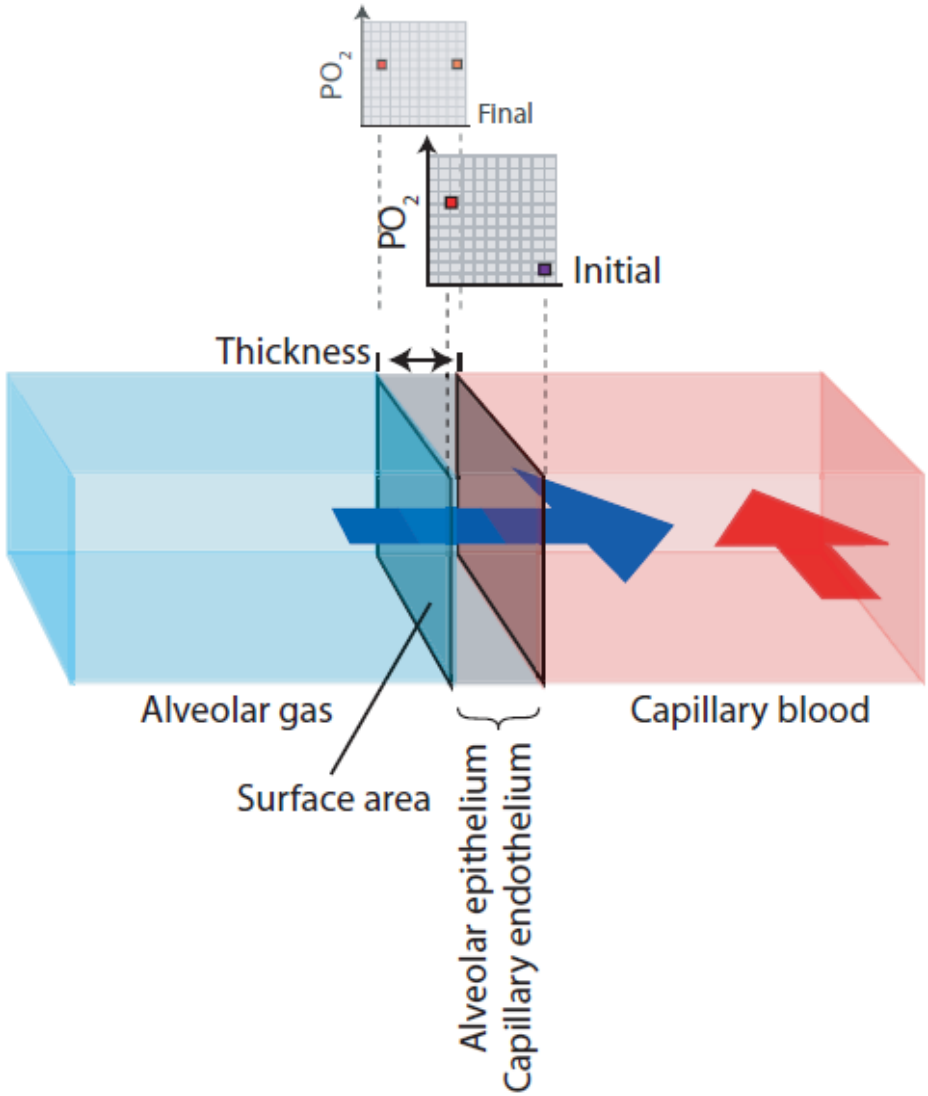


Two-Compartment Model of Static and Dynamic Compliance



Gas Exchange

- Speed of diffusion is determined by:
  - partial pressure gradient
  - thickness of barrier
  - solubility of oxygen in barrier
- Contact time is inversely proportional to the cardiac output
  - At rest is normally 0.75 s
  - At sea level, only 0.25 s is needed

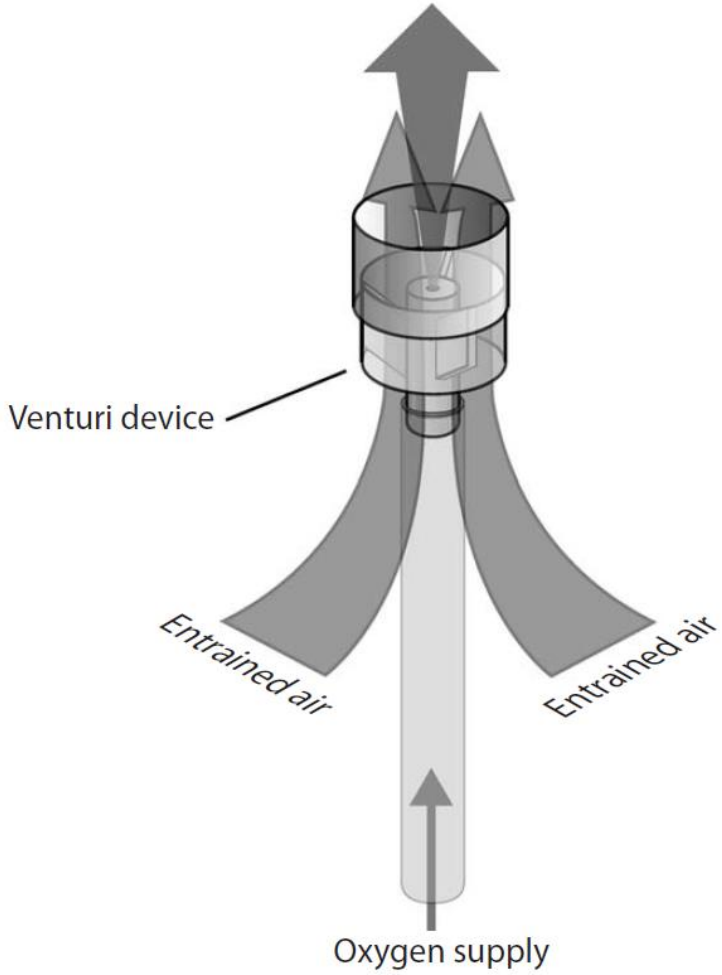


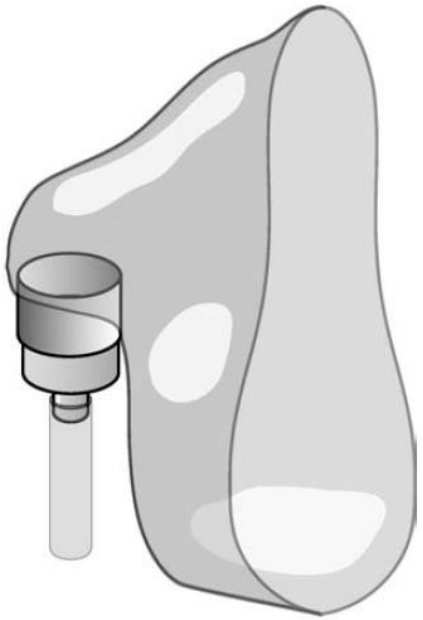
Devices for Administration of Oxygen

- A: Nasal cannulae
- B: Variable performance mask
- C: Variable performance mask with reservoir
- D: Fixed performance mask

Venturi Mechanism

- If oxygen is supplied to the venturi device at the correct flow rate, air will be entrained through the vents to provide an air/ oxygen mixture with a specific oxygen concentration

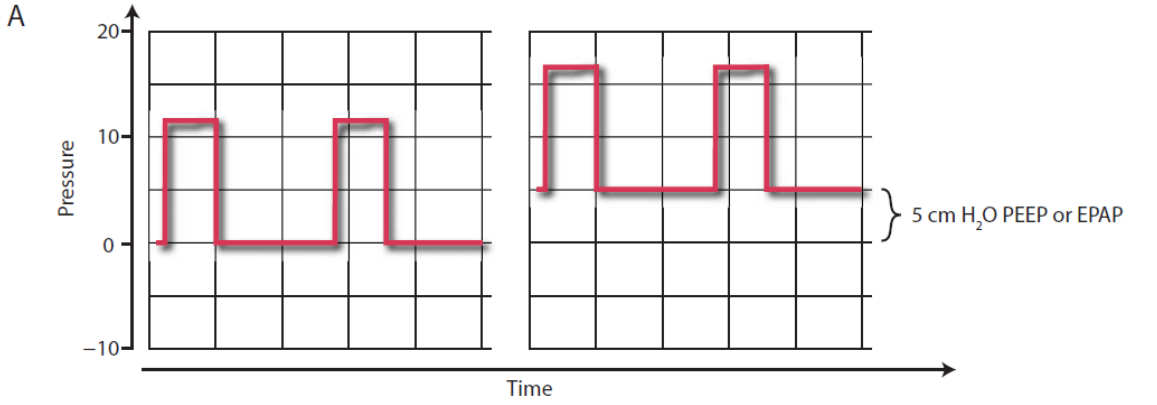




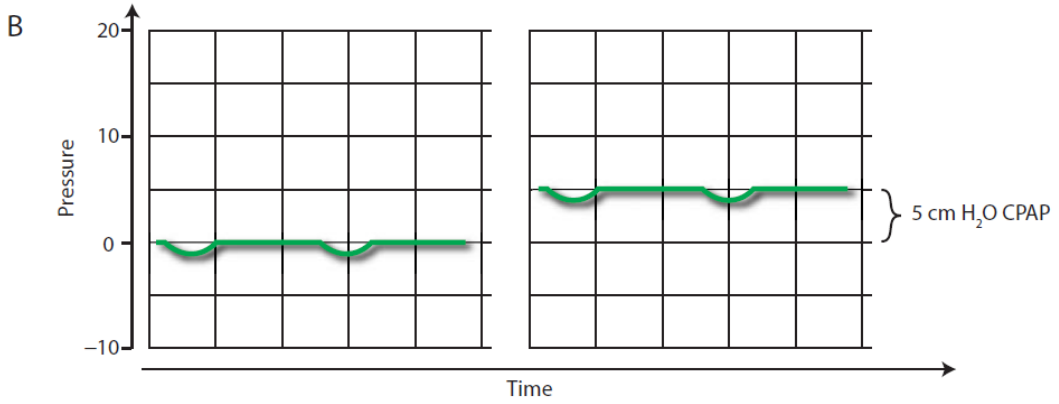
Non-Invasive Ventilation (NIV) vs. Continuous Positive Airway Pressure (CPAP)

- NIV: PEEP or EPAP
  - Positive end-expiratory pressure (PEEP)
  - Expiratory positive airway pressure (EPAP)

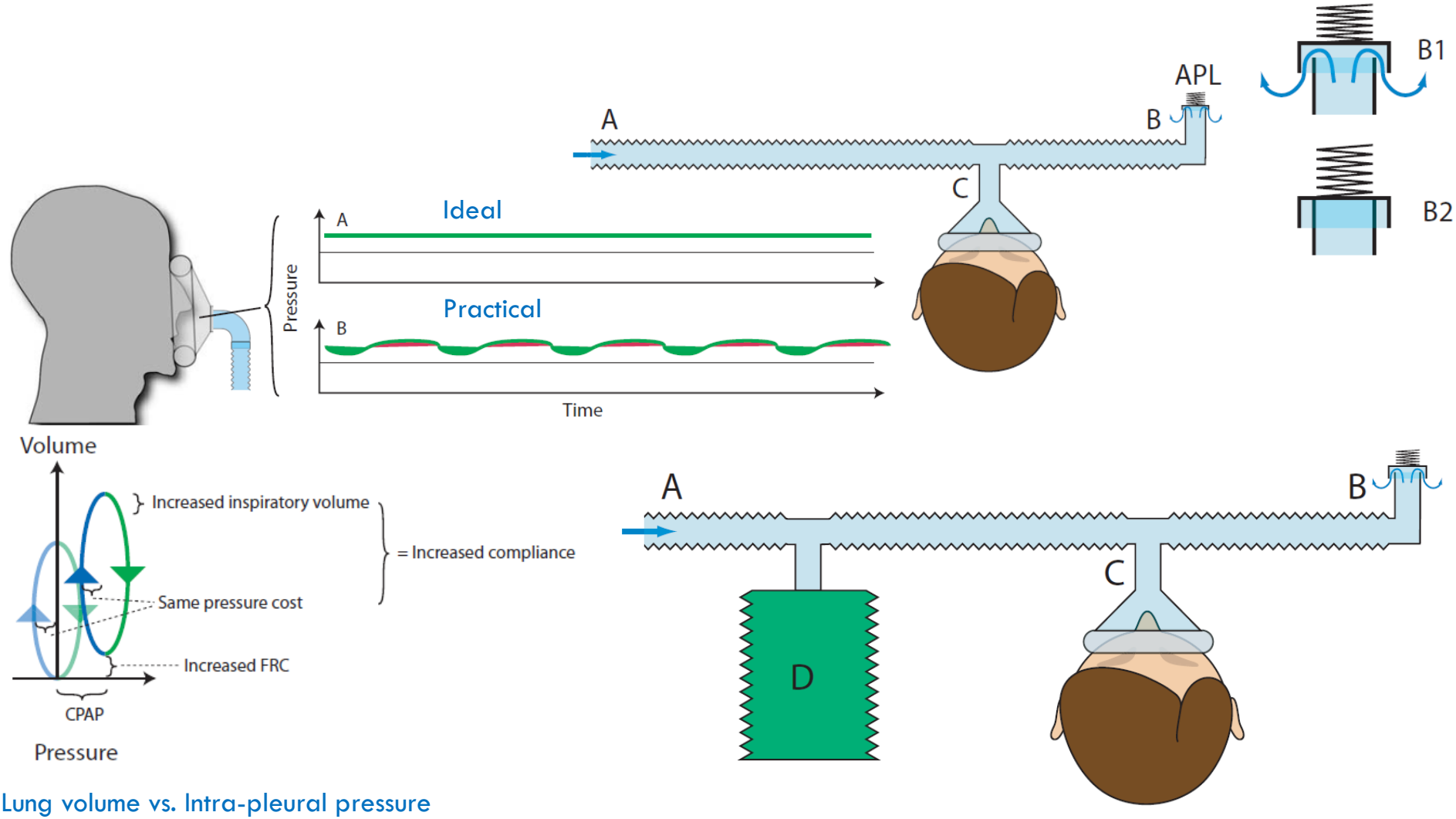
Pressure profile measured in the upper airway



Pressure profile measured just above the larynx



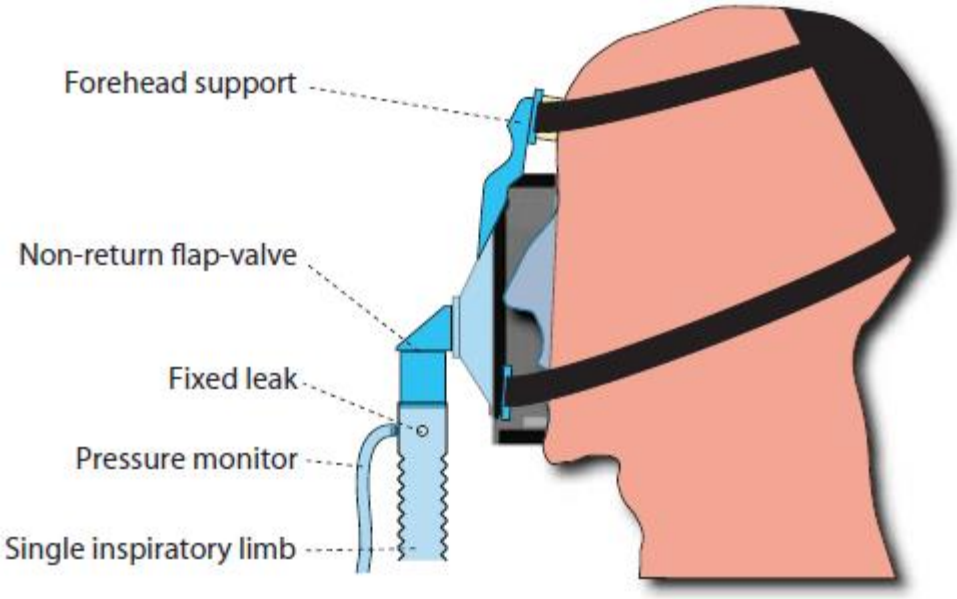
CPAP Circuit



Lung volume vs. Intra-pleural pressure

NIV Circuit

- Unlike ventilator circuits used for anesthesia or critical care which have two limbs, one taking fresh gas to the patient and a second returning expired gas to the ventilator, breathing circuits for non-invasive ventilation (NIV) only have one limb for taking fresh gas to the patient



Respiratory Cycle

$$T_I + T_E = T_C.$$

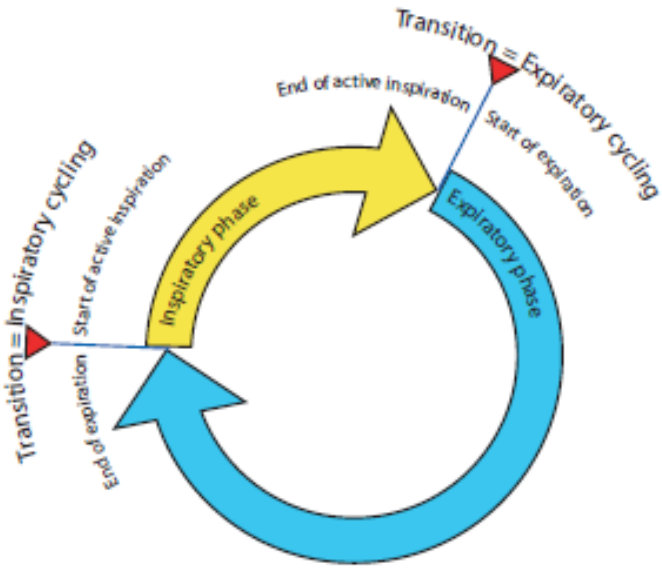
$$T_I = T_{Iflow} + T_{Ipause}$$

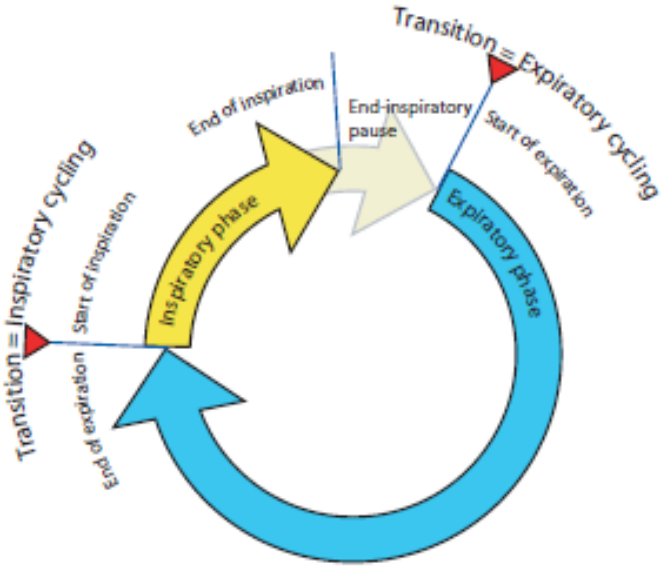
$$f = \frac{60}{T_C}.$$

$$\frac{T_I}{T_I + T_E} \times 100 = \frac{T_I}{T_C} \times 100 = \text{Duty cycle (\%)}.$$

$$f = \frac{\dot{V}}{V_T}.$$

$$\dot{V}_I = \frac{V_T}{T_I}.$$





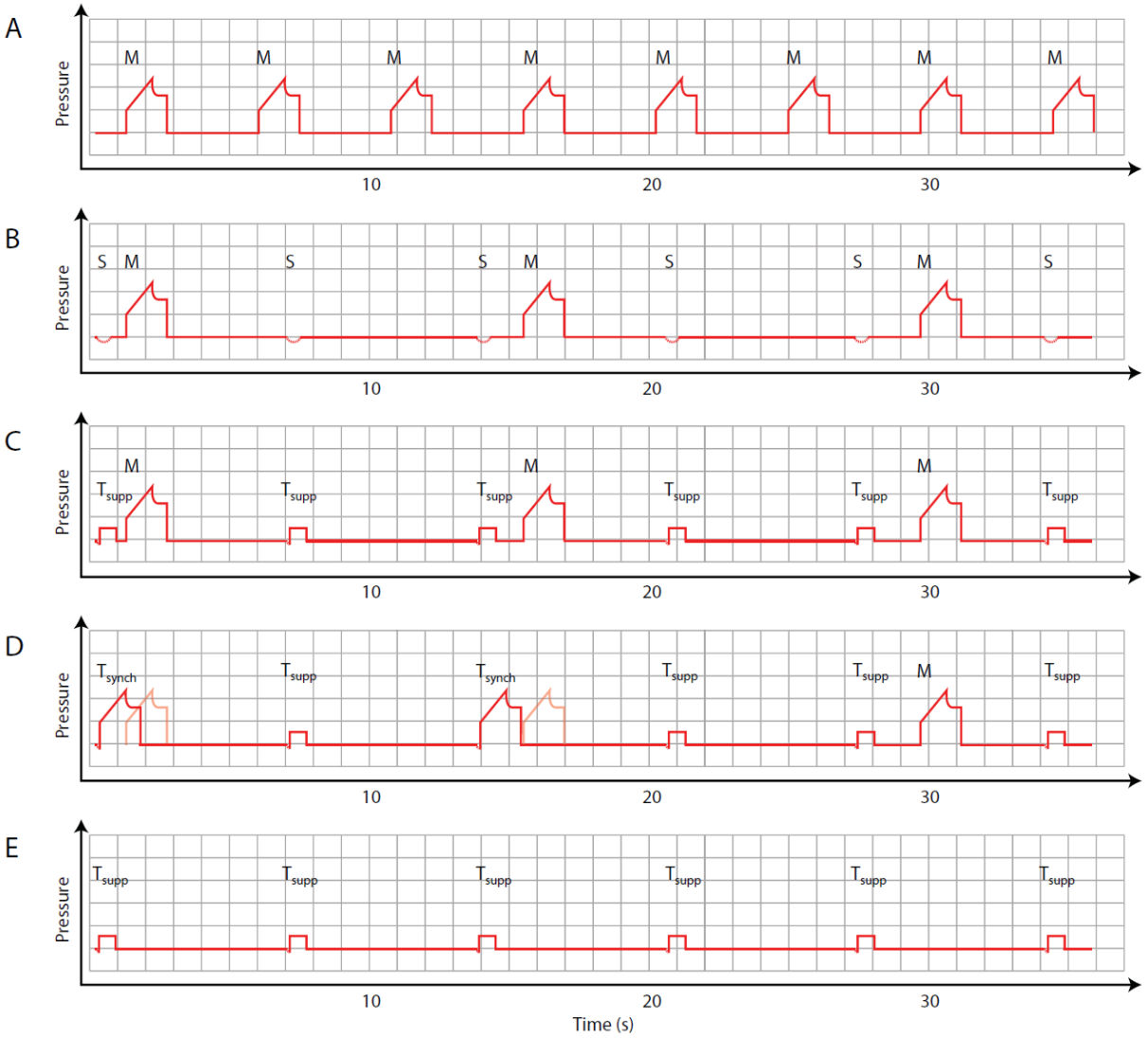
Trigger, Limit, Cycle, and Baseline Variables

- Trigger variable is one that is measured and used to start inspiration
- Limit variable is one that can reach and maintain a preset value before inspiration ends (i.e., does not end respiration)
- Cycle variable is one that is measured and used to end respiration
- Baseline variable is the parameter controlled during expiration
  - Pressure control is most practical and used in all modern ventilators

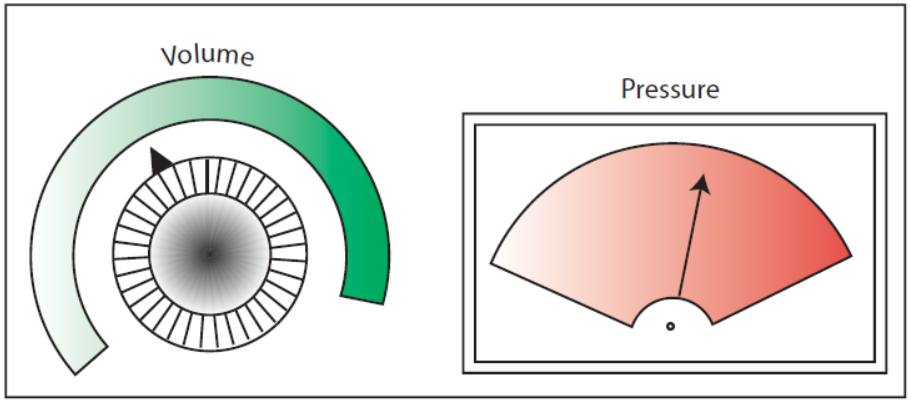
Inspiratory vs. Expiratory Cycling

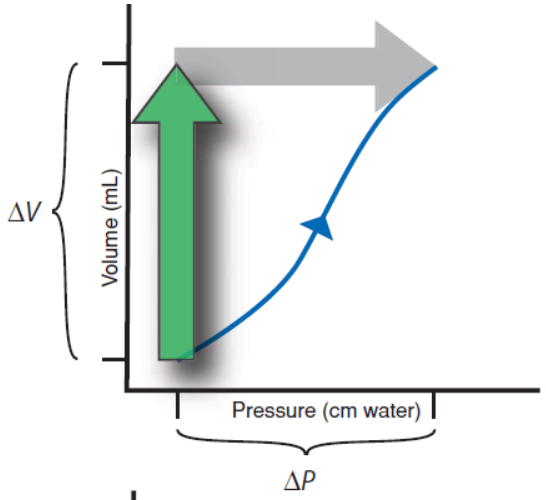
- Exactly when a phase transition occurs can either be determined by the ventilator or by the patient.
- Inspiratory cycling: time or spontaneous (patient)
- Expiratory cycling: time or flow
- Inspiratory triggering
  - Volume
  - Pressure

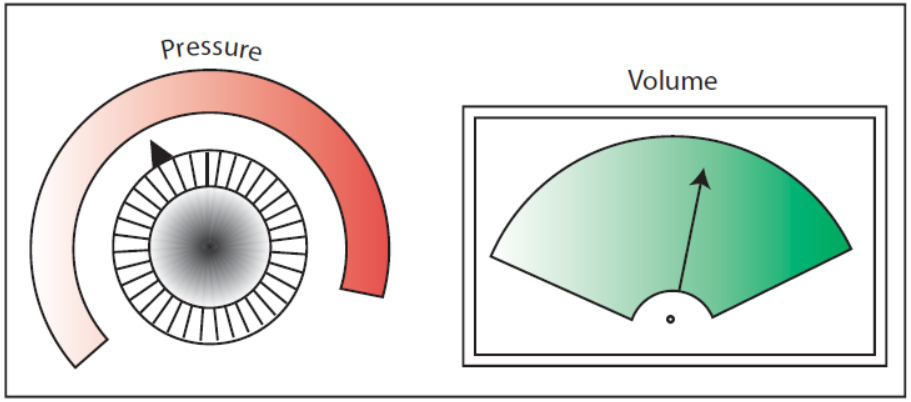
Mandatory, Spontaneous and Triggered Inspiratory Cycling

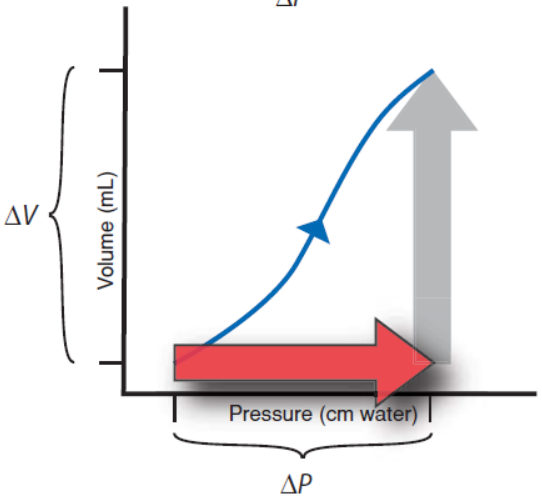


Volume- or Pressure-Driven Inspiration









Classifying Modes of Mechanical Ventilation

- A “mode” of mechanical ventilation can be generally defined as a predetermined pattern of interaction between a ventilator and a patient.
  - There are over 100 names for modes of ventilation on commercially available mechanical ventilators.
  - Neither the manufacturing community nor the medical community has developed a standard taxonomy for modes

Classification of Modes

- In mandatory breaths (if present)
  - What determines inspiratory cycling?
  - What drives inflation and what is the breath targeted to or limited by?
  - Is feedback intra-breath or inter-breath?
  - What determines expiratory cycling?
- In triggered breaths (if present)
  - What breath types are present? Mandatory-pattern, supported or both?
  - In supported breaths (if present), what drives inflation (control parameter) and what is the breath targeted to or limited by?
  - Is feedback intra-breath or inter-breath?
  - What determines expiratory cycling?
- Are spontaneous breaths accommodated and if so, when?

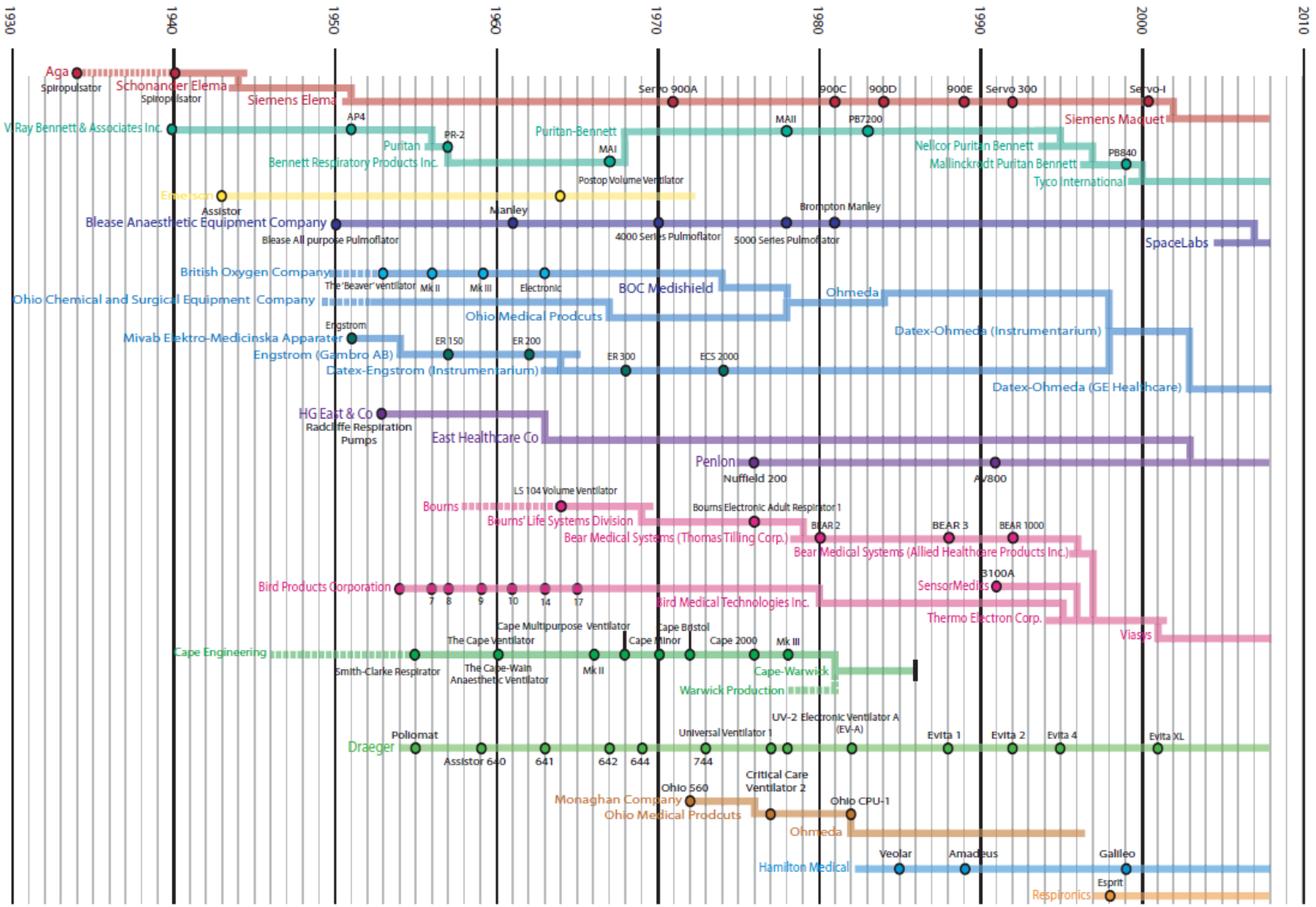
Mandatory Modes of Ventilation

Mandatory breaths				
Inspiratory cycling	Time	Time	Time	Time
Control	Volume[a]	Volume	Volume	(Pressure)
Target/Limit	–	–	Pressure-limited	Volume-targeted
Feedback	–	–	Intra-breath	Inter-breath
Expiratory cycling	Time	Time	Time	Time[b]
Triggered breaths				
Types	None	None	None	None
Supported breaths				
Control	–	–	–	–
Target	–	–	–	–
Feedback	–	–	–	–
Expiratory cycling	–	–	–	–
Spontaneous breaths				
During mandatory inspiration	Not accommodated[c]	Not accommodated	Not accommodated	Accommodated
Otherwise	Not accommodated	Accommodated	Not accommodated	Accommodated
Synonyms	IPPV (Draeger[d]), Controlled Mandatory Ventilation or (historically) Control Mode Ventilation	Intermittent Mandatory Ventilation	IPPV (Draeger[e])	IPPV (Draeger[f])

Triggered Modes of Ventilation

Mandatory breaths			
Inspiratory cycling	–	–	–
Control	–	–	–
Target	–	–	–
Feedback	–	–	–
Expiratory cycling	–	–	–
Triggered breaths			
Types	Supported breaths only	Supported breaths only	Supported breaths only
Supported breaths			
Control	Pressure[a]	(Pressure[b])	(Pressure[b])
Target/Limit	–	Volume-targeted	Flow and volume
Feedback	–	Inter-breath	Intra-breath
Expiratory cycling	Flow[c]	Flow[c]	Flow[c]
Spontaneous breaths			
During mandatory inspiration	–	–	–
Otherwise	–	–	–
Synonyms	Assisted Spontaneous Breathing (Draeger), Spontaneous mode (Hamilton, Puritan-Bennett), Pressure support (Maquet), CPAP (Respironic), Pressure Support Ventilation (Viasys)	Volume Support (Maquet, Puritan-Bennett)	Proportional assist ventilation, Proportional Pressure Support (Draeger), Proportional Assist Ventilation Plus (Puritan-Bennet)

Commercial Development of Ventilator Technology



Suggested Further Topics

- Sources of input power for ventilators
- Power conversion inside ventilator
- Alarms