國立陽明大學附設醫院
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Mechanical ventilation

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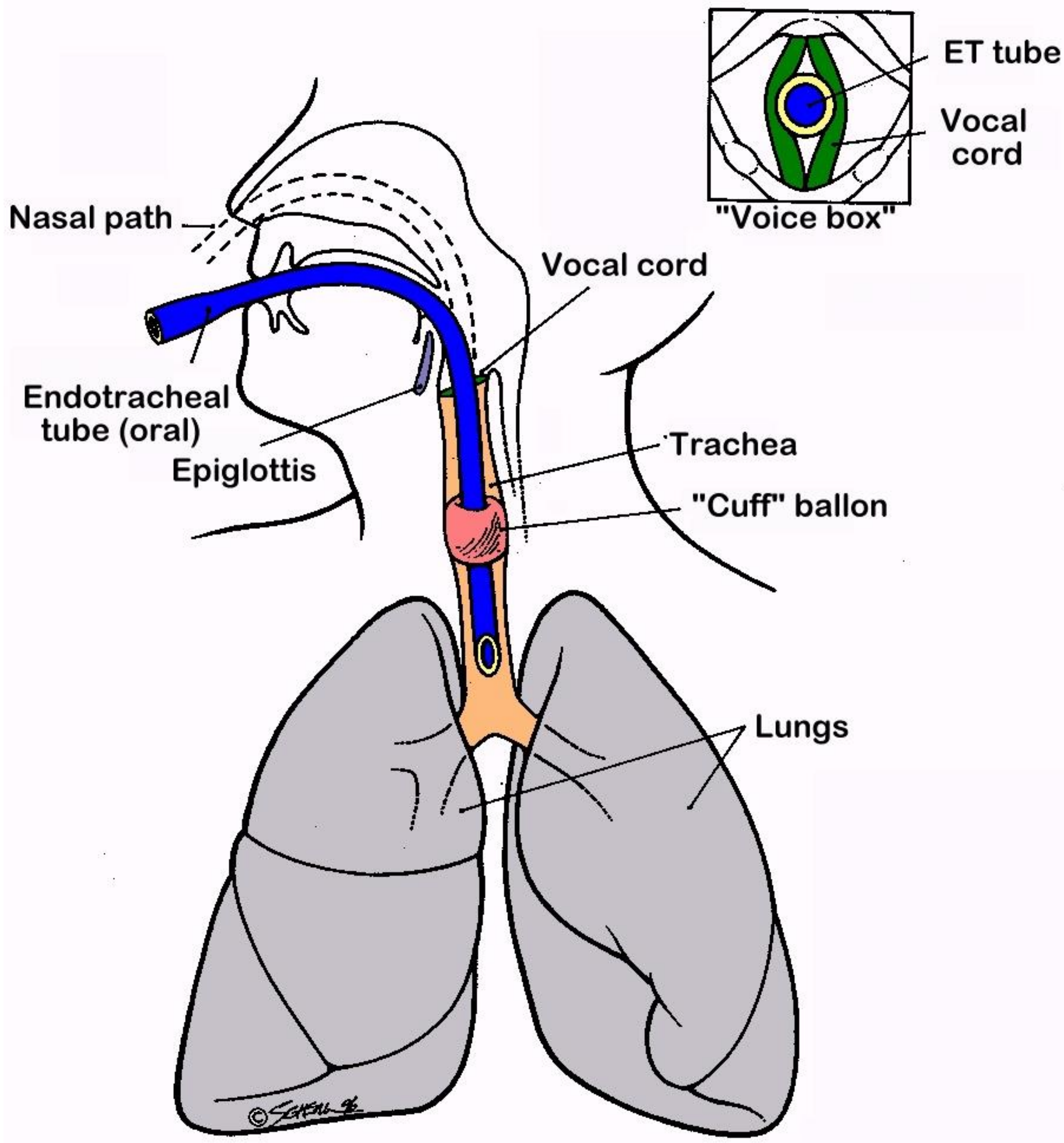
Endotracheal tube and ventilator


ET tube
Vocal
cord
"Voice box"
Nasal path
Vocal cord
Endotracheal
tube (oral)
Epiglottis
Trachea
"Cuff" ballon
Lungs

機械通氣的臨床應用.適應性

1.肺泡換氣不足 ($PaCO_2$, pH)

2.肺擴張不足 (V_T, V_C, f)

3.呼吸肌力不夠 (MIF, MVV,VC)

4.呼吸作功太大 (V_E, V_D/V_T, f)

5.呼吸驅動不穩定 (呼吸型式)

6. 嚴重低血氧症 ($P_{(A-a)}O_2$, PaO_2/PAO_2, PaO_2/FiO_2, $Q's/Q'_T$)

7.預防性使用：如手術後24小時的呼吸器

8.特殊狀況：阻塞性肺疾病,
連枷胸,
封閉性頭部外傷(closed head injury)

呼吸衰竭分類表

$PaO_2 < 50$

第二型呼吸衰竭

血二氧化碳過高症

$PaCO_2$ 上昇

- 換氣增加
  - *慢性支氣管炎
  - *肺氣腫
  - *哮喘
- 喚氣減少
  - *呼吸中樞受壓抑
  - *自發性神經肌肉病變

→ 呼吸肌肉衰竭

第一型呼吸衰竭

血二氧化碳過少症

$PaCO_2$ 下降

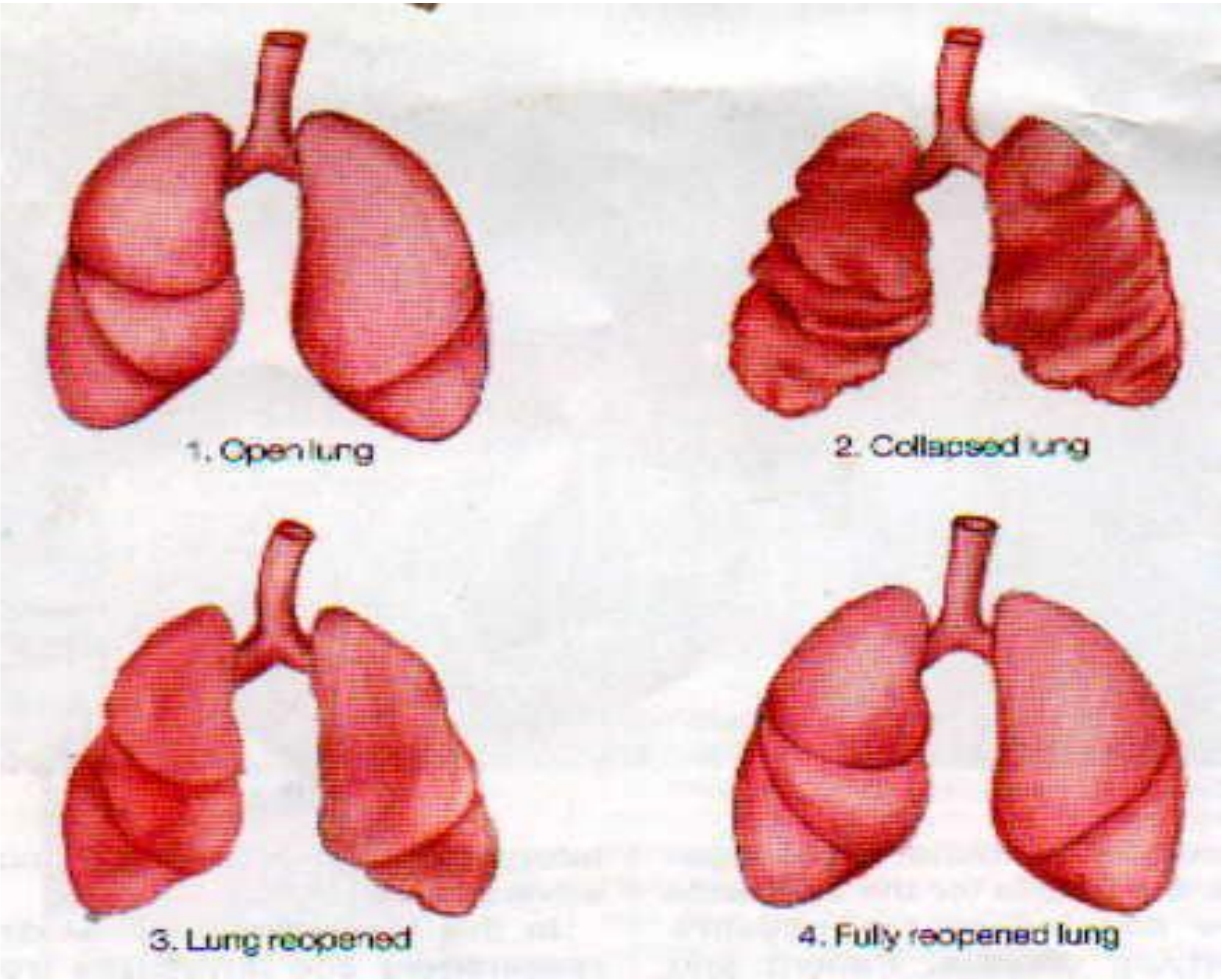
- 急性非特殊性疾病
  - *成人呼吸窘迫症候群
- 急性特殊性疾病
  - *肺炎
  - *肺水腫
  - *肺膨脹不全
- 慢性進行性疾病
  - *肺間質纖維化
  - *肺淋巴管轉移癌症

→ 肺實質衰竭

Goal of Mechanical Ventilation

- Provide adequate gas exchange
  - CO_2 elimination,
  - Arterial oxygenation and oxygen delivery
- Minimal side effects
  - Overdistension
  - High airway pressure
    - Barotrauma
    - Hemodynamic compromise

Open lung


1. Open lung
2. Collapsed lung
3. Lung reopened
4. Fully reopened lung

Why keep the lung open?

- No matter which ventilator mode you use, or whether you are treating a healthy or sick lung, keeping the lung open in all conditions is a must.
- Law of LaPlace
  - higher pressures are needed to re-open collapsed alveoli
  - critical opening pressure is inversely proportional to alveolar unit size
- Prevent loss of surfactant by artificial ventilation
- VQ mismatch

Laplace law

The Law of LaPlace

The Law of LaPlace teaches us that much higher pressures are needed to re-open collapsed alveoli and it can be seen that up to the FRC level almost only surface tension phenomena are responsible for the retractive forces.

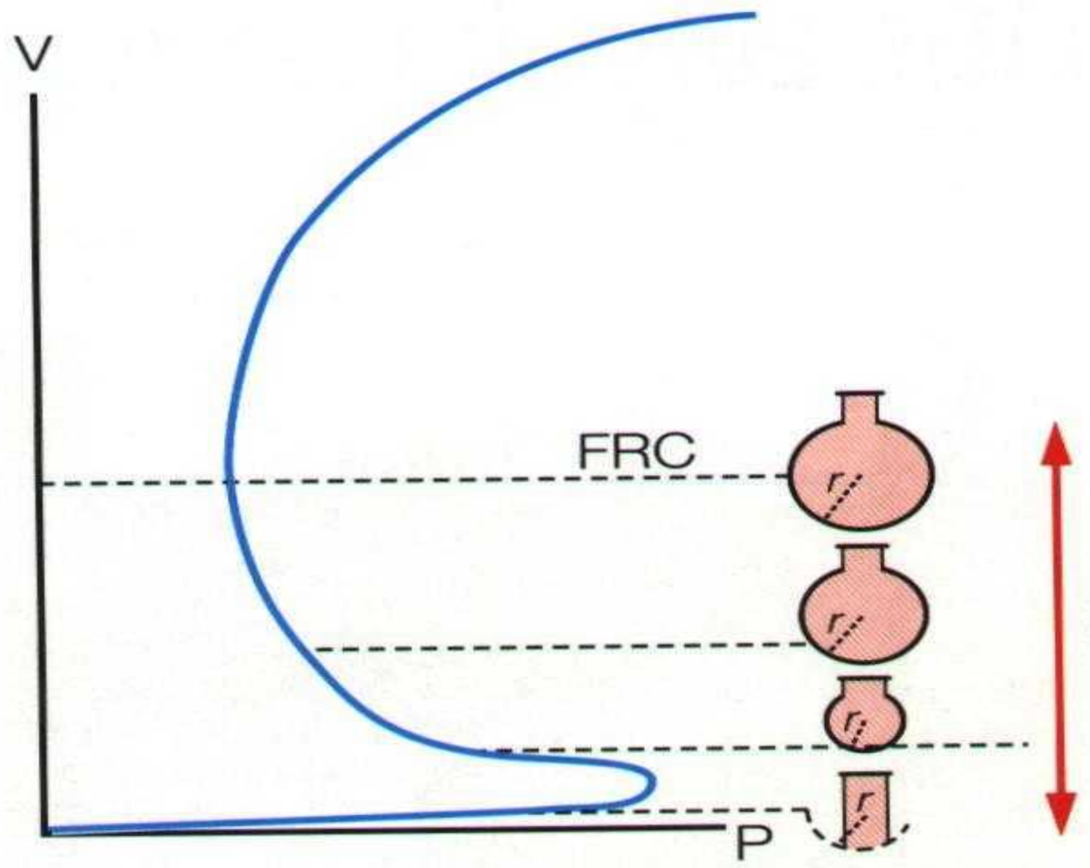


Fig. 1

Tailor to each patient

- lung mechanics differ in different diseases
- Respiratory drive higher in sepsis
  - Tang CCM, 1998
- Individual response to ventilator
  - age
  - sex
  - educational backgroun

Ventilator setting

- Mode select
- Pressure, rate & volume setting
- Ventilator select
- Correct underlying disease
- Sedation and muscle relaxant
- Prone position

通氣型態(Mode)

1. 控制式 (Control mode)
2. 輔助式 (Assist mode)
3. 控制-輔助式 (Control/Assist mode)
4. 間歇強迫通氣式 (Intermittent Mandatory Ventilation ; IMV)
5. 同步間歇強迫通氣式 (Synchronized IMV ; SIMV)
6. 壓力支持式 (Pressure Support)

CONTROLLED MECHANICAL VENTILATION

- Independent of the spontaneous efforts of the patient
- Pressure-controlled ventilators
  - Applies a desired pressure to the airways
- Volume-controlled ventilators
  - Delivers a predetermined volume of gas to the lungs

Indications for CMV

- Apnea (General Anesthesia)
- CNS depression (brain trauma, high spinal cord lesions)
- Drug overdose
- Neuromuscular diseases
  - Guillain- Barre Syndrome
  - myasthenia gravis
  - poliomyelitis

Advantages of CMV

- Improve gas exchange/oxygenation with oxygen-enriched air
- Decreases work of breathing
- Improves alveolar recruitment by increasing transpulmonary pressure

RISK FACTORS for CMV

- Barotrauma due to high pressure and volumes
- Cardiovascular system
  - reduction in venous return and cardiac output
- Impairment of the pulmonary surfactant system
- Reduction in pulmonary lymph flow
- Reduction in organ blood flow
- Decrease in hepatic and splanchnic blood flow
- Impairment of renal excretion
- Salt and water retention
- Infection

VOLUME-CONTROLLED VENTILATION

- Delivers a pre-determined volume of gas to the lungs
- Fixed flow
- Set rate

- Variables
  - Inspiratory time = volume/flow
  - Airway pressure
    - resistance, compliance

Definitions

- Tidal volume : cc per one breath
- Flow: L/min. gas in
- Peak airway pressure: peak pressure on a cycle
- Plateau airway pressure:
  - pressure after full inspiration without expiration
- Airway resistance = (Peak pressure-Pleural pressure) / Flow
- Dynamic compliance = Peak pressure / tidal V
- Static compliance = Plateau pressure / tidal V

呼吸器的構成要素 (Components of Ventilator)

1.通氣次數 (Rate)--以次/分鐘為單位

T. c (cycle time)指一次呼吸週期所需之時間,以秒為單位

$Tc = T_I$ (吸氣時間) + T_P (吸氣停滯時間, 通常為 0)

+ T_E (吐氣時間)

2.吸氣與吐氣之比 I : E ratio

- Rate : 10 次/分鐘, I : E ratio = 1 : 2

  T_c = 60/10 = 6 秒

  T_I = 6 × 1/3 = 2 秒

  T_E = 6 × 2/3 = 4秒

- Volume cycled ventilator

  T_I 可由Flow 及Volume 來決定

  T_I = Volume / Flow

3.流量 (Flow)

- 指單位時間的容積量,以L/min 為單位
- 大部分的呼吸器可直接設定 Flow 或由 MV × (I + E) 來推算

  如 : MV = 10 L　　　　I : E = 1: 3

  Flow = 10L × 4 = 40 L/ 分

4.潮氣容積 (Tidal Volume ; V_T)

- 指每次強制通氣之容積,以ml 或cc 為單位
- 大部分的呼吸器可直接設定 V_T
  或由MV/Rate 及Flow × T_I 來推算
  如 : a)MV = 10L Rate 10 次/min
  M_T = MV/Rate = 10L/10次 = 1L = 1000ml
  b)Flow = 30L/min = 0.5L/sec , T_I = 2 sec
  V_T = 0.5L/sec × 2 sec = 1000ml

5.壓力 (Pressure)

- 指呼吸器所監視到的氣道壓力, 以 cmH_2O為單位

  阻力 (Resistance ; R) = $\Delta P/F$ $cmH_2O/L/sec$

  順應性 (Compliance ; C) = $\Delta V/ \Delta P$ L/ cmH_2O

-阻力 Resistance = 機械性 Resistance+ 呼吸性 Resistance

-綜合順應性 total compliance = 胸廓compliance + 肺部的 compliance

- 呼吸道壓力 (Airway Pressure; P)

如: $V_T = 0.8$　Flow = 48L/min = 0.8L/sec

$R = 27.5\ cmH_2O/L/sec$

$C = 0.2\ L/cmH_2O$

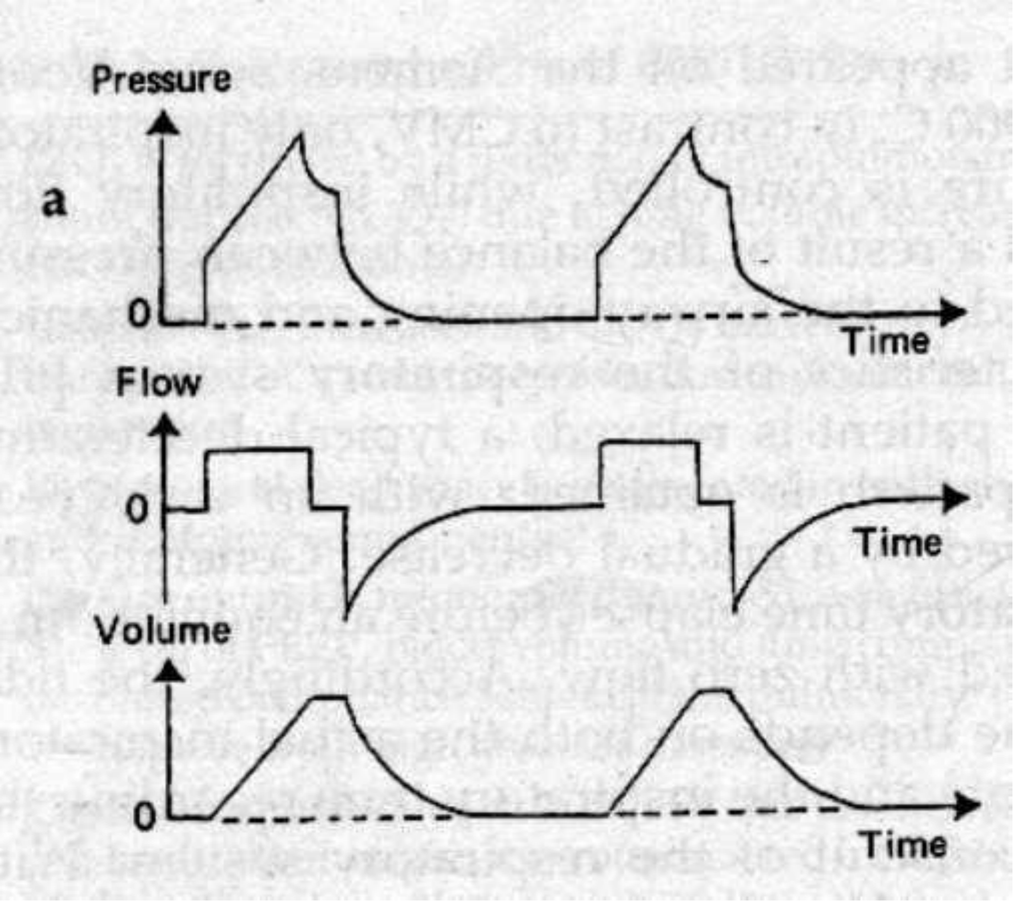
$P_1 = R \times F = 27.5 \times 0.8 = 22\ cmH_2O$

$P_2 = V/C = 0.8 / 0.2 = 4\ cmH_2O$

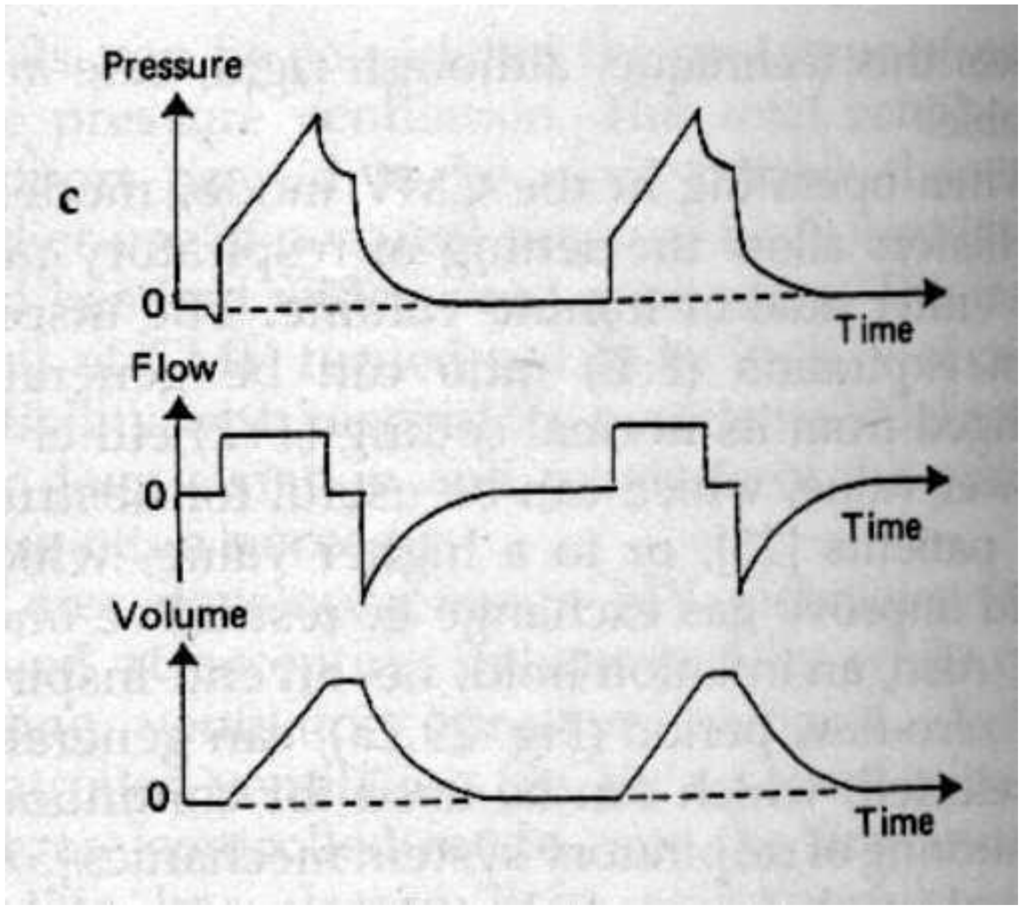
$P = P_1 + P_2 = R \times F + V/C$

$= 22+4=26\ cmH_2O$

Volume controlled mechanical ventilation with constant flow in a relax patient



Assist-controlled ventilation with constant flow, patient initiated cycle



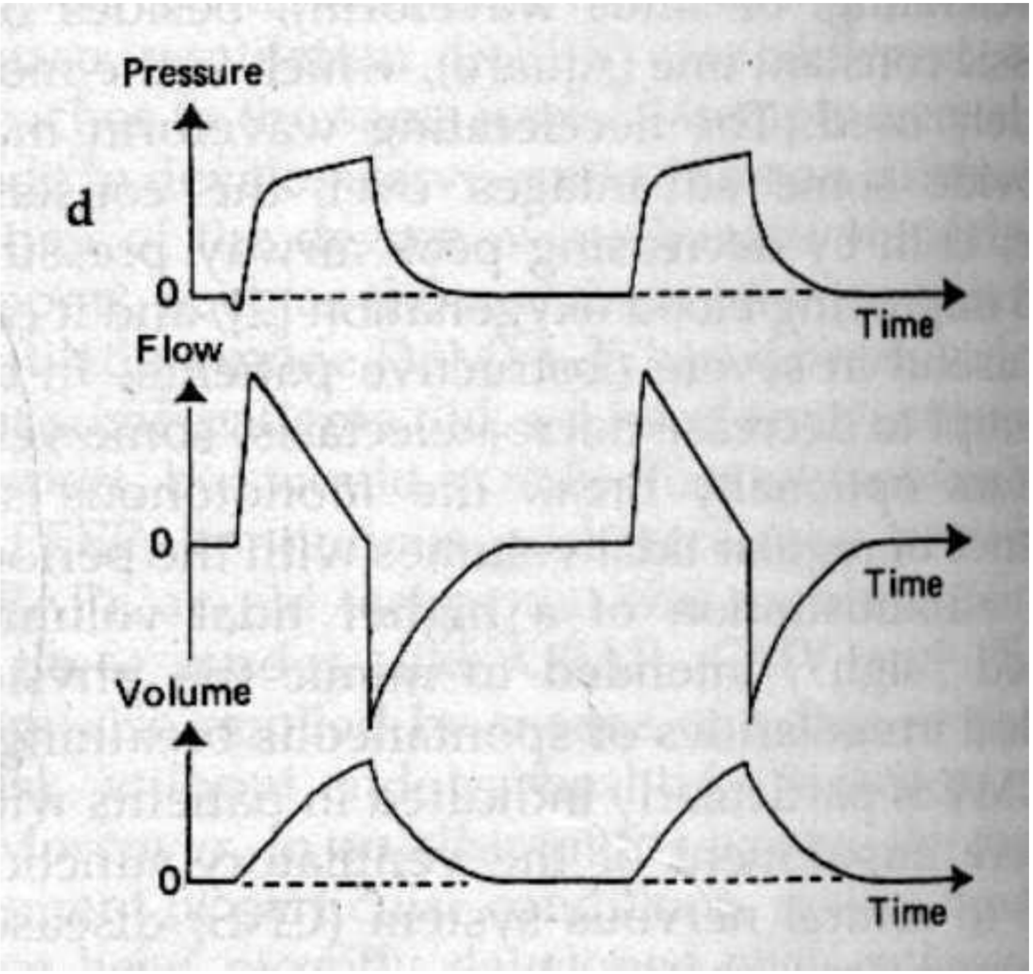
VOLUME-CONTROLLED VENTILATION

- Advantages:
  - Tidal volume is guaranteed
  - No hypo- or hyper ventilation
- Disadvantages:
  - Flow may not meet patient demand
  - Poor patient ventilator synchrony
  - Increasing the work of breathing
  - High airway pressure may occur
    - resistance and compliance
  - Poor distribution of gas within the lung

Pressure Controlled Ventilation

- Delivers a volume of gas at a constant pressure to the lung during the set inspiration time
- The volume received is determined by
  - set inspiratory pressure
  - respiratory rate
  - inspiratory time
  - lung compliance

Pressure-controlled ventilation in a relaxed patient



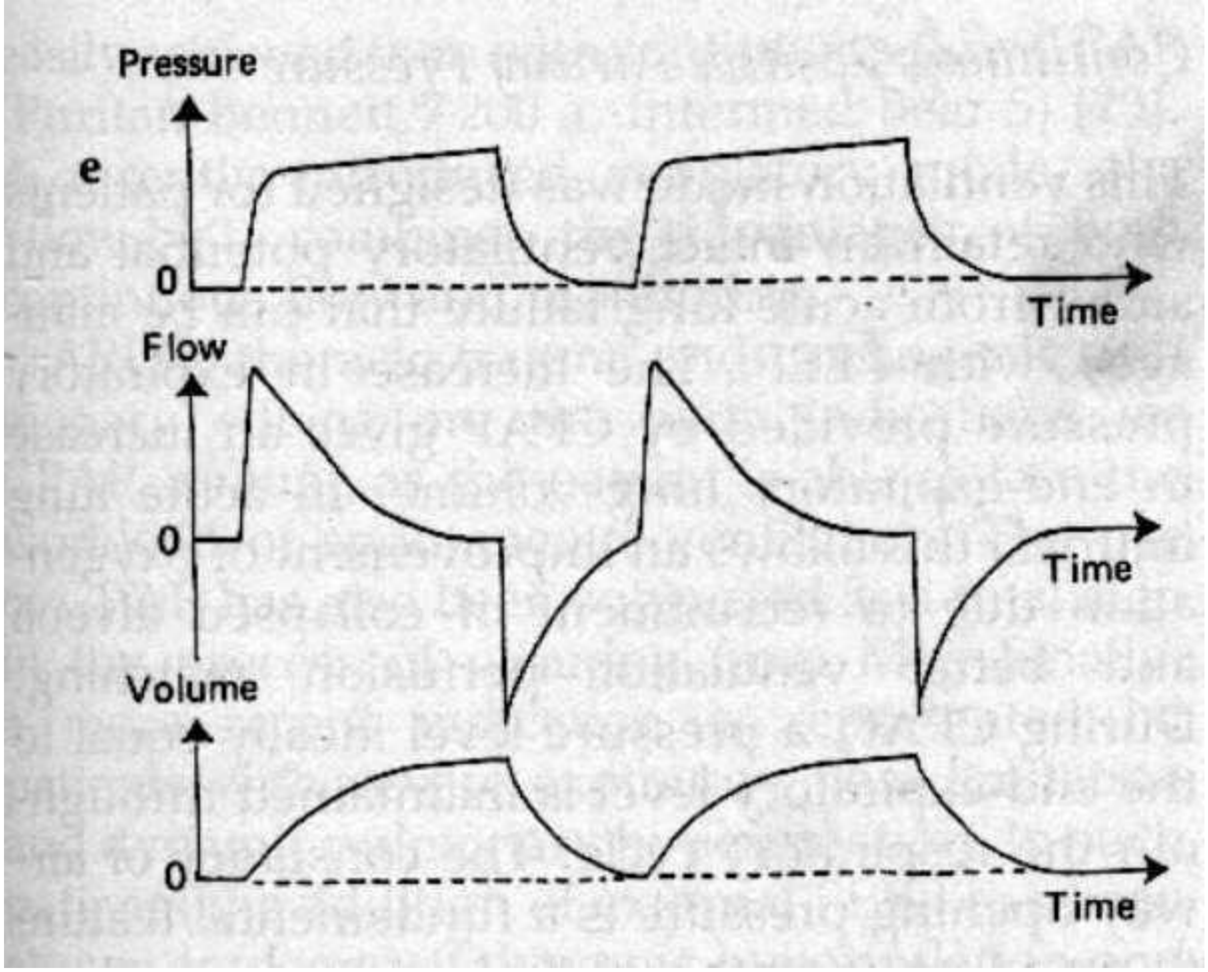
Advantages of PCV

- Flow rate is geared to reach PIP as quickly as possible
  - Flow will exceed patient demand
  - Improving patient ventilator synchrony
  - Decreasing the work of breathing
- Decelerating flow pattern and the square wave pressure pattern
  - distribution of gas within the lung can be improved.

Disadvantages of PCV

- Pressure remains constant
- Tidal volume may vary depending on
  - Compliance and/or airway resistance
- Hypo-ventilation may occur

Pressure-controlled ventilation with inverse ratio ventilation with I:E ratio 2:1



Spontaneous Ventilation

- Promote normal distribution of alveolar ventilation/perfusion ratio
- Minimizes ventilator-induced side effects.

Assisted Ventilation

- The ventilator triggered by the patient's inspiratory effort
- Number of ventilator breaths is determined by the patient's inspiratory effort
- Ventilators are activated when the patient withdraws a small volume of gas from the breathing circuit
- Creating a small negative pressure (1-2 cm H20 below baseline pressure) in the system
  - through activation of the respiratory muscles.

Too Tired to Trigger

- More respiratory work is necessary to create sub-atmospheric pressure
  - internal compliance of the ventilator is large
- flow-triggered assisted ventilation

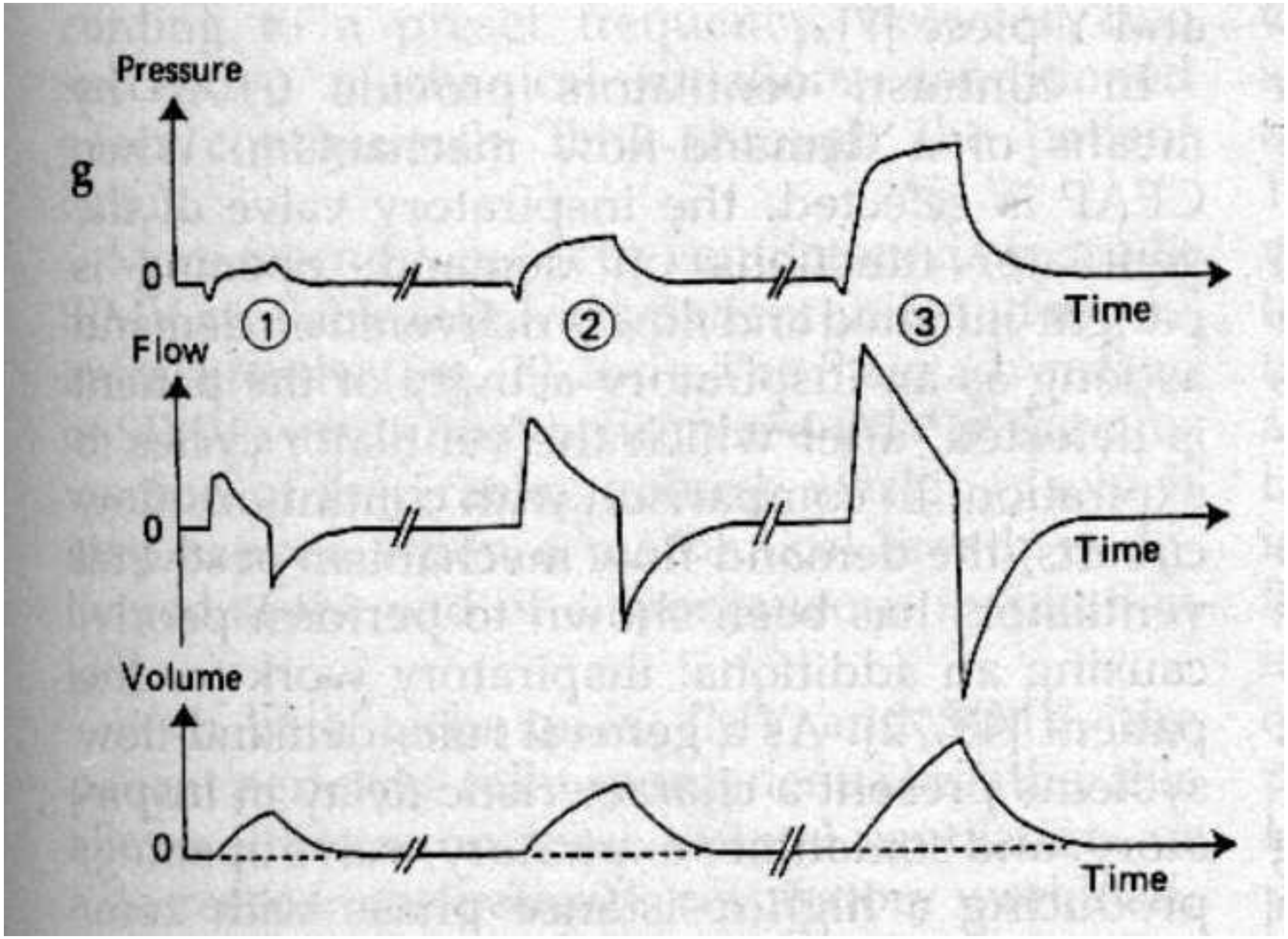
Indications for Assisted Ventilation

- Support patients with acute or chronic respiratory failure
- For patients fighting the ventilator
- For weaning from the ventilator
  - Response sensitivity must be preset
  - To avoid apnea episodes, a timing device is included

Modes of Assisted Ventilation

- Continuous Positive Airway Pressure (CPAP)
- Pressure Support Ventilation (PSV)
- Volume Support Ventilation (VS)
- Synchronized intermittent Mandatory Ventilation (SIMV)

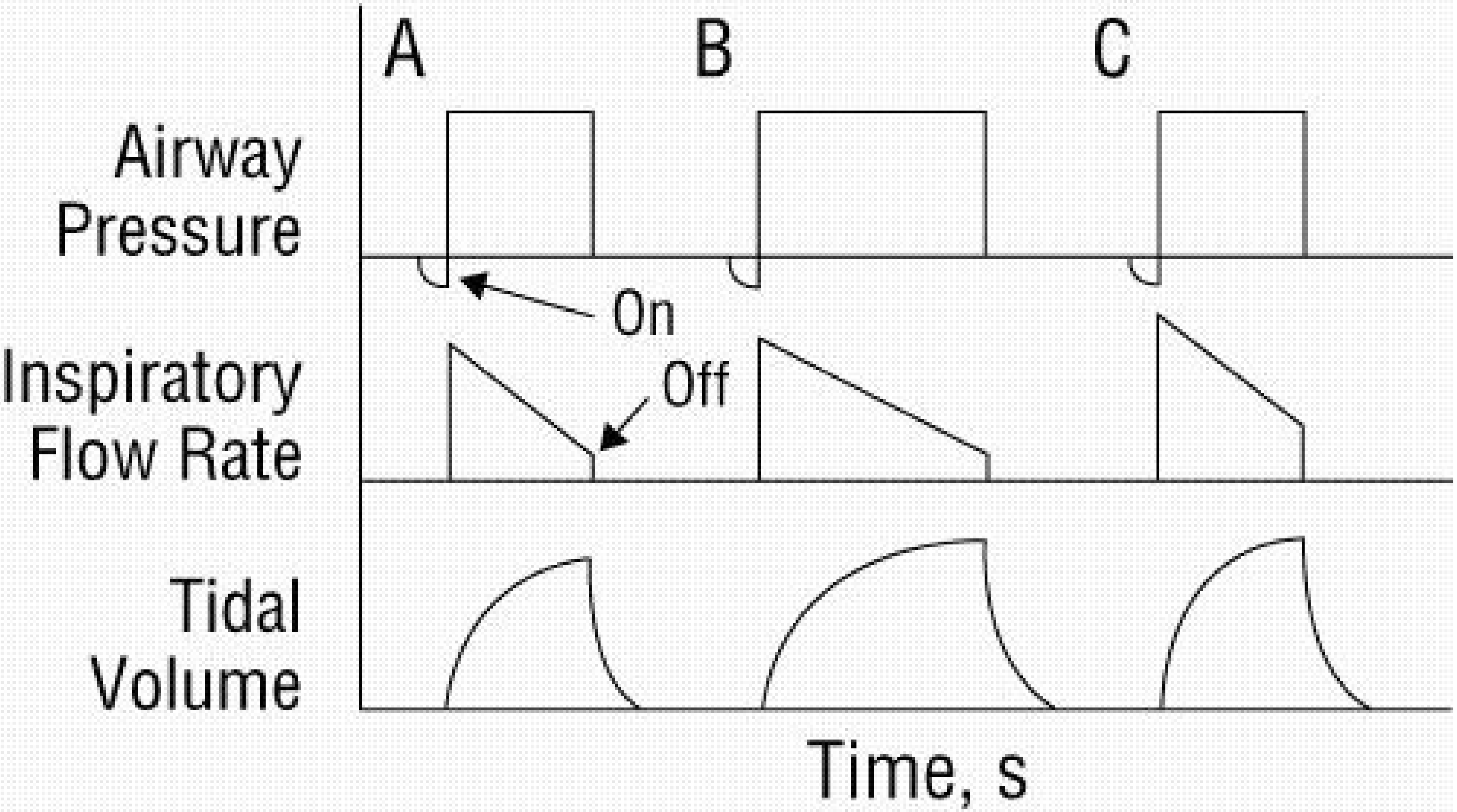
Pressure support ventilation set at three levels of pressure



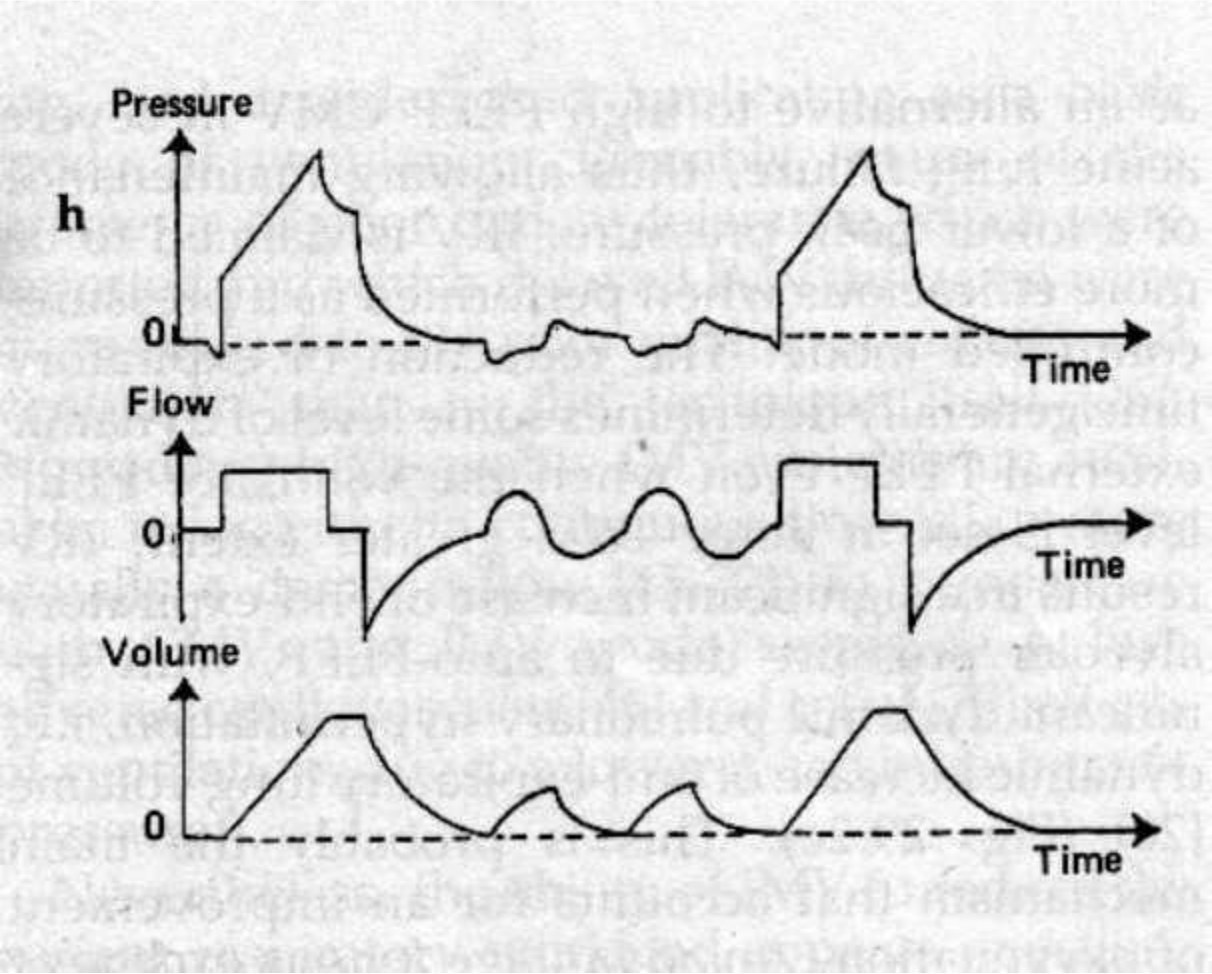
Pressure-support ventilation

- Sets a level of pressure
- Augment every spontaneous effort
- Airway pressure is maintained at a preset level
- Until the patient's inspiratory flow falls below a certain level
  - 25% of peak flow
- Tidal volume is determined by the level of pressure set, the patient's effort, and pulmonary mechanics.

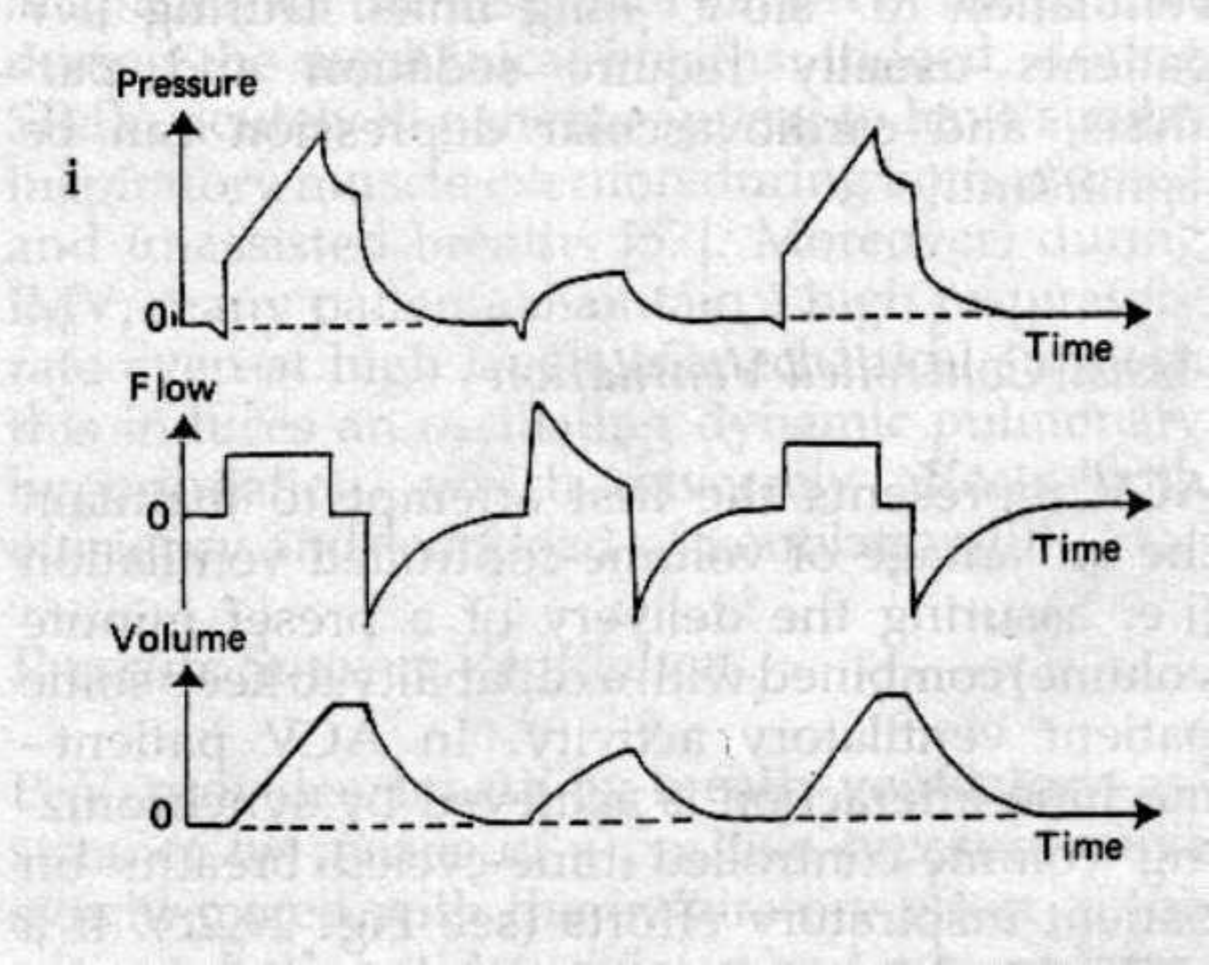
Pressure support



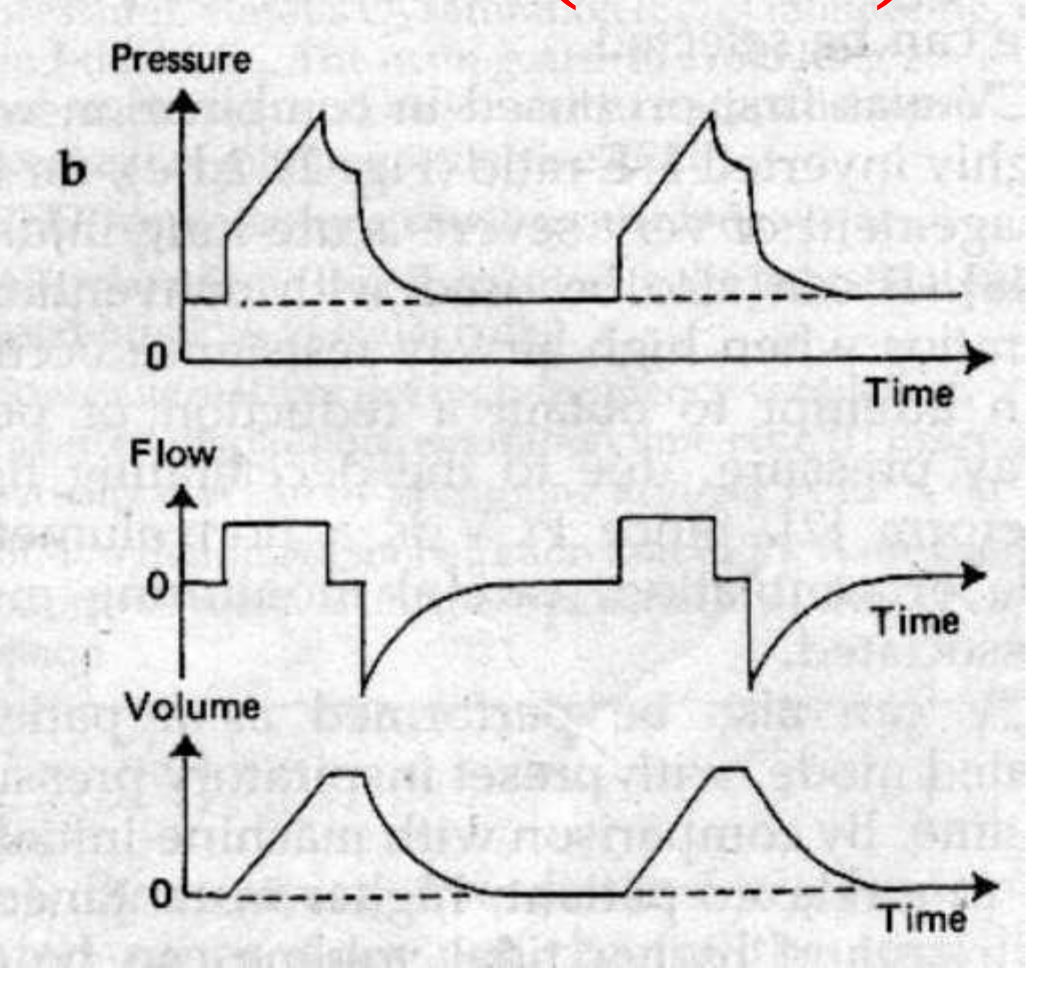
Synchronized intermittent mandatory ventilation (SIMV)



SIMV with PSV



Continuous positive pressure ventilation (CPAP)



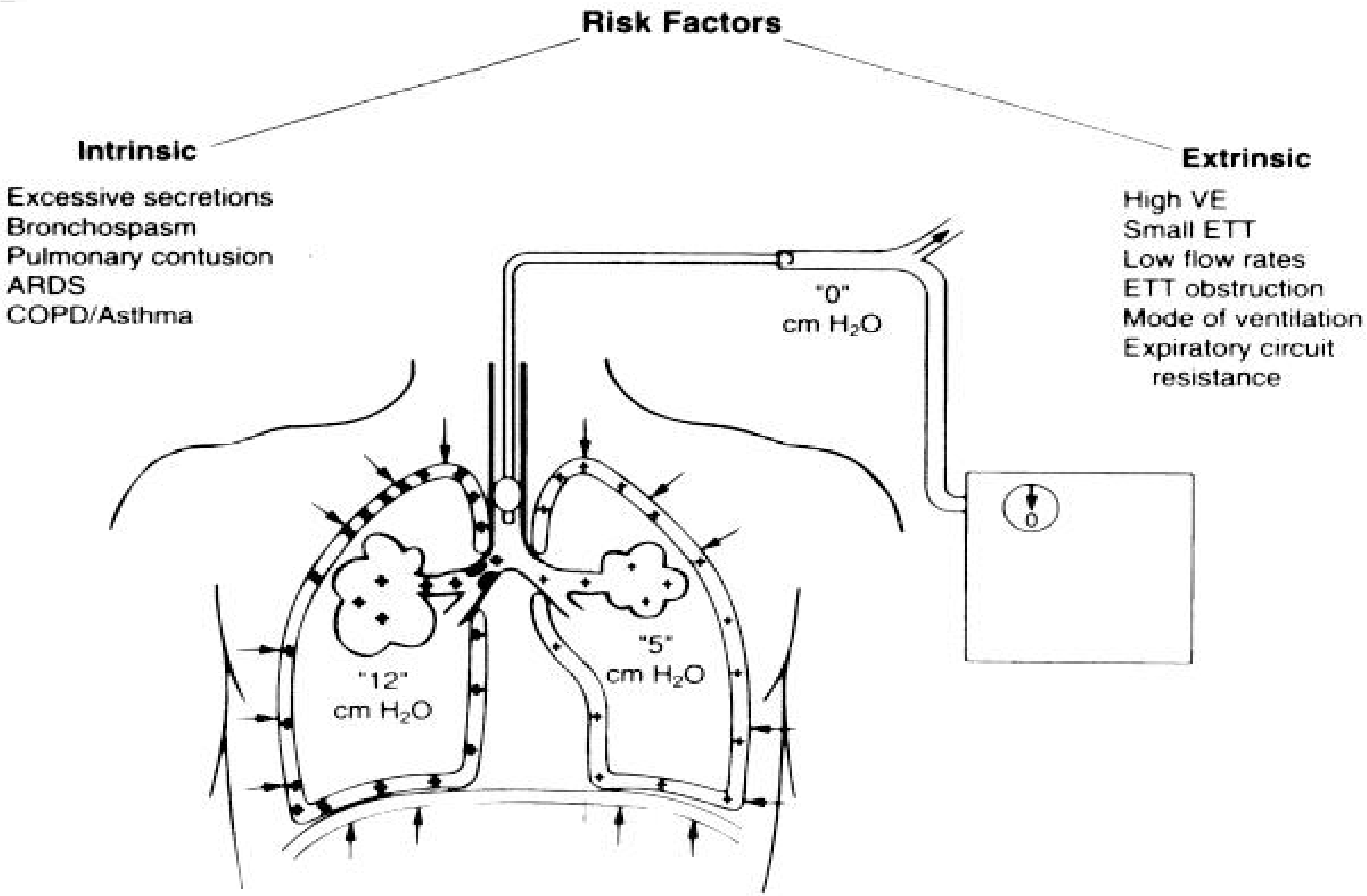
Methods to keep the lung open

1. intrinsic PEEP:
   - increased I:E ratio and constant frequency
   - High Frequency Ventilation (HFV)
2. External PEEP
3. Combined external and intrinsic PEEP
4. Pressure Regulated Volume Control (PRVC) mode
5. Surfactant replacement therapy

Risks of Mechanical Ventilation

- Excessively high concentrations of oxygen
- Large tidal volume
- High peak inspiratary pressure
  - for longer periods of time.
    - decrease in lung compliance with atelectasis
    - damage to the alveolar capillary membrane
    - followed by capillary leakage
    - pulmonary edema
    - inactivation of the surfactant system

AutoPEEP


Risk Factors
Intrinsic
Excessive secretions
Bronchospasm
Pulmonary contusion
ARDS
COPD/Asthma
Extrinsic
High VE
Small ETT
Low flow rates
ETT obstruction
Mode of ventilation
Expiratory circuit resistance
"0" cm H_2O
"12" cm H_2O
"5" cm H_2O
0

High Peak Inspiratary Pressure

- High shear forces can occur
  - Due to the presence of both collapsed and aerated parts of the lung
  - the major cause of structural damage
    - bronchiolar epithelium, alveolar epithelium)
    - formation of hyaline membranes
    - release of mediators from the disrupted parenchyma
    - triggering the pathophysiological mechanisms of ARDS.

Fighting

Clinical manifestations of patient Ventilator Incompatibility

- Ventilator alarm
- High peak airway pressure
- High respiratory rate
- Low or high minute ventilation
- Dyspnea
- Hypoxia

Management

- Sedation
- Muscle relaxant
  - Poor patient can not talk

Right step in manage ventilator fighting

- Physical Exam
- Respiratory and cardiovascular variables
- What is the cause of respiratory distress
- Manual bagging to differentiate ventilator or patient problem
- Correct or know the cause
- Sedation and muscle relaxant

Patient-Ventilator Incompatibility (Fighting)

- Immediately after Endotracheal intubation
  - cough and barking
  - inability to speak
- Endotracheal suctioning
  - Most horrible experience
  - acute cardiovascular changes
  - A red hot branding iron passed into trachea
    - WR Hayden. MD. A personal experience
- Change ventilation to positive airway pressure with fixed flow and tidal volume
- almost inevitable in alert patients
- Sedation

Patient Ventilator Interaction

- Two brains
  - Patient respiratory center
    - $PaCO_2$, PaO_2, pH, receptors in the airways and muscles, cortex
  - Ventilator
    - setting of the ventilator by the medical personnel, trigger and cycling-off mechanisms.
- Two pumps
  - **Patient respiratory muscle**
    - **Inspiratory negative pressure, active expiration**
  - **Ventilator**
    - **Inspiratory positive pressure, passive expiration**

High Ventilatory Requirements

- Hyperpnea or hyperventilation
  - Sepsis
    - Peripheral Neural Modulation of Endotoxin induced hyperventilation.
      - Tang, Crit. Care Med,1998
  - Brain injury
  - Anxiety
- Treatment
  - Increase circuit dead space
  - Sedation and Paralysis

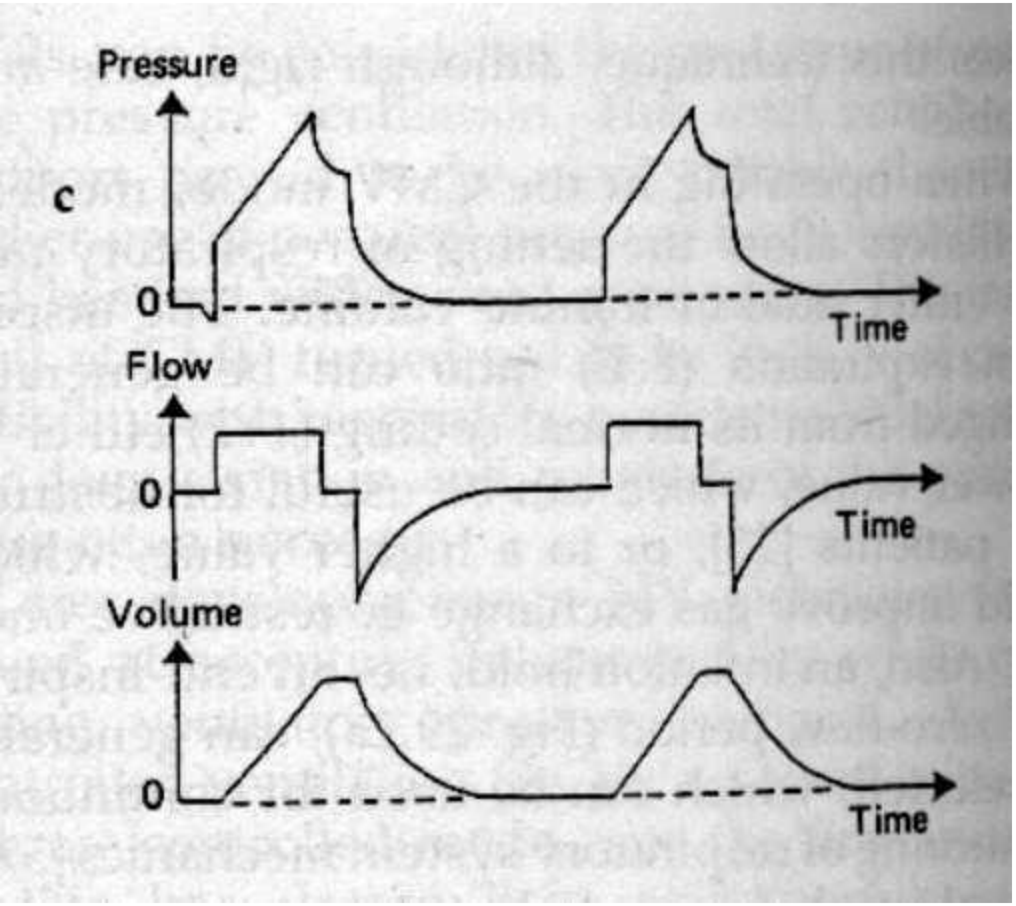
Physical Signs of Respiratory Distress

- **Diaphoresis and nasal flaring**
- **Heightened Sternomastoid activity**
- **Recession of the suprasternum and supraclavicular spaces**
- **Intercostal spaces recession**
- **Paradoxical motion of the abdomen**
- **Tachycardia and tachypnea**
  - **patients can not talk**

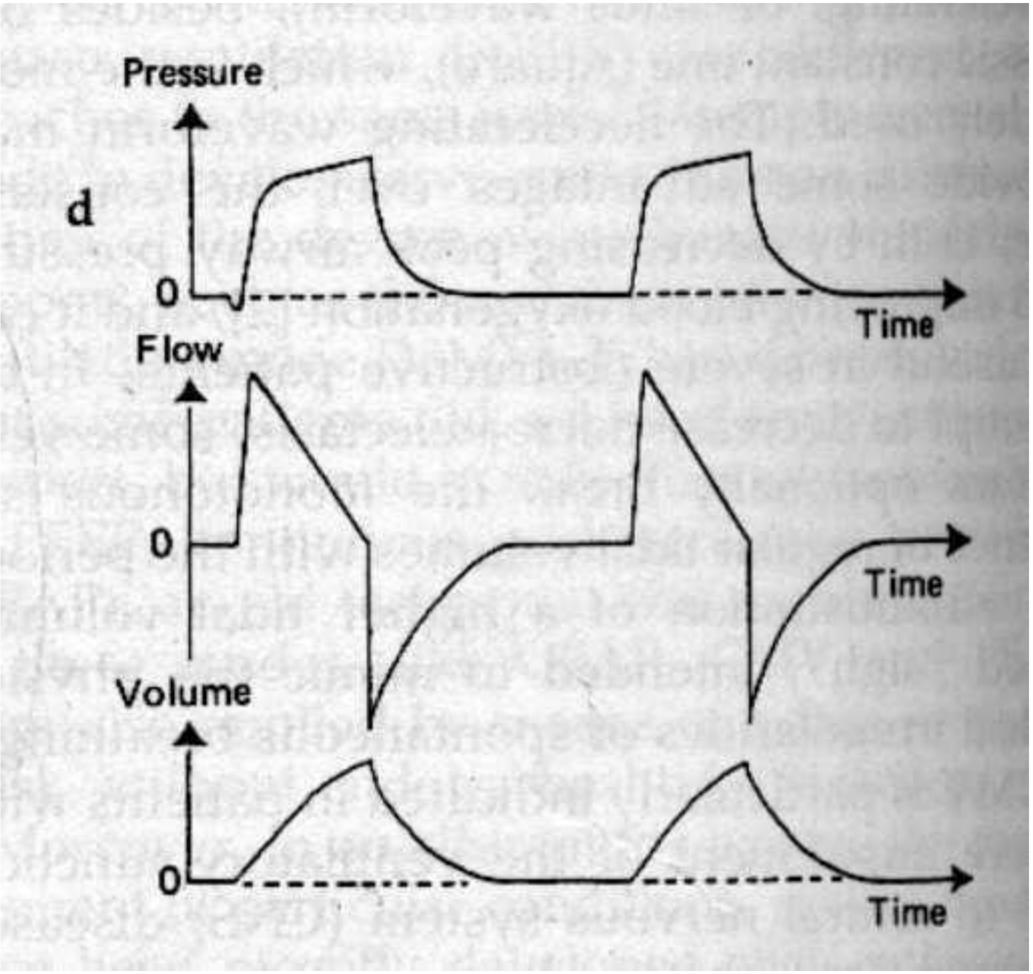
Management of Sudden Respiratory Distress in a Ventilator-supported Patient

- Remove the patient from the ventilator
- Initiate manual ventilation with 100% oxygen
- Physical examination and assess monitored indices
- Passing a suction catheter to check patency of the airway
- If death is imminent, consider and treat the most likely causes
  - pneumothoax, airway obstruction
- Once a patient is stabilized, find the most suitable ventilator setting

Assist-controlled ventilation with constant flow, patient initiated cycle



Pressure-controlled ventilation in a relaxed patient



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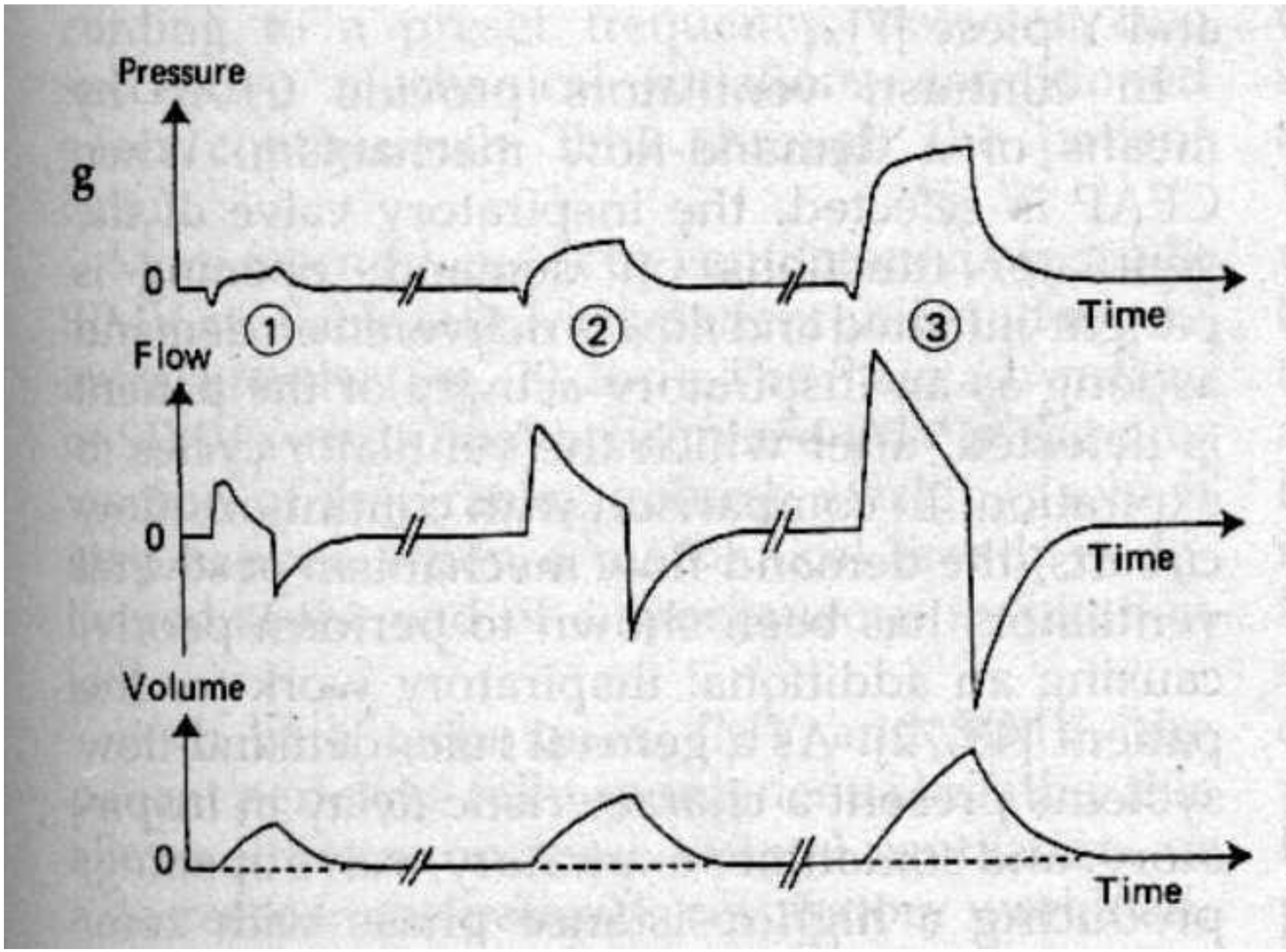
Pressure support ventilation



Ventilator setting

- Selecting the mode and settings of the ventilator is a dynamic process that is based on a patient's physiologic response rather than a fixed set of numbers. The settings require repeated readjustment over the period of dependency on the ventilator, and such iterative interaction requires careful respiratory monitoring

Patient-Related Causes of Respiratory Distres

- Artificial airway problem
- Pneumothorax
- Bronchospasm
- Secretions
- Dynamic hyperinflation (AutoPEEP)
- Pulmonary edema

- Abnormal respiratory drive
- Alteration in body posture
- Drug-induced distress
- Abdominal distension
- Anxiety
- Patient-ventilator asynchrony

Artificial Airway Problems

- Migration of ET tube
  - into main bronchus
  - One lung ventilation
- Cuff herniation
- Cuff leak
- Endotracheal tube kicking and obstruction

Secretions

- The most common problem.
- Too dry
  - avoid artificial nose
  - increase temperature setting of humidifier
- Too copious
  - CPT
  - Frequent suctioning
  - Bronchoscope suction

Tension Pneumothorax

- Vulnerable groups
  - – ARDS
  - – COPD
  - – Necrotizing pneumonia
- High peak airway pressure
  - – No pneumothorax if PAP < 60 cm H2O
  - – 43% if PAP > 70 cm H2O
    - Crit care Med, 1983.

Barotrauma

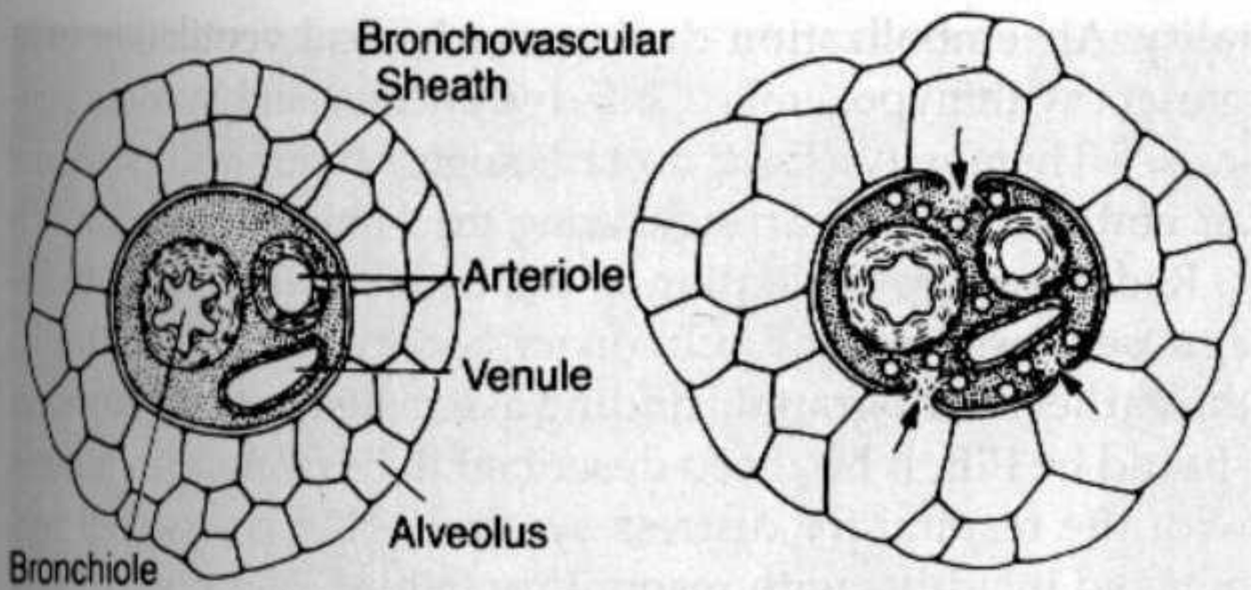
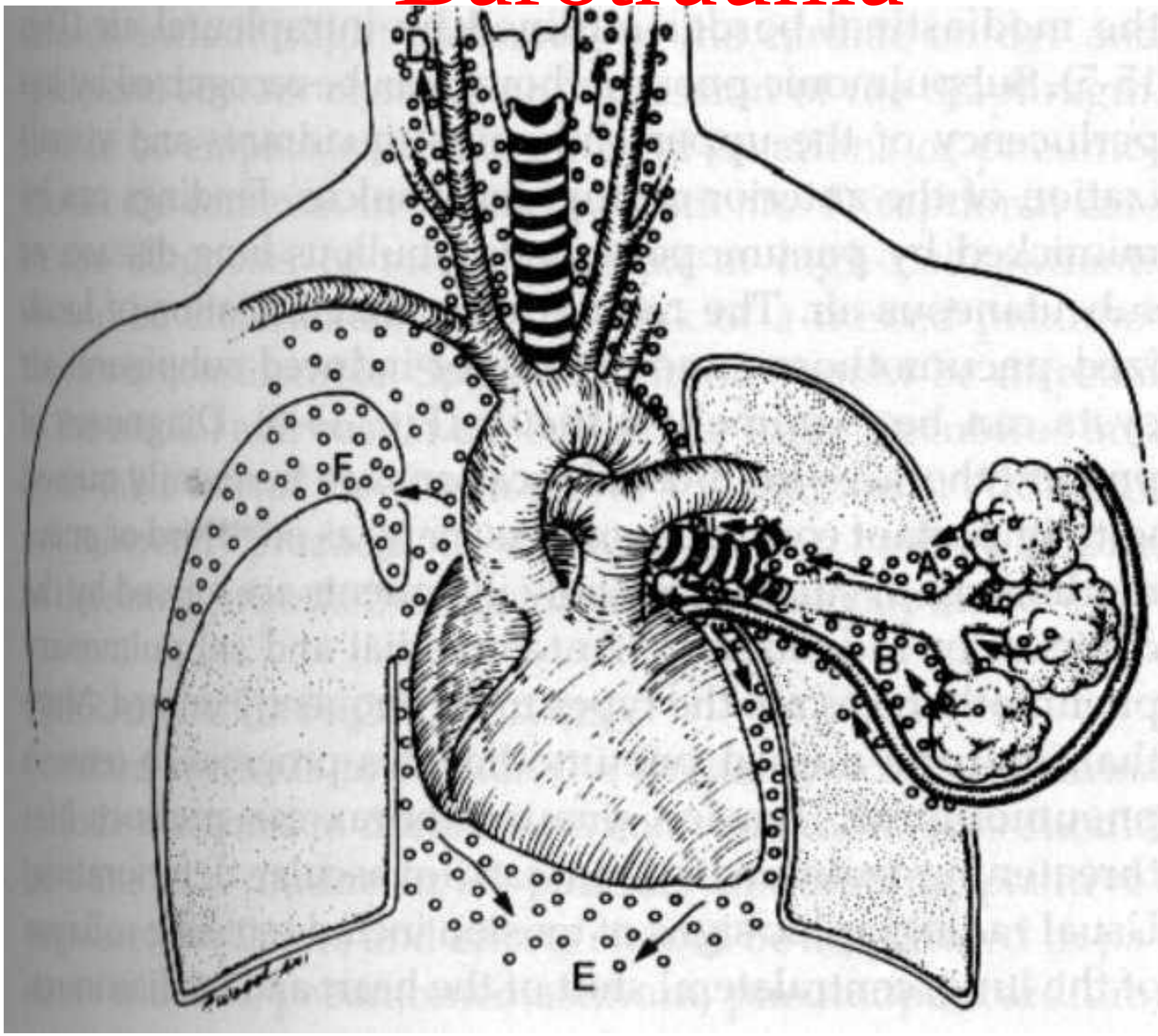
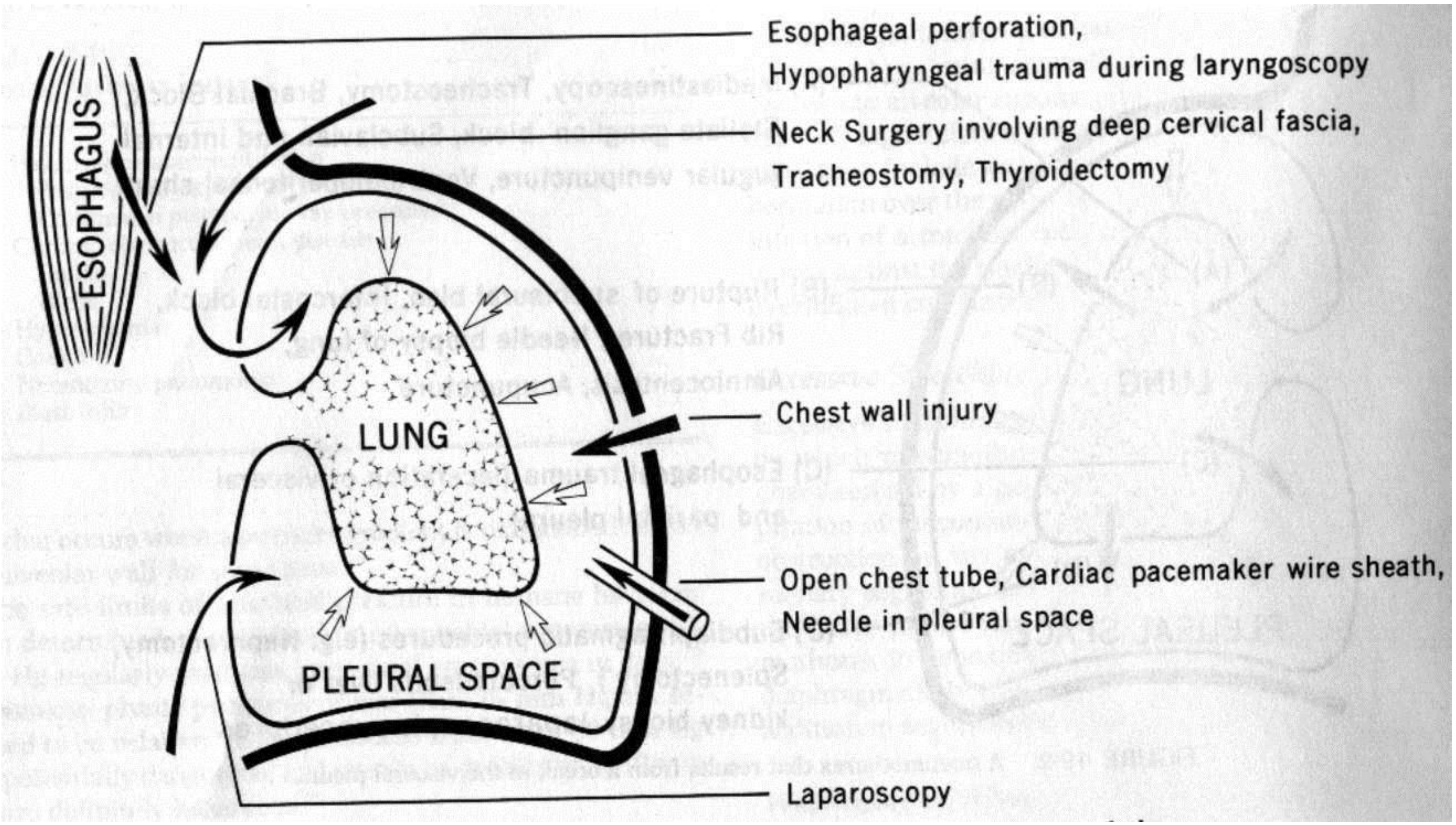


FIGURE 15-1 Cross-sectional diagram of bronchovascular bundle surrounded by alveoli in the normal state (*left*) and after alveolar rupture (*arrows, right*) resulting from overdistention. (*Reproduced with permission from Bowton et al.*[12])

Barotrauma



pneumothorax results from a break in the parietal pleura



Clinical manifestation of Tension Pneumothorax

- Respiratory distress
- High airway pressure
- Hyperresonance
- Decreased breathing sound
- Tracheal deviation to contralateral side
- Tachycardia and hypotension
- High CVP, pulsus paradoxus

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Management of Pneumothorax

- Stable
  - Chest tube drainage after CXR
- If cardiovascular collapse is imminent
  - 14 or 16 gauge needle attach to a liquid field syringe
  - Inserted into 2 nd intercostal space

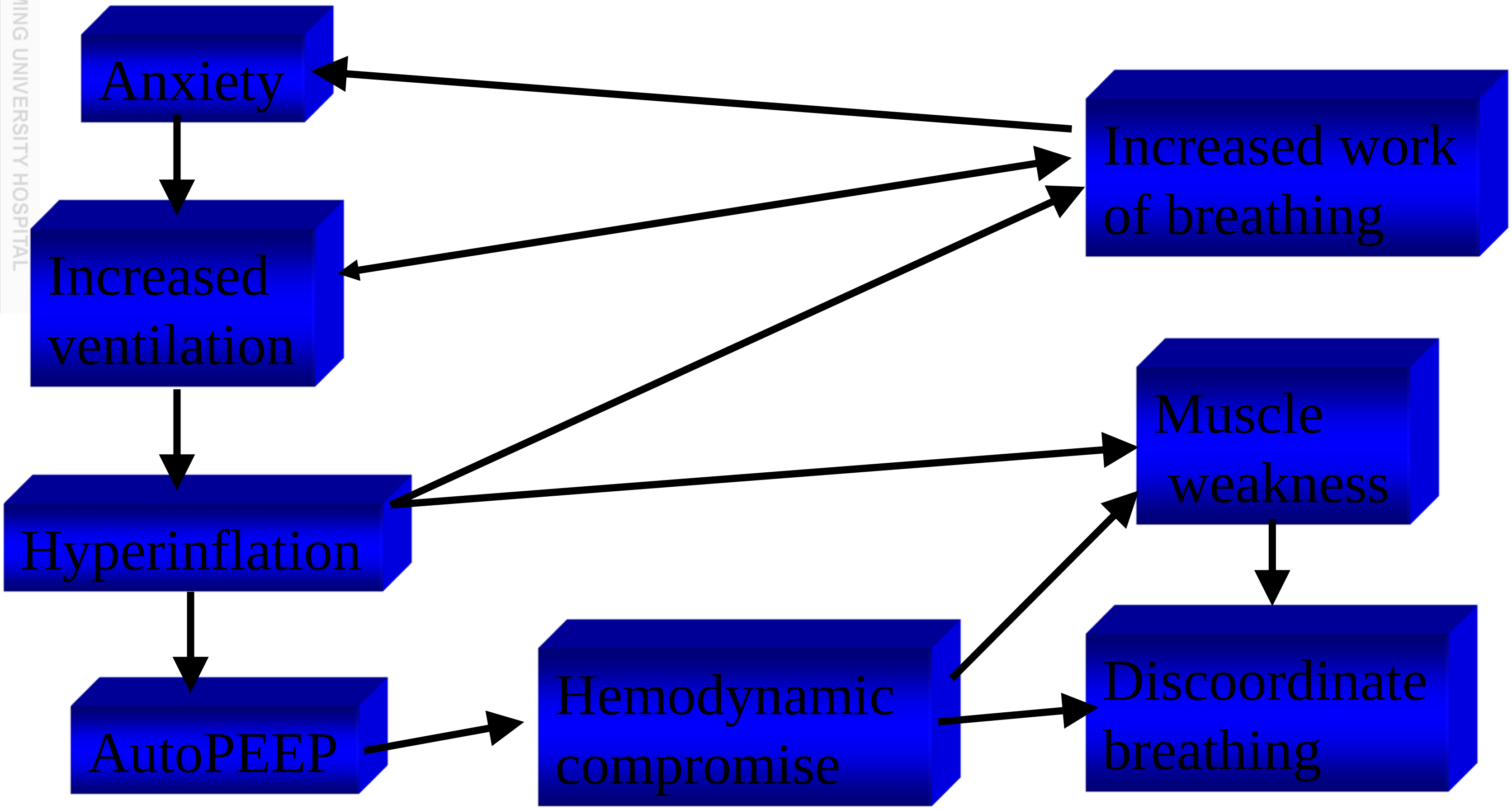
Bronchospasm

- Airway resistance increase
- High peak airway pressure
- Decrease dynamic compliance, normal static compliance
- Wheezing
- Increase work of breathing
- No airflow
  - Irritation of airway by endotracheal tube or secretion
  - Excerbation of the bronchial asthma

MANAGEMENT of BRONCHOSPASM

- Inhale bronchodilator
  - Beta 2 agonist
- Systemic or inhaled Steroid
- Theophylline
- Sedation
- Inhalation anesthetics

Panic Cycle of Patients with Severe Airflow Obstruction



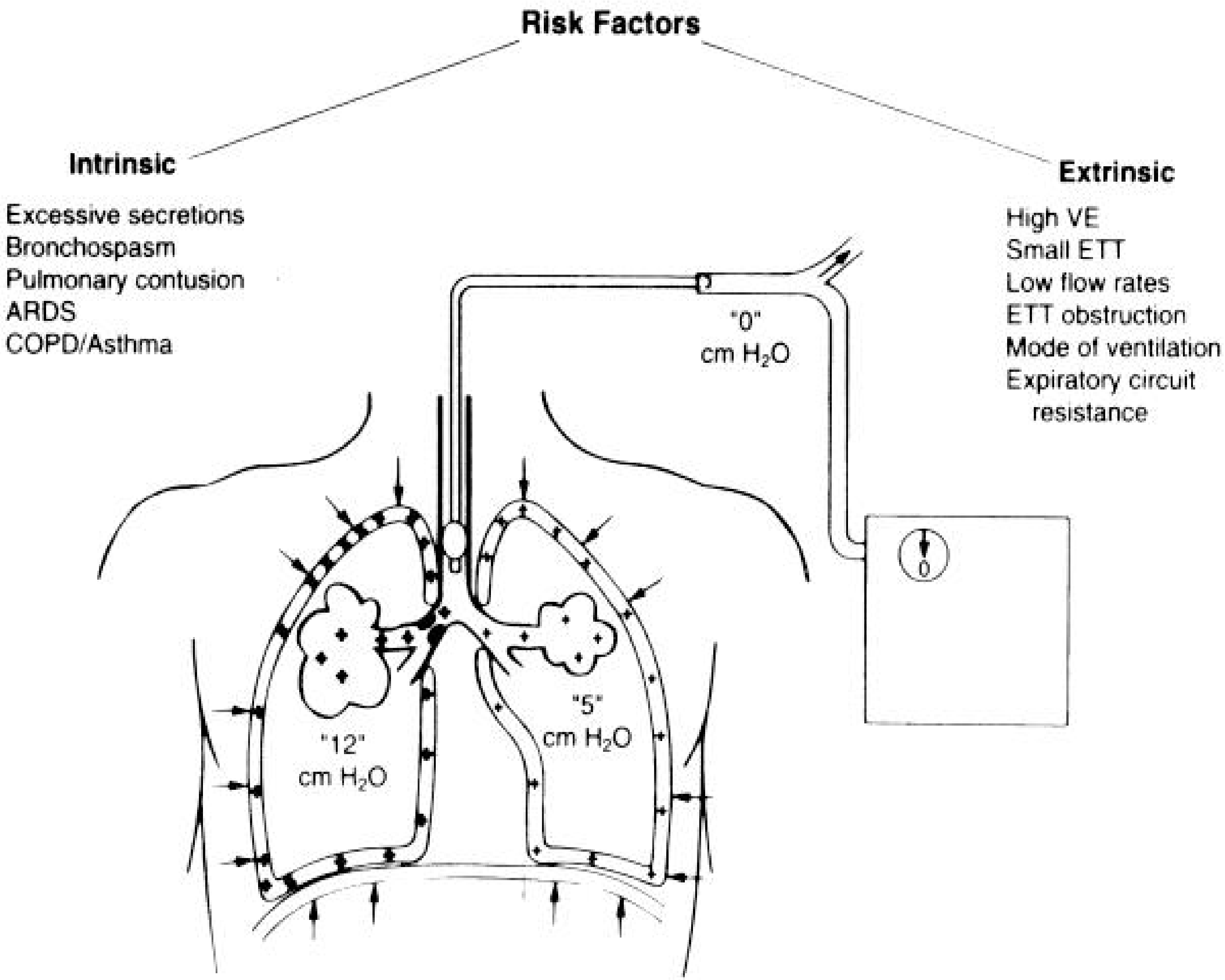
Auto PEEP

- Dynamic Hyperinflation
- Cause:
- Retarded expiratory flow
  - Increased airway resistance
  - Shortened expiratory time
  - Reduced elastic recoil of the lung
  - Hyperventilation

How auto PEEP induce fighting?

- Increase the triggering negative pressure
  - **to counterbalance autoPEEP**
- Predispose to barotrauma
- Impede venous return
- Increase the work of breathing
- Decrease work efficiency of respiratory muscle

auto PEEP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ETT obstruction
Mode of ventilation
Expiratory circuit resistance
"0" cm H_2O
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0

Strategies to Reduce AutoPEEP

- Facilitate airflow
  - bronchodilators and steroid
  - using larger endotracheal tubes
- Decrease inspiratory time
  - higher flow, lower rate, lower volume
- Increase expiratory time
- External PEEP to counterbalance autoPEEP

Abdominal Distension in Patients Receiving Ventilators

- Gastric distension
  - Tracheal P. > Cuff P. (mouth closed)
  - Mouth P. > P. of GE junction
  - Prolonged or difficult intubation
  - aerophagia
- Distension Basilar atelectasis
  Hypoxemia Respiratory distress

Sudden Respiratory Distress due to Ventilator-related Causes

- System leak
- Circuit malfunction
- Inadequate FiO2
- Inadequate ventilatory support
- Improper trigger sensitivity
- Improper inspiratory flow setting
- Patient-ventilator asynchrony

吸不到氣

- Trigger sensitivity (-1 cm H2O)
- More respiratory work is necessary to create sub-atmospheric pressure
  - Inspiratory muscle weakness or fatigue
  - AutoPEEP
  - Increased airway resistance (ET tube and circuit)
  - Delayed response time of the valve
- too sensitive
    - autocycling

Measures to Shorten the Trigger Phase

- Reduce autoPEEP
- Respiratory muscle rest
- Reduce airway resistance
  - bronchodilator, larger ET tube
- Flow trigger or flow-by
- Shift the pressure sensor near the ET tube
- Change ventilator

吸不到氣

- VC: Flow do not meet patient demand
  - Inspiratory-flow rate of 60 liters per minute
  - In patients with chronic obstructive pulmonary disease, anxiety
    - flow rate of 100 liters per minute
    - increase in expiratory time for complete emptying of gas-trapped regions

吸不到氣

- PS: Inadequate pressure
  - Increase pressure
- Resistance of ET tube and circuit
  - Large ET tube
  - Shorten the circuit

想要時沒有
不想要時太多

- Volume control
  - Fixed flow
  - Fixed tidal volume
  - Fixed inspiratory time
- Pressure support

Reduce Ventilatory Demand

- **Reduce CO_2 production**
- **Reduce deadspace**
- **Reduce ventilatory drive**
  - **correct metabolic acidosis**
  - **reduce psychogenic stress**

法寶

- Sedation
- Neuromuscular blocking agent
  - make sure
    - No hypoxia
    - No hypoglycermia
    - Correct the correctable