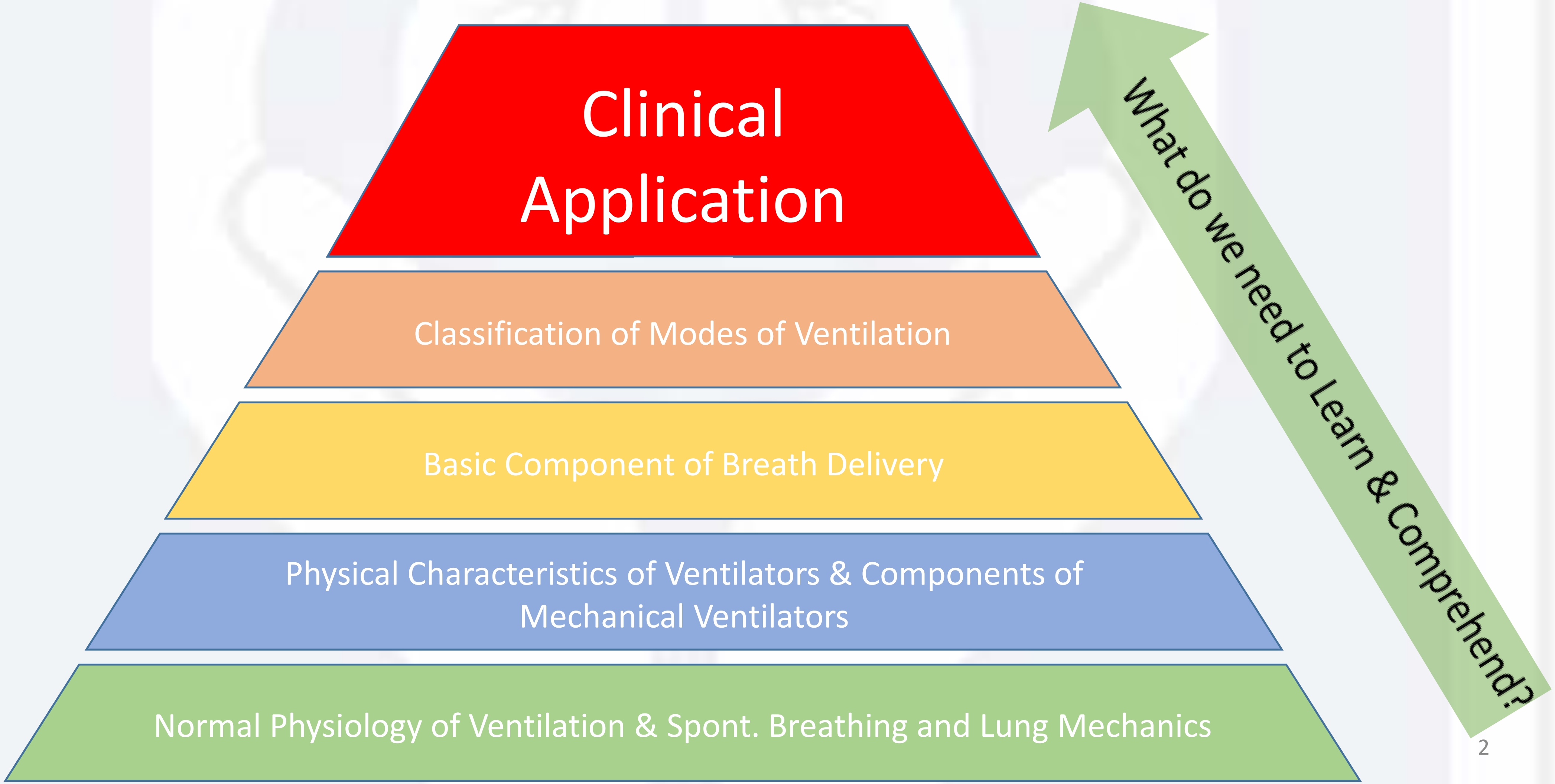
Mechanical Ventilation (101)

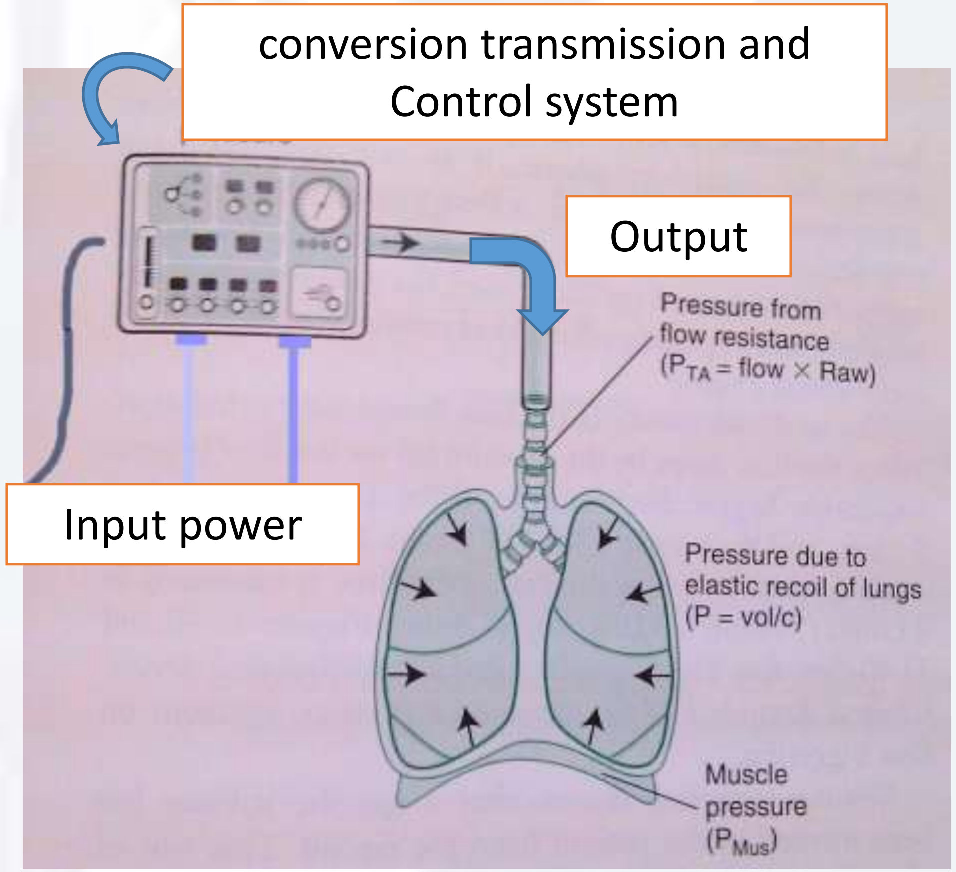
Mastering Mechanical Ventilation



Physical Characteristics of Ventilators & Components of Mechanical Ventilators

Ventilator characteristics

- Input power (Electrical, pneumatic)
- Power conversion and transmission
- Control system
- Output (flow: Pressure and volume)

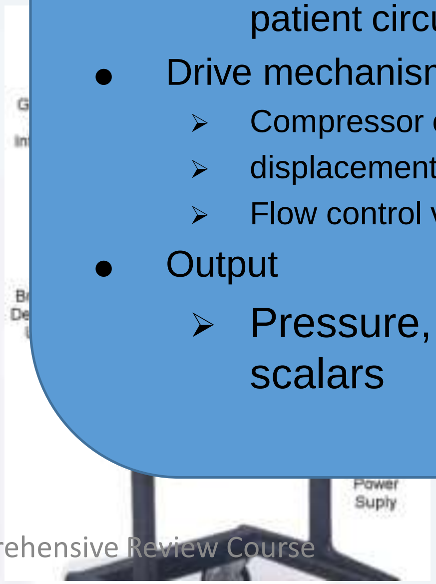


Components of a Ventilator

Those components are:

- User interface
- Breath Delivery [Patient] Unit
- Backup power supply [Rechargeable batteries]
- Air compressor.

- Physical characteristics
  - Ventilator power source
    - Electrically powered ventilator
    - Pneumatically powered ventilator
    - Combined Power Ventilators
- Positive or negative pressure
- Control systems and circuits
  - Open- and closed-loop systems
  - Control panel: user interface
  - Pneumatic circuit (internal and patient circuit)
- Drive mechanism
  - Compressor or Blowers
  - displacement
  - Flow control valves
- Output
  - Pressure, volumes, and flow scalars



Power Source

- **Ventilator power source**
  - Electrically powered ventilator
  - Pneumatically powered ventilator
  - Combined Power Ventilators
- **Combined Power Ventilators**
  - Current ICU ventilators use microprocessor control and 50 psi sources of oxygen and air and are Combined Power Ventilators
  - Current ICU ventilators are classified as Electrically Powered-Pneumatically Driven-Microprocessor Controlled Ventilators

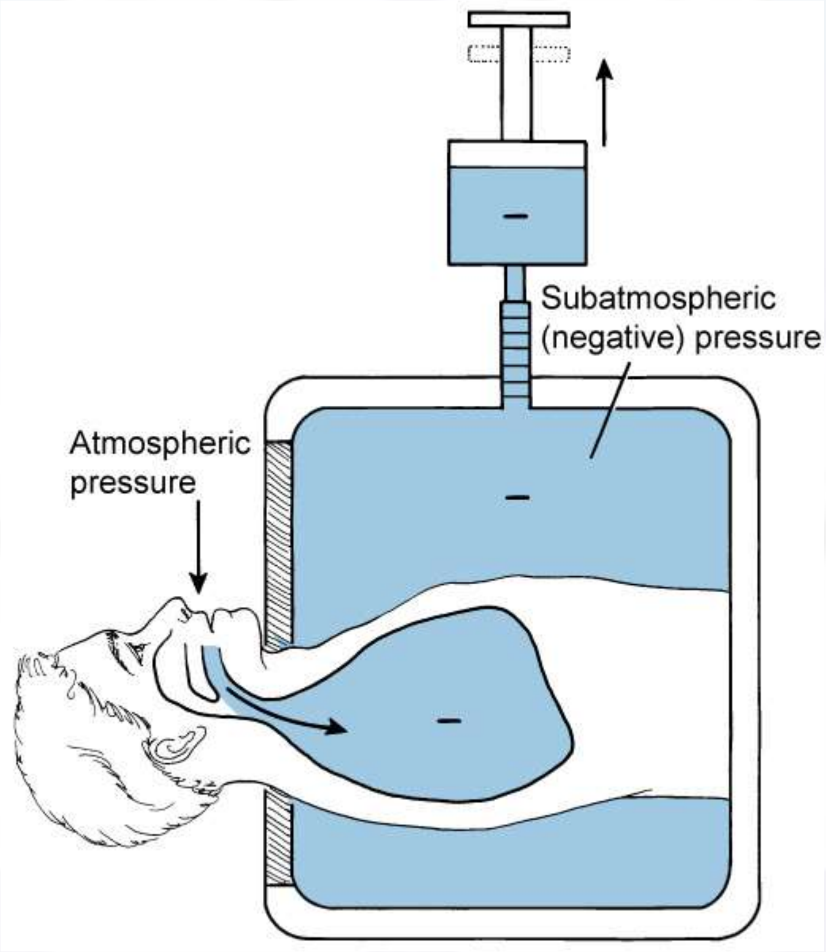
Pressure Delivery

- Negative-pressure ventilators
  - Iron lung
  - Chest cuirass
- Positive-pressure ventilators
  - Most ventilators used today are positive-pressure ventilators
  - Examples include: Puritan Bennett 840, Servo^{i}, and Hamilton G-5
- Combined Pressure Devices
  - High-frequency oscillators

Negative-Pressure Ventilators

- Attempt to mimic normal spontaneous ventilation
- When negative pressure is applied, thoracic volume is increased and air enters lungs
- During exhalation, negative pressure is removed and air leaves lungs

Negative-Pressure Ventilators (Cont.)

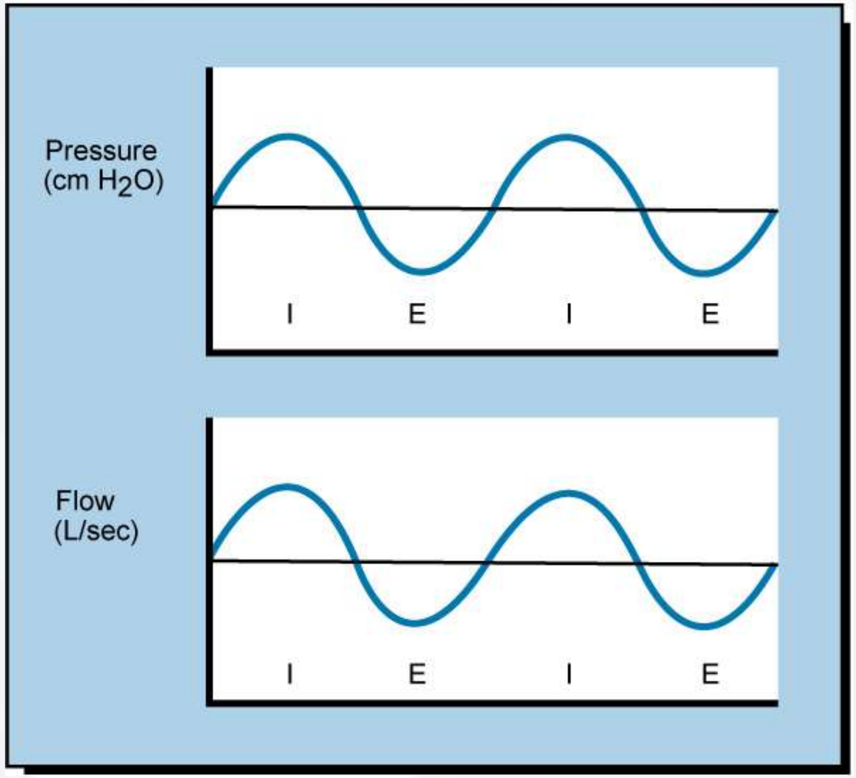


Negative-Pressure Ventilators (Cont.)

- Types of negative-pressure ventilators:
  - Chest cuirass: chest shell applies negative pressure only to chest
  - Tank ventilator: applies negative pressure to entire body
- Negative-pressure ventilators rarely used in ICU
- Sometimes used in home care setting

Combined Pressure Devices

- Most common application is high-frequency oscillator
- Sinusoidal pressure wave includes positive and negative pressure applied to airway

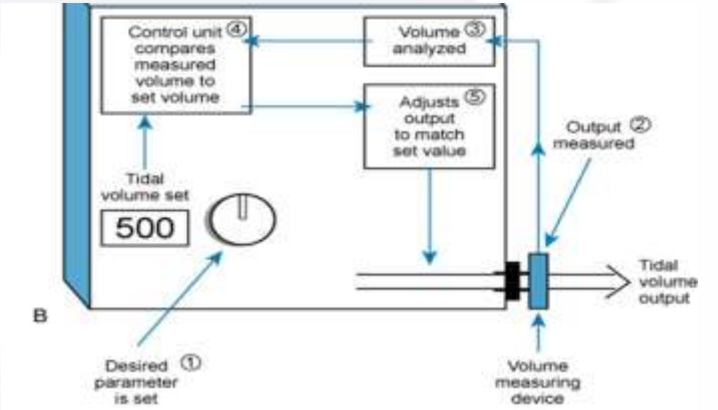


High-frequency oscillators

Control System & Circuit

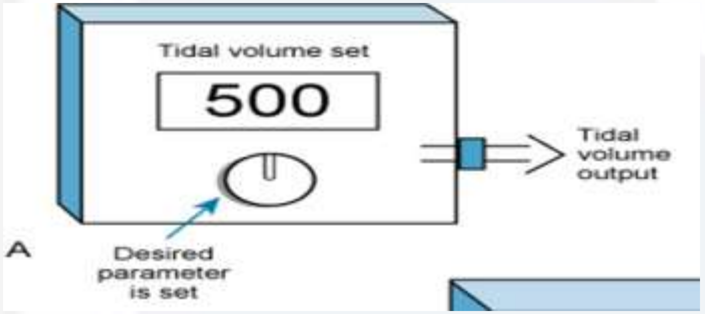
- Control systems and circuits
  - Open- and closed-loop systems (Control level)
  - Control panel: user interface
  - Pneumatic circuit (internal and patient circuit)

Control Type (level of control)



Open loop control system

- An open-loop system cannot distinguish between the volume actually delivered and the set volume and respond to this difference.
- Operator sets parameter that is delivered by ventilator
- No assurance that volume or pressure is actually delivered to lungs



Closed loop control system

- Closed-Loop systems are an intelligent system
- Flow/volume or pressure are set & measured, with feedback to drive mechanism altering output to maintain desired (set) levels
- Microprocessor is used to control ventilation
- When specific tidal volume is set, ventilator adds to volume if there is leak in circuit
- Ventilator adjusts delivered volume or pressure to ensure that set parameter is delivered

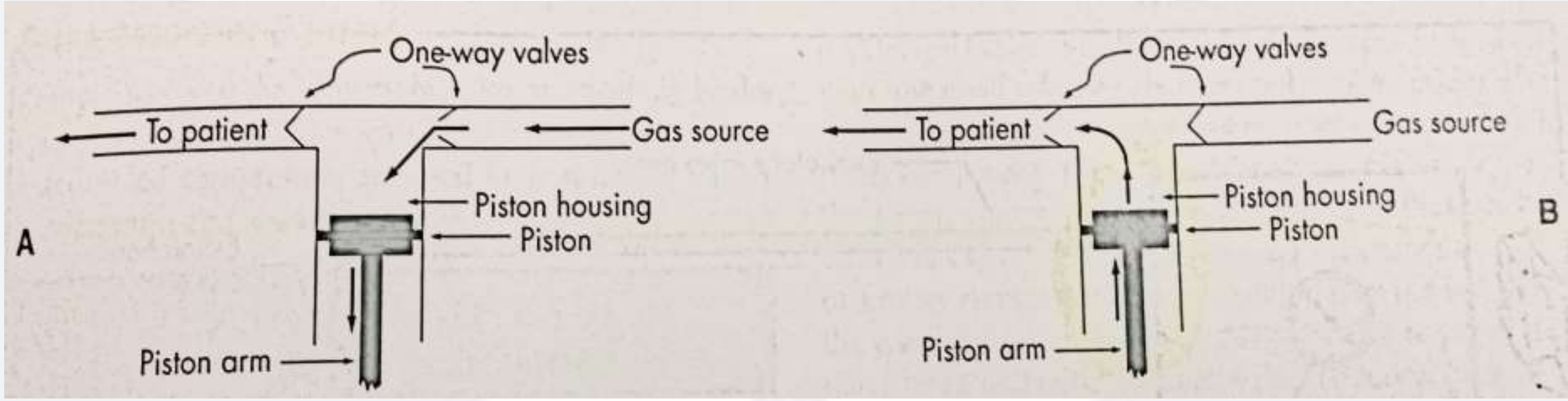
Pneumatic Circuit

- **Consists of two series of tubing:**

1. Internal Circuit: directs flow within the ventilator. It can be single or double circuit.
2. The External Circuit (Patient Circuit): directs the flow from the ventilator to the patient.

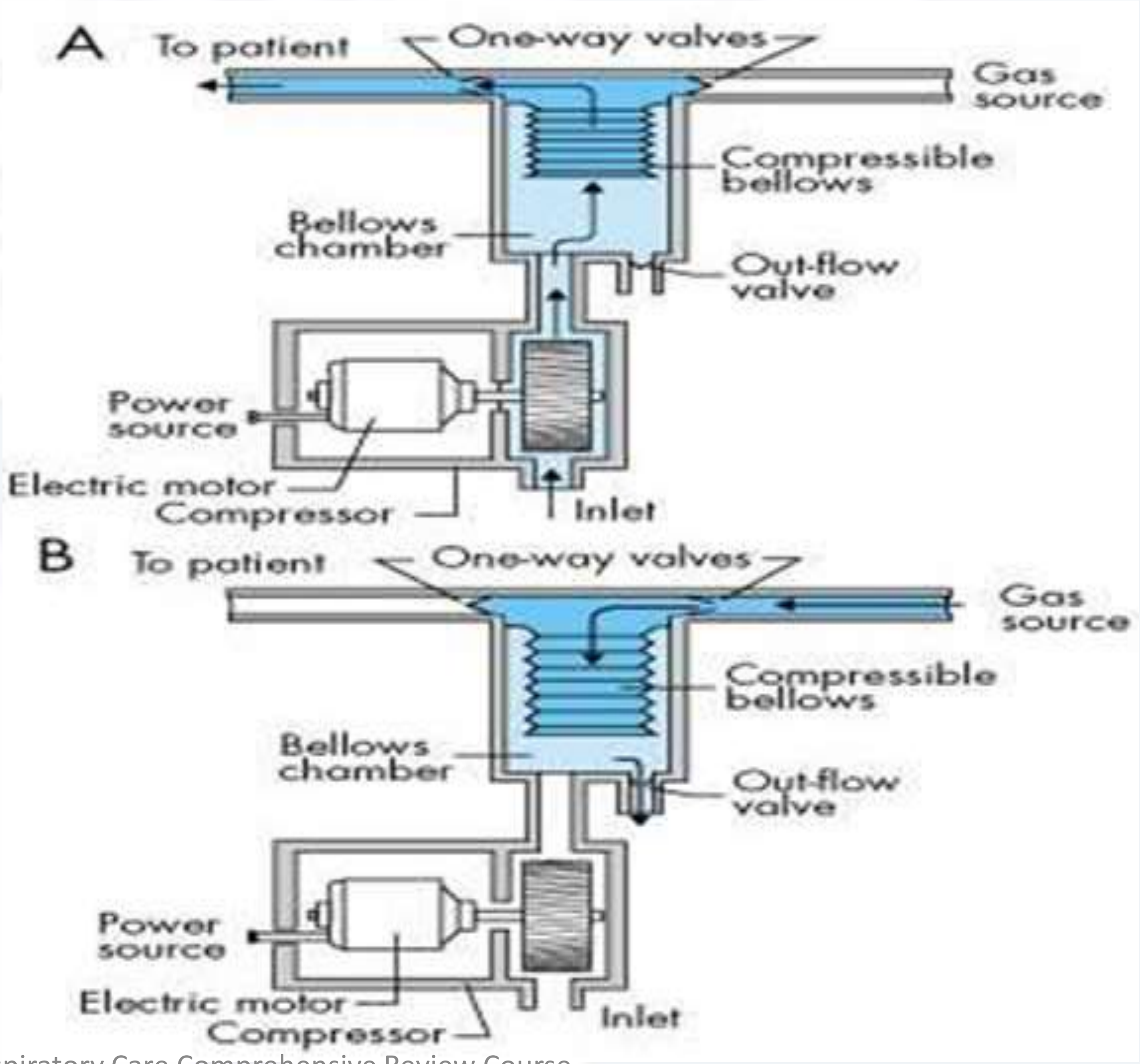
Internal Circuit (Single-circuit design)

- Single circuit: gas moves through ventilator and is delivered to patient circuit. Most commonly used

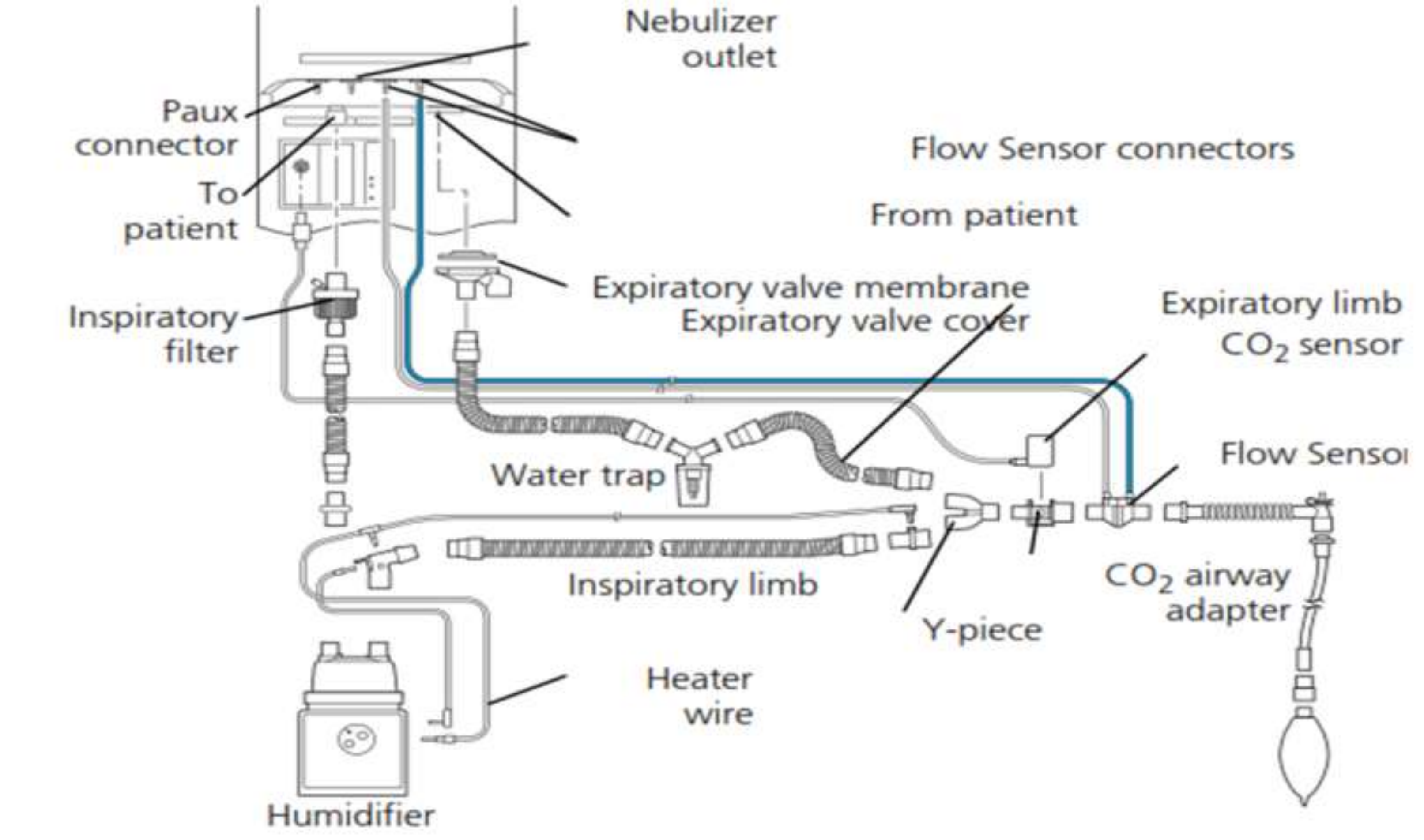


Internal Circuit (Double-circuit design)

- Double circuit includes bellows or a bag containing desired tidal volume
- Bag is compressed and desired tidal volume is delivered to lungs



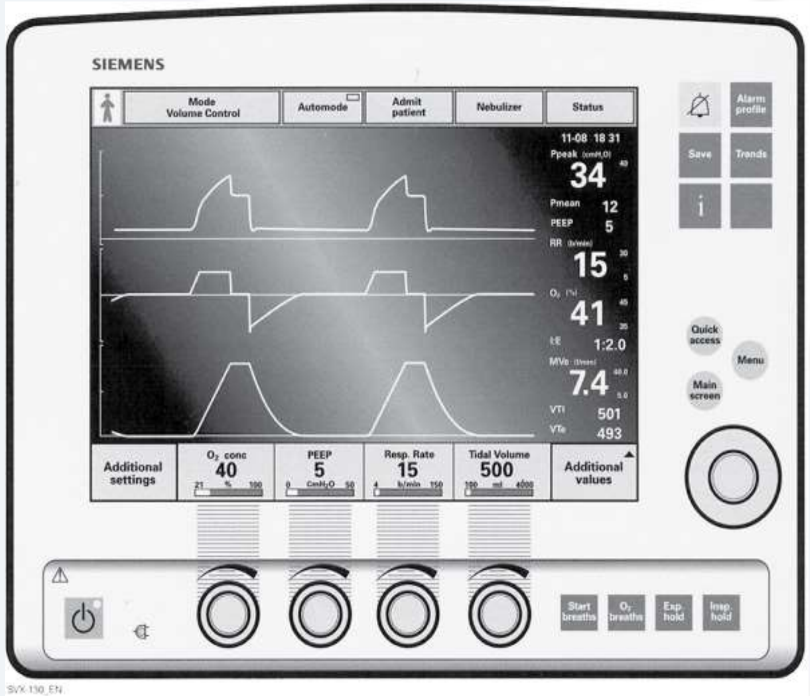
The External Circuit (Patient Circuit)

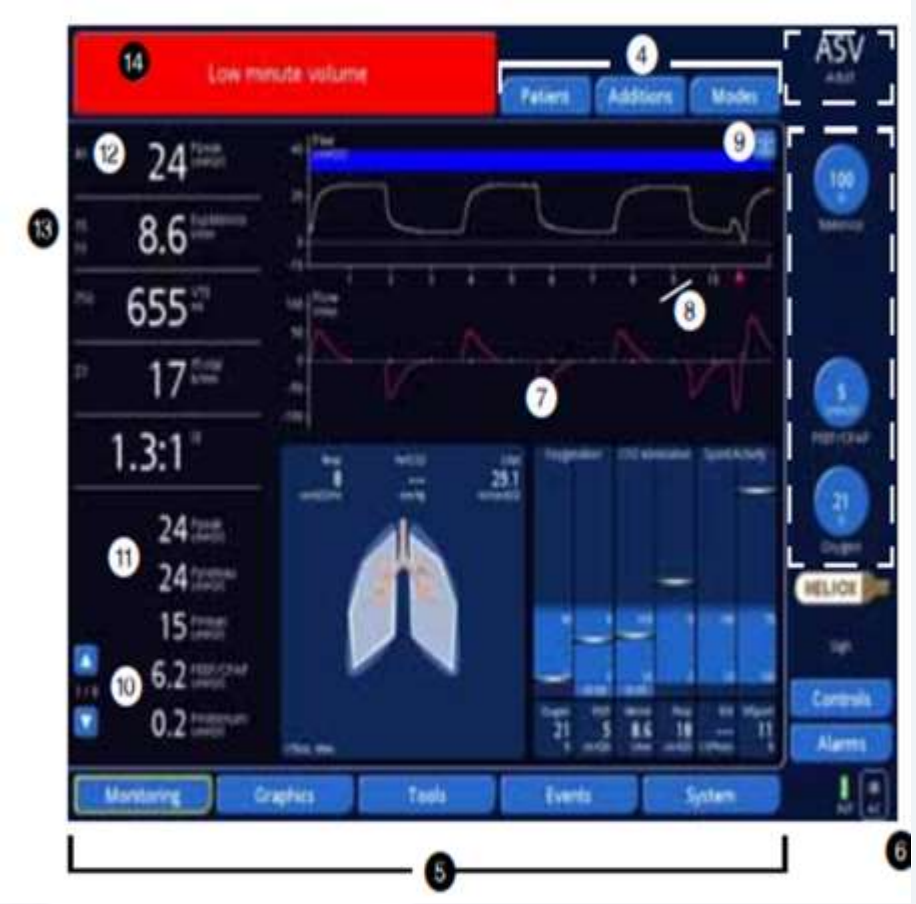


Control Panel

- Referred to as user interface
- It contains all controls used to set the ventilation and monitoring parameters
- As well as It displays other important parameters and graphics

Control Panel (Cont.)



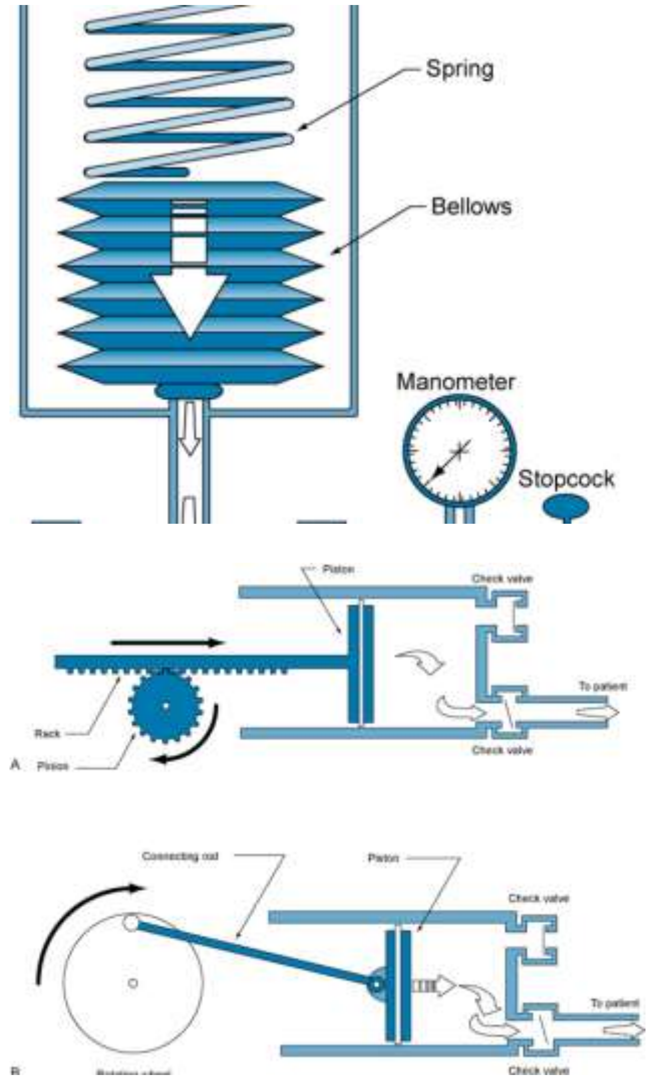


Drive mechanism (Power Transmission System)

- Drive mechanism is part of the breath delivery unit.
- Responsible for breath delivery to the patient
- Develop and control pressure gradient between ventilator and patient
- It contains pneumatic and electronic modules that control the breath delivery to the patient
- Electrically powered ventilators use compressors, blowers, or other volume displacement devices
- Pneumatic systems use compressed gas from wall to deliver volume to lung

Compressors or Blowers

- Can be driven by pistons, rotating blades, moving diaphragms, or bellows
- Most common type of compressor: rotary compressor
- Examples:
  - Viasys Avea
  - LTV ventilators



Volume Displacement Designs

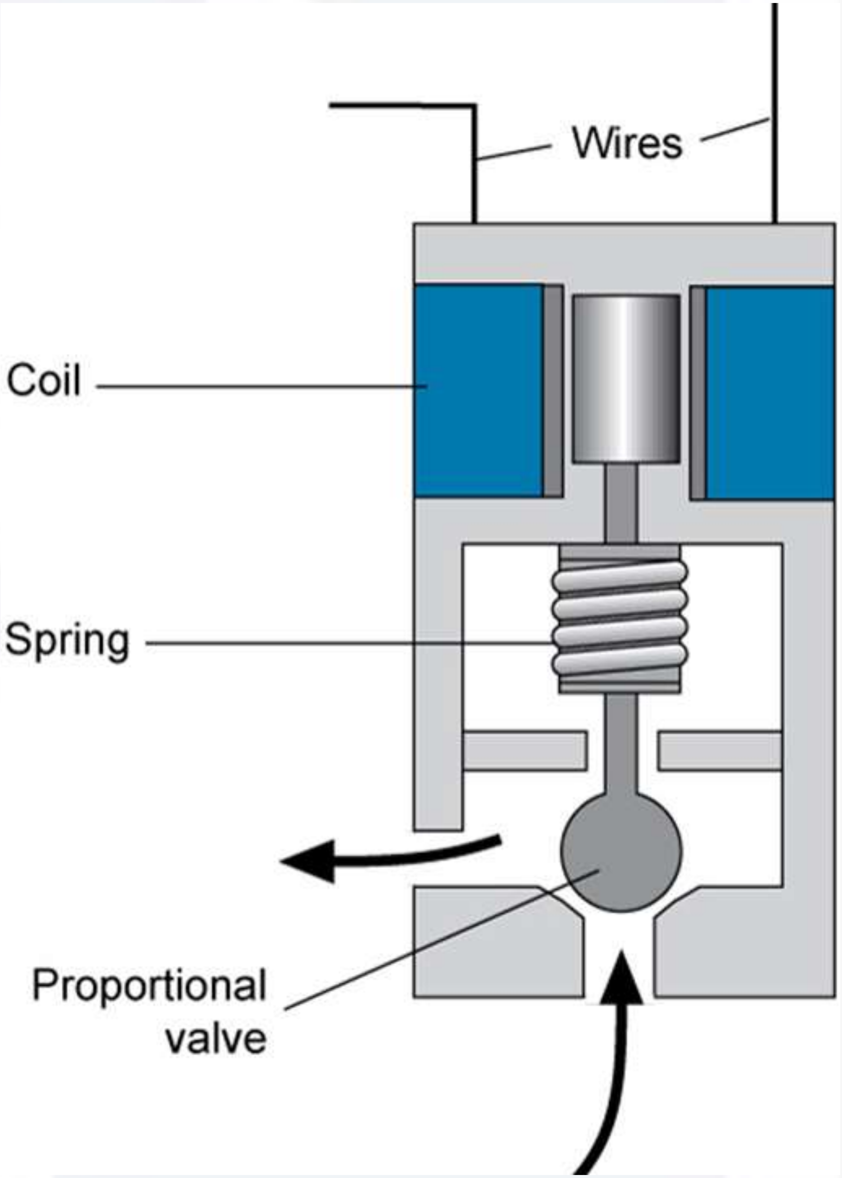
- Use displacement devices to deliver specific volume
- Includes pistons, bellows, or bag in chamber mechanisms
- Spring-Loaded Bellows
  - Operator adjusts tension on spring that is used to compress bellows
  - Not commonly used

Flow-Control Valves

- Three types of flow controlling valves

1. Proportional solenoid valve
2. Stepper motors with valve
3. Digital valves with on/off configuration

- Current ICU ventilators use Proportional solenoid valve.



Fluidic Ventilators

- Use fluidics to deliver gas to patient
- Do not use moving parts or electricity to function
- Used on Bio-Med MVP 10
- Compatible with use during MRI
- Two basic principles:
  - Beam deflection
  - Wall attachment (Coanda effect)

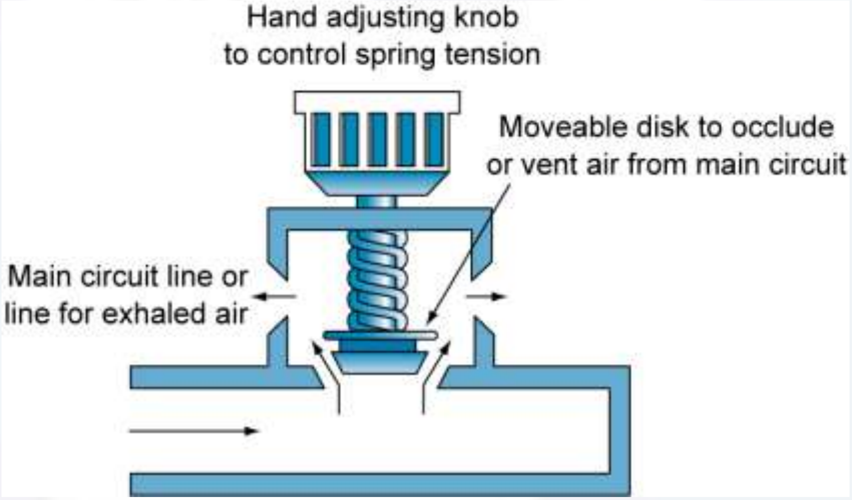
Expiratory Valves

Expiratory Valves

- Close during inspiration to direct gas flow to patient
- Open during exhalation allowing patient to exhale gas into atmosphere
- PEEP is used to improve oxygenation
- PEEP is provided by threshold resistor or flow resistance
- Both valves prevent complete exhalation of expired tidal volume

Spring-Loaded Valves

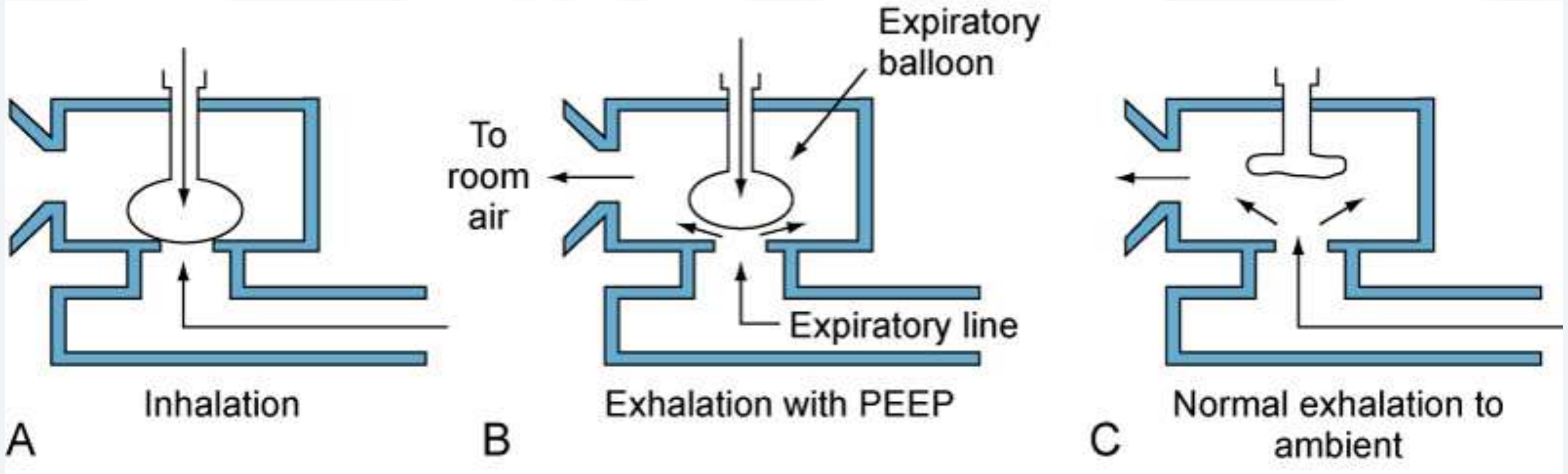
- Can be used to provide PEEP
- Spring is used to adjust amount of pressure applied against exhalation valve to prevent complete exhalation



Diaphragm Expiratory Valve

- Diaphragm over exhalation valve closes during inspiration
- During exhalation, pressure on diaphragm is released
- When PEEP is used, pressure against diaphragm is maintained thus preventing complete exhalation

Diaphragm Expiratory Valve (Cont.)

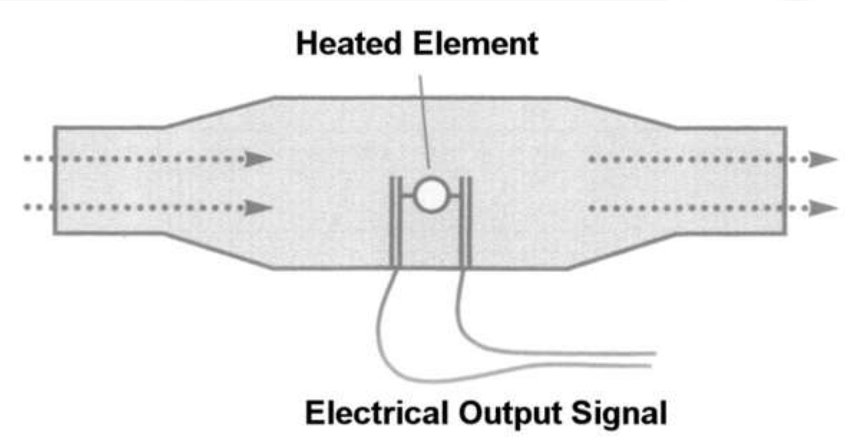


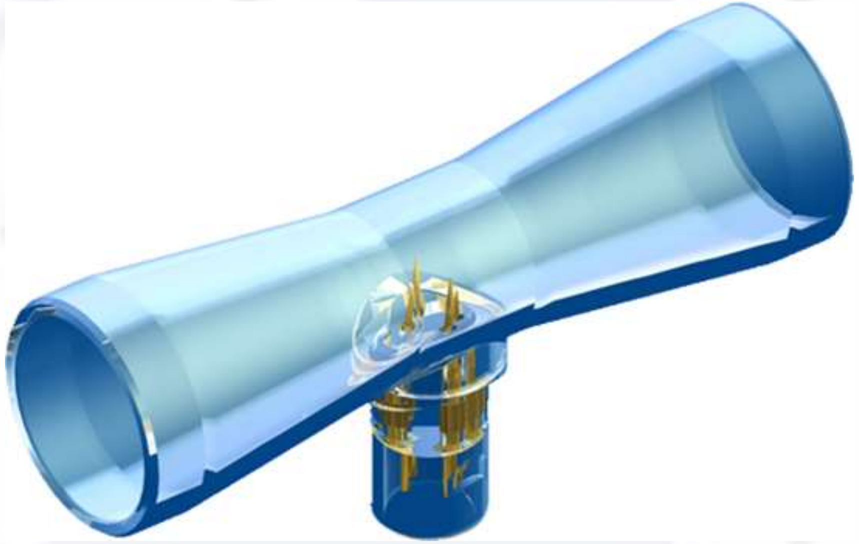
Electromagnetic Valves

- Amount of electrical current is adjusted to regulate amount of force applied to expiratory flow
- The higher the level of current, the more force applied to exhaled gas
- Increases PEEP level

Heated wire flow sensor

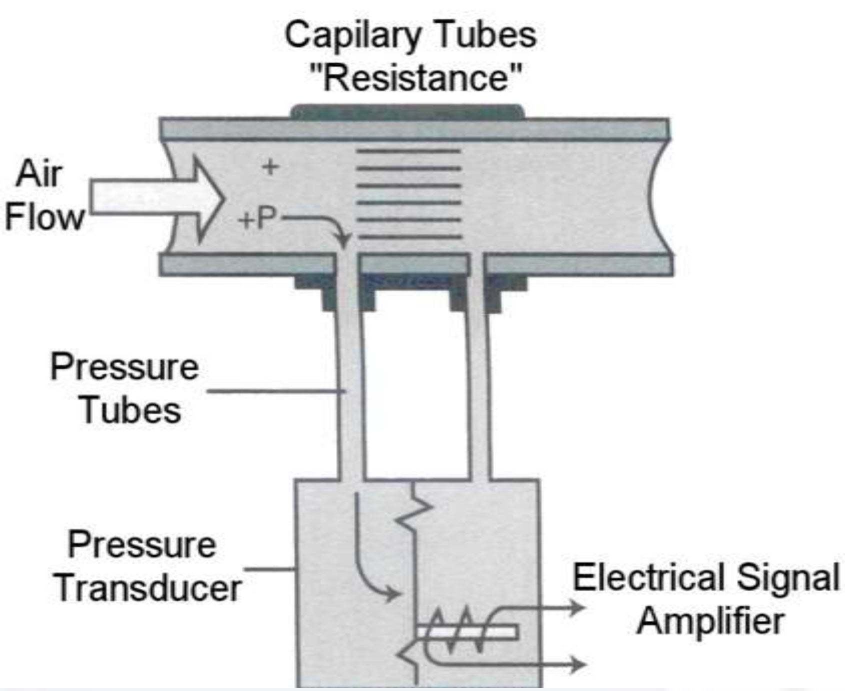
- As flow passes through the sensor, the ventilator tries to keep the wire temperature constant
- The electric currant consumed to keep this temperature is proportional to gas flow
- This type of sensors is affected by condensate, secretion and calcification.
- An example of a ventilator using this type of sensors is Dräger Evita XL™





Differential pressure flow sensor

- As flow passes through the sensor's resistive element a pressure deference develop
- Using Boyle's Law [P1V1 = P2V2] the gas flow can be calculated
- This type of sensors can be affected by condensate, secretion and calcification.
- An example of a ventilator using this type of sensors is Hamilton G5 & S1



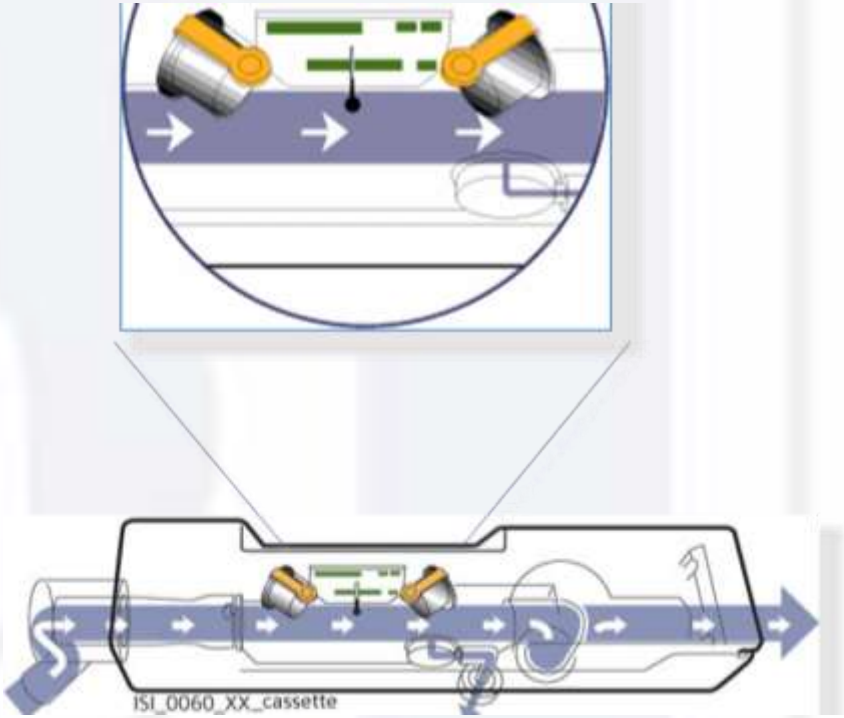
Ultrasonic Flow Sensor

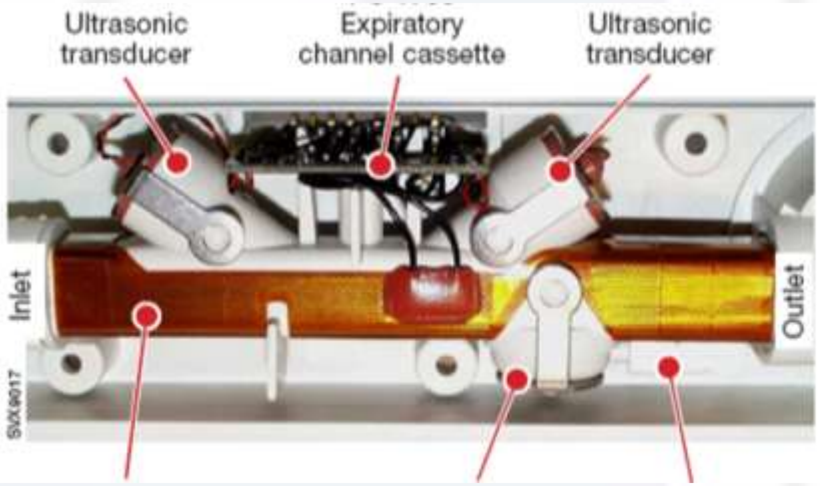
Ultrasonic transducer technology:

$$T_2 - T_1 = T_{diff}$$

T_{diff} is proportional to the gas flow

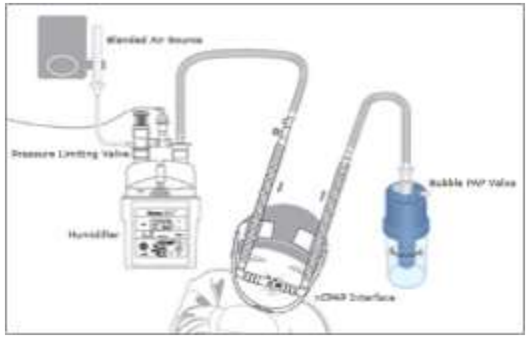
New measurement every 4 ms





CPAP Devices

- F_IO_2 is regulated with blender
- Inspired gas is warmed and humidified
- Threshold resistor prevents complete exhalation to maintain positive pressure in airway
- Problems with CPAP Systems
  - Inadequate gas flow to patient
  - Leaks in system
  - Loss of source gas flow
  - Jamming or obstruction of expiratory flow resistor



Basic Component of Breath Delivery

Primary Ventilator Control Variables

- Primary variable ventilator controls to cause inspiration
- 3 possible explicit primary variables
    1. Pressure controlled
    2. Volume controlled
    3. Flow controlled
- Only one can be controlled; other two become dependent variables

Pressure Controller

- Ventilator controls pressure (P), but volume & flow vary with changes in compliance (C) & resistance (Raw)
- Pressure waveform will be square (constant) during inspiration
- Positive or negative pressure controlled
  - i.e., iron lung controls with negative P

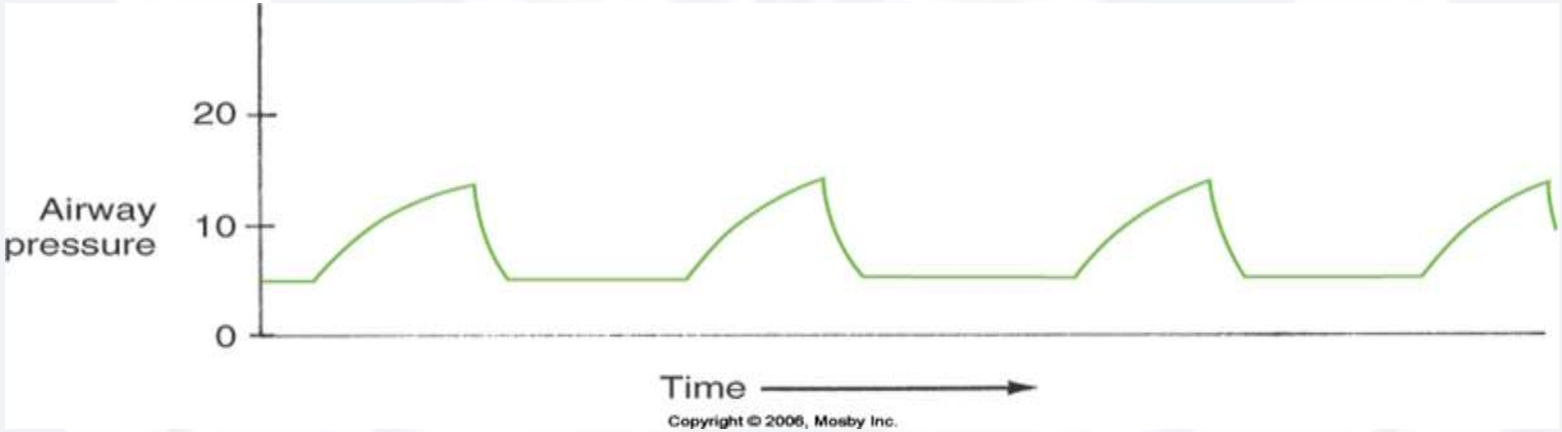
Volume & Flow Controllers

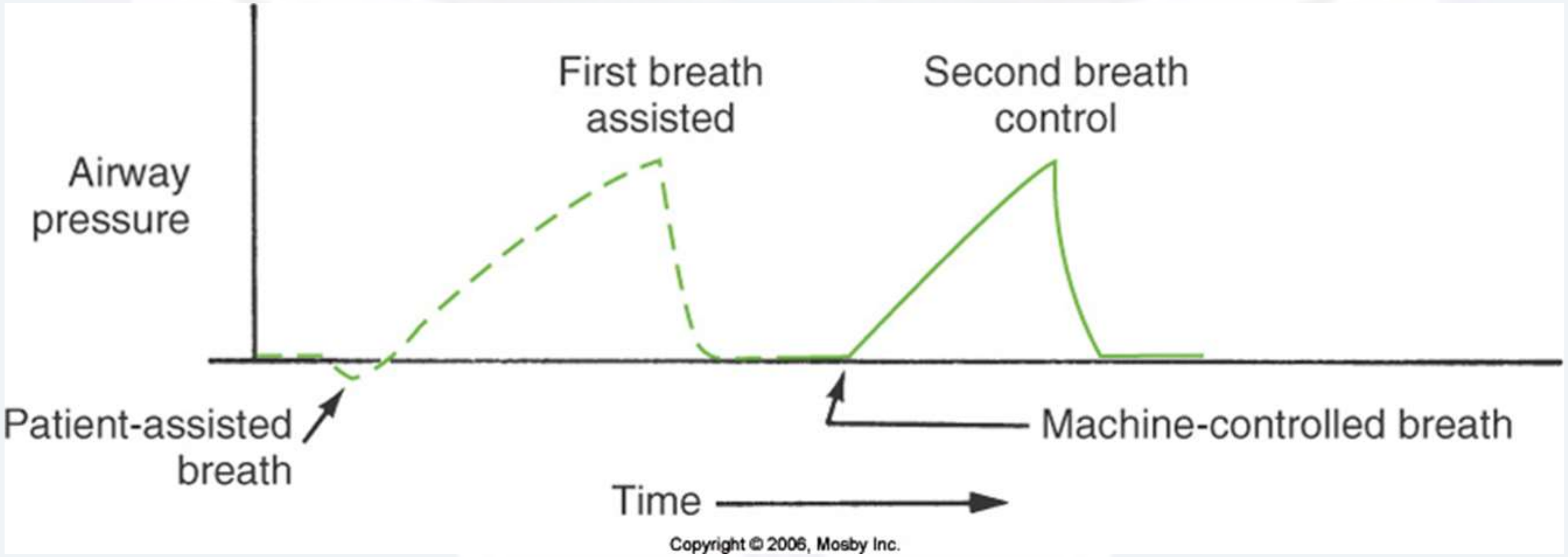
- Volume controller
  - Ventilator controls volume so will be constant
    - Flow is volume/time, so flow is also constant
  - Pressure will vary with changes in C & Raw
- Flow controller
  - As above, flow & thus volume constant
  - Pressure varies with changes in C and Raw
  - Old neonatal ventilators used flow interruption to deliver volume during inspiration

Two Breath Types

- Spontaneous
  - Patient triggers & cycles the breath
  - Patient effort may be supported by manual or mechanical ventilator
- Mechanical
  - Mandatory breath: breath is initiated by ventilator
  - Assisted breath: breath is triggered by patient but is delivered by ventilator

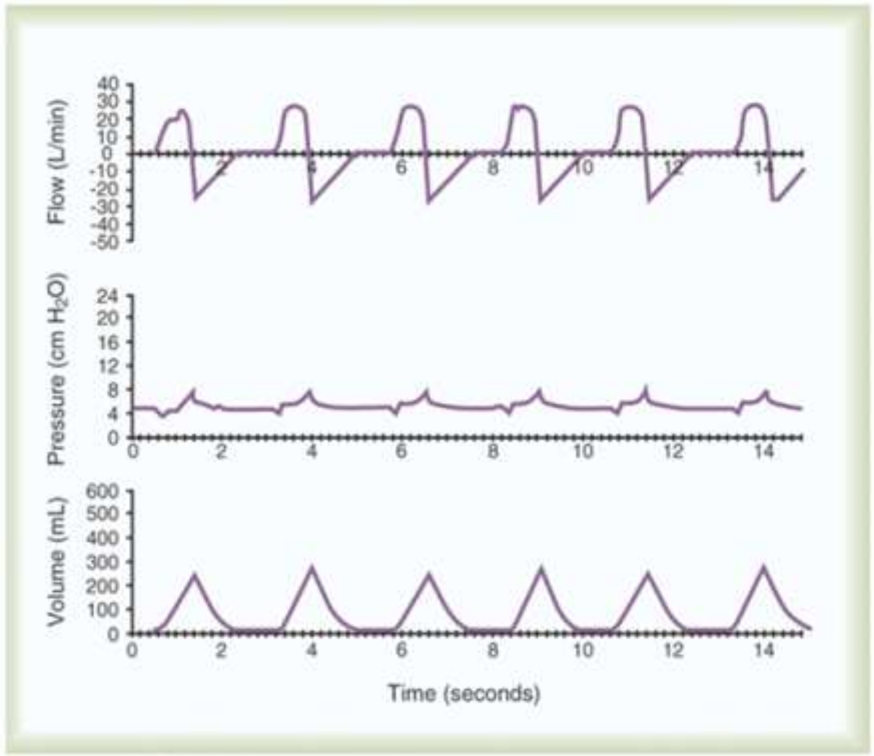
Types of Breath

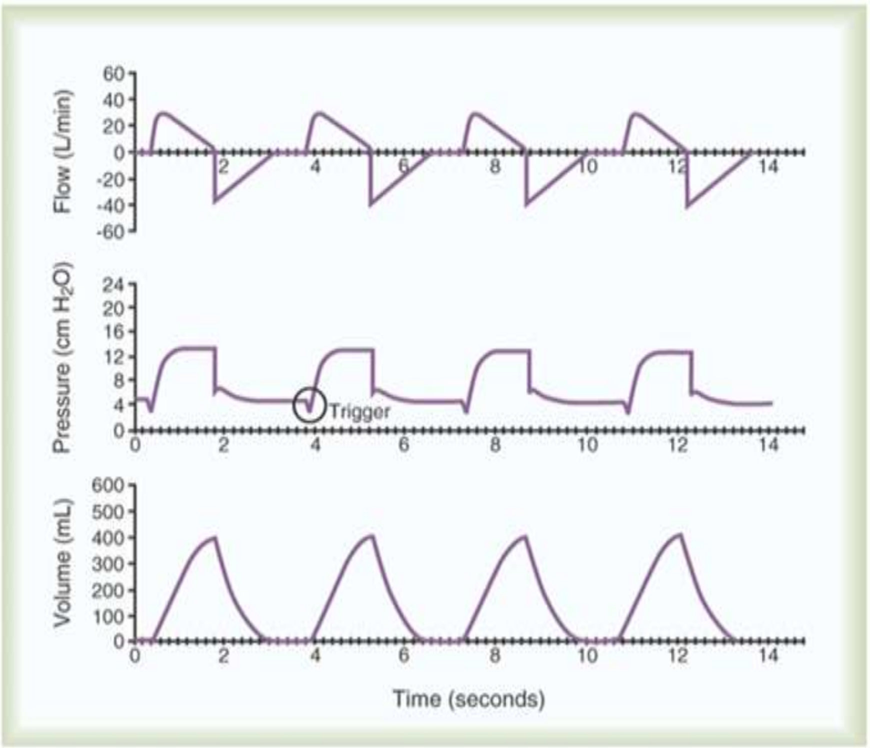




Types of Breath (Spontaneous breath)

- Without Support (CPAP)
- With Support (PSV)





Primary Breath Control Variable

- Volume control: V_T/flow set, while P depends on those settings & pulmonary mechanics
- Pressure control: P set, V_T /flow depend on P setting & pulmonary mechanics
- Dual control: Mixture of volume & pressure
  - Either starts breath in volume control & ends with pressure control or the reverse

Components (phases) of Breath Delivery

- End of expiration and beginning of inspiration
- Delivery of inspiration
- End of inspiration and beginning of exhalation
- Expiratory phase

Phase Variables

- Ventilator uses variables to initiate or limit each phase of ventilation
  - Initiation of inspiration (E to I)
  - Inspiration
  - End of inspiration (I to E)
  - Expiration

Initiation of Inspiration

- Trigger variable
  - Machine triggered
    - Time: determined by rate control
  - Patient triggered
    - Pressure
    - Flow (least work for patient to trigger)
    - Volume (rare)
  - Most ventilators provide a manual breath button that operator activates
  - Patient triggering: breath is triggered because of patient effort
  - Trigger sensitivity: amount of effort required by patient to initiate machine breath

Time Triggering

- Ventilator triggers breath at preset intervals
- Time for mandatory breath is based on cycle time
- Cycle time is calculated by dividing 60 by set rate
- Example: Set rate is 12 breaths/min
  - Cycle time = 60/12
  - Cycle time = 5 seconds

Pressure Triggering

- Ventilator breath is triggered by decrease in pressure below baseline
- Sensitivity is usually set at –0.5 to 1.5 cm H_2O
- Common locations for pressure sensor:
  - Internal ventilator circuit where main gas flow leaves ventilator
  - Where expired gas flow returns from patient to ventilator
  - At proximal airway (near wye connector)

Flow Triggering

- Base or bias flow, present during exhalation, is set
- Common level is 5 to 10 L/min
- Flow trigger is set at 1 to 5 L/min
- When patient decreases flow to set level of flow trigger, an assisted breath is delivered

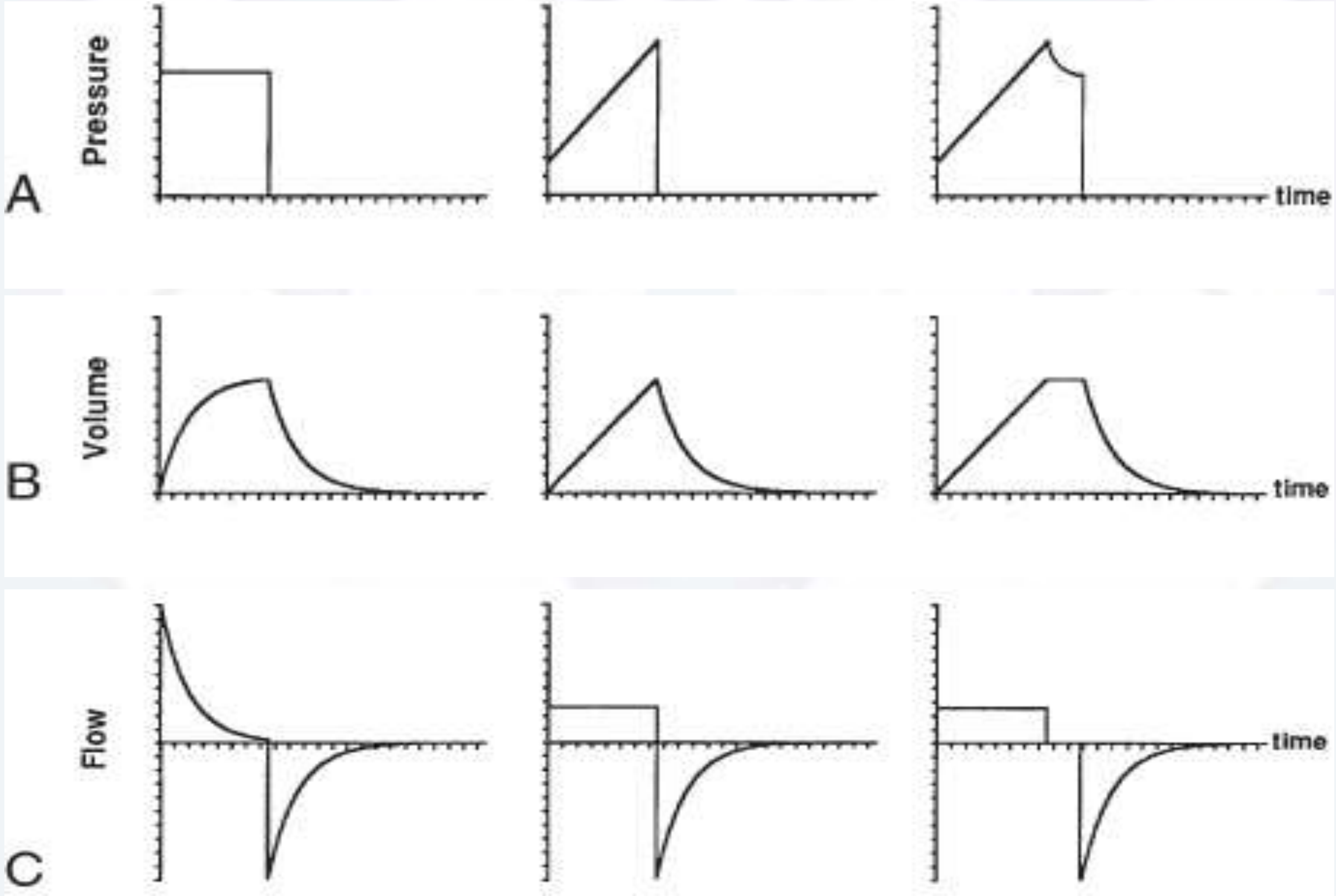
Other Triggering Methods

- Manual triggering: operator triggers ventilator breath
- Neural triggering: monitors electrical activity of diaphragm
- Method is used with neurally adjusted ventilatory assist (NAVA)

Inspiration: Target (Limit) Variable

- Limits inspiration but does not terminate the phase
  - Pressure limited
    - Limits peak inspiratory pressure (PIP) during inspiration
  - Volume limited
    - Limits amount of tidal volume (V_T) delivered during inspiration to set amount
  - Flow limited
    - Limits the amount of flow during inspiration

Target Variable



Inspiratory Phase (Cont.)

- Sloping or ramping
  - Ability to adjust how quickly flow is delivered during set inspiratory time
  - This feature is referred to as:
    - Ramping
    - Inspiratory rise time
    - Flow acceleration
    - Slope adjustment
    - Sloping

Maximum Safety Pressure

- Sets maximum pressure that can be delivered during inspiration
- Upper pressure limit is set 10 cm H_2O above peak inspiratory pressure (PIP)
- Terms for this setting:
  - Pressure limit
  - Upper pressure limit
  - Normal pressure limit
  - High pressure limit
  - Peak/maximum pressure

Maximum Safety Pressure (Cont.)

- Events that occur with activation of upper pressure limit:
  - Activation of visible and/or audible alarm
  - Termination of delivery of inspiratory breath
  - Decrease in inspiratory time

End of Inspiration

- Cycle variables terminate inspiratory phase
  - Pressure cycled
    - Inspiration terminates as preset pressure reached (hit alarm level)
  - Volume cycled
    - Inspiration terminates at preset V_T
  - Flow cycled
    - Inspiration terminates when flow drops to preset value (PSV)
  - Time cycled
    - Inspiration terminates when set inspiratory time is reached
      - Includes any inspiratory holds

Pressure Cycling

- When preset pressure is reached, inspiratory flow ends and expiratory flow begins
- In pressure control ventilation, preset pressure is maintained for set inspiratory time
- Only application of pressure cycled ventilation is administration of intermittent positive-pressure breathing (IPPB)
- Pressure cycling also occurs if upper pressure limit is reached in volume- or pressure-targeted ventilation

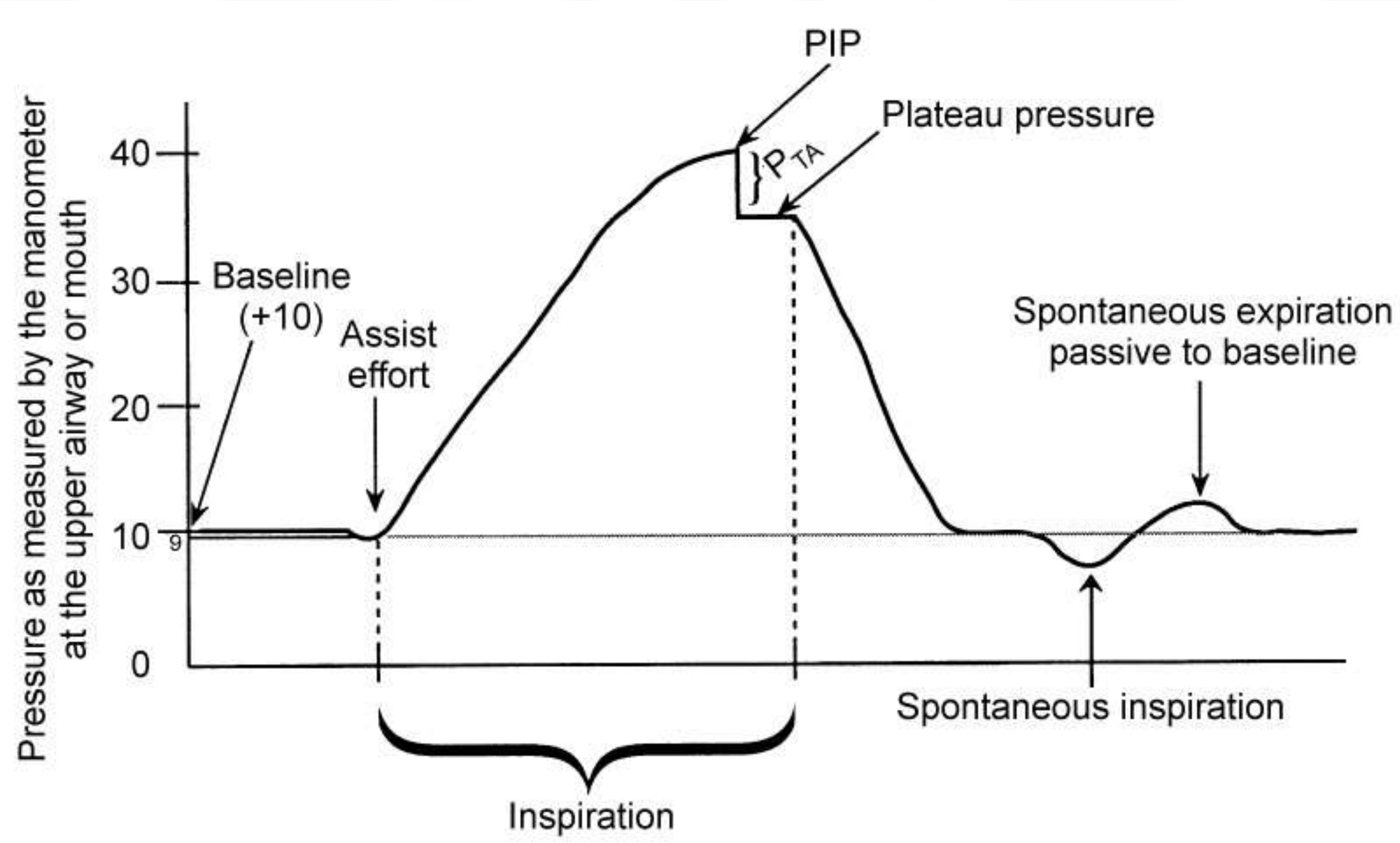
Time Cycling

- Length of inspiration is set by operator; then followed by ventilator ending inspiration and beginning expiration
- If inspiratory time is decreased, expiratory time is increased and I:E ratio is increased
- If inspiratory time is increased, expiratory time is decreased and I:E ratio is decreased

Inspiratory Pause

- Extension of inspiratory time by exhalation valve remaining closed after set tidal volume has been delivered
- Also referred to as:
  - Inflation hold
  - Inspiratory plateau
- Can be used with pressure or volume ventilation
- Common application is to obtain plateau pressure to calculate effective static compliance in VCV.
- In pressure-controlled ventilation, inspiratory time is long enough for pressure to equilibrate within lungs

Inspiratory Pause (Cont.)



Volume Cycling

- When preset volume is delivered, ventilator ends inspiration and begins expiration
- Most ventilators accomplish this by calculation of the amount of flow to deliver a set volume during the set inspiratory time
- Amount of volume actually delivered to patient may be less because of volume lost due to tubing compression

Tubing Compression

- During inspiration, tubing is distended and returns to normal size during exhalation
- Most adult ventilator circuits have tubing compression factor of 1 to 3 cm H_2O
- Many current ventilators calculate volume lost to tubing compression and add this to delivered tidal volume

Flow Cycled

- Inspiration ends when preset flow is reached
- Pressure support ventilation (PSV) is most common application of flow cycling
- In PSV, breaths end when inspiratory flow decreases to set percentage of initial flow rate
- When PSV was first developed, breaths ended when flow dropped to 25% of initial flow
- In current ventilators, pressure support breaths can be ended at percentages of expiratory flow ranging from 5% to 80% of initial inspiratory flow rate

Expiration: Baseline Variable

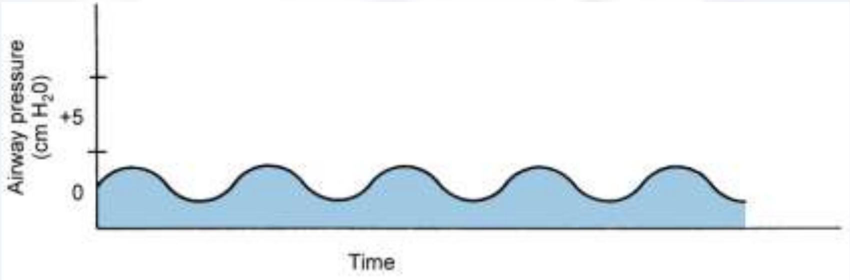
- Defined by how baseline or end expiratory pressure (EEP) relates to atmospheric pressure
  - PEEP— Positive or supra- atmospheric EEP
  - NEEP— Negative or sub-atmospheric EEP
  - ZEEP— Zero EEP equals sub-atmospheric pressure

Baseline Pressure

- Pressure at which inspiration begins
- Zero baseline pressure is equal to atmospheric pressure
- PEEP: resistance applied during exhalation preventing complete exhalation
- Applications of PEEP:
  - Increases FRC
  - Increases mean airway pressure
  - Improves lung recruitment
  - Improves oxygenation

Baseline Pressure (Cont.)

- CPAP
  - Baseline pressure is elevated
  - Patient is breathing spontaneously
  - Applications for CPAP are same as PEEP



Negative End-Expiratory Pressure

- Developed to minimize effects of positive pressure on blood flow
- Used during expiration during high-frequency oscillation

Continuous Gas Flow During Exhalation

- Referred to as "base flow" or "bias flow"
- Provides flow to patient during last portion of exhalation to the beginning of inspiratory effort
- Most current ventilators use bias flow to provide flow triggering

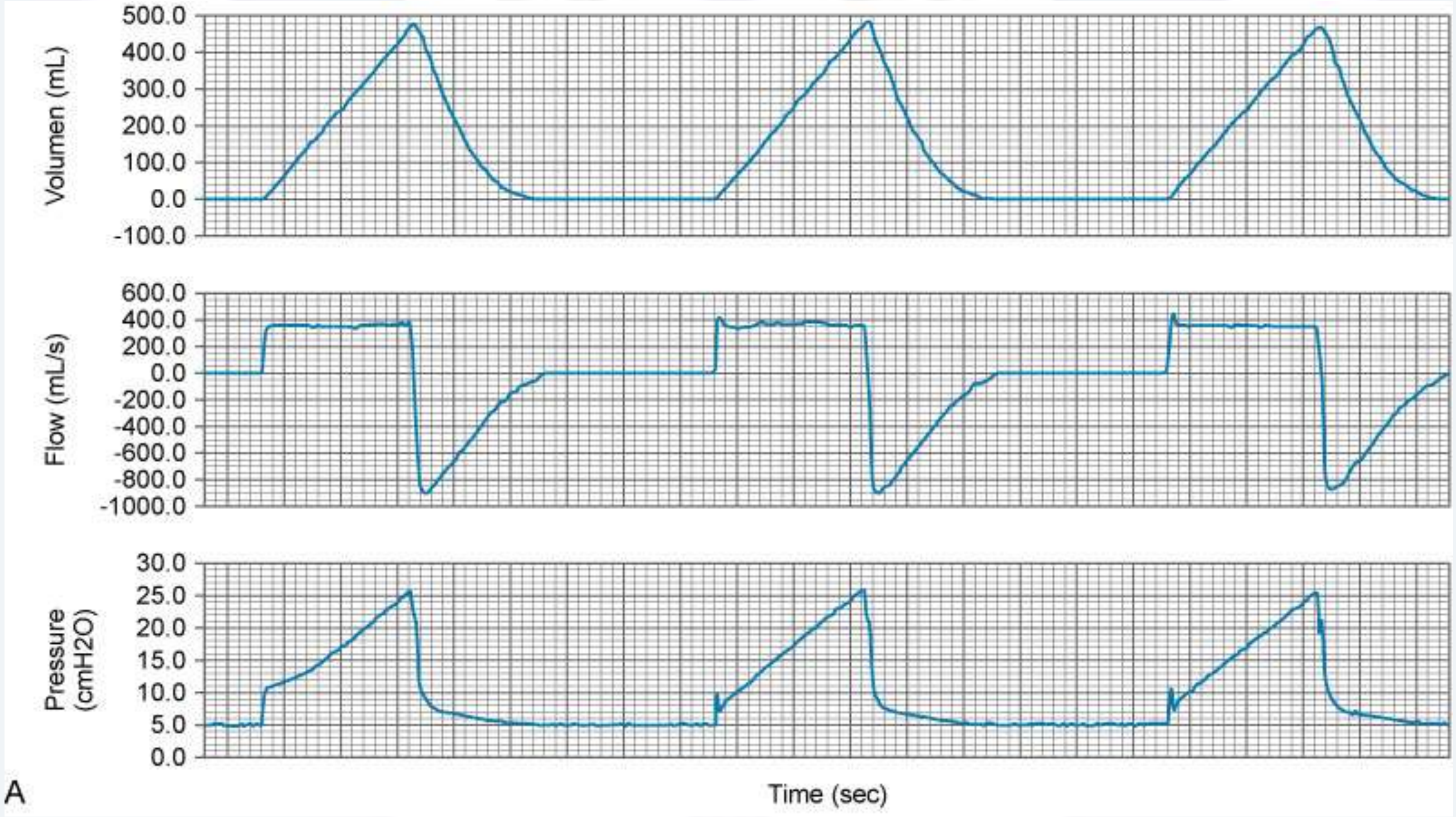
Expiratory Hold/End Expiratory Pressure

- Used to estimate amount of pressure in lungs caused by trapped air
- Pressure of trapped air is referred to as “auto-PEEP”
- Conditions increasing risk of developing auto-PEEP:
  - High minute volumes (>10 L/minute)
  - Patients with high airway resistance
  - Patients with active exhalation

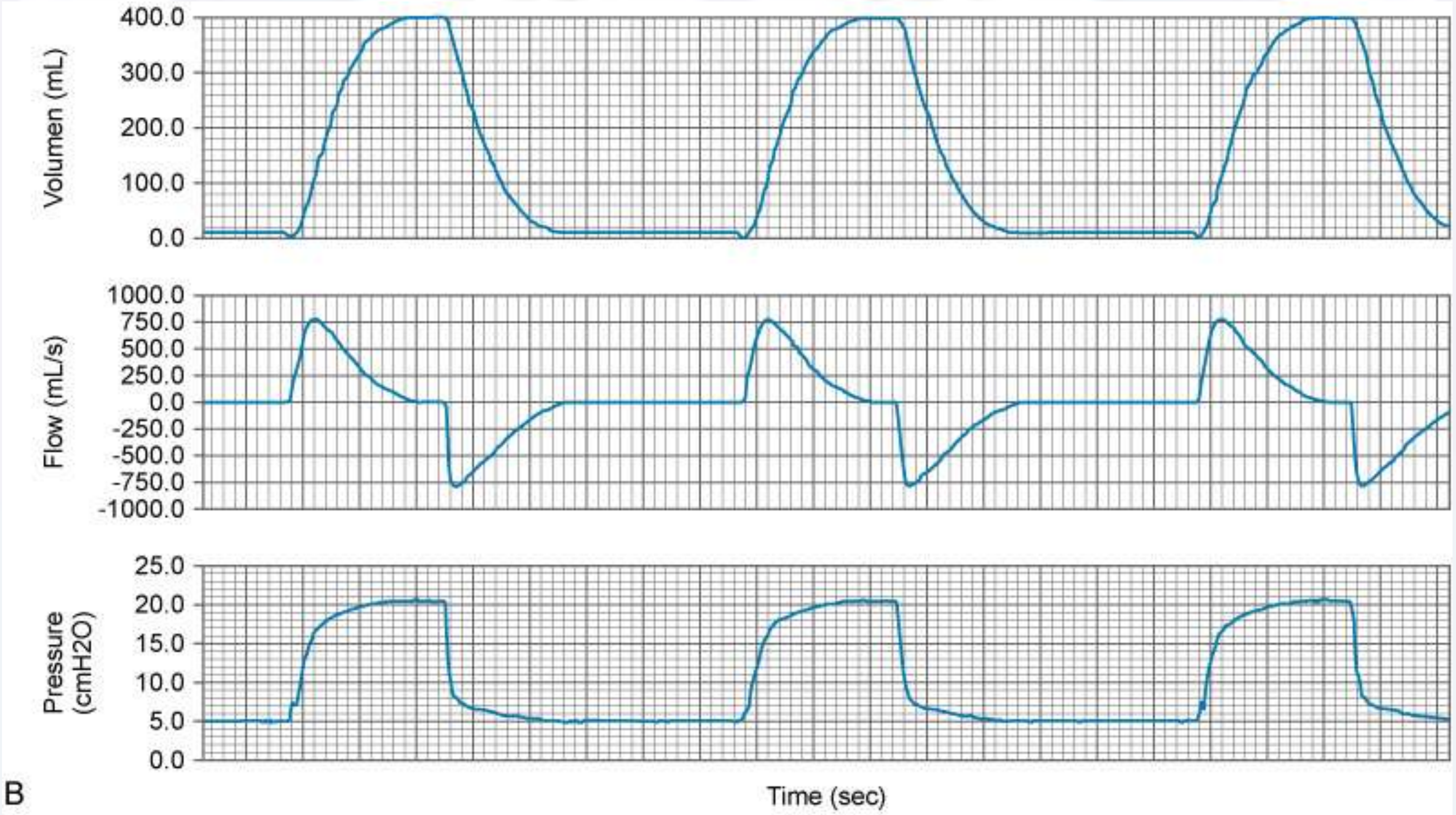
Waveforms and Graphics

- Scalar graphics
  - Pressure-time
  - Volume-time
  - Flow-time
- Loop graphics
  - Flow-volume
  - Pressure-volume

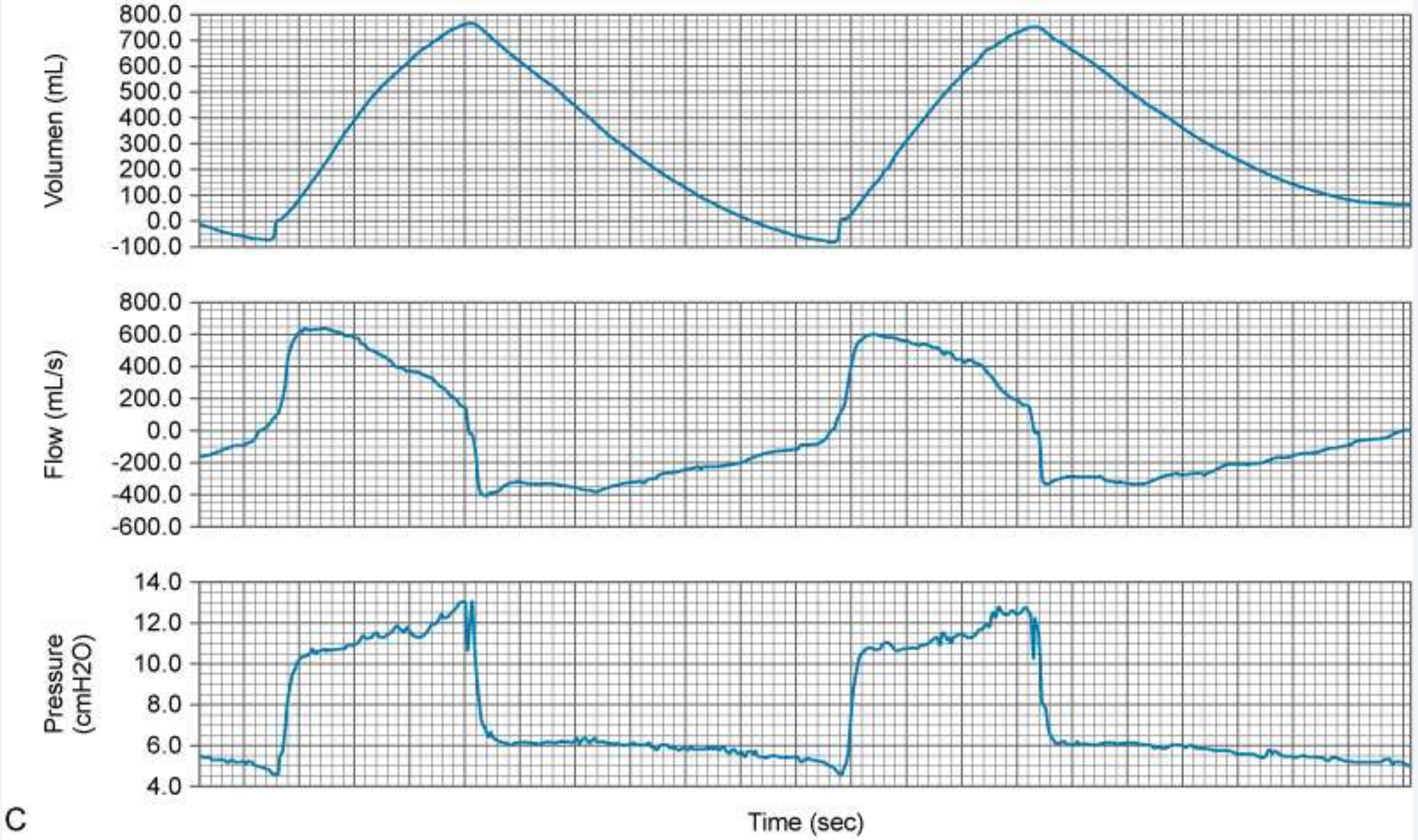
Scalar Graphics During Volume-Controlled Ventilation



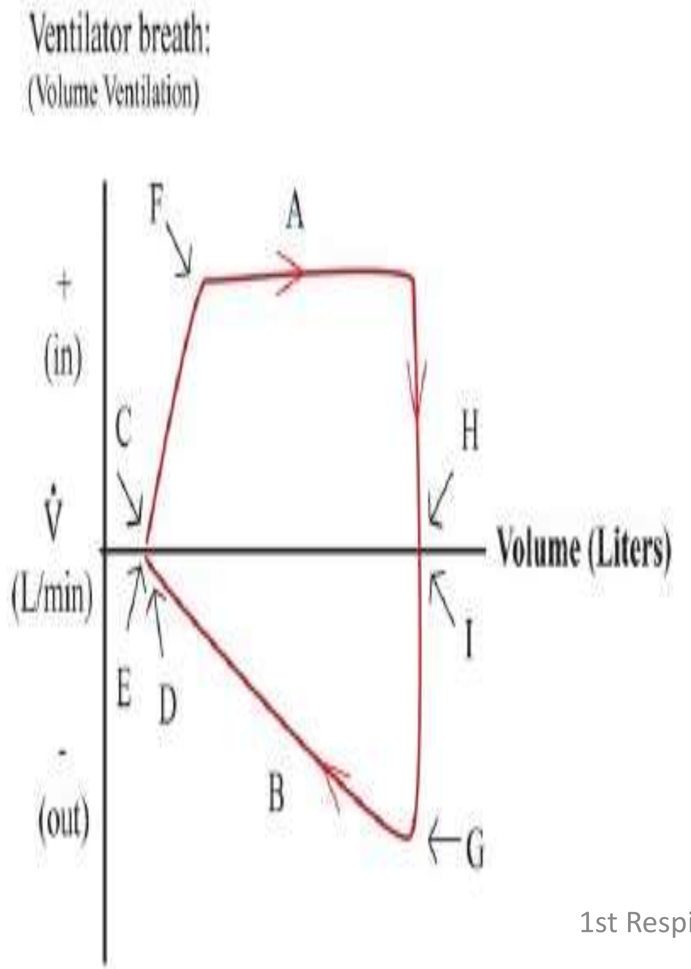
Scalar Graphics During Pressure-Controlled Ventilation



Scalar Graphics During Pressure-Support Ventilation

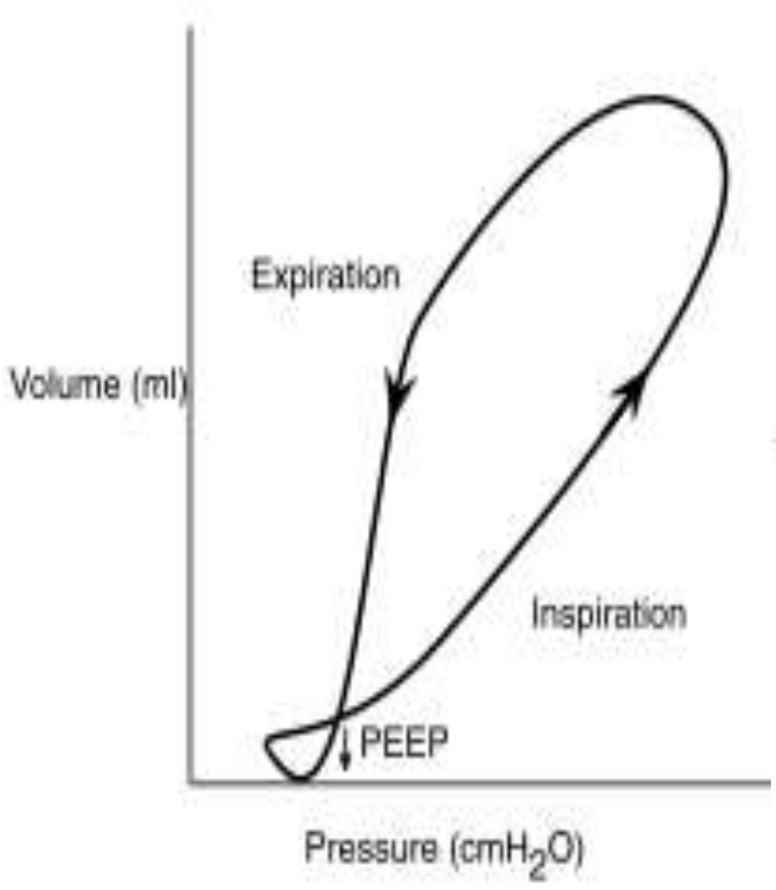


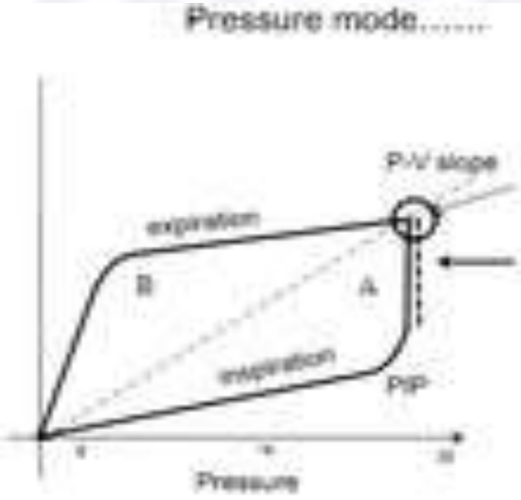
Loop graphics: Flow-volume

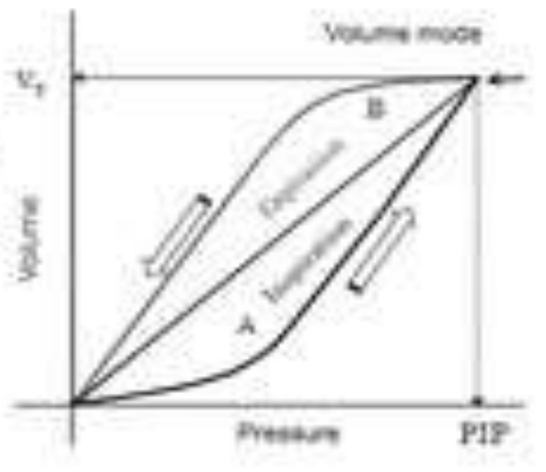


A Inspiratory curve
B Expiratory curve
C Begin inspiration
D End expiration
E Point on volume axis where I begins and E ends.
Note: C, D, and E should all be the same point.
F Peak inspiratory flow rate (VI)
G Peak expiratory flow rate
H Point on volume axis of maximum VT and end I
I Begin E

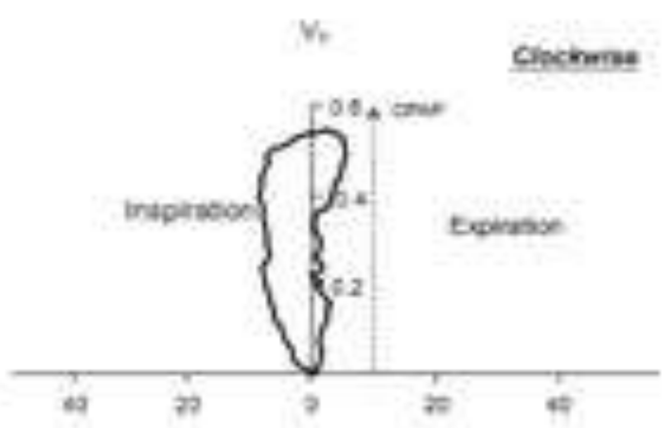
Loop graphics:







SPONTANEOUS BREATH



Mechanical Ventilation (2)

Classification of Modes of Ventilation

History

- Control v
  - V
  - re
- th sequence
  - Continuous mandatory vent
  - termittent mandatory ventilation (
  - inuous spontaneous ventilation (CSV)

CV

of Ventilation

- PSV

Advanced
Modes of
tion

- PRVC
- CMV Autoflow
- VSV
- ASV
- PAV
- VC+

Chatburn's Classification of Ventilator Modes

- Breathing pattern
  - Control variable
    - Volume
    - Pressure
- Breath sequence
  - Continuous mandatory ventilation (CMV)
  - Intermittent mandatory ventilation (IMV)
  - Continuous spontaneous ventilation (CSV)

Chatburn's Classification of Ventilator Modes (Cont.)

- Targeting scheme: Described as feedback control function of ventilator
  - Set-point
  - Dual
  - Servo
  - Adaptive
  - Optimal
  - Intelligent

Types of Targeting

- Set-point: operator sets target parameter, such as a tidal volume; ventilator delivers that volume
- Dual targeting: operator sets pressure and volume target. If desired volume is not reached with pressure; ventilator will increase pressure to reach volume target

Types of Targeting (Cont.)

- Servo targeting: output of ventilator is adjusted based on input
- Examples:
  - Proportional assist ventilation
  - Automatic tubing compensation
  - Neutrally adjusted ventilatory assist

Types of Targeting (Cont.)

- Adaptive Targeting: One target is adjusted automatically to achieve another target
  - Examples:
    - Pressure-Regulated Volume Control (PRVC): pressure is adjusted to obtain desired tidal volume
    - Mandatory minute ventilation

Types of Targeting (Cont.)

- Optimal Targeting: Target of ventilator is adjusted automatically to optimize target following predetermined model
- Used with adaptive support ventilation on Hamilton ventilators

Types of Targeting (Cont.)

- Intelligent Targeting: Modes and targets are adjusted according to patient needs
  - SmartCare found on Dräger ventilators
- Monitors patient's $P_{et}CO_2$, spontaneous tidal volume, and spontaneous respiratory rate
- Ventilator automatically adjusts ventilator parameters to maintain above parameters at acceptable levels

Table 1. Ten Basic Maxims for Understanding Ventilator Operation

(1) A breath is one cycle of positive flow (inspiration) and negative flow (expiration) defined in terms of the flow vs time curve.
(2) A breath is assisted if the ventilator provides some or all of the work of breathing.
(3) A ventilator assists breathing using either pressure control or volume control based on the equation of motion for the respiratory system.
(4) Breaths are classified according to the criteria that trigger (start) and cycle (stop) inspiration.
(5) Trigger and cycle events can be either patient-initiated or ventilator-initiated.
(6) Breaths are classified as spontaneous or mandatory based on both the trigger and cycle events.
(7) Ventilators deliver 3 basic breath sequences: CMV, IMV, and CSV.
(8) Ventilators deliver 5 basic ventilatory patterns: VC-CMV, VC-IMV, PC-CMV, PC-IMV, and PC-CSV.
(9) Within each ventilatory pattern, there are several types that can be distinguished by their targeting schemes (set-point, dual, bio-variable, servo, adaptive, optimal, and intelligent).
(10) A mode of ventilation is classified according to its control variable, breath sequence, and targeting schemes.

CMV = continuous mandatory ventilation
IMV = intermittent mandatory ventilation
CSV = continuous spontaneous ventilation
VC = volume control
PC = pressure control

Modes Used in Ventilator Classification

- VC-CMV
- PC-CMV
- VC-IMV
- PC-IMV
- CSV

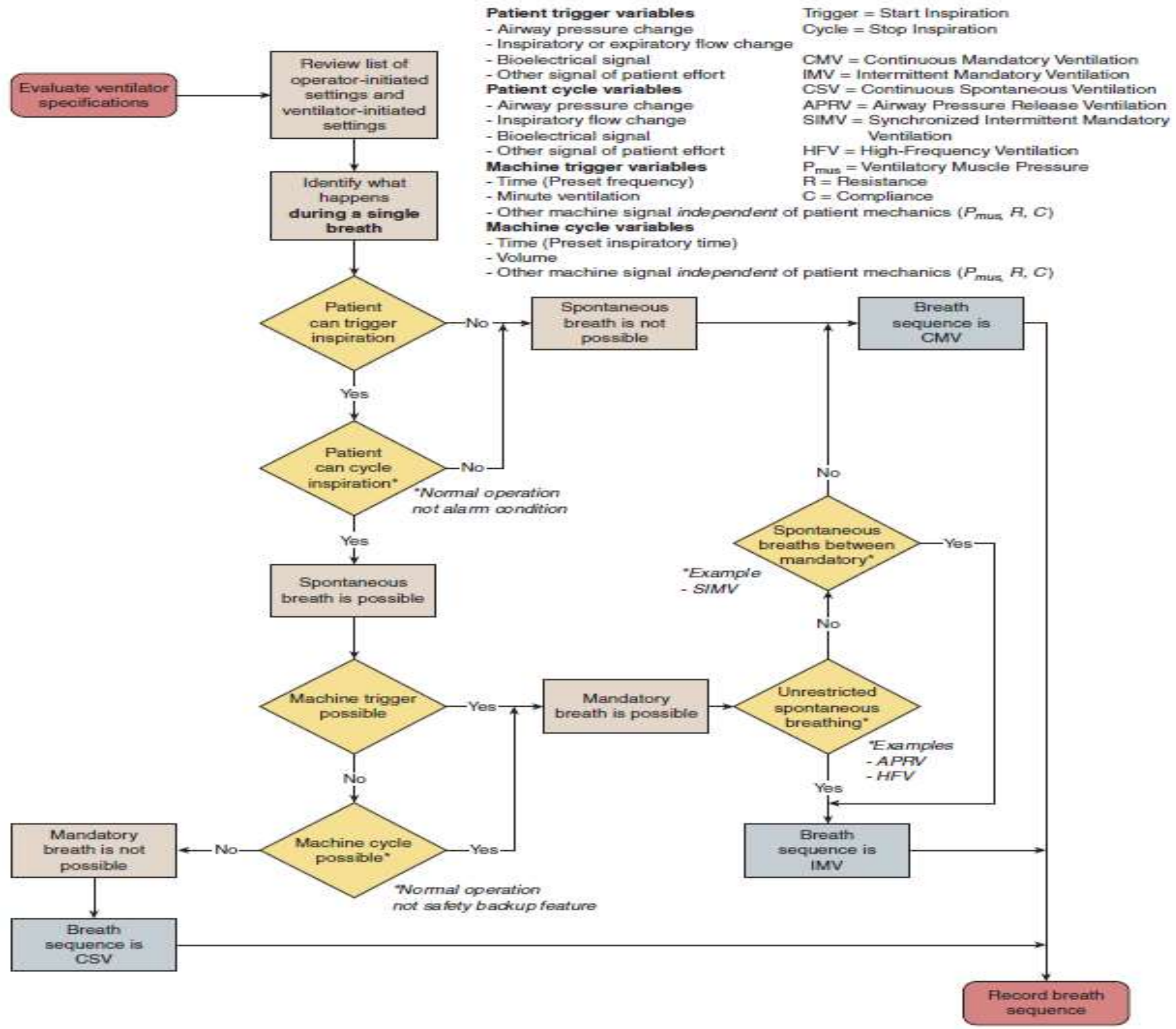


FIGURE 2-12 Algorithm for determining the breath sequence when classifying a mode. (Copyright 2011 by Mandu Press Ltd. and reproduced with permission.)

Continuous Mandatory Ventilation with Set-Point Targeting

- Use of time triggered volume-targeted or pressure-targeted breaths
- All breaths are time triggered or patient triggered
- Patient guaranteed minimum respiratory rate
- Sensitivity determines amount of effort required to trigger assisted breath

Pressure-Controlled Inverse Ratio Ventilation

- Inspiratory time exceeds expiratory time
- All breaths are pressure targeted
- Inverse ratios are used to increase mean airway pressure and improve oxygenation
- Increases risk of developing auto-PEEP
- Alveolar pressure (plateau pressure) should not exceed 30 cm H_2O to prevent lung injury

Intermittent Mandatory Ventilation with Set-Point Targeting

- Can be volume or pressure targeted
- Patient is allowed to breathe spontaneously between assisted breaths
- Volume-targeted IMV
  - Set target tidal volume, flow or inspiratory time, and mandatory rate
- Pressure-targeted IMV
  - Set pressure above PEEP, mandatory rate, and inspiratory time

Airway Pressure Release Ventilation

- Form of PC-IMV
- Uses two levels of CPAP, allowing spontaneous breathing at both levels
- Airway pressure release ventilation (APRV) is used to control mean airway pressure and improve oxygenation in patients with significant lung injury
- High level CPAP (P_{HIGH}) is usually set at a level close to mean airway pressure (20 to 25 cm H_2O)
- Pressure is allowed to decrease low level CPAP (P_{LOW}) for a brief period of time (0.2 to 1.0 seconds)
- Allows ventilation to occur

Settings Used in APRV

- CPAP High (P_{HIGH})
- CPAP Low (P_{LOW})
- Time High (T_{HIGH})
- Time Low (T_{LOW})

Dual Targeting

- Ventilator delivers pressure-targeted breath with decelerating flow curve; inspiratory time is preset
- Exhaled volume is monitored
- If volume does not meet minimum volume, pressure is increased or decreased in increments so desired tidal volume is delivered

CMV with Adaptive Targeting

- Also referred to as “dual control mode”
- Pressure is adjusted up or down to achieve target tidal volume
- Pressure is adjusted up or down in increments of 1 to 3 cm H_2O
- Maximum safety pressure is determined and pressure is not allowed to exceed this level
- This level is 5 cm H_2O below upper pressure limit

Pressure-Controlled CSV with Intelligent Targeting

- Used with SmartCare found on Dräger ventilators
- Spontaneous V_T, spontaneous rate, and $P_{et}CO_2$ are monitored
- Ventilation is adjusted to patient needs based on these values
- Used as a weaning mode
    - Found to be as effective as weaning done by experienced providers in CCU

Volume-Controlled IMV with Adaptive Targeting

- Described as “mandatory minute ventilation”
- Rate or pressure support level is adjusted automatically to ensure preset minute volume
- If patient reaches volume target, no support is provided
- Available on Dräger ventilators

Pressure-Controlled IMV with Adaptive Targeting

- Examples:
  - Maquet PRVC-IMV
  - Dräger SIMV + Autoflow
  - Hamilton PC-SIMV + Adaptive Pressure Ventilation
  - CareFusion PRVC SIMV
  - GE Engstrom Care Station SIMV

Pressure-Controlled IMV with Optimal Targeting

- Example: adaptive support ventilation
- Mandatory rate and tidal volume are adjusted to minimize patient's work of breathing
- Mandatory and spontaneous breaths are pressure limited
- Ventilator determines dynamic compliance

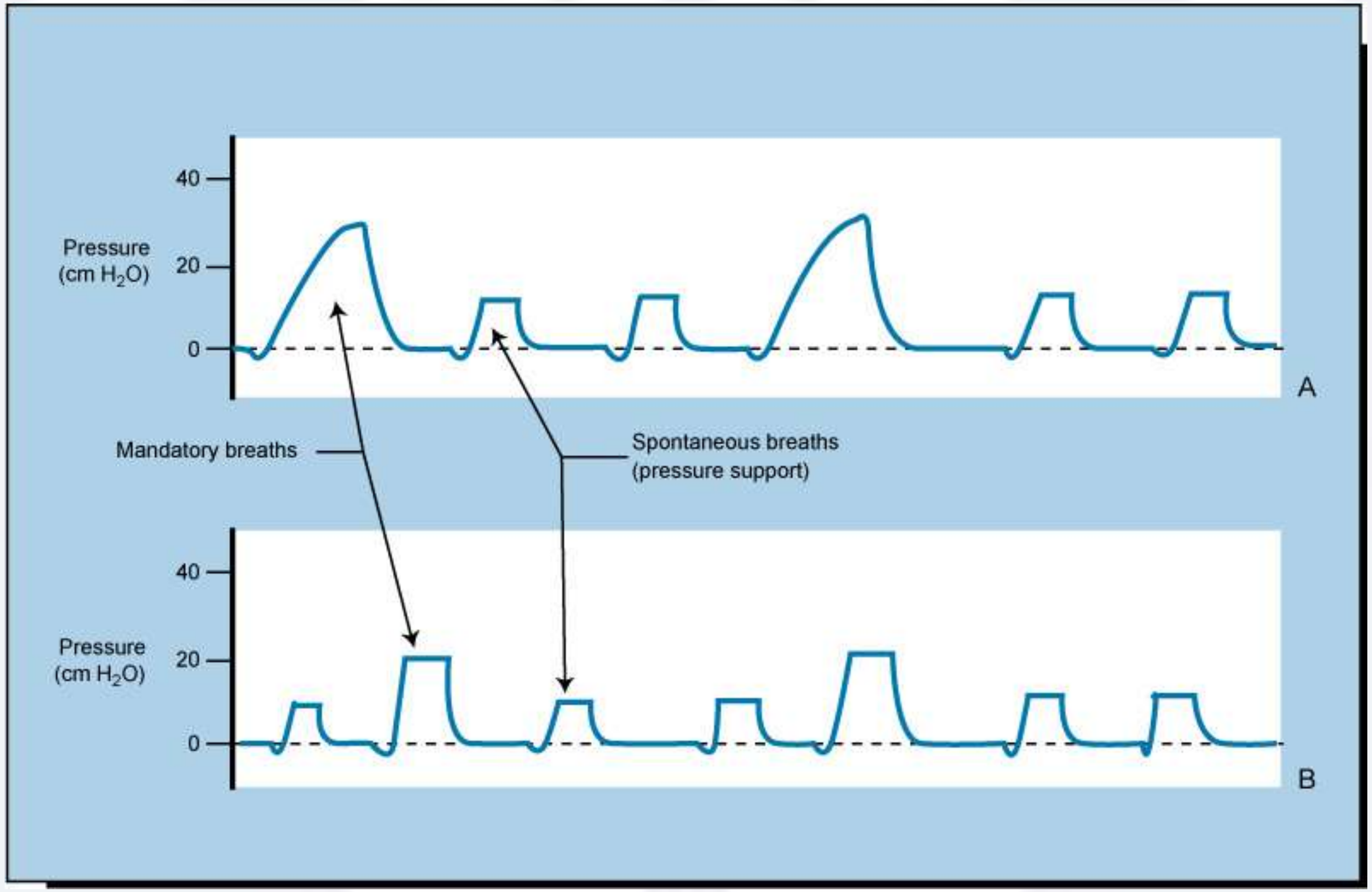
Pressure-Controlled IMV with Optimal Targeting (Cont.)

- Following parameters are set:
  - Patient's IBW and percentage of minute volume operator wants ventilator to provide
  - Maximum pressure limit and PEEP level
  - Pressure or flow trigger
  - Rise time

Pressure-Controlled IMV with Optimal Targeting (Cont.)

- When patient is spontaneously breathing, ventilator adjusts pressure to keep rate and V_T in optimum range

Pressure-Controlled IMV with Optimal Targeting (Cont.)



Pressure-Controlled CSV

- Patient is breathing spontaneously and support is adjusted to control work of breathing
- All breaths are patient triggered, pressure limited, and flow cycled
- Commonly referred to as “BiPAP”

Volume Delivered in Pressure Support

- Affected by three factors:
  - Set pressure
  - Patients’ compliance and resistance
  - Patients’ inspiratory efforts

Applications of Pressure Support

- Decreasing imposed work of breathing associated with artificial airway and ventilator circuit
- Supplementing patients’ spontaneous tidal volume to decrease work of breathing

Types of Patients Who Are Candidates for PSV

- Patients with artificial airway and any of the following conditions:
  - Artificial airways smaller than optimal size
  - Spontaneous respiratory rates greater than 20 breaths/min (adults)
  - Minute volumes greater than 10 L/min

Types of Patients Who Are Candidates for PSV (Cont.)

- Patients supported with IMV/SIMV or CPAP and any of the following conditions:
  - History of chronic obstructive pulmonary disease (COPD)
  - Evidence of ventilatory muscle weakness requiring ventilatory support

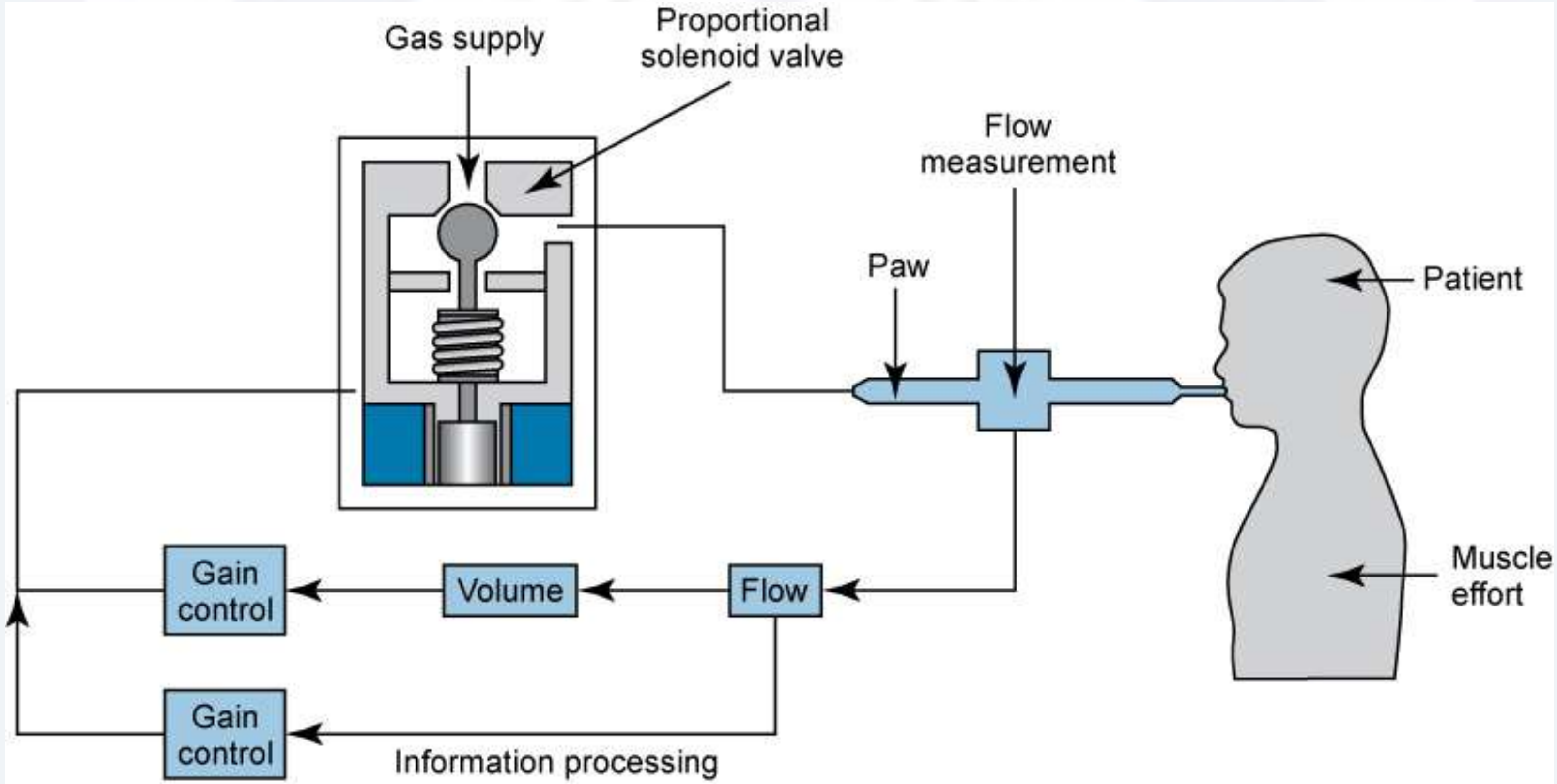
Volume Support Ventilation

- Breaths are patient triggered, pressure limited, and flow cycled
- Level of pressure support is adjusted to ensure delivery of mandatory tidal volume
- If patient becomes apneic, ventilator changes to pressure-regulated volume control (PRVC)
- Found on Maquet Servo[i]

Proportional Assist Ventilation

- Amount of work of breathing assumed by ventilator is adjusted
- Found on Covidien PB 840 ventilator
- Pressure, flow, and volume are automatically adjusted to ensure ventilator provides percentage of work of breathing

Proportional Assist Ventilation (Cont.)



Automatic Tubing Compensation

- Use of pressure support to overcome resistance of endotracheal tube
- Amount of pressure support necessary is calculated by measuring pressure at distal end of endotracheal tube
- Found on Dräger and Covidien PB 840 ventilators

Neurally Adjusted Ventilatory Assist

- Electrical activity of diaphragm is measured, determining amount of support necessary
- Specialized nasogastric tube is used to monitor electrical activity of diaphragm
- Ventilator begins inspiration as soon as diaphragm begins depolarization
- Depth of ventilation and length of breath are determined by electrical activity of diaphragm

Benefits of NAVA

- Reduced work of breathing
- Fewer trigger efforts missed
- Intrinsic PEEP does not affect triggering
- Improved synchrony and oxygenation
- Reduced need for sedation and paralysis
- Improved ventilation

Clinical Application

Criteria for Mechanical Ventilation

BOX 4-5 Standard Criteria for Instituting Mechanical

Ventilation

- Apnea or absence of breathing
- Acute ventilatory failure
- Impending ventilatory failure
- Refractory hypoxemic respiratory failure with increased work of breathing or an ineffective breathing pattern

Objectives of Mechanical Ventilation

BOX 4-1 Objectives of Mechanical Ventilation

Physiological Objectives

1. Support or manipulate pulmonary gas exchange:
   - Alveolar ventilation—Achieve eucapnic ventilation or allow permissive hypercapnia (NOTE: Permissive hypercapnia sometimes is required in the ventilation of patients with asthma, acute lung injury [ALI], or acute respiratory distress syndrome [ARDS] to protect the lung by avoiding high ventilating volumes and pressures.)
   - Alveolar oxygenation—Maintain adequate oxygen delivery ($CaO_2 \times$ Cardiac output)
2. Increase lung volume:
   - Prevent or treat atelectasis with adequate end-inspiratory lung inflation
   - Restore and maintain an adequate **functional residual capacity** (FRC)
3. Reduce the work of breathing

Clinical Objectives

1. Reverse acute respiratory failure
2. Reverse respiratory distress
3. Reverse hypoxemia
4. Prevent or reverse atelectasis and maintain FRC
5. Reverse respiratory muscle fatigue
6. Permit sedation or paralysis (or both)
7. Reduce systemic or myocardial oxygen consumption
8. Minimize associated complications and reduce mortality

Modified from Slutsky AS: *Chest* 104:1833, 1993.

Acute Respiratory Failure

- Recognizing the patient in distress
  - Determine the patient’s level of consciousness.
  - Assess the appearance and texture of skin.
  - Evaluate the patient’s vital signs.
    - Respiratory rate
    - Heart rate
    - Blood pressure
    - Body temperature
    - Oxygenation status

Physical Signs of Distress

CAUSE

Sudden Onset of Dyspnea

SIGNS

What Do YOU See?

What Would Patient Complain OF ?

What Would YOU Find out?

What About Panic Attack?

Respiratory Failure

Acute Hypoxemic Respiratory Failure (TYPE1)

- Definition
- Causes

Acute Hypercapnic Respiratory Failure (TYPE 2)

- Definition
- Causes

Failure to Recognize Patient in Acute & Impending RF May Lead to

Cardiac Dysrhythmias

Ventricular Fibrillation

Cardiac Arrest

TABLE 4-1 Conditions Seen with Hypoxemia and Hypercapnia

Hypoxemia		
	Mild to Moderate	*Severe*
Respiratory findings	Tachypnea Dyspnea Paleness	Tachypnea Dyspnea Cyanosis
Cardiovascular findings	Tachycardia Mild hypertension Peripheral vasoconstriction	Tachycardia (eventually bradycardia, arrhythmias) Hypertension (eventually hypotension)
Neurologic findings	Restlessness Disorientation Headaches Lethargy	Somnolence Confusion Delirium Blurred vision Tunnel vision Loss of coordination Impaired judgment Slowed reaction time Manic-depressive activity Loss of consciousness Coma
Hypercapnia		
	Mild to Moderate	*Severe*
Respiratory findings	Tachypnea Dyspnea	Tachypnea (eventually bradypnea)
Cardiovascular findings	Tachycardia Hypertension Vasodilation	Tachycardia Hypertension (eventually hypotension)
Neurologic findings	Headaches Drowsiness Dizziness Confusion	Hallucinations Hypomania Convulsions Loss of consciousness (eventually coma)
Signs	Sweating Skin redness	

BOX 4-6 **Indications for Invasive Mechanical Ventilation in Adults with Acute Respiratory Failure**

Invasive mechanical ventilation is indicated in any of the following circumstances:

1. Apnea or impending respiratory arrest
2. Acute exacerbation of chronic obstructive pulmonary disease (COPD)* with dyspnea, tachypnea, and acute respiratory acidosis (hypercapnia and decreased arterial pH) plus at least one of the following:
   - Acute cardiovascular instability
   - Altered mental status or persistent uncooperativeness
   - Inability to protect the lower airway
   - Copious or unusually viscous secretions
   - Abnormalities of the face or upper airway that would prevent effective noninvasive positive pressure ventilation
3. Acute ventilatory insufficiency in cases of neuromuscular disease accompanied by any of the following:
   - Acute respiratory acidosis (hypercapnia and decreased arterial pH)
   - Progressive decline in vital capacity to below 10 to 15 mL/kg
   - Progressive decline in maximum inspiratory pressure to below −20 to −30 cm H_2O
4. Acute hypoxemic respiratory failure with tachypnea, respiratory distress, and persistent hypoxemia despite administration of a high fraction of inspired oxygen (F_IO_2) with high-flow oxygen devices **or** in the presence of any of the following:
   - Acute cardiovascular instability
   - Altered mental status or persistent uncooperativeness
   - Inability to protect the lower airway
5. Need for endotracheal intubation to maintain or protect the airway or to manage secretions, given the following factors:
   - Endotracheal tube (ET) ≤7 mm internal diameter (ID) with minute ventilation >10 L/min
   - ET ≤8 mm ID with minute ventilation >15 L/min

If any of the conditions listed are not present, emergency intubation and invasive positive pressure ventilation may not be indicated for the following conditions until other therapies have been attempted.

- Dyspnea, acute respiratory distress
- Acute exacerbation of COPD
- Acute severe asthma
- Acute hypoxemic respiratory failure in immunocompromised patients
- Hypoxemia as an isolated finding
- Traumatic brain injury
- Flail chest

Physiologic Measurements

- Bedside measurements
  - MIP
  - VC
  - PEFR
  - FEV_1
  - Respiratory frequency (fb)
  - Expired volume per minute (V_E)
    - ($V_E = V_T \times fb$)

TABLE 4-3 Normal Adult and Critical Range Values

Ventilatory Mechanics	Normal Adult Range	Critical Value That May Indicate the Need for Mechanical Ventilation
Maximum inspiratory pressure (MIP) (cm H_2O)	−100 to −50	−20 to 0
Maximum expiratory pressure (MEP) (cm H_2O)	100	<40
Vital capacity (VC) (mL/kg)	65 to 75	<10 to 15
Tidal volume (V_T) (mL/kg)	5 to 8	<5
Respiratory frequency (f) (breaths/min)	12 to 20	>35
Forced expired volume at 1 second (FEV_1) (mL/kg)	50 to 60	<10
Peak expiratory flow (PEF) (L/min)	350 to 600	75 to 100

Physiologic Measurements—cont'd

- Partial pressure of carbon dioxide in arteries ($PaCO_2$)
  - Is the best indicator of adequate ventilation.
  - Suggests that V_D is increased relative to V_T.
- Partial pressure of oxygen in arteries (PaO_2)
  - Is a good indicator of oxygenation status.
- Oxygen saturation measured by pulse oximeter (SpO_2)
- Arterial content of oxygen (CaO_2)
- PaO_2/P_AO_2
- Ratio of arterial PO_2 to F_IO_2 (PaO_2/F_IO_2)

TABLE 4-2 Indications of Acute Respiratory Failure and the Need for Mechanical Ventilatory Support in Adults

Criteria	Normal Values	Critical Value
Ventilation*		
pH	7.35-7.45	<7.25
Arterial partial pressure of carbon dioxide (P_aCO_2) (mm Hg)	35-45	>55 and rising
Dead space to tidal volume ratio (V_D/V_T)	0.3-0.4	>0.6
Oxygenation†		
Arterial partial pressure of oxygen (P_aO_2) (mm Hg)	80-100	<70 (on $O_2 \geq 0.6$)
Alveolar-to-arterial oxygen difference $P_{(A-a)}O_2$ (mm Hg)	5-20	>450 (on O_2)
Ratio of arterial to alveolar PO_2 (P_aO_2/P_AO_2)	0.75	<0.15
P_aO_2/F_IO_2	475	<200

Selecting the Patient Interfaces

- NIPPV
  - CPAP
  - NIV
    - Pressure-triggered, pressure-limited, flow-cycled devices
    - Critical-care ventilators
- Invasive positive-pressure ventilation

Full and Partial Ventilatory Support

- Full ventilatory support
- Partial ventilatory support
  - Intermittent mandatory ventilation (IMV)
  - PSV
  - PAV
  - MMV

Volume-Targeted Ventilation

Advantages

- Guarantees a Specific MV regardless of the lungs mechanics

Maintains a certain level of PaCO2

Disadvantages

- Variable PIP based on the lungs mechanics
- Related to flow and sensitivity setting which may lead to patient-ventilator asynchrony. HOW?

Constant Flow may not match patient demand

Inappropriate Sensitivity setting may make it difficult for patient to trigger

Pressure-Targeted Ventilation

Advantages

- Allow clinicians to set a maximum pressure level.
- Decelerating flow pattern.
- More comfortable for patient who can breath spontaneously.
- Helps reduce WOB.

HOW?

Disadvantages

- Volume delivery varies
- Clinicians are less familiar with Pressure-Control Ventilation.
- V_T & VE decrease when lung characteristics deteriorate.

BOX 5-4 Factors That Affect Pressures During Volume-Controlled Ventilation

Patient Lung Characteristics

- Reductions in lung or chest wall compliance produce higher peak and plateau pressures; increased compliance produces lower peak and plateau pressures.
- Increased airway resistance produces a higher peak pressure; reductions in airways resistance produce lower peak pressures.

Inspiratory Flow Pattern

- Peak pressure is higher with a constant flow and lower with a decelerating flow pattern. Decelerating flow pattern has a higher mean airway pressure; constant flow generates the lowest mean airway pressure
- High inspiratory gas flow creates a higher peak pressure.

Volume Setting

- High volumes produce higher peak and plateau pressures; low volumes produce lower peak and plateau pressures.

Positive End-Expiratory Pressure (PEEP)

- Increasing PEEP increases the peak and mean pressures.

Auto-PEEP

- Increases in auto-PEEP increase the peak inspiratory pressure.

BOX 5-5 Factors That Affect Volume Delivery During Pressure-Controlled Ventilation*

Pressure Setting

- Higher pressure settings produce larger volumes, whereas lower pressure settings produce lower volumes. In other words, increasing the peak inspiratory pressure (PIP) while maintaining a constant end-expiratory pressure (EEP) increases volume delivery (and vice versa).

Pressure Gradient

- Increasing EEP (PEEP + auto-PEEP) while keeping PIP constant reduces the pressure gradient (PIP – EEP) and lowers volume delivery (and vice versa).

Patient Lung Characteristics

- Reduced compliance results in lower volume; increased compliance results in increased volume for a given inspiratory pressure.
- Increased airway resistance (R_{aw}) results in lower volume delivery if active flow is present; reductions in airway resistance results in higher volume delivery if active flow is present.

Inspiratory Time

- When the inspiratory time (T_I) is extended, volume delivery increases. Notice that this is true as long as flow is present during inspiration (i.e., the flow–time curve shows flow above zero when inspiration ends). However, if flow returns to zero before inspiration ends, further increases in T_I can decrease volume delivery if adequate time is not provided for exhalation.

Patient Effort

- Active inspiration by the patient can increase volume delivery.

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*See the Review Questions at the end of the chapter for practice problems, which provide examples of how these factors affect volume delivery during pressure ventilation.

Selecting Ventilator Initial Settings

To select initial ventilator settings you should take the following steps:

1. Identify the patient's underline acute condition, history, gender, and height.
2. Identify or calculate the patient's IBW or use the BSA if given.
   IBW male = 106 + 6 (H – 60)
   IBW female = 105 + 5 (H – 60)
   Height in inches and weight will be in lb to convert to Kg divide by 2.2
3. Calculate the appropriate MV based on IBW or BSA and gender
   IBW X 100 ml/Kg (male and female)
   BSA X 4 male
   BSA X 3.5 female
   Note: Correct the MV based on body temperature and respiratory acid/base status
4. Calculate the appropriate TV based on IBW and gender, and patient condition
5. Then from the MV and the TV you can calculate the appropriate Rate
6. PEEP is generally accepted to start with 3 to 5 cm H2O for optimal PEEP settings go to your reference book
7. Desired FiO2 you can start with the same FiO2 which patient was receiving if PaO2 and SaO2 are acceptable or higher if not. You can also use the following formula for estimated Desired FiO2 = Known FiO2 X Known PaO2 / Desired PaO2
8. For the initial PC settings can be estimated by given VC breathes to patient with same baseline pressure then use the plateau pressure as an initial pressure on PC ventilation. Or to start with 10 to 15 cm H2O then assess the exhaled TV to adjust the PC level to achieve the optimal TV.
9. For PSV is well accepted way is to use the difference (PIP – Pplat) then assess the exhaled TV to 4 to 8 ml/Kg IBW
10. Mode can be selected based on the patient condition or what therapist is more confidant with.

Sensitivity (Trigger)

- Trigger sensitivity: amount of effort required by patient to initiate machine breath
- Pressure Triggering
  - Ventilator breath is triggered by decrease in pressure below baseline
  - Sensitivity is usually set at –0.5 to 1.5 cm H_2O
- Flow Triggering
  - Base or bias flow, present during exhalation, is set
  - Common level is 5 to 10 L/min
  - Flow trigger is set at 1 to 5 L/min
  - When patient decreases flow to set level of flow trigger, an assisted breath is delivered

TABLE 7-1 **Initial Ventilator Settings Based on Pulmonary Disorder***

Lung Disease	Mode	V_T (mL/kg IBW)	Rate (breaths/min)	Flow (L/min)	Flow Waveform	T_I (sec)	PEEP (cm H_2O)	F_IO_2
Normal lungs	VC- or PC-CMV	6-8	10-15	60	Descending or constant	1	≤5	≤0.5
COPD†	VC- or PC-CMV	6-8	8-12	>60 (80-100)	Descending or constant	0.6-1.2	≥5 or 50% of intrinsic PEEP	<0.5
Neuromuscular disorder	VC-CMV	6-8	8-12	≥60	Descending or constant	1	5	0.21
Asthma	VC- or PC-CMV	6-8	10-14	60-70	Descending	≤1	Only to offset intrinsic PEEP and improve triggering	≥0.5
Closed head injury	PC- or VC-CMV	6-8	15-20	60	Descending or constant	1	0-5 with caution Only in severe hypoxemia	1.0
ARDS	PC- or VC-CMV	4-8	12-35	≥60	Descending or constant	1	5 to >15	1.0
CHF	VC- or PC-CMV	6-8	≥10	≥60	Descending or constant	1-1.5	5-10	1.0

Sources: Meade MO, Herridge MS: An evidence-based approach to acute respiratory distress syndrome, Respir Care 46:1368-1376, 2001; Slutsky AS, Ranieri M: Ventilator-induced lung injury, N Engl J Med 369:2126-236, 2013.

ARDS, Acute respiratory distress syndrome; *CHF*, congestive heart failure; *CMV*, continuous mandatory ventilation; F_IO_2, fractional inspired oxygen concentration; *IBW*, ideal body weight; *PC*, pressure control; *PEEP*, positive end-expiratory pressure; V_C, volume control; V_T, tidal volume.

*For all disorders it is very important that the plateau pressure be maintained lower than 30 cm H_2O.

†An initial attempt at bilevel PAP should be tried using NIV with IPAP = 10 to 12 cm H_2O and EPAP = 2 to 3 cm H_2O before intubation is considered. An exception would be a critical emergency with these patients.

Humidification

- HMEs
- Active Humidification

BOX 7-2 Contraindications for Heat-Moisture Exchangers

1. The presence of thick, copious, or bloody secretions. These secretions can accumulate on the heat-moisture exchanger (HME) and increase both inspiratory and expiratory resistance.
2. The patient's exhaled tidal volume (V_T) is less than 70% of inhaled V_T (e.g., in bronchopleural fistulas or when endotracheal tube cuffs are absent).
3. Body temperatures below 32° C (hypothermia).
4. Spontaneous high minute ventilation ($\dot{V}_E$) is greater than 10 L/min.
5. An aerosolized medication must be given.
6. Very small V_T must be delivered (lung protective ventilation); in which case the HME may significantly increase mechanical dead space (V_{Dmech}) and compromise CO_2 clearance. Notice that large V_T delivery may compromise the ability of the HME to humidify inspired gases.

BOX 7-3 Levels of Alarm and Example Events During Mechanical Ventilation

Level 1: Immediately Life-Threatening

Example events:

- Electrical power failure
- No gas delivery to patient
- Exhalation valve failure
- Excessive gas delivery to patient
- Timing failure

Level 2: Potentially Life-Threatening

Example events:

- Circuit leak
- Circuit partially obstructed
- Heater/humidifier malfunction
- Inspiratory-to-expiratory (I:E) ratio inappropriate
- Inappropriate oxygen level (gas/blender failure)
- Autocycling
- Inappropriate PEEP/CPAP level (too low/too high)

Level 3: Not Life-Threatening but a Potential Source of Patient Harm

Example events:

- Changes in lung characteristics (compliance/resistance)
- High respiratory rates
- Auto-PEEP
- Changes in ventilatory drive (e.g., central nervous system [CNS] or muscle function)

Sources: Hess D: Noninvasive monitoring in respiratory care—present, past and future: an overview, *Respir Care* 35:482-499, 1990; MacIntyre NR, Day S: Essentials for ventilator-alarm systems, *Respir Care* 37:1108-1112, 1992.

ALARMS

- Low-pressure alarms are usually set about 5 to 10 cm H2O below PIP.
- High-pressure alarms are set about 10 cm H2O above PIP.
- Total Respiratory Rate alarm set about : high 10 Breaths above the patient total rate; low as low as 6 to 8 BPM
- Low PEEP/continuous positive airway pressure (CPAP) alarms are usually set about 2 to 5 cm H2O below the PEEP level.
- Apnea alarms are used to monitor mandatory or spontaneous breaths. An apnea period of 20 seconds is the highest accepted maximum. In some situations, apnea alarms are set so the patient will not miss two consecutive machine breaths (apnea time > total cycle time [TCT] and < [TCT × 2]).
- Low exhaled VT: 10% to 15% below set VT.
- Low exhaled minute volume: 10% to 15% below average minute volume.
- FIO2: 5% above and below set oxygen percentage.

FINAL CONSIDERATIONS IN VENTILATOR EQUIPMENT SETUP

Before initiating mechanical ventilation, the respiratory therapist should perform a final check of the equipment to be used. This check should include the following steps:

1. Check ventilator and circuit function to ensure they are operating correctly and no significant leaks are present.
2. Fill the humidifier with sterile water, and set the humidifier temperature so that the final gas temperature at the airway will be approximately 31° to 35° C, or place an HME in line.
3. Place a temperature monitoring device near the patient connector when heated humidification is used.
4. Check the F_IO_2, set V_T (or inspiratory pressure) and f.
5. Adjust the alarms.
6. Ensure that the patient is connected to an electrocardiographic monitor.
7. Have an emergency airway tray available in case the patient's airway is removed or damaged.
8. Check that suctioning equipment is available and functioning.
9. Select a volume-monitoring device and an oxygen analyzer if one is not available with the ventilator.
10. Ensure that a manual resuscitation bag is available and easily accessible.

Once the decision has been made to connect the patient to a ventilator, several steps should be taken, including the following:

- Preparing the patient
- Establishing an airway interface
- Manually ventilating the patient
- Ensuring that the patient's cardiovascular status is stable
- Meeting ventilation needs
- Treating the cause of respiratory failure

Monitoring

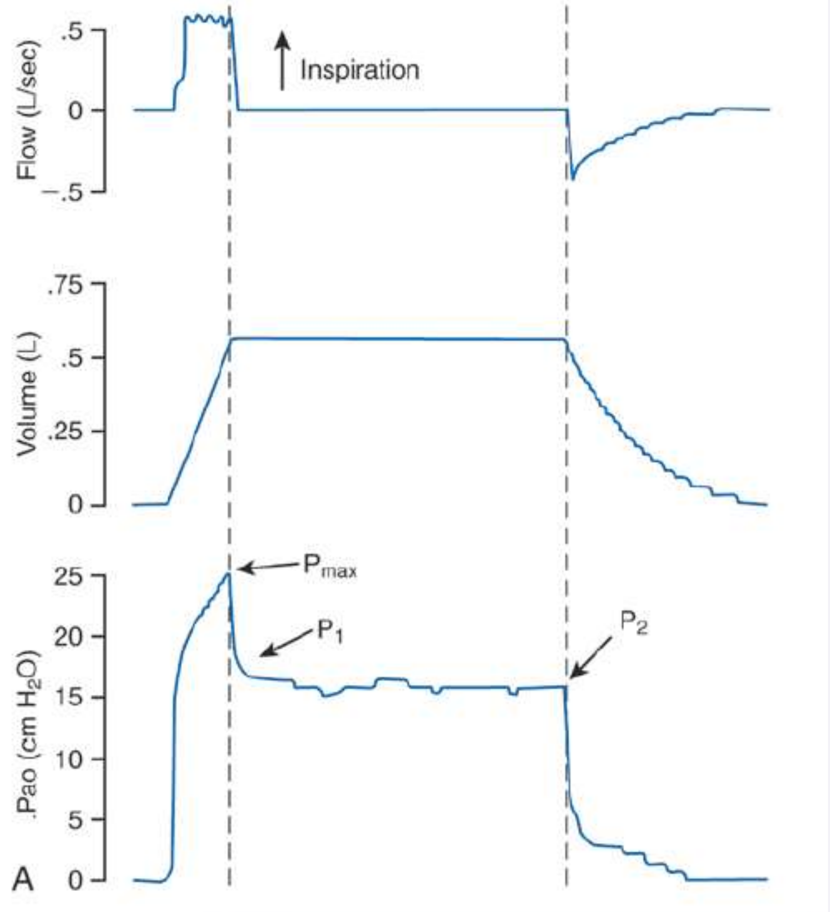
- Mode
- Sensitivity
- Tidal Volume, Rate, and Minute Ventilation
- Monitoring Airway Pressures
  - Peak Inspiratory Pressure
  - Plateau Pressure
  - Set Pressure
  - Transairway Pressure: PIP Minus Pplateau
  - Mean Airway Pressure
  - End-Expiratory Pressure
  - Pressure Limit
  - Checking the Circuit: Checking for Leaks

- Vital Signs, Blood Pressure, and Physical Examination of the Chest
  - Heart Rate
  - Temperature
  - Systemic Arterial Blood Pressure
  - Central Venous Pressure
  - Pulmonary Artery Pressure
  - Physical Examination of the Chest
- Management of Endotracheal Tube and Tracheostomy Tube Cuffs
  - Cuff Pressure Measurement
  - Tube and Mouth Care
- Monitoring Compliance and Airway Resistance
  - Static Compliance
  - Dynamic Characteristic (Dynamic Compliance)
  - Airway Resistance

BOX 8-6 Calculation of Alveolar Ventilation in VC-IMV

Calculations are made using the following data:

- Intermittent mandatory ventilation (IMV) rate = 5 breaths/min
- Tidal volume (V_T) = 600 mL
- Anatomic dead space (V_{Danat}) = 100 mL
- Added mechanical dead space (V_{Dmech}) = 50 mL
- Mandatory alveolar ventilation per minute ($\dot{V}_A$) = 5 × [600 – 100 – 50] = 2250 mL or 2.25 L/min
- Patient spontaneous rate = 10 breaths/min
- Spontaneous V_T = 350 mL
- Spontaneous alveolar ventilation = 10 × [350 – 100 – 50] = 2000 mL or 2 L
- Total alveolar ventilation = 2.25 + 2 = 4.25 L/min



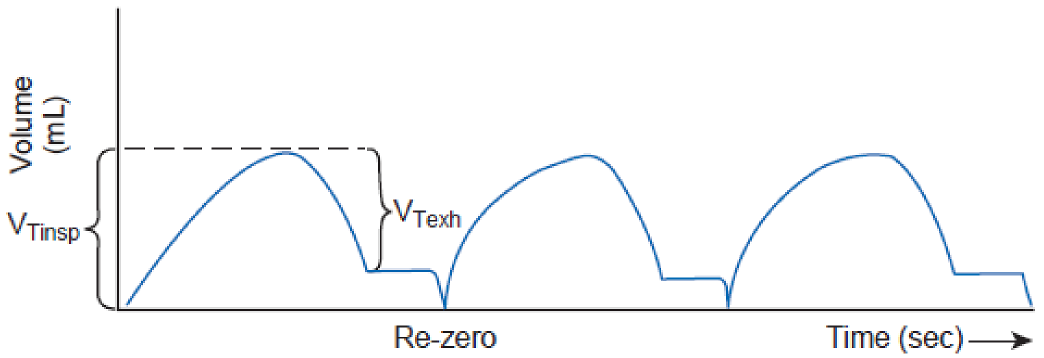


TABLE 8-1 Physical and Radiologic Findings in Common Pulmonary Disorders

Diagnosis	Auscultation	Percussion	Tracheal Excursion	Chest Wall Movement	Chest Radiograph
Asthma	High-pitched wheezing	Hyperresonant R and L	WNL	↓ R and L	↑ Radiolucency
Pneumonia (R)	Late inspiratory crackles	Dull (R)	WNL; if massive, L-shift	↓ R	Infiltrates (R)
Pleural effusion (R)	Friction rub, just above fluid level	Dull (R)	L-shift	↓ R	Blunting of costophrenic angle (R)
Pneumothorax (R)	Decreased or absent on R	Hyperresonant (R)	L-shift	↓ R	Lack of vascular markings (R); mediastinal shift (L)
Emphysema	Diminished; vary; early expiratory crackles	Hyperresonant	WNL	↓ R and L	↑ Radiolucency; widened rib spaces; flattened diaphragm

L, Left; *R*, right; *WNL*, within normal limits; ↓, decrease; ↑, increase.

Case Study 8-4

Patient Assessment Cases

Problem 1

Physical examination of a patient on mechanical ventilation reveals bilateral low-pitched lung sounds and normal resonance to percussion. The patient has a temperature of 39° C. Heart rate is 122 beats/min and blood pressure is 135/85 mm Hg. What is the possible cause of this patient's abnormal breath sounds? What therapeutic procedure is indicated?

Problem 2

On chest auscultation, the practitioner hears no breath sounds on the left, but distant breath sounds on the right. The percussion note on the left is hyperresonant, and the note on the right has normal resonance. The trachea is deviated to the right. In the past hour cardiac output has dropped from 6 L/min to 4.5 L/min. What is the most likely problem?

Problem 3

A female patient has been intubated for 4 hours and is receiving 100% oxygen. Auscultation of the patient's chest reveals normal breath sounds on the right, but no breath sounds on the left. The percussion note is normal on the right, and dull on the left. The oral endotracheal tube indicates a 26-cm marking at the teeth. What is the most likely problem?

Problem 1: Findings suggest that the patient has a respiratory infection. A chest radiograph and laboratory studies, including a white blood cell count, might confirm this diagnosis. The low-pitched rattles heard on auscultation (rhonchi) indicate secretions in the large airways. The patient may need to be suctioned. Also, a culture and sensitivity test of a sputum sample may be in order. Antibiotics may be indicated.

Problem 2: Pneumothorax on the left side.

Problem 3: Right mainstem intubation.

TABLE 8-2 Simplified Examples of Changes in Delivered Tidal Volume (V_T) and Peak Inspiratory Pressure (PIP) and Pressure Plateau ($P_{plateau}$) Reflecting Changes in Dynamic Compliance (C_D)

A. DECREASING C_D DURING PC-CMV

Time	PIP	V_T	C_D*
01:00	25	500	20
02:00	25	400	16
03:00	25	300	12

Constant pressures with decreasing volume.

B. DECREASING C_D DURING VC-CMV

Time	PIP	V_T	C_D
01:00	25	500	20
02:00	30	500	17
03:00	35	500	14

Constant volume with increasing pressures.

C. DECREASING C_S AND C_D DURING VC-CMV WITH CONSTANT R_{AW}

Time	PIP	C_D	$P_{plateau}$	C_S*	P_{TA}	Volume†
01:00	25	20	20	25	5	500
02:00	30	17	25	20	5	500
03:00	35	14	30	17	5	500

Increasing PIP and $P_{plateau}$. Volume and pressure lost to the airways are constant. The lung is less compliant.

D. DECREASED C_D, CONSTANT C_S DURING VC-CMV WITH INCREASED R_{AW}

Time	PIP	C_D	$P_{plateau}$	C_S	P_{TA}	Volume
01:00	25	20	20	25	5	500
02:00	30	17	20	25	10	500
03:00	35	14	20	25	15	500

Increasing PIP with constant volumes and $P_{plateau}$. R_{aw} is increased (P_{TA} = PIP – $P_{plateau}$).

E. IMPROVING C_D AND C_S DURING VC-CMV

Time	PIP	C_D	$P_{plateau}$	C_S	P_{TA}	Volume
01:00	25	20	23	22	2	500
02:00	23	22	21	24	2	500
03:00	20	25	18	28	2	500

PIP and $P_{plateau}$ are decreasing; delivered volume and P_{TA} are constant; the lungs are more compliant.

F. COMPLIANCE MEASUREMENTS WITH PEEP DURING VC-CMV

Time	PIP	C_D	$P_{plateau}$	C_S	P_{TA}	PEEP	Volume
01:00	30	20	28	22	2	+5	500
02:00	35	20	33	22	2	+10	500
03:00	40	18	37	20	3	+12	500

The addition of increasing PEEP results in increasing PIP and $P_{plateau}$. Delivered V_T and P_{TA} remain constant.

C_D, Dynamic compliance (C_D = Volume/[PIP – EEP]); *C_S*, static compliance (C_S = Volume/[$P_{plateau}$ – EEP]); *EEP*, end-expiratory pressure; *PEEP*, positive end-expiratory pressure; *PIP*, peak inspiratory pressure (cm H_2O); *PC-CMV*, pressure-controlled, continuous mandatory ventilation; *$P_{plateau}$*, plateau pressure (cm H_2O); *P_{TA}*, transairway pressure (cm H_2O); *R_{aw}*, airway resistance; *VC-CMV*, volume-controlled, continuous mandatory ventilation; *V_T*, tidal volume (mL).

*Volume is shown in mL throughout the table.

†Compliance is shown in mL/cm H_2O throughout the table.

Case Study 8-5

Exercises

Problem 1

While checking the ventilation parameters during VC-CMV, you notice the following changes in positive inspiratory pressure (PIP) and plateau pressure ($P_{plateau}$):

Time	Volume (L)	PIP (cm H_2O)	$P_{plateau}$ (cm H_2O)
01:00	0.7	23	15
03:00	0.7	28	16
05:00	0.7	35	17

What is the likely cause of the problem? How would you assess the patient to determine the appropriate treatment?

Problem 2

During PC-CMV, the following changes are noted:

Time	Volume (L)	Set Pressure (cm H_2O)
01:00	0.65	20
03:00	0.60	20
05:00	0.55	20

What is the likely cause of the problem? How would you assess the patient to determine treatment?

Adjusting Ventilator Settings

Ventilation: to maintain acceptable $PaCO_2$ and/or pH according to patient status or treating team plan

- **Increasing MV to eliminate CO_2 and improve respiratory acidosis:**
  1. You target the TV as long as you still have space to increase it based on the patient IBW and Pplat should not exceed 30 cm H_2O

     Volume Control Modes:
     Desired TV = Known TV X Known $PaCO_2$ / Desired $PaCO_2$

     Pressure Control Modes: Adjusting PC Based on Cs.
     Desired PC = Desired TV/Cs
     Example if the current TV is 400 ml and Cs is 35 ml/cm H_2O and you need to increase the volume to 500 ml
     Desired PC= 500/35 = 14 cm H_2O

  2. Increase the Rate as long as enough time is available for expiration or I:E is less than 1:1.
- **Decreasing MV to resolve respiratory alkalosis:**
  1. Decreasing the mandatory rate or switch from full support to partial support.
  2. Decreasing the TV if possible (maintaining acceptable TV for the patient)

Oxygenation: the goal is to maintain acceptable level of PaO_2 more than 60 mm Hg and SaO_2 more than 90%.

- **Increasing the FiO_2:**
  1. Desired FiO_2 = Known FiO_2 X Known PaO_2 / Desired PaO_2
  2. When increasing FiO_2 you have to evaluate the risk of high FiO_2 on the patient condition. Maintaining $FiO_2 \leq 60\%$ should be applied as long as possible to avoid oxygen toxicity and absorption atelectasis.
  3. If FiO_2 higher than 60% is required conceder increasing the PEEP
- **Increasing PEEP:**
  1. Initial PEEP of 3 to 5 cm H_2O is acceptable in most cases
  2. Therapeutic PEEP range of 5 cm H_2O or higher
  3. When increasing the PEEP, Pplat should always be maintained at ≤ 30 cm H_2O

Increase the PEEP by 3 to 5 cm H_2O for adults and by 2 to 3 for infants then watch for the effect on the patient (optimal PEEP study)

Weaning Mechanical Ventilation Support (Evidence-Based Weaning)

- **Criteria for weaning:**
  - Problem requiring ventilation resolved
  - Measurable criteria met for the patient's readiness to discontinue
  - Successful SBT

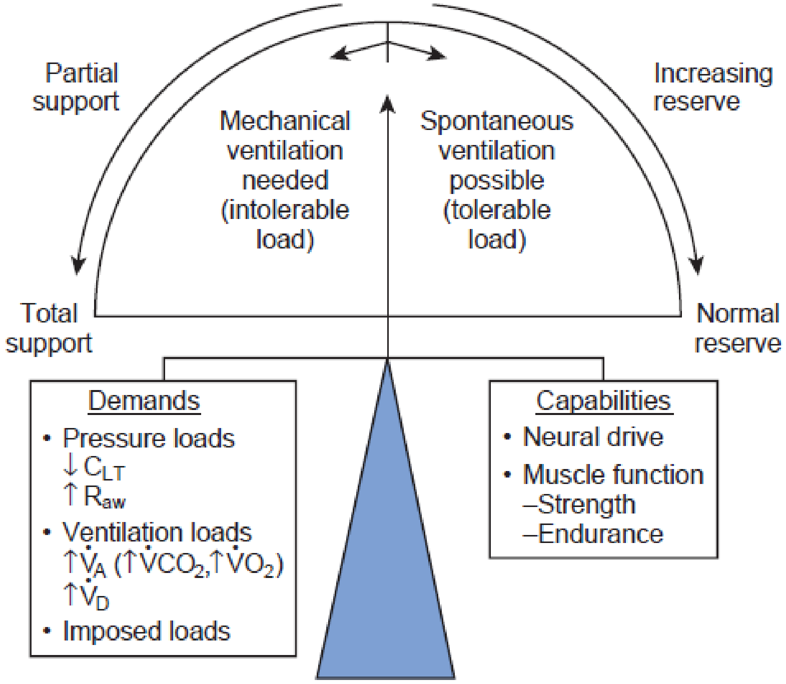


TABLE 20-1 Physiological Parameters for Weaning and Extubation of Adults

Parameter	Acceptable Value
Ventilatory Performance and Muscle Strength	
VC	>15 mL/kg (IBW)
$\dot{V}_E$	<10-15 L/min
V_T	>4-6 mL/kg (IBW)
f	<35 breaths/min
f/V_T	<60-105 breaths/min/L (spontaneously breathing patient)
Ventilatory pattern	Synchronous and stable
P_{Imax} (up to 20-sec measurement from RV)	< −20 to −30 cm H_2O
Measurement of Drive to Breathe	
$P_{0.1}$	>6 cm H_2O
Measurement and Estimation of WOB	
WOB*	<0.8 J/L
Oxygen cost of breathing*	<15% of total $\dot{V}O_2$
Dynamic compliance	>25 mL/cm H_2O
V_D/V_T	<0.6
CROP index	>13 mL/breaths/min
Measurement of Adequacy of Oxygenation	
P_aO_2	≥60 mm Hg (F_IO_2 <0.4)
PEEP	≤5-8 cm H_2O
P_aO_2/F_IO_2	>250 mm Hg (consider at 150-200 mm Hg)
P_aO_2/P_AO_2	>0.47
$P_{(A-a)}O_2$	<350 mm Hg (F_IO_2 = 1)
% $\dot{Q}_S/\dot{Q}_T$	<20% to 30%

Facts to Consider

- Patients may require support during weaning
- Supplemental O_2 and PEEP may be required
- Require an artificial airway
    - Extubation is different from discontinuation of support
- May require one or all of the above

Methods of Titrating Ventilator Support During Weaning

- Three approaches
  1. Intermittent mandatory ventilation (IMV)
  2. Pressure-support ventilation (PSV)
  3. T-piece weaning

Intermittent Mandatory Ventilation (IMV)

- Theory is that the patient’s respiratory muscles work during spontaneous breaths and rest during mandatory breaths
- Common practice
  - Reduce the mandatory rate at a pace that matches the patient’s improvement
  - Usually in steps of 1 or 2 breaths/min
- PSV can be added
  - 5-10 cm H_2O
- PEEP of 3 to 5 cm H_2O

Pressure-Support Ventilation (PSV)

- Patient controls the rate, timing, and depth of each breath
- Patient triggered, pressure limited, and flow cycled
- ICU ventilators allow form monitoring and alarm systems
- Establishing the level of PSV
  - Pressure support levels of 5-15 cm H_2O
  - Attempt to re-establish the patient’s baseline RR (15-25 breaths/min) and V_T (300-600 mL)

Pressure-Support Ventilation (PSV)—cont'd

- During weaning
  - Clinician gradually reduces level of support
  - Usually until about 5 cm H_2O
  - Need to monitor patient for signs of distress

T-Piece Weaning

- Oldest technique
- Humidified gas source connected to a T-piece (Briggs adapter) with large-bore tubing
- Then attached to ET tube
- Another piece of large-bore tubing attached to the exhalation side of T-piece
- Requires high level of staff attention
- When T-piece is used through a ventilator, CPAP is used

T-Piece Weaning—cont'd

- Not tolerated well in patient with
  - Underlying heart disease
  - Severe muscle weakness
  - Inclined to panic
  - Preexisting chronic lung conditions

Closed-Loop Control Modes for Ventilator Discontinuation

- Automatic tube compensation (ATC)
- Volume-targeted pressure-support ventilation
- Automode and variable pressure support/variable pressure control
- Mandatory minute ventilation (MVV)
- Adaptive support ventilation
- Artificial intelligence systems

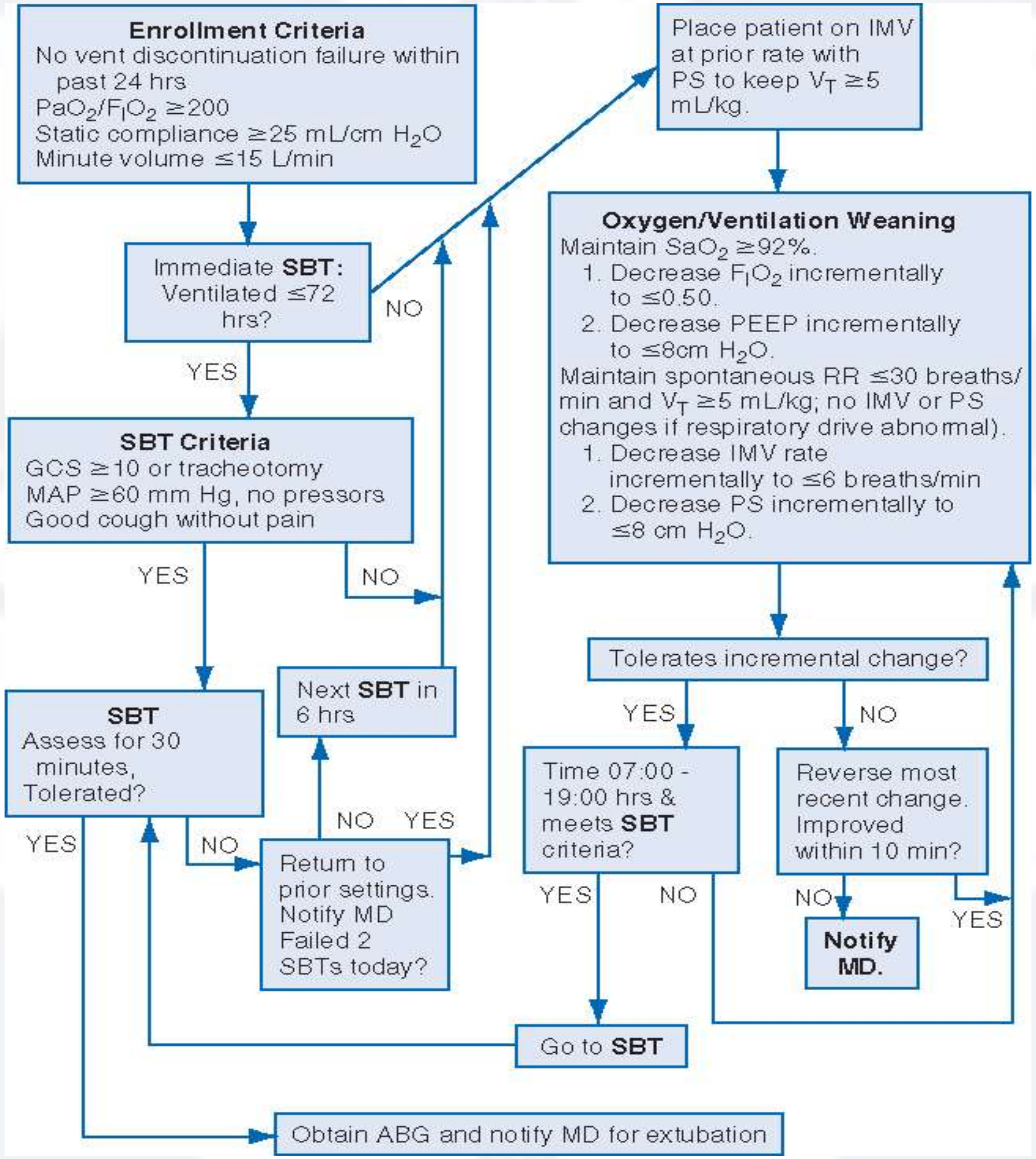
Weaning Mechanical Ventilation Support

BOX 20-8 Physical Signs and Measurements of Increased WOB

- Use of accessory muscles
- Asynchronous breathing (chest wall–diaphragm asynchrony)
- Nasal flaring
- Diaphoresis
- Anxiety
- Tachypnea
- Substernal and intercostal retractions
- Patient asynchronous with ventilator
- Measured WOB >1.8 kg/m/min or >0.8 J/L
- Measured WOB ≥15% of total oxygen consumption

BOX 20-9 Clinical Signs and Symptoms Indicating Problems During a Spontaneous Breathing Trial (SBT)

1. Respiratory rate exceeding 30 to 35 breaths/min (clinicians also should watch for increases of more than 10 breaths/min or decreasing below 8 breaths/min).
2. Tidal volume (V_T) decreasing below 250 to 300 mL.
3. Blood pressure changing significantly, as demonstrated by
   - A drop of 20 mm Hg systolic or
   - A rise of 30 mm Hg systolic or
   - Systolic values >180 mm Hg or
   - A change of 10 mm Hg diastolic (e.g., rise >90 mm Hg)
4. Heart rate increasing more than 20% or exceeds 140 beats/min.
5. Sudden onset of frequent premature ventricular contractions (more than 4 to 6 per minute).
6. Diaphoresis.
7. Clinical signs that indicate deterioration of the patient's condition or that demonstrate the patient is anxious, not ready for weaning, and must be returned to ventilatory support.
8. Deterioration of arterial blood gas values and oxygen saturation measured by pulse oximeter (S_pO_2).[85]


Enrollment Criteria
No vent discontinuation failure within past 24 hrs
PaO2/FIO2 ≥200
Static compliance ≥25 mL/cm H2O
Minute volume ≤15 L/min
Immediate SBT: Ventilated ≤72 hrs?
NO
YES
SBT Criteria
GCS ≥10 or tracheotomy
MAP ≥60 mm Hg, no pressors
Good cough without pain
YES
NO
SBT
Assess for 30 minutes, Tolerated?
Next SBT in 6 hrs
NO
YES
YES
NO
Return to prior settings. Notify MD Failed 2 SBTs today?
Place patient on IMV at prior rate with PS to keep VT ≥5 mL/kg.
Oxygen/Ventilation Weaning
Maintain SaO2 ≥92%.
1. Decrease FIO2 incrementally to ≤0.50.
2. Decrease PEEP incrementally to ≤8cm H2O.
Maintain spontaneous RR ≤30 breaths/min and VT ≥5 mL/kg; no IMV or PS changes if respiratory drive abnormal).
1. Decrease IMV rate incrementally to ≤6 breaths/min
2. Decrease PS incrementally to ≤8 cm H2O.
Tolerates incremental change?
YES
NO
Time 07:00 - 19:00 hrs & meets SBT criteria?
Reverse most recent change. Improved within 10 min?
YES
NO
NO
YES
Notify MD.
Go to SBT
Obtain ABG and notify MD for extubation

Weaning Mechanical Ventilation Support

- Removal of an Artificial Airway
  - Conceder factors that may contribute to extubation failure
  - Extubation equipment and procedure
  - Postextubation difficulties

Weaning Mechanical Ventilation Support

BOX 20-10 Factors That May Contribute to Extubation Failure

- Type of patient (i.e., medical versus surgical)
- Older age
- Severity of illness at weaning onset
- Repeated or traumatic intubations
- Use of continuous intravenous sedation
- Duration of mechanical ventilation
- Female gender
- Anemia (hemoglobin <10 mg/dL or hematocrit <30%)
- Need for transport out of the intensive care unit
- Initial severity of illness
- Indication for mechanical ventilation (e.g., cause of acute respiratory failure)
- Duration or number of individual spontaneous breathing trials before extubation
- Mode of ventilator support before extubation
- Protocol-directed weaning

BOX 20-13 Criteria for Instituting NIV After Failure to Wean from Invasive Mechanical Ventilation in Extubated Patients

- Resolution of problems leading to respiratory failure
- Ability to tolerate a spontaneous breathing trial for 10 to 15 minutes
- Strong cough reflex
- Hemodynamic stability
- Minimal airway secretions
- Low F_IO_2 requirements
- Functioning gastrointestinal tract
- Optimum nutritional status

BOX 20-4 Selected Recommendations from the American College of Chest Physicians (ACCP)/American Association for Respiratory Care (AARC)/Society of Critical Care Medicine (SCCM) Evidence-Based Weaning Guidelines Task Force

Recommendation 1: Pathology of Ventilator Dependence
All factors that may be contributing to ventilator dependence should be identified for patients requiring mechanical ventilation for longer than 24 hours. This is particularly true if attempts to withdraw the mechanical ventilator have failed. Reversing all possible ventilatory and nonventilatory issues is an important part of the ventilator discontinuation process.

Recommendation 2: Assessment of Readiness Using Evaluation Criteria
A formal patient assessment should be performed to determine whether the criteria have been met for discontinuation of ventilation. The following criteria are recommended:

1. Evidence of some reversal of the underlying cause of respiratory failure.
2. Adequate oxygenation: arterial partial pressure of oxygen (P_aO_2) ≥60 mm Hg with fractional inspired oxygen (F_IO_2) ≤0.4; ratio of arterial partial pressure of oxygen to fractional inspired oxygen (P_aO_2/F_IO_2) ≥150 to 200 mm Hg; required positive end-expiratory pressure (PEEP) ≤5 to 8 cm H_2O; F_IO_2 ≤0.4 to 0.5; and hydrogen ion concentration (pH) ≥7.25.
3. Hemodynamic stability; that is, no clinically important hypotension and no requirement for vasopressors or a

Spontaneous Breathing
Formal discontinuation assessments should be done during spontaneous breathing rather than while the patient receives substantial ventilatory support. An initial brief period of spontaneous breathing can be used to assess the patient's ability to perform a formal spontaneous breathing trial (SBT). The criteria used to assess a patient's tolerance of an SBT are (1) respiratory pattern, (2) adequacy of gas exchange, (3) hemodynamic stability, and (3) subjective comfort. Patients who tolerate an SBT of 30 to 120 minutes should promptly be considered for ventilator discontinuation.

Recommendation 4: Removal of the Artificial Airway
For patients whose support from the ventilator has been successfully discontinued, the decision regarding removal of the artificial airway should be based on assessment of airway patency and the patient's ability to protect the airway.

Recommendation 5: SBT Failure
If SBT fails, the causes of the failure and the reasons the patient continues to require ventilatory support should be determined and corrected. Once the reversible causes of failure have been corrected, and if the patient still meets the criteria described in Recommendation 2, an SBT should be performed every 24 hours.

Recommendation 6: Maintaining Ventilation with SBT Failure
Patients receiving mechanical ventilation for respiratory failure who fail an SBT should receive a stable, nonfatiguing, comfortable form of ventilatory support.

Recommendation 7: Anesthesia and Sedation Strategies and Protocols
Anesthesia and sedation strategies and ventilator management should be directed toward early extubation for patients who have had surgery.

Recommendation 8: Weaning Protocols
Protocols for ventilation discontinuation that are designed for clinicians other than physicians should be developed and implemented by intensive care units. These protocols should aim to optimize sedation.

Recommendation 9: Role of Tracheostomy in Weaning
When it becomes apparent that a patient will require prolonged ventilator assistance, tracheotomy should be considered. Tracheotomy should be performed after an initial period of stabilization

Recommendation 11: Clinician Familiarity with Long-Term Care Facilities
Critical care practitioners need to be familiar with facilities in their communities or units in their hospital that specialize in managing patients who require prolonged mechanical ventilation. Clinicians need to stay current with peer-reviewed data from long-term ventilation care units.

Patients who fail discontinuation attempts in the intensive care unit (ICU) should be transferred to long-term ventilation care facilities when they are medically stable. These long-term care facilities should have demonstrated competence, safety, and success in accomplishing ventilator discontinuation. These facilities are characterized by less staffing and less costly monitoring equipment; therefore they generate less cost per patient than do ICUs.

Recommendation 12: Weaning in Long-Term Ventilation Units
Weaning of a patient who requires prolonged ventilation should be slow paced and should include gradual lengthening of SBTs.

(Modified from ACCP/AARC/SCCM Task Force: MacIntyre NR: Evidence-based guidelines for weaning and discontinuing mechanical ventilatory support: a collective task force facilitated by the American College of Chest Physicians, the American Association for Respiratory Care, and the American College of Critical Care Medicine, Chest 120(6 Suppl):375S-395S, 2001; Also in: *Respir Care* 47:29-30, 2002; and MacIntyre N: Evidence-based ventilatory weaning and discontinuation, *Respir Care* 49:830-836, 2004.)

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THANK YOU