Principles of Mechanical Ventilation in the Neonate

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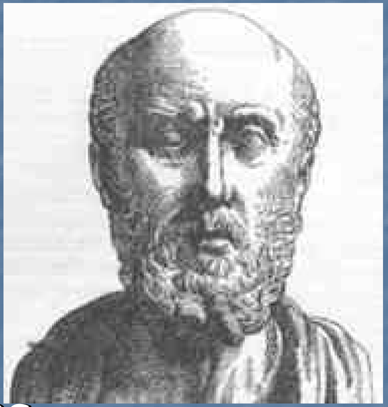
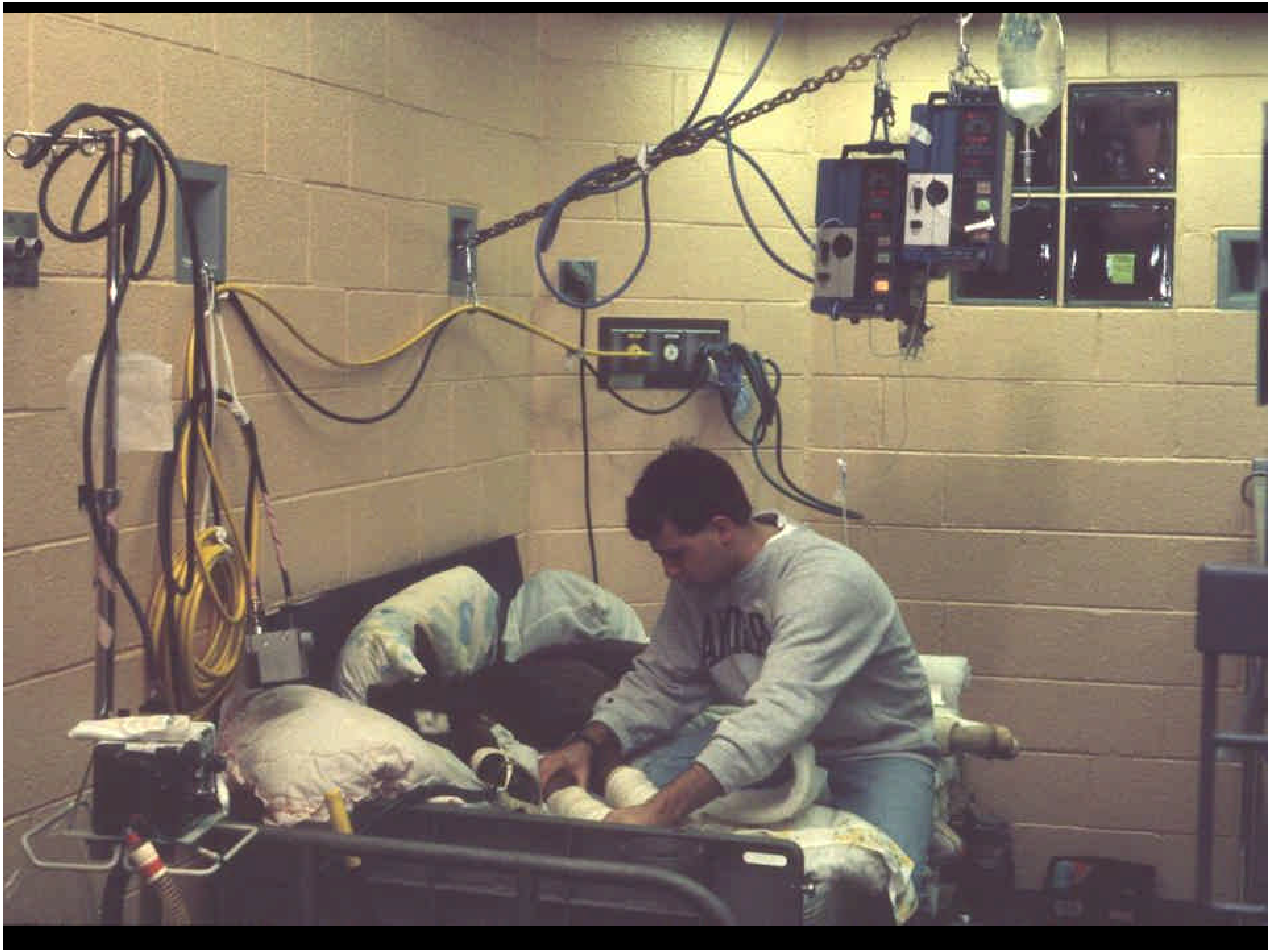
History of Pediatric Ventilation



- 10th Century BC - Hebrew doctors
- 4th Century BC - Hippocrates
- 1667 – Hooke - bellows inflate dog's lungs
- 1806 – Chaussier
  - O_2 Rx, Intubation/ventilation – premature/newborns
- 1845 – 1st ventilator manufacture
- 1887 – Case series – 50 children ventilated
- 1904 – Negative pressure ventilator
- 1905 – CPAP
- 1907 – Positive pressure mechanical ventilator
- 1960-1970 – Birth of neonatology
- 1963 – First baby successfully ventilated

First Successfully Ventilated Infant 1963



Ventilation of ICU Patients

- Human ICU
  - 2nd most common therapeutic intervention
  - 1 - 3 X 10^6 patients ventilated annually
  - 50,000 ventilators in US
  - Mature therapeutic modality
- Equine Neonatal ICU
  - Ventilation > 25 years
  - Ventilating foals without primary respiratory failure
    - 80% of such patients survive to discharged
    - Many become productive athletes

Positive Pressure Ventilation Goals

- Pulmonary gas exchange
  - Support exchange
  - Allow manipulation V/Q matching
- Manipulate lung volume
  - Returning normal FRC
- Decrease work of breathing
  - Allow fatigued muscles to rest
  - Decrease O_2 and energy utilization
  - Redirect perfusion

Positive Pressure Ventilation Clinical Indications

- Persistent pulmonary hypertension
- Acute respiratory failure
  - ARDS
  - Infectious pneumonia
  - Non-infectious pneumonia
- Neonatal Encephalopathy
- Weakness
- Hypoperfusion
- Septic shock
- Neuromuscular disorders

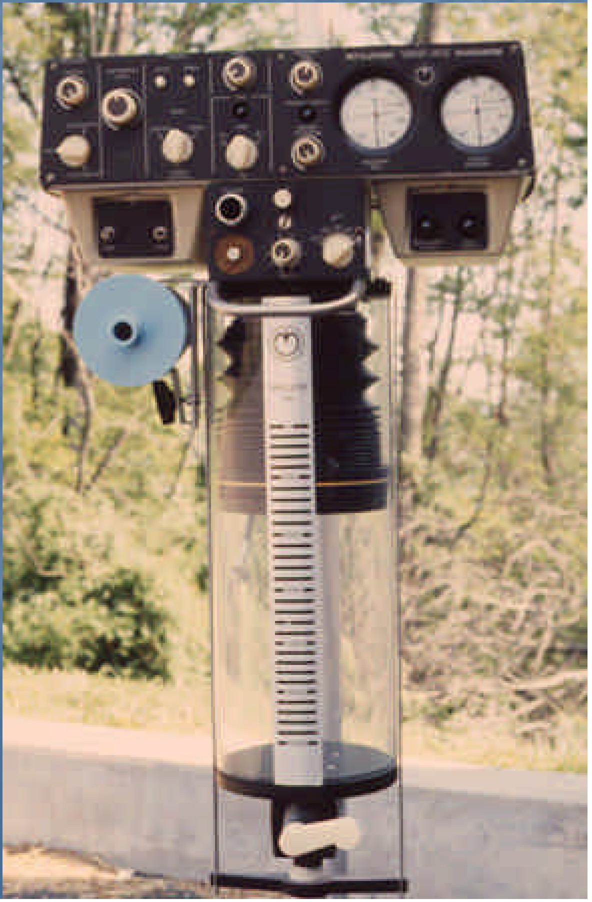
Upper Airway Dysfunction

Goal of Ventilation

Provide respiratory support while therapies for underlying cause of the acute event are initiated

Ventilator Mode Classification

- Many different classification systems
  - Positive pressure vs negative pressure
  - Noninvasive vs invasive
  - Controlled vs assisted
  - Conventional vs alternative
  - Cycling parameter
- Based on cycling parameter
  - Volume-cycled
  - Pressure-cycled
  - Flow-cycled
  - Time-cycled



Ventilator Modes

- Proprietary modes
- Controlled mandatory ventilation
  - Control ventilation
  - Assist/Control ventilation
  - Synchronized intermittent mandatory ventilation (SIMV)
- Assisted ventilation
  - Pressure support ventilation (PSV)
  - Continuous positive airway pressure (CPAP)

Control Ventilation

- Delivers preset breaths at a preset interval
- Not respond to respiratory effort
- Preset volume or pressure
- Not appropriate for any conscious foal
  - Foal will fight this mode
  - Absence of synchrony
  - Don’t sedate

Assist/Control Mode (A/C)

- Automatically cycles at preset rate
- Respiratory effort will trigger a breath
- Guaranteed breath rate
- Initiation of breaths
- Imposition of a preset breath
  - Unforgiving

Synchronized Intermittent Mandatory Ventilation (SIMV)

- Spontaneous and A/C ventilation
- Mechanical breath is synchronized with spontaneous breaths
- Mandatory set rate
- Spontaneous efforts
  - Can trip mandatory breaths
  - If mandatory rate high – A/C ventilation

Synchronized Intermittent Mandatory Ventilation (SIMV)

- If spontaneous breathing occurs faster
  - Extra breaths
    - Warmed, Humidified, Oxygen-enriched gas
  - No preset volume or pressure
- SIMV is better tolerated
  - Extra breaths completely patient controlled
    - Timing, Depth, Duration
  - Preset breaths
    - Unforgiving

Pressure Support Ventilation (PSV)

- Partial ventilatory support
  - Assisted ventilation
  - Flow-cycled mode
  - Support spontaneous breathing effort
  - Providing satisfactory oxygenation
- Breathing controlled by foal
  - Inspiratory time
  - Inspiratory flow rate
  - Tidal volume

Pressure Support Ventilation (PSV)

- Peak pressures controlled by ventilator
  - Attempts to attain a preset PIP
  - Strong inspiratory effort, < preset pressure
- Augmented breath
  - Inspiratory time
  - Inspiratory flow rate
  - Tidal volume
- Reduced work of breathing
- "Off-switch" value
  - 25% of the peak flow
  - Fixed low inspiratory flow rate
  - Target tidal volume

Pressure Support Ventilation Detrimental

- Dyspneic despite ventilation
  - Risk of alveolar collapse
- High initial flow rate
  - Early termination of PS
  - Not provide sufficient minute ventilation
- Low initial flow rate
  - Late termination
  - Deliver large TV
- Ventilator-patient dyssynchrony

Pressure Support Ventilation New Ventilators

- Pressure targeted, time-cycled breath
  - Control inspiratory time
- Control of the pressure slope
  - Rapid peak resulting in a higher peak flow and thus a shorter inspiratory time
  - Slow peak initial flow resulting in a longer inspiratory time
- Allow adjustment of the “off-switch”
  - Flow criteria

Positive End-Expiratory Pressure (PEEP) Continuous Positive Airway Pressure (CPAP)

- PEEP
  - Positive pressure between ventilator breaths
- CPAP
  - Positive pressure throughout spontaneous respiration
- Physiologic effect
  - Increase functional residual capacity (FRC)
  - Decreases intrapulmonary shunting
  - Decrease V/Q mismatch

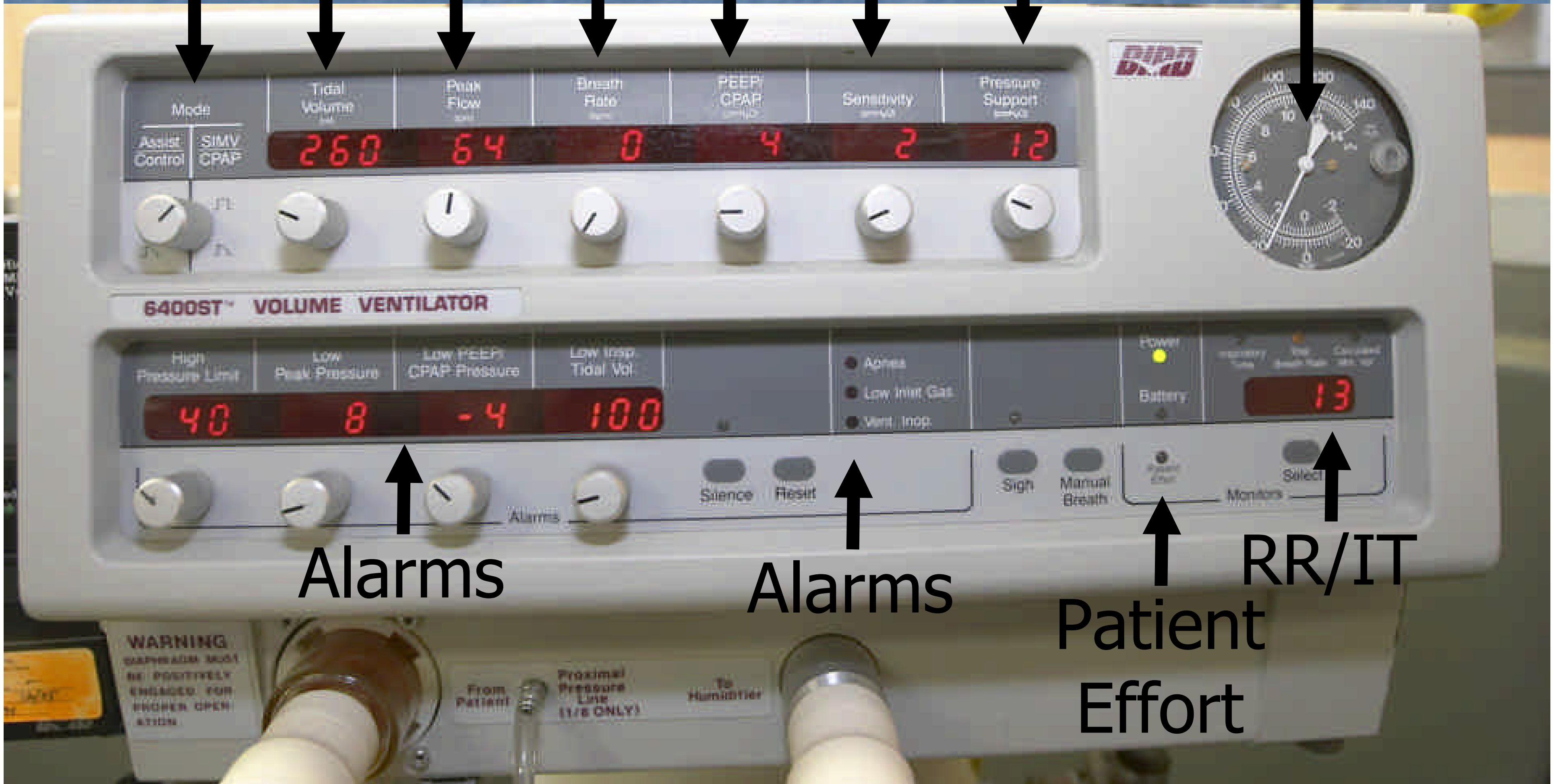
Ventilator Modes Used in ICUs

	1992	1996	1998
A/C	55%	47%	53%
SIMV	26%	6%	8%
SMIV-PSV	8%	25%	15%
PSV	8%	15%	4%

Currently SMIV-PSV is claimed to be the most popular ICU mode

- For weaning
- For ARDS

Where do I begin?



Ventilator Settings

- FiO_2
  - Dictate by
    - Pre-ventilation PaO_2
    - Response to INO_2
  - Usually 0.3-0.5 or 0.8-1.0
- TV
  - Depends on lung pathology
  - Goal – maintain low airway pressures
  - Usually 6 – 9 ml/kg
- Respiratory rate
  - Often set by patient
  - Machine rate – minimal rate
  - Set with TV to achieve a minute volume ($PaCO_2$)
  - Usually 20 – 30 and adjusted with $ETCO_2$

Ventilator Settings

- Peak Flow
  - Determines inspiratory time of machine breath
  - Setting depends on
    - Pulmonary mechanics
    - Airway resistance
    - Time constants
    - Airway pressure gradients
  - No clear formula
  - Initially set
    - Inspiratory time is similar to unventilated patient
    - I/E ratio of approximately 1:2
  - Dynamically adjusted
  - Improperly set peak flow
    - Source of patient-ventilator dyssynchrony

Ventilator Settings

- Trigger sensitivity
  - Pressure based or flow based
  - Pressure - 2-3 cm H_2O
    - Non-respiratory triggering
    - High pressure used in weaning
- PEEP/CPAP
  - Usually 4 – 9 cm H_2O
  - Initially 4 – 5 cm H_2O
  - Once the foal is stable adjust by aid of
    - Flow loops
    - Compliance grid
    - Pao_2 grid

Ventilator Settings

- Pressure Support
  - Level dependent on
    - Resistance and compliance of ventilator
    - Airway resistance
    - Lung compliance
    - Inspiratory effort
  - Absence of lung disease 8 – 12 cmH_2O
  - Low compliance as high as 20 – 25 cm H2O
  - Higher PS helpful in patient-ventilator dys-synchrony
    - When inspiratory effort exceeds rate of gas delivery

Ventilator Settings

- All ventilator settings
  - Adjusted dynamically
  - Success dependent on tailoring to the individual
  - Monitor
    - Simple pulmonary mechanics
    - $ETCO_2$
    - Airway pressures
    - Clinical status
    - ABG determinations

Preconditioning Ventilator Gases

- Heat and moisture must be added
  - Drying and cooling causes mucosal injury
  - Response of the trachea
    - Proliferation of goblet cells
    - Production of discharge
    - Becomes desiccated, tenacious
    - Obstruct airway/endotracheal tube
- Active humidifiers
  - External water source
  - Electrical power



Preconditioning Ventilator Gases

- Passive Humidifiers - HME filters
  - Trap heat and moisture from exhaled breath
  - Effective with average foal
  - Antimicrobial filter
- Limitations of HME filters
  - Foals > 70 kg
  - Large minute volumes
    - Adding a cold active humidifier
  - Hypothermic patients
  - Airway discharge
    - Obstruct the filter – dangerous situation

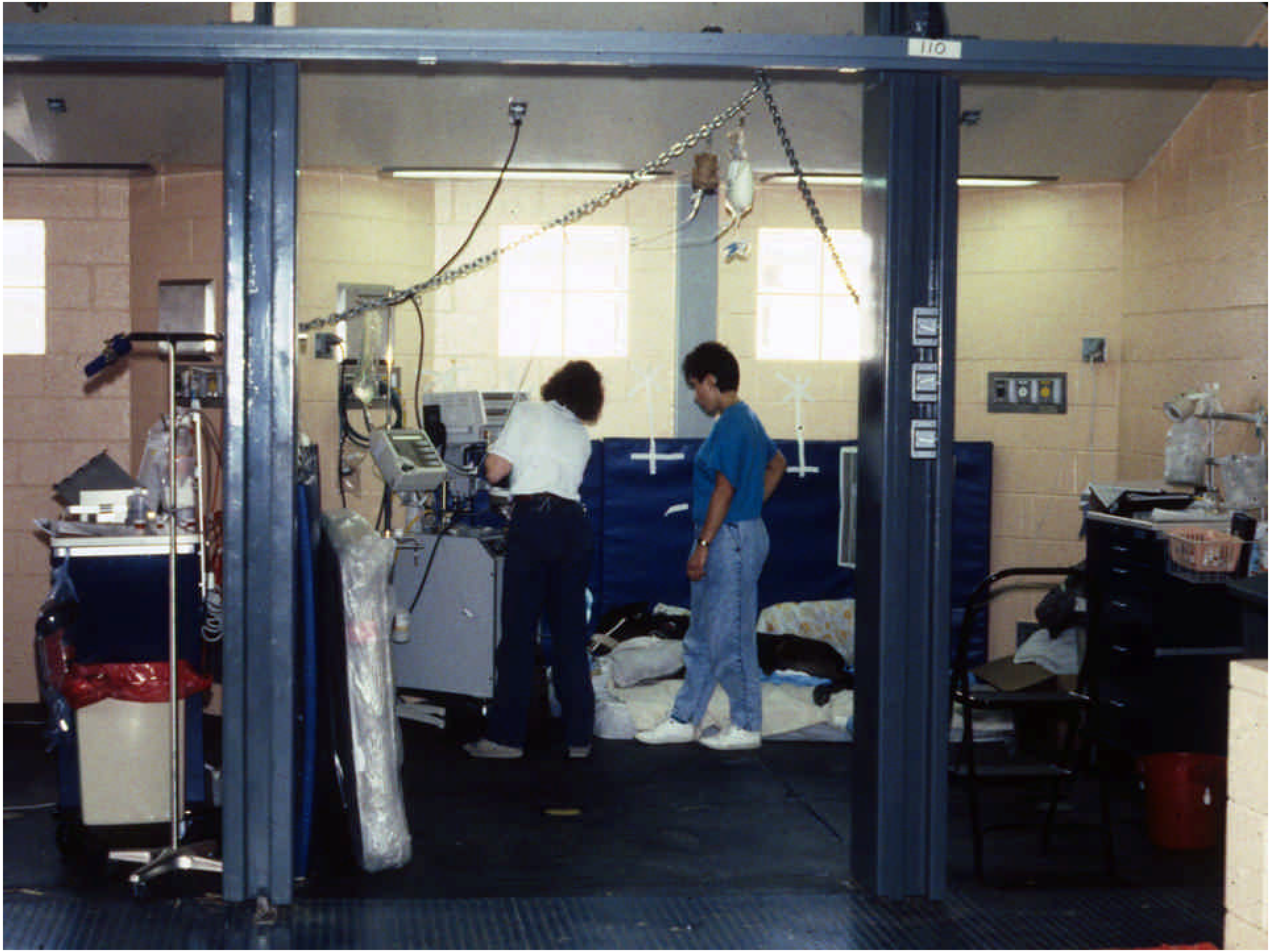
Cold Cascade Humidifier in line

Preparing to Place a Foal on a Ventilator

- Ventilator
- Access to oxygen
- Access to medical grade compressed air
- Interface lines
- Gas blender
- Capnograph with lines/adaptor
- Humidifying device (HME)

Preparing to Place a Foal on a Ventilator

- Ventilator circuit
- Endotracheal tube – duplicates/sizes
- Sterile gloves
- Sterile lubrication
- Means of securing the endotracheal tube
- Stethoscope
- Self inflating bag
- Adequate trained help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Preparing to Place a Foal on a Ventilator

- Circuit and other attachments inspected
- Circuit checked for leaks
- Select initial ventilator setting
- Check integrity endotracheal tube’s cuff
- Position equipment
- Intubate foal
- Turn on ventilator and make all attachments
- Monitor and dynamically adjust settings

Monitoring During Ventilation

- Arterial blood gas (ABG)
- Capnography
- FIO_2
- Tidal Volume/Minute Volume
- Airway pressure
- Compliance/Resistance
- Endotracheal tube

Weaning from Ventilation

- When?
  - Consider as soon as begin ventilation
  - Goal: keep ventilation period short
- Indications
  - Cardiovascular stability
  - Metabolic stability
  - Sepsis Controlled
  - Original problem has resolved/improved
- No reliable predictor foal is ready

Weaning from Ventilation

- Weaning trials
  - PSV
    - Gradual decrease in level of support
  - SIMV
    - Gradual decrease rate
    - Constant minimal PS
  - Spontaneous breathing trial
    - Extubation
    - Close observation at least 2 hours

Weaning from Ventilation

- Failure of a weaning trial
  - Hypoxemia
  - Tachypnea
  - Tachycardia
  - Sustained bradycardia
  - Hypertension
  - Hypotension
  - Agitation

PRINCIPLES OF MECHANICAL VENTILATION IN THE NEONATE

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Mechanical ventilation has been a valuable tool in our therapeutic armamentarium used in our battle to save critically ill neonates for a quarter of a century. Through this period, aided by our experience with countless neonates, this therapeutic modality has matured so that with the use of modern ventilators and techniques, it has become a routine therapeutic intervention with few risks and great benefit in many cases.

Clinical indications for mechanical ventilation in the neonate include persistent pulmonary hypertension, acute respiratory failure, neonatal encephalopathy associated weakness or central respiratory center failure, weakness associated with prematurity or IUGR, central or sepsis induced hypotension, septic shock and neuromuscular disorders such as botulism. Acute respiratory failure includes acute respiratory distress syndrome, organ dysfunction secondary to sepsis, infectious pneumonia (viral, bacterial or aspiration pneumonia), non-infectious pneumonia (meconium aspiration, interstitial pneumonia, aspiration pneumonia) and trauma secondary to fractures ribs. Typically the goal is to provide respiratory support while therapies for underlying causes of the acute event are initiated. The benefits of mechanical ventilation include improvement of gas exchange by increasing ventilation, improvement of ventilation-perfusion (V/Q) matching and decrease of intrapulmonary shunt fraction.

Ventilator Modes

Positive pressure ventilation is classified according to the parameter used to terminate inspiration. Common cycling parameters include volume, pressure, flow, and time. With volume-cycled ventilation inspiration is terminated after delivery of a preset tidal volume, irrespective of the airway pressure during delivery or inspiratory time. With pressure-cycled ventilation inspiration ceases when a preset maximum airway pressure is reached, irrespective of the volume delivered, inspiratory time or inspiratory flow rate. The delivered volume and inspiratory time varies with alterations in lung mechanics thus minute ventilation is not assured and may vary with time. With flow-cycled ventilation inspiration is terminated when a particular flow rate is reached. Finally, with time-cycled ventilation inspiration is terminated following a preset inspiratory time. Both the volume of gas delivered and the resulting airway pressure vary from breath to breath as a function of changes in lung mechanics. Many modern conventional ventilators incorporate several of these ventilator types in one machine.

The most important of clinically available ventilator modes which can be found on either pressure-cycled or volume-cycled ventilators are controlled mandatory ventilation, assist/control ventilation, synchronized intermittent mandatory ventilation (SIMV) all with positive end-expiratory pressure (PEEP). Other clinically important modes found on pressure-cycled ventilators are pressure support ventilation (PSV) and continuous positive airway pressure (CPAP).

With *controlled mandatory ventilation* the ventilator delivers breaths at a preset interval, regardless of any ventilatory effort made by the patient. The patient can not trigger a ventilator breath or take a spontaneous breath through the ventilator circuit. The delivered breath is a result of the preset volume or pressure, no larger and no smaller. This mode is not appropriate for any conscious foal since without extremely heavy sedation the foal will fight this mode and there will be an absence of synchrony. In general foals do not require any sedation for successful ventilation as long as they are in synchrony with the ventilatory mode. It is important to avoid sedation with its inherent complications. Sedation is not an acceptable substitute for choosing an appropriate mode and ventilator settings.

In *assist/control mode,* respiratory efforts by the patient will trigger a breath at the full preset volume or pressure. In the absence of any respiratory effort, the ventilator automatically cycles at a preset minimum background rate. For example, if the ventilator is set to deliver 12 breaths/min, the machine will deliver a breath every 5 seconds in the absence of spontaneous inspiratory effort. If the patient's inspiratory effort triggers an assisted breath, the ventilator's timer resets for another 5 seconds. The patient will be guaranteed at least the set breath rate but can breathe at a higher rate depending on the frequency of effective inspiratory efforts. The initiation of breaths synchronized with spontaneous efforts is welcomed by most foals but the imposition of a preset breath at a fixed and unforgiving volume or pressure is poorly tolerated.

Synchronized intermittent mandatory ventilation (SIMV) is a combination of spontaneous ventilation and assist/control ventilation. The delivery of the mechanical breath is synchronized to support the patient's spontaneous breaths at a preset rate, thus preventing the patient from stacking breaths (a mechanical breath being delivered at the same time as a spontaneous breath). Stacking may result in hyperinflation and volutrauma/barotrauma. If spontaneous breathing occurs at a rate faster than the ventilator set SIMV rate, the patient breathes gas from the ventilator circuit. These spontaneous, extra breaths consist of warmed, humidified, oxygen-enriched gas supplied from the ventilator's circuit, but with no preset volume or pressure. If the patient's spontaneous efforts slow or stop, the ventilator breathes by default at the SIMV rate. SIMV is better tolerated, especially since breaths above the preset rate are completely controlled by the patient (timing, depth, duration). The preset breaths are still at a fixed and unforgiving volume or pressure.

Pressure Support Ventilation (PSV) is a partial ventilatory support flow-cycled mode in which breathing is controlled by the foal and peak pressures are controlled by the ventilator. The primary goal of PSV is to support the foal's spontaneous breathing effort while providing satisfactory oxygenation. PSV attempts to attain a preset peak inspiratory airway pressure each time the foal initiates inspiratory effort. If the foal's inspiratory effort is strong, the preset airway pressure may never be attained as the inspiratory effort keeps the airway pressure below the pressure goal until the ventilator cycles off. Still, the inspiratory time, inspiratory flow rate, and tidal volume are augmented, whereas inspiratory work of breathing is reduced. The machine senses the end of inspiration by first measuring the peak inspiratory flow and then waiting until that flow falls to a preset "off-switch" value (typically 25% of the peak flow or some fixed low inspiratory flow rate), at which time exhalation is allowed to proceed spontaneously. So, a PSV breath is delivered when the ventilator senses a respiratory effort by opening a demand valve at a preset pressure. Gases are forced into the ventilator circuit in attempt to raise the airway pressure to the preset value, decreasing the work of inspiration. As the foal decides the tidal volume is sufficient, inspiratory flow slows and the demand valve shuts, ending inspiration and allowing expiration. Increasing levels of PSV decreases the work of breathing. Since the foal has complete control of initiation of breaths, inspiratory time and tidal volume the foal readily cooperates with the ventilator but since respiratory rate and tidal volume are not controlled, careful monitoring is required. Some new ventilators allow the clinician to set a target tidal volume. These ventilators titrate the delivered airway pressure based on feedback from past breaths. Frequently SIMV and PSV are used together so that spontaneous breaths in SIMV are supported helping to overcome the inherent resistance of the ventilator circuit and when the predominate mode is PSV the SIMV rate acts as a failsafe breath rate.

*Positive End-Expiratory Pressure (*PEEP*)* and *Continuous Positive Airway Pressure (*CPAP*).* PEEP refers to the maintenance of positive pressure in the airways between ventilator induced positive pressure inspiration (during exhalation and between breaths) so that the airway pressure never falls below the set PEEP value. CPAP refers to the maintaining positive airway pressure throughout spontaneous respiration (during inspiration, exhalation and between breaths). PEEP may be added to any of the ventilation modes discussed previously. The primary physiologic effect of PEEP is to increase functional residual capacity by maintaining patency of alveoli at the end of exhalation.

PEEP/CPAP affects pulmonary mechanics, cardiovascular stability and pulmonary vascular resistance. FRC is the volume of gas remaining in the lungs at the end of a normal expiration. At a low FRC (low volumes e.g. in diseased lungs), compliance is low. At higher FRC (volumes) compliance increases. At high FRC (over distension) compliance again decreases. Optimum FRC, which is also normal FRC, results an optimum compliance and the lowest work of breathing. Lung volume is also related to airway resistance. At low lung volumes airway resistance is high and since atelectasis is not resolved, the work of breathing is high. At optimum lung volumes airway resistance is low. PEEP/CPAP can improve distribution of ventilation to optimize FRC and therefore optimize both lung compliance and airway resistance. High PEEP/CPAP can have a detrimental effect on the cardiovascular system, compressing right sided vessels, decreasing cardiac return which will result in decreased cardiac output. The amount of PEEP/CPAP that is excessive and will produce this affect depends on the lung compliance. If the lung compliance is low, less intra-airway pressure will be transmitted to the plural space and cardiac compromise will be less. Hypovolemia will exacerbate the negative effect of high PEEP/CPAP. Over distension of the lung may cause direct pressure on pulmonary arterials and capillaries, increasing pulmonary vascular resistance and pulmonary artery pressure. Low levels of PEEP/CPAP do not resolve atelectasis. Atelectasis results in shunting of blood away from collapsed alveoli and regional increase in pulmonary vascular resistance. Optimal PEEP/CPAP will optimize the V/Q ratio.

In healthy individuals the functional residual capacity (FRC) is maintained so that almost all alveoli are open and ventilated. In foals that are weak or fatigued, the FRC can be significantly reduced resulting in poor ventilatory function. The lungs began to collapse to a volume, where alveoli collapse during expiration and must be opened on each breath to receive ventilation. Alveoli that repeatedly close in this manner will increase the risk of injury from the shear stress and tend to breakdown surfactant. As the amount of surfactant decreases it becomes more difficult to open these alveoli on inspiration and eventually atelectasis results. This further decreases the compliance of the lungs and further tends to cause collapse of more alveoli. The sum affect of this is progressive atelectasis. Even in those alveoli which are being ventilated, the ventilation is less evenly distributed because alveoli not already open will not open until partway through inspiration. Other alveoli that are already opened will accept gas throughout inspiration. This results in maldistribution of ventilation and perfusion. Also alveoli that close during expiration only participate in gas exchange during inspiration. Decreased FRC is most effectively treated through initiation of PEEP/CPAP. By increasing the airway pressure during expiration alveoli tend to stay open and on each new inspiration more alveoli may be recruited. Full recruitment using PEEP/CPAP requires 15-20 minutes. Optimal PEEP/CPAP can be found by producing a PEEP/CPAP grid. By adjusting PEEP/CPAP to 1 cm above and 1 cm below current levels and then, after 10-15 minutes to allow maximal recruitment, obtaining either a Pao2 or measuring effective compliance the optimum PEEP/CPAP can be identified. Because alveolar injury is often quite heterogeneous, PEEP that is appropriate in one region may not be appropriate in another being either suboptimal or excessive.

Optimizing PEEP is thus a balance between enrolling the recruitable alveoli in diseased regions without over distending already recruited alveoli in healthier regions. Another potential detrimental effect of PEEP is that it also raises mean and peak airway pressure potentially contributing to barotrauma/volutrauma.

Preconditioning ventilator gases

With the upper airway bypassed by tracheal intubation, sufficient heat and moisture must be added to the inspired gas mixtures to prevent mucosal injury secondary to drying and cooling. The response of the trachea to such injury is proliferation of goblet cells and production of discharge which as it becomes desiccated, becomes tenacious and can obstruct the airway or endotracheal tube. Passive humidifiers use simple heat-moisture exchange devices (HME filters) placed on the ventilator side of the endotracheal tube that utilizes heat and moisture trapped from expired gases. HME filters trap heat and moisture from the exhaled air and add both to the next breath as it passes through the filter. Foals > 70 kg or those who have large minute volumes for any reason may need more moisture than can be trapped by large HME filters. In these cases, adding a cold active humidifier to a circuit with an HME filter in place, may add enough moisture to allow effective ventilator gas preconditioning. An advantage of many HME filters is that the will act as a very efficient antimicrobial filter excluding nosocomial bacteria and viruses from the patient.

Typical Ventilator Settings

Initial ventilator settings depend on ventilator make and model, ventilator mode, goal of the ventilatory intervention and on the underlying cause of respiratory failure. The basic parameters to be set in volume-cycled ventilators in A/C or SIMV modes are Fi_{O_2} , tidal volume , rate, peak flow which in combination with rate will determine inspiratory/expiratory (I/E) ratio, trigger sensitivity and PEEP. Many ventilator models also allow setting an inspiratory pause (a brief hold at peak inspiration) and a failsafe ventilatory rate which is activated if apnea occurs or a preset minute volume is not achieved. On ventilators offering pressure support mode, the pressure support level can also be set as well as other pressure support parameters in some ventilators.

Setting the tidal volume is important for successful mechanical ventilation. The tidal volume should be set as low as practical with the goal of keeping the plateau airway pressure less than 30 cmH_2O even at the expense of mild hypercapnia. Thus the tidal volume should be set between 6 and 10 ml/kg depending on the plateau airway pressure.

Respiratory rate is often determined by the patient since most ventilator modes allow the patient to initiate more breaths than the set machine breath rate. The set rate on the machine is in essence is a minimum breath rate. For patients with poor central sensitivity to CO_2 the respiratory rate should be set in conjunction with the tidal volume to achieve a desired minute volume adequate to maintain P_{aco_2} in the range which results in an acceptable pH. Often critically ill neonates will have an abnormal acid base balance. Significant metabolic alkalosis is frequently present. The target P_{aco_2} is the one which returns the pH to the normal value. A P_{aco_2} of 60 or 65 torr may be appropriate if that level is required to buffer a significant metabolic alkalosis, keeping the pH < 7.45. This is not permissive hypercapnia with controlled hypoventilation. Permissive hypercapnia is the practice of allowing a P_{aco_2} higher than what is required to correct an acid pH avoiding possible lung trauma that could be caused in pursuit of full correction of the pH and allowing more optimal expiratory time. The goal of permissive hypercapnia is to maintain an arterial pH > 7.20 but not necessarily > 7.35. The practice of permissive hypercapnia is only needed when ventilating foals with significant underlying lung injury. When placing a foal on a ventilator, using a mode other than full pressure support, the initial ventilator rate between 20 and 30 is usually adequate. The rate should be adjusted during the first 30 minutes of ventilation with the aid of capnography which should be followed up by arterial blood gas measurements. The peak flow, which determines inspiratory time when machine generated breaths are delivered, should be set in conjunction with respiratory rate and tidal volume. Other factors that go into selecting and modifying peak flow include pulmonary mechanics, airway resistance, time constants and airway pressure gradients. There is no clear formula that can be used in setting peak flow, but usually it is initially set so that the inspiratory time is similar to the unventilated patient with a I/E ratio of approximately 1:2 and then it can be dynamically adjusted as needed. Improperly set peak flow can be a source of patient-ventilator dys-synchrony when the delivered gas is too rapid or slow for the situation. When airway pressure becomes negative (beyond the trigger point) during inspiration then the patient is demanding gas faster than the ventilator is delivering which may be because the peak flow is set too low.

The initial F_{IO_2} setting will be dictated by the pre-ventilation P_{aO_2} and the response seen to intranasal oxygen insufflation. If maintaining an acceptable P_{aO_2} has not been a problem, beginning with a F_{IO_2} of 0.3 should be sufficient. If high intranasal flows have been required to maintain blood oxygen, a F_{IO_2} of 0.5 should be initiated and if despite high intranasal flows the foal has remained hypoxemic, the initial F_{IO_2} should be between 0.8 and 1.0. In all cases, the F_{IO_2} should be titrated as directed arterial blood levels with the initial measurement within 30 minutes of initiating ventilation with the goal of $F_{IO_2} < 0.5$. An initial PEEP 4 to 5 cm H_2O is usually adequate. Once the foal is stable on the ventilator, the PEEP can be further adjusted by aid of flow loops or a compliance and/or P_{aO_2} grid can be constructed to insure that the PEEP is optimal for the patient.

The level of pressure support is dependent on the resistance and compliance of the ventilatory circuit, airway resistance, lung compliance and inspiratory effort of the patient. In the absence of lung disease, such as an uncomplicated botulism patient, 8 – 12 cm H2O is enough to overcome ventilatory circuit resistance and deliver an adequate tidal volume. In cases of low compliance, pressure support as high as 20-25 cm H2O or higher may be required.

All ventilator settings should be adjusted dynamically after initiation of ventilation since success is highly dependent on tailoring the setting to the individual. A combination of simple pulmonary mechanics, end-tidal CO_2 determination, ventilation pressures, clinical status, and arterial blood gas results should form the basis for the adjustments. Having a feel for which combination of ventilatory adjustments will improve successful gas exchange and improve ventilatory synchrony while at the same time decrease ventilator induced lung trauma only comes with experience and forms the basis of the art of successful ventilatory support.

Adapted with permission from: Palmer JE. Ventilatory Support of the Critically Ill Foal. Veterinary Clinics of North America: Equine Practice August 2005 21(2): in press.