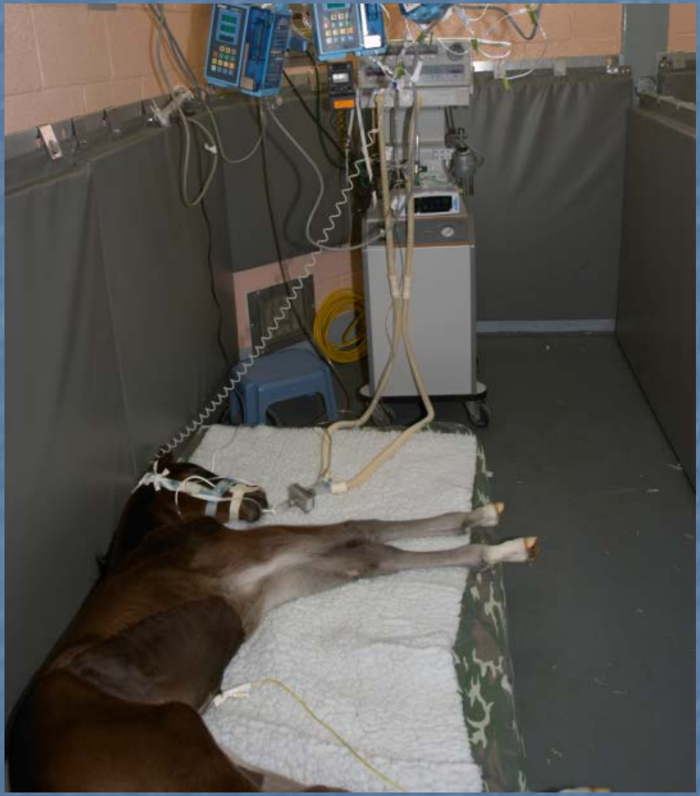
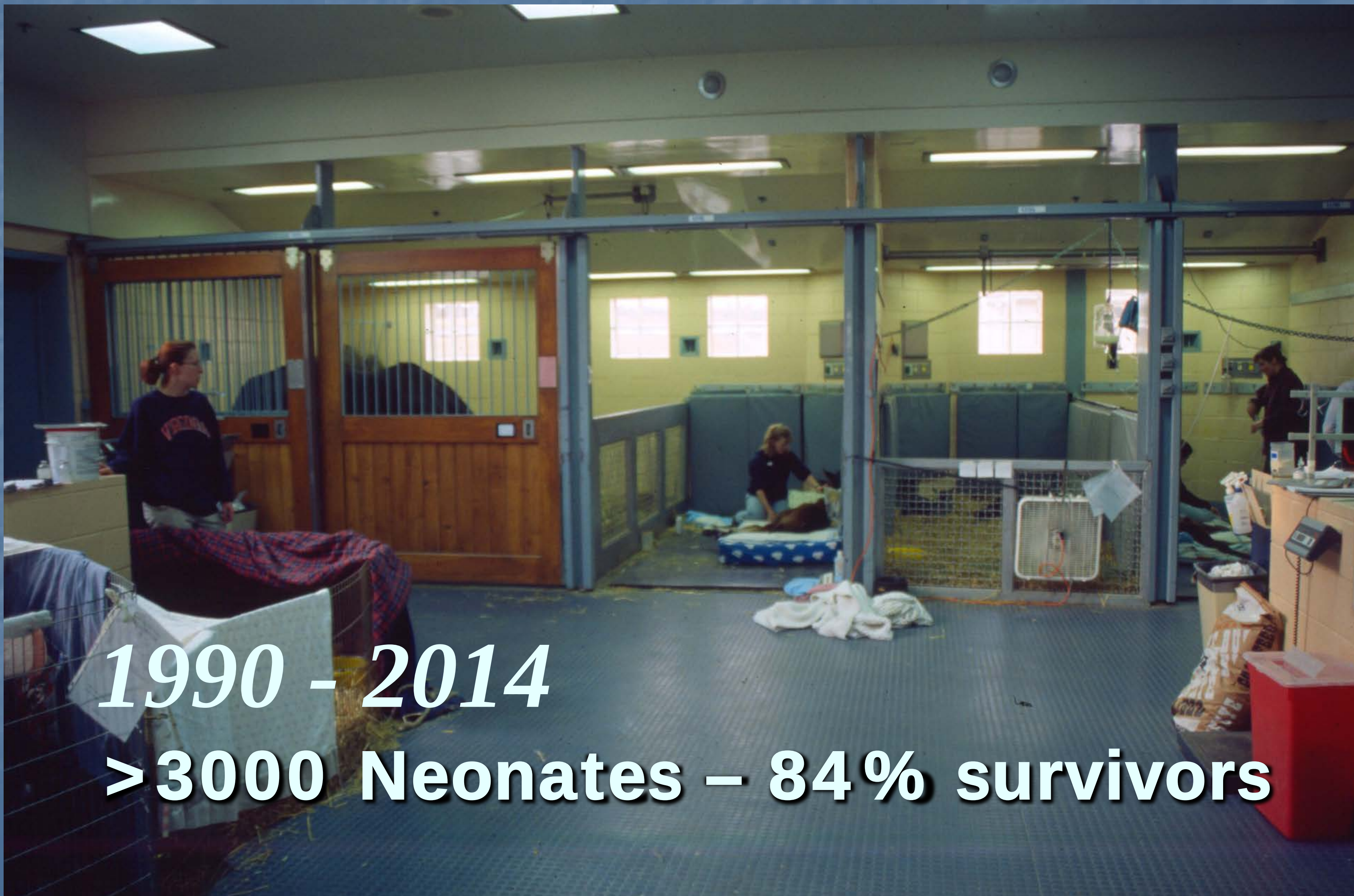
Mechanical Ventilation of the Neonatal Foal



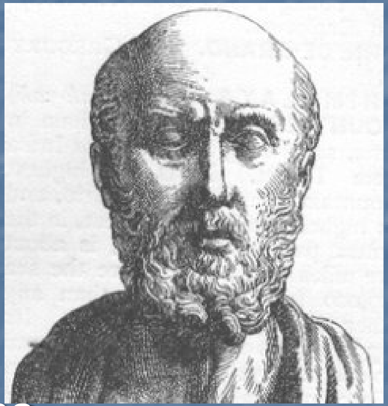
Jon Palmer, VMD, DACVIM

New Bolton Center

Graham French Neonatal Section
Connelly Intensive Care Unit

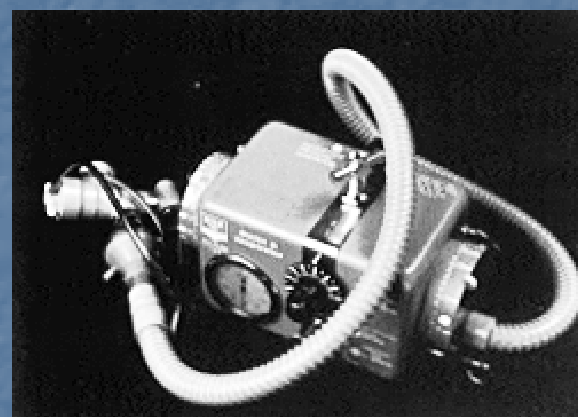


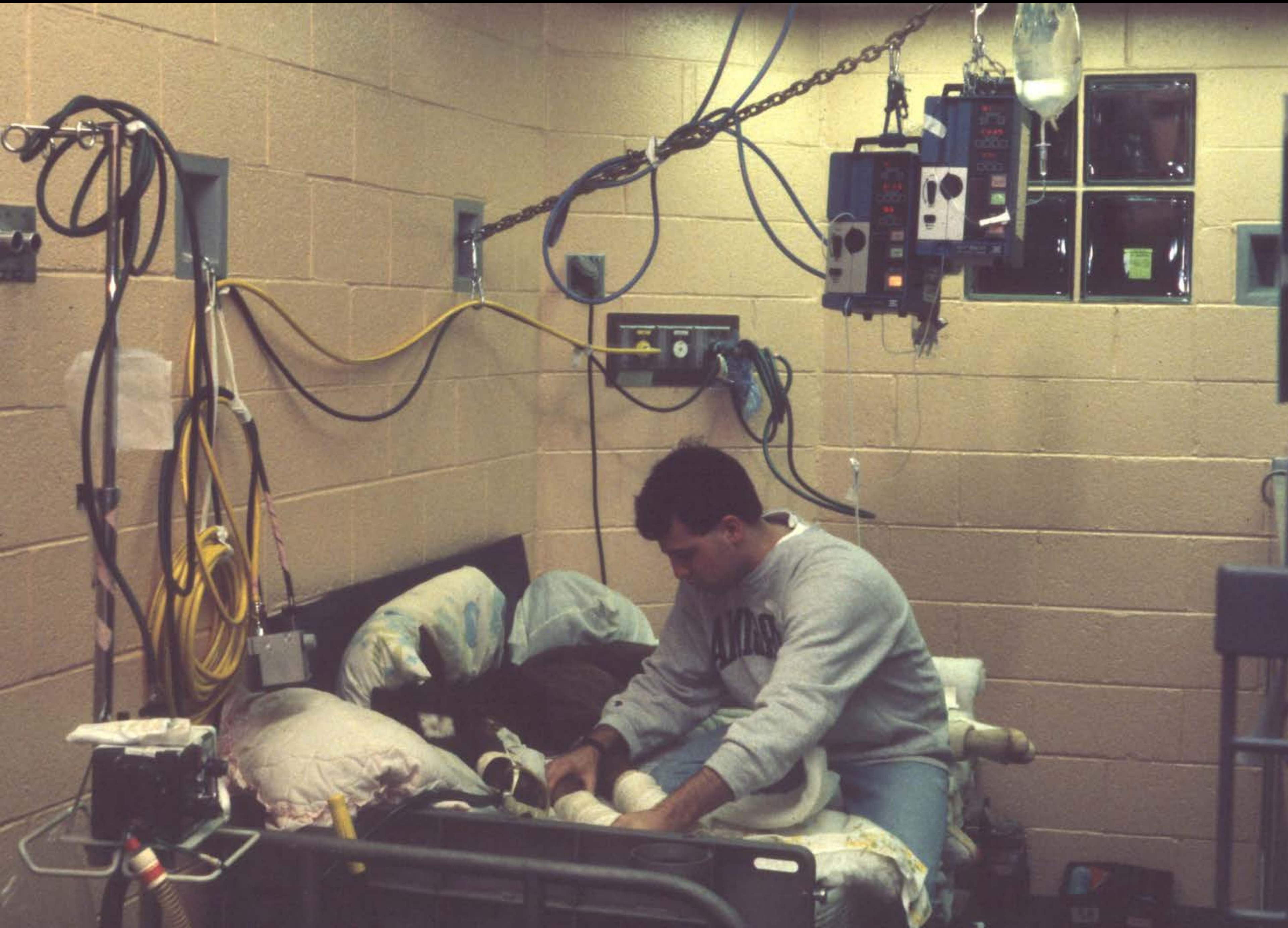
History of Pediatric Ventilation



- 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



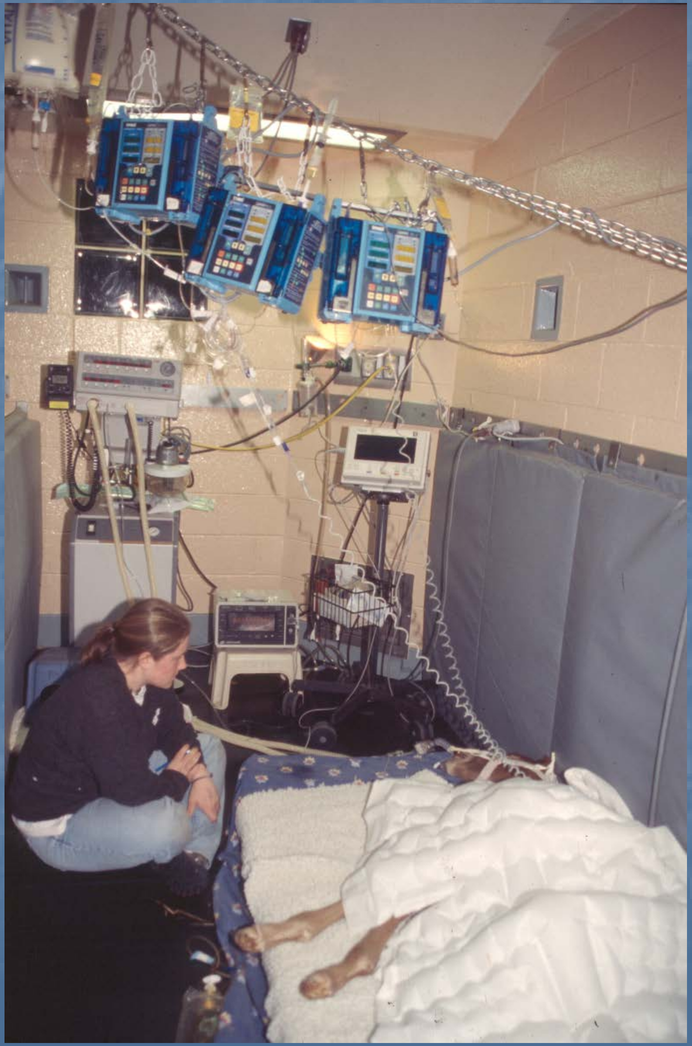


Ventilation of NICU Patients

- Equine Neonatal Intensive Care Unit
  - First foals ventilated 35 years
  - Ventilating foals with secondary respiratory failure
    - Botulism or neonatal encephalopathy
    - 80% of such patients survive to discharged
    - Many become productive athletes
  - Most challenging cases
    - Viral pneumonia
    - ARDS
    - Sepsis - MODS

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

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

Goal of Ventilation

Provide respiratory support while therapies for underlying cause of the acute event are initiated and allow time for recovery

Three cases

Case 1

- 50-day-old Morgan colt
- June 13
  - Normal in the morning
  - Evening found down in the field
  - Weak
- Rx
  - Intravenous fluids
  - Antibiotics
  - Tube fed milk
- June 14 6:00 a.m.
  - Respiratory distress
  - Cyanotic

Ventilation Case 1

- Admission Physical Exam
  - Weak, no eyelid tone
  - No tongue tone, weak tail tone
  - Shallow, rapid respiratory pattern
    - Mark nostril flare
- Therapy
  - Botulism antitoxin
  - Intravenous fluids
  - Intravenous ceftiofur sodium
  - Indwelling nasogastric tube
  - Ventilation

Case 1

	Adm	40 min	2 hr
pH	7.325	7.265	7.289
Pco_2	56	68	70
Po_2	40	229	243
SAT	64.5	99.7	99.7
HCO_3	29.6	31.1	33.5
BE	+2.7	+2.6	+5.5
	RA	10 lpm	10 lpm

Ventilator Modes

- Continuous mandatory ventilation (CMV)
  - Volume controlled (VC-CMV)
  - Pressure controlled (PC-CMV)
- Intermittent mandatory ventilation (IMV)
  - Volume controlled (VC-IMV)
  - Pressure controlled (PC-IMV)
- Continuous Spontaneous Ventilation (CSV)
  - Pressure support ventilation (PSV)
  - Continuous positive airway pressure (CPAP)
- Proprietary modes

Intermittent Mandatory Ventilation (IMV)

- Combination of spontaneous and CMV
- Mechanical breath is synchronized with spontaneous breaths
- Mandatory set rate
- Spontaneous efforts
  - Can trip mandatory breaths

Intermittent Mandatory Ventilation (IMV)

- If spontaneous breathing occurs faster
  - Extra breaths
    - Warmed, Humidified, Oxygen-enriched gas
  - No preset volume or pressure
- IMV is better tolerated than CMV
  - Extra breaths completely patient controlled
    - Timing, depth, duration
    - Pressure Support Ventilation (PSV)
  - Preset breaths
    - Unforgiving

Pressure Support Ventilation (PSV)

- Partial ventilatory support
  - Assist flow-cycled mode
  - Support spontaneous breathing effort
  - Providing satisfactory oxygenation
  - Decreased the work of breathing
- Breathing controlled by foal
  - Inspiratory time
  - Inspiratory flow rate
  - Tidal volume
- Reduced work of breathing
- "Off-switch" value
  - 25% of the peak flow
  - Fixed low inspiratory flow rate

Pressure Support Ventilation Detrimental

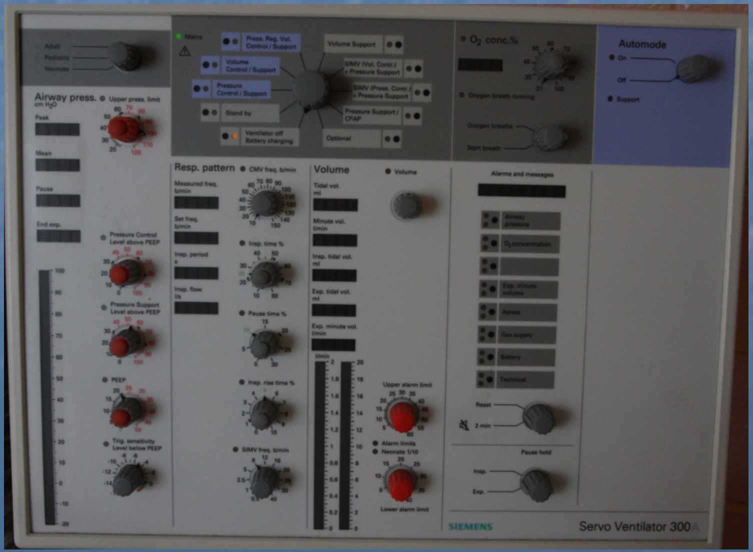
- Dyspneic despite ventilation
  - Risk of alveolar collapse
- High initial flow rate
  - Early termination of PS
  - Not provide sufficient minute ventilation
- Low initial flow rate
  - Late termination
  - Deliver large TV
- Ventilator-patient dyssynchrony

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

Pressure Support Ventilation New Ventilators

- Volume Support Ventilation
  - Pressure support
  - Target volume
    - Breath to breath changes in parameters
    - Adjust Pressure Support to a volume goal



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
  - Increase V/Q mismatch

PEEP/CPAP

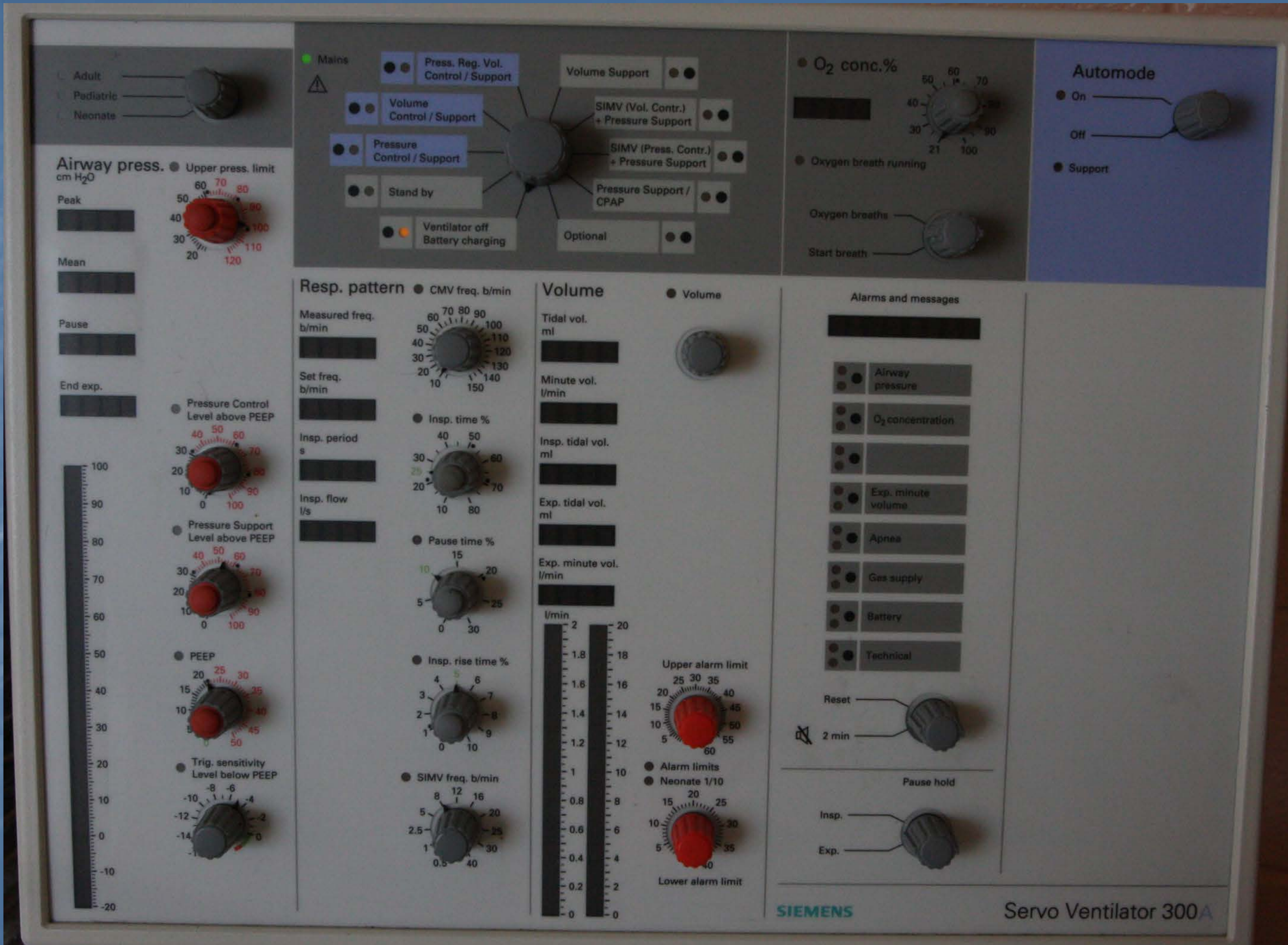
- Ideal FRC – best compliance
- Ideal FRC – least airway resistance
  - Less atelectasis
- Cardiovascular effects
  - Excessive PEEP
    - Decrease cardiac return
    - Increase pulmonary Resistance
  - Depends on the lung compliance
    - Low compliance less transmitted to vessels
  - Hypovolemia – increase negative effect
- V/Q matching

Progressive Atelectasis

PEEP

- Full recruitment
  - Requires 15 to 20 minutes
  - PEEP does not recruit but stabilizes lung
  - Break in circuit – begin again
- Optimal PEEP
  - Maximum improvement pulmonary function
  - Minimal hemodynamic compromise
  - Inflection points on PV curves
  - PEEP/CPAP grid
    - Pao_2
    - Static Compliance
- Optimal PEEP is a balance
  - Holding open recruitable alveoli - diseased regions
  - Not overdistending alveoli - healthier lung

PATIENT DATA
1cmH2O ≈ 1mbar
cmH2O (mbar)
-20 0 20 40 60 80 100 120
0 2 4 6 8 10 12
kPa
AIRWAY PRESSURE
cmH2O
MEAN AIRWAY PRESSURE
PEAK AIRWAY PRESSURE
PEEP/ CPAP
PLATEAU PRESSURE
ASSIST
SPONTANEOUS
SIGH
PLATEAU
RATE/I:E
RATE bpm
I:E RATIO
liters
TIDAL VOLUME
MINUTE VOLUME
SPONT. MINUTE VOLUME
VENTILATOR SETTINGS
PEEP/CPAP
TIDAL VOL liters
SET RATE bpm
PEAK FLOW lpm
O2%
TIDAL VOLUME
RESPIRATORY RATE
PEAK INSPIRATORY FLOW
SENSITIVITY
O2%
PLATEAU
HIGH PRESSURE LIMIT
LOW INSPIRATION PRESSURE
LOW PEEP/CPAP PRESSURE
LOW EXHALED TIDAL VOL
LOW EXHALED MINUTE VOL
HIGH RESPIRATORY RATE
7 8 9
4 5 6
1 2 3
0 . *
ENTER
CLEAR
CMV
SIMV
CPAP
++
100% O2 SUCTION
MANUAL INSPIRATION
MANUAL SIGH
AUTOMATIC SIGH
NEBULIZER
VENTILATOR STATUS
HIGH PRESSURE LIMIT
LOW INSPIRATORY PRESSURE
LOW PEEP/CPAP PRESSURE
LOW EXHALED TIDAL VOLUME
LOW EXHALED MINUTE VOLUME
HIGH RESPIRATORY RATE
I:E
APNEA
LOW PRESSURE O2 INLET
LOW PRESSURE AIR INLET
EXHALATION VALVE LEAK
LOW BATTERY
CAUTION
NORMAL
LAMP TEST
ALARM SILENCE
ALARM RESET


Adult
Pediatric
Neonate
Mains
Press. Reg. Vol. Control / Support
Volume Control / Support
Pressure Control / Support
Stand by
Ventilator off Battery charging
Volume Support
SIMV (Vol. Contr.) + Pressure Support
SIMV (Press. Contr.) + Pressure Support
Pressure Support / CPAP
Optional
O2 conc.%
Oxygen breath running
Oxygen breaths
Start breath
Automode
On
Off
Support
Airway press.
cm H2O
Upper press. limit
Peak
Mean
Pause
End exp.
Pressure Control Level above PEEP
Pressure Support Level above PEEP
PEEP
Trig. sensitivity Level below PEEP
Resp. pattern
CMV freq. b/min
Measured freq. b/min
Set freq. b/min
Insp. period s
Insp. flow l/s
Insp. time %
Pause time %
Insp. rise time %
SIMV freq. b/min
Volume
Tidal vol. ml
Minute vol. l/min
Insp. tidal vol. ml
Exp. tidal vol. ml
Exp. minute vol. l/min
Upper alarm limit
Alarm limits
Neonate 1/10
Lower alarm limit
Alarms and messages
Airway pressure
O2 concentration
Exp. minute volume
Apnea
Gas supply
Battery
Technical
Reset
2 min
Pause hold
Insp.
Exp.
SIEMENS
Servo Ventilator 300A

Ventilator Settings

- Fio_2
  - Dictate by
    - Pre-ventilation Pao_2
    - Response to INO_2
  - Usually 0.3-0.5
- TV
  - Depends on lung pathology
  - Goal – maintain low airway pressures
  - Usually 6 – 10 ml/kg
  - Species differences – stacking breaths
- Respiratory rate
  - Often set by patient
  - Machine rate – minimal rate
  - Set with TV to achieve a minute volume (Paco2)
  - Usually 20 – 30 and adjusted with ETCO2
  - Target pH not Paco2
    - Permissive hypercapnia vs appropriate hypercapnia

Ventilator Settings

- Peak Flow (insp time; insp rise time)
  - 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 (⅓ resp cycle)
  - Dynamically adjusted
    - Prevent negative airway pressures
  - Improperly set peak flow
    - Source of patient-ventilator dyssynchrony

Ventilator Settings

- Inspiratory pause
  - Depends on airway resistance
- Trigger sensitivity
  - Pressure based or flow based
    - Flow based smoother transition
  - 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 dyssynchrony
    - When inspiratory effort exceeds rate of gas delivery

No Sedation

Case 1
Ventilator Set Up

- Goals
  - Decrease work of breathing
  - Maintain FRC
- Mode: Pressure Support with CPAP
  - PS initially set at 9
    - Normal lungs
  - CPAP initially set at 4
    - Normal lungs
- Parameters set by foal
  - Tidal Volume = 5.6 – 6.2 ml/kg (7 ml/kg)
  - RR 32
  - PIP = 18-20 mmH_2O

Case 1

	7 hr	HD 2	HD 2	HD 7
pH	7.393	7.385	7.396	7.414
Pco_2	53	51	51	48
Po_2	97	74	127	114
SAT	96.7	92.8	98.4	98.4
Cont		17	17.4	17.1
HCO_3	32	31	31	31
BE	+6.5	+5.2	+6.0	+6.0
FIO_2	0.3	0.3	0.4	0.3
PEEP	4	4	5	5
$ETCO_2$	53	48	49	48
PS	9	11	11	11

mode	PS
TV	550-680
RR	32 – 26
PIP	20 – 18
P_{Plat}	24 – 18

Ventilator Settings

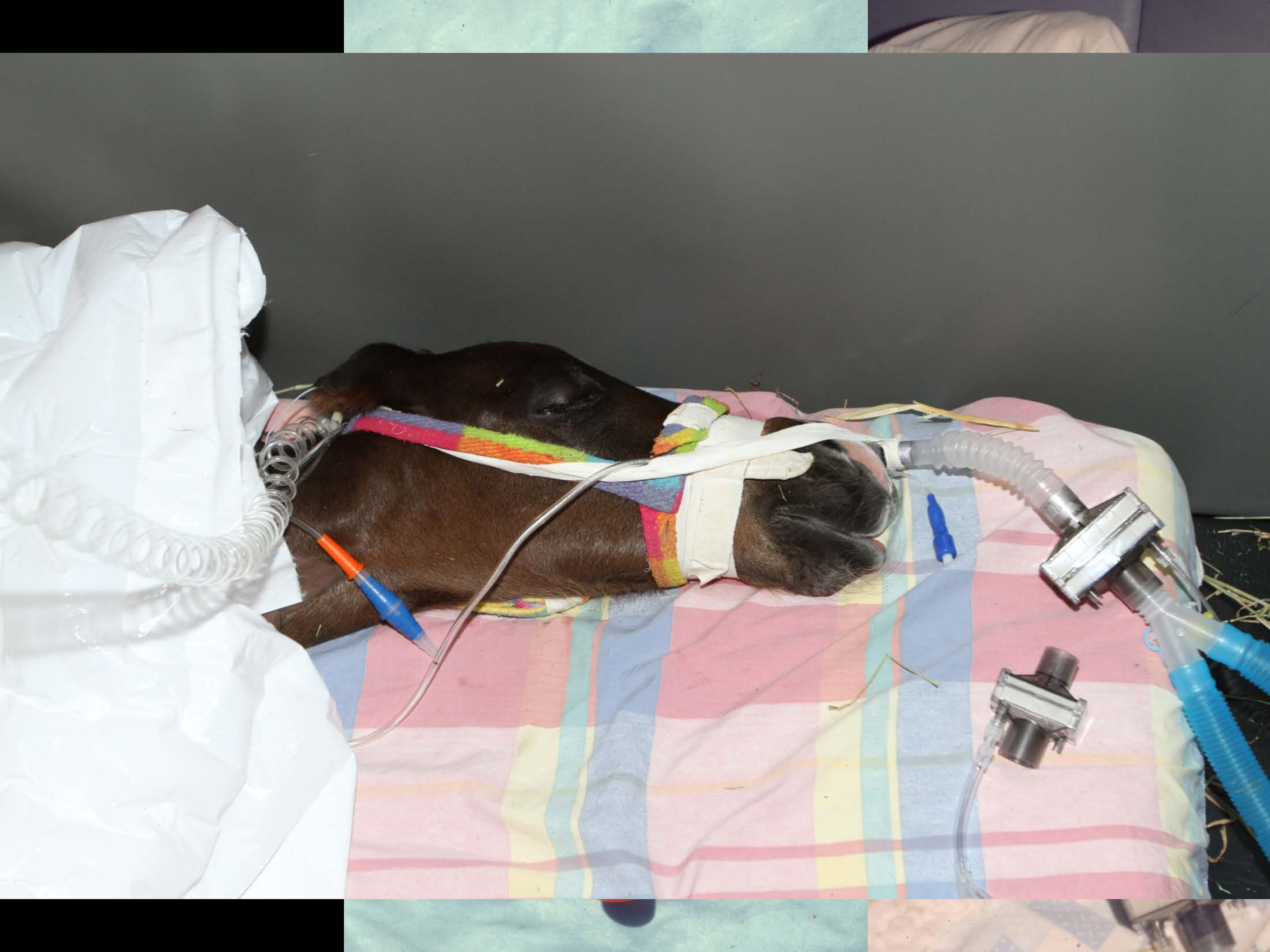
- All ventilator settings
  - Adjusted dynamically
  - Success dependent on tailoring to the individual
  - Monitor
    - Pulmonary mechanics
    - $ETCO_2$
    - Airway pressures
    - Clinical status
    - ABG determinations

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 powered heating elements
  - Intratracheal temperature > 35C
  - Water content > 40 mg/L

Preconditioning Ventilator Gases

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



Cold Cascade Humidifier in line

Monitoring During Ventilation

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

Capnography

- Endotracheal cuff integrity
- Ventilator leaks
- $ETCO_2$ depends on
  - $PaCO_2$
  - Cardiac output
  - Alveolar dead space ventilation
    - Pulmonary perfusion
  - Airway time constants (Rz)
  - CO2 production (metabolic rate)
  - Bicarbonate therapy
- Changing V/Q relations
- Other valuable information

Case 1
Problems

- $ETCO_2 = 0$
- Long inspiration
- Flow meter shows a dramatic ↓TV
- Common problem
  - Have foal sitter monitor cuff
  - Often slow leak
    - Bad valve – use hemostat or clamp
    - Leaking cuff – replace endotracheal tube

Case 1

	HD 9	HD 9
pH	7.304	7.443
Pco_2	76	52
Po_2	115	111
SAT	97.5	98
Cont	16.0	16.3
HCO_3	38	36
BE	+9.6	+10.8
FIO_2	0.35	0.35
$ETCO_2$	72	52
Mode	PS	PS
PS	20	12

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

Case 1
Weaning

- 1st weaning challenge HD 6
  - Off the ventilator
  - Good breathing efforts
  - ETCO2 increased
  - Foal became cyanotic (on INO2)
  - Aerophagia - increased abdominal size
  - 10 minute trial
- 2nd weaning trial HD 8
  - After 22 minutes $Paco_2$ 48 → 60

3^{rd} Weaning Attempt

	HD 10	3 pm	6 pm	3 am	6 am	HD 14
pH	7.443	7.365	7.394	7.338	7.031	7.420
Pco_2	52	55	50	64	129	49
Po_2	111	72	184	79	49	120
SAT	98	91	99	92	60	98
HCO_3	36	32	31	34	34	32
BE	+10.8	+5.4	+5.5	+6.7	-1.3	+7.0
FIO_2	0.35	8 lpm	10 lpm	8 lpm	0.5	4 lpm
$ETCO_2$	52				84	
Mode	PS	off	off	off	PS	off

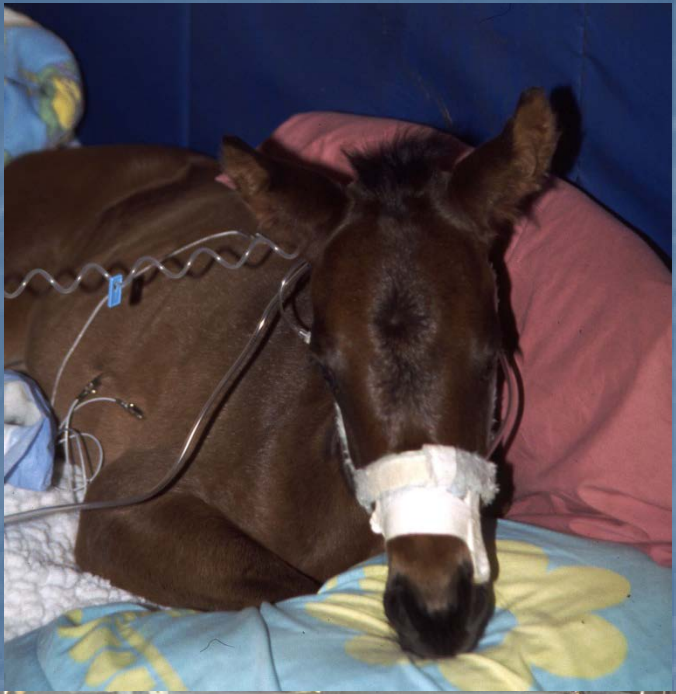
Outcome

- Successful weaning HD 14
- Standing day 15
- Dysphagia
  - HD 22 – able to swallow water
  - HD 23 – able to swallow solids
- Hospital Discharge HD 30

Case 2

Case 2
Clinical Problems

- Septic Shock
- Bacteremia/Sepsis
  - *Pantoea agglomerans*
- Neonatal Encephalopathy
  - Somnolent, Facial nerve paresis
  - Seizure-like activity
- Neonatal Enteropathy
  - Fetal diarrhea, dysmotility
- Neonatal Nephropathy
- Other problems
  - Urachitis, hepatomegaly
  - Linear dermal necrosis, patent urachus
  - Angular limb deformity



Case 2

	Adm	1 hr
pH	7.339	7.349
Pco_2	60	58
Po_2	44	144
SAT	77	100
Cont	13	15
HCO_3	32	32
BE	+5.6	+5.9
INO_2	RA	10 lpm

Neonatal Encephalopathy

- 4 hours
  - Respiratory effort decreased
  - Apneustic breathing (breath holding)

Case 2

	Adm	1 hr	4 hr	5 hr
pH	7.339	7.349	7.284	7.354
Pco_2	60	58	82	62
Po_2	44	144	80	250
SAT	77%	100	97	100
Cont	13.3	14.9	15.4	16.4
HCO_3	32	32	34	35
BE	+5.6	+5.9	+10.5	+8.2
INO_2	RA	10 lpm	10 lpm	15 lpm

Caffeine for Central Hypoventilation

- Naturally occurring methylxanthine
  - Theophylline, aminophylline
- Mechanism of action
  - Mild, direct general CNS stimulant
    - Increases respiratory center output
    - Increases chemoreceptor sensitivity to CO_2
  - Cardiac stimulate - increases cardiac output
  - Increases renal blood flow
  - Mild diuretic

Caffeine for Central Hypoventilation

- Response monitored through ABG
- High therapeutic index
  - Effective blood levels 5-20 µg/ml
  - Toxic levels > 40 - 50 µg/ml in humans
  - Safer than aminophylline
- Adverse effects
  - Hyperactive - more difficult to manage
  - Tachycardia - have not seen

Case 2
Neonatal Encephalopathy

- *10 hours*
  - *Apneic respiratory pattern*
    - *40 second apneic period*
    - *Cluster breathing in-between*

Case 2

	Adm	1 hr	4 hr	5 hr	10 hr	12 hr
pH	7.339	7.349	7.284	7.354	7.276	7.451
Pco_2	60	58	82	62	85	45
Po_2	44	144	80	250	105	141
SAT	77%	100	97	100	100	100
Cont	13.3	14.9	15.4	16.4	16.1	15.5
HCO_3	32	32	34	35	40	32
BE	+5.6	+5.9	+10.5	+8.2	+11	+7.4
INO_2	RA	10 lpm	10 lpm	15 lpm	10 lpm	10 lpm

Case 2
Neonatal Encephalopathy

- *12 hours*
  - *Periods of somnolence and nonresponsiveness*
  - *Apneic respiratory pattern with cluster breathing*
  - *Facial nerve paresis*
    - *Right ear lower and slower to respond*
    - *Ears are not synchronized*
- *21 hours*
  - *Seizure-like activity*
    - *Opisthotonus*
    - *Tonic/Clonic marching activity*
  - *Treated with intravenous phenobarbital*

Case 2

	27 hr	29 hr
pH	7.313	7.269
Pco_2	75	85
Po_2	118	119
SAT	100	100
Cont	14.5	14.7
HCO_3	38	39
BE	+10.4	+10.3
INO_2	10 lpm	10 lpm

Ventilate

- Goals
  - Increase alveolar ventilation
  - Maintain FRC
- Mode: IMV/PS with PEEP/CPAP
  - TV = 460 ml (8.5 ml/kg)
    - PIP = 18 cmH_2O
  - PS initially set at 9 cmH_2O
    - Normal lungs
  - PEEP/CPAP = 4 cmH_2O
    - Normal lungs
  - Peak flow = 60 lpm
  - RR = 24
    - Foal's rate 33
  - FIO_2 = 0.4

Case 2

	27 hr	29 hr	31 hr	36 hr		
pH	7.313	7.269	7.353	7.428	mode	SIMV
Pco_2	75	85	67	50	TV	460 ml
Po_2	118	119	96	164	PF	60
SAT	100	100	99	100	RR	36 / 38
Cont	14.5	14.7	13.9	14.4	PEEP	4
HCO_3	38	39	38	33	PS	9
BE	+10.4	+10.3	+10.9	+8.3	P_{peak}	24 / 28
FiO_2 / NO_2	10 lpm	10 lpm	0.4	0.5	P_{plat}	18
$ETCO_2$			54	46		

Weaning

- Began asking when? within 12 hours
- After 21 hours – PS trial

Case 2

	48 hr	52 hr	57 HR	60 hr
pH	7.447	7.473	7.392	7.412
Pco_2	45	40	54	50
Po_2	242	91	252	95
SAT	100	100	100	99.7
Cont	14.5	14.1	14.3	15.6
HCO_3	31	29	33	32
BE	+7.2	+6.0	+7.7	+7.4
FIO_2 / NO	0.5	0.35	10 lpm	3 lpm
$ETCO_2$	42	38		

	48 hr	52 hr
mode	SIMV	PS/CPAP
TV	460 ml	520-75
PS	60	
RR	36	22
PEEP	4	4
PS	9	6
P_{peak}	21	
P_{plat}	16	




Case 3
Septic Shock

Case 3

- Admission - 8 hr old
- Septic shock - *Streptococcus* bacteremia
  - Minimally responsive
  - Hypothermic (36.8 C)
  - Hypotonia
  - Pupils were pinpoint, iris edema
  - Inappropriately low heart rate
  - Cold legs, and poor peripheral perfusion
- Admission lab work
  - Leukopenic (WBC = 528 cells/ul)
  - Hypoglycemia – required 20 mg/kg/min to get > LO

Case 3
Therapy

- Intranasal oxygen
- Shock doses of fluids
- Plasma
- Antimicrobials
- Ventilation
- Dobutamine
- Norepinephrine

Benefits of Mechanical Ventilation

- Traditional
  - Improve gas exchange
  - Improve V/Q matching
  - Decrease shunt fraction
- Benefit of decreasing work of breathing
  - Normal quiet breathing
    - Inhalation active process
      - Requires energy
      - 3% - 5% O_2 consumed
    - Exhalation is a passive
      - Requires no energy, O_2

Benefits of Mechanical Ventilation

- Pulmonary failure 2ndary to septic shock
  - Respiratory distress
  - Work of breathing
    - O_2 required up to 50% of available O_2
    - Diverts perfusion resources
      - Accessory muscles recruited
- Relieving work of breathing
  - Redistribution of O_2
  - Redistribution of perfusion
  - Sparing energy resources
- Ventilation foals with septic shock
  - Improve perfusion, increase BP
  - Improved glucose balance


DINAMAP™ XL VITAL SIGNS MONITOR
MAP mmHg
30
SYSTOLIC mmHg
42
PULSE bpm
DIASTOLIC mmHg
21
BLOOD PRESSURE

Case 3

Ventilate

- Goals
  - Decrease the work of breathing
  - Correct pulmonary hypertension
  - Maintain FRC
- Initial settings
  - Mode: PS with CPAP
  - PS initially set at 18 cmH_2O
    - Based on easy of breathing and resulting TV
  - PEEP/CPAP = 8 cmH_2O
  - FIO_2 = 1.0
- Set by foal
  - TV = 180 ml (7 ml/kg)
    - PIP = 32 cmH_2O
  - RR = 48

Case 3

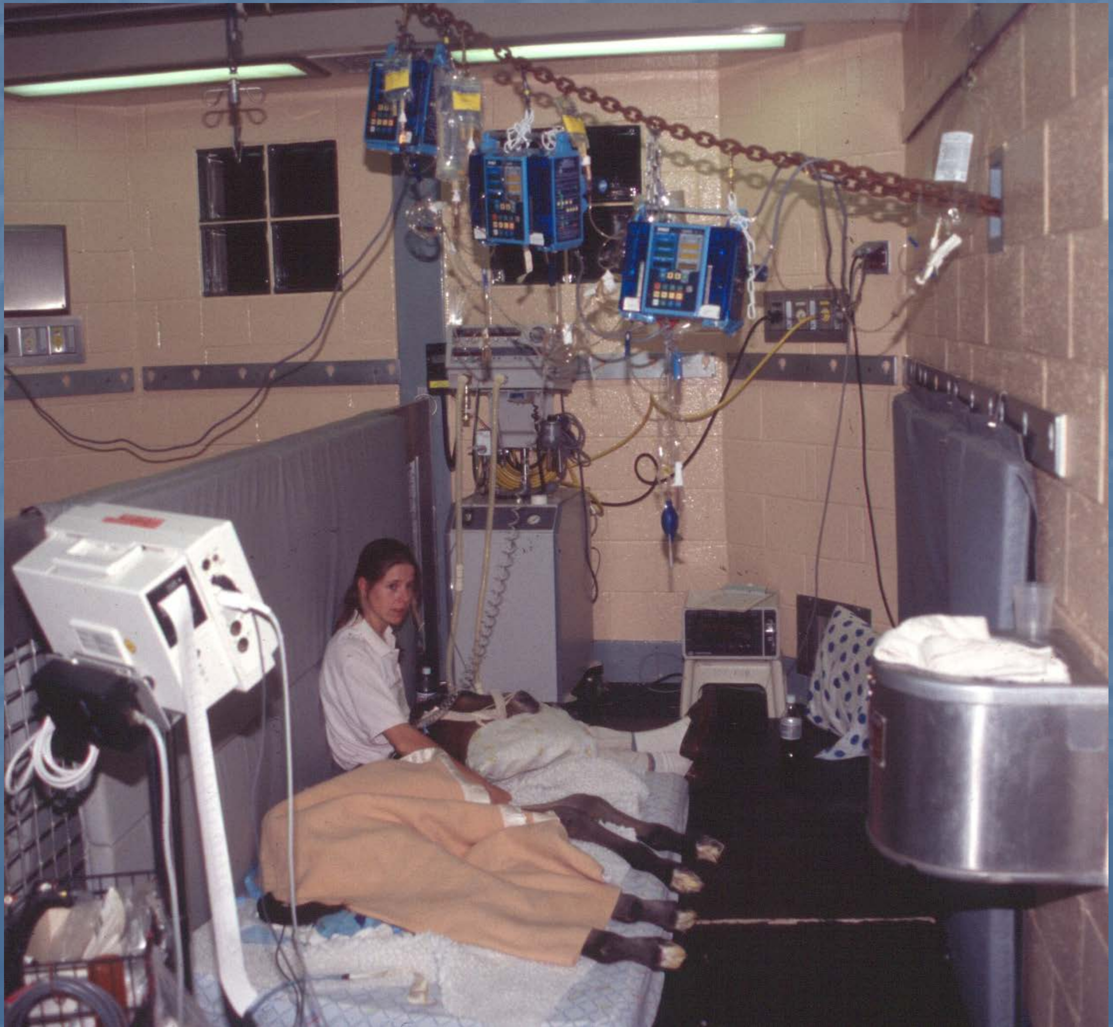
	Adm	1 hr	1.5 hr		
				Mode	PS
pH	7.220	7.072	7.073	TV	180
Pco_2	65	70	62	RR	48
Po_2	22	20	248	PEEP	8
SAT	27.7	21.2	99.6	PS	18
Cont	5.1	3.4	14.9	P_{peak}	32
HCO_3	27	20	18		
BE	-1.7	-9.6	-11.3	NO	20 ppm
FIO_2	0.21	1.0	1.0		

Case 3

	3.75 hr	4 hr	5 hr	6 hr	Mode	PS
pH	7.000	7.062	7.089	7.061	TV	220
Pco_2	96	92	84	98	RR	46
Po_2	73	25	146	96	PEEP	10
SAT	86.3	29.4	97.8	92.3	PS	24
Cont	11.4	4.1	14.1	13.2	P_{peak}	35
HCO_3	24	26	26	28		
BE	-7.5	- 4.6	- 4.6	- 3.1	NO	20 ppm
FIO_2	1.0	1.0	1.0	0.50		

Case 3

- Multifocal necrotizing interstitial pneumonia



Pulmonary Hypertension

- Sequela to many cases of ALI
- Increased pulmonary vascular resistance
  - Inflammatory mediators
  - Severe hypoxemia

Pulmonary Hypertension

- Neonate
  - Right to left shunting
    - Foramen ovale
    - Ductus arteriosus
  - Reversion to fetal circulation
    - Adaptive advantage
    - Achieve adequate systemic cardiac output
  - Neonate's unique ability
    - Exist in a hypoxemic state
    - Regain CO by shunting
    - Survive pulmonary hypertension without systemic ischemia

Pulmonary Hypertension

- 1.0 F_{IO2} trial
  - Pao_2 < 100 torr after 15-20 min
  - Shunt fraction > 30%
  - Cause of the hypoxemia extrapulmonary
    - Large cardiac shunt
    - PPHN

Pulmonary Hypertension

- Pulmonary hypertension
  - Failure to make the birth transition – PPHN
    - Imbalance of vasodilators and vasoconstrictors
    - Nitric oxide and endothelin
  - Regression to fetal circulation – PPHN
    - Perinatal hypoxemia
    - Cytokine showers
  - Secondary
    - Pulmonary disease
    - Septic shock
    - ALI

Pulmonary Hypertension Therapy

- Traditional therapy
  - Maximize exposure to O_2
    - Ventilation with 100% oxygen
  - Alkalinize arterial pH
    - Mild hyperventilation
    - Treatment with bases
  - Maintain systemic blood pressure
    - Counterbalance the pulmonary pressure
  - ALI will counteract these approaches
- Inhaled NO therapy
  - 5 to 20 ppm
  - Immediate effect
  - Significant pulmonary toxicity possible
    - Free radicals