Advanced Assessment Techniques in Critical Care

Arthur Jones, EdD, RRT

This Presentation is Approved for
1 CRCE Credit Hour

Learning Objectives

- Apply techniques for measuring & optimizing ventilatory mechanics
- Interpret common ventilator wave form abnormalities
- Explain the significance of end-tidal CO_2 measurements

Lung Mechanics

Purposes for Monitoring Mechanics

- Determine appropriate ventilator settings
  - Tidal volume
  - PEEP
  - Inspiratory flow rate/time
  - Pressure support

Purposes for Monitoring Mechanics

- Assess condition of lungs
  - Consolidation
  - Surfactant deficiency
  - Bronchospasm

Purposes for Monitoring Mechanics

- Evaluate therapeutic effects
  - Bronchodilators
  - Recruitment maneuvers
  - Surfactant
  - Weaning modes
- Determine when to wean or discontinue support

Parameters Monitored

- Dynamic compliance (C_{DYN}) - includes elastic recoil & resistance to flow
- Static compliance (C_{ST}) - elastic recoil of lung & thorax
- Inspiratory/expiratory resistance to flow
- Total PEEP

Parameters Monitored

- Total PEEP: imposed (set) PEEP + intrinsic PEEP (PEEPi)
  - PEEPi: end-expiratory pressure in lung that may exceed set PEEP, especially with
    - High rates
    - Obstructive disease
    - Active exhalation

Parameters Monitored

- PEEPi
  - Continuous monitoring possible at tip of ETT
  - Measurement requires end-expiratory pause & absence of active exhalation to measure
  - Significance of PEEPi
    - Impairs triggering
    - Causes hyperinflation

Parameters Monitored

- Intratracheal pressure - GE Engstrom Carestation™

2.0 mm OD sensor tube
ETT ≥ 6.5 mm

Images courtesy of GE Healthcare

FYI see links below for GE Engstrom Carestation™ website

Parameters Monitored

- Intratracheal pressure
  - Measured at distal end of ETT
  - More closely reflects alveolar pressure

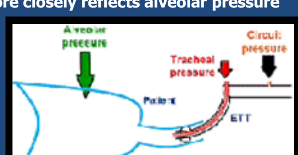
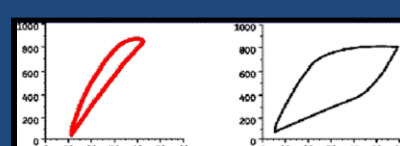


Image courtesy of GE Healthcare

Parameters Monitored

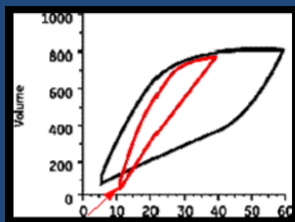
- Intratracheal pressure - GE Engstrom Carestation Spirodynamics™



Intratracheal Sensor   Ventilator Wye

Parameters Monitored

- Intratracheal pressure - GE Engstrom Carestation Spirodynamics™
  - Easy detection of total PEEP, with digital display



Parameters Monitored

- Intratracheal pressure - GE Engstrom Carestation Spirodynamics™
  - Dynostatic curve - uses alveolar pressures at different lung volumes
  - Compliance values calculated at three points along VP curve: 5 - 15%, 45 - 55%, & 85 - 95% of the inspiratory phase
  - Inflection points readily discernible

FYI see links below for article
Practical Assessment of Respiratory Mechanics

Measuring Compliance/Resistance

- Stabilize patient - tachypnea, active expiration will confound results by increasing intrinsic PEEP
- Measure
  - Exhaled TV
  - Peak inspiratory pressure (PIP)
  - PEEP (total)
  - Plateau pressure (Ppt) - for volume control mode

Measuring Compliance/Resistance

- In pressure control mode, including pressure control with volume guarantee, the peak pressure is also the plateau pressure
- Changing to volume control enables measuring plateau, but mechanics will not be the same
- Use dynamic compliance for mechanics

Measuring Compliance/Resistance

- Simple calculation
  - PEEPtotal = (PEEP + PEEPintrinsic)
  - Dynamic compliance = tidal volume/(PIP - PEEP)
  - Static compliance = tidal volume/(Ppt - PEEP)
  - Resistance = (PIP- Ppt)/flow

Measuring Compliance/Resistance

- Units of measurement
  - Compliance: V/P (Liters/cm H_2O)
    - Normal: > 0.06 L/cm H_2O
    - Very low: 0.02 L/cm H_2O
  - Resistance: P/flow (cm H_2O/L/sec)
    - Normal: 5 cm H_2O/L/sec
    - High: > 10 cm H_2O/L/sec

FYI see links below for article on ventilators & lung mechanics

Measuring Compliance/Resistance

- Changes in lung mechanics for an individual patient are more revealing than absolute numbers
- Everyone must measure by same technique
- System must be leak-free
- Examine trends & pre- post- therapy values

Abnormal Cst

- Decreased Cst (C_{DYN} if resistance is constant)
  - ARDS, ALI
  - Extrathoracic restriction
    - Obesity
    - Ascites, distension
  - Thoracic restriction
  - Volume-occupying lesions
    - Pneumothorax
    - Pleural effusion

Implications: Decreased Cst

- Increased work of breathing (WOB)
- Increased ventilation pressure requirements
  - Excessive shear forces on lung tissue, causing inflammation
  - Hyperinflation of compliant lung units, causing volutrauma

Implications: Increased Cst

- Appropriate PEEP setting
- Resolution of pathology

PEEP Therapy

Benefits of PEEP in ARDS

- Prevents alveolar collapse (AKA de-recruitment)
- Re-recruits collapsed alveoli
- Reduces shear forces required to ventilate collapsed alveoli - prevents atelectrauma
- Increases ventilation-perfusion matching - improves oxygenation

Adverse Effects of PEEP

- Increased pulmonary vascular resistance (PVR)
- Increased alveolar dead space (VD_A) - hypercapnia, hypoxemia
- Decreased venous return
  - Decreased cardiac output (Q_T)
  - Decreased mixed venous saturation ($S\bar{v}O_2$)
  - Decreased urine output

Adverse Effects of PEEP

- Hyperinflation - volutrauma
- Right-to-left shunt with patent foramen ovale (PFO)
  - PFO present in 15 - 25% normal adults
  - Increasing PEEP decreases PaO_2

FYI see links below for article on PFO & PEEP

Optimal PEEP

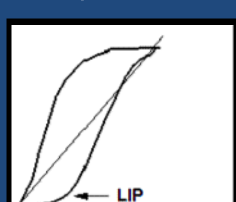
- Defined: level of PEEP that imposes favorable volume-pressure relationship on the majority of lung units
  - Greatest Cst
  - Greatest $S\bar{v}O_2$
  - Improved ventilation-perfusion (VQ) matching
  - Reduced shear forces required for ventilation

Optimal PEEP

- Methods for determination
  - Lower inflection point of PV curve
  - Stepwise incremental Cst measurement
  - Stepwise decremental Cst measurement
  - Alternative method (Mercat, et al)

Optimal PEEP

- Methods for determination
  - Locate lower inflection point (LIP) of PV curve
  - Optimal PEEP = LIP plus 2 - 3 cm H2O



Optimal PEEP

- Lower inflection point (LIP) of PV curve
  - Disagreement among observers
  - Controversy over significance of LIP

Stepwise Decremental Technique

- Adjust TV to desired level (<8 ml/kg IBW)
- Adjust FiO_2 to 1.0
- Increase PEEP by 5, up to 20 cm H_2O
  - Monitor vital signs
  - Monitor SpO_2
- Adjust FiO_2 for SpO_2 90 - 95%

FYI see links below for article that supports decremental technique

Stepwise Decremental Technique

- Decrease PEEP by 2 cm H_2O
  - Q3 min, or until stabilized
  - Monitor SpO2, S$\bar{v}$O2, vital signs
  - Measure Cst
- Optimal PEEP = level with greatest Cst, $S\bar{v}O_2$
- Monitored/adjusted each shift

Alternative Technique

- Methods
  - Adjust TV to 6 mL/kg IBW
  - Increase PEEP to achieve Ppt 28 - 30 cm H_2O
- Trial findings
  - No change in mortality
  - Decreased duration of ventilation & organ failure

Volume-Oriented PEEP

- Goal of PEEP: adjust FRC
- Direct FRC measurement
  - Body plethysmograph - PFT laboratory
  - CT scan - gold standard
  - He dilution
  - N_2 washin-washout - available on Engstrom Carestation™

Volume-Oriented PEEP

- FRC measurement rationale
  - Assess effects of PEEP & recruitment maneuvers
  - Monitor lung recruitment status
  - Detect overdistension
- PEEP INview™ - ventilator measures FRC at different levels of PEEP
- Lung INview™ - ventilator estimates volume of recruited volume

FYI see links below for comparative study on FRC methods

Optimal PEEP

- Select a procedure that works & make sure EVERYONE follows it precisely - that is, standardize
- Optimal PEEP changes with changes in pathology - adjust at least every shift & with changes in patient status
- A level of PEEP that is optimal one day might be detrimental the next day

Ventilator Graphics Analysis

Applications for Graphics

- Assess lung mechanics
  - Resistance
  - Compliance
  - WOB
- Detect ventilation problems
  - PEEPi
  - Lung overdistension
  - Patient/ventilator asynchrony

Applications for Graphics

- Evaluate interventions
  - Bronchodilator therapy
  - Ventilator settings
    - Primary mode
    - Tidal volume, drive pressure
    - PEEP
    - Ventilation times
    - Trigger level
    - Rise time
    - Expiratory flow limit (PSV)

Graphic Types

- Waves
  - Pressure-time
  - Flow-time
  - Volume-time

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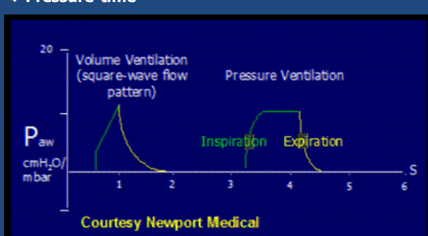
  - Pressure-time



Graphic Types

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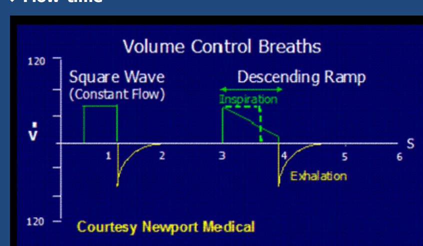
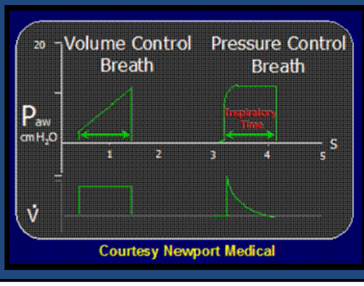


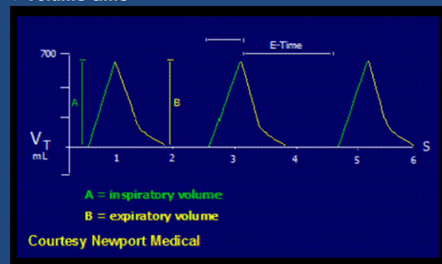
Graphic Types

- Waves: comparing volume vs. pressure control (PRVC, etc. = pressure control)



Graphic Types

- Waves
  - Volume-time



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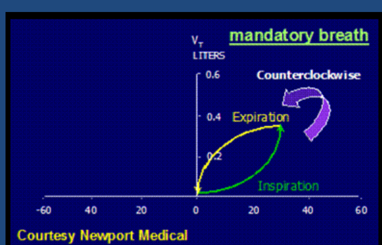
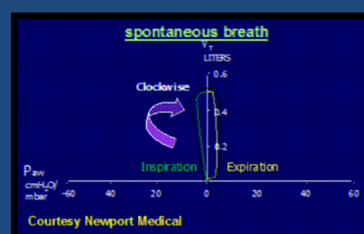


Graphic Types

- Loops
  - Pressure-volume



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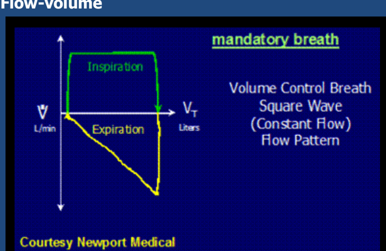

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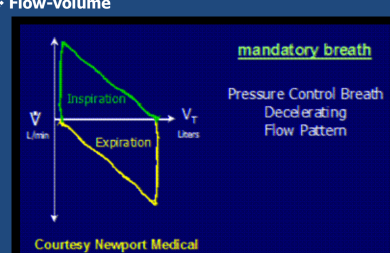
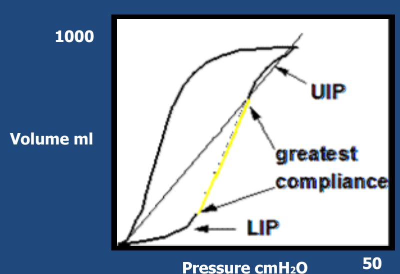


Clinical Applications for Graphics

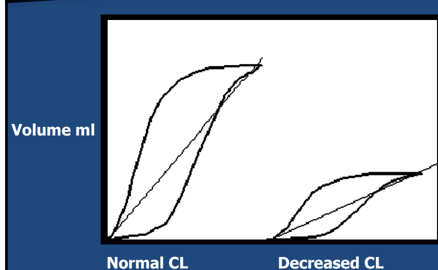
Compliance: Pressure Volume Curve

- Lower inflection point (LIP) - opening of atelectatic units
- Upper inflection point (UIP) - hyperinflation

Compliance: Pressure Volume Curve

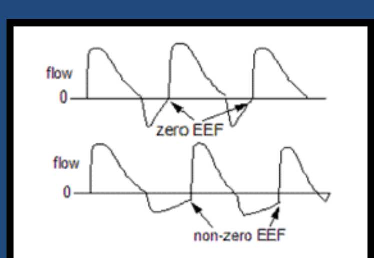


Qualitative Assessment of Compliance



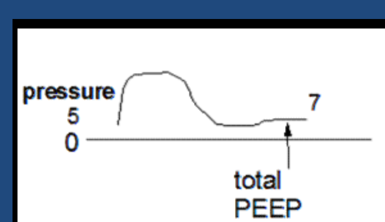
Detecting Intrinsic PEEP

- Zero end-expiratory flow (EEF) → zero PEEPi

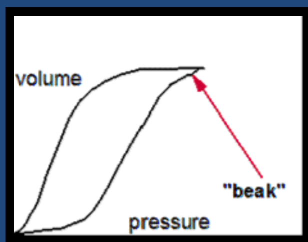


Detecting Intrinsic PEEP During Expiratory Hold

- Measured during absence of patient effort



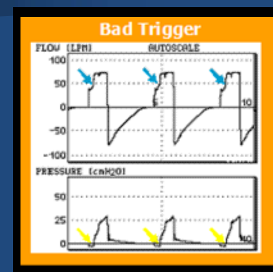
Lung Overdistension



Patient/Ventilator Asynchrony

Scooping on the upswing of the flow waveform

Significant pressure drop at the onset of patient effort

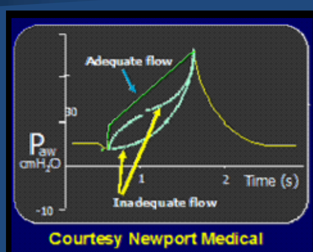


Courtesy Newport Medical

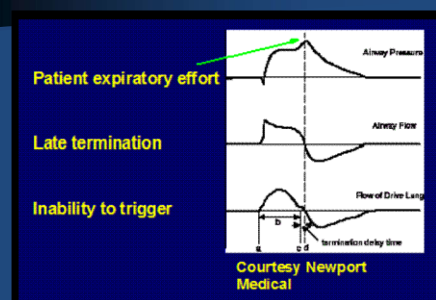
Inspiratory Flow/Rise: Pressure Wave

Linear or bowed upward rise in pressure after trigger on the pressure wave

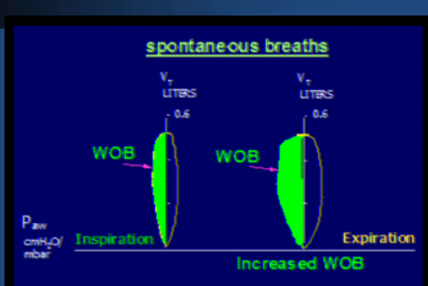
Slow rise in pressure, concave shape of the pressure wave



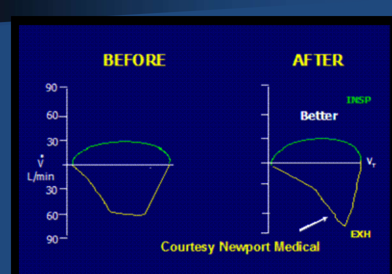
Expiratory Flow-Cycling (PSV)



Spontaneous WOB



Bronchodilator Effectiveness



End-Tidal CO_2 Monitoring

Applications

- Confirm ETT placement - reliable
- Estimate $PaCO_2$ - unreliable
- Monitor changes in $PaCO_2$ - unreliable
- Estimate dead space - reliable for finding dead space/tidal volume (Vd/Vt)
- Detect pulmonary embolism - reliable

Applications

- Evaluate chest compressions
- Compare condition of lungs during independent lung ventilation
- Predict weaning failure

Interpretation: $PetCO_2$

- Normal difference between $PaCO_2$ & $PetCO_2$ = 2 - 5 torr
- Increased $P(a\text{-}et)CO_2$ → dead space, e.g.
  - Pulmonary embolus
  - Excessive PEEP
- Bohr equation

$$Vd/Vt = \frac{PaCO_2 - P_ECO_2}{PaCO_2}$$

Interpretation: $PetCO_2$

- Decreased $PetCO_2$: ominous sign during resuscitation
  - Low perfusion
  - Embolization
- Increased $PetCO_2$
  - Hypoventilation
  - Administration of $NaHCO_3$

Summary & Review

- Pulmonary mechanics
  - Purposes for measurement
  - Implications
  - Measurement
- Optimal PEEP
  - Implications
  - Techniques for determination

Summary & Review

- Ventilator graphics
  - Types
  - Normal waveforms
  - Abnormal waveforms
- $ETCO_2$ monitoring
  - Applications
  - Interpretation of $P(a\text{-}et)CO_2$