

**Advanced Assessment  
Techniques in Critical Care**

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<http://www.geocities.com/jonesapjr/index.html>

**Learning Objectives:**

- ^ Describe techniques for measuring and optimizing ventilatory mechanics.
- ^ Interpret common ventilator wave form abnormalities.
- ^ Explain the significance of end-tidal CO2 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 and resistance to flow
- ▲ Static compliance ( $C_{ST}$ ) - elastic recoil of lung and thorax
- ▲ Inspiratory/expiratory resistance to flow
- ▲ Total PEEP

**Parameters Monitored**

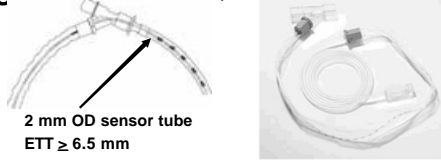
- ▲ Total PEEP - imposed (set) PEEP + intrinsic PEEP (PEEPi)
  - ◆ PEEPi - end-expiratory pressure in lung that may exceed set PEEP, esp. with
    - f* high rates
    - f* obstructive disease
    - f* active exhalation

**Parameters Monitored**

- ▲ PEEPi
  - ◆ continuous monitoring possible at tip of ETT
  - ◆ measurement requires end-expiratory pause and absence of active exhalation to measure
  - ◆ significance of PEEPi
    - f* impairs triggering
    - f* causes hyperinflation

**Parameters Monitored**

- ▲ Intratracheal pressure - GE Engstrom Carestation Spirodynamics(TM)



2 mm OD sensor tube  
ETT ≥ 6.5 mm

Images courtesy GE Healthcare

Click to visit GE Engstrom Carestation web site  
<http://www.gehealthcare.com/euen/respiratory-care/products/engstrom-carestation/index.html>

**Parameters Monitored**

- ▲ Intratracheal pressure
  - ◆ measured at distal end of ETT
  - ◆ more closely reflects alveolar pressure

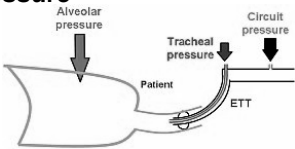
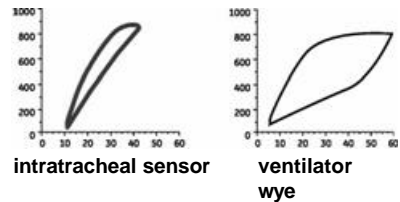


Image courtesy GE Healthcare

**Parameters Monitored**

- ▲ Intratracheal pressure - GE Engstrom Carestation Spirodynamics(TM)

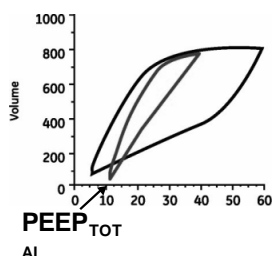


intratracheal sensor      ventilator wye

**Parameters Monitored**

▲ Intratracheal pressure - GE Engstrom Carestation Spirodynamics<sup>(TM)</sup>

- ◆ easy detection of total PEEP

**Parameters Monitored**

▲ Intratracheal pressure - GE Engstrom Carestation Spirodynamics<sup>(TM)</sup>

- ◆ Compliance values calculated at three points along VP curve: 5-15%, 45-55%, and 85-95% of the inspiratory phase.
- ◆ Inflection points readily discernable

FYI - click to download article: Practical assessment of respiratory mechanics  
<http://bjpa.oxfordjournals.org/cgi/content/full/91/1/92>

**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
- ◆ inspiratory flow

**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

- ◆  $PEEP_{total} = (PEEP + PEEP_{intrinsic})$
- ◆  $dynamic\ compliance = tidal\ volume / (PIP - PEEP)$
- ◆  $static\ compliance = tidal\ volume / (P_{pt} - PEEP)$
- ◆  $resistance = (PIP - P_{pt}) / flow$

FYI - Click for article on monitoring mechanics during ventilation  
[http://www.medscape.com/viewarticle/417584\\_6](http://www.medscape.com/viewarticle/417584_6)

**Measuring Compliance/Resistance**

▲ Units of measurement:

- ◆ Compliance- V/P -- Liters/cm H<sub>2</sub>O
  - $f_{normal} - > .06\ L/cm\ H_2O$
  - $f_{very\ low} - .02\ L/cm\ H_2O$
- ◆ Resistance- P/flow -- cm H<sub>2</sub>O/L/sec
  - $f_{normal} - 5\ cm\ H_2O/L/sec$
  - $f_{high} - > 10\ cm\ H_2O/L/sec$

**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 and pre- post-therapy values.

**Abnormal Cst**

- △ Decreased Cst ( $C_{DYN}$  if resistance is constant)
  - ◆ ARDS, ALI
  - ◆ Extrathoracic restriction
    - f* obesity
    - f* ascites, distension
  - ◆ Thoracic restriction
  - ◆ Volume-occupying lesions
    - f* pneumothorax
    - f* pleural effusion

**Implications- Decreased Cst**

- △ Increased work of breathing (WOB)
- △ Increased ventilation pressure requirement  $s==>$ 
  - ◆ 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 ( $SvO_2$ )
  - ◆ 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  $PaO_2$

**Optimal PEEP**

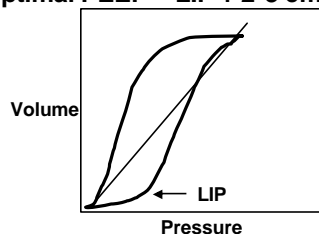
- ^ Defined- level of PEEP that imposes favorable volume-pressure relationship on the majority of lung units ==>
  - ◆ greatest Cst
  - ◆ greatest  $SvO_2$
  - ◆ improved ventilation-perfusion (VQ) matching
  - ◆ reduced shear forces required for ventilation

**Optimal PEEP**

- ^ Methods for determination
  - ◆ lower inflection point of PV curve
  - ◆ stepwise incremental Cst measurement
  - ◆ stepwise decremental Cst measurement
  - ◆ alternative method (Mercat, et al)
  - ◆ volume-oriented - FRC measurement

**Optimal PEEP**

- ^ Methods for determination
  - ◆ locate lower inflection point (LIP) of PV curve
  - ◆ Optimal PEEP = LIP + 2-3 cm H<sub>2</sub>O



**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<sub>2</sub> to 1.0
- ^ Increase PEEP by 5, up to 20 cm H<sub>2</sub>O
  - ◆ monitor vital signs
  - ◆ monitor SpO<sub>2</sub>
- ^ Adjust FIO<sub>2</sub> for SpO<sub>2</sub> 90-95%

**Stepwise Decremental Technique**

- ^ Decrease PEEP by 2 cm H<sub>2</sub>O
  - ◆ Q3 min, or until stabilized
  - ◆ monitor SpO<sub>2</sub>, SvO<sub>2</sub>, vital signs
  - ◆ measure Cst
- ^ Optimal PEEP = level with greatest Cst, SvO<sub>2</sub>
- ^ Monitored/adjusted each shift

**Alternative technique**

- ^ Methods:
  - ◆ Adjust TV to 6 mL/kg IBW
  - ◆ Increase PEEP to achieve Ppt 28-30 cm H<sub>2</sub>O
- ^ Trial findings
  - ◆ no change in mortality
  - ◆ decreased duration of ventilation and organ failure

**Volume - oriented PEEP**

- ^ Goal of PEEP - adjust FRC
- ^ Direct FRC measurement
  - ◆ Body plethysmograph - PFT laboratory
  - ◆ CT scan - gold standard
  - ◆ He dilution
  - ◆ N<sub>2</sub> washin-washout - available on Engstrom Carestation<sup>(TM)</sup>

Click for more information on Carestation<sup>(TM)</sup> FRC measurement

<http://www.gehealthcare.com/euen/respiratory-care/products/engstrom-carestation/inview-frc.html>

**Volume - oriented PEEP**

- ^ FRC measurement rationale
  - ◆ assess effects of PEEP and recruitment maneuvers
  - ◆ monitor lung recruitment status
  - ◆ detection of overdistension

FYI - Click for abstract of comparative study on FRC methods  
<http://ccforum.com/content/12/6/R150/abstract>

**Optimal PEEP**

- ^ Select a procedure that works and make sure that EVERYONE follows it precisely; that is, standardize.
- ^ Optimal PEEP changes with changes in pathology- adjust at least every shift and 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
    - f* primary mode
    - f* tidal volume, drive pressure
    - f* PEEP
    - f* ventilation times
    - f* trigger level
    - f* rise time
    - f* expiratory flow limit (PSV)

## Graphic Types

- ^ waves
  - ◆ pressure-time
  - ◆ flow-time
  - ◆ volume-time

## Graphic Types

- ^ waves
  - ◆ pressure-time



Courtesy Newport Medical

## Graphic Types

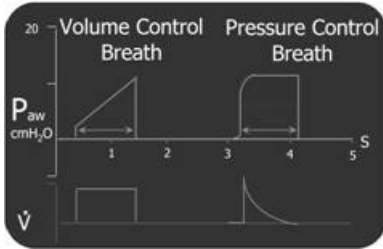
- ^ waves
  - ◆ flow-time



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**Graphic Types**

^waves- comparing volume, vs. pressure control (PRVC, etc. = pressure control)



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**Graphic Types**

^waves

◆volume-time



A = inspiratory volume

B = expiratory volume

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**Graphic Types**

^loops

◆pressure-volume

mandatory breath

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**Graphic Types**

^loops

◆pressure-volume

spontaneous breath



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**Graphic Types**

^loops

◆flow-volume



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**Graphic Types**

^loops

◆flow-volume

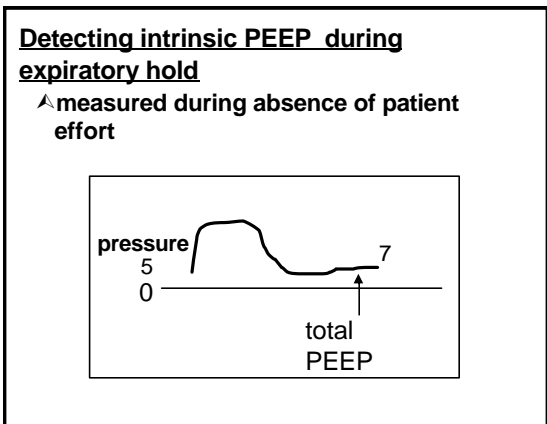
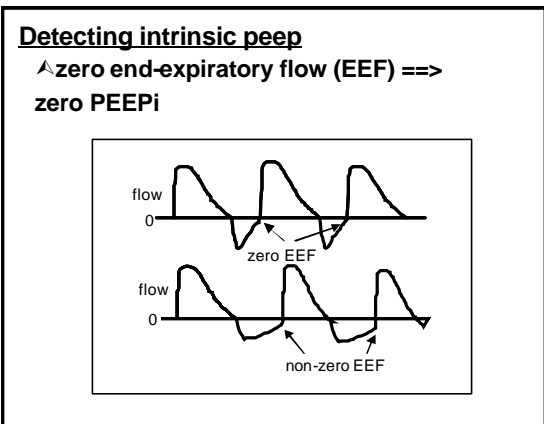
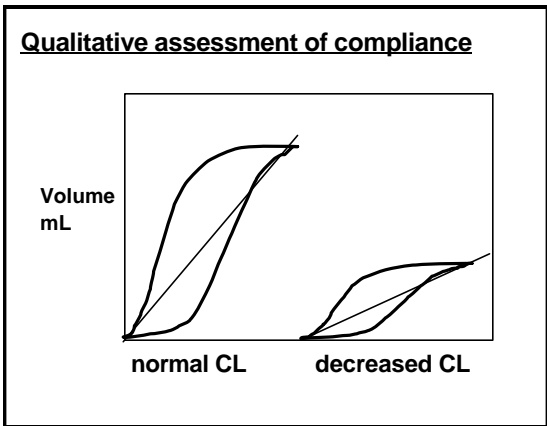
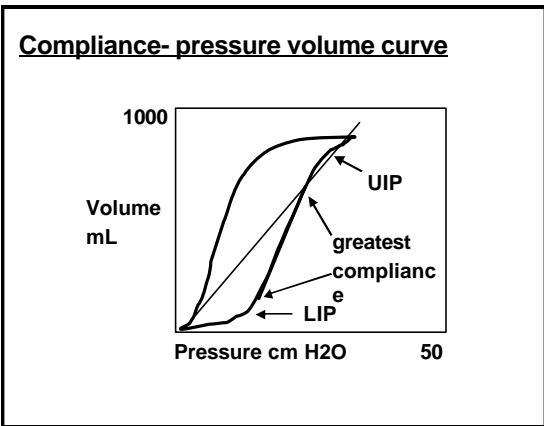


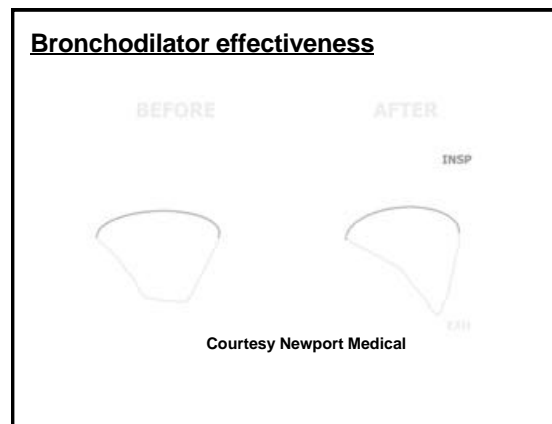
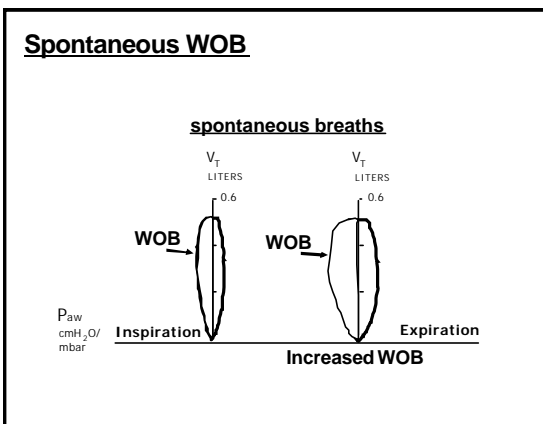
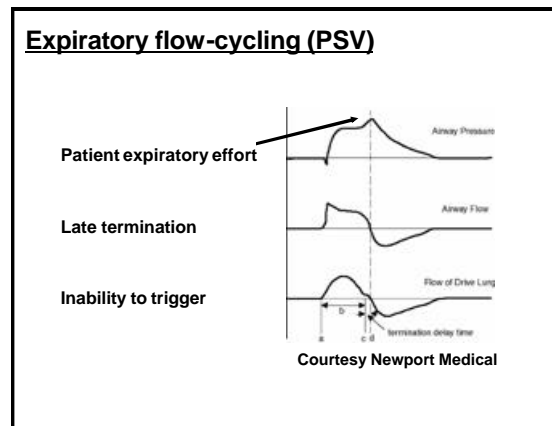
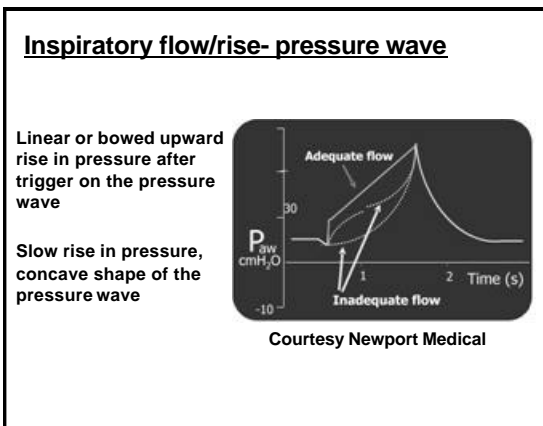
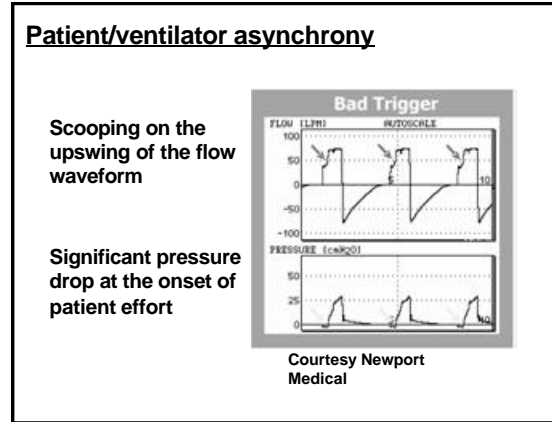
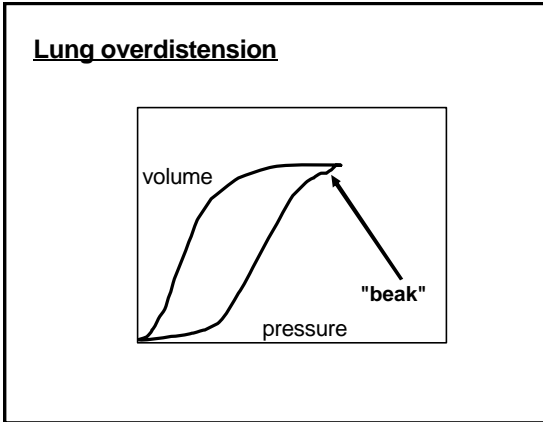
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# Clinical Applications For Graphics

**Compliance- pressure volume curve**

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





## End-Tidal CO<sub>2</sub> Monitoring

### Applications

- ▲ Confirm ETT placement- reliable
- ▲ Estimate PaCO<sub>2</sub>- unreliable
- ▲ Monitor changes in PaCO<sub>2</sub>- unreliable
- ▲ Estimate dead space- reliable for finding dead space/tidal volume (V<sub>d</sub>/V<sub>t</sub>)
- ▲ Detect pulmonary embolism- reliable

### Applications

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

### Interpretation- PetCO<sub>2</sub>

- ▲ Normal difference between PaCO<sub>2</sub>- PetCO<sub>2</sub> = 2-5 torr
- ▲ Increased P(a-et)CO<sub>2</sub> ==> dead space; e.g.:
  - ◆ pulmonary embolus
  - ◆ excessive PEEP
- ▲ Bohr equation:

$$V_d/V_t = \frac{PaCO_2 - P_{E}CO_2}{PaCO_2}$$

FYI - Link to capnography case studies  
[http://www.oridion.com/global/english/clinical\\_solutions/educational\\_resources/case\\_studies.html#CARE](http://www.oridion.com/global/english/clinical_solutions/educational_resources/case_studies.html#CARE)

### Interpretation- PetCO<sub>2</sub>

- ▲ Decreased PetCO<sub>2</sub>- ominous sign during resuscitation
  - ◆ low perfusion
  - ◆ embolization
- ▲ Increased PetCO<sub>2</sub>
  - ◆ hypoventilation
  - ◆ administration of NaHCO<sub>3</sub>

### Summary and Review

- ▲ Pulmonary mechanics
  - ◆ purposes for measurement
  - ◆ implications
  - ◆ measurement
- ▲ Optimal PEEP
  - ◆ implications
  - ◆ techniques for determination

**Summary and Review**

- ^ Ventilator graphics
  - ◆ types
  - ◆ normal waveforms
  - ◆ abnormal waveforms
- ^ ETCO2 monitoring
  - ◆ applications
  - ◆ interpretation of P(a-et)CO2

**END**

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