Respiratory monitoring

1) Clinical

*Respiratory rate:* Very sensitive marker of physiological change, but not specific

*Respiratory distress:* Neither sensitive nor specific but an indicator of abnormality.

2) SpO2

Operating principal = Beer-Lambert law. Two wavelengths emitted (660nm = red, 940nm = infrared). Difference in absorption gives \([\text{Hb-O2}}] / [\text{Hb-O2}}] + [\text{deoxy Hb-O2}}] = \text{SpO2}.\)

Non-invasive and trend is useful

Lag time (10 - 60s) and equipment, environment and patient confounders (e.g., local hypoperfusion, ambient light, Met- and CO-Hb, etc) hamper. Accurate to within 3% of true SaO2 if SpO2 > 80%. Calibrated to young, healthy individuals with minimal dyshaemoglobinaemias.

3) EtCO2

*Colorimetry* - used to confirm and monitor ETT placement

*Capnography* - Spectrophotometric analysis gives value and waveform.

Normal value: 35 - 45 mmHg

Used for:

- Confirmation of ETT position. False positive - carbonated beverage. False negative/low - low cardiac output, large shunt eg PE
- Waveform analysis: sharkfin, rising baseline, leaning tower, abrupt fall-off.
- PaCO\textsubscript{2}:EtCO\textsubscript{2} gap. Normally slightly negative. Widening suggests increased alveolar dead space (Valv); eg, low cardiac output, large shunt or alveolar overdistention. Both values raised but normal gradient => ventilatory fatigue or increased CO\textsubscript{2} production. Reversed gradient (EtCO\textsubscript{2} >> PaCO\textsubscript{2}) => CO\textsubscript{2} rebreathing

4) Lung volumes

- TLC (6L in 70kg male)
- Vt (6 - 10 ml/kg)
- IRV (3L)
- ERV (1.2L)
- VC (= IRV + Vt + ERV = 70ml/kg; approx 4.6L)
- FRC (RV + ERV = 2.5L in 70kg male)
- Closing volume (not specifically measured but significant if > FRC)

- FEV1 = 70 - 80% of VC

5) Lung dynamics

Important during PCV where changes in lung resistance or compliance can alter Vt.

Important during VCV in determining risks of volu- and barotrauma

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Principal components:
- Elastance (10 - 15 cmH2O/L) and its inverse, compliance (60 - 100 ml/cmH2O)
- Resistance
- PEEP_i
- Work of breathing

PiP (Peak inspiratory pressure) is a product of airway resistance and lung and chest wall elastance.
Pplat (Plateau pressure) is determined by lung and chest wall elastance. Both are measured at the ETT (large airway)

PiP:
Low => Leak, hyperventilation
High -> Look at Pplat

Pplat:
High PiP + Normal Pplat => Increased airway resistance; eg. bronchospasm, secretions, ETT obstruction.
(Mx: Suction the tube and airways. If no benefit, give bronchodilator. Watch for drop in PiP)
High PiP + Increased Pplat => Increased elastance (Low compliance); eg pulm oedema, consolidation, ARDS, pneumothorax, chest wall disease, abdominal distention, air trapping.
(Clinically examine chest & abdo, check CXR and flow-time curve)

Manouevres in a mechanically ventilated patient:
- **End-inspiratory hold**: Resultant pressure-time graph gives resistance \( \frac{(P_{peak} - P1)}{\text{Inspiratory Flow rate}} \)
  and elastance \( \frac{(P1 - P2)}{\text{Vol}} \)

- **End-expiratory hold**: Pressure-time graph gives iPEEP (measured PEEP - dialled PEEP) => dynamic hyperinflation.

- **Static V-P curve**: Acquired by super-syringe, Levy or automated methods, during which there is no flow; ie. static. Static compliance is the ratio of inspired volume to static airway pressure (Pplat); ie. \( C_{stat} = \frac{Vt}{(P_{plat} - \text{PEEP})} \). Lower inflection point (LIP) gives optimal PEEP setting. Upper inflection point (UIP) gives onset of alveolar overdistention. Portion between LIP and UIP is optimal ventilation setting to maximize compliance and reduce work of breathing.
*Note: When calculating Cstat from ventilator display, remember that the connector tubing is also compliant, resulting in the loss of 3mls for every cm H2O of distending pressure (PIP). If the set Vt = 500mls with a resulting PIP = 20cm H2O, in effect, 440mls (i.e. 500 - 3x20) reaches the lungs. So, when calculating Cstat from ventilator display, use Vt expired / (Pplat - PEEP), or Vt - (3xPIP) / (Pplat - PEEP).

**Dynamic V-P loop:** Acquired during ventilation at low flows; i.e. dynamic. Gives estimate of resistance, compliance and work of breathing

V-P loop data:
- Ventilator mode: PCV and PS modes are almost rectangular. VCV shows the more traditional hysteresis shape
- Vt = y intersect at top of loop, as long as FRC is the zero-point on the y-axis
- FRC = y intersect at bottom of loop
- Peak inspiratory pressure, PiP = x intersect at top of loop. Equivalent to Ppeak (Ppk)
- PEEP = x intersect at bottom of loop. Following an expiratory hold, the excess value above the set PEEp is an indicator of iPEEP.
- Lower inflection point (LIP) to upper inflection point (UIP) = optimal ventilation zone. PEEP often set around the LIP. Loop should not be allowed to extend much beyond UIP.

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• Bird’s beak appearance beyond UIP => alveolar distention; eg excessive inspiratory pressure, dynamic hyperinflation
• Insp WoB = Inspiratory work of breathing: the fatter the area, the greater the inspiratory work of breathing; eg upper airway obstruction, airway resistance
• Exp WoB = Expiratory work of breathing: the fatter the area, the greater the expiratory work of breathing; eg bronchospasm
• The flatter the slope of the curve, or, the shorter the overall height of the curve, the lower the compliance

*Spontaneous initiation of a breath is shown by a “pig tail” loop at the base of the Vol-Pr loop. The fatter the pig tail, the greater the effort required to trigger the ventilator
· Failure of the loop to close at the bottom => iPEEP / air trapping, or leak (cuff, tracheobronchial fistula, bronchopleural fistula

· Can perform inspiratory hold (Pplateau and static compliance and elastance) and expiratory hold (quantify iPEEP)

**Flow-Volume loops:**

Pattern useful

· Rounded inspiratory curve in spontaneous breath, squared in ventilator assisted breath
Expiratory loop usually an exponential decay, reflecting passive elastic recoil. More continuous (rounded, flattened) => active expiratory effort.

*Normal*
Small airways obstruction

Restrictive lung disease

Fixed upper airway obstruction

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Variable intrathoracic obstruction

Variable extrathoracic obstruction
iPEEP / Air trapping / Leak:

Water or secretions in tubing:

References:
2. The ICU Book, P. Marino, 2nd Ed.

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