Picture Quiz

Can you calculate the total respiratory, lung, and chest wall respiratory mechanics?

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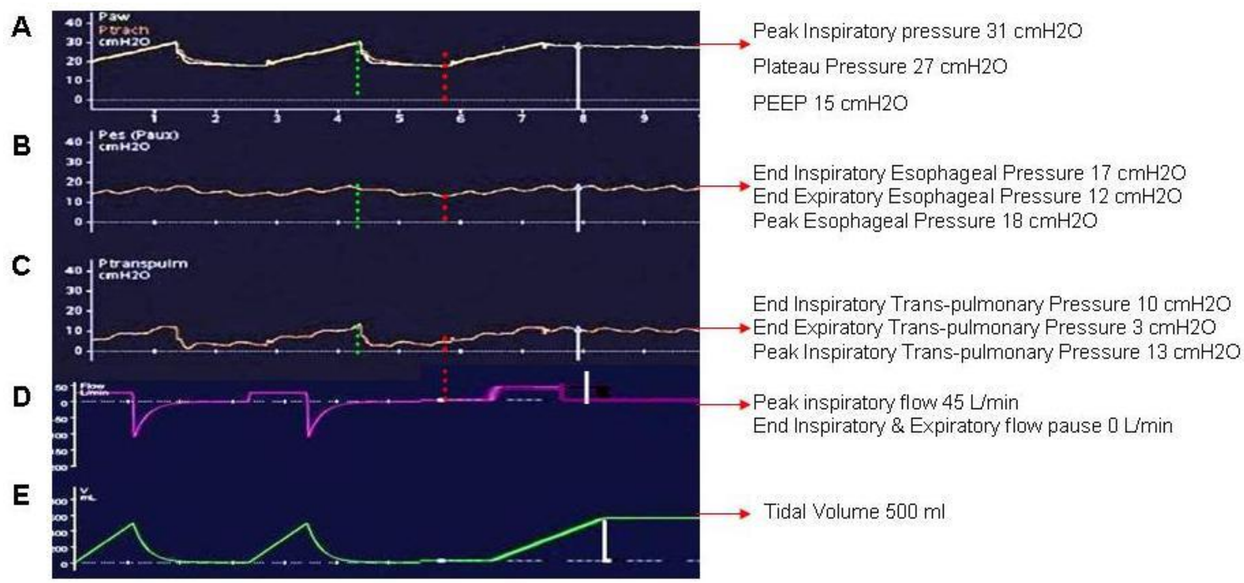

Figure: Waveforms for a patient undergoing mechanical ventilation with volume-controlled mode. Tidal Volume of 500 ml, PEEP 15, Constant inspiratory flow of 45 l/min
A: Airway pressure in cmH_2O, B: Esophageal pressure in cmH_2O, C: Trans-pulmonary pressure in cmH_2O, D: Flow in l/min, E: Tidal volume in ml
Red dashed horizontal line: values at end of expiratory occlusion maneuver, White solid horizontal line: values at end of inspiratory occlusion maneuver, Green dashed horizontal line: values during peak inspiratory pressure.

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Answers:

Total respiratory system compliance (C_{RS}) = 41.6 ml/cmH_2O
Chest wall compliance (C_{CW}) = 100 ml/cmH_2O
Lung compliance (C_L) = 71.4 ml/cmH_2O
Total respiratory resistance (R_{RS}) = 5.3 cmH2O/l/s
Chest wall resistance (R_{CW}) = 1.3 cmH2O/l/s
Lung resistance (R_L) = 4 cmH2O/l/s
Auto-PEEP = 0 cmH_2O

Findings compatible with mild restrictive disease

How did we calculate those parameters? [1,2]
(For more details please refer to the references)

Compliance is the change of volume per change of pressure: Δ Vol / Δ Pressure

Resistance is the change of pressure from one point to the other over the driving flow: P1 – P2 / Flow ($V^{\cdot}$)

The classic static respiratory mechanics have to be done with no patient effort (paralyzed patient) and has to be done using the Volume Controlled mode (VCV) using the constant (square) inspiratory flow wave form.

To obtain the total respiratory system mechanics, we need the values of airway pressure (Paw), tidal volume (VT), and inspiratory flow ($V^{\cdot}$). But to obtain the chest wall and lung mechanics separately, we need an esophageal balloon manometry to obtain the values of the pleural pressure P_{pl} (estimated by esophageal pressure P_{es}), and the trans-pulmonary pressure (P_L) which represent the distending forces acting on the alveoli (Pleural pressure – Airway pressure).

Two occlusion maneuvers have to be done. Each about 3-5 seconds)

- The end-expiratory occlusion maneuver is to obtain the value of the Total Positive End Expiratory Pressure ($PEEP_T$) which is equal to Applied PEEP + Auto-PEEP. It corresponds to the value of the airway pressure at the end of the maneuver. In the above example, the Total PEEP is 15 cmH_2O, Auto-PEEP 0 cmH_2O (Notice the expiratory flow returns to the baseline before the start of the new breath. It is important also to obtain the values of the esophageal pressure and trans-pulmonary pressure at end of exhalation for the calculations as below.
- The end-inspiratory occlusion maneuver is to obtain the Peak inspiratory pressure (P_{PIP}) and plateau airway pressure P_{Plat} (elastic recoil pressure of the respiratory system). It is important also to obtain the values of the esophageal pressure and trans-pulmonary pressure at end of inspiration for the calculations as below.

Of note the chest wall resistance is usually very low and hard to obtain from the heart noise of the esophageal balloon, additionally it is of no clinical importance.

In this example:

Total respiratory compliance
= VT / Paw - $PEEP_T$
= 500 / 27 - 15
= 41.6 ml/cmH_2O

Total respiratory resistance
= P_{PIP} - P_{plat} / V'
= 31 - 27 / 0.75 (45 L/min = 0.75 l/s)
= 5.3 cmH_2O/l/s

Chest wall compliance
= VT / End inspiratory P_{es} - End expiratory P_{es}
= 500 / 17 - 12
= 100 ml/cmH_2O

Chest wall resistance
= Peak P_{es} - End inspiratory P_{es} / V'
= 18 - 17 / 0.75
= 1.3 cmH_2O/l/s

Lung compliance
= VT / End inspiratory P_{PL} - End expiratory P_{PL}
= 500 / 7
= 71.4 ml/cmH_2O

Lung resistance
= Peak P_{PL} - End inspiratory P_{PL} / V'
= 13 - 10 / 0.75 (45 L/min = 0.75 l/s)
= 4 cmH_2O/l/s

Another way of calculating lung mechanics once Total respiratory system and chest wall values are calculated is:

Lung compliance

= 1 / (1/ Total respiratory system compliance) - (1/ Chest wall compliance)
= 1 / (1/41.6) - (1/100)
= 1 (0.024) - (0.01)
= 71.4 ml/cmH_2O

Lung resistance

= Total respiratory resistance - Chest wall resistance
= 5.3 – 1.3
= 4 cmH_2O/l/s

Discussion

Knowledge of the respiratory mechanics is crucial for monitoring and treating patients undergoing mechanical ventilation. Clinicians usually depend on only knowing the tidal volume and plateau pressures as advised by the ARDS network [3] but that shows only one side of the coin. The measurement of the pleural pressure as estimated with the esophageal pressure give the clinician the whole full picture of respiratory mechanics. [4] Despite the ample of research and information obtained from the esophageal balloon, unfortunately it remains mostly confined to research labs.

The draw backs of measuring static respiratory mechanics are that the patient has to have no inspiratory efforts (heavy sedation or chemical paralysis) and could be time consuming. New generation ventilators calculate dynamic respiratory mechanics (compliance, resistance and Auto-PEEP) using the linear least squares fitting method (LSF). It is a computed regression analysis derived from the respiratory equation of motion, which allows for breath-by-breath display of respiratory mechanics in any mode of ventilation without any holding maneuvers or certain flow pattern. However, our previous work showed that those measurements may be accurate in the passive patient, while are undependable and inaccurate in the patient with spontaneous respiratory effort. [5]

References

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