EDITORIAL

Respiratory Mechanics: To Balance the Mechanical Breaths!!

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The monitoring of any ventilated patient is incomplete without the assessment of respiratory mechanics, especially in airway and parenchymal diseases, where the changes in resistance (R) and compliance (C) play a major role in the treatment course. An understanding of the respiratory mechanics hence is essential for planning the optimal ventilator settings.

Respiratory mechanics is an umbrella term used to reflect the lung function using the measures of pressure and flow.[1] These measures can be broadly categorized as: (1) statics, depicting the forces acting on the lungs, related to its volumes and the elastic behavior; (2) dynamics, reflecting the movement of air and related areas like flow patterns and resistance.[1] The pressure gradient required for to and fro movement of air in the thorax is determined by the compliance, resistance, and inertia of the lungs; however, the inertial forces are negligible while the patient is on mechanical ventilation. This has many clinical implications at the bedside of a ventilated patient; for instance, any disease or disorder that alters the airway resistance (bronchiolitis, asthma, etc.) lung compliance (pneumonia, pulmonary edema, etc.), or chest wall compliance (chest wall deformities) can seriously disrupt the normal mechanics of ventilation.

In a prospective observational study from two pediatric intensive care units in Brazil, Andreolio et al.[2] evaluated the respiratory mechanics in infants with acute viral bronchiolitis (AVB) requiring invasive ventilation and have tried to predict the course and outcome of mechanical ventilation based on the respiratory mechanics. The authors must be commended on this study on respiratory mechanics and the subsequent ventilation strategy in infants with AVB. Acute viral bronchiolitis presents with a mixed pattern of airway and parenchymal involvement, resulting in gross impairment in respiratory mechanics. There is a paucity of literature regarding the reference values regarding the respiratory mechanics in pediatrics. This study shall help the similar projects to obtain or benchmark normalized values of respiratory mechanics in pediatric population and its correlation with evolution of the illness. The authors have used a structured approach to measure respiratory mechanics, which takes us for revision dive into respiratory physiology.

Elastance of the respiratory system (E_{RS}) reflects the capacity of the respiratory system to return back to its resting position and hence indicates the recoil pressure over a given volume. Since elastance is expressed as, $E = 1/C$, where, C is the compliance of the respiratory system (C_{RS}) is referred as the elastic forces that oppose lung inflation. More specifically, the compliance is expressed as the change (Δ) in volume (V) that occurs when certain amount of pressure (P) is applied to the system: $C = \Delta V/\Delta P$.

C_L is the total compliance of both lungs, measuring the extent to which the lungs will expand (change in volume of lungs) for each unit change in the transpulmonary pressure and is expressed as $C_L = \Delta V/\Delta P$, where ΔP is the change in transpulmonary pressure, i.e., alveolar pressure (P_{ALV}) – pleural pressure (P_{PL}). For clinical purposes, based on the method of measurement, lung compliance is categorized as dynamic static or lung compliances.

Dynamic lung compliance (C_{DYN}) represents the pulmonary compliance calculated at each point representing changes during spontaneous breathing and it measures both the lung compliance and airway resistance.[3] However, C_{DYN} is not an accurate assessment of lung compliance because of the multifactorial involvement like the patient's chest wall and lung elastance, airway resistance (R_{AW}), endotracheal tube (ET), absence of paralysis, and the patient ventilator circuit.[4] C_{DYN} is calculated from the formula: ΔV/(PIP–EEP), where PIP is the peak inspiratory pressure and EEP is the end expiratory pressure.

The lung compliance of a patient primarily depends on the size of the lung and, therefore, the height of the patient and also the age in pediatric population. Importantly to emphasize on the pediatric practice, the chest wall is nearly three times as compliant as the lungs in infants during the first year of life, and with progression in age and weight, the chest wall stiffens to the point that the chest wall and lung compliances approximate to be equal.[5] The higher the compliance, the larger the volume delivered. The chest wall is compliant in neonates and does not add a considerable elastic load compared with the lungs. Total C_{RS} in neonates who have normal lungs ranges from 3 to 6 mL/cm H_2O compared to those in neonates who have RDS, found to be as low as 0.5–1 mL/cm H_2O as in this study.[6]

Since lung compliance is directly proportional to the lung volume, any loss of volume as in atelectasis, pneumonia, or pulmonary edema will result in a significant drop in compliance. The concept of "baby lung" in acute respiratory distress syndrome (ARDS) depicts the same, where the C_{RS} is related to the size of the amount of normally aerated lung tissue, indicating low lung volume and poor C_L.[7] In a ventilated adult supine patient, the C_{STAT} of the respiratory system will be usually lower than a healthy subject in the upright position, ranging between 40 and 70 mL/cm H_2O. It is understood that when the compliance reduces further to 25 mL/cm H_2O or lower as seen in severe ARDS, the work of breathing increases

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by four to six times, with an increased energy consumption.[8] Hence in other words, any change in the lung compliance will reflect the amount of aerated lung volume, reflecting the severity of the ARDS process in the whole lung.

The next measure by the authors is the static compliance (C_{STAT}), which is a more specific indicator of lung compliance as it is measured during no airflow in the airway or in the patient-ventilator circuit and it requires patient-ventilator synchrony and with absent patient effort. The normal C_{STAT} of an intubated and ventilated patient will be approximately 70–100 mL/cm H_2O and will have decreased values as seen in ARDS, pneumonia, pulmonary edema, atelectasis, pneumothorax, pleural effusion, etc.[4] C_{STAT} is best explained when transpulmonary pressure equals the elastic recoil pressure of the lungs, hence it only measures the elastic resistance. C_{STAT} is calculated based on the formula: $\Delta V/(P_{plat}–EEP)$, where P_{plat} is the plateau pressure.

Respiratory system resistance is categorized into two parts: tissue resistance and airway resistance. Tissue resistance accounts for only about 20% of total resistance and is the friction caused by the moving organs and chest wall during the respiratory cycle, whereas airway resistance (R_{AW}) is the friction caused by the movement of air throughout the respiratory system and conducting airways. Resistance is simplified as the change in pressure per unit change in flow, i.e., $R = \Delta$ Pressure/Δ Flow. Specifically, R_{AW} depends on multiple factors like airway radius, length of the airways, gas flow rate, and the density and viscosity of gas.

In a spontaneously breathing nonintubated subject, the R_{AW} is approximately about 0.6–2.4 cm H_2O/L/second,[4] whereas the R_{AW} in an intubated, mechanically ventilated patient is about 5–10 cm H_2O/L/second.[9] Secretions, bronchospasm, ET compression, kinking and biting, or mucus plugging inside the ET also may tend to increase R_{AW}. Airway resistance is an important area of concern, when attending pediatric population. Smaller ET tubes may significantly add airway resistance, especially during higher flow rates are used, leading to turbulent flow. The respiratory resistance (tissue + airway) in a nonintubated neonate ranges approximately between 20 and 40 cm H_2O/L/second, whereas in an intubated neonate, it ranges from 50 to 150 cm H_2O/L/second.[6]

Another area of interest in respiratory mechanics is the time constant (TC). When the respiratory system is subjected to certain change in pressure (ΔP), time is needed until a change in volume (ΔV) occurs, and this time necessary to inflate 63% of its volume is called the TC.[10] One TC is the time required to fill or empty 63% of the lung unit, whereas two and three TCs are required to fill 86 and 95% of the lung units, respectively, and with five TCs the lung is said to be 100% full. This happens when the lung is free from any disease condition.[11] In a normal lungs, with a compliance of 0.1 L/cm H_2O and an airway resistance of 1.0 cm H_2O/L/second, the time constant is 0.1 second. However, we understand that the compliance and resistance of alveolar units are not always equal throughout the lung, and therefore by definition there will be different TCs for different lung zones. An alveolar unit with low resistance and low compliance will fill quickly and is known as "fast alveolus" whereas a unit with high resistance and high compliance will take a long time to fill, known as "slow alveolus." This concept is not significant while we ventilate in normal lung conditions. The clinical application of the TC reflects that very short inspiratory times may lead to incomplete delivery of tidal volume and, therefore, lower PIP and MAP, resulting in hypercapnia and hypoxemia. Similarly, inadequate expiratory time may result in increased functional residual capacity and unwanted PEEP, resulting in gas trapping, hyperinflation, decreased compliance, and impaired hemodynamics.

As mentioned in the article,[2] any deterioration of a ventilated patient related to any airway or parenchymal issues can be identified easily by monitoring graphical interpretations of respiratory mechanics, i.e., the changes in PIP, P_{plat}, and the difference between the PIP and P_{plat}, as seen in the volume control ventilation. The PIP represents the summation of both resistive and elastic work of breathing, whereas P_{plat} only represents the elastic factors or the alveolar distention. The difference between these two is known as transairway pressure. If both the PIP and P_{plat} are increasing with a constant pressure difference between them and no change in the delivered tidal volume, it indicates a drop in C_{STAT} reflecting poor lung compliance. Increased airway resistance is accounted, if the PIP is significantly increasing with an increased transairway pressure (PIP–P_{plat}), without any change in the P_{plat}.

The aforementioned variables reflecting the respiratory mechanics thus help the clinicians to provide safe ventilation for their patients by balancing the benefits and harms, in terms of ventilator-related complications like barotraumas, volutraumas, and lung injuries.

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