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Simulation of Respiratory Mechanics

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Contents

1 Introduction

This report is based on the results of the simulator developed by David Leonardo Rodriguez Sarmiento and Daniela Acevedo Guerrero (2020) to look into the complicated mechanics of breathing in people, both when they are healthy and when they are sick. Taking care of your lungs is very important, and when you have a lung disease, knowing minute ventilation is very important. The main goal of the study is to simulate three different situations: normal, restrictive lung disease, and obstructive pulmonary disease. We want to find out what changes happen to respiratory mechanics when we look at ventilation patterns and minute ventilation .

2 Normal Respiratory Condition

Investigating a basis of respiratory health, our simulation accurately shows the normal balance in breathing. Respiratory muscles, lung compliance, and airway resistance work together to facilitate efficient air exchange. The efficiency of the process can be reflected by minute ventilation, which indicates the volume of air inhaled and exhaled per minute. Emphasizing typical circumstances establishes the foundation for a comparison. Establishing the standard functionality of respiratory mechanics provides a basis for identifying deviations in scenarios involving restrictive and obstructive pulmonary diseases.

- Values for healthy person under normal conditions
  - Lung compliance = 0.1 L/cmH2O
  - Thoracic compliance = 0.1 L/cmH2O
  - Airway central resistance = 3 cmH2O/(L/s)
  - Peripheral airways resistance = 0.5 cmH2O/(L/s)
  - Airway tissue compliance = 0.005 L/cmH2O
- When a healthy individual is connected to a ventilator under the specified conditions, the outcomes are displayed in the graphs.
  - Breathing frequency = 15
  - PEEP value = 0 cmH2O/(L/s)
  - Peak pressure = 10 cmH2O/(L/s)
- Respiratory minute volume = 7.5 L/min

2.1 Simulation results-Normal Condition

The graphs generated under these conditions offer a visual representation of the expected ventilation patterns for a healthy individual connected to a ventilator.

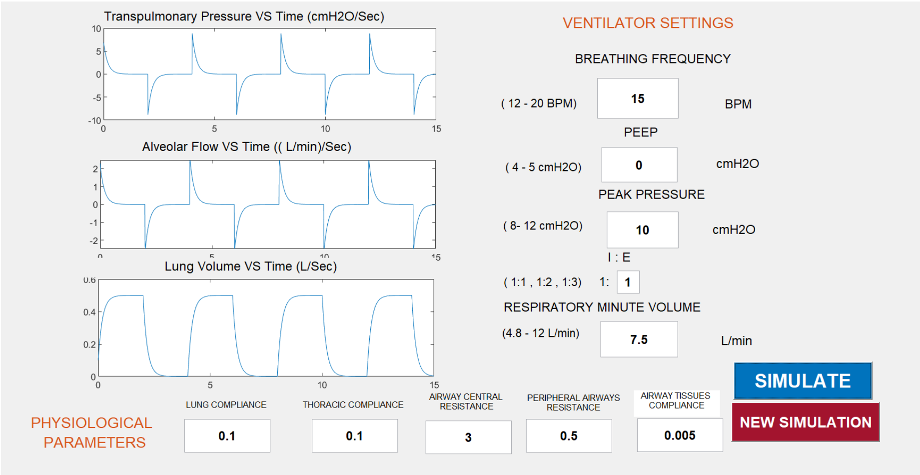

Figure 1: Ventilator settings GUI - Normal Condition

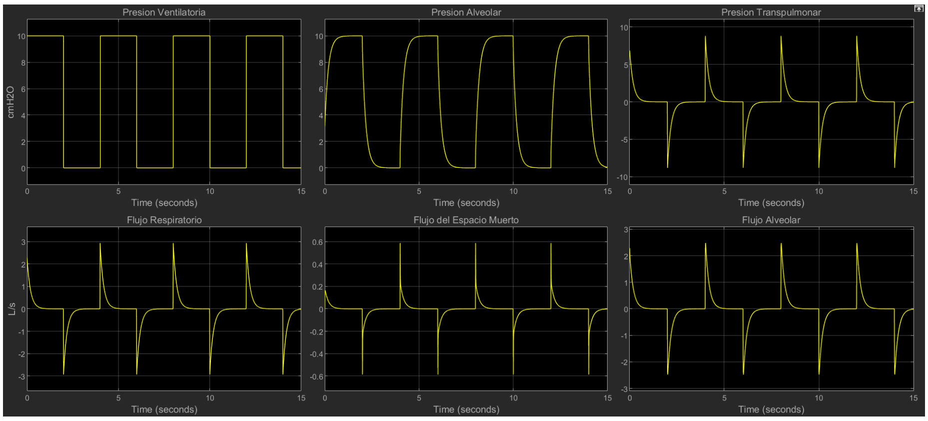

Figure 2: Output of Flow and Pressure Monitor - Normal Condition

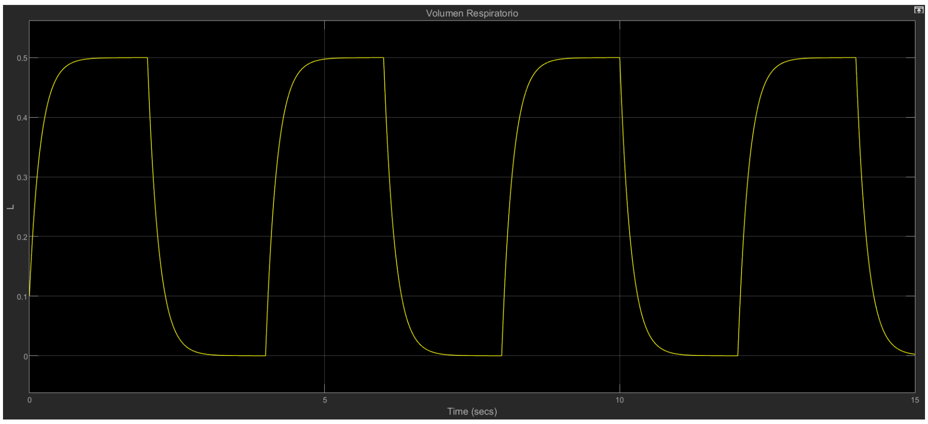

Figure 3: Output of Lung Volume Monitor - Normal Condition

3 Restrictive pulmonary disease

Restrictive pulmonary diseases constitute a group of respiratory conditions characterized by diminished lung compliance, affecting the lungs' capacity to expand during inhalation. The key manifestation is a decline in lung compliance due to changes in the chest wall and lung parenchyma, resulting in stiffened lung tissue that hampers complete expansion during breathing. Thoracic compliance is also affected, attributed to chest wall abnormalities.

These disorders primarily impact lung and thoracic compliance, with minimal direct influence on airway tissue compliance. Restrictive lung disease, causing reduced lung volume, arises from diminished lung elasticity or chest wall expansion issues. Examples include asbestosis, sarcoidosis, and pulmonary fibrosis.

Symptoms encompass cough, shortness of breath, wheezing, and chest pain, reflecting the consequences of altered compliances and resistances in affected individuals.

In the report's context, I will analyse pulmonary fibrosis as a representative case of restrictive lung disease.

3.1 Pulmonary Fibrosis

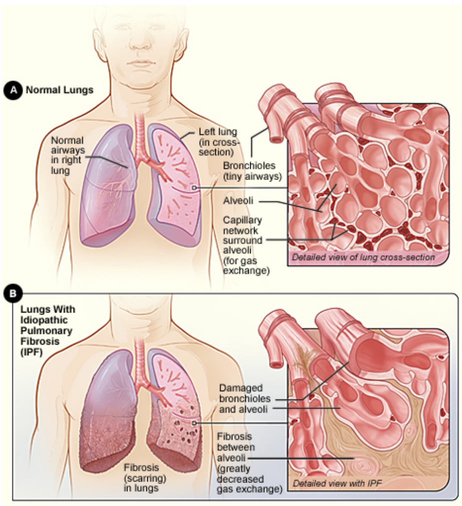

Figure 4: Pulmonary Fibrosis

Damage to and scarring of lung tissue results in pulmonary fibrosis, a lung disease. The lungs have a harder time functioning normally because of this inflexible, swollen tissue. Over time, pulmonary fibrosis deteriorates. Some people's conditions can remain constant for a very long time, whereas in others, they deteriorate more quickly. People experience increasing dyspnea as the condition worsens.

Numerous factors can contribute to the scarring that results from pulmonary fibrosis. Doctors and other medical professionals frequently are unable to identify the root cause of an issue. Idiopathic pulmonary fibrosis is the term used to describe the illness when a cause is not identified.

Middle-aged and older persons are typically affected with idiopathic pulmonary fibrosis. Infants and children can occasionally be diagnosed with pulmonary fibrosis, but this is not typical.

Pulmonary fibrosis damages the lungs and cannot be healed. Sometimes, treatments and medications can help reduce fibrosis symptoms, enhance quality of life, and slow down the disease's progression. A lung transplant may be an option for certain individuals.

Lung compliance decreases dramatically in a weakened respiratory state, like pulmonary fibrosis, making it difficult for the lung to expand and contract effectively. In parallel, there is an increase in airway resistance, which is an obstruction to airflow and makes breathing difficult. Under these circumstances, the modified values for a person with pulmonary fibrosis illustrate deviations from ideal parameters:

- Values for a person with pulmonary fibrosis
  - Lung Compliance:0.04 L/cmH2O Decreased
  - Thoracic Compliance: 0.04 L/cmH2O Decreased
  - Airway Central Resistance: 3 cmH2O/(L/s) Unchanged
  - Peripheral Airways Resistance: 0.5 cmH2O/(L/s) Unchanged
  - Airway Tissue Compliance:0.005 L/cmH2O Unchanged
- Respiratory minute volume = 3 L/min

3.1.1 Simulation results- Pulmonary Fibrosis

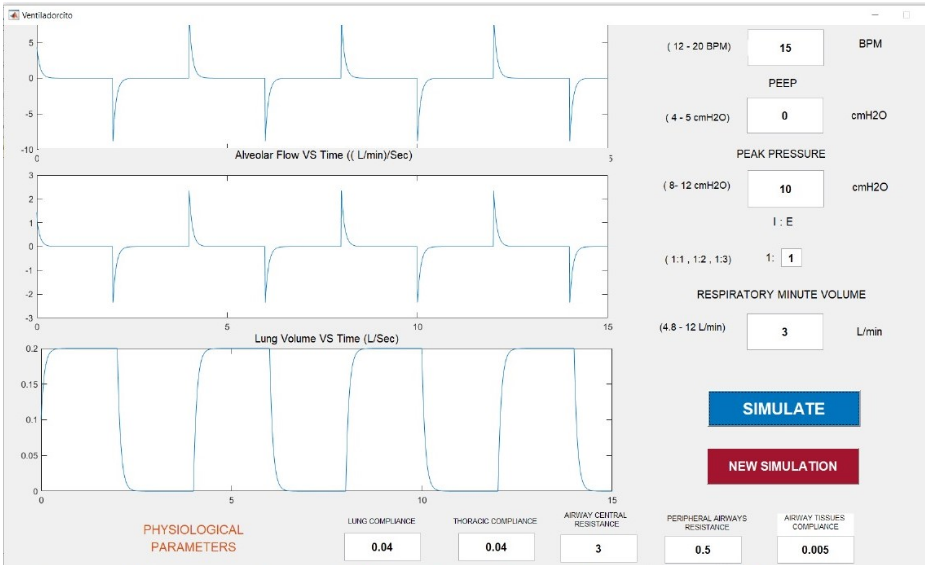

Figure 5: Ventilator settings GUI - Pulmonary Fibrosis

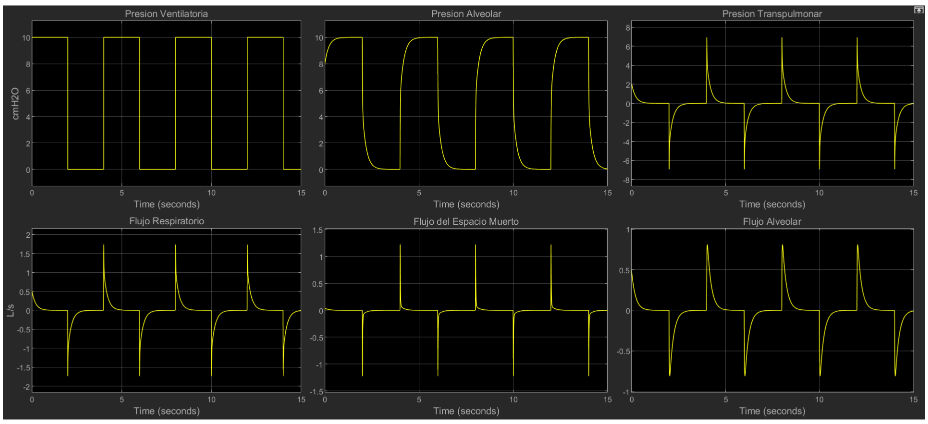

Figure 6: Output of Flow and Pressure Monitor - Pulmonary Fibrosis

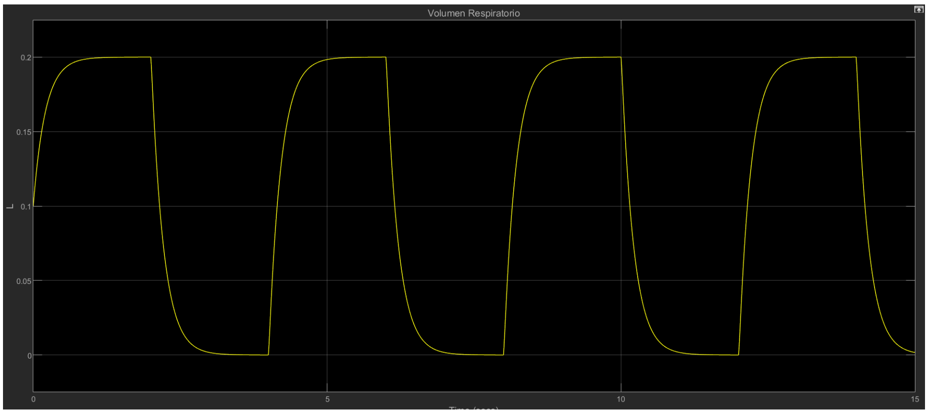

Figure 7: Output of Lung Volume Monitor - Pulmonary Fibrosis

3.1.2 Adjusting Ventilator Setting to Accomodate Breathing for a fibrosis patient

- Breathing Frequency (Respiratory Rate):17 breaths per minute

  Moderate rate (12-20 breaths per minute) to balance ventilation and pressure.

- PEEP (Positive End-Expiratory Pressure): 10 cmH2O/(L/s)

  Individualized value to maintain lung recruitment and prevent alveolar collapse.

- Peak Pressure: 15 cmH2O/(L/s)

  Kept as low as possible while delivering adequate tidal volume, individualized based on patient tolerance.

- I:E Ratio (Inspiratory to Expiratory Ratio):1:2

  Adjusted (e.g., 1:2 or 1:3) to manage gas exchange and auto-PEEP, individualized based on the patient's condition.

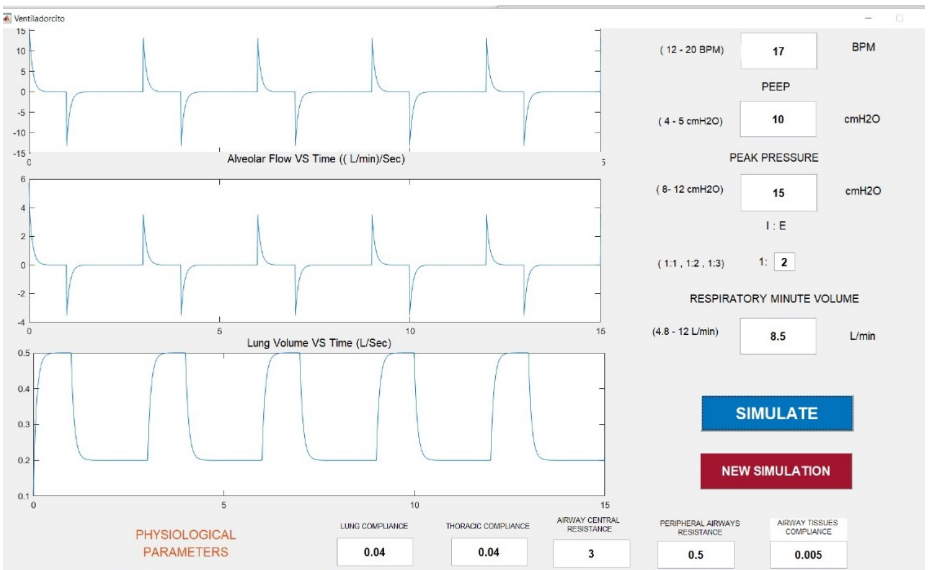

Figure 8: Results after adjusting ventilator settings to accomodate breathing for Fibrosis patient

4 Obstructive pulmonary diseases

People with obstructive lung disease struggle to breathe because it's challenging for them to completely exhale air from their lungs. This difficulty arises due to lung damage or the narrowing of airways inside the lungs, causing the exhaled air to come out slower than normal. This often leads to an accumulation of excess air in the lungs after a full exhale.

The main reasons behind obstructive lung disease include:

- Chronic obstructive pulmonary disease (COPD), covering emphysema and
- chronic bronchitis.
- Asthma
- Bronchiectasis
- Cystic fibrosis

Obstructive lung disease makes breathing tougher, especially during activities like exercise. When your breathing rate increases, it becomes harder to expel all the air before taking in another breath. This difficulty in exhaling is a common challenge for individuals dealing with obstructive lung diseases.

In the report's context, I will analyse Bronchitis as a representative case of obstructive lung disease

4.1 Bronchitis

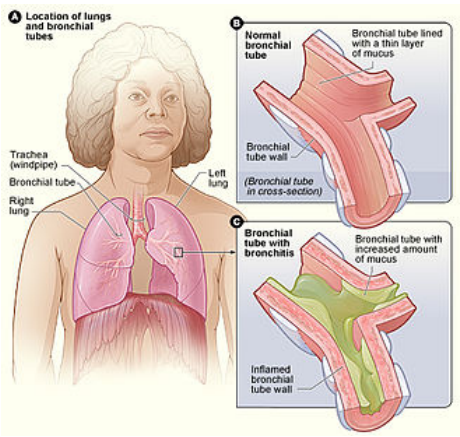

Figure 9: Pulmonary Fibrosis

Bronchitis happens when the airways in lungs get swollen and irritated, usually because of an infection. Most of the time, it gets better on its own in about 3 weeks.

Sometimes, the inflammation in the lung tubes sticks around for a long time, and that's called chronic bronchitis. When it becomes a long-term thing, it's part of a bigger issue called chronic obstructive pulmonary disease (COPD).

To figure out bronchitis,symptoms that might feel like a cold or the flu:

- Coughing –might cough up clear, white, yellow, or green mucus.
- Chest pain when coughing.
- Shortness of breath.

- A sore throat.
- A runny nose.
- A high temperature.

These signs are symptoms of bronchitis, and if it lasts a long time, it might be chronic bronchitis, which is a type of COPD.

Thoracic and lung compliance levels would rise as a result. Because of the narrower airways, it would be harder to exhale, but it would require less pressure to inflate the lungs.

An obstruction of the airways would impact the values for airway tissue compliance, airway central resistance, and peripheral airway resistance. It would be more difficult to exhale due to an increase in the central and peripheral airway resistance of the airways. The lungs would become more stiff and challenging to inflate as a result of the decreased airway tissue compliance

- Values for a person with bronchitis
  - Lung Compliance: 0.15 L/cmH2O Increased
  - Thoracic Compliance: 0.1 L/cmH2O Unchanged
  - Airway Central Resistance: 3 cmH2O/(L/s) Unchanged
  - Peripheral Airways Resistance: 7 cmH2O/(L/s) Moderately increased
  - Airway Tissue Compliance:0.005 L/cmH2O Unchanged
- Respiratory minute volume = 9 L/min

4.1.1 Simulation results-Bronchitis

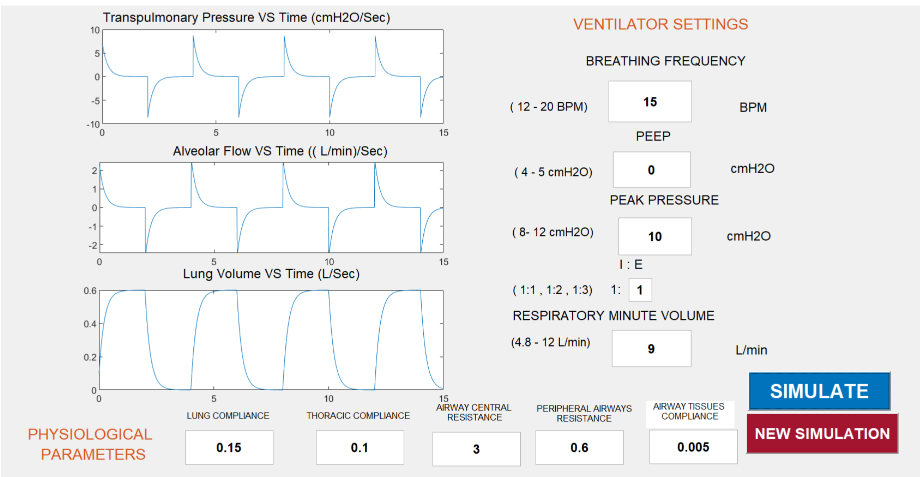

Figure 10: Ventilator settings GUI - Bronchitis

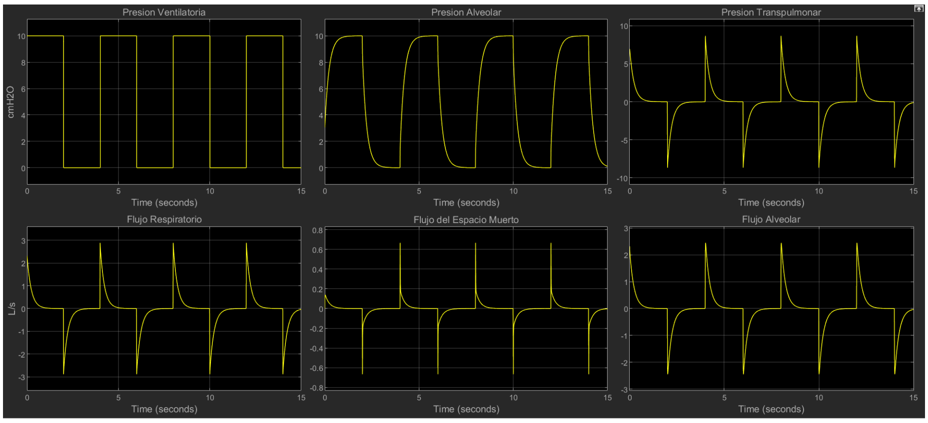

Figure 11: Output of Flow and Pressure Monitor - Bronchitis

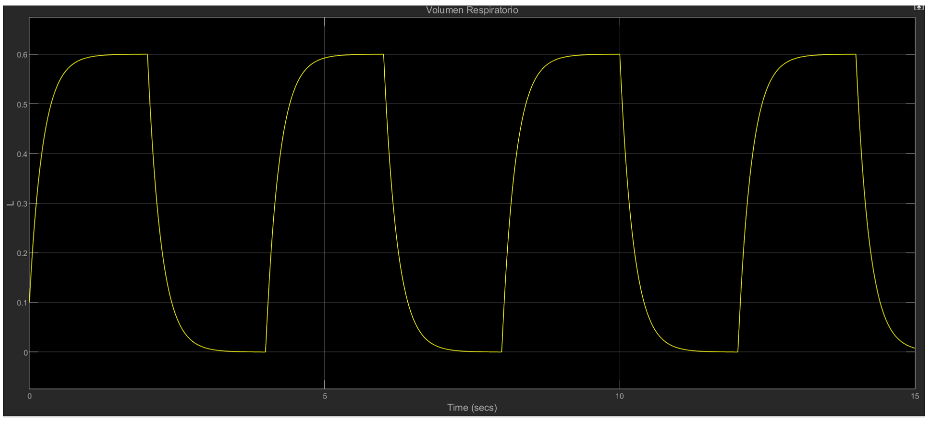

Figure 12: Output of Lung Volume Monitor - Bronchitis

4.1.2 Adjusting Ventilator Setting to Accomodate Breathing for a bronchitis patient

- Breathing Frequency (Respiratory Rate): 20 breaths per minute

  A higher respiratory rate may be considered to help compensate for increased airway resistance and to enhance the removal of carbon dioxide. Respiratory rate of **20 breaths per minute.**

- PEEP (Positive End-Expiratory Pressure): 6 cmH2O

  PEEP can be used to prevent airway collapse, but the optimal level may vary. It is often titrated based on the individual's response. PEEP value of **6 cmH2O**, adjusted as needed.

- Peak Pressure: 15cmH2O

  While it's essential to ensure adequate tidal volume delivery, high peak pressures may increase the risk of barotrauma, which is a concern in bronchitis. Example: Peak pressure should be set to achieve adequate tidal volume while avoiding excessive pressure, typically about **15cmH2O.**

- I:E Ratio (Inspiratory to Expiratory Ratio): 1:2

  Adjusting the I:E ratio can impact gas trapping and airway clearance. A longer expiratory phase may help in bronchitis. I:E ratio of**1:2** to allow for a prolonged expiration.

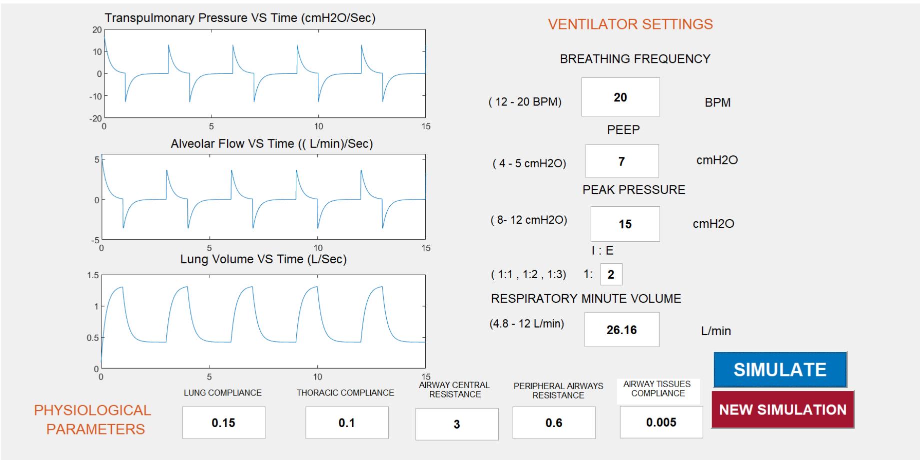

Figure 13: Results after adjusting ventilator settings to accomodate breathing for bronchitis patient

5 Differences in minute ventilation for the same setting of the ventilator

Minute ventilation (MV) is a pivotal respiratory parameter representing the total volume of air exchanged by the lungs in one minute.

5.1 Minute Ventilation

$$\text{Minute Ventilation} = \text{Tidal Volume (TV) X Respiratory Rate(RR)}$$

MV reflects the efficiency of the respiratory system in gas exchange. In clinical and mechanical ventilation settings, understanding and adjusting minute ventilation are crucial for assessing and optimizing respiratory function. Minute ventilation is impacted by factors such as lung compliance, airway resistance, and specific respiratory pathologies, making it a key metric in evaluating and managing respiratory health.

5.2 Factors Influencing Minute Ventilation in same Ventilation Settings

- Disease-specific factors:
  - Restrictive Pulmonary Disease:
    Minute Ventilation = 3 L/min In restrictive pulmonary diseases, such as pulmonary fibrosis, lung compliance is reduced, leading to stiffening of the lungs. This restriction makes it challenging for individuals to inhale a normal tidal volume. To compensate, they increase their respiratory rate, resulting in a lower minute ventilation compared to a healthy person. The limited ability to draw in and expel air per breath is a consequence of reduced lung compliance.
  - Obstructive Pulmonary Disease:
    Minute Ventilation = 9 L/min Obstructive diseases like bronchitis are characterized by increased airway resistance, hindering smooth exhalation. To counteract this, individuals often elevate their breathing rate while maintaining or even increasing tidal volume. Consequently, minute ventilation rises as the increased respiratory rate compensates for the airflow limitation, allowing them to expel enough air during exhalation.
- Additional factors influencing minute ventilation:
  - Patient Effort:
    The efficiency of breathing can be influenced by the patient's level of effort and respiratory muscle strength. Those with weakened respiratory muscles, as seen in neuromuscular disorders, may struggle to breathe comfortably. This decreased effort can contribute to a lower minute ventilation.
  - Anatomical Variations:
    Anatomical differences in airway anatomy, such as upper airway blockages or tracheal stenosis, can affect airflow. Increased resistance due to these variations may result in lower minute ventilation, as the respiratory system encounters additional obstacles to the smooth movement of air.
  - Auto PEEP (Intrinsic PEEP):
    Auto PEEP occurs when air is retained in the lungs at the end of expiration. This condition can impact ventilation and increase effective positive end-expiratory pressure (PEEP). While the ventilator settings may remain the same, the actual ventilation may be reduced due to the presence of auto PEEP.

In summary, variations in minute ventilation among individuals with different pulmonary diseases and health conditions are influenced by a combination of patient-specific factors, disease-related factors, patient effort, anatomical variations, and the presence of conditions like auto PEEP. Understanding these factors is crucial for healthcare professionals when managing ventilator settings and providing personalized respiratory care to individuals with diverse respiratory needs.

6 Conclusion

This report delves into the intricacies of respiratory mechanics and minute ventilation, utilizing a simulator developed by Rodriguez Sarmiento and Acevedo Guerrero. The study simulates normal, restrictive pulmonary disease (pulmonary fibrosis), and obstructive pulmonary disease (bronchitis) scenarios to understand deviations in minute ventilation. For a healthy individual, the balanced respiratory mechanics result in a minute ventilation of 7.5 L/min. In contrast, restrictive disease showcases reduced compliance and minute ventilation (3 L/min), while obstructive disease exhibits increased airway resistance and higher minute ventilation (9 L/min). The report underscores the significance of minute ventilation in respiratory health assessment and the need for personalized ventilator settings based on specific pathologies, contributing valuable insights for clinicians managing diverse pulmonary conditions.