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Simulation of Respiratory Mechanics

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BM2102 - Modelling and Analysis of Physiological Systems

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1 Normal Person

1.1 Normal Person Parameters

Values for a normal person under normal conditions.

Lung compliance :	$0.1\,L/cmH_2O_0$
Thoracic compliance :	$0.1\,L/cmH_2O_0$
Airway central resistance :	$3\,cmH_2O/(L/s)$
Peripheral airway resistance :	$0.5\,cmH_2O/(L/s)$
Airway tissue compliance :	$0.005\,L/cmH_2O_0$

1.2 Ventilator Settings

This is the result for the normal person who has connected to a ventilator under.

Breathing frequency :	15 breaths/min
PEEP :	$0\,cmH_2O$
Peak pressure :	$10\,cmH_2O$

***PEEP (Positive End-Expiratory Pressure)**

1.3 Ventiladorcito MATLAB Window

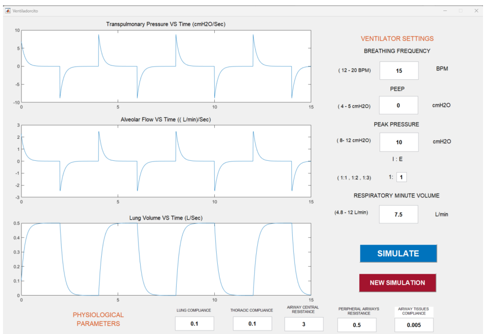

Figure 1: Ventiladorcito MATLAB Stimulation Window for normal person

The following graphs provide further explanations

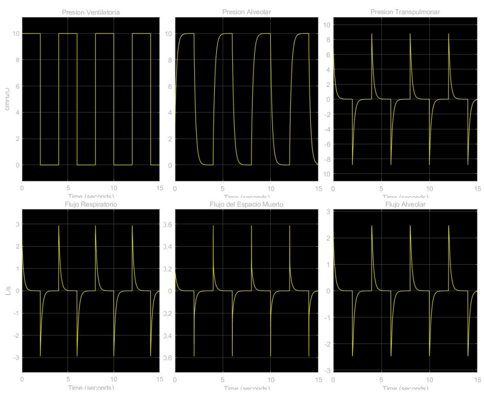

Figure 2: Flow and pressure monitor graphs for normal person

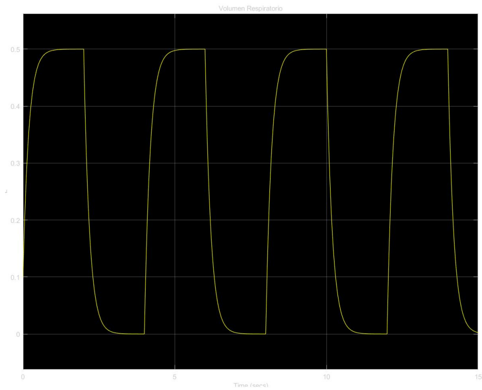

Figure 3: Lung Volume Monitor - Normal Person

2 Restrictive Pulmonary Disease

- **The selected Restrictive Pulmonary Disease :** Idiopathic Pulmonary Fibrosis

Idiopathic Pulmonary Fibrosis (IPF) is a challenging and progressive Restrictive Pulmonary Disease, distinguished by the relentless scarring and fibrosis of lung tissue with an unknown origin. The hallmark physiological parameter affected in IPF is lung compliance, which is consistently reduced due to the stiffening of lung tissue resulting from fibrosis. Unlike obstructive diseases, IPF has a more direct impact on the lung parenchyma, leaving airway resistance generally unaffected. Thoracic compliance in IPF can vary, being either normal or reduced, contingent upon chest wall and pleural space involvement. Central airway resistance and peripheral airway resistance, however, are typically normal in this condition. Notably, airway tissue compliance experiences a reduction due to fibrotic changes, contributing to the overall decline in lung function. Individuals with IPF often experience a progressive and irreversible decline in lung capacity, leading to worsening dyspnea and respiratory function, marking IPF as a severe restrictive pulmonary disease associated with a poor prognosis.

Lung Compliance :	$0.06\ L/cmH_2O$ (Decreased) - Signifies impaired lung expansion.
Thoracic Compliance :	$0.1\ L/cmH_2O$ (Decreased) - Indicates reduced chest wall compliance.
Airway Central Resistance :	$3\ cmH_2O/(L/s)$ (Unaffected) - Central airway resistance remains normal.
Peripheral Airway Resistance :	$0.5\ cmH_2O/(L/s)$ (Unaffected) - Peripheral airways are not significantly impacted.
Airway Tissue Compliance :	$0.001\ L/cmH_2O$ (Unaffected) - Tissue compliance remains within the normal range.

Respiratory Minute Volume: 5.62 cmH_2O

2.1 Ventiladorcito MATLAB Window

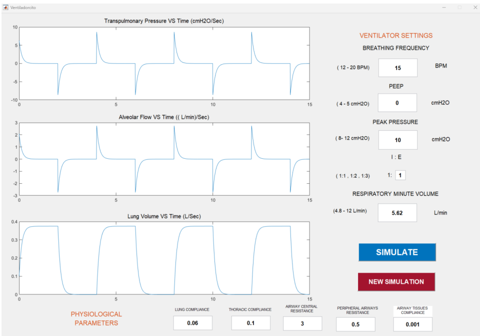

Figure 4: Ventiladorcito MATLAB Stimulation Window for Restrictive Pulmonary Disease

The following graphs provide further explanations

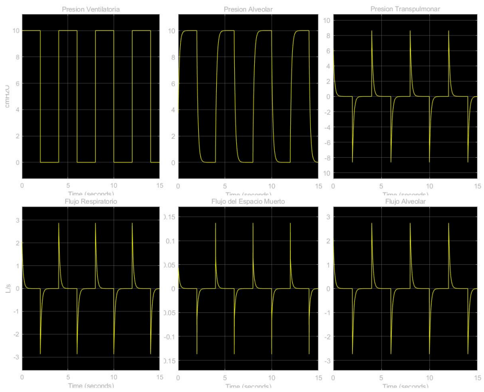

Figure 5: Flow and pressure monitor graphs Restrictive Pulmonary Disease

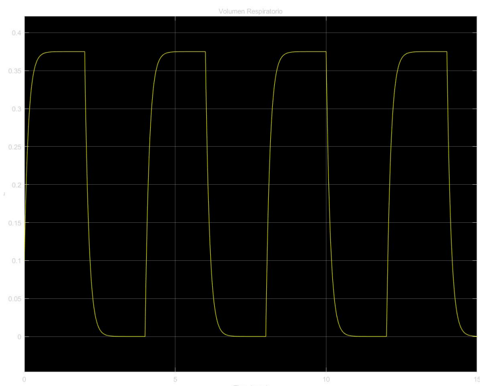

Figure 6: Lung Volume Monitor- Restrictive Pulmonary Disease

3 Obstructive Pulmonary Disease

- **Selected Obstructive Pulmonary Disease:** Chronic Obstructive Pulmonary Disease (COPD)

Obstructive Pulmonary Disease, particularly Chronic Obstructive Pulmonary Disease (COPD), manifests through a constellation of physiological changes in the respiratory system. The condition is characterized by an elevated lung compliance, primarily attributable to lung hyperinflation resulting from the retention of air. This hyperinflation leads to the overstretching of lung tissue, diminishing elastic recoil. While thoracic compliance generally remains unaffected, airway resistance is a central feature in COPD. Increased resistance is observed due to the narrowing of airways caused by inflammation, mucus accumulation, and structural alterations. Exacerbations further exacerbate central airway resistance, and peripheral airway resistance rises due to obstructions in smaller airways. Interestingly, airway tissue compliance in COPD may exhibit normal or increased values. These physiological intricacies collectively contribute to the distinct clinical profile of COPD, marked by symptoms such as dyspnea, chronic cough, and sputum production. In summary, the chosen obstructive pulmonary disease is Chronic Obstructive Pulmonary Disease (COPD).

3.1 Physiology

Lung Compliance :	0.14 L/cmH_2O (Increased) - Suggests facilitated lung expansion.
Thoracic Compliance :	0.1 L/cmH_2O (Increased) - Reflects improved chest wall compliance.
Airway Central Resistance :	3 cmH_2O/(L/s) (Increased) - Elevated resistance in central airways.
Peripheral Airway Resistance :	0.7 cmH_2O/(L/s)(Increased) - Higher resistance in peripheral airways.
Airway Tissue Compliance :	0.005 L/cmH_2O (Decreased)

Respiratory Minute Volume: 13.09 cmH_2O

3.2 Ventiladorcito MATLAB Window

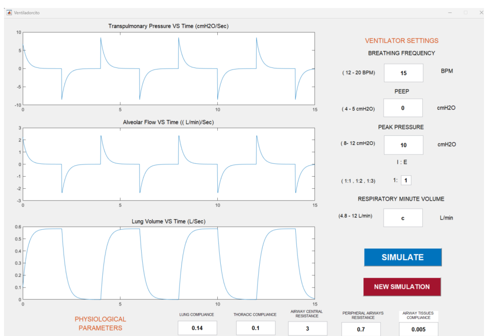

Figure 7: Ventiladorcito MATLAB Stimulation Window for Obstructive Pulmonary Disease

The following graphs provide further explanations

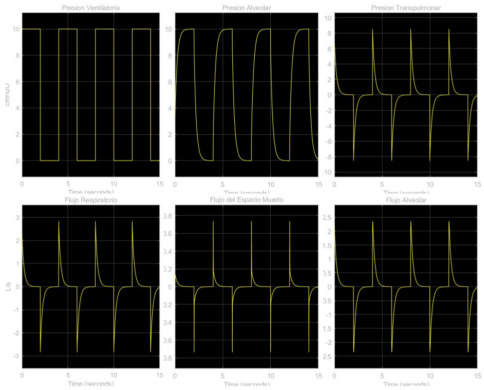

Figure 8: Flow and pressure monitor graphs Obstructive Pulmonary Disease

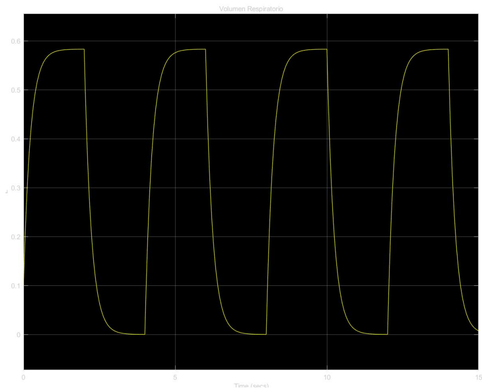

Figure 9: Lung Volume Monitor- Obstructive Pulmonary Disease

4 Differences in Minute Ventilation

Minute ventilation is defined as:

Minute Ventilation = Tidal) Volume (TV) × Respiratory Rate (RR)

Minute ventilation (MV), representing the volume of air entering the lungs per minute, is determined by multiplying the respiratory rate (RR) and tidal volume (VT). Despite consistent ventilator settings, MV can vary due to several factors.

The patient's underlying condition is a critical determinant. Patients with different medical conditions may exhibit distinct respiratory rates and tidal volumes, even under identical ventilator settings. For instance, a patient with pneumonia might have a higher respiratory rate than one with asthma. Additionally, the patient's size contributes to MV variability, with larger patients and larger lung capacities tending to have a higher MV than their smaller counterparts.

MV differences are not only patient-dependent but also influenced by the ventilator itself. Different ventilator models may yield varying MVs, even when set to the same parameters, owing to distinct algorithms for MV calculation. Patient effort further impacts MV, where actively breathing patients naturally have a higher MV than those not actively participating in the breathing process.

Monitoring MV is crucial for ventilated patients to ensure appropriate ventilation. Inadequate MV may lead to insufficient oxygenation, while excessively high MV may put the patient at risk of barotrauma—a lung injury caused by excessive pressure.

Condition	Minute Ventilation (L/min)	Deviation
Normal	5.62	-
Restrictive Pulmonary Disease	7.5	Low
Obstructive Pulmonary Disease	13.09	High

Table 1: Comparison in minute ventilation in three cases.

Illustrating how identical ventilator settings can lead to different MVs, consider these examples: In the case of a patient with pneumonia, a respiratory rate of 20 breaths per minute and a tidal volume of 500 mL result in an MV of 10,000 mL per minute. Conversely, a patient with asthma, under the same ventilator settings, might have a respiratory rate of 15 breaths per minute and a tidal volume of 300 mL, resulting in an MV of 4500 mL per minute. Furthermore, a larger patient with a respiratory rate of 18 breaths per minute and a tidal volume of 600 mL could exhibit an MV of 10,800 mL per minute.

In restrictive lung diseases like pulmonary fibrosis, the lungs' reduced compliance leads to decreased tidal volume, resulting in low minute ventilation. Conversely, obstructive lung diseases such as COPD cause increased airway resistance, leading to elevated minute ventilation despite prolonged expiration and increased respiratory rates.

References

[1] David Leonardo Rodriguez Sarmiento and Daniela Acevedo Guerrero (2020). Simulation of Respiratory Mechanics on Simulink with GUI, MATLAB Central File Exchange. Retrieved May 3, 2020. (`https://www.mathworks.com/matlabcentral/fileexchange/75335-simulation-of-respiratory-mechanics-on-simulink-with-gui`