Prasad Pamu*, Atharva Shinde, Nihar Pandya

Opening Time of Alveolar Layer According To Gaussian Distribution

Abstract: **Introduction**: Opening of collapsed or infected alveoli is termed as recruitment while closing of the alveoli is referred as derecruitment. Recruitment happens when the effective air pressure is more than the critical pressure which is significantly increased during mechanical ventilation. Hickling built a first order model (FOM) to illustrate how airway pressure affects lung capacity of patients having acute respiratory distress syndrome. Later, the Salazar and Knowles equations were used to modify this model. **Methods:** A model was implemented to give a constant flow of inhalation into lungs. Lung was divided into 30 layers, containing 9000 alveoli in each layer which opens at different pressure levels and a pressure vs time graph was observed at each interval. We created a layered dynamic recruitment model which open Alveolar layers to Gaussian distribution instead of opening it with the uniform one**.** **Result:** The simulated model of modified Hickling's model with a controlled volume of flow, simulated results of opening layer percentage according to gaussian distribution. **Discussion:** The relation between volume and alveolar pressure for different PEEP values also simulated model for percentage of layer opened at various time. **Conclusion**: After the implementation of mathematical expressions into Hickling model we were able to identify the opening for each blanket of alveoli.

Keywords: Acute respiratory distress syndrome (ARDS), Recruitment, Gaussian distribution, Hickling Model Headline.

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1 Introduction

Acute respiratory distress syndrome (ARDS) is a fatal condition in which the lungs is unable to provide our body's essential organs with enough oxygen [4]. The common cause of getting ARDS is sepsis, which is also called as septicaemia also blood poisoning, in which tissues of our body overreacts with the infection happened which eventually starts to affect the body's other vital organs and tissues [5].

In ARDS, the infected lung is expected to go through 3 phases which are exudative, proliferative, and fibrotic [4]. So, in order to avoid these problems with infected lung mathematical models was created. In our project, we tried to implement Hickling's Model that was able restore lung's pressure volume correlation with ARDS lung [2]. Lungs in our body are used to perform a process of gas exchange called as respiration in which the oxygen from the incoming air inhaled from the surrounding enter the blood cells and carbon dioxide which is a waste gas leaves the blood. So, when the lung is unable to do this basic function of giving fresh oxygen to the body and take out this waste gas out from the blood this condition is fatal and requires external assistance Lungs are made up of smaller units called lobes [6]. These lobes are separated from each other by a narrow opening called as Fissures.

The left lung comprises of 2 lobes which are named as superior lobe and inferior lobe whereas the right lung is made up of lobes as of the left one but has one middle lobe in addition [5]. These Lungs comprises of many tiny, elastic air sacs which we call as alveoli.

There are near to 480 million of alveoli in an adult human lung [6]. These alveoli's takes in oxygen with each inhalation of air and get filled up and releases carbon dioxide, this process of gas exchange goes on without any difficulty but sometimes these air sacs get filled with fluid instead of air, this condition give rise to Pulmonary edema [4]. Due to the water that gets filled inside the alveoli makes it difficult for the person to breath normally and also causes poor oxygenation of blood. Similar conditions cause ARDS that is Acute respiratory distress syndrome. Because of the fluid that gets filled in the lungs causes less oxygen flow in the bloodstream which eventually affects the organs which requires oxygen to function [5].

ARDS tends to happen when lungs become critically inflamed due to this condition or any other injury on the lung. Injury or such condition causes the liquid which is around the blood vessels to enter these tiny air sacs of the lungs making it difficult for a person to inhale oxygen and accordingly the oxygen in the blood tends to drop. Positive end-expiratory pressure is the pressure on the alveoli that is more than the atmospheric pressure that exist at the end of the expiration which helps to open the lungs [6].

2 Method

Our project was performed in a stepwise manner; our first task was to implement simple lung model by just changing the constant compliance term to a pressure driven recruitment process by maintaining a controlled flow of inspiration and was implemented in MATLAB with both simple FOM and modified Hickling model were simulated and documented. We have used nonlinear compliance and Volume from Hickling's and Salazar Knowles respectively. Bates suggested the mathematical representation as shown below to find opening time [3].

$$dOpen/dt = Const * (P(t) - P\_critical\ ) \ldots \ldots . \ldots . . (1)$$
$$if\ P(t) > P\_critical$$

The open variable is calculated in equation (1). For each layer, this reveals the correlation between pressure and time. The constant is 0.05 cmH_2 O.

P (effective) is the effective pressure at the lung layer and that is the alveolar pressure minus the superimposed pressure. For a simple FOM model.

$$\dot{P}\_a = \dot{V}/C\_FOM \quad \ldots\ldots (2)$$
$$P\_aw = R\_(FOM\ )\ \dot{V} + \dot{P}\_a \ldots\ldots (3)$$

where, $\dot{P}\_a$ = Derivative of alveolar pressure,$\dot{V}$ = Flow rate (ml/s), $R\_(FOM\ )$ is the bronchial resistance at a certain level $(cmH_2O * s/cm3)$ and P_aw is the airway pressure in (cmH_2O).

$$C\_FOM = \ V/P\_efective \quad \ldots\ldots (4)$$

C_FOM represents the first order model of the compliance, that is the calculated based on Hickling's model. V is the volume inside the lung unit.

3 Results

Our project was performed in a stepwise manner, our first task was to implement simple lung model by just changing the constant compliance term to a pressure driven recruitment process by maintaining a controlled flow of inspiration and was implemented in MATLAB with both simple FOM and modified Hickling model were simulated and documented using equation (2) and equation (3).

We have assumed a flow of 500 l/min, viscosity of air to be 10^{-5} and PEEP value of 5. In figure 1. we observe a non-linear compliance behaviour in combined Hickling model and simple first order model, we can see a slow increase in volume up to a pressure of 15 cmH_2O and after that the pressure and volume show a linear increase in P/V Curve.

The pressure versus time curve shows a non-linear

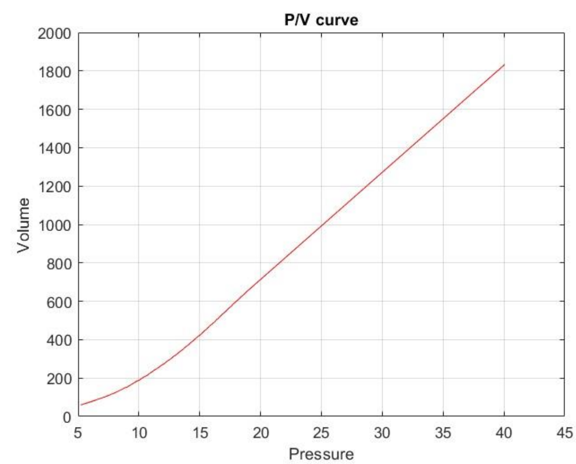

***Figure 1**: Pressure versus Volume curve of combined Hickling's model*

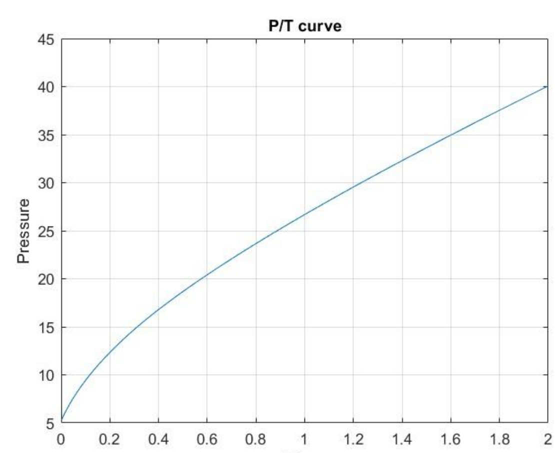

***Figure 2**: Pressure versus time curve of the simulated model.*

behaviour with pressure increases with increase in time as shown in figure 2.

In second the task was to implement a modified Hickling model in a 30-layer model and by using Hickling and Salazar model we got a relation between pressure and

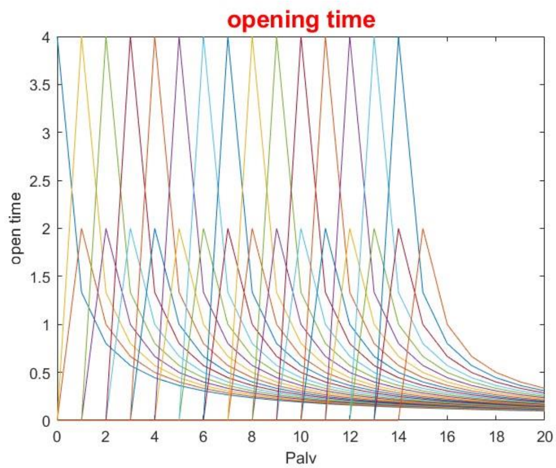

***Figure 3**: Opening time versus alveolar pressure for different layers.*

time for each layer showing the threshold pressure and time needed to open each layer. In figure 3. the layer wise pressure time relation is shown.

For various PEEP values we can see the simulated results in figure 4. shows the alveolar pressure vs volume relation curves for PEEP values ranging from 0 to 25 mbar (0,5,10,15,20,25), we observed that the model is working properly for different values of PEEP.

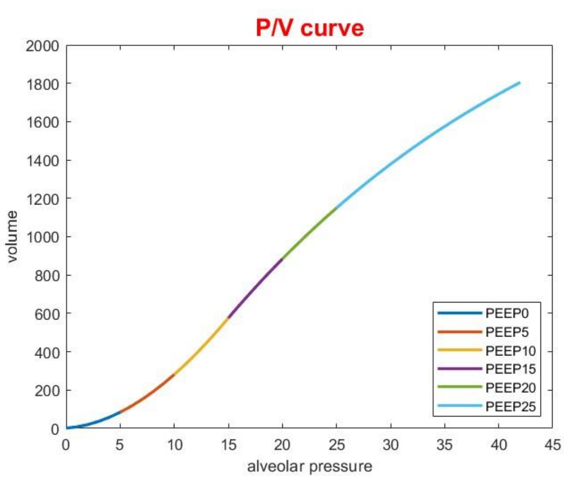

***Figure 4**: Volume versus alveolar pressure for different values of PEEP.*

Third task was to implement Gaussian distribution curve for every layer, Figure 5. shows the percentage of opening of a layer for respective threshold pressure. We can see that only 10% of layer is opened at threshold pressure of

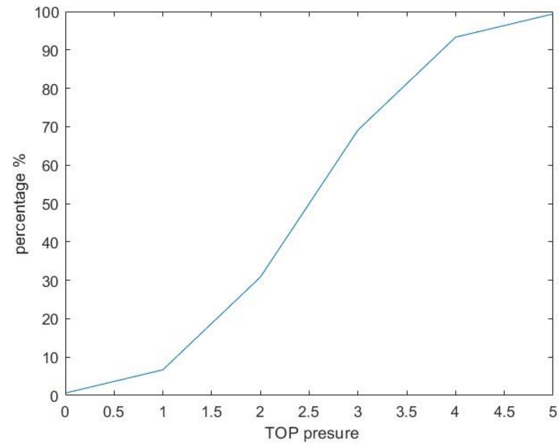

***Figure 5:** The Gaussian probability for a single layer*

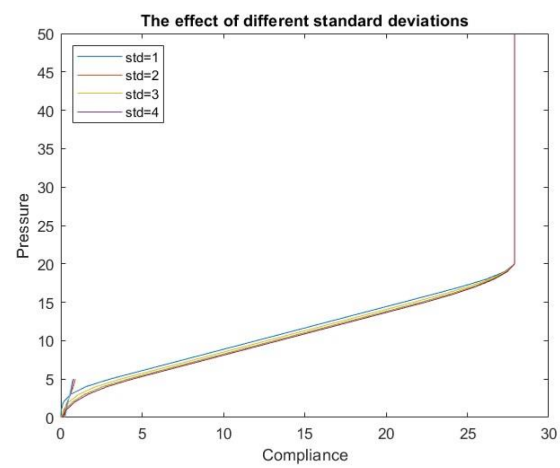

***Figure 3:** Pressure versus compliance for different values of standard deviation*

1 mbar. Similarly in figure 6 we can see that we have set a max pressure of 50mbar and we can see that pressure increases as compliance increases but it may collapse maybe above 50mbar.

4 Discussion

As we can see in the result the opening time for all the 30 layers is much high at low pressures. At maximum pressure the opening time for alveolar is around 0.1 seconds, which is very less.

Figure 4. shows that at different PEEP levels the simulation works as predicted. The PEEP value gives a very good insight in maintaining patients health during ventilation like how much pressure should be maintained to avoid puncture of lungs. The gaussian probability for

single layer as shown in figure 5. shows that the percentage of opening the units shows a nonlinear behaviour and at Threshold opening pressure of 5mbar there's a 100% chance of the alveolar unit to be forced to open.

5 Conclusion

A mathematical model which was developed shows the importance of opening of alveoli based on the Hickling model and its importance for the ARDS patients. In our project, we were successfully able to calculate the opening time by using simple FOM model and then with the Hickling's model. Further we were able to simulate the actual lung with the help of Gaussian distribution. In order to obtain more precise and trustworthy results, further study would still have to be conducted.

Acknowledgment

This paper has been submitted to the course: Physiological Modelling (Summer Semester 2022). The authors confirm that this assignment is their own work, is not copied from any other person's work (published or unpublished) and has not been previously submitted for assessment either, at Furtwangen University (HFU) or elsewhere.

Acknowledgment

Research funding: The authors state no funding involved. Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research related to human use complies with all the relevant national regulations, institutional policies and was performed in accordance with the tenets of the Helsinki Declaration and has been approved by the authors' institutional review board or equivalent committee.

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