Relation of Respiratory System Elastance and Expiratory Time Constant : Are They from the Same Lung?

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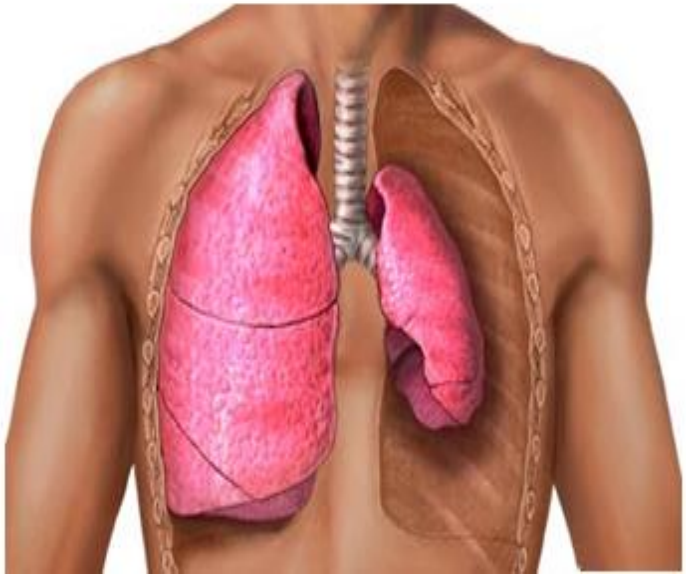
Canterbury District Health Board Te Poari Hauora ō Waitaha

Introduction



Respiratory Failure: Collapsed lung , impaired lung function, poor gas exchange

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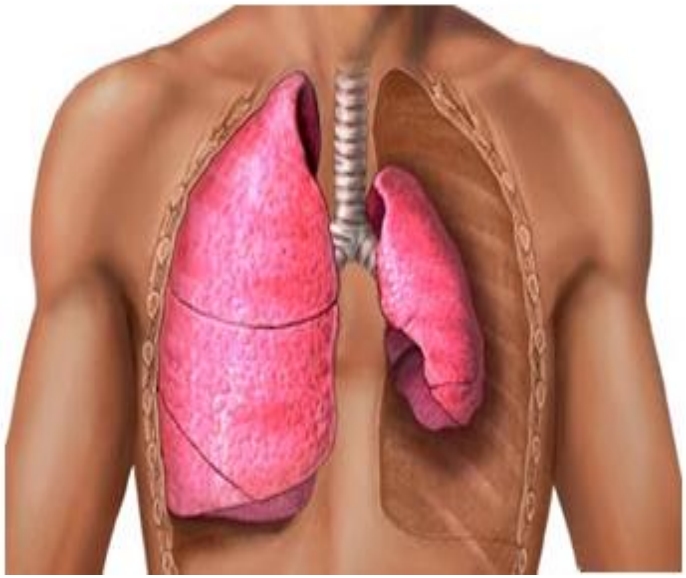

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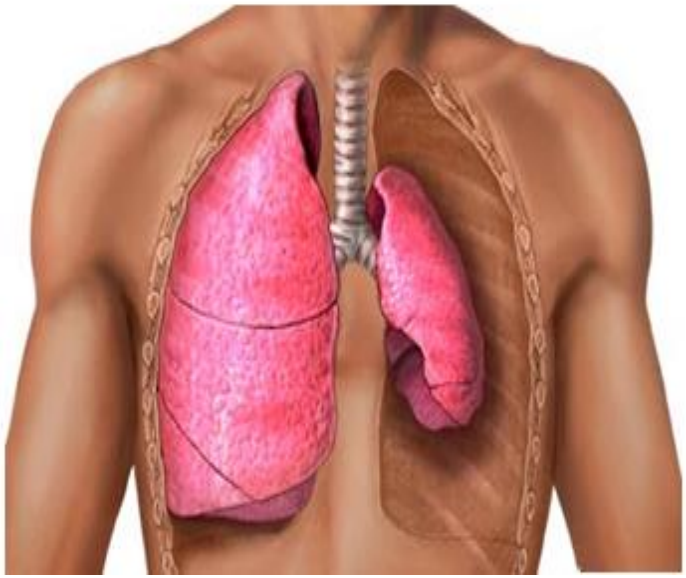

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Mechanical Ventilator (MV) to assist breathing

People are different, and each patient responds differently.
But how do you choose the best MV setting?!?

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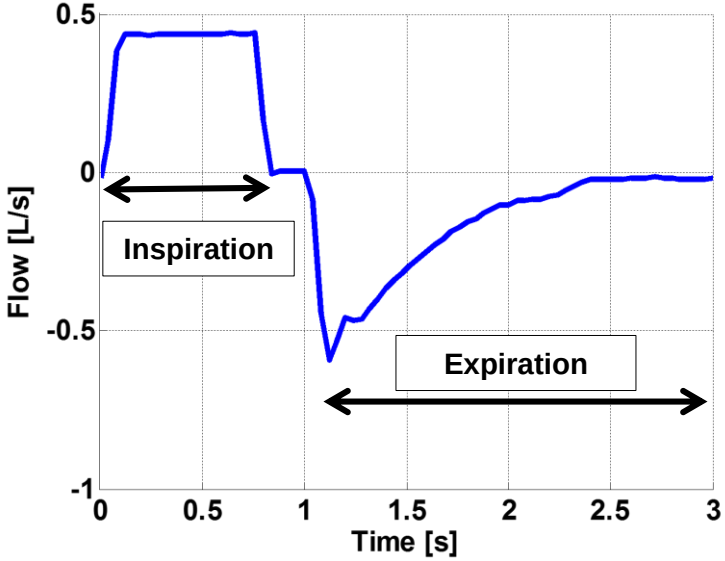
- Most of the developed lung models only focus on inspiration data and neglect the expiration data.



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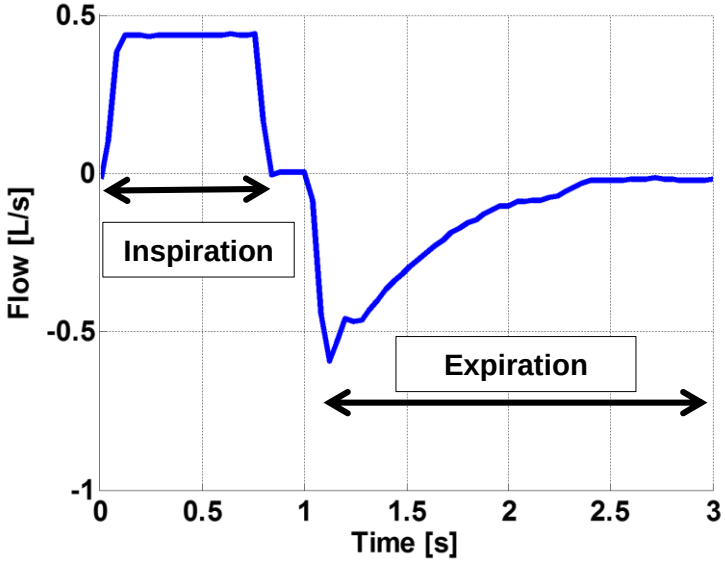

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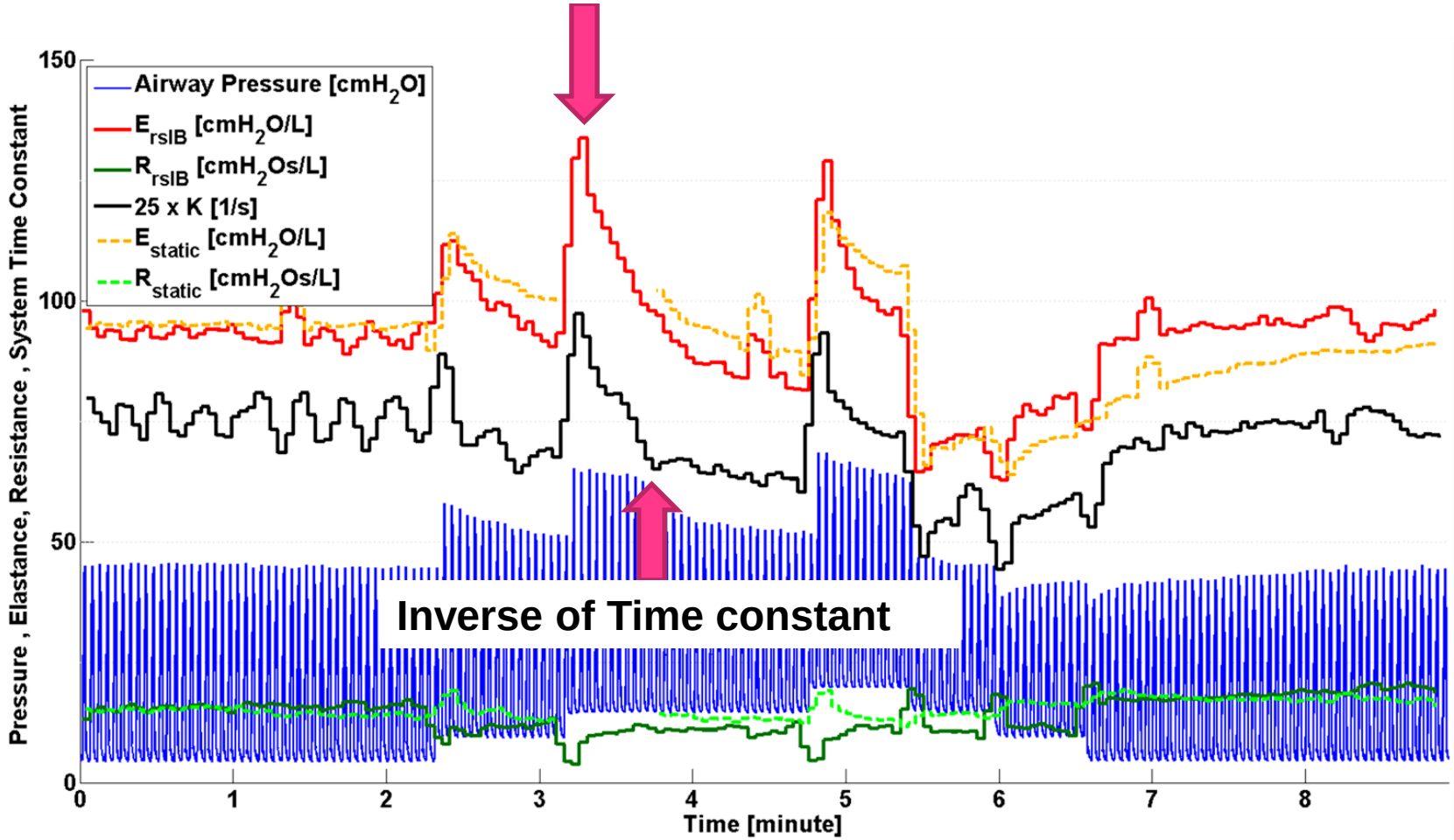
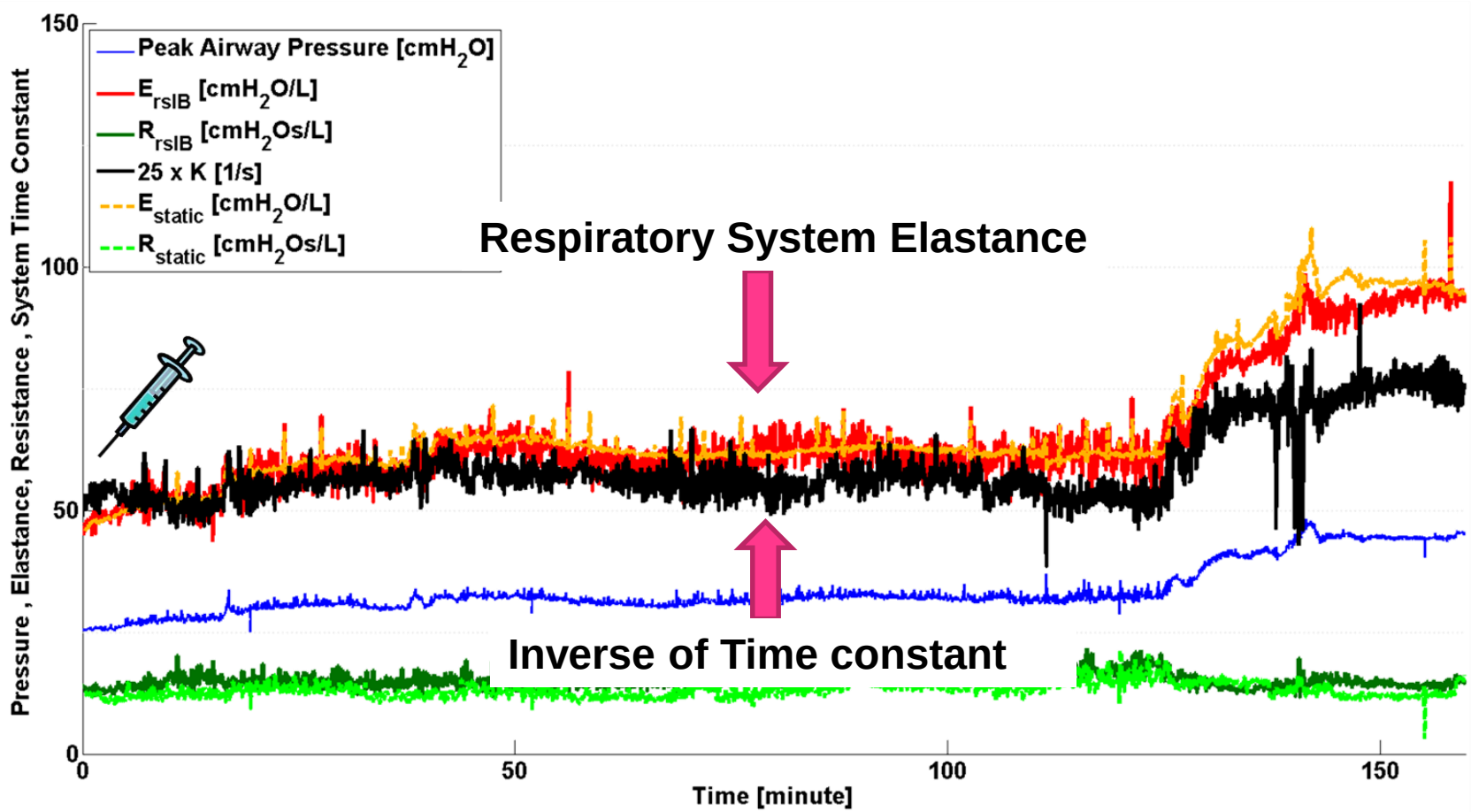
Respiratory System Elastance



Van Drunen et al., 2013 Oleic acid animal study



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- **Thus, the motivation of this research is to extend the investigation on the relation of expiratory time constant with respiratory system elastance by using the retrospective clinical data**.

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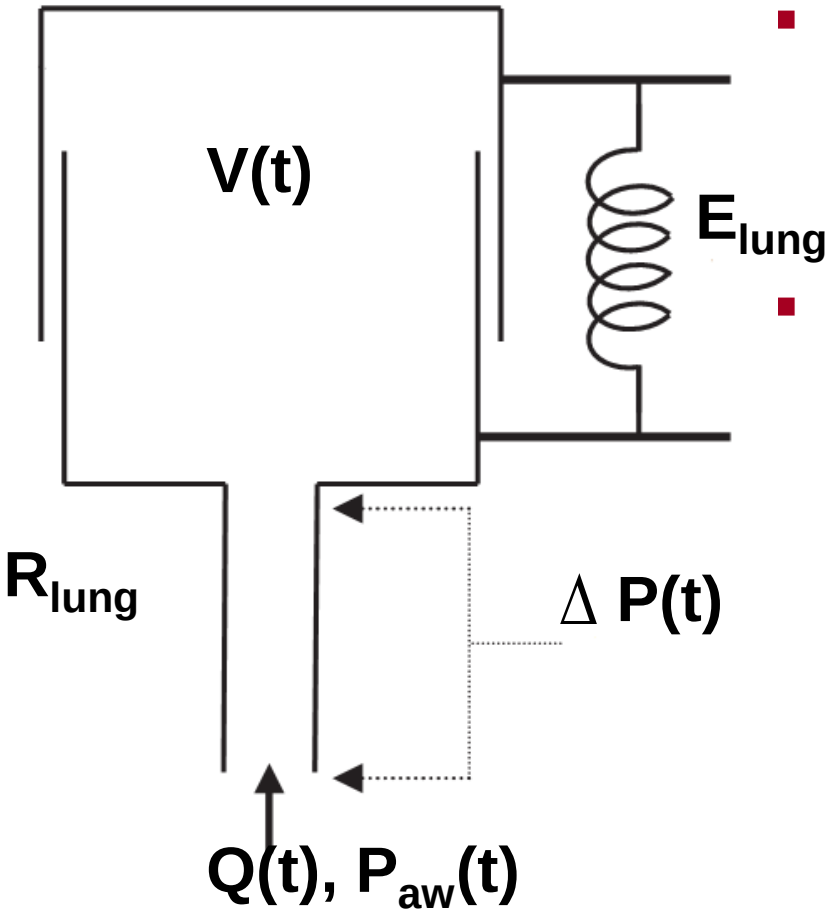
Lung Model and… Lung Model



- **Single compartment linear lung model**
  - *Using inspiratory data*

$$P_{aw}(t) = R_{lung}*Q(t) + E_{lung}*\int Q(t) + P_o \qquad (1)$$

- **Expiratory Model**
  - *Using expiratory data*

$$P_o = R_{lung}*Q(t) + E_{lung}*\int Q(t) + P_o \qquad (2)$$

$$dQ(t)/dt + E_{lung}/R_{lung}*Q(t) = 0 \qquad (3)$$

$$Q(t) = Q_0*e^{(-t/tau)} \qquad (4)$$

$$tau = R_{lung}/ E_{lung} = 1/K \qquad (5)$$

So… $K = E_{lung}/R_{lung}$ *is it?*

J. H. T. Bates, *Lung mechanics an inverse modelling approach* vol. 1. United States of America: Cambridge University Press, 2009.

Patient Data

- Data from 2 retrospectives ARDS cohorts were used:

Cohort 1 – 10 patients ventilated with 5-8 different PEEP levels using a decreasing inspiratory flow profile

Patients are fully sedated and ventilated using Puritan Bennett PB840 with volume control (tidal volume = 6-8 mL/kg)

Cohort 2 – 12 patients ventilated over stepped recruitment maneuver

All patients are fully sedated and ventilated using Puritan Bennett 7200ae ventilators under volume control mode (tidal volume = 8-10 mL/kg) and a square-wave inspiratory flow.

1. A. Sundaresan, J. G. Chase, G. M. Shaw, Y. S. Chiew, and T. Desaive, "Model-based optimal PEEP in mechanically ventilated ARDS patients in the intensive care unit," *Biomed Eng Online,* vol. 10, p. 64, 2011.

2. A. D. Bersten, "Measurement of overinflation by multiple linear regression analysis in patients with acute lung injury," *Eur Respir J,* vol. 12, pp. 526-532, Sep 1998.

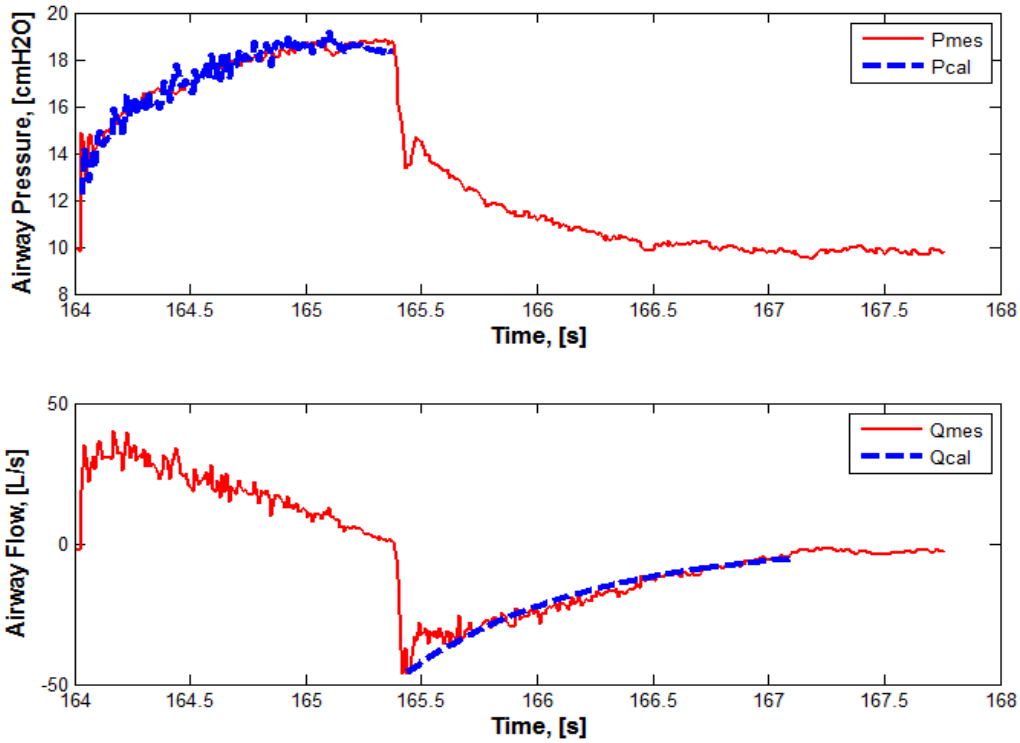
Data Analysis

- Inspiration and expiration in the respiratory system are two different dynamic processes ***that are often assumed to be similar***.

- The trend for the estimated ***K*** values are compared with the inspiration derived values $\boldsymbol{E_{lung}/R_{lung}}$ and $\boldsymbol{E_{lung}}$.

- Performance was assessed by trend correlation coefficient (R^2) where comparisons between the estimated ***K*** for expiration, and both $\boldsymbol{E_{lung}/R_{lung}}$ and $\boldsymbol{E_{lung}}$ for inspiration were made.
  - Good correlation indicates similarity as often assumed
  - Poor correlation indicates the need to treat them separately

Results and Discussion



- The calculated airway pressure using the inspiration lung elastance model results in good fit to measured airway pressure from the ventilator
- Similar fitting is observed using the time expiratory time constant

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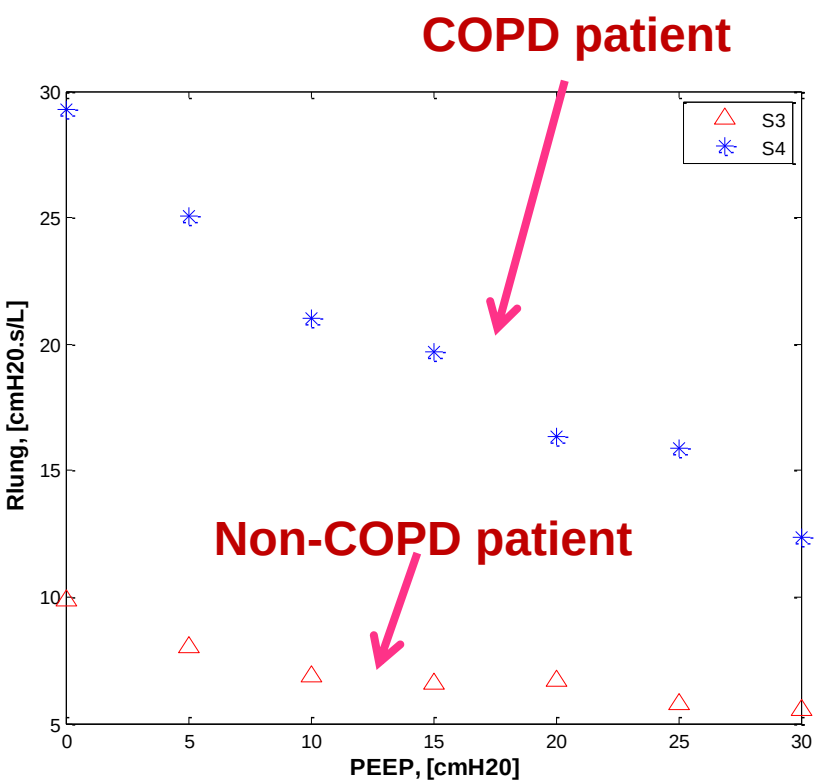

- Cohort 1 includes COPD patients that have higher resistance in the lung compared to other patients.
- Higher lung resistance exists due to the obstructed airways at lower pressures and PEEP in COPD.
- Significant variations in R_{lung} may lead to poor correlation between K and E_{lung} (van Drunen *et. al*)
- **K for Cohort 1 is 1.57 [1.33-1.99] and Cohort 2 is 1.20 [1.13-1.34]**

1. van Drunen, E. J., Chiew, Y. S., Chase, J. G., Shaw, G. M., Lambermont, B., et al. (2013). Expiratory model-based method to monitor ARDS disease state. *Biomed Eng Online,* 12**,** 57.

2. Lourens, M. S., Van Den Berg, B., Aerts, J. G., Verbraak, A. F., Hoogsteden, H. C., et al. (2000). Expiratory time constants in mechanically ventilated patients with and without COPD. *Intensive Care Med,* 26**,** 11**,** 1612-8.

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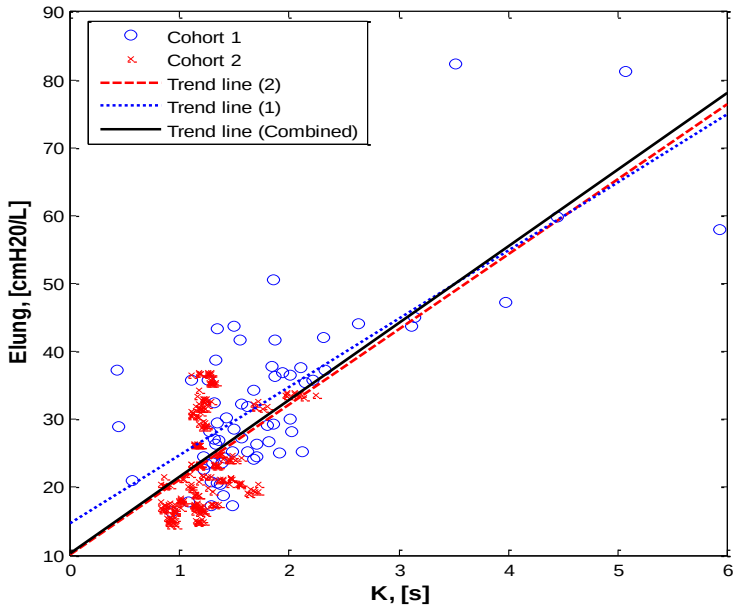

***K* vs *E*$_{lung}$ for both data sets with**

R^2 = 0.568 for Cohort 1
R^2 = 0.184 for Cohort 2
R^2 = 0.435 for both Cohorts

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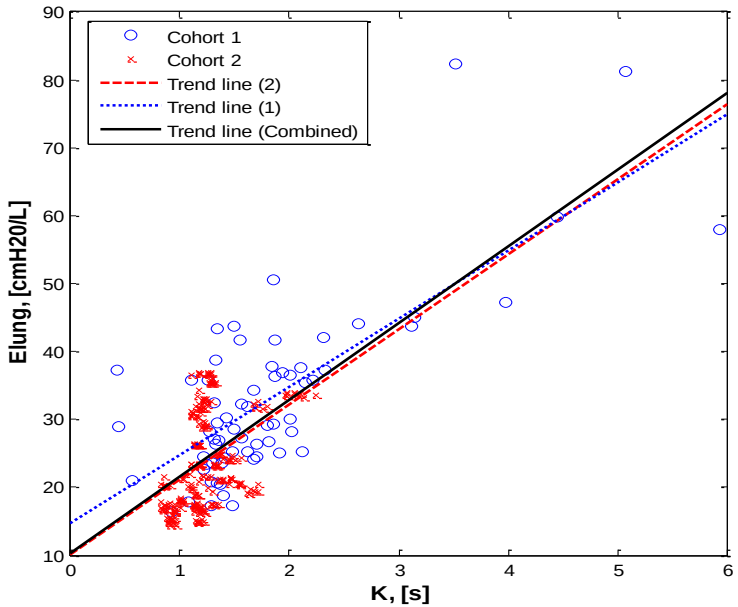

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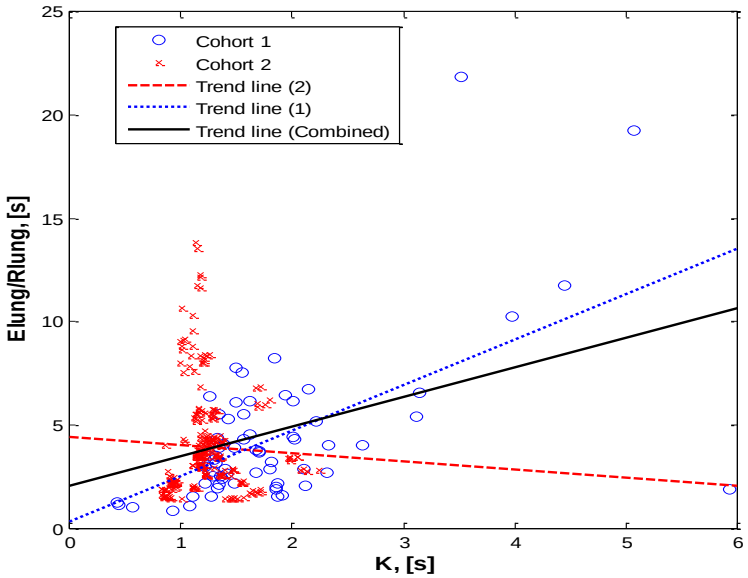

K **vs** E_{lung}/R_{lung}

R^2 **= 0.340 for Cohort 1**
R^2 **= 0.002 for Cohort 2**
R^2 **= 0.078 for both Cohorts**

This lack of correlation may be a subject-specific response due to the increasing severity of ARDS collapsing airways within the lungs, thereby increasing the resistance of the conducting airways (R_{lung}) .

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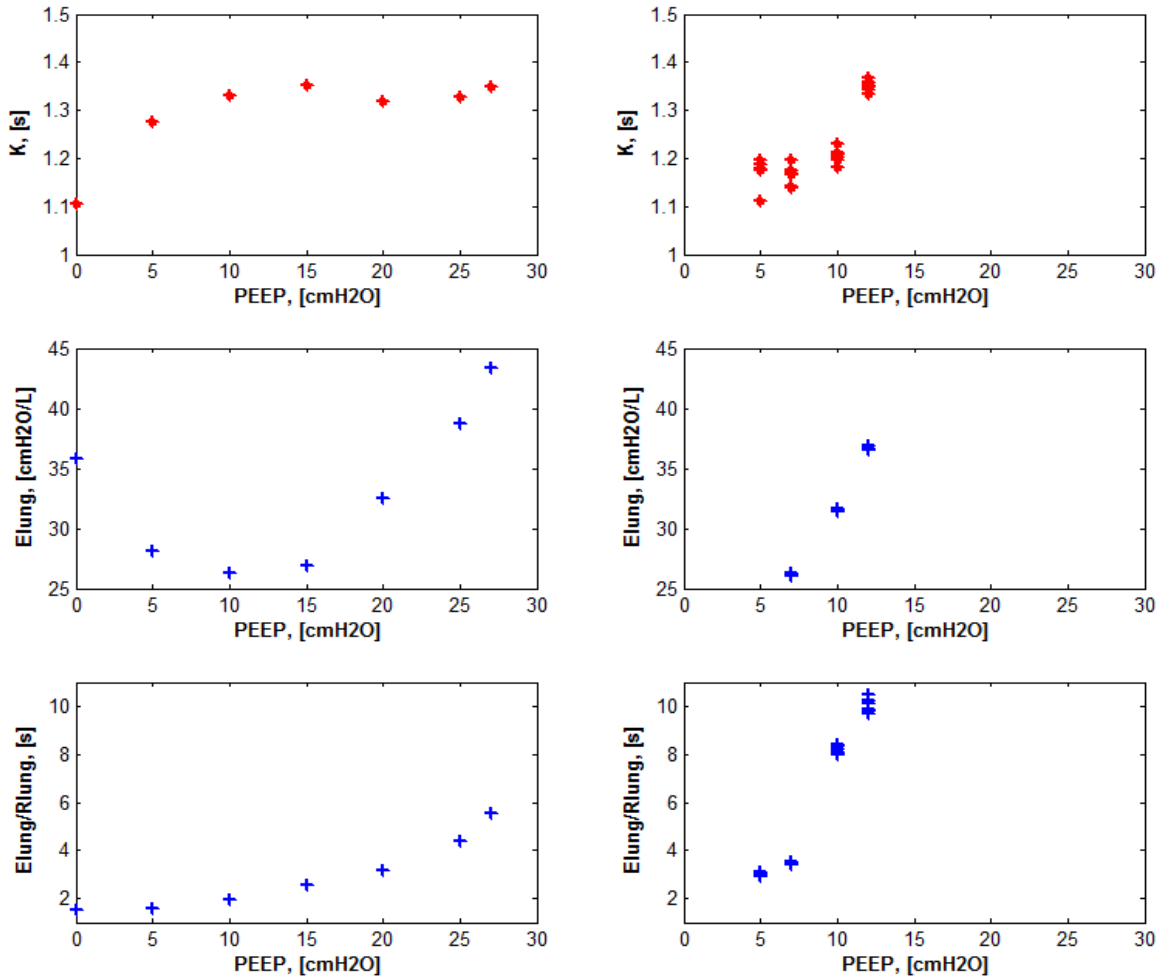

K derived from Expiration using expiratory model

E_{lung} derived from Inspiration using single compartment model

E_{lung}/R_{lung} derived from Inspiration using single compartment model

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- This result indicates that, although *K* is defined as E_{lung}/R_{lung} from inspiration for expiration, it does not deliver the same result as those same values in inspiration
- Each expiration and inspiration should be considered separately when determining lung mechanics properties

Conclusion and Future Work

- In this study, it shows that variations in lung resistance may lead to a lower correlation between $\boldsymbol{K}$ and $\boldsymbol{E_{lung}}$.
- However, there is a relation exists between the time constant, $\boldsymbol{K}$ and $\boldsymbol{R_{lung}}$ especially for COPD patients.
- $\boldsymbol{K}$ has a potential in tracking the changes in disease state for MV patients in real-time but warrants further investigation.
  - $\boldsymbol{K}$ can be extended to determine real-time lung parameters using expiration data especially for spontaneously breathing (SB) patients

Acknowledgement

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QUESTIONS?