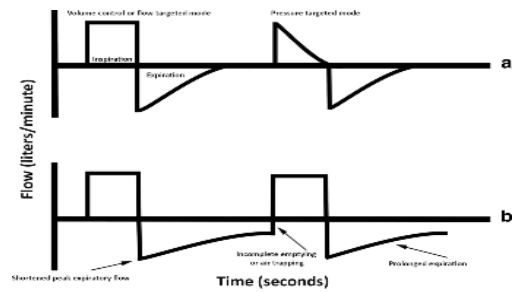
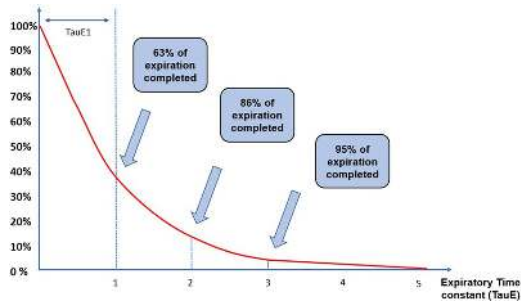


# The Role of Time Constants in Ventilation

Patrick McDonagh MS.RRT-NPS, ACCS, C-NPT



## Disclosures

No Disclosures to Report

## Objectives

## 1. The Role of the Expiratory Time Constant with Lung Mechanics

Airway Resistance and Lung Compliance

## 2. Utilizing the $RC_{exp}$ to Optimize Exhalation

Limiting Autopeep

What is a Time Constant?

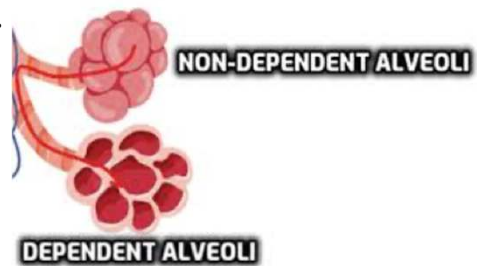
- Time Constant equals the length of time in seconds required for lung units to inflate and deflate to a certain % of their total volume based on Compliance and Resistance.

- Compliance equals Volume  
Mean Airway Pressure Matters

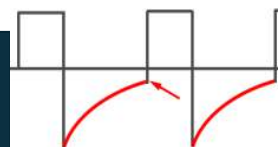
Inspiratory time

Exhalation time

Tidal volume and Rate



***Focusing on the Expiratory Time Constant to Minimize Autopeep***



## Total Respiratory Cycle Time

BEGINS AT  
START OF

INSPIRATION.

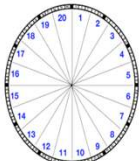
STOPS AT START OF  
NEXT INSPIRATION

EXPIRATION

CONTAINS  
ALL OF BOTH

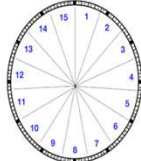
60 SECONDS DIVIDED BY RESPIRATORY RATE

RR 20



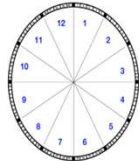
$$60/20=3\text{sec}$$

RR 15

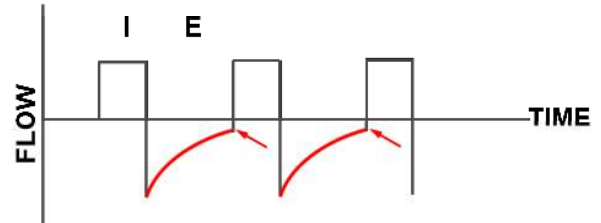
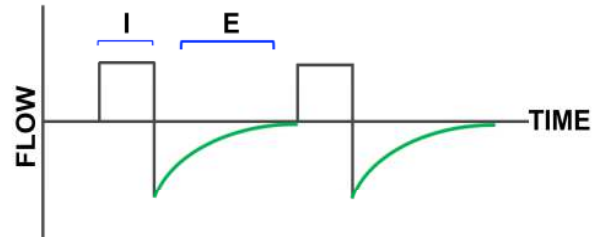


$$60/15=4\text{sec}$$

RR 12



$$60/12=5\text{sec}$$



## Some Common Scenarios

### ABG Shows a Respiratory Acidosis?

1. Increase RR and Decrease the  $T_i$  to manage the I:E Ratio
2. Increase the  $V_T$  and Lower the **RR** to manage Autopeep

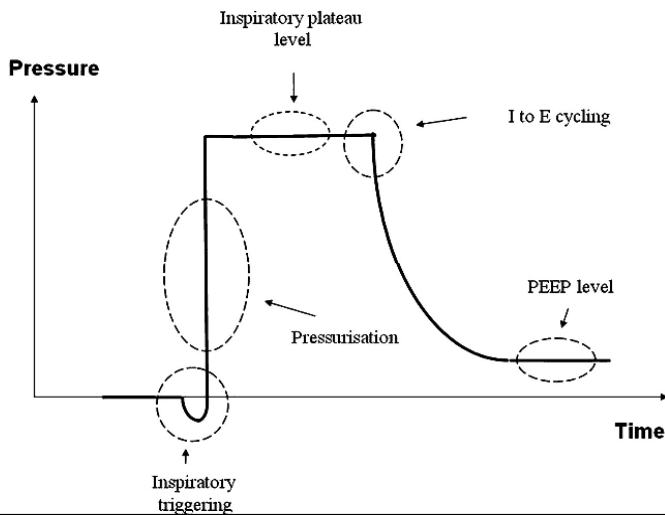
### Utilizing the $R_{Cexp}$ to know the minimum $T_e$ and limit Autopeep

- Allow us to increase the  $V_T$  or RR and not lower the inspiratory time
- The inspiratory time is important for oxygenation

## Inspiratory Time: Inflation Time for Oxygenation

**Ti Short**  
High Flow & PIPS  
Less Recruitment

**Ti Long**  
Lower Flow & PIPS  
More Recruitment



## Pendelluft Phenomenon: The Asynchronous Filling and Emptying of the Alveoli

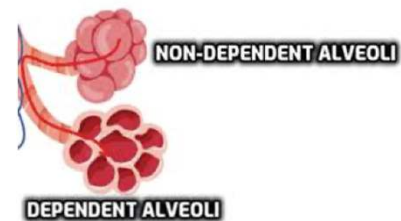
Editorial > *Respir Care*. 2021 Jan;66(1):1-10. doi: 10.4187/respcare.07880. Epub 2020 Sep 8.

### Effects of Ventilatory Settings on Pendelluft Phenomenon During Mechanical Ventilation

Yusuke Enokidani <sup>1</sup>, Akinori Uchiyama <sup>2</sup>, Takeshi Yoshida <sup>1</sup>, Ryuichiro Abe <sup>1</sup>, Tomonori Yamashita <sup>3</sup>, Yukiko Koyama <sup>1</sup>, Yuji Fujino <sup>1</sup>

Affiliations + expand

PMID: 32900913 DOI: 10.4187/respcare.07880



**Pendelluft phenomenon is defined as the displacement of gas from a more recruited nondependent (ND) lung region to a less recruited dependent (D) lung region. This phenomenon may cause lung injury.**

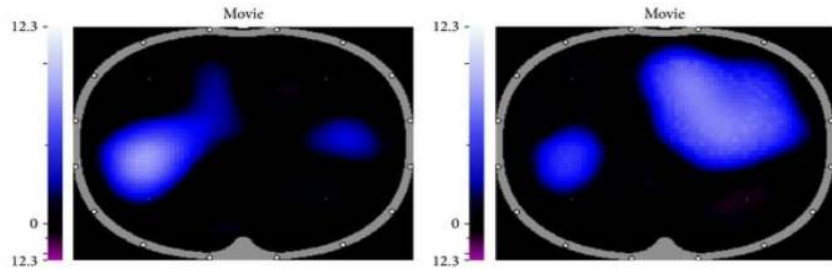
Pendelluft Phenomenon: The Asynchronous Filling and Emptying of the Alveoli

The movement of flow between two regions of the lung affected by airway resistance and alveolar compliance.

**Expiratory Time Constant**

Informs us of 2 Things

- 1- Airway Resistance
- 2- Lung Compliance

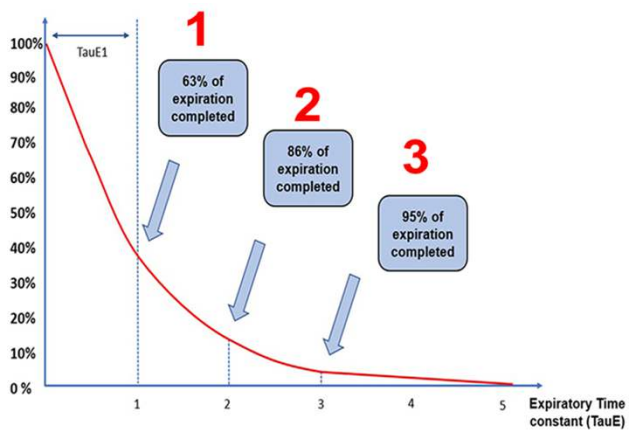


Pendelluft. It refers to asynchronous emptying of lungs. When the right lung is in the inspiration phase, the left lung starts to empty, and vice versa.

Rapid inflation-deflation is injurious in both passive and active patients that may cause local overstretching of the lungs.

Why Trend the RCexp? Respiratory Equation of Motion

**$P_{mus} + P_{vent} = Resistance \times Flow + Elastance \times Volume$**   
**Breath Delivery = Airway Resistance + Lung Compliance**



RC<sub>exp</sub>: Expiratory Time Constant

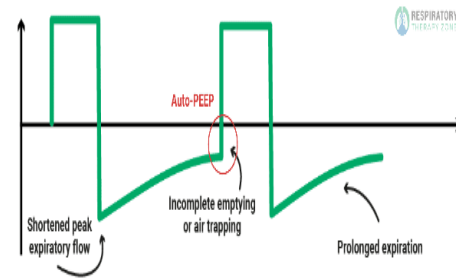
- **Normal Range**
- < 0.5 sec = Decreased Compliance
- > 0.7 sec = High R<sub>insp</sub> and/or Compliance

- **Pseudo Normal**
  - High R<sub>insp</sub> and low C<sub>stat</sub>

**R<sub>insp</sub> cmH<sub>2</sub>O/L/sec x C<sub>stat</sub> ml/cmH<sub>2</sub>O**

**R<sub>insp</sub> cmH<sub>2</sub>O/L/sec x C<sub>stat</sub> L/cmH<sub>2</sub>O**

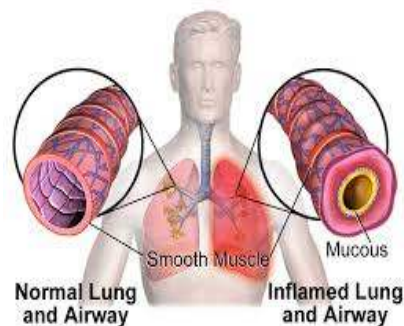
**RC<sub>exp</sub> x Desired Time Constant = *Minimum Exhalation Time***



## Delivering Flow and Managing the Ventilator

**Normal Airway Resistance**  
**Normal Alveolar Compliance**  
 All the Alveoli will fill and empty equally  
**Normal RC<sub>exp</sub>**  
**Management?**

**Normal Airway Resistance**  
**Low Alveolar Compliance**  
 Alveoli Fill incompletely or be overstretched  
**Low RC<sub>exp</sub>**  
**Management?**



**High Airway Resistance**  
**Normal Alveolar Compliance**  
 All the Alveoli will fill and empty Slowly  
**High RC<sub>exp</sub>**  
**Management?**

**High Airway Resistance**  
**Low Alveolar Compliance**  
 Alveoli Fill slowly and incompletely  
**Pseudo Normal RC<sub>exp</sub>**  
**Management?**

# RCexp: A Closer Look to Balancing each Breath

[Indian J Crit Care Med](#). 2021 Jan; 25(1): 10–11.  
doi: [10.5005/jp-journals-10071-23700](#)

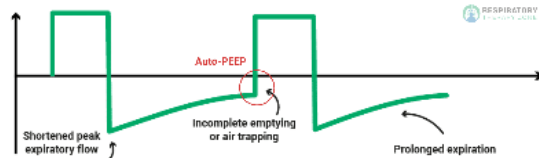
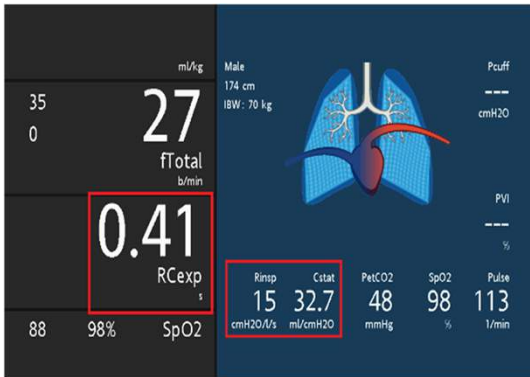
PMCID: PMC7874283  
PMID: [33603294](#)

## Respiratory Mechanics: To Balance the Mechanical Breaths!!

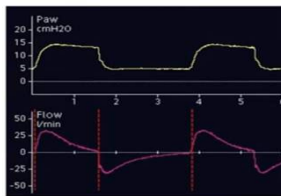
Manu Sundaram<sup>1</sup> and Manjush Karthika<sup>2</sup>

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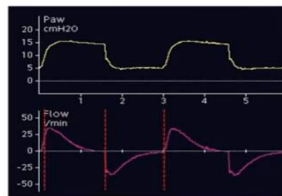
The compliance and resistance of Alveolar units are not always equal throughout the lung, and therefore by definition there will be different TCs for different lung zones.  
Inadequate expiratory time may result in gas trapping, hyperinflation, decreased compliance, and impaired hemodynamics.



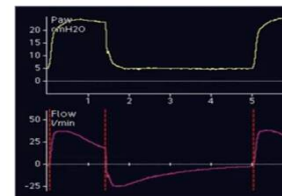
## Minimum Te: Can We Just Guess It and Always Meet It?



**Normal**  
Normal Cstat and Rinsp or combination of decreased Cstat and increased Rexp  
Cstat = 60 ml/cmH2O



**Restrictive disease**  
Decreased Cstat: ARDS, atelectasis, chest wall stiffness  
Cstat = 22 ml/cmH2O



**Obstructive disease**  
Increased Rexp: COPD, asthma, or bronchospasm, ETT obstruction or incorrect positioning  
Cstat = 70 ml/cmH2O

Time Constant of 1 = 0.1 sec inhale/exhale 63% of Lung Volume

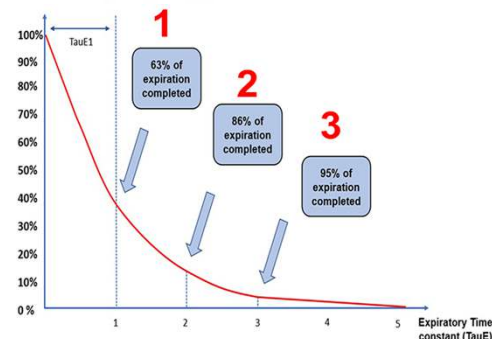
Time Constant of 2 = 0.2 sec inhale/exhale 86% of Lung Volume

**Time Constant of 3 = 0.3 sec inhale/exhale 95% of Lung Volume**

Time Constant of 4 = 0.4 sec inhale/exhale 98% of Lung Volume

Time Constant of 5 = 0.5 sec inhale/exhale 100% of Lung Volume

**Can we always meet the required Time Constant?**



Minimum 2 and Maximum 5 Time Constants

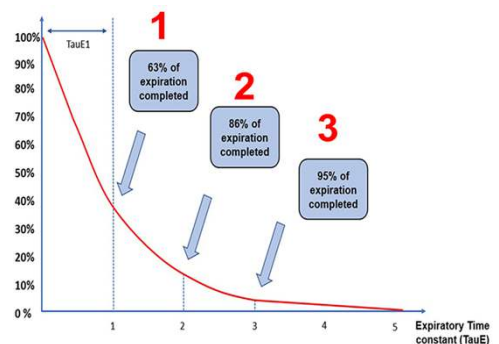
	Normal	Restrictive	Obstructive
<b>Compliance ml/cmH20</b>	65.3	29.4	93.2
<b>Resistance cmH20/L/sec</b>	10	12	20
<b>RCexp (Sec)</b>	0.65	0.35	1.86
<b>Minimum Te</b>	1.3 – 3.25	0.7 – 1.75	3.72 – 9.3

What is the RCexp and minimum exhalation time?

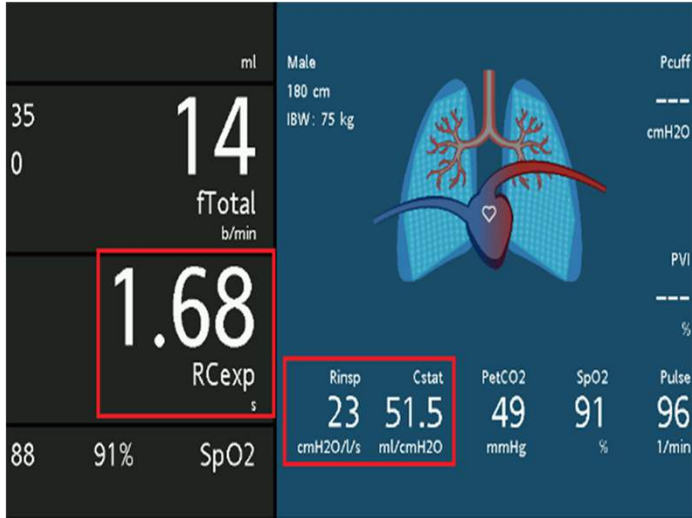


**RCexp: 0.41**  
**Min etime:**  
 $0.41 \times 2 = 0.82$   
 $0.41 \times 3 = 1.23$   
 $0.41 \times 4 = 1.64$   
 $0.41 \times 5 = 2.05$

**RR Set 20**  
**TCT = 3 sec:**  
 $Ti(3 - 0.82) = 2.18$   
 $Ti(3 - 1.23) = 1.77$   
 $Ti(3 - 1.64) = 1.36$   
 $Ti(3 - 2.05) = 0.95$

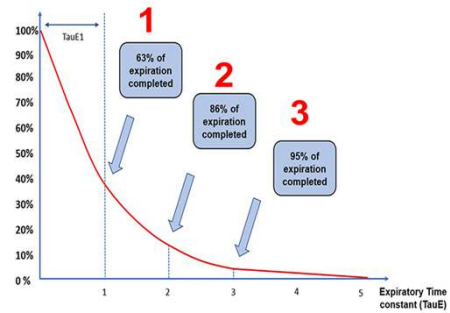


What is the RCexp and minimum exhalation time?



**RCexp: 1.68**  
**Min etime:**  
 $1.68 \times 2 = 3.36$   
 $1.68 \times 3 = 5.04$   
 $1.68 \times 4 = 6.72$   
 $1.68 \times 5 = 8.4$

**RR Set 10**  
**TCT = 6 sec:**  
 $Ti(6 - 3.36) = 2.64$   
 $Ti(6 - 5.04) = 0.96$   
 $Ti(6 - 6.72) = XXX$   
 $Ti(6 - 8.40) = XXX$

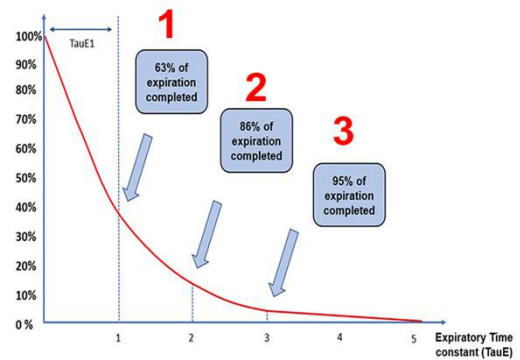


What is the RCexp and minimum exhalation time?



**RCexp: 0.60**  
**Min etime:**  
 $0.60 \times 2 = 1.2$   
 $0.60 \times 3 = 1.8$   
 $0.60 \times 4 = 2.4$   
 $0.60 \times 5 = 3$

**RR Set 20**  
**TCT = 3 sec:**  
 $Ti(3 - 1.2) = 1.8$   
 $Ti(3 - 1.8) = 1.2$   
 $Ti(3 - 2.4) = 0.6$   
 $Ti(3 - 3.0) = XXX$

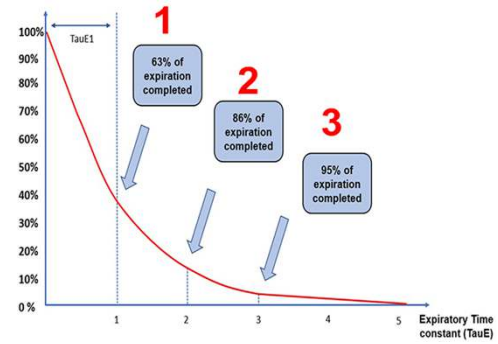


What is the RCexp and minimum exhalation time?



**RCexp: 0.19**  
**Min etime:**  
 $0.19 \times 2 = 0.38$   
 $0.19 \times 3 = 0.57$   
 $0.19 \times 4 = 0.76$   
 $0.19 \times 5 = 0.95$

**RR Set 20**  
**TCT = 3 sec:**  
 $Ti(3 - 0.38) = 2.62$   
 $Ti(3 - 0.57) = 2.43$   
 $Ti(3 - 0.76) = 2.24$   
 $Ti(3 - 0.95) = 2.05$

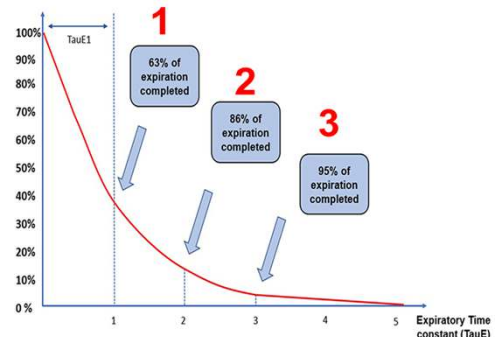


What is the RCexp and minimum exhalation time?

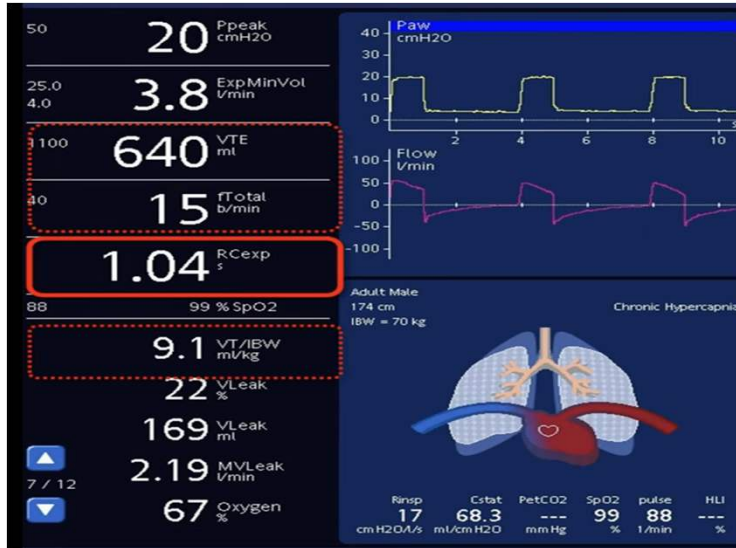


**RCexp: 4.46**  
**Min etime:**  
 $4.46 \times 2 = 8.92$   
 $4.46 \times 3 = 13.38$   
 $4.46 \times 4 = 17.84$   
 $4.46 \times 5 = 22.3$

**RR Set 10**  
**TCT = 6 sec:**  
 $Ti(6 - 8.92) = \text{XXX}$   
 $Ti(6 - 13.38) = \text{XXX}$   
 $Ti(6 - 17.84) = \text{XXX}$   
 $Ti(6 - 22.3) = \text{XXX}$

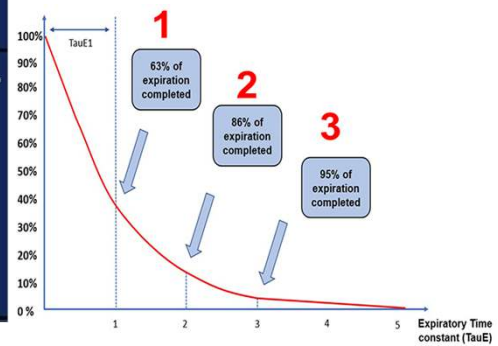


What is the RCexp and minimum exhalation time?

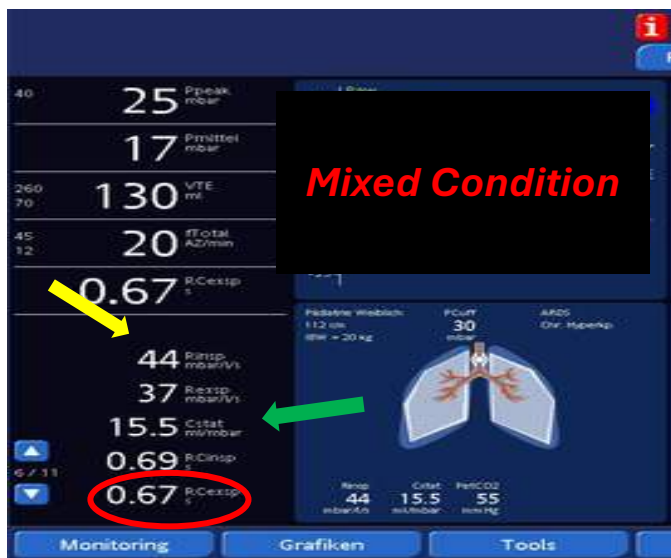


**RCexp: 1.04**  
**Min etime:**  
 $1.04 \times 2 = 2.08$   
 $1.04 \times 3 = 3.12$   
 $1.04 \times 4 = 4.16$   
 $1.04 \times 5 = 5.2$

**RR Set 15**  
**TCT = 4 sec:**  
 $Ti(4 - 2.08) = 1.02$   
 $Ti(4 - 3.12) = 0.88$   
 $Ti(4 - 4.16) = \text{XXX}$   
 $Ti(4 - 5.2) = \text{XXX}$

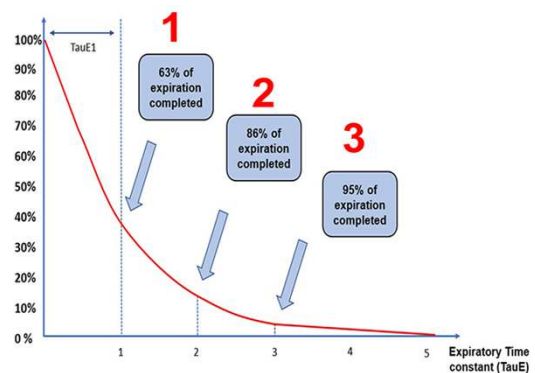


What is the minimum exhalation time for a TC of 3?



**RCexp: 1.04**  
**Min etime:**  
 $0.67 \times 2 = 1.34$   
 $0.67 \times 3 = 2.01$   
 $0.67 \times 4 = 2.68$   
 $0.67 \times 5 = 3.35$

**RR Set 20**  
**TCT = 3 sec:**  
 $Ti(3 - 1.34) = 1.66$   
 $Ti(3 - 2.01) = 0.99$   
 $Ti(3 - 2.68) = 0.32$   
 $Ti(3 - 3.35) = \text{XXX}$



Would the RCexp Be Increased or Decreased?

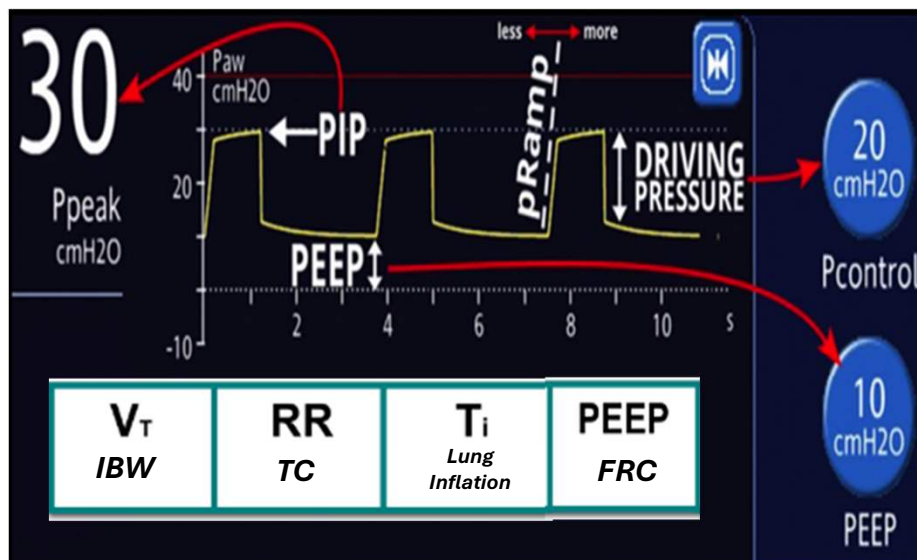
- Secretions or Bronchoconstriction or Kinked ETT?
  - Increased
- Prone with an increased RCexp?
  - Recruitment or Kinked ETT
- Prone with a decreased RCexp?
  - Decruitment
- Sudden desaturation without a change in RCexp?
  - Indicates a drop in cardiac output or a severe pulmonary embolism.

**True or False?**

A Normal RCexp with a high Rinsp and low Cstat is accurate

**False**

Mean Airway Pressure

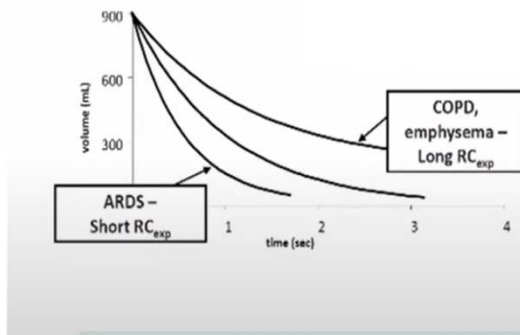


## Summary

$RC_{exp} = \text{Compliance}(\Delta\text{Volume} / \Delta\text{Pressure}) \times \text{resistance}(\Delta\text{Pressure} / \Delta\text{Flow})$

$RC_{exp} = \Delta\text{Volume} / \Delta\text{Flow}$  - assumes equal resistance throughout breath

### Expiratory time constant



### Expiratory time constant ( $RC_{exp}$ )

**$RC_{exp} \times \text{Desired Time Constant} = \text{Minimum Exhalation Time}$**

#### Optimizing $T_E$

