The Time Constant of The Respiratory System

by Enrico Bulleri

Today's post aims to facilitate the understanding of a difficult but fascinating concept of mechanical ventilation: the time constant. In the previous post we introduced the PCV or pressure controlled ventilation aimed at applying a constant positive pressure. Hence the inspiration for an insight that we believe will certainly be useful from a theoretical point of view, but which presents "practical" aspects of utmost importance.

What is the time constant?

To answer, let's start from a chapter from the book "Measures of respiratory mechanics during artificial ventilation" by two well-known and famous Italian doctors (Iotti G. and Braschi A.) and Dr. Natalini's post published on Ventilab.org. We recommend reading both bibliographic sources for the important insights and reflection ideas they offer.

Before defining the time constant, it is necessary to understand the effect of a *square* wave pressure applied to the respiratory system, that is, the effect of a pressure that instantly changes and then keeps constant at the new level for a given time (as in pressure controlled ventilation modalities, see post on 03/07/17). A square wave corresponding to a pressure variation (ΔP) generates a volume variation (ΔVol). Each given value of ΔP can generate a certain maximum volume variation (ΔVol, max), which is the function of total respiratory system compliance (Crs), according to the equation:

ΔVol, max = ΔP • Crs

For example, a patient with a Crs of 100 ml / cmH2O ventilated in PCV and whose set pressure above PEEP is 10 cmH2O (hence a ΔP of 10 cmH2O). In other words it can be said that the volume of the respiratory system increases by 100 ml for each cmH2O of pressure applied and specifically by applying 10 cmH2O of inspiratory pressure to a patient with 100 ml / cmH2O compliance, it could achieve a maximum inspiratory volume (ΔVol, max) of 1000 ml. However, *volume variation is a process that takes time to develop*, so it can happen that the value of ΔVol, max potential is not reached when the square wave of pressure ends before reaching the new equilibrium. In Figure 1, we can see on the graphical monitoring the features in the example just mentioned (ΔP 10 cmH2O and Crs 100 ml / cmH2O).

"*To give maximum control over graphical monitoring and work in a controlled environment (excluding other variables that could affect the result) I used the Dräger simulator (free on the site) for this post with an ICU ventilator, Evita Infinity V500.*"

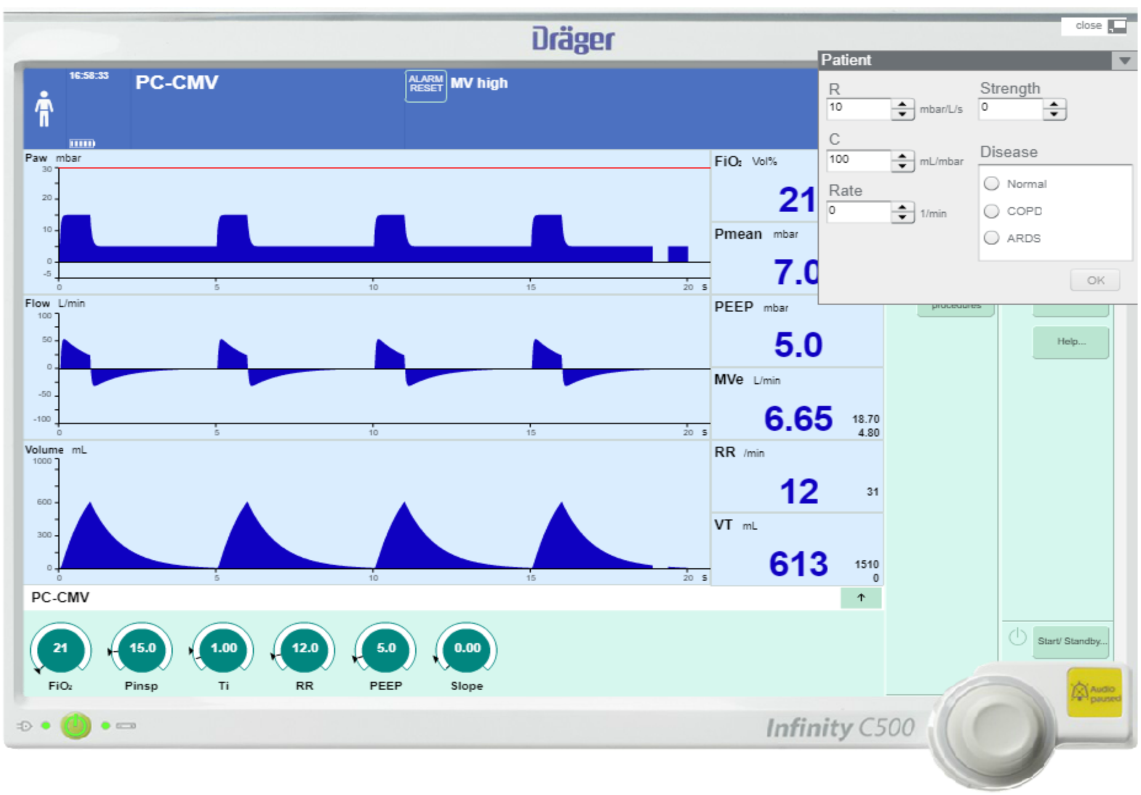

Figure 1

In Figure 1, the inspiratory phase ends before the inspiratory flow returns to zero. In this patient, an inspiratory time of 1 second was not sufficient to reach ΔVol, max (1000 ml), but it doesn't matter because the current volume obtained is more than enough (613 ml).

The system has not returned to equilibrium (inspiratory flow to zero) and hence the ΔVol, max has not been reached, which is not surprising because as mentioned earlier, volume variation is a time-consuming process and we may not have all that time available. **The time constant (τ, read "tao") resumes its essence precisely in this moment** because it describes the speed of the whole process, being a parameter that has the time dimension (sec). It specifies how much time it takes for the patient to generate a variation of sufficient volume to ensure adequate tidal volume during inhalation and how much time it takes to eliminate it during physiological expiration.

The exponential function assumes that for each duration of a square wave pressure there is a corresponding volume variation equal to a given percentage of ΔVol, max (Figure 2):

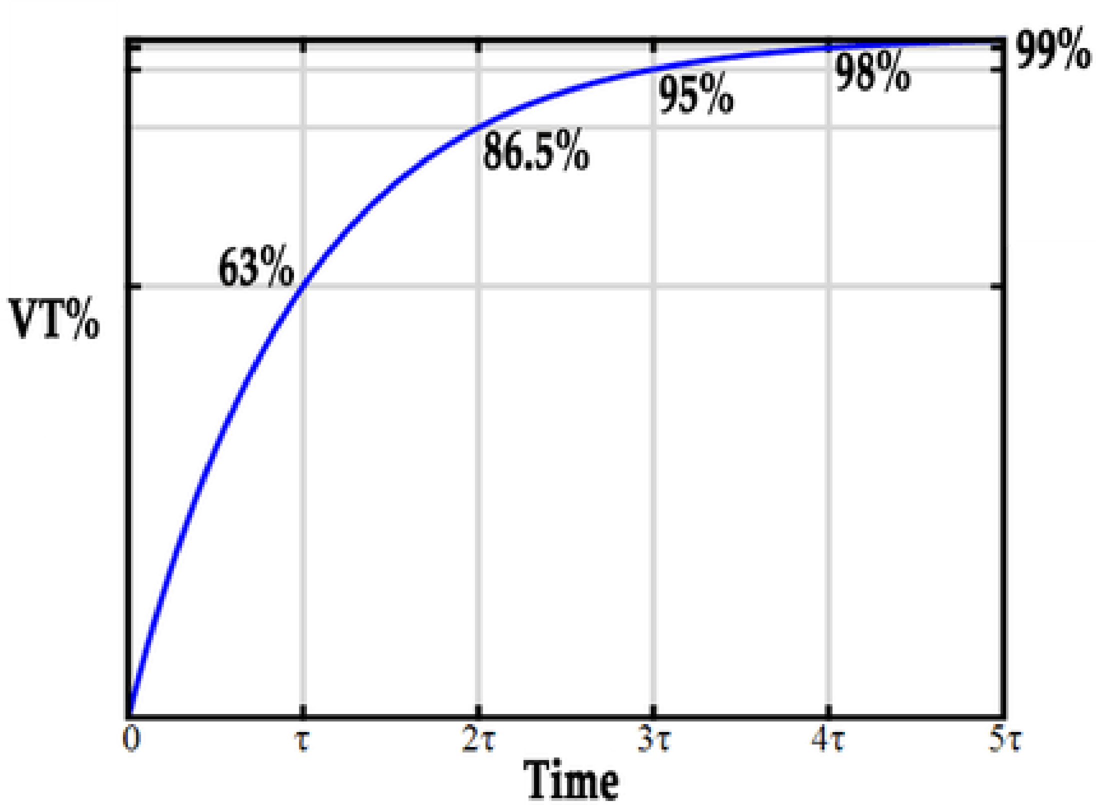

Figura 2: percentage change of the maximum volume corresponding to the time constant.

A time constant (τ) indicates the **time required to achieve 63% of the maximum volume variation** when applying constant pressure to the respiratory system under muscular relaxation (passive patient) or physiological exhalation (2), two time constants (2τ) indicate the time required to obtain 86.5% of ΔVol, max, three time constants (3τ) 95%, 4τ 98%, and 5τ 99%.

The τ mathematically corresponds to the **resistance and compliance product**. This means that the higher the compliance and/or resistance, the slower the ΔVolmax. (1)

$\tau = R \times C = R / E$

In other words it can be said that the time constant indicates the speed with which the respiratory system (passive) responds to a pressure variation. A short time constant corresponds to a quick response, while a long time constant corresponds to a slow response. To understand this concept we compare two scenarios in the image below (Figure 3), where the same setting (ΔP 10 cmH2O, Ti 1 sec, RR 20 min–1) is used in two patients. The left one has an acute respiratory distress syndrome or **ARDS** (low compliance) and the right one is affected by a **COPD** or chronic obstructive disease (high compliance), intentionally maintaining identical resistances in both pathologies (though in reality this is often not the case).

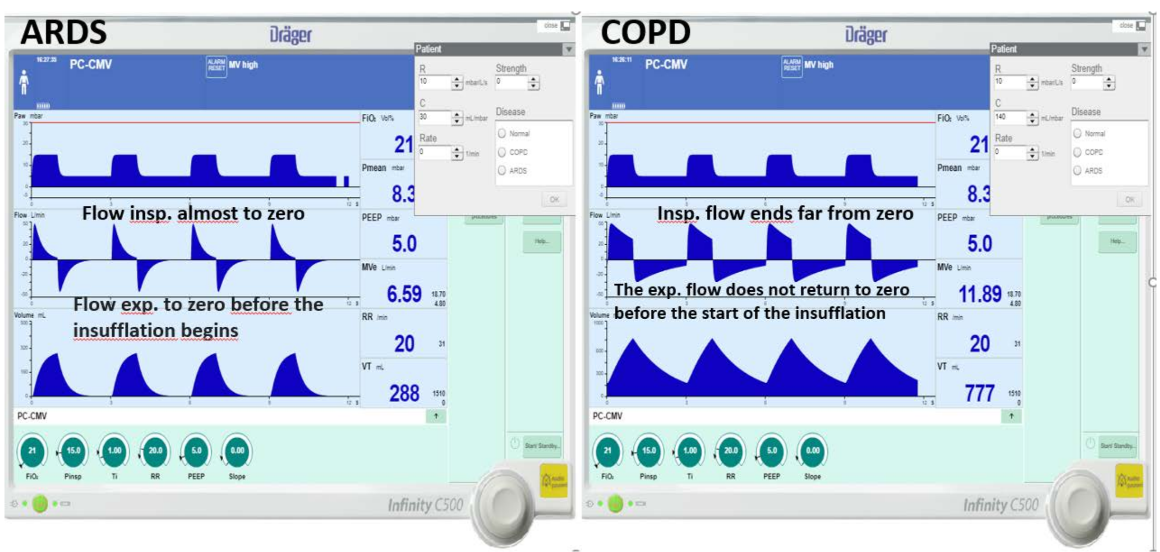

Figura 3: Time constant variation in two patients with different pathology: ARDS and COPD compared.

How to estimate the patient's time constant?

During INSPIRATION, the time constant can only be evaluated in the pressure controlled ventilations, as they ensure a constant insufflation pressure.

- Subjects with a "*short" time constant* (**left monitor in Figure 3**) have a rapidly decreasing inspiratory flow that ends with a phase of zero flow or almost at the end of the inhalation. In exhalation, the time constant can be evaluated regardless of the ventilation mode (provided exhalation is passive) and, as in the inspiration, subjects with "short" time constants have a rapidly decreasing flow that easily reaches the zero line before the beginning of the next inspiration.
- In subjects with a "*long" time constant*, instead, the inspiratory flow (in pressurized ventilation) and the expiratory flow slowly decrease, to such an extent that at the end of inhalation and exhalation the flow has not reached the zero (**right monitor in the figure 3**).

In clinical practice, we do not really need to know how many seconds is the patient's time constant. A simple **qualitative assessment** is instead useful to tell us if the patient has a "long" or "short" time constant, i.e. if the respiratory system "fills" and "empties" slowly (τ long) or quickly (short τ). (2)

Best wishes to everyone in your Tao constant estimations!

Enrico Bulleri and Cristian Fusi

Bibliography

1. Iotti GA, Braschi A. Measurements of respiratory mechanics during mechanical ventilation. Rhäzüns, Switzerland: Hamilton Medical AG; 2001.

2. Natalini G. Costante di tempo dell'apparato respiratorio [Internet]. Italia: ventilab; 2016 jun 30 [cited 2017 lug]. Available from: http://www.ventilab.org/2016/06/30/costante-di-tempo-dellapparato-respiratorio-prima-parte/