

# Relationship Between Dynamic Expiratory Time Constant $\tau_{\text{edyn}}$ and Parameters of Breathing Cycle in Pressure Support Ventilation Mode

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## Summary

Study of the relationship between ventilation parameters: monitored expiratory time constant –  $\tau_{\text{edyn}}$  and breathing – trigger frequency ( $f_{\text{trig}}$ ) and time of breathing cycle ( $T_{\text{cy}}$ ) are main goals of this article. Parameters were analyzed during last 4±2 h before weaning from ventilation in 66 patients ventilated in pressure support mode (PSV). We have found out, that there exist mathematical relationships, observed during adequate gas exchange, yet not described. Monitored parameters are represented by  $\tau_{\text{edyn}}$ ,  $f_{\text{trig}}$  and  $T_{\text{cy}}$ . The analysis showed close negative correlation between  $T_{\text{cy}}$  and  $f_{\text{trig}}$  ( $R^2=0.903$ ). This implies that each increasing of  $\tau_{\text{edyn}}$  causes decreasing of  $f_{\text{trig}}$  and vice versa. The calculation of regression equation between  $\tau_{\text{edyn}}$  and  $T_{\text{cy}}$  outlined that  $T_{\text{cy}} = 5.2625 * \tau_{\text{edyn}} + 0.1242$  ( $R^2=0.85$ ). Regulation of respiratory cycles by the respiratory center in the brain is probably based on evaluation of  $\tau_{\text{edyn}}$  as the  $\tau_{\text{edyn}}$  probably represents a regulatory element and  $T_{\text{cy}}$  regulated element. It can be assumed, that respiratory center can optimize the work of breathing in order to minimize energy in system patient + ventilator. The unique relationship, described above could be useful in clinical practice for development of new ventilation modes.

## Key words

Time constant • Weaning from ventilator • Time of breathing cycle • Breathing cycle

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## Introduction

The most important part of weaning from artificial lung ventilation (ALV) is the last four hours before patient disconnection from ventilator. Patient – ventilator synchrony during this time is crucial. Ventilation parameters are usually changed according to physician personal experiences (Boles *et al.* 2007, Petter *et al.* 2003, Tassaux *et al.* 2002). Synchrony between spontaneous breathing activity (trigger) and ventilator settings is essential for successful weaning. The  $f_{\text{trig}}$  is controlled by patient's spontaneous breathing activity. According to our experiences the best and mostly used weaning ventilation mode is pressure support ventilation (PSV) (Solsona *et al.* 2009, Tassaux *et al.* 2002). The patient's respiratory center keeps respiratory rhythm (frequency and inspiratory/expiratory time ratio) to maintain adequate minute ventilation. The settings of pressure support (by physician) are essential for adequate tidal volume (VT) in nonsufficient spontaneous ventilation. The exact, yet simple indicator for correct

pressure support settings does not exist. We have studied the relationship between parameters of ventilation and physical properties of lungs. Our previous study discovered significant difference (150-700 %) between measured Tau ( $\tau_{\text{meas}}$ ) and Tau calculated ( $\tau_{\text{calc}}$ ).

By definition  $\tau_{\text{calc}} = \text{airway resistance (Raw)} * \text{total lung compliance (Ctot)}$ . Therefore calculated  $\tau$  is inappropriate for evaluation of lung mechanics. In this study we are using a measured expiratory time constant termed as dynamic time constant ( $\tau_{\text{dyn}}$ ). Measured  $\tau_{\text{dyn}}$  shows real time changes in pneumatic system properties. System consists of patient's lungs, airways, endotracheal tube (ET) and ventilator with actual ventilation parameters settings. The goal was to clarify relationship between breathing parameters and  $\tau_{\text{dyn}}$  (in system lungs + ventilator), which could be usable in clinical practice for ventilator setting.

## Material and Methods

The retrospective study was done in 66 patients with following demographics parameters: weight  $82 \pm 17$  kg, height  $168 \pm 12.5$  cm and age  $59 \pm 12$  years. The patients have been ventilated for various diseases including pulmonary edema, ARDS, postoperative respiratory insufficiency and convulsions. Duration of artificial lung ventilation (ALV) was  $4.5 \pm 2.3$  days, and then the patients were observed during the last  $4 \pm 2$  h before disconnection from ALV in PSV mode. Average ventilation parameters are in Table 1.

**Table 1.** Mean value of ventilation parameters: pressure of pressure support (Pps), positive end expiratory pressure (PEEP), minute ventilation (MV), breathing frequency (f), switching from inspirium to expirium (PSi/e) in percentage of maximal flow (Qi/e),  $f_{\text{trig}}$ .

<i>Pps (cm H<sub>2</sub>O)</i>	$6.8 \pm 1.5$
<i>PEEP (cm H<sub>2</sub>O)</i>	$5.2 \pm 1.3$
<i>MV (l/min)</i>	$7.9 \pm 1.4$
<i>f (breath/min)</i>	$17.5 \pm 2.4$
<i>Qi/e (%)</i>	5
<i>Trigger sensitivity (l/min)</i>	1

Data are expressed as mean  $\pm$  SD, from 66 patients during  $4 \pm 2$  h of weaning.

During the first  $2 \pm 1$  h from the beginning of measurement, patients were lightly sedated Richmond Agitation-Sedation Scale (RASS -1+1) using Propofol

(Fresenius, Germany) titration. During the last two hours of measurement the Propofol infusion was stopped. Aerosol of Marcaine 0.5 % (Janssen, Sweden) in dose 2 ml/2 h was applied intratracheally for minimizing patient – ventilator asynchrony. After the last measurement we disconnected the patient *via* T-piece. Inclusive criteria were hemodynamic stability,  $\text{PaO}_2/\text{FiO}_2 > 300$  mm Hg, no pain using the Critical Care Pain Observation Tool (CPOP 0-1), no severe brain damage or other pathology potentially affecting ventilation. Only PSV mode was used for weaning from ALV. We have used the servo ventilator (Aura-V, Chirana a.s., Slovakia) with lung mechanics monitor and data collection with ProfiLung® software. The data were collected by computer every 3 min followed by multiparametric analysis of dependency of monitoring parameters showed relationship between  $\tau_{\text{dyn}}$ ,  $f_{\text{trig}}$  and time of breathing cycle ( $T_{\text{cy}}$ ). Relationships between  $T_{\text{cy}}$ ,  $\tau_{\text{dyn}}$  and spontaneous breathing frequency ( $f_{\text{trig}}$ ) were further evaluated.

### Methodology of measurement of $\tau_{\text{dyn}}$

We measured  $\tau_{\text{dyn}}$  by using the iterative method. After recording the expiratory flow curve in time, the computer algorithm calculated the tidal volume (VT – flow integral over time) from patient breath. Then, the program searched time values, when expiratory volume reached 63 %, 85 %, and 96 % of expiratory volume. Because gas flow curve during expirium is degressive (exponential), the time required to reach 63 %, 85 % or 96 % of expiratory volume, represent the time constant  $\tau_{\text{dyn}1}$ ,  $\tau_{\text{dyn}2}$ , or  $\tau_{\text{dyn}3}$ . Generally for further calculation the first expiratory dynamic time constant value is used  $\tau_{\text{dyn}1}$ , indicated further as  $\tau_{\text{dyn}}$ .

Why, we choose  $\tau_{\text{dyn}1}$ ? In the first phase of expirium, when flow is highest also resistance is highest. During next phases of expirium represented by decreased flow,  $\tau_{\text{dyn}2}$  and  $\tau_{\text{dyn}3}$  are shorter, therefore no important and without big influence on our measurement. Therefore we choose value of  $\tau_{\text{dyn}1}$  as value which we used. Described procedure has been repeated for each breath cycle. The sampling frequency of expiratory flow was 1 kHz.

### Calculated and the measured value of Tau ( $\tau$ ) explanation of differences

Tau calculated  $\tau_{\text{calc}}$  could be expressed as  $\tau_{\text{calc}} = \text{Raw} * \text{Ctot}$ . In this formula only the airway resistance (Raw) and the total compliance of the lungs and thorax (Ctot) are considered. On the other hand during measured

Tau  $\tau_{\text{meas}}$  the flow sensor is connected inside ventilator circuit, therefore the measured value of  $\tau_{\text{dyn}}$  reflects properties of all pneumatic elements including breathing circuit and mechanical properties of the lungs. In our patient group we use ALV using endotracheal tube (ET). The difference between the calculated and the measured value can be significantly different, which make the  $\tau_{\text{calc}}$  unusable in clinical practice.

Because of retrospective study, the Ethical committee approval was not necessary. However our data comes from previously study “The computer assisted ALV”, which was approved by Ethical committee of the East Slovakian Institute of Cardiovascular Diseases: EK no. VZ/7 / KardO/2011.

## Results

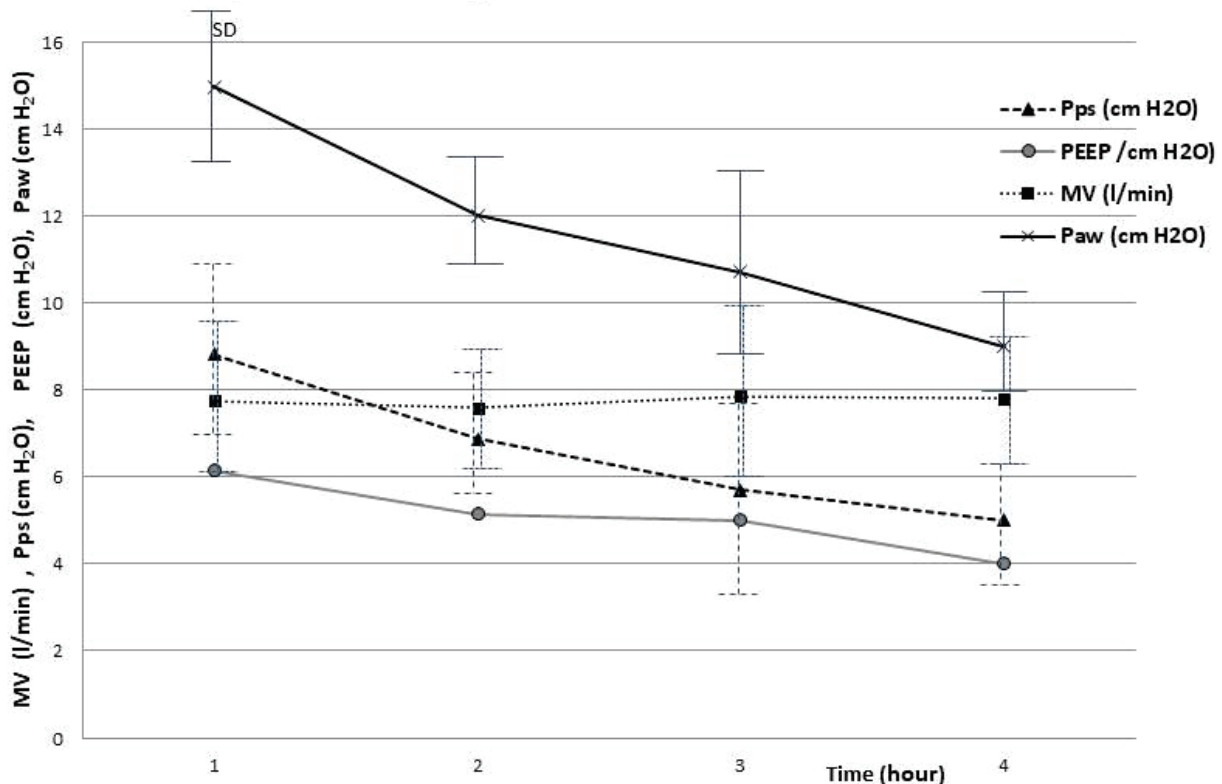
The presented results describe the new relationship of  $\tau_{\text{dyn}}$ ,  $f_{\text{trig}}$  and time of breathing cycle parameters  $T_{\text{cy}}$ . The Figures 2 and 3 showed relationship between  $\tau_{\text{dyn}}$  and  $f_{\text{trig}}$  as well as  $T_{\text{cy}}$  during weaning. The results come from 66 patients during last four hours of ALV before disconnection form ventilator. Figure 1

shows changes of indicated ALV parameters during the weaning procedure lasting 4 h. We can see that the parameters of ventilator support pressure (Pps), peak airway pressure (Paw), positive end expiratory pressure (PEEP) decreased during weaning procedure (adjusted by physician), but minute ventilation (MV) remained stable. According to our experience, this pattern represents proper weaning (Tables 1 and 2). This was necessary to obtain for correct data collection.

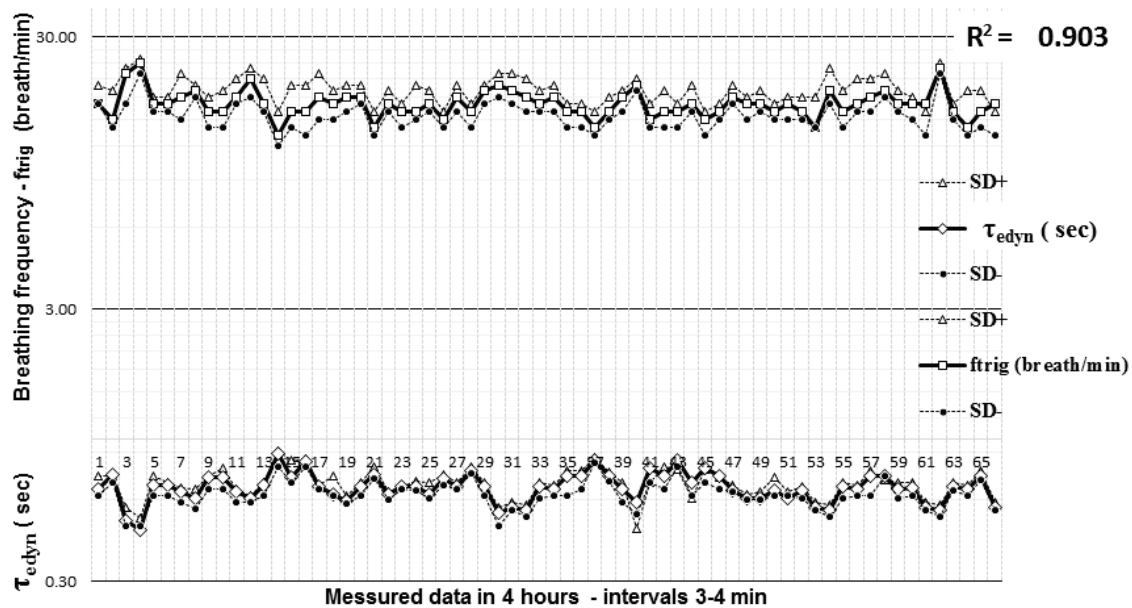
**Table 2.** Blood gas exchange parameters during weaning.

$FiO_2$	$0.35 \pm 0.07$
$PaO_2 / FiO_2$ (mm Hg)	$378 \pm 69$
$PaCO_2$ (mm Hg)	$42 \pm 4.9$
$PaO_2$ (mm Hg)	$132 \pm 34$
$pH$	$7.41 \pm 0.08$
Lactate (mmol/l)	$1.6 \pm 0.43$

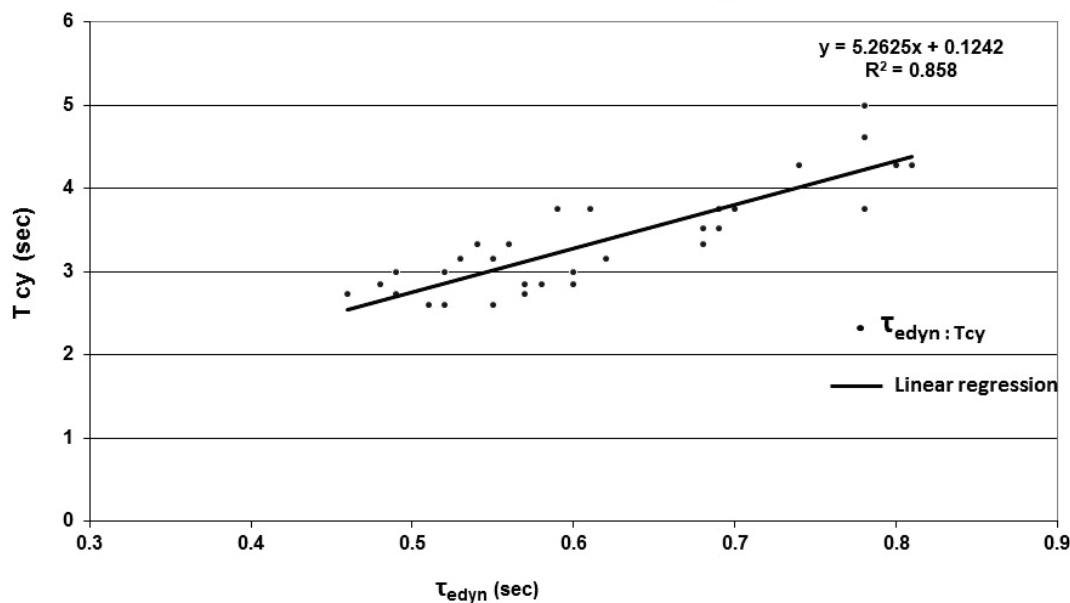
Data are expressed as mean  $\pm$  SD, from 66 patients during  $4 \pm 2$  h of weaning. It indicates adequate gas exchange; therefore correction of ventilator settings during weaning procedure was not necessary.



**Fig. 1.** ALV ventilation parameter settings. Pps – pressure of pressure support, PEEP – positive end expiratory pressure, Paw – airway pressure, MV – minute ventilation, expressed in mean ( $\pm$ SD) in 66 patients during 4 h of weaning (parameters Pps, PEEP was setting by physician during weaning).



**Fig. 2.** Average values of  $f_{trig}$  and  $\tau_{edyn}$  during weaning. More precise analysis shows strong negative correlation between  $f_{trig}$  and  $\tau_{edyn}$ .  $R^2=0.903$ . Increasing of  $\tau_{edyn}$  leads to decrease in  $f_{trig}$  and vice versa.



**Fig. 3.** Linear regression between  $T_{cy}$  and  $\tau_{edyn}$  during weaning (mean values,  $n=66$ ).  $T_{cy} = 5.2625 * \tau_{edyn} + 0.1242$  ( $R^2=0.858$ ). It shows new interesting relationship between time of breathing cycle ( $T_{cy}=60/f_{trig}$ ) and  $\tau_{edyn}$ .

## Discussion

Discovery of relationship between ventilation parameters influenced by breathing regulation center are important. Understanding of principle of regulatory mechanism of breathing is crucial for setting of ventilation parameters during ALV. Weaning from ALV represents the procedure in which patient is completely disconnected from ventilator and ET tube is withdrawn (Boles *et al.* 2007, Meade *et al.* 2001). The exact indicator for correct weaning from ALV does not exist

(Boles *et al.* 2007, Petter *et al.* 2003). Weaning is suitable model for study of interaction between patient natural breathing pattern and ventilator parameter settings. Our goal was to find possible new patients + ventilator relationship as well as internal principles, which plays a major role, which was not yet published. Monitoring of  $\tau_{edyn}$  as presented in Figures 2 and 3 provides information about dynamics of gas exchange. Parameter of  $\tau_{edyn}$  determines relationship between ventilation work and gas volume necessary for adequate ventilation ( $CO_2$  elimination and  $O_2$  supply). Measured  $\tau_{edyn}$  varies

during each breath cycle.  $\tau_{\text{edyn}}$  depends on flow, inspiratory and expiratory time, frequency of breathing, resistance of lungs-ventilator system ( $R_{\text{sys}}$ ), compliance and inhomogeneity of gas distribution in the lungs. It is impossible to easily assess  $\tau_{\text{edyn}}$ , but it is possible to measure it by described iteration method using ventilator computer.  $\tau_{\text{edyn}}$  value reflects all influences of ventilation settings, mechanical properties of the lungs as well as whole lung + ventilator system resistance ( $R_{\text{sys}}$ ). The prolongation of  $\tau_{\text{edyn}}$  leads to drop in the  $f_{\text{trig}}$  and vice versa as can be seen in Figure 2. The reason for this is probably to assure lowest energy consumption for gas exchange. The close relationship between  $\tau_{\text{edyn}}$  and  $f_{\text{trig}}$  on Figure 3, could be also explained, that the breathing center optimizes ventilation to assure the lowest energy consumption. Work of breathing is reduced by lowering the resistance of airways by decreasing flow of gas. During stable clinical condition  $\tau_{\text{edyn}}$  represent probably regulatory component and  $T_{\text{cy}}$  regulated component. The indirect indicator of ventilator pattern is  $f_{\text{trig}}$ . Changes in the duration of  $\tau_{\text{edyn}}$  depend mainly on changes in the parameters of the pulmonary mechanics. To achieve effective gas exchange, the other ventilator parameters must probably adapt to  $\tau_{\text{edyn}}$ . Those parameters can be changed by patient's natural breathing regulatory mechanism or during ALV by ventilator parameter settings. However in the PSV mode, the only adjustable parameter is Pps and PSi/e.

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## Conclusions

We revealed and described a possible internal relationship between  $\tau_{\text{edyn}}$  and  $T_{\text{cy}}$  in the system patient + ventilator. We observed negative correlation between  $f_{\text{trig}}$  and  $\tau_{\text{edyn}}$ . According to our results, could be assume, that the respiratory center is probably reacting to changes of resistance and compliance by adjustment of breathing pattern according to changes in  $\tau_{\text{edyn}}$ . The respiratory center is able to set the optimal breathing pattern, even in the conditions, when patient is connected to ventilator by tubing, ET, connectors etc.  $\tau_{\text{edyn}}$  probably represents integrated value of the lung mechanics. Parameters  $T_{\text{cy}}$ , VT and  $f_{\text{trig}}$ , probably continuously adapt to the  $\tau_{\text{edyn}}$  with aim to reach the most effective gas exchange.

The relationship described above  $T_{\text{cy}} = 5.2625 * \tau_{\text{edyn}} + 0.1242$ , may have practical implication for adjusting ventilator settings during artificial lung ventilation and creation of better ventilator algorithm. Only using of iteration methods of measurement allowed monitoring of  $\tau_{\text{edyn}}$  during artificial lung ventilation in the system patient lungs + ventilator. This is a novelty of this study and brings practical benefit for clinical use. According to our knowledge described relationship was not published yet.

## Conflict of Interest

There is no conflict of interest.