Relationship between dynamic expiratory time constant τ_{edyn} and parameters of breathing cycle in pressure support ventilation mode.

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Short title: Relationship between time constant and breathing cycle time.

Summary:

Study of the relationship between ventilation parameters: monitored expiratory time constant - τ_{edyn} and breathing – trigger frequency (f_{trig}) and time of breathing cycle (T_{cy}) are main goals of this article. Parameters were analyzed during last 4 hour ± 2 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: τ_{edyn}, f_{trig} and T_{cy} . The analysis showed close negative correlation between T_{cy} and f_{trig} (R^2 = - 0.903). This implies that each increasing of τ_{edyn} causes decreasing of f_{trig} and vice versa. The calculation of regression equation between τ_{edyn} and T_{cy} outlined, that $T_{cy} = 5.2625 * \tau_{edyn} + 0, 1242$ ($R^2 = 0.85$). Regulation of respiratory cycles by the respiratory centre in the brain is probably based on evaluation of τ_{edyn} as the τ_{edyn} probably represents a regulatory element and T_{cy} regulated element. It can be assumed, that respiratory centre 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

Tab: 2

Fig: 3

Literature: 5

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_{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 centre 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 non sufficient 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 (τ_{meas}) and Tau calculated (τ_{calc}).

By definition τ_{calc} = airway resistance (Raw) * total lung compliance (Ctot). Therefore calculated τ is inappropriate for evaluation of lung mechanics. In this study we are using a measured expiratory time constant termed as dynamic time constant (τ_{edyn}). Measured τ_{edyn} 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 τ_{edyn}, (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 ±17kg, height 168±12.5cm and age 59±12 years. The patients have been ventilated for various diseases including pulmonary oedema, ARDS, postoperative respiratory insufficiency and convulsions. Duration of artificial lung ventilation (ALV) was 4.5± 2.3 days, and then the patients were observed during the last 4±2 hour before disconnection from ALV in PSV mode. Average ventilation parameters are in Tab. 1.

Tab. 1.

Tab 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 from maximal flow (Qi/e), f_{trig}, expressed in mean (±SD) in 66 patients during 4 hours of weaning.

During the first 2±1 hours from the beginning of measurement, patients were lightly sedated Richmond Agitation-Sedation Scale (RASS -1 +1) using Propofol (Fresenius) titration. During the last two hours of measurement the Propofol infusion was stopped. Aerosol of Marcaine 0.5% (Janssen) in dose 2 ml/2 hour was applied intratracheally for minimising patient – ventilator asynchrony. After the last measurement we disconnected the patient via T-piece. Inclusive criteria were hemodynamic stability, PaO_2/FiO_2 >300 mmHg, no pain using the Critical Care Pain Observation Tool (CPOT 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 minute followed by multiparametric analysis of dependency of monitoring parameters showed relationship between τ_{edyn}, f_{trig} and time of breathing cycle (T_{cy}). Relationships between T_{cy}, τ_{edyn} and spontaneous breathing frequency (f_{trig}) were further evaluated.

Methodology of measurement of τ_{edyn}

We measured τ_{edyn} 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 degresive (exponential), the time required to reach 63%, 85% or 96% of expiratory volume, represent the time constant $\tau_{edyn1,}$ $\tau_{edyn2,}$ or τ_{edyn3}. Generally for further calculation the first expiratory dynamic time constant value is used τ_{edyn1}, indicated further as τ_{edyn}. (Why, we choose τ_{edyn1} ? In the first phase of expirium, when flow is highest also resistance is highest. During next phases of expirium represented by decreased flow, τ_{edyn2} and τ_{edyn3} are shorter, therefore no important and without big influence on our measurement. Therefore we choose value of τ_{edyn1} 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 (τ) explanation of differences:

Tau calculated τ_{calc} could be expressed as τ_{calc} = Raw *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 τ_{meas} the flow sensor is connected inside ventilator circuit, therefore the measured value of τ_{edyn} 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 τ_{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 Head of Committee Stanislav Juhas, MD, PhD.

Results:

The presented results describe the new relationship of τ_{edyn} , f_{trig} and time of breathing cycle parameters T_{cy}. The Figures 2 and 3 showed relationship between τ_{edyn} and f_{trig} as well as T_{cy} during weaning. The results come from 66 patients during last four hours of ALV before disconnection form ventilator. Fig 1 shows changes of indicated ALV parameters during the weaning procedure lasting 4 hours. 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 see in Tab. 1 and Tab. 2. This was necessary to obtain for correct data collection.

Fig. 1

Tab. 2

Tab 2 Parameters of blood gases, pH and lactate during weaning in mean (±SD). It indicates adequate gas exchange; therefore correction of ventilator settings during weaning procedure was not necessary.

Fig 2

Fig 3

Discussion:

Discovery of relationship between ventilation parameters influenced by breathing regulation centre 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 τ_{edyn} as presented in Fig 2 and 3 provides information about dynamics of gas exchange. Parameter of τ_{edyn} determines relationship between ventilation work and gas volume necessary for adequate ventilation (CO_2 elimination and O_2 supply). Measured τ_{edyn} varies during each breath cycle. τ_{edyn} depends on flow, inspiratory and expiratory time, frequency of breathing, resistance of lungs-ventilator system (R_{sys}), compliance and inhomogenity of gas distribution in the lungs. It is impossible to easily asses τ_{edyn} , but it is possible to measure it by described iteration method using ventilator computer. τ_{edyn} value reflects all influences of ventilation settings, mechanical properties of the lungs as well as whole lung + ventilator system resistance (R_{sys}). The prolongation of τ_{edyn} leads to drop in the f_{trig} and vice versa as can be seen in Fig 2. The reason for this is probably to assure lowest energy consumption for gas exchange. The close relationship between τ_{edyn} and f_{trig} on Fig 3, could be also explained, that the breathing centre 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 τ_{edyn} represent probably regulatory component and T_{cy} regulated component. The indirect indicator of ventilator pattern is f_{trig}. Changes in the duration of τ_{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 τ_{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.

Conclusion:

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

The relationship described above $T_{cy} = 5.2625 * \tau_{edyn} + 0, 1242$, 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 τ_{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.

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Tab. 1. Mean value of ventilation parameters.

Ventilation parameters (n=66)	
Mean during 4 ± 2 hour	
Pps (cm H2O)	**6.8 ± 1.5**
PEEP (cm H2O)	**5.2 ± 1.3**
MV (l/min)	**7.9 ± 1.4**
f (breath/min)	**17.5 ± 2.4**
Qi/e (%)	**5**
Trigger sensitivity (l/min)	**1**

Tab. 2

Parameters of blood gas exchange (n=66)	
Average during 4 hour	
FiO_2	**0.35 ±0.07**
PaO_2/ FiO_2 (mmHg)	**378 ± 69**
$PaCO_2$ (mmHg)	**42 ± 4.9**
PaO_2 (mmHg)	**132 ± 34**
pH	**7.41 ± 0.08**
Lactate (mmol/l)	**1.6 ± 0.43**

Fig. 1

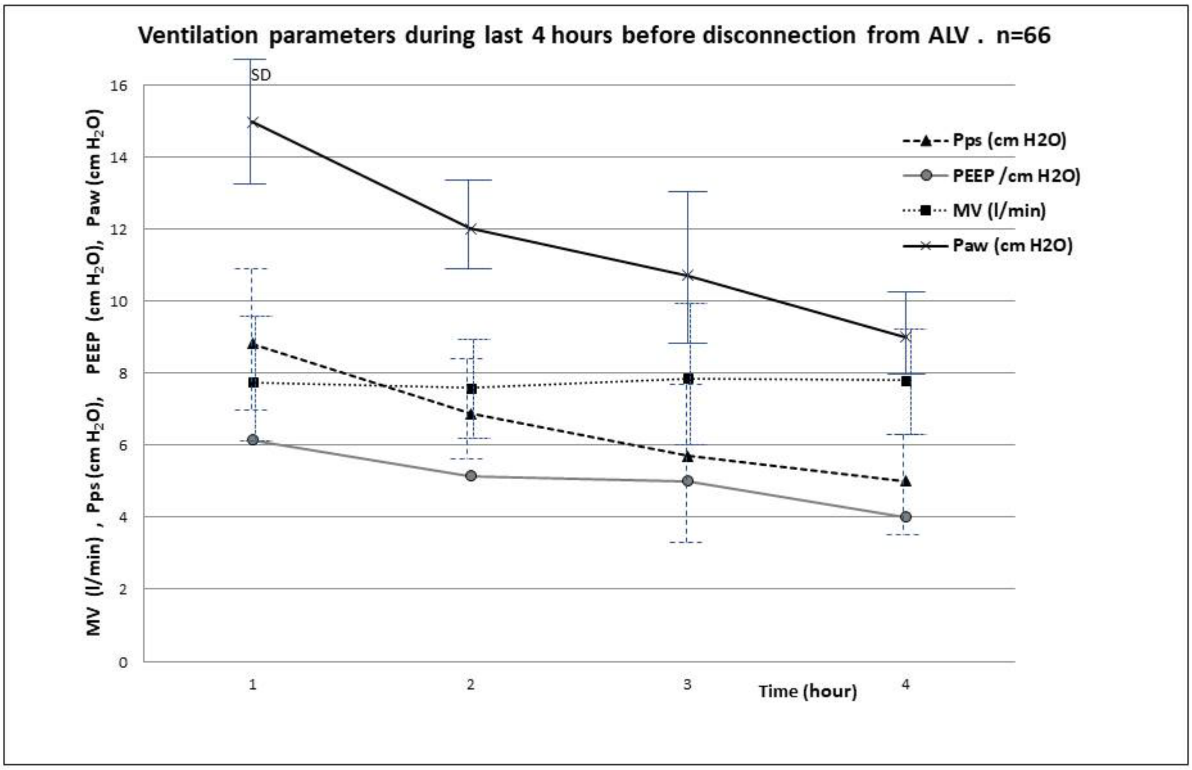

Fig. 1 ALV ventilation parameter settings (pressure of pressure support (Pps), positive end expiratory pressure (PEEP), airway pressure (Paw), minute ventilation (MV), expressed in mean (±SD) in 66 patients during 4 hours of weaning (parameters Pps, PEEP was setting by physician during weaning).

Fig 2

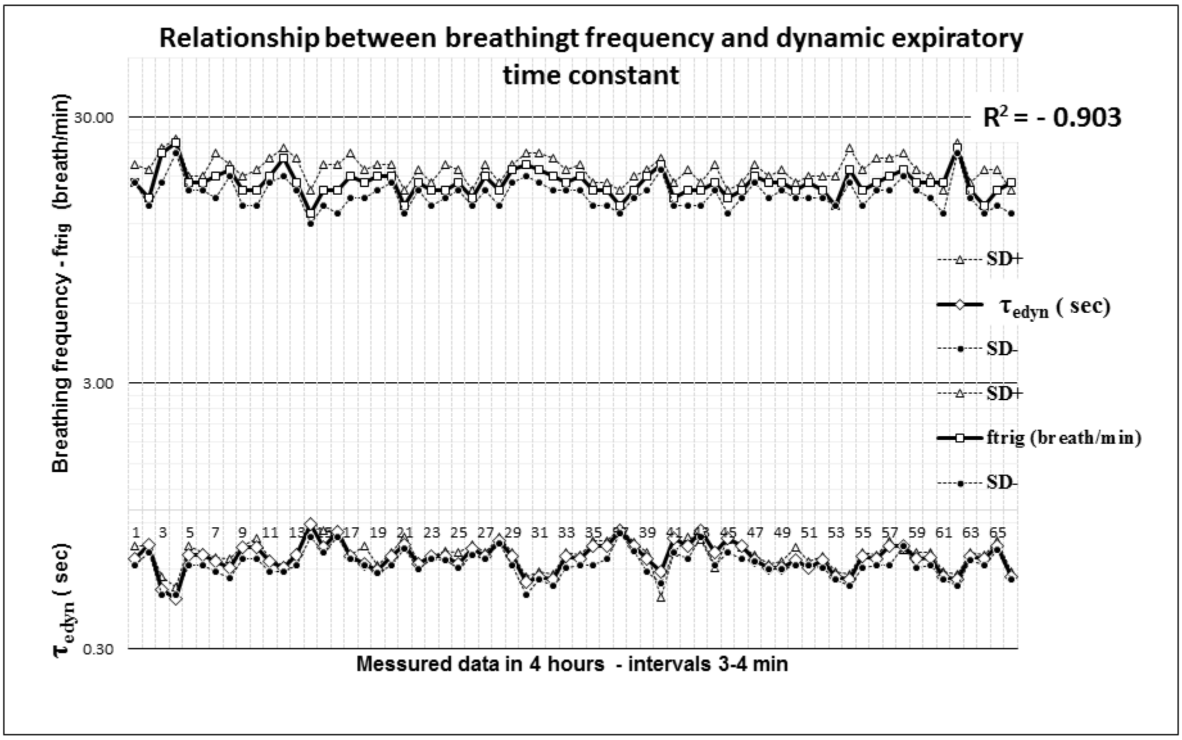

Fig 2 shows average values of f_{trig} and τ_{edyn} during weaning. More precise analysis shows strong negative correlation between f_{trig} and τ_{edyn}.

(R^2= -0.903). Increasing of τ_{edyn} leads to decrease in f_{trig} and vice versa.

Fig 3

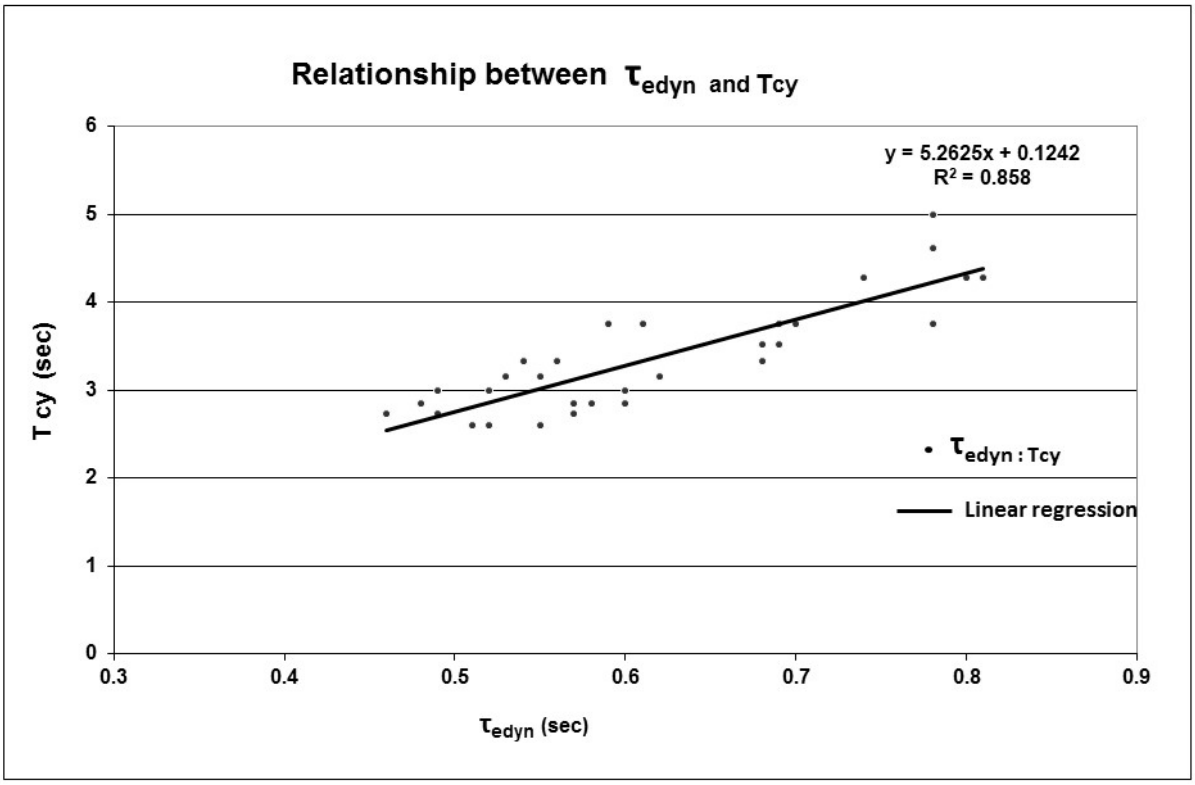

Fig 3 shows linear regression between T_{cy} and τ_{edyn} during weaning (mean values, n=66), (T_{cy} = 5.2625 * τ_{edyn} + 0, 1242, R^2 =0.858). It shows new interesting relationship between time of breathing cycle (T_{cy} = 60/$_{ftrig}$) and τ_{edyn}.