Analysis of dynamic respiratory mechanics profits from breathing-phase selective filtering
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Abstract: Cardio-pulmonary coupling induces cardiogenic oscillations to the respiratory signals, which appear most prominently in the expiration. We hypothesized that the analysis of respiratory system mechanics profits from the breathing phase-selective filtering of expiratory data. Using the gliding-SLICE method, intratidal dynamic respiratory system mechanics were analyzed without and with low-pass filtering (cut-off-frequency f=4 Hz) of expiratory or inspiratory data separately. The quality of data analysis was derived quantitatively from the coefficient of determination (R²). The selective filtering of expiration data eliminates negative side-effects of cardiogenic oscillations thus leading to a significant improvement of the analysis of dynamic respiratory system mechanics.

Keywords: controlled mechanical ventilation, dynamic respiratory mechanics, cardiogenic oscillations

Introduction
Analysis of individual respiratory mechanics is used to guide the ventilator setting under conditions of lung protective mechanical ventilation in intensive care medicine [1]. In the last years the focus on the analysis in respiratory mechanics concentrates on dynamic conditions [2], which mean that the analysis is performed during uninterrupted mechanical ventilation with the inspiratory and expiratory airflow rate being different from zero [3].

During inspiration the ventilator provides the mechanical energy for respiratory gas transport into the lungs. The mechanical energy stored in the elastic tissue elements of the respiratory system drives the passive expiration which is characterized by exponential flow decay. Thus, after an initial expiratory peak flow the flow rate is very low during expiration. At low flow rates the transfer of mechanical energy from the beating heart to the lungs known as mechanical cardio-pulmonary coupling becomes visible as cardiogenic oscillations (COS) superimposed on the respiratory signals pressure and flow.

We hypothesised that filtering of the respiratory data obtained from the expiration phase would improve the analysis of intratidal respiratory system mechanics. Hence, the purpose of this study was to introduce the method of breathing-phase selective filtering and to test this approach by means of retrospective analysis of respiratory data from mechanically ventilated patients.

Methods
Patient data
We retrospectively analyzed data from a multicenter-study (28 patients with injured lungs, under volume-controlled ventilation) and from two additional studies (3 lung healthy patients and 3 with injured lungs, under pressure-controlled ventilation). For each patient, data streams were recorded at different positive end-expiratory pressure levels.

Analysis of dynamic lung mechanics
The volume-dependent respiratory system compliance was calculated using the gliding-SLICE method [4]. The gliding-SLICE method is based on multiple linear regression analysis (MLRA) to determine compliance Crsi, resistance Rrsi and the dynamic pressure base P0i for each slice by a least-squares fit of the equation of motion (see Eq. 1) to the pressure, flow and volume data of the respective slice i:

\[
p = \frac{1}{C_{rsi}} \cdot V + R_{rsi} \cdot \dot{V} + P0_i
\]

Quality test of the lung mechanics analysis
The quality of the lung mechanics analysis, i.e., the “goodness” of the gliding-SLICE method was examined by calculating the coefficient of determination, R², for each slice.

Signal filtering
Expiratory and inspiratory periods were filtered separately in order to test for the effect of breathing-phase selective signal filtering. Airway pressure, volume and flow rate signals were filtered for a breathing-phase when the R² value was below 0.995.

We took advantage of the differences in the frequency content between cardiogenic oscillations and breathing signals. Therefore we used a low-pass filter with a cut-off frequency of 4 Hz.

Validation of filtering
The gliding-SLICE method was applied to the filtered signals of airway pressure, flow and volume to re-determine the values for compliance and resistance. Furthermore, the “goodness” of fit was analyzed after filtering.
ing to verify if these re-determined parameters better adapted to the model (equation of motion). The quality of fit according to the $R^2$-values was classified as “high” for $R^2$ above 0.995, “medium” for $R^2$ between 0.995 and 0.990 and as “low” for $R^2$ below 0.990.

**Results**

For 69% of the data streams from patients under volume-controlled ventilation, the fit quality was already “high” before filtering and remained “high” after filtering. In 28% of the cases the fit quality improved from “medium” and “low” to “high” after the application of the low-pass filter. In 3% of the cases the quality of fit remained constant before and after the application of the filter. Low $R^2$-values were found accumulated in the lowest volume ranges. Particularly at the end of expiration, volume and pressure values underlie considerable disturbances which introduced an accumulation of high frequency signals.

Fig. 1 gives a synoptic view over the quality of lung mechanics analysis without filtering (Fig. 1a) and after breathing-phase selective filtering (Fig. 1b) for the 25 patients included in the multicenter-study.

![Fig. 1: without filtering (a) and after breathing-phase selective filtering (b) for 25 patients from the multicenter-study.](image)

The quality of fit, represented by $R^2$, never became worse with filtering. On the contrary, the $R^2$-value of every single slice within every single breath increased after the application of the low-pass filter.

**Discussion**

In this study we present a method for breathing-phase selective filtering of respiratory data obtained from patients under controlled mechanical ventilation. As the main result of our study we found a significant improvement of the analysis of dynamic respiratory system mechanics on a breath-by-breath basis when expiratory but not when inspiratory data were filtered.

Fluctuations in the expiratory phase can be seen where the airflow rate decays exponentially from an initial expiratory peak flow towards zero flow. As a possible explanation we identified COS reflecting the mechanical cardio-pulmonary coupling, i.e., the transfer of mechanical energy from the beating heart to the lungs [5].

In conclusion, we were able to demonstrate that cardiogenic oscillations interfere with the lung mechanics analysis during the expiration phase. Breathing-phase selective filtering of respiratory data limited to the expiration could significantly improve the quality of the breath-by-breath analysis of dynamic intratidal lung mechanics.

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**Bibliography**


