Noise in respiratory signals influences dynamic respiratory system compliance analysis: A simulation study

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Abstract: The aim of the study was to verify the influence of noise in respiratory signals to the analysis of dynamic respiratory system compliance (C_{rs}). The respiratory signals were simulated under volume control ventilation mode. Volume-dependent C_{rs} was set to an exponential function. White noise and colored noise at signal-to-noise ratio (SNR) of $+\infty$, 60 dB and 30 dB were added to the simulated respiratory data. Three dynamic methods for C_{rs} analysis (the SLICE method, the dynostatic algorithm, and the adaptive slice method) were examined. We found that the estimates from different dynamic methods were different due to the presence of noise in the respiratory signals. Approaches that increase the SNR may improve the accuracy of the volume-dependent C_{rs} analysis.

Keywords: dynamic respiratory system compliance; signal-to-noise ratio; dynamic methods; noise; respiratory signals

Introduction

The analysis of dynamic respiratory system compliance (C_{rs}) is important for the treatment of patients in intensive care units [1]. Compliance is actually not constant even within one breath but may be depended on volume, flow and respiratory frequency [2]. Volume-dependent compliance may indicate the correctness of ventilator settings and therefore should be monitored at the bedside [3]. There were different methods proposed to calculate volume-dependent C_{rs} based on the first order equation of motion [4-6]. In a previous study, we found that the estimates delivered by these dynamic methods are not identical [6]. We hypothesized that noise in the respiratory signals influences the analysis of volume-dependent C_{rs} and causes the difference in estimates of these methods. In the present study, we simulated noise in respiratory data at different signal to noise ratio (SNR) levels in order to prove our hypothesis.

Methods

A. Breath Simulation

The detail of the simulated respiratory data was described in a previous study [6]. In brief, a breath under volume controlled ventilation was simulated with MATLAB (The MathWorks Inc., Natick, MA, USA). Tidal volume, inspiration-to-expiration ratio and ventilatory frequency were set to 500 ml, 1:2 and 10 min⁻¹, respectively. Airway resistance and C_{rs} were set to 2.22×10^{-3} cmH₂O·s·ml⁻¹ and $30 + 20 \cdot e^{-\text{Volume}(t)/100}$ ml·cmH₂O⁻¹ to simulate volume dependent

C_{rs} . Both white noise and color noise were added to the respiratory data (airway pressure, airway flow and volume) with three different SNR ($+\infty$, 60 dB, 30 dB). The white noise had a mean value of 0 and a standard deviation of σ :

$$\sigma = A \cdot \sqrt{\frac{(10^{-\text{SNR}/10})}{2}} \quad (2)$$

where $A/\sqrt{2}$ is the effective value of the respiratory signals. The color noise was generated by filtering the white noise with a low pass filter.

B. The analysis of C_{rs}

Three dynamic methods to calculate C_{rs} were applied in the study, namely the SLICE method [5], the dynostatic algorithm (DSA) [4], and the adaptive slice method (ASM) [6]. These dynamic methods linearize the volume-dependent C_{rs} by dividing the respiratory data into several iso-volume intervals and assuming the C_{rs} to be constant within every interval. The SLICE method applies least-squares fit method to each interval [5]. The DSA calculates first the alveolar pressure by subtracting resistive pressure from tracheal pressure. C_{rs} is then calculated by dividing volume with alveolar pressure in each volume interval [4]. The ASM analyzes the C_{rs} in certain intervals that are selected according to the confidence interval of the fitting parameters [6]. Relative error was defined as the absolute difference between calculated C_{rs} and preset C_{rs} divided by preset C_{rs} . Mean relative error was defined as sum relative error divided by the number of estimates delivered with one dynamic method. For example, the SLICE method returned 6 C_{rs} values at 6 different volume levels, so that the number of estimates was 6.

Results

Volume-dependent C_{rs} is calculated with SLICE, DSA and ASM methods. The results are plotted against volume in Fig. 1. When no noise is presented in the respiratory data (Fig. 1, top, SNR = $+\infty$), the estimations of different dynamic methods are almost identical. When the noise ratio increases to 30dB (Fig. 1, middle and bottom), the dynamic methods deliver the estimations with considerable deviation. The observations are similar both in data with white and colored noise.

Mean relative error of each method and total error at each SNR level are summarized in Table 1. The error of the estimates increases when the SNR decreases.

Discussion

In the present study, noise in the respiratory signals were confirmed to be the main reason influencing the analysis

of volume-dependent C_{rs} . The estimates of the dynamic methods were similar at high SNR level. High noise component in the respiratory data diversified the results of the methods (Fig. 1 and Table 1).

The dynamic methods are based on the simple first order equation of motion but showed the potential of clinical applications [7-8]. A close monitoring of volume-dependent C_{rs} may lead to a new bedside diagnostic tool in the intensive care unit. However, the C_{rs} values are not consistent, depending on which method is chosen for analysis. The respiratory signals measured in daily clinical routine consist of real signals and noise (etc. from devices, environment). The presence of noise in the respiratory signals is inevitable but can be reduced through

Fig. 1. Calculated volume-dependent C_{rs} with SLICE (red *), DSA (black $\diamond$) and ASM (blue $\circ$) at a SNR level of $+\infty$ (top) and 30dB (white noise, middle and colored noise, bottom). The black line indicates the preset C_{rs} value.

filtering and some other techniques [9], so that the analysis of C_{rs} will become more accurate according to the finding of the present study. In further studies, approaches to raise the SNR in the signals should be examined.

The main limitation of the present study is that the conclusion is based on the simulation. Unfortunately, real C_{rs} values are not available in animal experiments or in studies with patients. Further validation studies should be conducted with physical models (phantoms).

Table 1: Mean relative error of different dynamic methods and total error at different SNR levels.

Noise \ Method		SLICE	DSA	ASM
SNR = $+\infty$		0.002	0.007	0.001
SNR = 60 dB	White	0.002	0.007	0.007
	Colored	0.004	0.010	0.023
SNR = 30 dB	White	0.044	0.142	0.025
	Colored	0.086	0.190	0.031

Conclusion

The estimates from different dynamic methods may be different due to the presence of noise in the respiratory signals. Approaches that increase the SNR may improve the accuracy of the volume-dependent C_{rs} analysis.

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