Time-Frequency Coherence Between Cardiac And Respiratory Signals During Anesthesia Induction

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Abstract. Anesthesia induction is related to the change of cardio-autonomic control. The coordination between cardiovascular and respiratory system behaviors could represent autonomic nervous system functionality. We conducted a short time Fourier transform coherence to explore the linearity between heart rhythm and respiration at different frequency bands during anesthesia induction. Total 32 eligible subjects were enrolled. During induction, the subjects demonstrated significant reduction of high frequency coherence (coh-HF) with significant increases of low frequency coherence (coh-LF) and very low frequency coherence (coh-vLF) as compared with pre-induction period. Besides, the subjects had decrease of linearity at high frequency band (coh-HF>0.5) and increase of linearity at low frequency (coh-LF>0.5) and very low frequency (coh-vLF>0.5) bands as compared with pre-induction period.

1 Introduction

During anesthesia induction, the biosignals such as heart rhythm, respiration and blood pressure have significantly rapid changes characteristics. The interaction among heart rate, respiration, and blood pressure could reflect autonomic nervous system (ANS) functionality, reflex mechanisms, and driving forces.[1] However, due to the non-stationary change of these biosignals, little is known about the cardio-respiratory interaction during anesthesia induction. Respiration oscillation can modulate autonomic nervous system activity and present as respiratory sinus arrhythmia (RSA). The kind of interaction between cardio-vascular and respiratory systems has been used as a monitoring index of sedation score and anesthesia depth. [2]

The exact mathematical relationship of interaction among physiologic systems is not fully understood. Presumptively, there is highly linearity among interaction of different physiologic system behaviors. Coherence analysis is a method of quantifying the existence and strength of linearity between system signals in frequency domain, with high linearity for coherence greater than 0.5.[3] Altered cardio-respiratory coherence is also noted in patients with acute severe brain disorders, or those under anesthesia.[4,5] However, most studies with coherence analysis are based on the assumption of stationary characteristics of system signals. Furthermore, most are focused on physiologic system behaviors under full spectrum (0-0.5Hz).

This study aimed to investigate the dynamics of cardio-respiratory interaction during anesthesia induction. Due to the non-stationary character of bio-signals during anesthesia induction, a time-frequency method of coherence has been developed to explore the dynamics of physiologic systems.

2 Methods

2.1 Study protocol

The local institutional review board approved the study and all patients had signed written informed consent before the anesthesia induction. The study enrolled 32 eligible adult patients (healthy patients or those with mild systemic diseases ASA I-II, aged 18-65 years) without cardio-vascular, pulmonary, endocrinologic, neurologic, or psychiatric disorders. All of them underwent elective surgery under general anesthesia..

The study patients were calm down and received continuous electrocardiogram (ECG), blood pressure (BP), pulse oximetry (SpO2), and respiration signal (end-tidal CO2; etCO2) monitoring once at the operation room. Anesthesia was induced by intravenous propofol infusion. Clinical endpoints included loss of consciousness, and apnea throughout the induction periods assessed by an independent anesthesiologist. The induction of anesthesia was completed by tracheal intubation in the presence of neuromuscular blocking agents The whole time course of propofol-induction was classified as follows: (1) stage 1, baseline; (2) stage 2, from start (S) to end (E) of propofol infusion; and (3) stage 3, from end (E) of propofol infusion to apnea (AP). There was no desaturation or unstable hemodynamics during the anesthesia induction.

2.2 Data acquisition and signal processing

The study used a portable measuring instrument (BP 508; Colin Co, Nippon, Japan) to acquire the cardiovascular (ECG) and respiratory (etCO2) signals. These signals were digitized onto a personal computer via analogue to digital conversion at a sampling rate of 500 Hz. Detection of peaks of R waves and calculations of RR interval sequences were performed. The RR interval sequence was converted into instantaneous RR time series re-sampled at 5 Hz. The respiratory signal was also down sampled to 5 Hz.

2.3 Short-time frequency transformation coherence

The coherence function of two time series signals was defined as their cross correlation, also known as the cross-spectral density normalized by the auto-spectral density of the two original signals.

$$C_{xy}(f) = \frac{\left|P_{xy}(f)\right|^2}{P_{xx}(f)P_{yy}(f)}$$

where x and y were the two time series signals. P_{xx} denoted the auto-spectral density of input signal x (respiration), P_{yy} denoted the auto-spectral density of output signal y (RR time series) and P_{xy} denoted the cross-spectral density.

In this study, to understand the short-term dynamics of cardio-pulmonary interaction during anesthesia induction, the time-frequency method (short-time Fourier transform, STFT) was applied to calculate the magnitude-squared coherence (MSC) between RR time series and respiration signal.[6] The power of each spectrum in MSC was calculated at different frequency bands. The very low (vLF), low (LF), and high (HF) frequencies were defined as 0 to 0.04 Hz, 0.04 to 0.15 Hz, and 0.15 to 0.50 Hz, respectively. Instantaneous coherence at one instant was calculated as the average of instantaneous MSC within these different frequency bands (i.e. coh-HF: 0.15-0.5 Hz; coh-LF: 0.04-0.15 Hz; and coh-vLF: 0-0.04 Hz).

2.4 Data analysis and statistics

The mean of instantaneous coherence within these different time intervals was calculated as the mean coherence (i.e. mean coh-HF, mean coh-LF, and mean coh-VLF) at different stages. Moreover, the study sought to investigate the change of linearity between RR signal and respiration signal, such that the percentage of time interval for instantaneous coherence greater than 0.5 at different stages was also calculated.

All of the time-frequency analysis of MSC was performed based on the software of MATLAB (MathWorks Inc., MA, USA).Analysis was carried out using the SPSS 11.0.1

software (SPSS Inc., Chicago, USA). Data were presented as mean ± standard deviation. Wilcoxon signed-rank test was used for two continuous dependent variables. A p value <0.05 was considered statistically significant.

3 Results

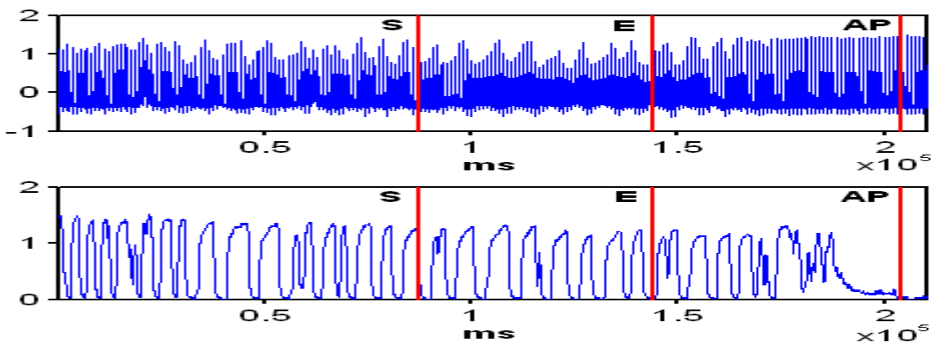
Demographic data in gender, age, body weight, and body height were shown (Table 1).

Male/Female	8/24
Age (yr)	45.44±10.26
BW(kg)	61.08±10.30
BH(cm)	160.29±5.93

Tab 1. Demographic data.

The original tracings of ECG and respiration signal in a patient during propofol induction were shown in Figure 1A. The time series of RR interval was shown in Figure 1B. The time course of changes of instantaneous coherence during anesthesia induction was shown Figure 2. There were increases in instantaneous coh-LF and instantaneous coh-vLF in the patient during anesthesia induction.

A



B

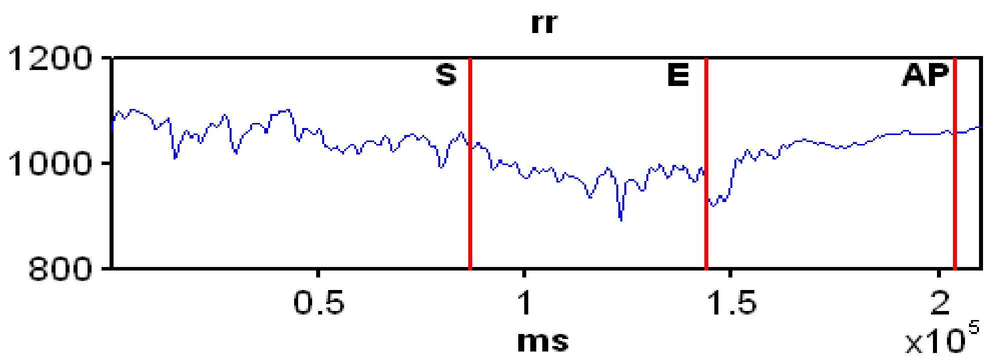


Fig 1. Under anesthesia induction, the subject's original tracings. A: upper and lower panels: original tracings of ECG and respiration signals; B: RR interval time series. S: start of propofol infusion; E: end of propofol infusion; AP: apnea.

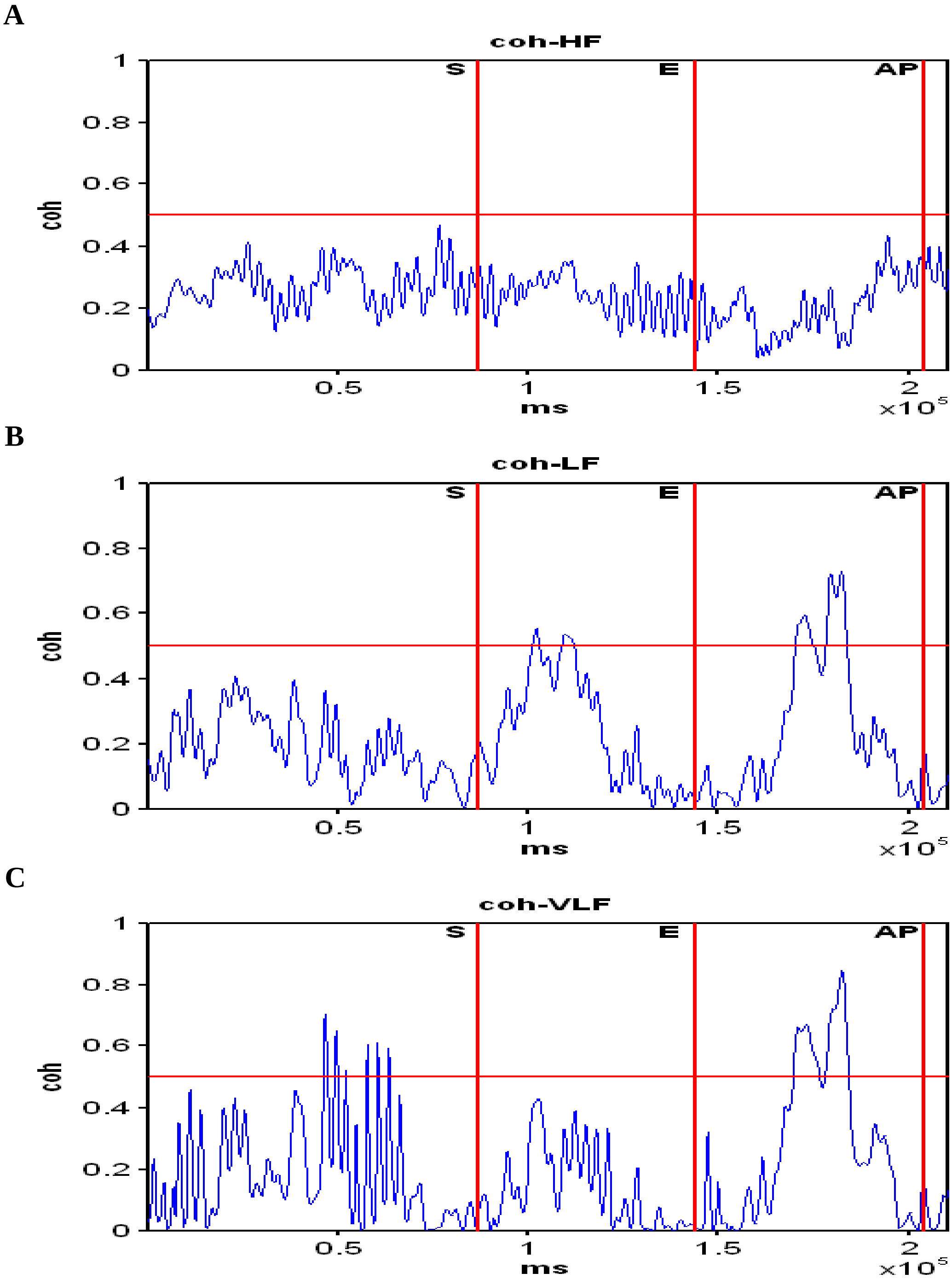


Fig 2. Under anesthesia induction, the subject presents increased instantaneous LF and instantaneous vLF coherences A: instantaneous coherence at HF band (0.15-0.5 Hz); B: instantaneous coherence at LF band (0.04-0.15 Hz); C: instantaneous coherence at vLF band (0-0.04 Hz). Red horizontal line represents coherence value equal to 0.5. S: start of propofol infusion; E: end of propofol infusion; AP: apnea.

During anesthesia induction, breathing frequency (BF 1/min) decreased significantly during stages 2 and 3 compared to stage 1. Furthermore, the mean HF band coherence decreased significantly during the induction period compared to the pre-induction period . Meanwhile, mean LF and vLF band coherences increased significantly. The numerical values of the above parameters were shown on Table 2.

To further investigate changes in linear interaction between cardio-vascular and respiratory systems, percentage of time interval for instantaneous coherence >0.5 was used as the evaluation index. Coherence >0.5 represented existence of linear relation between two system behaviors. The percentage of time interval for cardio-respiratory linearity significantly decreased at HF band during propofol induction. At the LF band, the patients had significantly increased percentage of time interval in stage 3 compared to baseline stage. At the vLF band, there was significantly increased percentage of linearity in stage 2 and stage 3 as compared to baseline stage during propofol induction. (Table 2)

	stage1	stage2	stage3
BF(1/min)	15.25 ± 3.19	13.19 ± 4.16*	10.13 ± 5.04*
Mean coh-HF	0.38 ± 0.12	0.33 ± 0.12*	0.26 ± 0.11*
Mean coh-LF	0.21 ± 0.07	0.27 ± 0.13*	0.24 ± 0.12
Mean coh-VLF	0.16 ± 0.07	0.21 ± 0.10*	0.24 ± 0.13*
Percentage of time interval for instantaneous coh-HF>0.5	0.26 ± 0.26	0.16 ± 0.25*	0.11 ± 0.18*
Percentage of time interval for instantaneous coh-LF>0.5	0.05 ± 0.07	0.15 ± 0.20	0.13 ± 0.19*
Percentage of time interval for instantaneous coh-VLF>0.5	0.06 ± 0.09	0.13 ± 0.14*	0.18 ± 0.20*

Tab 2. Breathing frequency, mean coherence and percentage of time interval for coh > 0.5 at different stages during anesthesia induction. Values expressed as mean ± standard deviation. * $p < 0.05$ as compared with stage 1(baseline stage).

4 Discussion

A previous study has demonstrated that anesthesia with sevoflurane is associated with an initial reduction and subsequent increase in cardio-respiratory coherence.[5] Galletly has found high cardio-ventilatory coupling in patients undergoing general anesthesia.[7] However, there is paucity of studies specifically on the cardio-respiratory interaction of the patients undergoing anesthesia induction. We developed a time-frequency coherence method to estimate the cardio-respiratory interaction in different frequency bands during anesthesia induction. It demonstrates that the trends of change in cardio-respiratory coherence depend on different frequency bands instead of a single band.

Cardio-respiratory coherence analysis can provide more information about the cardio-respiratory dynamics and autonomic nervous system functionality under different physiologic and pathologic conditions. The Zwiener's study also reveals severe acute brain disorder patients with low incidence of specific cardio-respiratory coherence pattern have poor outcome.[4] Our previous study with time-frequency method also revealed altered cardio-autonomic control during anesthesia induction.[8] As anesthesia with propofol induction, the current study reveals a reduction in mean HF coherence with increase in mean LF and vLF coherences, which may be associated with altered functionality of ANS during anesthesia induction. Besides, from the results of percentage of time interval for coherence greater than 0.5, the study also revealed loss of linearity of cardio-respiratory interaction at HF band, with increase of linearity at LF and vLF bands during anesthesia induction.

5 Conclusions

This study has successfully developed a time-frequency coherence to disclose the short-term dynamics of cardio-respiratory interaction in different frequency bands during propofol-induction. It demonstrates altered cardio-respiratory dynamics at different frequency bands during anesthesia induction.

Acknowledgement

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