ORIGINAL ARTICLE

ECG-Derived Respiration as a Screening Tool for OSA

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Abstract

Introduction: Respiratory rate is conventionally recorded using nasal thermocouples, spirometers and plethysmographs and is useful in ambulatory monitoring. As ECG is also a commonly used ambulatory diagnostic tool. An attempt has been made to derive respiratory signals from ECG in this study.

Methods and Materials: Development of the algorithm was based on the fact that respiration causes modulation of the R peak in the ECG. This algorithm was applied to signals acquired from Physionet, BioPac and Polysomnograms for validation.

Results: When the ECG-derived respiratory (EDR) signal obtained by applying the algorithm to ECG was correlated with traditionally recorded respiratory signals, the correlation coefficient ranged between 0.7 and 0.75. Besides, the plot of fast Fourier transform (FFT) of both signals was found to be similar.

Conclusions: This study can be further extended for real-time processing of signals in PSG. Besides, it can be used to detect apnoeas in patients undergoing Holter ECG.

Keywords: ECG-derived respiration, sleep apnoea

Introduction

Respiratory signals are traditionally recorded either by placing a nasal thermocouple at the nose or by wrapping a band with pressure sensors around the chest or abdomen. These methods are associated with some disadvantages. First, the device used might interfere with natural breathing. Second, such devices cannot be used in certain clinical situations like ambulatory or long-term monitoring in naturalistic settings. Third, these methods require the equipment to be connected to the patient during recording, which may lead to patient discomfort.

Owing to the above-mentioned reasons, the development of a convenient method to record or estimate respiratory signals is important from a clinical perspective. Since ECG is a commonly used ambulatory diagnostic tool, it is advantageous to investigate how a respiratory signal can be extracted from ECG. Such signals are called ECG-derived respiratory (EDR) signals.

Rationale for the study

ECGs recorded from the surface of the chest are influenced by the motion of electrodes with respect to the heart and chest, which in turn is influenced by changes in electrical impedance of thoracic cavity. Thus, changes in thoracic impedance reflect the filling and emptying of the lungs.

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These physical influences of respiration result in variation of R-wave amplitude. According to the dipole model of the cardiac electrical activity, respiration induces an apparent modulation in the direction of the mean cardiac electrical axis, which can then be correlated with respiration. By interpolating between axis measurements for each normal QRS, a continuous EDR or EDR signal can be obtained [1,2].

Wavelet transform can be used to extract respiratory signals from ECG by several decompositions of the original signal into subsignals [3]. This method involves more implementation complexity compared with the method stated in this paper.

This study aims to derive EDR values from ordinary ECG using the QRS amplitude algorithm. EDR values can be acquired from QRS area variations, and finally a respiratory waveform will be obtained through interpolation [4,5].

Comparison of this signal with a simultaneously recorded respiratory signal would help in validating the algorithm. This method is particularly effective if two or more lead ECG signals are used.

Materials and Methods

This study was carried out in three phases:

1. Deriving an algorithm using signals downloaded from a database.
2. Applying the algorithm to recorded ECG and respiratory signals from healthy volunteers using BioPac systems. Informed consent was obtained from all volunteers.
3. The algorithm was applied to overnight PSG data of patients with diagnosed obstructive sleep apnoea after obtaining Ethical Review Board clearance.

The steps involved in the algorithm are outlined in Figure1.

For signal acquisition from the BioPac system, ECG leads and transthoracic inductance bands were hooked onto volunteers in the supine position. Lead I configuration was utilised to obtain ECG signal, and the inductance band was used at the chest to acquire respiratory signals.

Signals from overnight sleep studies of patients were used in the final phase of validation. The respiratory signal obtained from the nasal cannula and from inductance bands were used to validate the EDR signal derived from Leads I and II of the ECG.

Statistical Methods

Applying the algorithm to the ECG signal yielded a respiratory signal (EDR) that was compared with the respiratory signal obtained using conventional methods, simultaneously recorded with ECG. This step was important for validation of the algorithm.

The EDR signal and the respiratory signal were subjected to fast Fourier transform (FFT) for comparison in the frequency domain. The plot of FFT of both the signals (EDR and respiratory signal) was found to be similar.

The correlation coefficient was also computed for better validation of the algorithm. The correlation coefficient was calculated using the formula given by:

$rxy = (n\sum xy - \sum x\sum y) / (\sqrt{}\sum(n\sum x2 - (\sqrt{}\sum x)2)) (\sum (n\sum y2 - (\sum y)2))$.

Further validation was conducted by finding the respiratory rate from the EDR signal and the original respiratory signal.

Results

Respiratory signals derived using conventional methods (nasal cannula and inductance bands in subjects undergoing polysomnography and inductance bands in the BioPac system) were compared with those derived from ECG after applying the algorithm and correlation between the two sets of signals was computed.

The correlation coefficient ranged from 0.7 to 0.75 for all subjects. This shows that the respiratory pattern of EDR and traditionally acquired respiratory signal are 70-75% similar. This has been depicted by plotting the number of subjects versus the correlation coefficient as shown in Figures 2a and 2b. Figure 3 shows that the respiratory rate from EDR and the conventionally acquired respiratory signal varies between 12 and 20 breaths per minute depending on the subject.

Discussion and Conclusions

ECG is a widely used tool in the clinical setting for continuous monitoring of heart rate. In this study, an attempt was made to derive a respiratory signal from ECG and a good correlation was obtained between a conventionally recorded respiratory signal and an EDR signal.

Multi-modality monitors that are presently being used in hospitals display respiratory signals, which have been derived from ECG, but this requires a special hardware

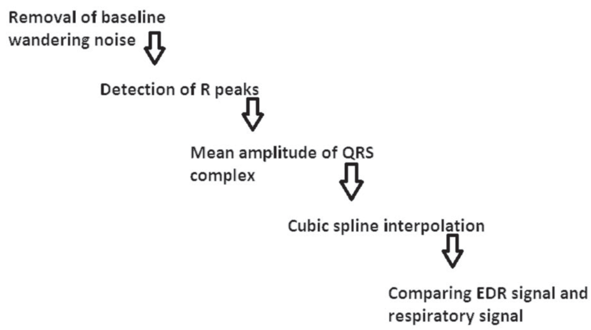
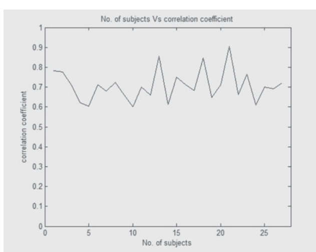


Figure 1: Steps in the algorithm



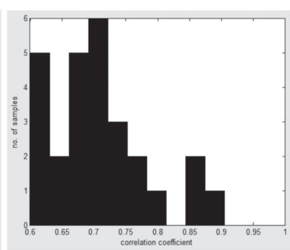


Figure 2a **Figure 2b**

Figure 2a and b: Correlation between EDR signal and conventional respiratory signal

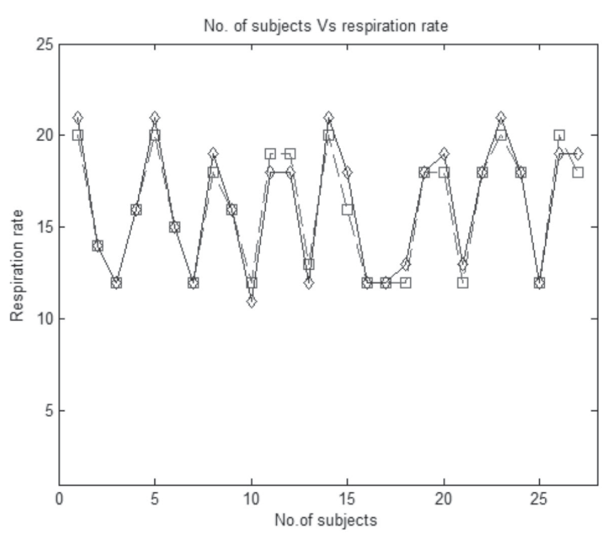


Figure 3: Comparison of EDR rate and respiration rate in individual subjects

as the signals are taken from electrodes placed on the patient rather than from the ECG signal. The method followed in this study is purely software based and therefore does not require additional hardware.

Since this study was based on the fact that respiratory movement causes modulation of the R-wave amplitude and respiratory sinus arrhythmia (RSA), the drawback associated is that RSA may not be pronounced in few subjects, and this may cause a variation in the derived signal and thus reduced correlation.

From the trial conducted on the data acquired from the data acquisition techniques, it was inferred that the ECG signal alone was enough to derive a respiratory signal with the correlation coefficient ranging between 0.7 and 0.75 for the EDR signal and the traditional respiratory signal.

This study can be further extended for real-time processing of signals in PSG. Since Holter ECG is performed for patients with suspected cardiac arrhythmias, the EDR method can be applied to obtain the respiratory rate and pattern along with the ECG and can also be used to detect obstructive sleep apnoea in patients undergoing Holter ECG [6][7] .

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