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Identification of Velcro rales based on Hilbert–Huang transform

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HIGHLIGHTS

- Based on HHT, many parameters having physical meaning were exacted.
- Features were exacted from lung sounds collected from an electronic stethoscope.
- It was proved that these parameters could be used for Velcro rales identification.
- Relatively high classification accuracy was obtained.

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ABSTRACT

Velcro rales, as a kind of crackles, are relatively specific for lung fibrosis and usually the first clinical clue of interstitial lung disease (ILD). We proposed an automatic analytic tool based on Hilbert–Huang transform (HHT) for the computerized identification of Velcro rales. In particular, HHT was utilized to extract the energy weight in various frequency bands (EW_{FB}) of crackles and to calculate the portion of crackles during late inspiration. Support vector machine (SVM) based on the HHT-derived measures was used to differentiate Velcro rales from other crackles. We found that there were significant differences in the extracted parameters between Velcro rales and other crackles, including EW_{75-200}, $EW_{500-1000}$ and the proportion of crackles that appeared during the late inspiration. The discrimination results obtained from SVM achieved a concordance rate up to 92.20% ± 1.80% as confirmed by the diagnosis from experienced physicians. For practical purpose, the proposed approach may have potential applications to improve the sensitivity and accuracy of auscultation and conduct automatic ILD diagnose system.

1. Introduction

Lung sound contains abundant information concerning the physiological condition of the respiratory system. As a simple and efficient medical device, stethoscope gives comparatively direct and objective information of patients to the physicians. Compared to other conventional diagnostic measurements such as CT scan, Chest X rays, varieties of blood tests and

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pulmonary function tests, the unique advantage of auscultation is that it provides a convenient, economic and noninvasive way for pulmonary diagnosis. Over the last 30 years, auscultation has been computerized. Application of the electronic stethoscope assisted the physicians to make permanent records of lung sounds and provide quantitative analysis for further investigation and understanding of the pulmonary diseases.

Velcro rales, which were referred to as fine crackles, are the soft, high-pitched and brief adventitious sound from patients with interstitial lung disease (ILD) [1]. The presence of Velcro rales in auscultation provides the most important evidence in the early diagnosis of ILD [2]. However, the transient time duration of crackles would make it difficult to identify Velcro rales, especially for physicians under poor listening conditions [3,4]. Moreover, individual variations due to differences in training, interest, and attention may often result in inter-examiner disagreement of crackles identification [5,6], or even misdiagnose and mistreatment.

Many efforts have been taken to exact features of Velcro rales for the computerized identification of ILD. These features are mainly from two aspects: time domain and frequency domain. In the time domain, the time expanded waveform analysis (TEWA) was widely used to quantitatively investigate crackles from morphology [7–11]. In the frequency domain, Fourier transform or wavelet transform was applied for various frequency distributions of different kinds of crackles [6,12–14]. However, there are still many problems that need to be solved: (a) lung sounds and crackle sounds are non-linear and non-stationary; (b) through respiration remove filter, the original waveform of crackle was probably disturbed and its time-domain parameters are vague [15]; (c) the information of crackle appearance time is important but difficult to be obtained just using the digital stethoscope, i.e. Velcro rales generally occur in mid to late portion of inspiration, while coarse crackles mostly appear in early inspiration [1].

In 2007, Villalobos et al. found that crackles could be separated from respiratory sounds using empirical mode decomposition (EMD) [16], which is the first step and main feature of Hilbert–Huang transform (HHT).

HHT, proposed by Huang et al. in 1998, is an innovative signal processing method [17], which can better extract intrinsic mode functions (IMFs) from non-stationary signals and enable the reliable assessment of instantaneous oscillatory frequency and amplitude at different times. It has been proved to be more reliable than the classical methods in describing the complex behavior of physiological and biological signals, such as electroencephalogram [18] and electrocardiogram [19]. Recent simulation studies have attempted to apply HHT to classify Velcro rales from coarse crackles [16,20,21], and provided evidence that the HHT can achieve better temporal-frequency resolutions for crackles analysis [20,21]. However, their works mainly focused on the characteristics of frequency distribution of single coarse and fine crackle. Moreover, compared to clinical lung sounds, the simulated data employed in those studies offer less helpful information for us to understand the real crackles.

In this work, we paid more attention on the statistical features of crackles acquired from patient data other than simulated data, aiming to extract physically meaningful parameters which could be used as potential markers for identifying different kinds of crackles. By using EMD, we obtained the respiratory sound and crackles at first. Then respiratory phase was exacted from the respiratory sound. Therefore, crackles appearance information was quantitatively acquired. Combined with the parameters characterized frequency distribution, which were calculated through Hilbert Transform, classification could be accomplished by using the support vector machine (SVM). Compared to the diagnosis made by experienced physicians, identification results show the advantage of exacted features mentioned above for computerized Velcro rales identification.

2. Material and methods

2.1. Study design and subjects selection

All data of this study were obtained from the Peking University First Hospital. Since this is a retrospective research, and we did not use any other information of patients, no statement of patient consent and approval of Internal Review Boards were included.

From Jun, 2009 to Dec, 2011, consecutive patients with crackles, who presented to the Respiratory Department, in either outpatient or in-patient settings were enrolled. High resolution thoracic computed tomography (HRCT) scans from the pre-operative period were obtained. Based on the auscultation and diagnosis, patients were then divided into 2 groups: (1) patients with uncomplicated ILD and fine crackles most during inspiration (Velcro rales); (2) patients with other pulmonary or cardiovascular diseases that caused coarse crackles in lung sounds.

Diagnoses were made by three independent experienced physicians based on patients' clinical information. Clinical examination was considered positive when the examiners provided the same diagnosis result. Only the patients with positive examinations ($n = 111$) were included in this study. Patients who were unable to be seated without assistance were also excluded.

Lung sounds from 111 patients with crackles (the mean age $\pm$ SD was 70.4 ± 10.2, 59 male and 52 female were included) were enrolled in this study. Among these 111 patients, 69 were diagnosed with ILD, 15 with congestive heart failure (CHF), 14 with chronic obstructive pulmonary disease (COPD), 6 with bronchiectasis, 4 with acute bronchitis and the remaining 3 with pneumonia. 1 patient with ILD combined COPD was excluded. 2 cases were excluded because complete clinical or radiographic data were unavailable.