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REAL TIME DETECTION OF S1 AND S2 HEART SOUNDS

S1 VE S2 KALP SESLERİNİN GERÇEK ZAMANLI TESPİTİ

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Öz

Giriş: S1 ve S2 kalp seslerinin otomatik algılanması, kalp sesini karar verme aracı olarak kullanan teşhis karar destek sistemleri için kritik öneme sahiptir. Literatürde offline çalışan karar verme yöntemleri mevcuttur fakat bu yöntemlerde analiz daha sonra yapılmaktadırlar. Bu yöntemler oskültasyonla eş zamanlı olmadıklarından da kullanımı pratik değildir. Bu çalışmanın amacı S1 ve S2'nin gerçek zamanlı tespiti için bir algoritma geliştirilmesidir. Materyal ve Metod: Toplam 25 hasta çalışmaya dahil edilmiştir. Grup 1 sağlıklı bireylerden oluşmaktadır. Grup 2, sistolik üfürümleri, diyastolik üfürümleri, fizyolojik veya paradoksal bölünmesi olan hastalardan oluşmaktadır. Grup 3, patolojik atriyal ve ventriküler gallop içermektedir. Önerdiğimiz yöntem önce ses verilerini filtrelemekte, sonrasında sinyal enerjisinden bir zarf oluşturmaktadır. Zarfın standart sapması, tepe tespiti için bir eşik değeri olarak kullanılmaktadır. S1 ve S2'nin şimdiki ve gelecekteki yerlerini ve kalp hızını tahmin etmek için ardışık üç tepe değeri kullanılmaktadır. Bu tahminler, bir sonraki kalp döngüsünün S1 ve S2 konumlarındaki yanlış yorumlamaları optimize etmek için kullanılır.
Bulgular: Grup 1, çalışma grubunun %24'ünü; Grup 2 hastaların %64'ünü ve Grup 3 hastaların%12'sini oluşturmaktadır. Grup 1, Grup 2 ve Grup 3 hastalarında tespit oranı sırasıyla %92, %75 ve %46'dır. Tüm çalışma populasyonu için toplam başarı oranı %75'tir.
Sonuç: Bu çalışmada, S1 ve S2'nin gerçek zamanlı tespitinin fizibilitesi gösterilmiştir. S1 ve S2 sesleri çoğu vakada belirgin olmamasına rağmen, yöntem Grup 2 hastalarında %75 başarı oranına ulaşmıştır. Grup 3 hastalarda başarı oranındaki düşüş görülmektedir. Bu durum ileri gallop vakalarında S3 ve S4'ün genellikle S1 ve S2 olarak yanlış yorumlanması nedenli olmaktadır ve bu sonuçlar literatürle uyumludur.

Anahtar kelimeler: Kardiyak oskültasyon, kalp sesi segmentasyonu, fonokardiyogram, S1 S2 algılama, zarf, gerçek zamanlı algılama

Abstract

Introduction:Automatic detection of S1 and S2 heart sounds is critical for diagnostic decision support systems that use heart sound as a means for decision making. There were previously suggested methods in the literature but offline nature of these analysis is impractical since the output is needed during the auscultation not later. The aim of this study was to provide an algorithm for real-time detection of S1 and S2.

Materials and Methods: A total of 25 patients were included for the study. Group 1 consisted of healthy individuals. Group 2 consists of patients with systolic murmurs, diastolic murmurs, physiological or paradoxical splitting. Group 3 consisted of pathological atrial and ventricular gallops. The suggested method first filtered the audio data then an envelope is constructed from the signal energy. The standard deviation of the envelope is employed as a threshold value for peak detection. Consecutive three peak values are utilized to estimate current and future locations of S1 and S2 and heart rate. These future estimates are used to optimize misinterpretations in S1 and S2 locations of the next heart cycle.

Results: Group 1 included 24% of the study group; Group 2 included 64% and Group 3 included 12% of the patients. The detection rate was 92%, 75% and 46% for Group 1, Group 2 and Group 3 patients, respectively. The overall success rate for all study population was 75%.

Conclusion: In this study, the feasibility of real time detection of S1 and S2 is shown. The method achieved 75 % success rate in Group 2 patients, although S1 and S2 sounds were barely visible in most of the cases. The fall in success rate in Group 3 patients is consistent with the findings in literature, since S3 and S4 are usually misinterpreted as S1 and S2 in severe gallop cases.

Keywords: Cardiac auscultation, heart sound segmentation, phonocardiogram, S1 S2 detection, envelogram

Introduction

Auscultation is a rapid and accessible technique for initial diagnosis and clinical follow-up of heart diseases. It provides invaluable data in undiagnosed valvular heart diseases and heart failure as a warning sign. In addition, it's concomitant utilization with other modalities have synergistic effect on diagnostic value[1]. Auscultation requires no complex equipment or hardware but only a stethoscope. Although it's use in subsequent diagnostic processes is limited compared to other sophisticated tools that has a higher sensitivity and less inter-observer variability i.e. echocardiography; auscultation continues to be the mainstay of initial clinical suspicion in cardiac diseases[2].

In recent years, by means of development in artificial intelligence, visual wavelets of auscultated heart sounds, stated in other words phonocardiogram, had been used to develop electronic stethoscopes. These devices use phonocardiogram to detect first heart sound (S1, lub) and second heart sound (S2, dub) as segments or lobes of sound waves and localize them in the cardiac cycle. Thereafter, further evaluation of each sound in terms of clinical significance can be possible. For detection of S1 and S2, algorithms using ECG reference or signal processing and/or statistics are utilized. One of two ECG-dependent methods performs ECG-based instantaneous energy detections; while the other initially detects QRS and T-waves; then localizes S1 with R-waves and S2 with T-waves synchronously[3,4]. Disadvantages of ECG-dependent methods are bulky equipment use; need for complex, elaborated placement of wiring on patient's chest wall and difficulties in synchronization of ECG and phonocardiogram. Besides, in cases where T-waves are not clear, ECG-independent methods are eventually employed to detect S2. ECG-independent methods use only phonocardiogram and include normalized average Shannon energy, high-frequency-based methods, and studies using statistical modelling like neural network classifiers and decision trees[5-8]. Other studies adding S1-S2 and S2-S1 interval recognition and further assumptions to these methods may improve classification performance but have use only in normorhythmic hearts[9].

In this study we aim to present an algorithm which detects S1 and S2 heart sounds in real time without ECG reference.

Materials and Methods

Study population consisted of three groups of patients: Group 1 included patients with normal cardiac auscultation findings. Group 2 consisted of patients with systolic murmurs, diastolic murmurs, physiological or paradoxical splitting. Group 3 consisted of pathological atrial and ventricular gallops. Examples of the study groups are shown in Figure 1. The proposed method starts with receiving raw audio signal from an e-stethoscope through the audio channel of the processing unit. The signal is first low-pass filtered then an envelope is constructed from the signal energy. The standard deviation of the envelope is employed as a threshold value for peak detection. Consecutive three peak values are utilized to estimate current and future locations of S1 and S2 and heart rate (Figure 2).

These future estimates are used to optimize misinterpretations in S1 and S2 locations of the next heart cycle.

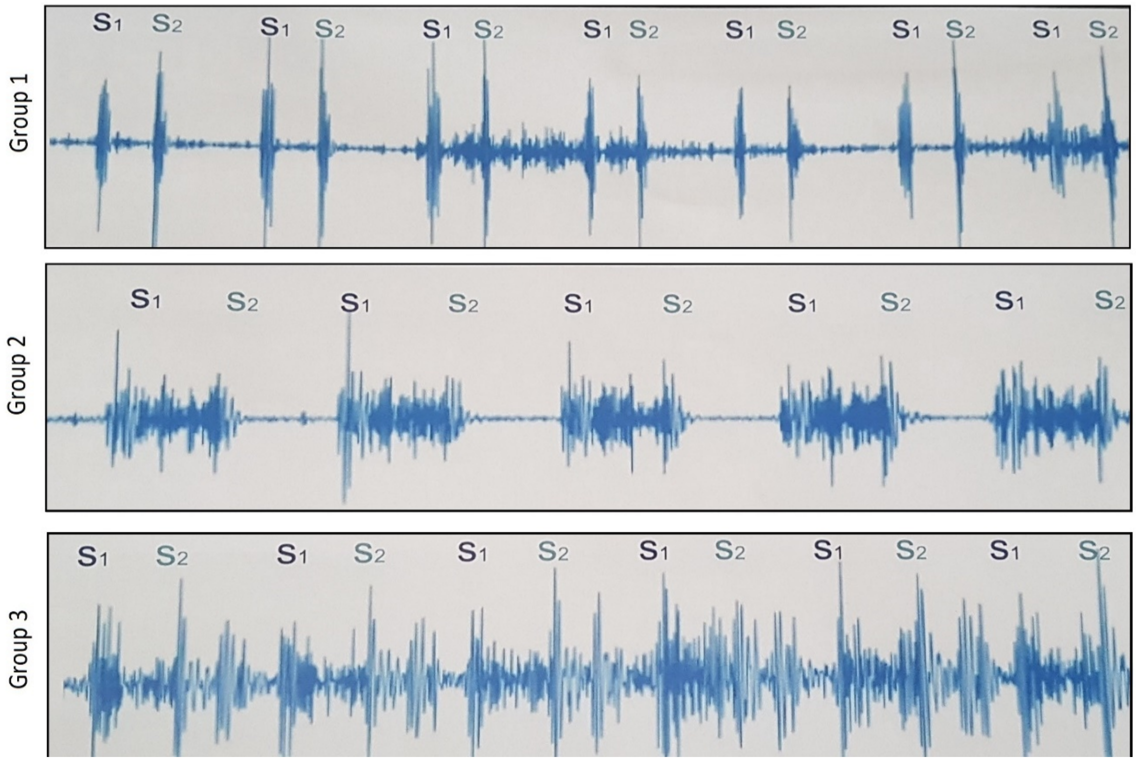

Figure 1 The examples for the patient groups.

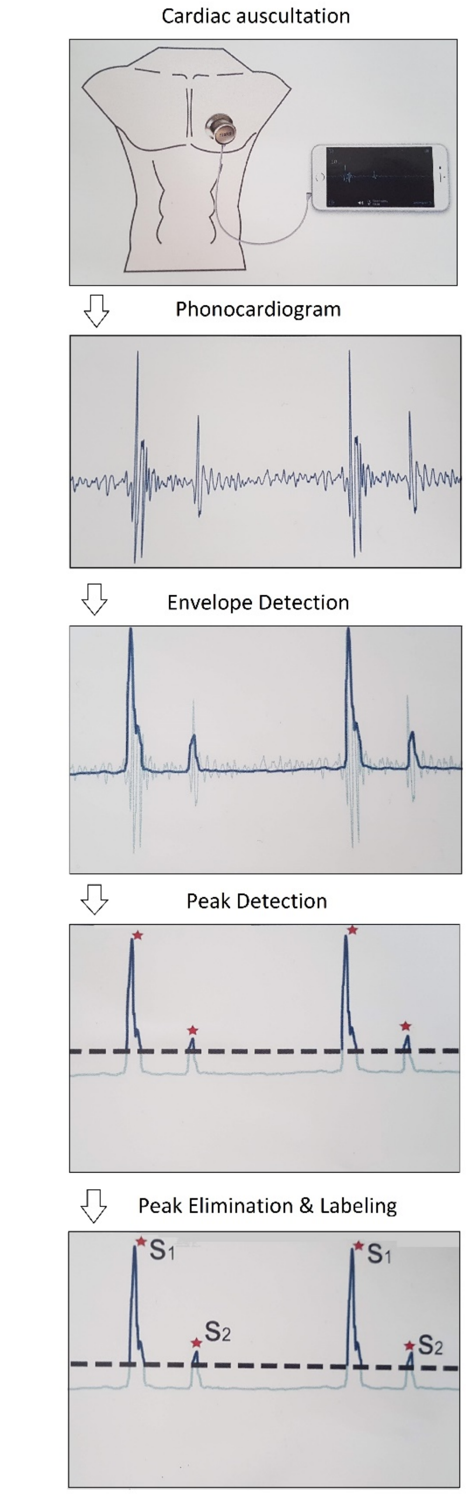

Figure 2 Steps of extracting S1 and S2 heart sound from raw audio data

Results

The performance of the algorithm was tested on a study population of 25 patients. Group 1 included 24% (n=6) of the study group; Group 2 included 64% (n=16) of the patients and Group 3 included 12% (n=3) patients. The detection rate was 92% for Group 1, 75% for Group 2 and 46% for Group 3 patients. The overall success rate was 75% for the whole study population.

Table 1 The success rates for each patient group

	Patients % (n)	Success Rate
Group 1	24% (n=6)	92%
Group 2	64% (n=16)	75%
Group 3	12% (n=3)	46%

Discussion

Our study aimed to detect S1 and S2 heart sounds in real time without ECG reference. While the success of the algorithm is higher in healthy individuals and individuals with systolic murmur, it is seen that the success rate decreases relatively when S3 is present.

We can simply divide the techniques used to distinguish S1 and S2 heart sounds into two ECG referenced and independent from ECG reference[10]. Techniques working with the ECG reference use the QRS wave on ECG to detect S1 and T wave to detect S2. One of the authors who detected S1 and S2 using QRS and T waves is El Segaier et al.[4] In the cases where ECG quality is lower and T waves are not clear, the method published by Carvalho et al.[11]

can be used. Techniques using ECG reference can give more precise results, but these methods require additional hardware to obtain ECG. Therefore, methods that do not use ECG reference are being developed.

Kumar et al.[10] developed a three-stage algorithm to detect S1 and S2 heart sounds without ECG reference. At the first they used a fast wavelet transform and Shannon energy to identify fundamental heart sound lobes. At the second stage the lobes are identified as S1 and S2 based on Mel-frequency coefficients and non-supervised neural network, and then the heart cycles are identified by a post-processing stage. Our algorithm also works on 3 stages. First, we extract the envelope of the phonocardiogram record. Then we make peak detection in the recording. Then we do peak elimination and labelling. An important difference from other studies is that we can make S1 and S2 detection in real time. In our study, we can connect the electronic stethoscope to the algorithm via mobile phone and perform S1 and S2 detection simultaneously. Also since the study of Kumar et al. was performed using prosthetic valve patients, it also differs from our study in terms of patient population.

Detection of S1 and S2 heart sounds is the basis for heart sound analysis. Because S1 and S2 are the heart sounds that should normally exist in healthy people and they are the basis for determining where all other sounds originate from. Gavrovska et al.[12] studied fractal theory and shape context to identify S1 and S2 heart sounds on pediatric population. This study presents a method to improve the structure characterization based on shape context and structure assessment. We didn't use fractal theory and shape context which is rarely used in S1 and S2 heart sound detection which is a major difference from this study.

Hassani et al.[13] presented a method to detect S1, S2 by using discrete wavelet decomposition and reconstruction to create phonocardiographic intensity envelopes. This method is tested in a various of clinical conditions in this paper. It is seen that when the cardiac pathology becomes more complex, the accuracy of the method decreases. In or study the accuracy for healthy subjects was 92% but if the patient has S3 heart sound, the accuracy of the algorithm decreases to 46%. S3 heart sound comes after S2. When the heart sound phonocardiogram is enveloped, the S3 heart sound manifests itself as another protrusion with its peak. This causes S3 heart sound to interfere with S1 or S2. For example, in our study there is holosystolic murmur in some of the Group 2 patients, and this murmur between S1 and S2 appears as a continuous activity on the phonocardiogram. Although this affects the appearance of S1 and S2, it does not disrupt the success of the algorithm as much as S3. Because, as in S3, the murmur does not have a separate peak. This confusion is a problem that can be fixed with the ECG reference, but as mentioned earlier, the algorithms with ECG reference require additional hardware and our aim is to ensure that we successfully differentiate S1 and S2, which are the basis of heart sound auscultation, using only our stethoscope and the suggested algorithm.

Conclusion

This proposed algorithm is a study that can detect S1 and S2 heart sounds in real time using only the electronic stethoscope and the algorithm. The total success of this method is 75%. The fall in success rate in Group 3 patients are consistent with the current literature since S3 and S4 are usually misinterpreted as S1 and S2 in severe gallop cases.

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Conflict of Interest

The authors declare that they have no conflict of interest

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