An Intelligent Method for Discrimination between Aortic and Pulmonary Stenosis using Phonocardiogram

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Abstract— ***This study presents an artificial intelligent-based method for processing phonocardiographic (PCG) signal of the patients with ejection murmur to assess the underlying pathology initiating the murmur. The method is based on our unique method for finding disease-related frequency bands in conjunction with a sophisticated statistical classifier. Children with aortic stenosis (AS), and pulmonary stenosis (PS) were the two patient groups subjected to the study, taking the healthy ones (no murmur) as the control group. PCG signals were acquired from 45 referrals to the children University hospital, comprised of 15 individuals of each group; all were diagnosed by the expert pediatric cardiologists according to the echocardiographic measurements together with the complementary tests. The accuracy of the method is evaluated to be 90% and 93.3% using the 5-fold and leave-one-out validation method, respectively. The accuracy is slightly degraded to 86.7% and 93.3% when a Gaussian noise with signal to noise ratio of 20 dB is added to the PCG signals, exhibiting an acceptable immunity against the noise. The method offered promising results to be used as a decision support system in the primary healthcare centers or clinics.***

Keywords— **Aortic stenosis, phonocardiogram, pulmonary stenosis, decision support system, primary healthcare centers.**

I. Introduction

Cardiovascular diseases are congenitally seen in about one percent of children at birth, among which 20% to 30% of them have valvular obstruction either in aortic or pulmonary valve [1]. An obstruction against the blood flow through the aortic or pulmonary valve is named, aortic stenosis (AS) or pulmonary stenosis (PS), respectively. Clinical diagnosis of the pediatric heart disease is preliminary based on the cardiac auscultation and thereafter a suspected patient is prescribed to undergo echocardiography together with appropriate complementary investigations for an accurate assessment [2]. Cardiac auscultation provides important information about the mechanical activity of heart, known as the phonocardiogram when it comes with the recording and/or displaying. A phonocardiographic (PCG) signal normally has two basic sounds: the first and second heart sounds. Valvular heart diseases mostly associate extra sounds to the PCG signal, whereas presence of an extra sound cannot be interpreted as a sign of a heart abnormality. Systolic murmur is a group of the extra sounds that can be heard in large number of children, even in the normal ones. Auscultatory manifestation of the both AS and PS is a systolic ejection murmur which is sometimes preceded by a systolic ejection click, the extra sound heard during the valve opening [2]. The murmur created by AS can be clinically differentiated from the one by PS as the later varies with respiration whereas the former is rather consistent over the cycles [2]. However, detection and recognition of the murmurs is a complicated task that needs both expertise and experience especially in children with high heart rate. Consequently, a large number of healthy children are sent to the hospitals by the practitioners in the primary healthcare centers or family doctors for cardiac examinations while a number of the diseased ones are overlooked. Studies showed that the screening accuracy is still low in the primary healthcare centers [3][4].

Several studies aimed to develop an accurate method for screening pediatric heart disease in favor of processing PCG signal [5][6]. Our previous study (internationally patented by patent publication number: US 2011/0021939 A1, PCT number: PCT/EP09/51410) proposed a novel method for classifying pathological heart murmurs based on the heart parts, initiating them [7]. The method showed high reproducibility after being tested by a large dataset from different individuals [8]. However, development of an intelligent method for finding the pathological part of the heart creating the murmur has been considered as a research gap. Discriminating between the pathological murmur caused by AS and PS corresponds to a particular, but important, application of this context.

This study presents a method for discrimination between AS and PS by analyzing systolic murmur. Our previous studies proposed efficient methods for detecting AS using the PCG signal [9][10]. However, accuracy of the proposed methods might be impaired due to the PS as the murmurs are similar. The method of this study, serves as a secondary classification to our previous methods towards diagnosing

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the heart part, creating the murmur. They can be ultimately incorporated into a portable computer to be employed by the practitioners, nurses or family doctors to improve the diagnosis accuracy in the primary healthcare centers.

II. MATERIALS AND METHODS

A. Data preparation

The PCG signals were recorded from 30 pediatric voluntaries, referred to the Tehran University hospital of Children Medical Center, due to the ejection murmur. Our reference group is comprised of 15 normal individuals to this hospital, previously detected as having innocent murmur, referred for the regular checkups. The synchronous ECG signal was recorded together with the PCG for the accurate segmentation as well as demonstration. An electronic stethoscope of WelchAllyn Meditron Analyzer along with a DELL laptop equipped with a 16 bit sound card was used for data acquisition. Each recording contains 10 second of the synchronous 16-bit PCG and ECG, with a sampling frequency of 44100 Hz. All the referrals underwent echocardiography and gave their informed consent to participate in the study according to the Good Clinical Practice (GCP). The study conformed to the World Medical Association and Declaration of Helsinki, and approved by the institutional review board of ethics. Table 1 shows characteristics of the participants.

Table 1 The patient characteristics of the three groups: healthy (NM), aortic stenosis (AS) and pulmonary stenosis (PS)

Total number of patients	45
Number of patients with AS	15
Age range of the AS patients (years)	1 – 8
Average age of the AS patients ± SD (years)	3.7 ± 2.3
Number of patients with PS	15
Age range of the PS patients (years)	1 – 10
Average age of the PS patients ± SD (years)	4.2 ± 2.9
Number of patients with NM	15
Age range of the NM patients (years)	2.5 – 12
Average age of the NM patients (years)	6.2 ± 2.2

B. The processing method

A PCG signal is preprocessed and segmented prior to the processing. The preprocessing includes down-sampling and signal conditioning. The segmentation phase involves our automatic method for annotating the systolic part of each cardiac cycle, locating between the end of the first heart sound and the beginning of the second heart sound. Details of the segmentation process are found in [11] and [12]. The main contribution of this study corresponds to the processing method through which the systolic parts of a PCG signal is ultimately mapped to a binary number, indicating whether the murmur is caused by AS or PS.

Our processing method relies on the fact that the spectral content of a heart murmur relates to the heart part initiating the murmur [7]. Figure 1 demonstrates two PCG signals, from the patients with AS and PS, together with the corresponding power spectral density function obtained by using periodogram [7]. As can be seen, the two murmurs show slightly discriminant over a certain frequency range. Nevertheless, the discriminative band should necessarily be obtained in a statistical fashion to cope with the non-stationary properties of the PCG signal.

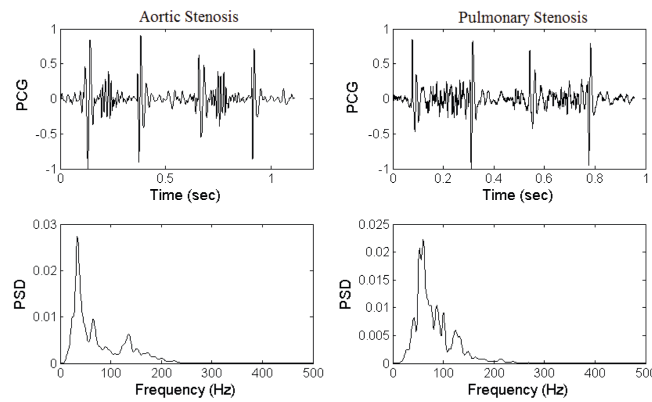

Fig. 1 PCG signal of a child with aortic stenosis (top-left), pulmonary stenosis (top-right) and the corresponding power spectral density function (PSD) represented below the graphs

We use our original algorithm for finding the two discriminative frequency bands for the AS and PS, providing an optimal segregation. The algorithm which has been internationally patented (patent publication number: US 2011/0021939 A1, PCT number: PCT/EP09/51410), employs the discriminant analysis for finding the bands. Details of the method are found in [7]. Spectral energy of a PCG over the bands, serves as an input for the classification. The discriminative frequency band is separately found for the AS and PS, taking the reference group as the baseline. Then, the memberships to the two classes are estimated by finding the statistical distribution function of the spectral energies for the both classes. The membership values are employed by a binary classifier for the final classification. The support vector machine technique was favored to this study as the binary classifier due to its convexity and robustness to the outlier values [13]. We employed the quadratic kernel for the nonlinear classification.

It is important to note that the main objective of this study is to discriminate between AS and PS where the signal has already been diagnosed as having a pathological ejection murmur.

C. Evaluation

The method is evaluated by using two well-known validation methods: the 5-fold and leave-one-out method. In the 5-fold validation, both of the groups (AS and PS) are separately partitioned into 5 non-overlapping subsets with equal length (3 individuals). Then, one subset from each group is selected for testing and the rest for training the method. This procedure is repeated 5 times, such that each recording is used only once for the testing. In the leave-one-out validation, a single recording is employed for the testing and the rest for training. This procedure is repeated 30 times with each recording is used exactly once for the testing. The accuracy P_{ac} is selected as the performance measure for the both validation methods.

$$P_{ac} = \frac{100\left(N_{TA} + N_{TP}\right)}{N_{TA} + N_{TP} + N_{FA} + N_{FP}}$$

where N_{TA} and N_{TP} are the number of correctly classified signals for AS and PS, respectively. N_{FA} and N_{FP} are the number of incorrectly classified for the AS and PS, groups.

III. Results

The spectral features are evaluated by depicting the scatterplot of the membership values. Figure 2 represents the membership values.

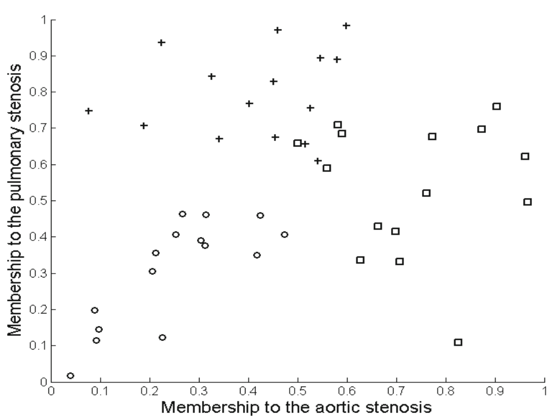

Fig. 2 The membership value of the spectral features to the two classes: aortic stenosis (AS) and pulmonary stenosis (AS). The AS, PS and healthy, are denoted by □, + and ○, respectively.

As could be seen, the membership features provides a noticeable segregation. In order to quantitatively evaluate the performance of the method, the 5-fold and leave-one out procedures are employed. Table 2 lists results of the validation. The high performance in discrimination is implied from the results, confirming the discrimination power depicted in Fig. 2.

In order to verify robustness of the method against the background noise, a white noise is added to the recordings and the same validation procedures are applied. Table 2 shows the results, obtained by using the contaminated signals.

Table 2 Results of the validation with and without the Gaussian background noise

	5-fold (%)	Leave-One-Out (%)
Without noise	90.0	93.3
With noise	86.7	93.3

The performance of the method is not substantially impaired by the background noise, exhibiting sufficient robustness against the background noise.

IV. Discussion

This paper suggests an artificial intelligence-based method for processing the PCG signal in order to discriminate between two important valvular heart diseases in children, aortic and pulmonary stenosis. The proposed method can be integrated in our previous intelligent methods to increase the accuracy of AS screening. It can also open the way toward the development of an automatic device for the cardiac assessments.

In order to obtain a solid understanding about the performance of method, there is a need to a larger database with a broader range, since the method relies on the statistical techniques for the classification, where the training data plays an important role in learning. On the other hand, a broader database provides a way for the coarser segregation, by finding different discrimination band for different degrees of the underlying pathology. This might lead to the severity assessment which will outspread applicability of the method to the clinical setup.

One of our recent studies suggested a novel method for screening systolic ejection click, the pathological sign that can be heard in children with the mild obstruction [14]. Obviously, integration of the two methods can improve the ultimate accuracy for a large database as the click is respiration-dependent for the PS cases, in contrary with the AS [1]. Taking this dynamic behavior of the PS-related murmur into account can provide further enhancement on the performance of the method.

In this study, the proposed method was evaluated by using the 5-fold and leave-one-out methods, since the group size of the classes is relatively small. For a larger database, a repeated random sub sampling gives a better evaluation as different combination of the training and testing data are employed. It can also turn out to estimating the corresponding confidence interval.

The method has the potential to be evolved for diagnosing more disease-related murmurs by adding the corresponding spectral energies and membership functions in conjunction with a multi-class support vector machine.

Incorporation of the proposed method into a portable computer along with the other related method provides either a screening device for the primary healthcare centers or decision support tool for the clinics to decrease unnecessary echocardiography which is by far a more expensive approach.

V. Conclusions

This study presented a processing method for discrimination between the murmur caused by AS and the one by PS. The method is based on our unique method for finding the disease-related frequency bands. The 5-fold and leave-one-out validation evaluated the accuracy of the method to be 90.0% and 93.3%, respectively. The proposed method can be incorporated into the existing methods to provide a noninvasive and inexpensive decision support tool for cardiac examinations.

Acknowledgments

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Conflict of Interest

The authors declare that they have no conflict of interest.

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