An Internet-Based Tool for Pediatric Cardiac Disease Diagnosis Using Intelligent Phonocardiography

Arash Gharehbaghi(✉) and Maria Lindén

Department of Innovation, Design and Technology,
Mälardalen University, 72123 Västerås, Sweden
{Arash.ghareh.baghi,Maria.linden}@mdh.se

Abstract. This paper suggests an internet-based tool for cardiac diagnosis in children. The main focus of the paper is the intelligent algorithms for processing heart sounds that are implementable on an internet platform. The algorithms are based on the statistical classification methods, tailored for the heart sound signal processing. The algorithms, applied to 55 healthy and 45 children with congenital heart diseases. The accuracy of the algorithm is estimated to be 86.0 % in screening the children with pathological murmurs, and 95.7 %, 92.9 % and 91.4 % in detecting the children with aortic stenosis, pulmonary stenosis and mitral regurgitation, respectively, showing an acceptable performance to be employed as a decision support tool.

Keywords: Heart sounds · Phonocardiogram · Intelligent phonocardiography · Artificial intelligence

1 Introduction

Timely assessment of a pediatric heart disease plays an important role in the disease management. The assessment is firstly performed by physicians using heart sound auscultation. Then, the diseased children are often supervised by pediatric cardiologists for finding appropriate therapeutic procedure after being precisely investigated. Phonocardiogram is a recording of the acoustical wave, emanating from heart, so called heart sound. Heart sound auscultation is a complicated task which needs expertise and experiences especially in children with high heart rate. However, access to expert cardiologists is not easy especially in the developing countries and rural places. This makes development of an internet-based decision support system been sophisticated for pediatric cardiac disease, a priority by which the screening, assessments and supervision is remotely feasible. The key part of such a system is the automatic algorithm for processing heart sounds that attributes intelligence to the system. Our long term studies on heart sound signals revealed that screening of congenital heart disease with sufficient accuracy and sensitivity is possible [1, 2]. The studies have been continued toward extracting diagnostic features from the heart sound which may eventually lead to an automatic system for the disease diagnosis [3–5].

This paper presents an internet-based tool for timely screening of pediatric heart disease using heart sound signal. The main focus of the paper is on the automatic

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processing algorithms for screening diseased children and extracting pathological signs from the heart sounds. The resulting system, which we call the intelligent phonocardiography, offers a noninvasive, inexpensive and easy-to-use approach for cardiac diagnosis, employable by the nurses, practitioner or family doctors in primary healthcare centers to increase diagnosis accuracy, as studies showed that the screening accuracy is still low in these centers [6, 7]. This causes a large number of the children with normal heart to be referred to the referral hospitals, and on the other hand a number of the diseased children to be overlooked, during cardiac auscultation in the primary healthcare centers. The proposed system can drastically decrease unnecessary echocardiography, which is by far a more expensive approach.

2 Backgrounds

Phonocardiogram is a rhythmic signal, characterized as having two basic sounds; the first heart sound (S1) and the second heart sound (S2). The rhythm frequency and the cycle period are termed as the "heart rate" and "cardiac cycle", respectively. S1 is a result of the closure of the mitral and tricuspid valves, where the tricuspid component follows the mitral ones. Closure of the aortic and pulmonary valves, creates the second heart sound. In contrary to the basic sounds, there may be extra sounds in each cycle, heard between the basic sounds. The temporal interval between S1 to S2 is called "systolic phase" while the one between S2 to S1 is termed by "diastolic phase". An extra sound can be considered as a sign of the cardiac abnormality; however, the presence of the extra sounds is not necessarily a sign of the disease. The extra sounds, caused by the heart defects, are called pathological sounds, in contrast with the physiological ones, which are initiated by a healthy heart. Prevalence of the physiological murmurs can be as high as 70 % [6, 7]. Heart murmur is a group of the extra sounds that can be heard either in systolic or in diastolic phase. Systolic murmur is by far the most important extra sounds as can be considered either as a physiological sound, called innocent murmur, or as a pathological sound in valvular or septal defects. Auscultating and interpreting heart sounds along with the discrimination between pathological and physiological murmurs, are complicated tasks.

3 Methods

The method is based on performing a first level of analysis, aimed to detect the presence of a pathological murmur. The phonocardiogram (PCG) with a detected pathological sign is sent to the server where an expert physician investigates the PCG using our complementary intelligent methods. Figure 1 illustrates functional block diagram of the tool. The PCG signal is automatically segmented, where the S1, S2 along with the systolic and diastolic phases are annotated on the recording. Details of our automatic algorithms for PCG segmentation can be found in [8, 9]. The segmented PCG is processed through our unique intelligent method based on the combination of the neural network and discriminant analyses. This method which has been internationally patented (patent publication number: US 2011/0021939 A1, PCT number: PCT/EP09/51410)

performs a binary classification on the segmented PCG and sends the pathologically detected recording to the server for the further analysis. Details of the method are found in [1]. The transferred recording is investigated by the physicians who use our complementary intelligent analysis to explore the presence of the valvular diseases, by invoking temporal and spectral representation of the recording. This level of processing is preferred to be performed by a physician who is accustomated to the phonocardiogram, as the outcomes convey medical information regarding the pathology. Accurate interpretation of these signs, and sometimes proper employment of the proposed methods [10–13], needs some extent of the medical background.

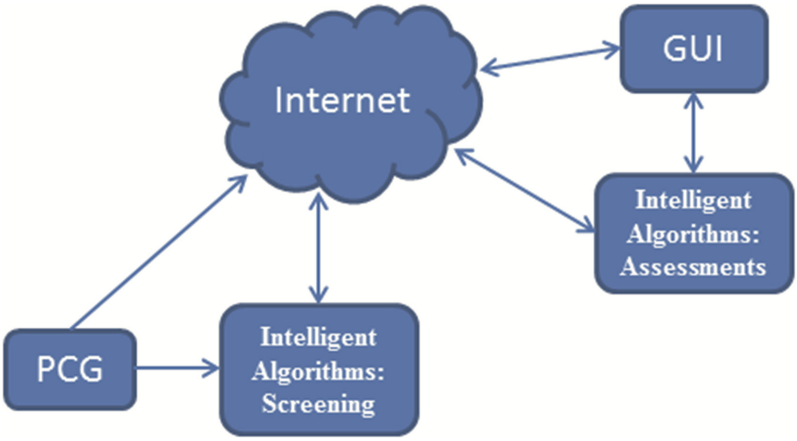

Fig. 1. Block diagram of the tool.

4 Data Preparation

PCG signals of 10 s duration were acquired from the referrals to the Children Medical Center of Tehran University. All the referrals or their legal guardians gave their informed consent for record and use of the data prior to undergoing echocardiography, according to the guidelines of the University which are in compliance with the Declaration of Helsinki. A WelchAllyn Meditron Analyzer electronic stethoscope together with a Dell laptop equipped with 16 bit soundcard was used for data acquisition. The characteristics of the patient population are listed in Table 1.

Table 1. The patient characteristics.

Condition	Number	Age (year)
Normal	30	3–15
Innocent murmur	25	2–14
Aortic stenosis	15	1–8
Pulmonary stenosis	15	1–10
Mitral regurgitation	15	4–18

5 Results

Performance of the intelligent methods was differently evaluated using the leave-one-out method where accuracy and sensitivity were considered as the performance measures. In the leave-one-out method, one patient is employed for testing and the rest for training the method. This procedure is repeated *N* times, with each single patient used only once for testing, where *N* is the total number of the patients. The accuracy and sensitivity were defined as the percentage of the total referrals and unhealthy patients which were correctly classified by the method, respectively. Table 2 demonstrates results of the evaluation.

Table 2. Results of the leave-one-out validation for the screening and assessment.

Group	Accuracy (%)	Sensitivity (%)
Pathological murmurs	86.0	86.7
Aortic stenosis	95.7	93.3
Pulmonary stenosis	92.9	86.7
Mitral regurgitation	91.4	80.0

Remark. In the accuracy calculation, either for the screening or the assessment, an abnormal group was compared against the healthy group including the normal and the innocent murmur.

6 Discussion

This study suggested the use of the modern artificial intelligence method for cardiac diagnosis in children, where an internet platform serves as the communication tool providing a connection among the patient, nurse and cardiologist. Results showed that the constituted tool, which we call intelligent phonocardiography, has the potential to be employed in the clinical settings as a decision support system for an enhanced diagnosis, as the accuracy of the intelligent algorithms show superior performance comparing to the physicians. However, unlike the screening task, the ultimate assessment for the management should be performed by the cardiologists who use echocardiography, due to complexities in the management and disease control. Nevertheless, the intelligent methods provide important clues even for the cardiologists.

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