CARDIAC DIAGNOSING BY A PIEZOELECTRIC-TRANSDUCER-BASED HEART SOUND MONITOR SYSTEM

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Keywords: Piezoelectric transducer (PZT) sensor, Heart sound, Super low frequency sound, Cardiac diagnosis, Phonocardiographic diagnosis.

Abstract: A variety of diagnosis that auscultation enables is not necessarily conducted thoroughly by all of the physicians because of its difficulty in judging by means of listening to evanescent sounds with their ears. A system that displays heart sounds continuously on a computer screen may be convenient for cardiac diagnosis. Recently, we made a monitor system with employing a piezoelectric transducer (PZT) sensor, which detected 1st and 2nd sound and murmurs clearly. In addition, the sensor was capable of detecting inaudible low-frequency sounds of below ~20Hz. Using the PZT sensor, we recorded heart sounds at left second intercostals space in 12 patients susceptible to cardiac diseases in parallel with ECG recording, and analysed the raw heart sounds and band-pass (20–100 Hz) filtered signal. Second sound in the filtered signal was completely or often absent and/or a sharp deflection, which appears coincidently with R wave, with a peak-peak voltage of >20 mV and a duration of <25 ms was missing in the raw sound signal in 90% (9/10) of the patients diagnosed as having cardiac dysfunctions. Thus, we believe that the PZT-based heart sound monitor system may contribute to the advance of the phonocardiographic diagnosis of cardiac diseases.

1 INTRODUCTION

The stethoscope was invented by Laennec in 1816 and a diaphragm stethoscope, which was invented by Bowels in 1894, made a great progress in stethoscope as it increased the sensitivity in mid-high frequency range to detect heart sounds (1st and 2nd sound) clearly. However, the diagnosis by auscultation is not necessarily conducted by all of the physicians because of its difficulty in judging by means of listening to evanescent sounds with their ears. A monitor system that enables us to observe those heart sounds continuously on a computer screen may be of help for the phonocardiographic diagnosis of cardiac dysfunctions.

Monitoring of heart sound using a piezoelectric transducer (PZT) sensor seems to be an alternative to the auscultation using a stethoscope. In fact, we were able to continuously observe the heart sound signal of an anesthetized small animals on a computer screen using the PZT sensor (Sato et al., 2006; Japan patent 4015115; US patent 7174854) with a custom heart-sound detector circuit (Sato., 2008). Furthermore, the PZT sensor was capable of analysing the change in development of cardiac function during the early postnatal period in mice (Sato, 2008). Following the animal experiments, we performed long-term measurements of heart rate of newborn infants in the neonatal intensive care unit (NICU) with a PZT sensor that was modified for the use for the neonates. The study demonstrated that

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the PZT sensor is quite non-invasive and practically available as a cardio-respiratory monitor for use in the NICU (Sato et al., 2010). Recently, we have made a new heart sound monitor system with employing a PZT sensor (patent pending), which can be used as a stethoscope and detected 1st and 2nd sound and murmurs as clearly as an electronic stethoscope did. In addition, the sensor was capable of detecting inaudible low-frequency sounds of below ~20Hz (super low frequency sound). In the present preliminary study, we recorded heart sounds at left second intercostals space in 12 patients susceptible to cardiac diseases using the PZT sensor in parallel with ECG recording. Then we analysed the raw heart sounds and band-pass (20–100 Hz) filtered heart sound signal to find out the differences between the patients with and without cardiac dysfunctions.

2 METHOD

2.1 PZT Heart Sound Monitor System

The PZT heart sound monitor system consists of a PZT sensor, A/D converter (Power Lab 26T, ADInstruments) and a computer, which contains a signal analysis software (Chart5, ADInstruments) (Fig. 1). The first prototype PZT sensor consists of a plastic cylinder (20 mm outer diameter, 90 mm long and 1 mm-thick wall) and a disk-shaped thin ceramic-PZT (20 mm diameter), which was adhered on one open edge of the cylinder.

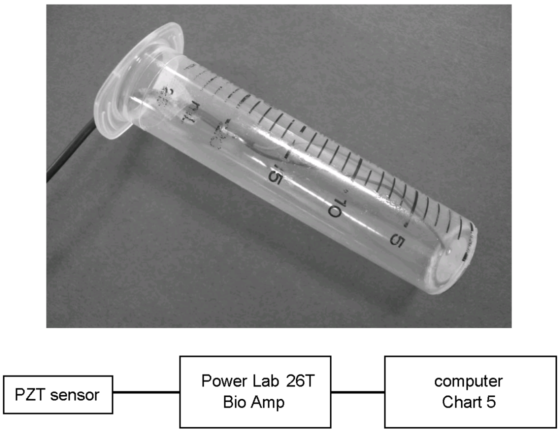

Figure 1: A photograph of the first prototype PZT sensor (upper) and block diagram of the PZT heart sound monitor system.

2.2 Output Signal of the PZT Sensor and an Electronic Stethoscope

Although the PZT sensor detects a wide frequency range of heart sound from a patient including super low frequency sound of below ~20Hz, first and second heart sound signals were clearly separated from the PZT-sensor output signal by filters with pass band of 20–100 Hz, which were comparable with heart sounds obtained by an electronic stethoscope (Littman Model 3100) from the same patient as shown in Fig. 2.

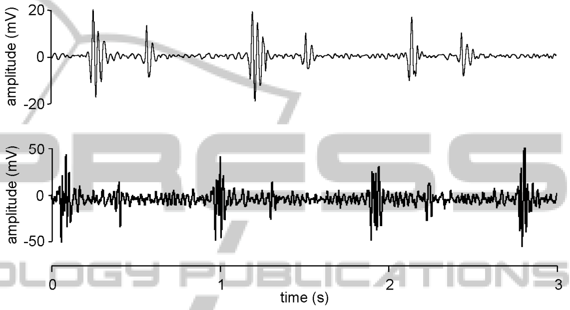

Figure 2: Heart sounds obtained by the PZT sensor (upper) and an electronic stethoscope (lower).

2.3 Cardiac Signal Recording

Twelve outpatients who visited to the cardiology outpatient department (internal medicine) in the Akita University Hospital were enrolled in this study. In parallel with ECG recording, cardiac signal recording by the PZT-sensor was performed at second, third, fourth and fifth left-intercostals spaces (apex region) in addition to the second right-intercostals space of the patients. Each recording time at these sites was within 10 seconds and stored into a computer at a sampling rate of 5 kHz. Sound filtering condition was set by using the Chart5 software for the separation of 1st and 2nd sounds from other lower frequency components.

2.4 Heart Sound Analysis

In the present study, the analysis of heart sounds was performed with the signals obtained at the left second intercostals spaces of the patients. The raw heart sound signal was analyzed with focusing on the period of the QRS wave of simultaneously recorded ECG. A sharp deflection, which appeared coincidently with R wave, was measured by its peak-to-peak voltage (Vp-p, mV) and its rising or falling time (ms: duration). While, the 1st and 2nd

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sounds in the band-pass filtered PZT sensor signal were qualitatively scored as “Y” (perceivable) or “N” (non-perceivable). Regardless of the sound analysis, cardiac diagnosis of the patients was performed in a conventional way by a physician in the cardiology outpatient department.

3 RESULT

According to the result of diagnoses conducted by the physician in the cardiology department, 10 out of total 12 patients had following one or several cardiac dysfunctions; aortic valve regurgitation (AR), mitral valve regurgitation (MR), pulmonary valve regurgitation (PR), Aortic valve sclerosis (AVS), or dilated cardiomyopathy (DCM). In the heart sound analysis, second sound in the filtered signal [arrows at middle trace in Fig. 3(a)] was completely or often absent in 6 out of the 10 patients who had above described cardiac dysfunctions [middle trace in Figs 3(b) and (d)].

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Table 1: Results of cardiac diagnosis and sound analysis.

patient	*heart disease*	*2nd sound*	*Vp-p (mV)*
1	normal	Y	58
2	AR, MR, PR	Y	-
3	AR, MR, PR	N	-
4	DCM	N	-
5	AR	N	27.6
6	MR, PR	Y	10.5
7	MR, PR, DCM	Y	-
8	normal	Y	25.5
9	AVS	N	22.5
10	AR, MR, PR	N	-
11	MR	Y	58.4
12	AR	N	-

Furthermore, a sharp deflection [arrows at top trace in Fig. 3(a)], which appears coincidently with R wave in healthier patients, with an average of three consecutive peak-to-peak voltages (Vp-p) of >20 mV and a duration of <25 ms was missing in the raw sound signal in 7 out of the 10 cardiac patients [top trace in Figs 3(b) and (d), Table 1]. Accordingly, patients who had at least either one of above 2 heart sound deficits were 90% (9/10) of the patients diagnosed as having cardiac dysfunctions. Two other patients were scored as normal with cardiac function by both the sound analysis and a diagnosis conducted by the physician.

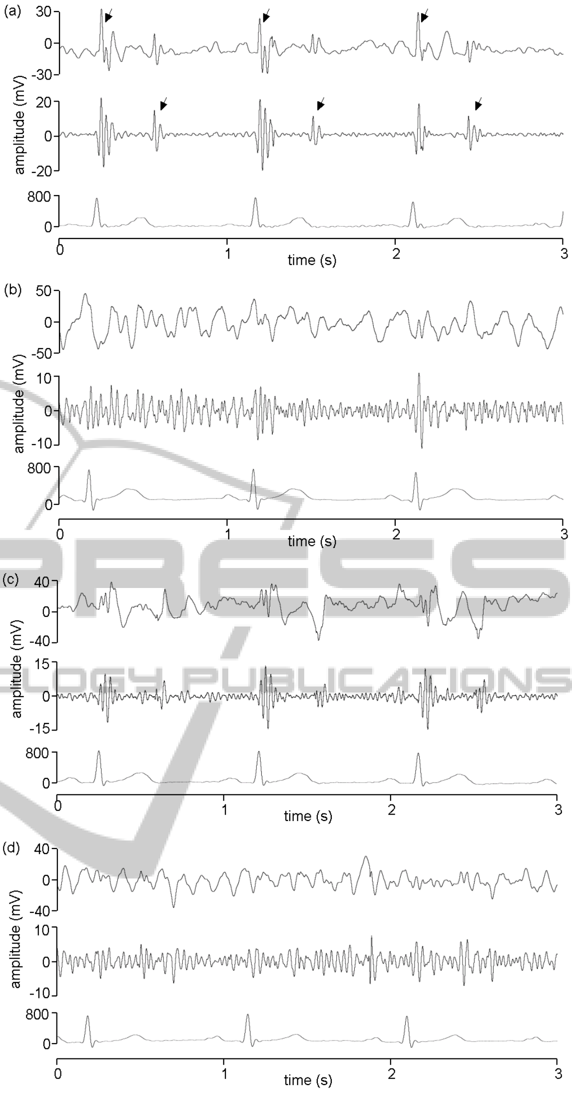

Figure 3: From top to bottom trace; raw heart sounds, band-pass filtered heart sounds, and ECG of (a) patient #1 with normal cardiac function and patients (b) #3, (c) #6, (d) #10 with cardiac dysfunctions as shown in Table 1.

4 DISCUSSIONS

Since two decades ago, many researchers argued the possibility in analysing cardiac function by using heart sounds or phonocardiogram signal processing technique (Rangayyan and Lehner, 1988; Durand and Pibarot, 1995; Manecke et al., 1999). Electronic stethoscope, though it is cutting edge equipment and commercially available these days, it seems that it still not has an overwhelming advantage against the conventional stethoscope.

The striking difference between our PZT heart sound monitor system and the electronic stethoscope is the sound detection element; a small vibration detecting PZT disk adhered on the top of a plastic cylinder (Fig. 1) directly touch a patient's chest and record heart sounds, while heart sounds are detected by a microphone via the air inside the head of the electronic stethoscope. The construction of the PZT sensor is crucial for the detection of super low frequency sound of below ~20Hz, which may be out of range for an electronic stethoscope because its sensor head is diaphragm type that intends to detect mid-high frequency range sounds.

In the present study, we analysed the raw heart sound signal that contained the super low frequency sound, and we found that the raw sound signal of cardiac patients lacked a sharp deflection that appears in coincidently with R waves on ECG. We also found that 2nd sound in the filtered heart sound was missing in most of the cardiac patients. However, the 2nd sounds were often observed in the heart sound signal recorded at 3rd, 4th or 5th (apex) intercostals spaces. Accordingly, the recording of heart sound signal with the PZT sensor at left 2nd intercostals space seems to be effective for the diagnosis of patients susceptible to cardiac diseases. It should be noted that the analysis of the super-low-frequency sound is likely to be useful for cardiac diagnosis (see Fig. 3).

As we only found a small part of information hidden in the low frequency heart sound, we need further investigate the sounds created by the heart in cardiac patients with developing a quantitative method for the cardiac diagnosis including such as frequency domain analysis. Furthermore, we should develop a simple and easy to use heart sound monitor system, which continuously displays the cardiac signal of a patient and provides us a tool for visually diagnosing for the use in cardiology outpatient department in hospitals.

In conclusion, the present study demonstrated that the PZT-based heart sound monitor system has a performance suitable for detecting heart sounds including super low frequency sound. Although our results are very preliminary and we may need to do a further comparative analysis with other electronic stethoscopes, we believe that phonocardiogram-based analysis with the PZT heart sound monitor system may provide us a new strategy for the diagnosis of cardiac diseases.

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