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Technical Note

Detection of features of prosthetic cardiac valve sound by spectrogram analysis

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ABSTRACT

Prosthetic cardiac valve sounds are thought to be useful for evaluating valve function. In a previous report, we showed that a stethoscope with a small microphone inserted in its tube could be used to record mechanical cardiac valve sounds in daily medical care. In this study, we used such a stethoscope to record prosthetic cardiac valve sounds and analyzed the sounds by spectrogram. The results indicated that mechanical cardiac valve sounds are well characterized by the high frequency components of the spectrogram.

1. Introduction

Although medical diagnostic technologies, such as echocardiography, are well developed, diagnosing malfunctions of prosthetic cardiac valve is usually difficult in the early stages of malfunctions. Malfunctions of prosthetic cardiac valves are often discovered when thromboembolic complications or severe hemodynamic changes have already occurred [1]. Therefore, it is necessary to find a better way to detect malfunctions of prosthetic cardiac valves early in daily clinical situations.

Some researchers have reported that the sounds radiating from mechanical cardiac valves can be useful in the diagnosis of their malfunctions [2–7]. The sounds in previous reports were mainly recorded using condenser microphones or accelerometers; however, these recording instruments are unfamiliar and not easy to use in daily clinical situations, such as hospital wards or outpatient clinics. In addition, the data were analyzed on the basis of the spectrum of sounds generated, which cannot consider changes over time. In our previous studies, the signal to noise ratios (SNRs) and frequency characteristics of condenser microphones, accelerometers, a stethoscope with a small microphone inserted in its tube, and an electrostethoscope, were compared to find a better way to record mechanical cardiac valve sounds in daily clinical situations [8]. A stethoscope with a small microphone inserted in its tube was shown to be the best way to record such sounds.

Experimental studies of the hydromechanical apparatus, using thrombosed valve models, indicate that the high frequency components (2–6 kHz) generated by a prosthetic valve are attenuated by a thrombus [9]. This indicates that the attenuation of the high frequency components generated by a prosthetic valve might be useful for detecting a thrombosed valve in daily clinical situations. Therefore, to quantify the variation of high frequency components, which can be caused by thrombosed valves, this study evaluated the sounds of prosthetic cardiac valves recorded using a stethoscope with a small microphone inserted in its tube [8], in daily clinical situations.

2. Methods

Prosthetic cardiac valve sounds were recorded from 22 subjects, comprising 10 men and 12 women who had undergone mitral or aortic valve replacement with one of the following types of mechanical valves, the Advancing the Standard valve (ATS), the bicarbon valve (BC), the Medtronic-Hall valve (MH) or the St. Jude Medical valve (SJM). The valves were defined to be normal by transthoracic echocardiography. Native cardiac valve sounds were recorded from two men for comparison. The subjects were aged between 31 and 90 years. All subjects enrolled in this research gave informed consent. The study was approved and the protocol found acceptable by our institutional committee on human research.

The sounds of prosthetic and native cardiac valves were measured in subjects in a supine position and without clothes in our outpatient clinic. The stethoscope (Littmann Master Classic II

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Stethoscopes; Sumitomo 3M, Tokyo, Japan) with a small condenser microphone (AT805F; Audio-Technica, Tokyo, Japan) inserted in its tube was positioned on a subject's chest wall at the site where the sound of the prosthetic valve was loudest, mostly in the left third of the intercostal space just lateral to the sternum. After amplification, the signal was digitized with an A/D converter (UA-1000; Edirol, Tokyo, Japan) at a sampling frequency of 44.1 kHz, with 16-bit resolution, and then stored in a computer for analysis. A computer program (DigiOnSound4; DigiOn, Fukuoka, Japan) was used for recording and an electrocardiogram (ECG) was obtained simultaneously [8]. A series of prosthetic cardiac valve sound signals acquired for approximately 10 s contained more than 10 valve sounds.

Fig. 1 shows an example of (a) native, (b) ATS, (c) BC, (d) MH, and (e) SJM valve sounds, which contain the two major sounds, that is, a first sound (S1) and a second sound (S2). S1 is caused by the sudden block of reverse blood flow owing to the closure of the atrioventricular valves, namely, the mitral and tricuspid valves, at the beginning of ventricular contraction, or systole. S2 is caused by the sudden block of reverse blood flow owing to the closure of the aortic valve and pulmonary valve at the end of ventricular systole, namely, the beginning of ventricular diastole.

The data were analyzed by short-time Fourier transform (STFT). The STFT is defined by:

$$\mathrm{STFT}\{x(t)\} = X(\tau, \omega) = \int_{-\infty}^{+\infty} x(t)\omega(t-\tau)e^{-j\omega t}dt, \tag{1}$$

where $\omega(t)$ is the window function, and $x(t)$ is the signal to be transformed. $X(\tau, \omega)$ is essentially the Fourier transform of $x(t)w(t-\tau)$, a complex function representing the phase and magnitude of the signal over time and frequency. The STFT is obtained by calculating the Fourier transform of a sliding windowed version of the time signal $x(t)$. The location of the sliding window adds a time dimension and enables a time-varying frequency analysis. The magnitude squared of the STFT yields the spectrogram of the function:

$$\mathrm{spectrogram}\{x(t)\} = |X(\tau, \omega)|^2. \tag{2}$$

The data were also analyzed by a continuous wavelet transform (CWT). The CWT is defined by:

$$\mathrm{CWT}\{x(t)\} = X(a, b) = \frac{1}{\sqrt{a}}\int_{-\infty}^{+\infty} x(t)\psi^*\left(\frac{t-b}{a}\right)e^{-j\omega t}dt, \tag{3}$$

where $\psi(t)$ is a continuous function in both the time domain and the frequency domain called the mother wavelet, which was the

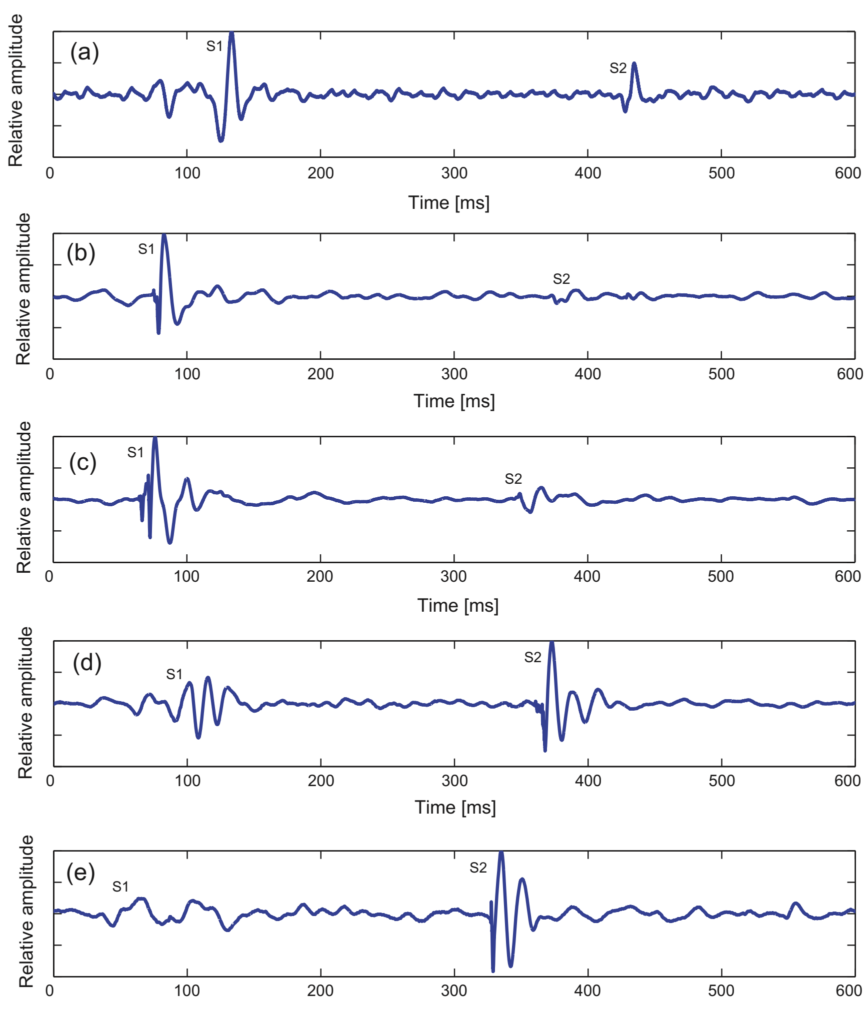

Fig. 1. Examples of (a) native, (b) ATS, (c) BC, (d) MH, and (e) SJM valve sounds that contain the two major sounds, specifically, the first sound (S1) and the second sound (S2). The data in (b) and (c) were collected from subjects who had undergone mitral valve replacement. The data in (d) and (e) were collected from subjects who had undergone aortic valve replacement.