Propagation of Electric Excitation and Vibrations in the Human Heart*

Hiroshi KANAI†**
** Department of Electronic Engineering, Department of Biomedical Engineering, Graduate School of Engineering, Tohoku University, 6-6-05 Aramaki-aza-Aoba, Sendai 980-8579, Japan
E-mail: kanai@ecei.tohoku.ac.jp

Abstract
We have found that the pulsive vibration is excited on the myocardium 15 ms after the electrical stimulation to an isolated heart. In this study, we transcutaneously detected the propagation of vibration caused just around R-wave of the ECG using ultrasound. The method was noninvasively applied to healthy subjects. Just after the Q-wave of the ECG, the propagation started at the interventricular septum to the base side of the heart, which shows the propagation of electrical excitation. After the R-wave of the ECG, shear waves caused by the mitral-valve closure started to propagate from the base to the apex. The method noninvasively reveals the propagation of electrical conduction wave by measuring myocardial response to it.

Key words: Echocardiography, Action potentials, Elasticity, Imaging, Shear waves, Electrocardiogram

1. Introduction

If the propagation of electrical excitation and mechanical vibration in the heart wall could be directly visualized, regional tissue damage related to both ion channel gating, which generates the electrical action potentials, and the regional myocardial mechanical properties due to heart diseases could be transthoracically detected. We have previously found that pulsive vibration occurs in response to electrical stimulation of the extracted myocardium of a rat(1). Therefore, transcutaneous measurement of the minute vibration caused by the electrical excitation has potential to reveal the propagation of the electrical excitation in the heart wall in vivo.

2. Methods

To measure the original wall vibrations of the heart sounds, which are audible by a stethoscope, we have developed a novel ultrasound-based transthoracic method to measure the minute vibrations in the heart wall as waveforms and to show their spatial distribution. The measurement of the vibration is simultaneously applied to several thousand points preset at 51.3-μm intervals along about 10 ultrasonic beams, which are scanned sparsely in the heart wall to maintain a high frame rate. The spatial distribution with regard to the waveform or the instantaneous phase of the specific frequency component is shown at every 2 ms, precisely revealing the propagation of the vibration waves on the ultrasonic cross-sectional plane of the heart wall(2)-(3).

3. Results

For a healthy subject, the consecutively obtained phase distributions are shown in the upper panel of Fig. 1. The upper panel shows the consecutive instantaneous phase
distributions \( \{ \varphi_{jk}(t; f_i) \} (j = 1, 2, \ldots; k = 4; |t-T_Q| \leq 100 \text{ ms}) \) for the \( f_i = 41 \) Hz components involved in the vibrations \( \{ v_{j,k}(t) \} \). From the lower panel, it is possible to show the propagation of the vibration in the transmural direction from the LV side to the RV side in the center of the IVS.

**Figure 1:** Consecutive spatial distributions of color-coded phase values for the 42-Hz components of the measured waveforms for a healthy subject. The upper panel shows the consecutive distribution along the center of the IVS from the apex to the base. The lower panel shows the consecutive distribution in the transmural direction from the LV side to the RV side.

4. Discussion

For the propagation component which starts at the time of the Q-wave \((T_Q)\) of the ECG, the propagation speed is 0.9 m/s, which corresponds to the conduction speed in the myocardium. On the other hand, for the components around \( T_I \), there is no time delay between the LV and RV sides of the IVS. To conclude, by observing rapid, minute vibration components simultaneously at several thousand points in the human heart wall to visualize the wave propagation along the heart wall, we found for the first time that there are several types of vibration propagation which start at \( T_Q \) and \( T_I \). By considering the time, the propagation direction, and the dispersion properties of each vibration, the vibration at \( T_Q \) was seen to correspond to the response of the myocardium to electrical stimulation, which propagates from the Purkinje fiber-myocyte junctions to the whole heart, and the vibrations at \( T_I \) correspond to the propagation of the waves mechanically excited by closure of the atrioventricular valves. These phenomena have potential for detection of regional myocardial tissue damage related to propagation of the action potentials and regional myocardial viscoelasticity.

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References

