REAL-TIME MEASUREMENT SYSTEM FOR ACQUIRING MURINE LEFT VENTRICULAR PRESSURE-VOLUME RELATIONS

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ABSTRACT

Myocardial functions can be characterized from ventricular pressure-volume relations. In small animals, the instantaneous ventricular volume is typically measured by using a miniaturized conductance catheter. In this work, a DSP-based conductance catheter measurement system is proposed, which adopts the admittance measurement method to estimate the myocardial contribution, and Wei’s nonlinear equation to convert the blood conductance to volume. In vivo rat experiments were performed with the proposed measurement system, and real-time left ventricular pressure-volume relations can be obtained.

Index Terms— Conductance catheter, pressure-volume relation, admittance measurement, biomedical instruments.

1. INTRODUCTION

Real-time ventricular pressure-volume relations provide a method to characterize myocardial and ventricular functions, independent of loading conditions [1-2]. However, it is difficult to measure real-time ventricular volumes in small animals, such as mice and rats. In recent decades, miniaturized conductance catheter technique was developed to measure the instantaneous ventricular conductance, which is then converted to ventricular volumes [3-5].

The first conductance-to-volume conversion equation was proposed by Baan et al. in 1984 [3]. However, its accuracy is mainly limited by three factors: inhomogeneous electric field, parallel myocardial conductance, and the deviations of catheter position [5-7]. For the issues of the inhomogeneous electric field and the catheter position deviations, a nonlinear conductance-to-volume conversion equation was proposed by Wei et al. in 2005 to solve or improve these problems [5-6]. As to the parallel myocardial conductance, there have been several approaches proposed to estimate this parallel conductance [3, 4, 8, 9], and the one we adopted is done by measuring the time-varying complex ventricular admittance, which is referred to as admittance measurement method [8].

In this work, a DSP-based conductance catheter measurement system was developed to measure instantaneous ventricular pressure and admittance, through which the myocardial contribution and the blood conductance can be calculated. Then, the nonlinear conductance-to-volume conversion equation was used to convert the blood conductance to volume. As a result, real-time left ventricular pressure-volume relations can be obtained.

2. METHODOLOGY

A. Conductance Catheter Measurement System

The adopted rat catheter is SPR-838, manufactured by Millar Instruments, Houston, Texas, USA. The catheter consists of four electrodes and a pressure transducer. Each electrode is a 0.25-mm-long ring with a radius of 0.2 mm, and is made of platinum. The interelectrode spacing is 0.5, 9.0, and 0.5 mm, respectively. In addition, the instrument, MPCU-200, also manufactured by Millar instruments, was partially used to generate an input signal for the pressure transducer and to preprocess the sensed pressure signal.

Fig. 1 shows the block diagram of the DSP-based conductance catheter measurement system, which was modified from our instrument developed earlier [10]. A 30-kHz sin wave was generated by a signal generator, and then was converted to an ac current signal, which was applied on the two outer electrodes of the catheter. Three signals (the voltage between the two inner catheter electrodes, a reference signal copied from the applied current signal, and the sensed pressure signal) were amplified and sampled by the 12-bit built-in ADCs of a DSP chip, TMS320F2812, manufactured by Texas Instruments, Inc., Texas, USA. The ADC sampling rate is set to 600 kHz.
In the DSP chip, the digitized signals were filtered by 30-kHz bandpass filters (BPFs) to remove the noise outside the signal band, and then the magnitude and phase of the sensed voltage were detected. Some digital signal processing techniques were used to reduce the data rate of the signals, and, thus, the outputting rate of the detected magnitude, phase, and pressure signals is 1 kHz [10]. The outputs of the DSP chip are fed to a PC through a digital IO card, LPCI 7200S, manufactured by ADLINK Technology, Inc., Taiwan. LabVIEW is used to post-process and record the measured signals. As a result, the real-time pressure-volume relations can be observed from the LabVIEW graphic user interface.

B. In Vivo Rat Experiment

White female Wistar rats were used in the experiment, and they were anesthetized by inhalation induction of isoflurane in an anesthetic chamber, intubated with a 16G angiocatheter, and ventilated with positive-pressure ventilation using a Harvard ventilator. Anesthesia was maintained by 2% inhaled isoflurane with mechanically ventilated at a rate of 60 breaths/min. The catheter was inserted through the right carotid artery into the left ventricle (LV) of the heart. The other end of the catheter was connected to our developed DSP-based ventricular pressure-volume measurement system.

An independently measured stroke volume (SV) is needed to determine the empirical calibration factor of the adopted nonlinear conductance-to-volume conversion equation [5]. The rat SV was measured by a commercially available echocardiographic system (Sonos 5500; Hewlett-Packard, Les Ulis, France) under lightly sedated with isoflurane, and a 12-MHz transducer was used [11]. Fig. 2 shows the measured graph of the echocardiographic system.

C. Myocardial Contribution and Blood Conductance

It has been proved that myocardium is both resistive and capacitive, while blood is only resistive [4, 8, 12]. Hence, the measured ventricular admittance, \( Y_{\text{meas}} \), coming from the blood and the myocardium, can be represented as

\[
Y_{\text{meas}} = g_b + Y_m = g_b + g_m + j2\pi f C_m
\]

where \( g_b \) is the blood conductance, \( Y_m \) is the myocardial admittance, \( g_m \) is the myocardial conductance, \( C_m \) is the myocardial capacitance, and \( f \) is the frequency of the injected current signal [8]. From Eq. (1), the imaginary part of \( Y_{\text{meas}} \) comes from the myocardial capacitance only, and, thus, \( C_m \) can be calculated by the measured magnitude and phase of the ventricular admittance, \( |Y_{\text{meas}}| \) and \( \phi \):

\[
C_m = \frac{|Y_{\text{meas}}| \sin(\phi)}{2\pi f}
\]

Then, the myocardial conductance \( g_m \) can be calculated through a well-known conductance-capacitance analogy:
\[ g_m = C_m \frac{\sigma_m}{\varepsilon_m} \]  

where \( \sigma_m \) is the myocardial conductivity, \( \varepsilon_m \) is the myocardial permittivity, and the ratio of \( \sigma_m/\varepsilon_m \) is set to \( 1.3 \times 10^6 \) S/F according to the data shown in previous literature [12]. Finally, the blood conductance \( g_b \) is given by

\[ g_b = |Y_{\text{meas}}| \cos(\phi) - g_m \quad (4) \]

the magnitude of the LV admittance, the phase of the LV admittance, and the LV pressure. Fig. 4(a-c) compares the waveforms of three important signals in the admittance measurement method: the measured magnitude of LV admittance \( |Y_{\text{meas}}| \), the magnitude of the estimated myocardial admittance \( |Y_m| \), and the blood conductance \( g_b \), calculated by Eq. (4). Fig. 5(a) plots the measured magnitude versus the LV pressure signal, while Fig. 5(b) shows the LV pressure-volume loops after the volume conversion.

3. RESULTS

Fig. 3(a-c) shows the three measured signals, respectively:
4. DISCUSSION AND CONCLUSION

In Fig. 3, the phase decreases with the increasing magnitude, as expected [8]. The imaginary part of the LV admittance comes from the myocardium only. Therefore, when the magnitude of the LV admittance, which is proportional to LV volume, is increasing during diastole, the myocardium gets far from the catheter. Therefore, the myocardial contribution to the measured LV admittance decreases, which can be further verified in Fig. 4, and the measured phase decreases as well. Fig. 6 plots the relationship between the magnitude and phase. The phase is approximately inversely proportional to the magnitude.

A DSP-based ventricular pressure-volume measurement system has been developed to measure and process instantaneous ventricular admittance and pressure signals. The admittance measurement method is adopted to estimate the myocardial contribution, and the nonlinear conductance-to-volume conversion equation is used to convert the measured admittance to volume. As a result, real-time pressure-volume loops can be obtained by the proposed system.

5. REFERENCES