The left ventricular ejection time fraction affects the spectrum of the arterial pulse wave

Subtitle: LVETF affects the spectrum of arterial pulse wave

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Abstract—The left ventricular ejection time (LVET) and heart rate are two independent parameters which have been highly studied for aging and cardiovascular diseases. To reduce the effect caused by the individual specificities of subjects, we defined a new dimensionless parameter: the left ventricular ejection time fraction (LVETF= LVET/period of heart beat), and tube simulations were performed to investigate its possible effects on the arterial pulse wave. The pulsatile blood input from the left ventricle was simulated by a pulsatile water input generated by a stepper motor with a controllable frequency and ejection time. We found that the harmonic components of the induced pressure waves altered as the fraction of the water ejection duration changed. According to our previous studies, the harmonic components of the arterial pressure pulse can reflect the condition of individual subjects, we thus conclude that LVETF is an important factor to study the effect of ventricular output on arterial systems.

Keywords- left ventricular ejection time, pressure wave

I. INTRODUCTION

The left ventricular ejection time (LVET) is a parameter which can be measured and derived from phonocardiogram, electrocardiogram and blood pressure pulse tracing[1]. Many studies revealed that in addition to the heart rate, LVET is related to age[2], PWV[3] and cardiovascular diseases[4]. The LVET also plays an important role in the evaluation of left ventricular systolic function[5]. Nevertheless, there are few studies to discuss the effects of the two parameters simultaneously.

Most of the clinical results showed large standard deviations in the magnitudes of LVET and the heart rate due to the individual specificities of the subjects. Hence, we will introduce a dimensionless parameter, the left ventricular ejection time fraction (LVETF= LVET/period of heart beat), and study how this parameter affects the arterial pulse wave by tube simulations.

II. METHOD

We investigate the correlation of the left ventricular ejection time on the pressure wave response in the arterial system by tube simulations.

The experiment was similar to that described in our previous work [6]. The experimental setup is shown in Figure 1. The components of the experimental setup are described below.

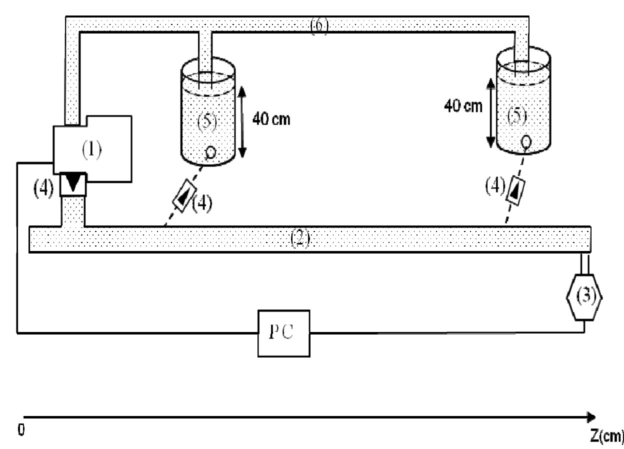

Figure 1. Main components of the experimental setup: (1) 120-cm latex tube, (2) stepping motor at *Z*=0 cm, (3) pressure transducer, (4) one-way valves at *Z*=0, 20, and 100cm, (5) reservoirs, and (6) silicon tube. The dashed lines indicate the levels of water in the reservoirs.

A. Aorta model

The aorta was simulated by a 120-cm latex tube (Qualatex, Australia) with uniform dimensions and mechanical properties. The two ends of the tube were clamped using hemostatic forceps to represent the arterial terminations. Two reservoirs simulating all of the peripheral arterial beds were connected by two one-way valves, with the long silicon tube simulating the venous drainage (Figure 1). The height of the two reservoirs was adjusted so that they were 40 cm above the longitudinal axis of the tube, thereby producing an initial hydrostatic pressure of 3.9 kPa. The mechanical properties of the tube are listed in Table 1.

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The mechanical properties of the latex tube			
Diameters(mm)	Wall thickness(mm)	Linear density(g/cm)	$E_P(10^5\ N/m^2)$
11.4±0.1	0.3 ±0. 1	0.11 ±0.01	0.61 ±0.02

Table 1. The mechanical properties of the latex tube

B. Heart model

The stepper motor (ASM46AA, Oriental Motor, Japan), which was controlled by a PC, could rotate periodically to inject water into the latex tube from the reservoir via the one-way valve. This was used to simulate the function of the heart.

(a) A single impulsive source

The stepper motor was set to rotate by one revolution to allow a one-way valve to inject a 0.7-ml aliquot of water into the tube from the reservoir within 50 ms to produce a single impulsive source.

(b) Periodic input

The stepper motor was set to rotate in a pulsatile fashion to inject water periodically into the tube from the reservoir during each revolution. The PC was used to control the period and ejection time. The ratio of the ejection time to the period of the water input (LVETF) was chosen to be either 30% or 40%.

C. Instrumentation

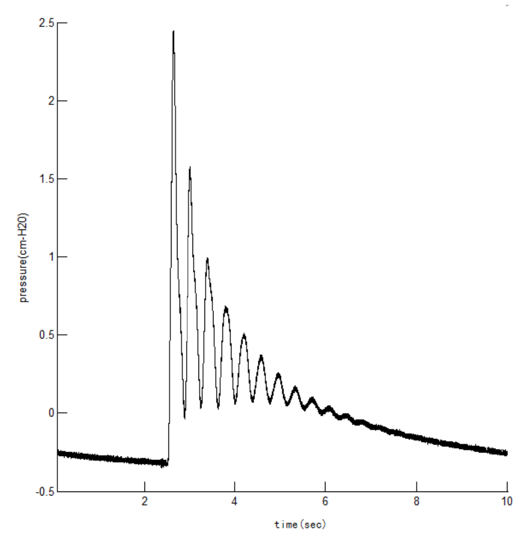
The pressure response was measured by attaching a small patch of 1.6-mm-thick (area, 248.9 mm^2) latex membrane (Kent Elastomer, USA) to the latex tube, and then connecting it to a pressure transducer. The pressure responses at different locations along the tube were measured for 10 s by the pressure transducer (DP103, Validyne, USA). The pressure signals were amplified by a signal amplifier (CD223, Validyne) and then transferred to a PC via an A/D converter (PCI-9111, ADLINK, Taiwan) at a sampling rate of 4096 Hz. The pressure signals were analyzed by Fast Fourier Transform using the MATLAB program (MathWorks, USA). Every measurement was repeated six times to enable statistical evaluation of the reliability and reproducibility of the measured data.

III. RESULTS

A. The natural frequency of the latex tube

We first use impulse method[7] to determine the natural frequency of the system**.** Figure 2a shows the time-domain impulse response near the right end of the 120-cm latex tube, as measured by the pressure transducer for 10 s. Its spectrum is shown in Figure 2b. The spectrum (Figure 2b) contained three peaks at 2.6±0.1, 5.2±0.1 and 7.8±0.1 Hz. These were thus identified as the natural frequencies of the latex tube.

(a)



(b)

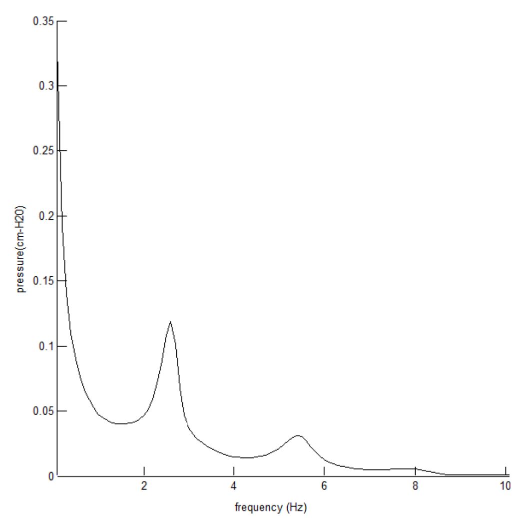


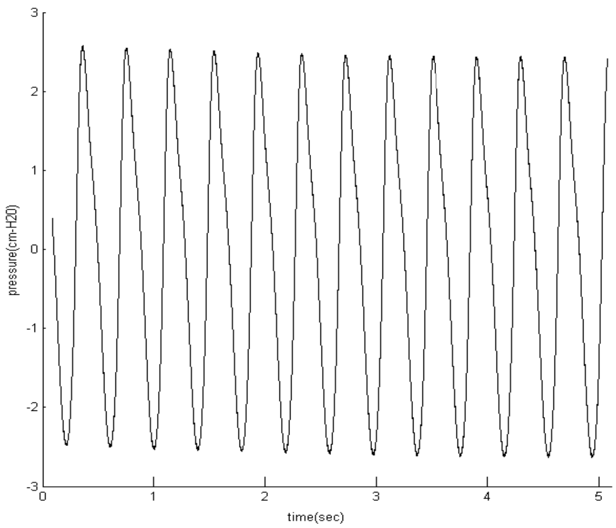
Figure 2. Determination of the natural frequency of the latex tube by the impulse response of the 120-cm latex tube measured near *Z*=120 cm in the time (a) and the frequency (b) domains.

B. The pressure response of the latex tube by periodic inputs of frequency 2.6 Hz

Then we set the pumping frequency of the stepper motor to 2.6 Hz (i.e., the first natural frequency of the latex tube), and measured the pressure response at the right end of the 120-cm latex tube for the water ejection durations (simulated the LVET) to be 115 ms and 153 ms. The pressure responses in the time domain for two cases are shown in Figure 3.

Table 2 shows the amplitude of the first five pressure harmonic components A_n for the ejection time fraction being 30% and 40% respectively.

(a)



(b)

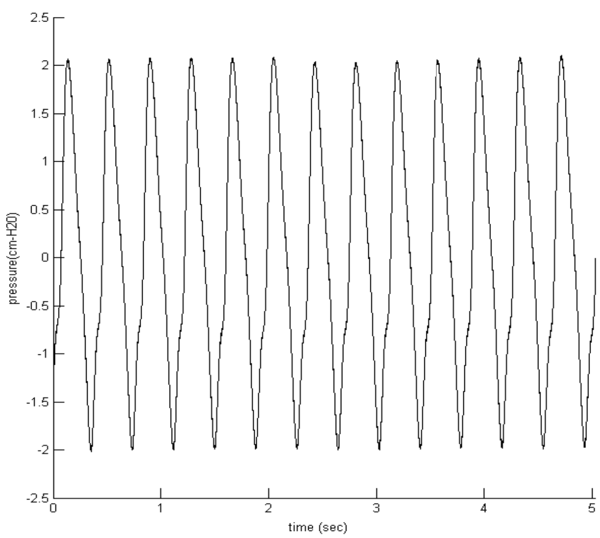


Figure 3. The pressure response of the 120-cm latex tube measured near z=120 cm in the time domain, for the ejection time fraction being (a) 30% and (b) 40% respectively.

A_n	The LVETF of the input force	
	30%	40%
A_1	5.89 ± 0.15	5.01 ± 0.03
A_2	5.78 ± 0.11	4.45 ± 0.06
A_3	1.38 ± 0.01	0.54 ± 0.16
A_4	0.46 ± 0.01	0.60 ± 0.01
A_5	0.10 ± 0.00	0.35 ± 0.00

Table 2. The spectrum of the pressure response for the 120-cm latex tube- the amplitude of the first five pressure harmonic components A_n for the ejection time fraction being 30% and 40% respectively.

IV. CONCLUSION

Table 2 shows that increasing the water ejection duration fraction of the simulated heart may alter the harmonic spectrum of the pressure response in the arterial simulated tube; even there is no significant pulse shape change in the time domain. In our previous studies, we claimed that harmonic analysis of the pressure pulse wave provides useful information about the health condition of an individual [8]. In this study, we confirm that it can also be applied to evaluate the effect of the left ventricular ejection time fraction on the arterial system.

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