

Evaluation of Left Ventricular Ejection Function by an Automatic Doppler Signal Quantification System

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Abstract

In the present study. An automatic quantification program was developed for flow tracing from Doppler flow images. Five important parameters, (1)ejection period (EP), (2)ratio of one-third-time ejected volume and ejected volume (1/3EV:EV), (3)ratio of two-third-time ejected volume and ejected volume (2/3EV:EV), (4)averaged flow acceleration during increasing flow duration (AFA) and (5)peak flow acceleration (PFA) were calculated from the traced flow. Six normal volunteers (mean age 23.5 years) were included in this study. They were studied using continuous wave Doppler echocardiography and during a controlled venous injection of dobutamine. From normal steady state, six stages were performed, each stage has approximate five minutes with injection rate increment of 2.5 $\mu\text{g}/\text{kg}/\text{min}$. The results show that the 1/3EV:EV and 2/3EV:EV varied in a very small range. On average, PFA increased from 7.1905 m/sec^2 to 25.0498 m/sec^2 and average AFA increased from 4.9501 m/sec^2 to 16.1201 m/sec^2 . It was concluded that based on the benefit of reproducibility and efficiency of Doppler flow image measurement, our image quantification system not only benefits daily diagnostic usage but also provides a reliable data analysis for left ventricular contractility evaluation.

1. Introduction

It is well known that the information of blood flow contains a lot of important parameters to the body healthy conditions. The aortic blood flow directly react the contractile condition of left ventricle.

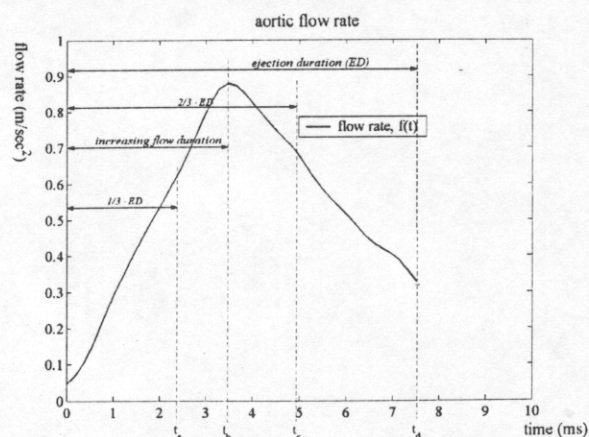
Many researchers devoted themselves to this technology to investigate the factors between blood flow and left ventricular (LV) function[1, 2, 3]. In 1984, Bennett ED et al used contineous-wave Doppler blood velocity meter to measure ascending aortic blood mean velocity, maximum acceleration, stroke volume and cardiac output [4]. They concluded that ascending aortic blood velocity allows non-invasive monitoring of LV contractile state with

considerable ease and repidity. In 1986, Mahta N et al accessed three important variables (peak velocity, maximal acceleration and systolic velocity integral) to evaluate the LV function of acute myocardial infarction patients [5]. However, these variables all have one common property. That is, blood flow profile must be obtained first of all the variable can be calculated. Unfortunately, nowadays, most of Doppler ultrasound system don't have this function supported.

In this study, a graphic user interface program, FlowTracer, were developed to trace the blood flow profile from Doppler flow image. Six normal volunteers were underwent dobutamine injection and Doppler flow image scanning to exam the feasibility and practicability of the program, FlowTracer.

2. Notation

The description of five parameters calculated from traced flow of Doppler flow image is as follows:



- EP (Ejection period):

$$EP = Time_{aortic\ valve\ opening} - Time_{aortic\ valve\ closing} = t_d$$

- 1/3EV:EV (Ejection volume of $\frac{1}{3}$ EP : Ejection volume):

$$1/3EV : EV = \int_0^{t_a} f(t) : \int_0^{t_d} f(t)$$

- 2/3EV:EV (Ejection volume of $\frac{2}{3}$ EP : Ejection volume):

$$1/3EV : EV = \int_0^{t_a} f(t) : \int_0^{t_d} f(t)$$

- AFA (Averaged fbw acceleration during increasing fbw duration):

$$AFA = \frac{f(t_b) - f(0)}{t_b}$$

- PFA (Peak fbw acceleration during ejection):

$$PFA = \text{maximal value of } f'(t)$$

3. Material and Methods

3.1. Subjects

Six male normal healthy volunteers, with no history of cardiac disease, were included in this study. The mean age was 23.5 ± 1.8708 years. Before any test, all volunteers were non-invasively diagnosed with two-dimensional echocardiography and Doppler flow image. No anomaly and functional deficiencies were found of all subjects. Informed consent was obtained from all normal subjects.

Table 1. The basic information about 6 subjects.

No.	Age	Height(cm)	Weight(kgw)	Gender
1	22	175	69	M
2	23	168	68	M
3	24	182	89	M
4	22	169	72	M
5	27	166	78	M
6	23	175	60	M

3.2. Drug administration

Each subject was administered with venous injection of dobutamine in a controlled speed in order to progressively enhance the myocardial contractility. Dobutamine injection speed was increased from $0 \mu\text{g}/\text{min} \cdot \text{kgw}$ to $15 \mu\text{g}/\text{min} \cdot \text{kgw}$ with an injection speed increment of $2.5 \mu\text{g}/\text{min} \cdot \text{kgw}$. Seven stages were performed (stage 0 to stage 6). Excluding baseline (stage 0), each stage was approximately lasted in 5 minutes for the effect of medication and measurement of Doppler aortic flow image. Because the subjects' heart rate and blood pressure varied once the

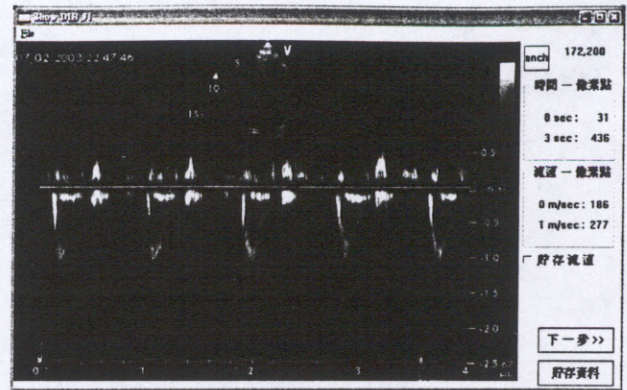


Figure 1. The user interface of FlowTracer

injection speed changed. Three minutes were remained after the injection speed changing. We await Doppler flow scanning after 3 minutes after injection speed changing. Electrocardiogram and blood pressure were monitored during entire experiment. All the invasive experiment was hold in the intensive care unit of Kaohsiung Veteran General Hospital (VGHKS) and was admitted by the Clinicaltrial Committee of VGHKS.

3.3. Data acquisition

The GE vivid 7 ultrasound system was employed for continuous Doppler flow scanning during each stage of drug injection. The Doppler flow images were exported as the bitmap formatted file to the FlowTracer, i.e the program we developed for tracing the flow profile from the Doppler flow images. Once the blood flow signal was traced, the five parameters (1/3EV:EV, 2/3EV:EV, PFA, AFA and Ejection period) were calculated. Figure 1 shows the semblance of FlowTracer. Graphic user interface makes it easier for using and data acquisition could be accomplished by just mouse clicking and few keyboard buttons pushing. FlowTracer was developed using *microsoft Visual C environment under windows system*.

4. Results and conclusion

4.1. AFA and PFA

Figure 2 and figure 3 is the result of averaged fbw acceleration and peak fbw acceleration respectively. AFA and PFA had a significant increase with the dose increase of dobutamine. For AFA, the minimal increase is from $5.3085 \text{m}/\text{sec}^2$ (stage 0) to $6.8481 \text{m}/\text{sec}^2$ (stage 6), the maximal increase is from $5.7829 \text{m}/\text{sec}^2$ (stage 0) to $24.8919 \text{m}/\text{sec}^2$ (stage 6). For PFA, the minimal increase is from $9.0991 \text{m}/\text{sec}^2$ (stage 0) to $13.4994 \text{m}/\text{sec}^2$ (stage 6), the maximal increase is from $7.1709 \text{m}/\text{sec}^2$ (stage 0)

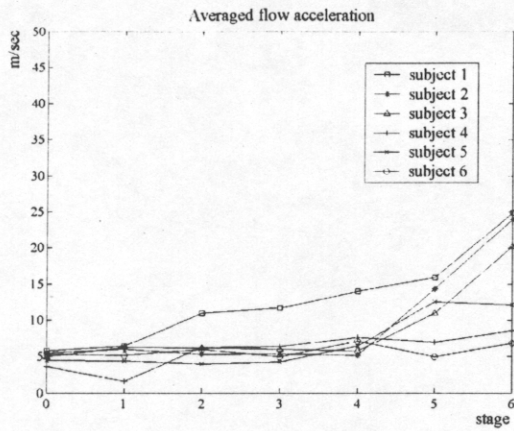


Figure 2. The result of AFA of six subjects.

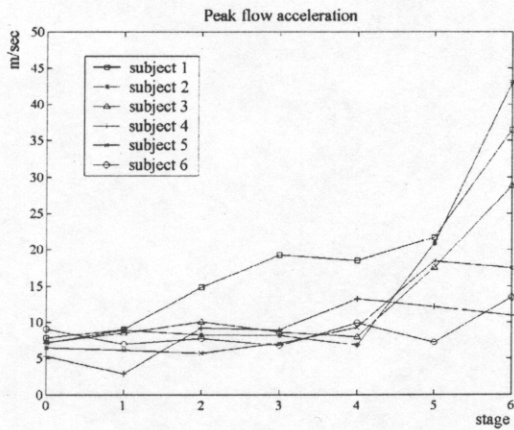


Figure 3. The result of PFA of six subjects.

to $42.9905\text{m}/\text{sec}^2$ (stage 6). As expected, the acceleration obtained from FlowTracer had a well agreement with the myocardial contractility.

4.2. 1/3EV:EV and 2/3EV:EV

The result of 1/3EV:EV and 2/3EV:EV are shown in figure4 and figure5 respectively. The table2 and table3 shows the mean±standard deviation of 1/3EV:EV and 2/3EV:EV respectively. The results showed that the 1/3EV:EV and 2/3EV:EV varied in a very small range while the dose of drug increase. Moreover, the value of 1/3EV:EV and 2/3EV:EV approximated to 0.2812 and 0.7299 respectively. This result imply that the partial ejection volume remained a certain ratio to the total ejection volume while the myocardial contractility varied.

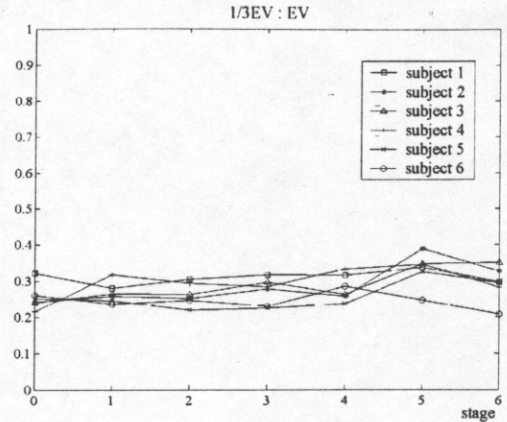


Figure 4. The result of 1/3EV:EV of six subjects.

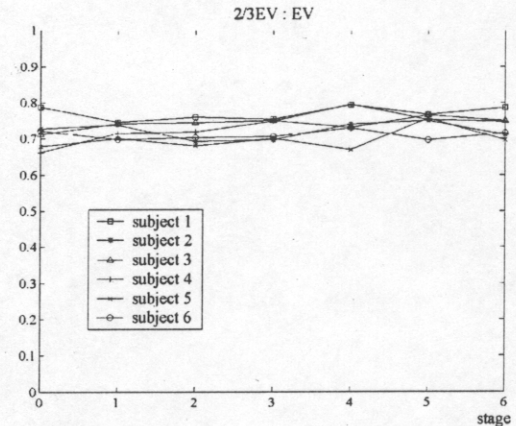


Figure 5. The result of 2/3EV:EV of six subjects.

Table 2. Averaged 1/3EV:EV of 6 subjects with its standard deviations.

stage	mean ±standard deviation
0	0.2556±0.0325
1	0.2676±0.0264
2	0.2640±0.0285
3	0.2722±0.0330
4	0.2826±0.0333
5	0.3331±0.0428
6	0.2929±0.0444

Table 3. Averaged 2/3EV:EV of 6 subjects with its standard deviations.

stage	mean \pm standard deviation
0	0.7155 \pm 0.0401
1	0.7237 \pm 0.0201
2	0.7168 \pm 0.0283
3	0.7263 \pm 0.0257
4	0.7436 \pm 0.0243
5	0.7487 \pm 0.0243
6	0.7350 \pm 0.0300

4.3. Ejection period

Ejection period had a notable decrease with the increase of myocardial contractility (figure 6). On average, ejection period decreased by 28.81%. This result suggested that while the myocardial contractility enhanced with the loading condition unaltered, the heart itself has the tendency to shorten the ejection period and vice versa.

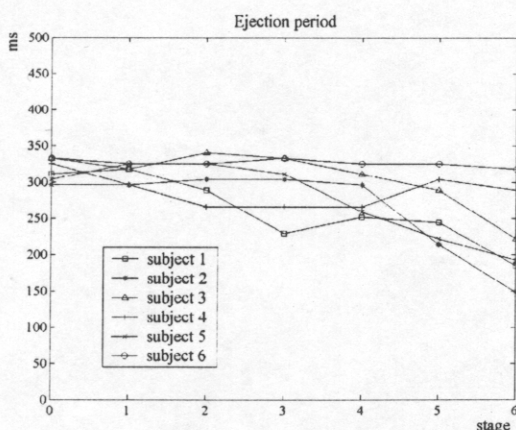


Figure 6. The result of ejection period of six subjects.

5. Discussion

A very preliminary result was given in this study. We developed a software environment to make the routine work more available and feasible.

However, first, the purport of the ratio of partial ejection volume to entire ejection volume has not been discussed in this study. We found the value of the 1/3EV:EV and 2/3EV:EV but we still cannot tell if it has any relation to the LV function clearly. Second, we didn't discuss the error and bias of the flow signal traced from FlowTracer. A future study of more subjects (patients and normal subjects) and more software environment integrations may clarify the precision and mechanism of the LV function.

Acknowledgements

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