Postprandial Hemodynamic Changes Evaluated by a Doppler Echocardiographic Method

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SUMMARY
To evaluate postprandial hemodynamic changes, Doppler measurements of stroke volume before and after lunch were carried out in 10 healthy volunteers (all men) with a mean age of 28 years. The stroke volume was calculated as the product of echocardiographically determined aortic valve area and the ejection flow velocity integral obtained by continuous wave Doppler. The stroke volume before lunch was 61±7 ml, which was increased to 72±8 ml 1 hour after lunch and remained constant for the next 4 hours. Five hours later the stroke volume was then decreased to the baseline. M-mode echocardiography revealed an increase in left ventricular end-diastolic dimension and ejection fraction after lunch.

Another 9 healthy subjects (6 women and 3 men) with a mean age of 52 years received a 75 g oral glucose tolerance test (OGTT) instead of a common lunch; stroke volumes were not altered in association with the elevation of plasma glucose level.

In conclusion, ingestion of food had a positive inotropic effect and caused circulating blood volume expansion with an increment of heart rate. Therefore, Doppler studies that are not standardized for patients’ mealtimes may affect the validity of data in serial studies of left ventricular function. (Jpn Heart J 35: 35–42, 1994)

Key words: Doppler echocardiography Cardiac output Postprandial hemodynamic change

MEASURING cardiac output by a Doppler method has been validated in various laboratory examinations, and has proven to be a simple, inexpensive, and reliable method without the need for cardiac catheterization. This method requires calculation of temporal mean aortic ejection flow velocity de-
derived from Doppler spectral waveform and an estimate of aortic cross-sectional area. The reproducibility of a Doppler method has proven to be reasonably good with less than a 6% coefficient of variation.\textsuperscript{3,4)

Although Doppler estimation of cardiac output has been widely applied in exercise testing or under various pharmacological manipulations, the possibility of hemodynamic changes in response to a meal has not been considered. Moreover, the mechanisms controlling this postprandial hyperemic response are not well understood.\textsuperscript{5,6)

The purpose of this study was to investigate the influence of meal ingestion on cardiac function and to determine the optimum timing during a day for measuring stroke volume.

**Methods**

**Study subjects:** *Group A:* Ten healthy volunteers (all men) with a mean age of 28 years (range 21–38) were assigned to have their serial stroke volume and plasma glucose measurements before and after lunch. *Group B:* Nine healthy subjects including 6 women and 3 men with a mean age of 52 years (range 25–69) received 75 g oral glucose tolerance test (OGTT) instead of a common lunch. Serial stroke volume measurements were carried out simultaneously with blood glucose level estimation.

Each subject in Group A took about 800 Kcal of lunch with 100–200 ml of water. Group B subjects agreed to be involved in the protocol in order to have their general physical condition and blood chemistry checked. No subject was taking any form of medication, and no subjects showed any evidence of cardiac disease or diabetes mellitus. Satisfactory echocardiographic images were obtained in each subject.

**Doppler echocardiographic measurements:** In Group A, Doppler echocardiographic studies were performed before, 30 minutes after and every 1 hour after lunch for 5 hours. In Group B, Doppler echocardiographic studies were performed before, and 1 and 2 hours after the intake of 75 g of glucose in a solution of 225 ml of flavored water. Echocardiographic examination was performed in all subjects in the left lateral position. Cross-sectional and continuous wave Doppler echocardiograms were recorded by one skilled investigator using a cross-sectional phased array echocardiographic Doppler system (Hewlett-Packard 77020AC) with a 2.5 MHz phased array transducer or with a 1.95 MHz dedicated independent continuous wave transducer. The images were recorded on VHS videotape for computer analysis.

**Measurement of aortic valve area (AVA):** The aortic valve diameter (D) was measured in systole, immediately after the opening of the aortic valve leaflets, in
Figure 1. Stroke volume was calculated as a product of echocardiographically-determined cross-sectional area of the aortic annular size and the flow velocity integral measured by continuous wave Doppler.

the parasternal long-axis plane at the level of the aortic orifice just proximal to the left ventricular outflow tract. The AVA was calculated from the equation $\pi(D/2)^2$.

**Measurements of Doppler spectral waveform:** The aortic ejection flow velocity was obtained from the apex by continuous wave Doppler in the left lateral decubitus position. The area under the aortic ejection flow velocity curve (velocity integral: VI) was determined by the tracings from the baseline around the velocity curve using a digitizer linked microcomputer system. Six consecutive wave forms were traced, and the average mean VI was obtained for stroke volume measurement (Figure 1).

**Calculation of stroke volume (SV):** SV was determined by a method proposed by Lewis et al.
SV (ml) = VI (cm) × AVA (cm²)
CO (l/min) = SV (ml) × HR (/min)/1000

**Intra- and inter-observer accuracies:** To analyze the intra-observer accuracy, the same observer remeasured random samples of the tracings 2 weeks after the initial measurement was carried out. Two observers made 2 independent and blind measurements to obtain inter-observer variabilities. These variabilities were expressed as a percent error for each measurement.

**Statistical analysis:** All variables are expressed as mean ± standard deviation. The average variation was determined by paired t-test. A p value of <0.05 was considered significant. Inter-observer and intra-observer interpretative variability was calculated by analysis of variance.

**RESULTS**

Satisfactory recordings of both aortic diameter and aortic ejection flow velocity were obtained in all subjects. The mean diameter of aortic valve orifice was 2.2±0.1 cm (range 1.9–2.5 cm). Doppler hemodynamic changes before and after meal ingestion in Group A are summarized in Table I. The mean stroke volume was 61±7 ml (range 52–75 ml) before lunch and it increased gradually after ingestion of food. One hour later the stroke volume increased significantly to 72±8 ml (range 63–90 ml), and remained constant for the next 4 hours, and then 5 hours later the stroke volume decreased to the baseline. Mean cardiac output before lunch was 3.8±0.5 l/min which increased significantly after lunch in all subjects. Although cardiac output varied depending on the heart rate, all measurements gradually returned to baseline. Reproducibility of cardiac output and stroke volume measurements at 1 hour after lunch were evaluated in the following 2 reexamination studies which were performed at 2 and 4 weeks after

<table>
<thead>
<tr>
<th>Time after lunch (hour)</th>
<th>0.5</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate (b/min)</td>
<td>63 ±7</td>
<td>75 ±7**</td>
<td>74 ±7**</td>
<td>70 ±10**</td>
<td>69 ±9**</td>
<td>69 ±9**</td>
</tr>
<tr>
<td>Stroke volume (ml)</td>
<td>61 ±7</td>
<td>65 ±7*</td>
<td>72 ±8**</td>
<td>71 ±7**</td>
<td>71 ±8**</td>
<td>71 ±8**</td>
</tr>
<tr>
<td>Cardiac outputs (l/min)</td>
<td>3.8 ±0.5</td>
<td>4.9 ±0.7**</td>
<td>5.2 ±0.5**</td>
<td>4.9 ±0.7**</td>
<td>4.8 ±0.5**</td>
<td>4.9 ±0.5**</td>
</tr>
<tr>
<td>Flow integral (cm/sec)</td>
<td>15.5±2.5</td>
<td>16.6±2.5*</td>
<td>16.8±2.3**</td>
<td>18.0±2.3**</td>
<td>17.8±2.5**</td>
<td>17.6±2.4**</td>
</tr>
<tr>
<td>Max velocity (cm/sec)</td>
<td>77 ±10</td>
<td>88 ±10**</td>
<td>94 ±8**</td>
<td>93 ±10**</td>
<td>91 ±10**</td>
<td>90 ±8**</td>
</tr>
<tr>
<td>Mean velocity (cm/sec)</td>
<td>50 ±5</td>
<td>59 ±5**</td>
<td>63 ±5**</td>
<td>62 ±6**</td>
<td>62 ±6**</td>
<td>60 ±6**</td>
</tr>
<tr>
<td>Plasma glucose (mg/dl)</td>
<td>82 ±5</td>
<td>112±12**</td>
<td>118±8**</td>
<td>101±6**</td>
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</tr>
</tbody>
</table>

Statistical comparison was made between the values at baseline (before lunch) and after lunch. *p<0.05, **p<0.01
Figure 2. Reproducibility of cardiac output and stroke volume measurements at 1 hour after lunch were evaluated at the following 2 reexamination studies performed within a month (see text). Stroke volume data were more stable than cardiac output measurements.

Figure 3. The changes in left ventricular dimensions caused by meal ingestion in a typical case. The left echocardiogram was obtained before lunch, and the right one after lunch. LVDd and LV ejection fraction were significantly increased.
Table II. Changes in Plasma Glucose Levels and the Parameters of Cardiac Function by 75g OGTT in Healthy Subjects (Group B).

<table>
<thead>
<tr>
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<th>Before</th>
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<tbody>
<tr>
<td>Plasma glucose (mg/dl)</td>
<td>89 ±8</td>
<td>113 ±20**</td>
<td>110 ±21**</td>
</tr>
<tr>
<td>Heart rate (b/min)</td>
<td>61 ±9</td>
<td>64 ±6*</td>
<td>61 ±10</td>
</tr>
<tr>
<td>Stroke volume (ml)</td>
<td>73 ±14</td>
<td>74 ±13</td>
<td>72 ±13</td>
</tr>
<tr>
<td>Cardiac output (l/min)</td>
<td>4.2 ±0.8</td>
<td>4.7 ±0.7**</td>
<td>4.2 ±0.8</td>
</tr>
</tbody>
</table>

Statistical comparison was made between the values at baseline and after lunch. *p<0.05, **p<0.01.

the initial study. As shown in Figure 2, more reliable values for stroke volume measurements were obtained when compared to the values for cardiac output. The variability of cardiac output measurements was caused mainly by the variable response to the heart rate. M-mode echocardiography revealed that left ventricular diastolic dimension (LVDd) increased from 4.9±0.4 cm at baseline to 5.3±0.3 cm at 1 hour after lunch, and ejection fraction from 74±2% to 81±0.6%, (Figure 3).

The mean percentage error of the measurements made following a 2 week interval was 5.2±0.9%. All measurements were highly reproducible. The percent difference was 5.4±0.5% when duplicate measurements by the same-observer were compared and 7.8±0.7% for measurements made by 2 independent observers.

In Group B, as shown in Table II, 1 hour after taking a 75g glucose solution, the plasma glucose levels were increased from 89±8 mg/dl to 113±20 mg/dl. However, the stroke volume remained nearly the same before, and 1 and 2 hours after ingestion (73±14 ml, 74±13 ml and 72±13 ml, respectively).

DISCUSSION

In previous studies, postprandial hemodynamic studies demonstrated that a substantial meal caused a significant increase in stroke volume in healthy and ischemic subjects determined by Swan-Ganz cardiac catheterization and radio-  nuclide angiography. However, there are no Doppler echocardiographic reports on changes in cardiac output related to meal ingestion. The reliability of cardiac output determination by a Doppler method has been considered to be as sensitive as an invasive catheterization approach. Doppler echocardiography is superior to other methods in terms of its low cost, performance and convenience and it can be performed repeatedly at bed side.

For the evaluation of therapeutic efficacy in heart failure or pharmacologic effects on cardiac function, hemodynamic changes secondary to meal ingestion should be considered in measuring cardiac output. Kelbaek et al and Brown et
al\textsuperscript{(10)} reported that meal ingestion caused significant inotropic and chronotropic effects on cardiac function.

In the present study, we planned to feed the candidate about 800 ml of water with protein, lipids and carbohydrates. The heart rate, stroke volume and cardiac output increased from 30 minutes to 4 hours after meal ingestion. M-mode echocardiography revealed a significant increase in left ventricular end-diastolic dimension (LVDd), and it is postulated that the postprandial increase in the stroke volume was caused by an increase in preload. Our results were concordant with the data reported by previous investigators.\textsuperscript{8-10} In addition to the concept of circulation loading (changes in LV end-diastolic dimensions), Kelbaek presented the postprandial elevation of plasma norepinephrine concentrations. In the present study, we also found positive inotropic effects (increased LV ejection fraction) on cardiac function in M-mode echocardiography.

Koh et al\textsuperscript{6} reported that glucose ingestion increased the serum insulin concentration and subsequently increased the secretion of noradrenalin. It has also been reported that activation of the sympathetic nervous system due to glucose ingestion causes an increase in the rate-pressure product (the product of heart rate and systolic blood pressure).\textsuperscript{11} In our study, heart rate increased significantly at 1 hour after glucose ingestion in the OGTT, but no significant changes were detected in the stroke volume. The glucose flavored water administered in the 75 g OGTT contains 225 ml of water and carbohydrates only. No change was observed in the stroke volume when only the blood glucose level was elevated in OGTT, although this may have been due to the difference in the loading volume. It is possible that the ingestion of water with carbohydrates alone and the ingestion of an ordinary lunch which contains proteins, lipids and carbohydrates may result in different responses involving 1) digestion and absorption in the digestive tract, 2) the degree of decrease in the mesenteric vascular resistance and the change in the blood flow redistribution\textsuperscript{12,13} 3) the influence on the nervous system, and 4) the responses of the endocrine system, such as anti-natriuretic hormone or plasma renin activity.\textsuperscript{14} However, further investigation of the mechanisms of hemodynamic changes resulting from meal ingestion is needed.

In conclusion, the influence of ingestion of food cannot be ignored because differing mealtimes may affect the validity of hemodynamic data in serial comparative measurements.

The present study suggests that it is desirable either to assess cardiac function during a steady state period (1 to 4 hours after a meal) for consecutive short term studies, or assess the function in the fasting state for week-to-week follow-up studies.
ACKNOWLEDGMENT

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REFERENCES