Evaluation of left ventricular performance during supine exercise by transoesophageal M-mode echocardiography in normal subjects

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SUMMARY In order to evaluate left ventricular function during dynamic exercise transoesophageal M-mode recordings of the left ventricle were carried out with a newly developed transducer gastroscope system. Twelve healthy subjects performed a graded supine bicycle exercise test. Stable and good quality images of the left ventricle at rest and during exercise at different steps up to a maximum workload of 100 watts were obtained in all patients. Isotonic maximum exercise resulted in a significant increase in fractional shortening of the left ventricle, peak shortening rate, and peak lengthening rate of the left ventricular minor axis. Left ventricular end-diastolic dimension decreased significantly. With increasing workload the pressure rate product increased significantly. It is concluded that transoesophageal M-mode echocardiography is a useful method of evaluating left ventricular performance during dynamic exercise.

M-mode echocardiography is an accurate and reproducible technique for assessing left ventricular size and performance at rest in normal sized hearts without segmental wall motion abnormalities.1–4 The technique, however, is severely limited by the difficulty of obtaining high quality echocardiograms of the left ventricle during dynamic exercise.5–7 In order to overcome this restriction transoesophageal left ventricular echocardiograms at rest and during dynamic exercise were recorded with a newly developed transducer gastroscope system.

Subjects and methods

Twelve healthy volunteer subjects (seven men, five women), aged 18 to 23 years, were studied. All had a normal cardiovascular history, physical examination, and 12 lead electrocardiogram at rest and during maximum exercise. None of the subjects was taking any drugs. Informed consent was obtained from them all.

TRANSDUCER GASTROSCOPE SYSTEM

A 3.5 MHz non-focused Aerotech ultrasound transducer fixed to the tip of a commercially available gastroscope with an outer diameter of 7 or 9 mm (Fig. 1) was used. The transducer was mounted in a 24×14×11 mm³ casing with rounded edges for easy swallowing. The tip of the gastroscope could be angled in all directions and fixed in a definite position by means of two knobs at the proximal end of the gastroscope (Fig. 1). Thus, a close contact between the transducer and the moist surface of the mucosa of the oesophageal wall was guaranteed without the need for a coupling agent.

TRANSOESOPHAGEAL EXAMINATION TECHNIQUE

Because the fibreoptics system of the gastroscope was replaced by the transducer cable, the gastroscope had to be introduced blind. Therefore, before the ultrasound examination, each patient had to have an x-ray examination of the oesophagus in order to exclude a diverticulum of the oesophagus. Subjects were fasted and, one hour before the examination, received 0.5 mg atropine sulphate subcutaneously to avoid reflex bradycardia and gagging. The investigation was carried out with the patient in a supine position.

After insertion of the gastroscope to a level of about...
Fig. 1 The transoesophageal ultrasound gastroscope system. The outer diameter of its shaft is 9 mm. The transducer, covered with soft plastic material, is incorporated into the tip of the gastroscope. Angulation of the transducer is possible by turning two external knobs.

Fig. 2 Transoesophageal M-mode scan from the aorta to the left ventricle at the level of the papillary muscle. Ao, aorta; ASLVW, anteroseptal wall of the left ventricle; ECG, electrocardiogram; LA, left atrium; LV, left ventricle; MV, mitral valve leaflets; PCG, phonocardiogram; PLVW, posterior wall of the left ventricle.
Transoesophageal M-mode exercise echocardiography

40 cm, the aortic root echo could be identified. Advancing 1 to 2 cm further and rotating counter clockwise permitted recordings of the left ventricle at rest and during exercise at the level of the free edges of the mitral leaflets (Fig. 2), thus showing the posterior and the free anteroseptal walls.

Each subject performed a supine bicycle exercise test at workloads of 25, 50, 75, and 100 watts. The load was increased stepwise at three minute intervals. Left ventricular echocardiograms and blood pressures were simultaneously recorded at rest and at the third minute of each workload level.

The transoesophageal echocardiographic examination took about 20 minutes for each patient. There were no complications.

Echocardiographic measurements and calculations

Transoesophageal echoes were recorded on standard echocardiographic equipment at a paper speed of 50 or 100 mm/s. The recorded echocardiograms were digitised and processed, using a previously described computerised method.8

Echocardiographic variables of particular interest in this study were:
(a) End-diastolic left ventricular diameter (DD in mm), measured at the onset of the R wave.
(b) End-systolic diameter (DS in mm). The smallest distance between the posterior and the anteroseptal wall of the left ventricle.
(c) Fractional shortening (FS as %) of the minor axis of the left ventricle, calculated according to the following formula:

$$FS = \frac{DD - DS}{DD} \times 100$$

(d) Peak shortening rate (VCFmaxs⁻¹) of the left ventricular minor axis:

$$VCF_{max} = \left( \frac{1}{D} \times \frac{dD}{dt} \right)_{min}$$

(e) Peak lengthening rate (VLRmaxs⁻¹) of the left ventricular minor axis:

$$VLR_{max} = \left( \frac{1}{D} \times \frac{dD}{dt} \right)_{max}$$

In each subject, three successive cardiac cycles at rest and at different levels of workload were analysed and averaged. Statistical analysis was carried out using Friedmans's test for examination of the general tendency of the data and Wilcoxon's test to analyse the step-to-step difference between the control measurements and those at the different workloads.

In accordance with recent data by Matsumoto et al.,9 we found a good correlation between the left ventricular diastolic dimensions measured by the transoesophageal approach and the standard transthoracic method (r=0.90; standard error of estimate ±0.1 mm). In order to assess the reproducibility of the transoesophageal measurements the gastroscope was drawn back up to the level of the ascending aorta and introduced a second time in order to identify the largest left ventricular minor axis in eight subjects (Fig. 3, r=0.90; standard error of estimate ±0.25 mm).

Results

The mean values of the echocardiographic variables at rest and at the different levels of workload are listed in the Table for all 12 subjects. Fig. 4 represents typical recordings of a normal subject at rest and during exercise. Results for relevant echocardiographic variables are shown in Fig. 5.

Dynamic exercise resulted in a significant increase in heart rate (89±13 up to 142±22/min; p<0.01), systolic blood pressure (132±9 up to 155±13 mmHg; p<0.01) and, accordingly, in the pressure rate product (11 800±2100 up to 22 100±4840 mmHg/min; p<0.01) from rest to the endpoint of exercise. Left ventricular end-diastolic dimension decreased significantly from 52±6 mm at rest to 48±7 mm after three minutes of 100 watts (p<0.01). The decline in systolic dimension was even more pronounced, resulting in a steady increase in fractional shortening (36±4

Fig. 3 Comparison between transoesophageal echocardiographic left ventricular end-diastolic dimension of two independent examinations in the same subject (n=8).
Table  Mean values (±1 standard deviation) of different echocardiographic variables in 12 normal subjects (Friedman's test performed for the analysis of central tendency of sequential data)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Rest</th>
<th>3' 25W</th>
<th>3' 50W</th>
<th>3' 75W</th>
<th>3' 100W</th>
<th>Friedman test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate/min</td>
<td>89±13</td>
<td>106±13</td>
<td>117±15</td>
<td>131±19</td>
<td>142±22</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td>Systolic blood pressure (mmHg)</td>
<td>132±9</td>
<td>135±9</td>
<td>140±14</td>
<td>149±15</td>
<td>155±13</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td>Pressure rate product (mmHg/min×10⁵)</td>
<td>11-8±2-1</td>
<td>14-4±2-0</td>
<td>16-3±2-8</td>
<td>19-6±4-5</td>
<td>22-1±4-8</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td>End-diastolic diameter (mm)</td>
<td>52±6</td>
<td>51±7</td>
<td>49±6</td>
<td>48±7</td>
<td>48±7</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td>End-systolic diameter (mm)</td>
<td>33±6</td>
<td>32±6</td>
<td>30±6</td>
<td>28±6</td>
<td>27±6</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td>Fractional shortening (%)</td>
<td>36±4</td>
<td>38±4</td>
<td>40±5</td>
<td>42±5</td>
<td>44±5</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td>VCF max&lt;sub&gt;1&lt;/sub&gt;</td>
<td>2-4±0-3</td>
<td>2-7±0-4</td>
<td>3-0±0-5</td>
<td>3-6±0-9</td>
<td>4-2±1-0</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td>VLR max&lt;sub&gt;1&lt;/sub&gt;</td>
<td>4-0±0-9</td>
<td>4-6±0-9</td>
<td>5-2±0-9</td>
<td>6-1±1-2</td>
<td>7-0±1-7</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td>VCF max&lt;sub&gt;2&lt;/sub&gt;</td>
<td>2-4±0-3</td>
<td>2-7±0-4</td>
<td>3-0±0-5</td>
<td>3-6±0-9</td>
<td>4-2±1-0</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td>VLR max&lt;sub&gt;2&lt;/sub&gt;</td>
<td>4-0±0-9</td>
<td>4-6±0-9</td>
<td>5-2±0-9</td>
<td>6-1±1-2</td>
<td>7-0±1-7</td>
<td>p&lt;0.001</td>
</tr>
</tbody>
</table>

VCF<sub>max</sub>: peak shortening rate of the left ventricle; VLR<sub>max</sub>: peak lengthening rate of the left ventricle.

Fig. 4  This composite figure shows transoesophageal M-mode echocardiograms at the stages of rest and during different steps of exercise up to a maximum workload of 100 watts.

Fig. 5  Graphic display of the mean values (±1 standard deviation) of the different variables at rest and during different steps of exercise. (p values refer to Wilcoxon’s test.)

up to 44±5%; p<0.01) and in the peak rate of left ventricular shortening (2-4±0-3 up to 4-2±1-0/s; p<0.01). This improvement in systolic performance during exercise was accompanied by a significant increase in left ventricular peak lengthening rate (4-0±0-9 up to 7-0±1-7/s; p<0.01).
Discussion

The main purpose of this study was to document the usefulness and the advantages of exercise transoesophageal echocardiography. Since the first clinical application of transoesophageal echocardiography by Frazin et al. in 1976, a few studies only have appeared on the evaluation of left ventricular function at rest by the transoesophageal approach. This was partly because of the unusual character of the technique and partly because of problems of transducer control.

In order to apply the technique further to exercise evaluation of left ventricular function, the transducer system had to be improved. The incorporation of the ultrasound transducer into the tip of a gastroscope enabled controlled manipulation of transducer orientation (rotation and angulation) which made the recording of left ventricular exercise echocardiograms much easier. Published reports of exercise echocardiography using the parasternal approach indicate technical problems in obtaining adequate images. These difficulties are usually caused by chest wall movement and by the interference of lung tissue between the transducer and the heart resulting from exercise-induced hyperventilation. The major advantages of the method described in this paper are that, because of the close anatomical relation of the oesophagus and heart, respiration and chest wall movement do not interfere with left ventricular imaging.

Our echocardiographic investigation disclosed a progressive decrease in end-systolic dimension during dynamic exercise, corresponding to an increase in stroke volume. This is in agreement with recent angiographic and radionuclide studies. The concept that an increase in stroke volume seems to be the normal response to dynamic exercise is thus supported and is thought to be caused by an increased contractility. This is indicated in our results by a significant increase in left ventricular fractional shortening as well as in the peak shortening rate of the left ventricular minor axis. The end-diastolic diameter, on the other hand, did not increase, so that the Frank-Starling mechanism seems to have no influence on the improvement of left ventricular systolic performance during supine exercise in normal subjects. The reasons for the decrease in end-diastolic dimension are probably related to a decrease in filling time with increasing heart rate and to an activation of the sympathetic tone, as has already been pointed out.

This study shows that high quality transoesophageal M-mode echocardiograms of the left ventricle at rest and during dynamic exercise can be obtained. The technique has the advantage of being non-invasive, repeatable, and inexpensive. It allows study of instantaneous events in each cardiac cycle rather than the results in several cycles needing to be combined. There is no radiation exposure involved and, because of the high resolution of the ultrasound technique, the evaluation of cavity dimension and wall thickness changes can be assessed more easily than with gated blood pool scans or the other techniques now available.

Although transoesophageal echocardiography does give rise to some discomfort for the patient, and skill is required to introduce the ultrasonic probe into the oesophagus, the high success rate, good stability, and the quality of continuous left ventricular images more than make up for the disadvantages.

References

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