Clinical Application of Echocardiographic Imaging to Diagnosis of Coronary Artery Disease

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Ergometer two-dimensional echocardiography was performed in 28 subjects complaining of chest pain but without myocardial infarction. Sequential ergometer loading was initiated at 50 or 75 watts, and increased in several stages. Apical four-chamber view two-dimensional echocardiograms were recorded onto video tape, and video images were converted into digital computer signals. After cine-loop display, computer image processing included noise reduction and edge enhancement, M-mode measurements were made at a designated level on the two-dimensional echo images. Wall motion was also analyzed directly from the two-dimensional echo images, using an auto-edge detection method. The derived data were compared with results from coronary angiograms. No echo abnormality was observed at rest, whereas during exercise wall motion was depressed at the diseased site of the angiogram; the amplitude of excursion and the changes in systolic and diastolic velocity were disturbed at the septum in LAD-involved patients, and in the posterolateral wall in both Cx and RCA patients. The imaging success rate using the computer-aided analysis was found to be 92.9%. Sensitivity for diagnosis of coronary artery disease was 82.1% and specificity 89.3%. Ergometer two-dimensional echocardiography with assisted computer image processing appears to be one of the most valuable tools for clinical real time evaluation of coronary artery disease.

Two-dimensional echocardiography is one of the most suitable real time noninvasive methods for evaluation of various heart disease abnormalities. Some organic lesions, such as those seen in valvular heart disease, are readily detected in terms of echocardiographic changes. However, no specific echo features may be observed at rest in coronary artery disease, unless sufficient exercise loading is superimposed to produce characteristic heterogeneity of left ventricular wall motions along with altered electrical conduction. A bicycle-ergometer two-dimensional echocardiographic study was performed to diagnose coronary artery disease, applying computer-assisted cross-sectional image analysis during staged exercise.

SUBJECTS AND METHODS

Two-dimensional echocardiography was carried out in 28 subjects (22 male, 6 female; 56.2 ± 7.4 years old), complaining of chest pain but without myocardial infarction. Bicycle-ergometer (Lode BV Instrumenten, Groningen, Holland) loading was carried out in a left lateral recumbent position (20~30°). The initial load was 50 or 75 watts at a constant rate of 60 rpm, and it was
Two-dimensional echocardiogram
  
  Video image
  
  A/D conversion
  
  Computer image memory
  
  Cine loop
  
  Image processing
    
    Noise reduction
      
      SIGMA filter, Median filter,
      
      Lowpass filter, Gaussian filter, etc.
    
    Edge enhancement
      
      Sobel filter, Laplacian filter, etc.
  
  M-mode echocardiogram
    
    Auto-edge detection (Radial search method)
  
  Analysis
    
    Systolic function
    
    Diastolic function
  
  Regional wall motion

Fig. 1. Diagram of steps in computerized echo image analysis.

Increased stepwise by 25 watts every 3 min. Blood pressure was measured using an automatic manometer (Nihon Colin, CO., 28, 423-1), and the electrocardiogram was recorded using leads II, aVR, V	ext{5} and V	ext{4}–6 every minute before and during the exercise, as well as for 5 min after termination of the exercise. Exercise was stopped when subjective symptoms appeared, such as chest pain, dyspnea and leg fatigue, or when the systolic or diastolic blood pressure rose above 230 mmHg or 130 mmHg, respectively.

Two-dimensional echocardiograms (Hewlett Packard Ultrasound Imaging System, 770, 220 A, 2.5 MHz transducer) were video-recorded (National, AG 6,300). Image analysis was carried out with computer assistance (Kontron, Mipron; Fig. 1); the video-tape analog signals were converted into a digital form and a cine-loop was employed for continuous viewing of a single cardiac cycle. After noise reduction and edge enhancement had clarified the border between the endocardium and left ventricular cavity, M-mode echo analysis was specifically applied at an arbitrary site in the interventricular septum and the posterolateral wall of the two-dimensional echo apical four-chamber view (Fig. 2).

Results and velocity of wall motions at these locations were then calculated (Kontron computer, Cardio 80) prior to and during exercise. Corresponding regional wall motion of the left ventricle was also evaluated by the area method (the floating system), using auto-edge detection, from the end-diastolic and end-systolic two-dimensional echo images (Fig. 3).

Coronary angiography was performed in all patients one week before and after the echocardiographic study, and the results compared with the echo data. No alteration in symptoms or electrocardiograms appeared during the intervening periods.

All data were expressed as mean ± standard error (SE), and statistical comparison was performed using the paired and unpaired Student’s t test.

**RESULTS**

1. Regional wall motion analysis by M-mode echocardiogram (Fig. 4).

   1) Changes in the left ventricular dimension

   Percent systolic fractional shortening of the inner dimension of the left ventricle was 25.7–34.8% at rest. This increased during exercise to 37.6 ± 2.8% (increment of 12.6 ± 8.2%) in normal subjects, but decreased significantly to 16.9–18.9% in angina patients (p < 0.001). In normal subjects, wall velocity derived from inner echo dimension excursion curves increased significantly during exercise in both systole and diastole, above velocity values observed at rest. However, in angina patients the velocity decreased significantly during exercise (p < 0.001–0.01).

   2) Interventricular septum

   The excursion amplitude of the septum was 0.82 ± 0.09 cm at rest. In normal subjects this increased to 0.93 ± 0.08 cm during exercise, while the velocity of the septal movement increased in both systole and diastole. The amplitude in LAD patients decreased from 0.75 ± 0.11 cm to 0.43 ± 0.10 cm, and velocity also decreased significantly (p < 0.05–0.01).

   3) Left ventricular posterolateral wall

   The excursion amplitude of the posterolateral wall in normal subjects was not changed during exercise, but the velocity of the wall movement increased in both systole and diastole. The amplitude decreased significantly from 0.80 ± 0.11 cm to 0.57 ± 0.07 cm in CX patients, and from 0.87 ± 0.10 cm to 0.56 ± 0.10 cm in RCA.
patients (p < 0.05 for both). In contrast to normal subjects, the velocity of the posterolateral wall movement was not significantly changed by exercise in angina patients, and there were no differences in the velocities observed in LAD, Cx and RCA angina patients.

2. Left ventricular wall motion analysis by auto-edge detection (Table).

The auto-edge detection method was applied to two-dimensional echocardiographic images from the apical four-chamber view. Echo density interfered with auto-edge analysis in a few cases during diastole, and a manual correction was required at the apical portion in end-systole in 60~65% of all images analyzed with the most suitable selection of filter and centering position for automated radial search.

Regional wall motion was analyzed as percent changes in the regional cavity (fractional area changes) for the septal and posterolateral walls of the left ventricle. Fractional area change of the septum in normal subjects was 39.5% at rest, and this increased significantly to 64.9% during exercise (p < 0.001). However, it decreased significantly during exercise in patients with LAD stenosis (p < 0.05). Fractional area change of the posterolateral wall was 35.8% at rest, and this increased significantly in normal subjects during exercise (p < 0.001), while it decreased significantly to 26.4% in Cx patients (p < 0.05) and 27.7% in RCA patients (p < 0.01) during exercise.

3. Image success rate

Images suitable for computer analysis, including the cine-loop method, were obtained in 26 of the 28 patients (92.9%). Two of the 28 cases (7.1%) were not adequate for analysis, because of a respiratory artifact and an excessive dislocation of images during exercise.
DISCUSSION

It is usually difficult to obtain reliable echo images for analysis during exercise. There are several reasons for this: (1) respiration may interfere with a qualitative imaging, (2) the transducer can dislocate, and (3) the heart may exhibit global rotation and translation. If not corrected, these artifacts can change the observed echo wall motions of the heart during exercise. Our success rate for computer-aided exercise echo analysis of the echo images was 92.9% and much higher than that previously reported in the literature.1 We believe this was due to

(1) patients were recumbent in the left lateral position (20°-30°), (2) expiratory breath was held for a few seconds during the echo recording, (3) the echo transducer was adjusted to maintain the same echo images, and (4) an apical four-chamber cross-sectional view was employed.

Cine-loop display, i.e. one cardiac beat being repeatedly and continuously replayed, has been found to be useful for detection of an abnormal wall motion of the left ventricle, even when an abnormality in endocardial motion cannot be reliably detected from a stopped image.2 Control of respiration is also helpful during exercise for cine-loop echo image acquisition. Gain setting is

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Fig. 4. Results of M-mode echo analysis.
The top bar charts show changes to the inner dimension of the left ventricle. On the left is the percent fractional change, before and during exercise (shown by thin and thick bar enclosures), in normal subjects and patients with LAD, Cx or RCA coronary involvement. On the right are indicated changes of velocity in systole (left) and diastole (right), derived from the inner dimension curve of the left ventricle. The left middle bar charts show the amplitude of excursion of the septum before and during exercise in normal subjects and in LAD-involved patients. The right chart indicates corresponding changes in systolic and diastolic velocity during exercise. The bottom bar charts on the left demonstrate the amplitude of excursion of the PW before and during exercise in normal subjects as well as in Cx and RCA patients, and on the right are changes in systolic and diastolic velocities during exercise.

considered one of the most influential factors for correctly deciding on the endocardial border. Ambiguous definition of lateral borders is another factor, because the echo beam parallels the lateral endocardium. The left ventricular endocardial border can be clarified using computer
### TABLE REGIONAL WALL MOTION ANALYSIS OF THE LEFT VENTRICLE BY AUTO-EDGE DETECTION

<table>
<thead>
<tr>
<th></th>
<th>Segmental fractional change (%)</th>
<th>% Change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>At rest</td>
<td>During exercise</td>
</tr>
<tr>
<td>Normal</td>
<td>39.5 ± 2.6 **</td>
<td>64.9 ± 3.9 ***</td>
</tr>
<tr>
<td></td>
<td>35.8 ± 2.4 **</td>
<td>54.0 ± 3.0 ***</td>
</tr>
<tr>
<td>LAD</td>
<td>48.0 ± 6.6 **</td>
<td>22.2 ± 8.9 **</td>
</tr>
<tr>
<td></td>
<td>38.1 ± 3.2 **</td>
<td>31.2 ± 2.8 **</td>
</tr>
<tr>
<td>Cx</td>
<td>50.3 ± 6.7 **</td>
<td>47.3 ± 8.8 **</td>
</tr>
<tr>
<td></td>
<td>38.0 ± 2.5 **</td>
<td>26.4 ± 4.5 **</td>
</tr>
<tr>
<td>RCA</td>
<td>48.7 ± 5.3 **</td>
<td>23.2 ± 14.7 **</td>
</tr>
<tr>
<td></td>
<td>36.3 ± 1.9 **</td>
<td>27.7 ± 3.3 **</td>
</tr>
</tbody>
</table>

**Abbreviation:** Normal = normal subjects; LAD = patients with LAD stenosis; Cx = patients with Cx stenosis; RCA = patients with RCA stenosis; Ant = anterior wall; Post = posterolateral wall

("p < 0.01, **p < 0.05, ***p < 0.001")

image processing, consisting of noise reduction by SIGMA and median filters, endocardial edge enhancement by a Sobel gradient filter, and a Laplacian high pass filter.

Coronary artery disease exhibits regional wall motion abnormalities (including akinesis and hypokinesis), local abnormalities in wall thickness (systolic wall thinning), enlargement of the ventricular lumen, and regional impairment of systolic and diastolic function. A M-mode echocardiogram, constructed from two-dimensional echocardiograms in a particular portion of the abnormally moving wall, can help quantitate the regional function of the left ventricle, and thus detect coronary artery disease, even in its early stage.

It is essential to obtain clear echo images. When the initial views were "unsatisfactory", only 60% of the images could be utilized, even in short axis sections and with auto-edge detection. Since echo images from the apical four-chamber views are more difficult to analyze automatically than those from short axis views, a narrow range for endocardial dropout should be supplemented using a binary function or an averaging operation based on a couple of successful images. Endocardium can be delineated precisely when the filter for auto-edge detection is properly selected, and when the computer searching center used in radial search method is placed in the middle of the echo noise, so as to minimize the influence of noise. In our study, manual correction was needed in the vicinity of the apex at end-systole, even though in the apical four-chamber view the computer could automatically and correctly delineate endocardium at end-diastole. The computerized auto-edge detection method is suitable for analysis, requiring many images to be continuously analyzed in a frame-by-frame fashion. The method avoids variability of analysis even for different echo gray levels or different analyzers. In comparison with the manual method it also saves analysis time. However, the image processing employed in the current study could not be applied to myocardial tissue characterization, due to significant changes in back-scattered echo reflections from the myocardium.

When two-dimensional echocardiography is performed immediately after treadmill exercise, an excellent image success rate is obtainable. But the evoked post-exercise changes are not in

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real time, whereas graded loading ergometer two-dimensional echocardiography can provoke the earliest detectable changes in coronary artery disease, e.g. alteration of diastolic function, followed by systolic function alterations, electrocardiographic changes, and chest pain. The sensitivity of ergometer two-dimensional echocardiography for diagnosis of coronary artery disease was 82.1% (23/28), while specificity was 89.3% (25/28). These figures are higher than those obtained by Visser \(^4\) and almost equal to those of treadmill two-dimensional echocardiography.\(^5\) The sensitivity of treadmill electrocardiography, performed in the same patients, was, however, significantly lower (67.9%; 19/28).

Thus, ergometer two-dimensional echocardiography, with computer-assisted image processing, appears to be a very promising tool for diagnostic and therapeutic evaluation of coronary artery disease. In the near future, economic and readily applicable computerized echo devices should become available for effective diagnostic applications in the clinical setting of coronary artery disease.

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REFERENCES