PATHOPHYSIOLOGY AND NATURAL HISTORY
VENTRICULAR PERFORMANCE

Effects of spontaneous respiration on left ventricular function assessed by echocardiography

KAI ANDERSEN, M.D., AND HARALD VIK-MO, M.D.

ABSTRACT The effects of quiet respiration on assessment of left ventricular function by two-dimensional echocardiography were investigated in 12 healthy men. End-diastolic area in the parasternal short-axis view decreased with inspiration (from 17.3 ± 2.1 [mean ± SD] to 16.0 ± 2.1 cm²; p < .01), while end-systolic area did not change (from 7.6 ± 1.4 to 7.7 ± 1.5 cm²; NS). A fixed cursor that was located through the center of the left ventricular area at end-expiration made a tangential cut of the area at end-inspiration as the heart moved medially during inspiration. Thus left ventricular dimensions at end-inspiration were smaller along the cursor than through the center of the short-axis area both at end-diastole (1.9 ± 1.7 mm; p < .01) and end-systole (3.8 ± 4.0 mm; p < .01). Our results suggest a need for standardization with regard to respiratory phases in assessment of left ventricular function by two-dimensional echocardiography and indicate the occurrence of inspiratory reduction of left ventricular stroke volume associated with decreased diastolic filling. Motion of the heart relative to the echo beam may play a part in the respiratory variations in left ventricular dimensions assessed by M mode echocardiography.


LEFT VENTRICULAR stroke volume decreases from expiration to inspiration during spontaneous breathing. However, it is not clear whether this is caused by decreased diastolic filling or impeded systolic emptying. This physiologic variation might have importance for the reproducibility of left ventricular volumes and function assessed by two-dimensional echocardiography. M mode echocardiography in normal subjects has shown inspiratory reduction in end-diastolic dimension and ejection fraction with no significant change in end-systolic dimension. It was discussed whether this reflected respiratory variations in left ventricular function or rotation of the heart relative to the echo beam. This can be investigated by two-dimensional echocardiography, which provides a means for beat-to-beat analysis of left ventricular function and of spatial orientation of a single echo beam.

The purpose of this study in normal subjects was to investigate (1) the importance of quiet respiration on the assessment of left ventricular function by two-dimensional echocardiography, (2) the mechanism of the respiratory variations in left ventricular dimensions and derived function found by M mode echocardiography, and (3) the mechanism of respiratory variations in left ventricular stroke volume.

Subjects and methods

Twelve men 22 to 41 years old were studied. None had evidence of cardiopulmonary disease as judged by history, physical examination, blood pressure at rest, electrocardiogram, M mode and two-dimensional echocardiograms, vital capacity, and forced expiratory volume in 1 sec. Two others were excluded from the study, one with a history of exercise-induced asthma and one because of technically unsatisfactory recordings.

Recording. The subjects were examined in a slight left lateral decubitus position during quiet respiration. Two-dimensional echocardiograms were obtained in the parasternal short-axis view at the papillary muscle level by a 78 degree phased array sector scanner (Toshiba Sonolayergraph SSH-10A) with a 2.4 MHz hand-held transducer. Before recording, a steerable cursor was directed through the center of the left ventricle at end-expiration. The echocardiogram, one-lead electrocardiogram, and respiratory tracing by a nasal thermistor were recorded by a Sony video camera and were stored on and replayed from a video tape recorder (Victor Co. of Japan Ltd.). The electrocardiogram and the respiratory tracing were recorded simultaneously on a Honeywell strip chart recorder with a paper speed of 50 mm/sec. Care was taken to keep the body position and the transducer position unchanged during the recording.

Measurements and calculations. The heart beats selected for analysis were the last beats during expiration and inspiration with the onset of the QRS complex in the electrocardiogram before the onset of the next respiratory phase. The length of the cardiac cycles just preceding the selected beats were measured. The inner margin of the left ventricular cavity at end-diastole

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874
and end-systole, the top of the echo sector, and the cursor line were traced from the video screen on transparent plastic. End-diastolic was defined as the onset of the QRS complex, end-systole as the time of the smallest left ventricular area. A line was drawn on the transparency from the top of the echo sector through the midpoint between the papillary muscles at end-diastole; this will be referred to as the line through the center of the left ventricular area. The angle was measured between this line and the fixed cursor, which was aimed through the center of the left ventricular area at end-expiration before the recording was made. The cursor location was corrected before measurements were made if the tracing disclosed that the cursor at end-expiration deviated from the line through the center of the left ventricle. End-diastolic dimension (EDD) and end-systolic dimension (ESD) were measured along the line through the left ventricular center and along the cursor as the distances between their intersections with the area tracing. Left ventricular short-axis areas, excluding the papillary muscle areas, and minor-axis dimensions were determined by means of a graph pen microcomputer system (Cardio 80, Kontron Ltd.). End-expiratory and end-inspiratory values of variables for each subject represent the average of measurements during five consecutive respiratory cycles. Based on these values, stroke area was calculated as the difference between end-diastolic area (EDA) and end-systolic area (ESA), fractional area change as (EDA - ESA)/EDA × 100%, and fractional shortening as (EDD - ESD)/EDD × 100%.

The variability of echocardiographic measurements were assessed by tracing the areas by one observer at two different occasions and by two independent observers. The end-expiratory and end-inspiratory cardiac cycles from one randomly selected respiratory cycle in each subject were selected for analysis (total 24 cardiac cycles). The intraobserver and interobserver variability were expressed as coefficient of variation of duplicate measurements and were less than 8% for all measured variables.

In 10 subjects, end-expiratory and end-inspiratory left ventricular volumes were determined from echocardiograms in the apical four-chamber view by the area-length method as 8A²/3L, where A is the area of the ventricle and L is the long axis from the apex to the midpoint of a line crossing the mitral valve anulus. The values for each subject represent the average of determinations during five consecutive respiratory cycles. Stroke volume was calculated as the difference between end-diastolic and end-systolic volumes, and ejection fraction as the percentage of stroke volume relative to end-diastolic volume.

**Statistical analysis.** The data are expressed as mean ± SD. The difference of variables between end-expiration and end-inspiration and between those obtained through the left ventricular center and along the cursor at end-inspiration were evaluated by Wilcoxon's test (two-tailed) for comparison of paired data.** Differences were regarded as significant at p < .05.

**Results**

Cardiac cycle length, left ventricular short-axis areas, location of the line through the center of the area relative to the cursor, and minor-axis dimensions at end-expiration and end-inspiration are shown in table 1. The cycle length was slightly but significantly shorter at end-inspiration than at end-expiration. EDA and stroke area decreased significantly during inspiration without alteration in ESA. Fractional area change did not decrease significantly. The individual data of area measurements are shown in figure 1. EDD decreased with inspiration both through the center of the left ventricle and along the cursor (table 1 and figure 2). ESD did not change significantly when measured through the center in contrast to the marked reduction when measured along the cursor (table 1 and figure 2).

The line through the center of the left ventricle in the

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**TABLE 1**

<table>
<thead>
<tr>
<th>Cardiac effects of respiration in 12 normal men†</th>
<th>End-expiration</th>
<th>End-inspiration</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle length (msec)</td>
<td>1060 ± 175</td>
<td>1035 ± 175</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>EDA (cm²)</td>
<td>17.3 ± 2.1</td>
<td>16.0 ± 2.1</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>ESA (cm²)</td>
<td>7.6 ± 1.4</td>
<td>7.7 ± 1.5</td>
<td>NS</td>
</tr>
<tr>
<td>Stroke area (cm²)</td>
<td>9.7 ± 1.6</td>
<td>8.3 ± 1.7</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Fractional area change (%)</td>
<td>55.9 ± 6.1</td>
<td>51.8 ± 7.6</td>
<td>NS</td>
</tr>
<tr>
<td>Medial deviation from the cursor of the line</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Through the LV center (degrees)</td>
<td>0 ± 0</td>
<td>5.2 ± 2.1</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>EDD (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Through the LV center</td>
<td>51.3 ± 3.4</td>
<td>48.3 ± 4.0</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Along the cursor</td>
<td>51.3 ± 3.4</td>
<td>46.3 ± 4.6</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>ESD (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Through the LV center</td>
<td>34.3 ± 3.7</td>
<td>33.3 ± 3.6</td>
<td>NS</td>
</tr>
<tr>
<td>Along the cursor</td>
<td>34.3 ± 3.7</td>
<td>29.5 ± 5.9</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Fractional shortening (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Through the LV center</td>
<td>33.4 ± 5.2</td>
<td>31.0 ± 6.3</td>
<td>NS</td>
</tr>
<tr>
<td>Along the cursor</td>
<td>33.4 ± 5.2</td>
<td>37.0 ± 10.3</td>
<td>NS</td>
</tr>
</tbody>
</table>

Values are mean ± SD.

LV = left ventricular.

†The left ventricular areas and dimensions were obtained by two-dimensional echocardiography in the parasternal short-axis view at the papillary muscle level. The dimensions through the left ventricular center were measured along a line from the top of the echo sector through the midpoint between the papillary muscles at end-diastole.
short-axis view deviated medially with inspiration in all 12 subjects (table 1 and figure 3). Thus the fixed cursor that was located through the center of the left ventricle at end-expiration was laterally off the center at end-inspiration, making a tangential cut of the left ventricular area (figure 4). As a result, the dimensions at end-inspiration were smaller along the cursor than through the left ventricular center both at end-diastole (1.9 ± 1.7 mm; p < .01) and end-systole (3.8 ± 4.0 mm; p < .01) (figure 5). Fractional shortening at end-inspiration was significantly higher along the cursor than through the center (figure 5).

Left ventricular end-diastolic volume decreased with inspiration (from 88.3 ± 24.9 to 74.3 ± 22.7 ml; p < .01) as did end-systolic volume (from 35.4 ± 14.1 to 31.1 ± 12.6 ml; p < .01). Stroke volume also decreased (from 52.9 ± 12.3 to 43.2 ± 11.9 ml; p < .01), while ejection fraction did not change significantly (from 60.6 ± 5.1% to 58.7 ± 5.2%).

**Discussion**

**Methodologic aspects.** In the present study, EDA decreased during inspiration with concomitant decrease in stroke area while ESA did not change significantly. This probably reflects changes in global ventricular function, since the calculated reduction in left ventricular short-axis area has been found to closely ap-
proximate the ejection fraction. Thus our findings indicate the occurrence of inspiratory decreased left ventricular stroke volume associated with reduced diastolic filling.

The role of quiet respiration in measurements of left ventricular function by two-dimensional echocardiography has not been assessed previously. Spontaneous respiration has been shown to cause changes in measurements of left ventricular dimensions by M mode echocardiography. It has been recommended that recording of left atrial and right and left ventricular dimensions by M mode echocardiography should be done with simultaneous tracing of the respiratory phases and that measurements should be made at end-expiration. Our results suggest a need for similar standardization with regard to respiratory phases in two-dimensional echocardiographic assessment of left ventricular volumes and function, which might have importance for the reproducibility of measurements.

The respiratory variations in left ventricular minor-axis dimensions were in keeping with the variations in the short-axis areas when measured through the center of the left ventricle. However, different results were obtained when the measurements were made along a fixed cursor transecting the left ventricular area centrally at end-expiration. The heart was found to move medially in the short-axis view during inspiration, making an inspiratory tangential cut by the cursor. Thus the inspiratory dimensions were smaller along the cursor than through the center of the short-axis area. ESD along the cursor decreased significantly with inspiration in contrast to that through the center. M mode echocardiography has shown wide variations.
in inspiratory change in ESD between different individuals. This might be caused by motion of the heart, with different effects on the measured dimension depending on the spatial orientation of the beam at end-expiration. In our study, fractional shortening at end-inspiration was significantly higher along the cursor than through the center of the left ventricular area. This is in accordance with a recent M mode and two-dimensional echocardiographic study in which fractional shortening increased with increasing deviation of the echo beam from the left ventricular meridian. Our results thus demonstrate that motion of the heart relative to the echo beam may play a part in the respiratory changes in left ventricular dimensions assessed along a fixed beam direction.

**Physiologic aspects.** The fixed short-axis plane might have transected the left ventricle at various levels during respiration, since the heart was allowed to move through the plane. If so, it would be expected to affect the size of both EDA and ESA, while in our study EDA decreased without concomitant change in ESA. The circular shape of the areas obtained both at end-expiration and end-inspiration suggests no major change of the angle between the echo plane and the long axis of the left ventricle during respiration. To exclude the possibility that the results were merely due to vertical motion of the heart, volume calculations were made from area and long-axis measurements in the apical four-chamber view. End-diastolic volume and stroke volume decreased with inspiration in addition to a small reduction in end-systolic volume. The apical transducer position has been shown to be cranial to the anatomic apex in most patients, which suggests a further echocardiographic tangential cut of the ventricle during inspiration as the diaphragm descends. Reduction in volume determinations by this mechanism would be expected to be of greatest relative importance at end-systole. In our study, the relative volume reduction was most pronounced at end-diastole and suggests decreased ventricular filling in addition to the possible role played by a further tangential cut of the ventricle. Thus the volume measurements support the findings in the short-axis view that indicate the occurrence of inspiratory decrease in left ventricular stroke volume associated with reduced diastolic filling.

The inspiratory decrease in stroke volume is in accordance with invasive measurements of decreased stroke volume during inspiration in both humans and dogs. The evidence of reduced left ventricular filling is in agreement with the inspiratory decrease in diastolic dimension found in dogs by use of intramyocardial radiopaque markers. It is also supported by the directional respiratory changes in left ventricular dimensions between epicardial markers shown in patients after cardiac surgery, although those variations were small. However, conflicting results were reported in an experimental study in dogs, in which measurements of left ventricular dimensions by ultrasonic crystals indicated inspiratory decrease in stroke volume caused by increased end-systolic volume without change in end-diastolic volume.

The reduced EDA during inspiration in the present study may reflect a real decrease in left ventricular end-diastolic volume despite the inspiratory rise in transmural diastolic pressure shown in experimental studies. Through ventricular interaction, left ventricular filling pressure for a given end-diastolic volume has been found to increase with augmented right ventricular volume. Accordingly, the inspiratory increased right ventricular filling might cause decreased left ventricular compliance, which would limit filling volume despite enhancing filling pressure. A recent study in conscious dogs demonstrated that end-diastolic volume was the major preload determinant of systolic function during ventricular interaction, independent of chamber pressure and shape. Thus,
the results of our study suggest the occurrence of inspiratory decreased stroke volume by means of the Frank-Starling filling mechanism as a result of reduced left ventricular filling volume. Experimental studies have shown that transmural aortic pressure increases during inspiration, representing inspiratory increased impedance to left ventricular emptying. Therefore the decrease in left ventricular stroke volume during inspiration is probably the result of both decreased preload and increased afterload.

In summary, our findings suggest a need for standardization with regard to respiratory phases in assessment of left ventricular volumes and function by two-dimensional echocardiography. Motion of the heart relative to the echo beam may play a part in the respiratory variations in left ventricular dimensions assessed by M mode echocardiography. Our results also indicate the occurrence of inspiratory decrease in left ventricular stroke volume associated with reduced end-diastolic volume.

References

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