Left Atrial Function as a Reliable Predictor of Exercise Capacity in Patients With Recent Myocardial Infarction*

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Study objective: To examine the relation between left atrial (LA) function and exercise performance.

Design and setting: Retrospective study at a referral cardiopulmonary exercise laboratory in a university hospital.

Patients: Forty-one patients with recent myocardial infarction.

Interventions: M-mode echocardiography and cardiopulmonary exercise testing combined with radionuclide ventriculography.

Measurements and results: Hemodynamic measurements were obtained at rest and peak exercise. LA fractional shortening at rest was used as an index of global LA function. LA fractional shortening had fair correlations with peak oxygen consumption (r=0.67, p<0.01) and exercise duration (r=0.71, p<0.01). Although there were no significant relations between LA fractional shortening and hemodynamic measurements at rest, LA fractional shortening was positively related to peak cardiac output (r=0.61, p<0.01) and peak stroke volume (r=0.57, p<0.01), and negatively related to peak pulmonary arterial wedge pressure (r=-0.44, p<0.05). In addition, LA fractional shortening correlated significantly with an increase in left ventricular (LV) end-diastolic volume from rest to peak exercise (r=0.48, p<0.02), but did not correlate with the changes in ejection fraction and end-systolic volume during exercise. An increase in LV end-diastolic volume during exercise was significantly related to peak oxygen consumption (r=0.46, p<0.02), peak cardiac output (r=0.60, p<0.01), and peak stroke volume (r=0.53, p<0.01), whereas the changes in ejection fraction and end-systolic volume during exercise were not related to these indexes.

Conclusions: Exercise capacity and LV performance during exercise were mainly dependent on LV diastolic filling rather than systolic contraction during exercise. LA fractional shortening at rest reflected LV diastolic filling during exercise and, therefore, predicted cardiac output and stroke volume responses to exercise and exercise capacity in patients with recent myocardial infarction.

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Key words: exercise capacity; left atrial function; myocardial infarction

Abbreviations: LA=left atrial; LV=left ventricular

In patients with left ventricular (LV) dysfunction, impaired exercise tolerance is one of the most common clinical manifestations. Previous studies have demonstrated poor correlations between indexes of LV systolic function and peak aerobic capacity.1–6 In contrast, recent reports have emphasized the importance of LV diastolic function to maintain exercise capacity not only in patients with hypertension and hypertrophic cardiomyopathy with preserved systolic function7–11 but also in those with dilated cardiomyopathy and myocardial infarction with impaired systolic function.12–14 Nevertheless, it is often difficult to predict precise exercise capacity with the measurements of common hemodynamic parameters at rest because LV diastole represents a complex interplay of multiple fac-
tors, including active and passive properties of ventricle and atria as well as heart rate, sympathetic tone, and loading condition.\textsuperscript{13}

We have hypothesized that left atrial (LA) function at rest, which is closely related to resting LV diastolic filling, can reflect LV diastolic function during exercise and, therefore, predict exercise capacity in patients with LV dysfunction. To test this hypothesis, the present study was designed to measure LA fractional shortening at rest, a global index of LA function,\textsuperscript{16} and to correlate it with exercise capacity and LV performance during invasive cardio-pulmonary exercise testing in patients with recent myocardial infarction.

**Materials and Methods**

**Patient Population**

We evaluated 41 male patients who not only underwent both exercise test and coronary arteriography but who also had patent infarct-related coronary artery with normal results of exercise test. The mean age of the patients was 50±11 years (range, 34 to 67 years) with resting LV ejection fraction 40±15\% (range, 14 to 59\%). All the patients included in this study had had their first acute Q-wave myocardial infarction 6 to 8 weeks before the study, and none of the patients had postinfarction angina, critical arrhythmia, or uncontrolled congestive heart failure for at least 2 weeks prior to the study. Before entry into the study, each patient underwent a complete physical examination, and patients were excluded from the study if they had mitral regurgitation, physical or radiographic signs of obstructive lung disease, or intermittent claudication that limited their exercise capacity. Treatment with all medication was discontinued for at least 48 h before the study. The risks of the study were fully explained and informed consent was obtained from each patient before the study.

**Echocardiography**

Echocardiographic studies were performed (ALOKA SSD-870 systems; ALOKA; Tokyo, Japan). M-mode echocardiograms were recorded using a left parasternal window with the patient in the left lateral decubitus position before the exercise testing. Maximal LA dimension was determined using M-mode echocardiography according to the recommendation of the American Society of Echocardiography.\textsuperscript{17} Minimal LA dimension was measured from the same M-mode echocardiogram at the onset of QRS complex of the ECG.\textsuperscript{18}

**Exercise Testing Protocol**

Patients were studied in the supine position at rest and during bicycle ergometric exercise. Supine bicycle exercise was performed to familiarize the patients with an isokinetic bicycle ergometer (Monark 881E ergometer; Sweden) 2 or 3 days before the study. On the day of the study, a Swan-Ganz catheter was inserted through the internal jugular vein and advanced to the pulmonary artery. After 30 min, bicycle exercise testing was performed with expired gas analysis and ECG recording. Exercise began at a workload of 15 W with the pedal speed maintained at 60 rpm and increased by 15 W every 3 min until symptom-limited maximum.

**Expired Gas Analysis**

The concentration of expired oxygen was analyzed continuously (with an Oxycon–4; Mijnhardt Company; Holland). Instruments were calibrated at the beginning of each study and before every measurement. From these data, oxygen consumption were measured at supine rest on the bicycle, and continuously during exercise. Averaged measurements during the last 30 s of each exercise stage were used for analysis.

**Hemodynamic and Radionuclide Angiographic Measurements**

Pulmonary and systemic arterial pressures were recorded continuously, and pulmonary arterial wedge pressure was recorded at rest and at each exercise stage (with DS-3300 system; Fukuda Denki; Japan). Blood samples were drawn simultaneously from the radial and pulmonary arteries at rest and peak exercise. The blood samples were used for the immediate measurements of pH, PO\textsubscript{2}, PCO\textsubscript{2} (Radiometer ABL2; Radiometer Company; Copenhagen Denmark), as well as oxygen saturation and hemoglobin concentration (Radiometer OSM2). Of the 41 men entering the study, 34 patients underwent radionuclide angiography at rest and peak exercise. LV end-diastolic volume and end-systolic volume were determined by the first-pass method with a computerized multiscrystal gamma camera (Baird Atomic System 77; Baird Corp; Boston) in the anterior projection. LV ejection fraction was determined from the background corrected representative cardiac cycle as follows: (end-diastolic counts-end-systolic counts)/end-diastolic counts×100. LV end-diastolic volume was calculated by the area-length method of Dodge et al,\textsuperscript{19} with the ellipse of revolution modified for the single anterior plane projection as 0.54×A\textsuperscript{2}/L, where A is the area obtained by planimetry, and L is the longest diameter measured from the aortic valve to the apex of the left ventricle. The reliability and reproducibility of this method have been reported previously.\textsuperscript{20,21}

**Derived Variables**

Cardiac output was determined by the Fick principle with use of systemic arteriovenous oxygen difference and directly measured systemic oxygen consumption. Stroke volume was calculated as follows: cardiac output/heart rate. LA fractional shortening was estimated as follows: (maximal LA dimension-minimal LA dimension)/maximal LA dimension×100, and was used as an index of global LA function.\textsuperscript{16}

**Statistical Analysis**

All data are presented as mean±SD. The least-squares regression was used to assess the relation between the two variables. Probability values of <0.05 were considered to be significant.

**Results**

In all 41 patients, the bicycle exercise was limited by exercising muscle fatigue but not by dyspnea. No patients developed angina or ischemic ST segment changes during exercise. There were no significant correlations between left atrial fractional shortening at rest and heart rates at rest and at peak exercise.

**Relation Between LA Function and Exercise Capacity**

Maximal LA dimension was 32±5 mm, and minimal LA dimension was 24±5 mm. LA fractional
shortening at rest ranged from 6.8 to 37.1% (mean, 25.0±8.9%). Ergometric data at peak exercise are summarized in Table 1. LA fractional shortening had fair correlations with peak oxygen consumption (r=0.67, p<0.01) and exercise duration (r=0.71, p<0.01) (Fig 1).

Relation Between LA Function and LV Function

Hemodynamic and radionuclide angiographic measurements at rest and peak exercise are summarized in Table 2. There were no significant relations between LA fractional shortening and hemodynamic and radionuclide angiographic measurements at rest. However, LA fractional shortening was positively related to peak cardiac output (r=0.61, p<0.01) and peak stroke volume (r=0.57, p<0.01), and negatively related to peak pulmonary arterial wedge pressure (r=0.44, p<0.05) (Fig 2). In addition, LA fractional shortening had a positive correlation with an increase in LV end-diastolic volume from rest to peak exercise (r=0.48, p<0.02), whereas no similar correlations were found between LA fractional shortening and the changes in LV ejection fraction and end-systolic volume during exercise (Fig 3).

Relation Between Exercise Capacity and LV Function

LV ejection fraction and end-systolic volume at peak exercise and their changes during exercise did not correlate with peak oxygen consumption, peak cardiac output, and peak stroke volume. However, an increase in LV end-diastolic volume during exercise was significantly related to peak oxygen consumption (r=0.46, p<0.02), peak cardiac output (r=0.60, p<0.01), and peak stroke volume (r=0.53, p<0.01) (Fig 4), indicating that exercise capacity and LV performance during exercise were mainly dependent on diastolic filling rather than systolic contraction during exercise.

Discussion

The present study demonstrated that LA fractional shortening at rest was closely associated with exercise performance during maximal supine bicycle exercise in patients with recent myocardial infarction. In addition, we observed that the patients with preserved LA function (high fractional shortening) at rest had better LV diastolic filling and greater increases in cardiac output and stroke volume during exercise. These findings confirm the previous observation of patients with dilated cardiomyopathy that indexes of LA function are related to peak aerobic capacity. We extend these observations by demonstrating that LA fractional shortening at rest re-

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<th>Table 2—Hemodynamic and Radionuclide Angiographic Measurements at Rest and Peak Exercise</th>
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<td>Cardiac output, L/min</td>
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fleeted LV diastolic filling during exercise and, therefore, predicted exercise capacity and LV performance during exercise.

We have recently observed that exercise capacity was not limited by LV systolic dysfunction but primarily by diastolic dysfunction in patients with mild LV systolic dysfunction after myocardial infarction. This is consistent with recent studies demonstrating that LV diastolic rather than systolic function has an important role in determining exercise performance in patients with congestive heart failure, hypertension, and hypertrophic cardiomyopathy. Previous studies have demonstrated that stroke volume response to exercise is the major determinant of exercise capacity. During isotonic exercise, stroke volume increases as a result of an increase in LV end-diastolic volume by means of Frank-Starling mechanism and as a result of increased systolic contraction reflected by an increase in ejection fraction. In patients with LV dysfunction, however, the Frank-Starling mechanism is pri-
marily responsible for an increase in stroke volume response to exercise because of impaired systolic contraction due to structural alterations of the myocardium.\textsuperscript{12,13,30} In this study, we also observed a significant relation between peak oxygen consumption and an increase in LV end-diastolic volume during exercise, whereas similar relations were not found between peak oxygen consumption and indexes of systolic function. In this setting, it is not surprising to find that LA fractional shortening at rest, which can reflect LV diastolic filling during exercise, reliably predicts stroke volume response to exercise and in part exercise capacity in patients with LV dysfunction.

Many studies have described the contribution of LA function to LV diastolic filling at rest.\textsuperscript{31–34} During LV diastolic filling, the LA has phases of passive atrial emptying, atrial diastasis, and active atrial emptying.\textsuperscript{18,35} In patients with myocardial infarction, LA contraction has been reported to have a larger contribution to LV filling and, therefore, stroke volume is relatively maintained despite the impairment of LV function.\textsuperscript{32} Matsuda et al\textsuperscript{18} observed that the ratio of LA volume change to LV stroke volume in patients with remote myocardial infarction was 65%, which was significantly higher than 48% in normal subjects. They concluded that the increase in this ratio was primarily dependent on enhanced active atrial emptying due to Frank-Starling mechanism of LA. Similar compensatory increase in LA contribution to LV filling was reported in patients with asymptomatic or mildly symptomatic dilated cardiomyopathy.\textsuperscript{36} Conversely, in patients with more advanced heart failure or highly symptomatic dilated cardiomyopathy, this compensatory response of LA contraction is reduced and attributed to elevated LV filling pressure.\textsuperscript{36–38} In these patients, passive atrial emptying remains to be the primary contributor to overall LV diastolic filling with only limited contribution by LA contraction. These different contributions of passive and active atrial emptying to LV filling in patients with heart failure may be the results of observations obtained at different time points of dynamically evolving disease processes or different severities of impaired LV function. Although we did not separately examine the contributions of passive and active atrial emptying to LV filling, it is reasonable that LA fractional shortening, a global index of LA function including both factors of passive and active LA emptying, was closely associated with LV filling during exercise in our patients who had various degrees of LV dysfunction after myocardial infarction.

\textbf{Limitations}

Three possible limitations of our study should be mentioned. First, the left atrium is a three-dimensional structure, but we used left atrial fractional shortening using one dimension. Recent reports demonstrated that there was an excellent correlation between the posterior aortic wall motion of M-mode echocardiography and the change in the left atrial angiographic area.\textsuperscript{39,40} Therefore, left atrial frac-
tional shortening obtained by M-mode echocardiography can reflect the left atrial volume change.

Second, there was wide scatter of correlation between left atrial fractional shortening and exercise capacity. Nevertheless, using the least-squares regression analysis, the correlation was significant. Therefore, left atrial fractional shortening at rest, in part, can reflect exercise capacity.

Third, all patients included in this study had myocardial infarction and no patients had other forms of cardiac disease. In addition, we used a supine bicycle exercise to estimate maximal exercise capacity. Therefore, it remained to be seen whether LA fractional shortening is a useful variable to estimate exercise capacity in patients with other forms of cardiac disease or in upright posture.

**CONCLUSION**

Previous studies have emphasized the difficulty of predicting exercise capacity with the measurements of hemodynamic variables at rest, and recommended maximal exercise testing to evaluate accurate functional status in patients with LV dysfunction. However, the present study demonstrates that LA fractional shortening at rest, which can be easily obtained by M-mode echocardiography, fairly reflects LV diastolic filling and cardiac output and stroke volume responses during maximal exercise and, therefore, it may be a useful and reliable predictor of exercise capacity in patients with recent myocardial infarction.

**REFERENCES**


3 Conn EH, Williams RS, Wallace AG. Exercise responses before and after physical conditioning in patients with severely depressed left ventricular function. Am J Cardiol 1982; 49:296-300


15 Plotnick GD. Changes in diastolic function: difficult to measure, harder to interpret. Am Heart J 1989; 118:637-41


19 Dodge HT, Sandler H, Ballow DW, et al. The use of biplane angiography for the measurement of left ventricular volume in man. Am Heart J 1960; 60:762-76


29 Sullivan MJ, Cobb FR, Higginbotham MB. Stroke volume
increases by similar mechanisms during upright exercise in normal men and women. Am J Cardiol 1991; 67:1405-12
34 Linden RJ, Mitchell JH. Relation between left ventricular diastolic pressure and myocardial segment length and observations on the contribution of atrial systole. Circ Res 1960; 8:1092-99
37 Lavine SJ, Arends D. Importance of the left ventricular filling pressure on diastolic filling in idiopathic dilated cardiomyopathy. Am J Cardiol 1989; 64:81-5