

Time Course of Recovery of Left Ventricular Filling Pressure After Exercise in Healthy Subjects

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Background It has been recently demonstrated that the hemodynamic consequences of exercise-induced increase in left ventricular (LV) filling pressure can be demonstrated noninvasively with supine bicycle exercise Doppler echocardiography. One of the practical drawbacks of Doppler echocardiography for assessing LV filling during exercise is the technical difficulty obtaining adequate signals for meaningful analysis during the rapid heart rates achieved during exercise. The purpose of this study was to assess LV filling pressures during the recovery period, as well as at rest, in healthy subjects to establish reference values of Doppler LV filling indices during recovery after exercise.

Methods and Results Seventy-three healthy subjects (age 38 ± 14 years, 62 males) underwent supine bicycle exercise. Mitral inflow and annular velocities were recorded at baseline and during recovery at 2, 5, and 10 min after cessation of exercise. The ratio of the mitral inflow early diastolic filling velocity (E) to the mitral annular early diastolic velocity (E') was used as an estimation of mean left atrial pressure (E/E'). The mean E/E' ratio at rest was 7.6 ± 1.8 and it was < 15 in all patients. Mean exercise duration was 837 ± 184 s (range, 390–1,260). The E/E' ratio during recovery 2, 5, and 10 min after cessation of exercise was 8.8 ± 1.9 , 8.2 ± 2.0 and 7.8 ± 1.8 , respectively, and none of the patients had an E/E' > 15 during the recovery phase.

Conclusion In healthy subjects, the E/E' is less than 15 at rest, as well as during the recovery period up to 10 min after cessation of exercise. Because the E/E' is not elevated in healthy subjects, an elevated E/E' during the recovery period may be helpful for detecting exercise-induced diastolic dysfunction in subjects with tachycardia, even with low levels of exercise. (Circ J 2008; 72: 186–188)

Key Words: Diastole; Exercise; Heart failure

It has been recently demonstrated that the hemodynamic consequences of exercise-induced increase in left ventricular (LV) filling pressure can be demonstrated noninvasively with supine bicycle exercise Doppler echocardiography.^{1–3} One of the practical drawbacks of using Doppler echocardiography for assessing LV filling during exercise is the technical difficulty obtaining adequate signals for meaningful analysis during the rapid heart rates achieved during exercise. Previous studies have shown that ischemia-induced abnormalities in diastolic function may resolve more slowly during resolution of the ischemia and that diastolic dysfunction induced by myocardial ischemia may persist well beyond the recovery of normal systolic function after brief coronary occlusion during coronary

angioplasty.^{4–6} Additionally, the pulmonary capillary wedge pressure has been shown to return to baseline 1 h after symptom limited bicycle exercise in patients with LV dysfunction.⁷ These results imply that exercise-induced diastolic dysfunction may persist for several days. Therefore, we hypothesized that the LV filling pressures, assessed noninvasively using the E/E' ratio, would return to baseline immediately after cessation of exercise in healthy subjects. The purpose of this study was to assess the LV filling pressures during the recovery period, as well as at rest, in healthy subjects to establish reference values of Doppler LV filling indices during recovery after exercise.

Methods

Study Population

Seventy-three healthy volunteers (age 38 ± 14 years, 62 males) underwent supine bicycle exercise. Mitral inflow and annular velocities were recorded at baseline and during recovery 2, 5, and 10 min after cessation of exercise. All subjects gave informed consent and study approval was obtained from the Internal Review Board of Yonsei University College of Medicine.

Diastolic Stress Echocardiography¹

Standard 2-dimensional measurements (LV diastolic and systolic dimensions, ventricular septum and posterior wall thickness, left atrial volume) were obtained with the patient

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in the left lateral position. The LV ejection fraction was calculated by the modified Quinones method⁸ After obtaining the rest images from the standard parasternal and apical views, a multistage supine bicycle exercise test was performed with a variable load bicycle ergometer (Medical Positioning, Inc, Kansas City, MO, USA). Subjects pedaled at a constant speed, beginning at a workload of 25 W, with an increment of 25 W every 3 min. Echocardiography was performed using a GE Vingmed System 7 ultrasound system with 2.5-MHz transducer during rest, each stage of exercise, and recovery in the sequence described as follows. From the apical window, a 1–2-mm pulsed Doppler sample volume was placed at the mitral valve tip and mitral flow velocities from 5 to 10 cardiac cycles were recorded. The mitral inflow velocities were traced and the following variables were obtained: peak velocity of early (E) and late (A) filling, and deceleration time of the E wave velocity. Tricuspid regurgitant jet velocity was also obtained to estimate pulmonary artery systolic pressure using continuous-wave Doppler, if measurable. Mitral annular velocity was measured by Doppler tissue imaging using the pulsed wave Doppler mode. The filter was set to exclude high frequency signals, and the Nyquist limit was adjusted to a range of 15–20 cm/s. Gain and sample volume were minimized to allow for a clear tissue signal with minimal background noise. Early diastolic (E') and systolic (S') velocities of the mitral annulus were measured from the apical 4-chamber view with a 2- to 5-mm sample volume placed at the septal corner of the mitral annulus. These measurements were performed

Table 1 Baseline Echocardiographic Findings

Left ventricular end-diastolic dimension (mm)	50±4
Left ventricular end-systolic dimension (mm)	34±4
Ejection fraction (%)	65±6
Interventricular septal thickness (mm)	9±2
Posterior wall thickness (mm)	9±2
Left atrial volume index (ml/m ²)	19±6

*Data are mean±SD.

at baseline, at each stage of exercise, and during recovery 2, 5, and 10 min after cessation of exercise in the same sequence. All data were stored digitally and measurements were made at completion of each study.

Statistical Analysis

All data are expressed as mean±SD. For comparison, data at baseline, during exercise and at recovery were compared using repeated ANOVA test. A p value <0.05 was considered significant.

Results

The baseline echocardiographic findings are presented in Table 1. Mean exercise duration of the study subjects was 837±184 s (range, 390–1,260). Leg fatigue was the most common reason for stopping the exercise, which was the case for 49 of 73 patients; 14 patients stopped exercise because of dyspnea. Heart rate, systolic blood pressure, and

Table 2 Change in the Hemodynamic and Doppler Variables During Exercise and the Recovery Period

	Rest	Exercise		Recovery		
		25 W	50 W	2 min	5 min	10 min
HR (beats/min)	65±11	92±11	103±12	97±17	88±14	83±13
Systolic BP (mmHg)	120±14	138±19	147±18	146±22	127±17	120±13
Diastolic BP (mmHg)	72±10	81±11	84±10	73±10	70±11	70±10
E (cm/s)	73±16	97±15	106±16	100±23*	83±20*	72±15
A (cm/s)	49±14	72±17	80±18	81±22*	64±18*	53±13*
E/A	1.6±0.6	1.4±0.4	1.4±0.4	1.3±0.4*	1.4±0.5*	1.4±0.5*
DT (ms)	178±33	147±23	140±24	154±32*	162±34*	170±41
TR (m/s)	2.1±0.2	2.4±0.3	2.7±0.3	2.5±0.3	2.3±0.3	2.2±0.3
E' (cm/s)	10.1±2.9	11.8±2.6	12.6±2.7	11.6±2.6	10.5±2.5	9.6±2.5
A' (cm/s)	7.5±1.8	9.3±2.7	10.9±3.2	10.2±2.9	8.4±2.4	7.3±2.2
S' (cm/s)	7.6±1.4	8.3±1.5	9.2±1.6	12.7±3.2	10.5±2.3	8.7±1.7

*p<0.05 when compared with baseline value.

HR, heart rate; BP, blood pressure; E, peak velocity of early mitral flow; A, peak velocity of mitral flow during atrial contraction; DT, deceleration time of early mitral flow velocity; TR, tricuspid regurgitation velocity; E', early diastolic mitral annular velocity; A', mitral annular velocity during atrial contraction; S', systolic mitral annular velocity.

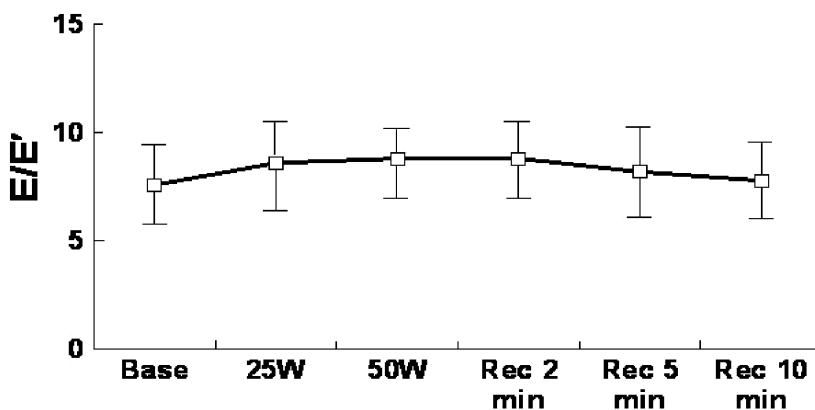


Fig 1. Change in the E/E' ratio from rest to exercise and during recovery phase. No significant changes from rest to exercise and recovery. E, peak velocity of early mitral flow; E', early diastolic mitral annular velocity.

diastolic blood pressure were increased after exercise compared with at rest (Table 2). The effect of supine bicycle exercise on Doppler echocardiographic indices is also shown in Table 2. During exercise, the peak E and A velocities were significantly increased. Similarly, the mitral annular systolic and diastolic velocities were increased with exercise. However, the E wave deceleration time was shortened. In contrast, the E/A ratio and TR velocity did not change significantly during exercise. Despite the changes in these variables during exercise, the mitral inflow and annular velocities returned to baseline within 10 min after cessation of exercise. The mean E/E' ratio at rest was 7.6 ± 1.8 and was <15 in all subjects. The E/E' ratio during 25 and 50 W of exercise, during recovery 2, 5, and 10 min after cessation of exercise was 8.6 ± 2.2 , 8.8 ± 1.9 , 8.8 ± 1.9 , 8.2 ± 2.0 and 7.8 ± 1.8 , respectively, and none of the subjects had an E/E' >15 during either exercise or the recovery phase (Fig 1).

Discussion

The principal finding of this study is that in healthy subjects the E/E' is less than 15 at rest, as well as during the recovery period up to 10 min after cessation of exercise. Because the E/E' is not elevated in healthy subjects during the recovery period, an elevated E/E' after exercise may be helpful for detecting exercise-induced diastolic dysfunction in subjects with tachycardia, even at low levels of exercise.

Clinically, it is critical to differentiate LV diastolic dysfunction from normal physiologic variations in LV diastolic filling during exercise, particularly in patients who have exertional dyspnea and normal LV systolic function. Recently, the concept of the "diastolic stress test" using exercise Doppler echocardiography has been suggested¹⁻³ and a preliminary study has shown that diastolic stress echocardiography using supine bicycle exercise is technically feasible for demonstrating changes in the E/E' ratio and tricuspid regurgitant velocity during exercise caused by changes in exercise-induced diastolic filling pressures! However, there are technical challenges in measuring E, A, E', and the deceleration time of the E wave when the heart rate increased. Although patients with marked diastolic dysfunction revealed diagnostic changes, even at mild or moderate exertion with moderately increased heart rate, a subset of patients develop premature tachycardia even at mild exertion, which makes a meaningful analysis difficult. In a previous report, the test was unsuccessful in 10% of enrolled patients because of tachycardia with low levels of exercise and exercise-induced atrial tachyarrhythmia! If the evaluation of mitral flow and annular velocities during exercise is not optimal because of premature tachycardia, another way is to evaluate these parameters during the recovery period after cessation of exercise.

Previous studies have shown that exercise-induced diastolic dysfunction associated with myocardial ischemia⁴ or LV systolic dysfunction⁹ causes diastolic dysfunction that may persist for several days. In other words, it can be speculated that the LV filling pressures, assessed non-invasively using the E/E' ratio, will return to baseline immediately after cessation of exercise in healthy subjects. In our study, we have shown that in healthy subjects the E/E' was <15 at

rest as well as during recovery, for up to 10 min after cessation of exercise.

We believe supine bicycle exercise is the best way to demonstrate exercise-induced diastolic dysfunction because it allows continuous acquisition of images of the LV filling pattern during exercise and of the increase in LV filling pressures with supine exercise. However, treadmill exercise echocardiography is the most frequently used exercise echocardiography in which images are acquired immediately after exercise. For the detection of regional wall motion abnormalities caused by exercise-induced myocardial ischemia, treadmill exercise echocardiography is limited because peak stress imaging is not possible and imaging is obtained shortly after the cessation of exercise when ischemia may be resolving. In contrast to the detection of myocardial ischemia using the treadmill exercise test, the assessment of the LV filling pattern during the recovery period after treadmill exercise may be an alternative to supine bicycle exercise. The results of our study imply that the assessment of LV filling pressure after cessation of exercise using treadmill exercise testing will be acceptable.

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