Mechanism of Overshoot in Cardiac Function During Recovery From Submaximal Exercise in Man*

Hiroshi Kano, MD; Akira Koike, MD; Takashi Yajima, MD; Yoshiharu Koyama, MD; Fumiaki Marumo, MD; and Michiaki Hiroe, MD

**Background:** A sudden increase (overshoot) in the left ventricular ejection fraction during the recovery from maximal exercise has been reported in patients with coronary artery disease, but its mechanism has not been fully clarified. We investigated whether this phenomenon may occur in normal subjects, and whether it depends on the intensity of exercise.

**Methods:** Thirteen normal subjects (mean \[\pm SD\] age, 59 \[\pm 8\] years old) performed two levels (25 W and 50 W) of mild-intensity, constant-work-rate exercise for 6 min on a cycle ergometer. Left ventricular function was monitored continuously during the recovery from exercise using a computerized cadmium telluride detector.

**Results:** An overshoot was observed in the ejection fraction during the first minute of recovery compared with the end-exercise value. The overshoot in the ejection fraction during recovery after the 50-W exercise was greater than that seen after the 25-W exercise. An overshoot phenomenon in stroke volume was also observed during the recovery from 50-W exercise.

**Conclusions:** The overshoot in cardiac function observed during the early phase of recovery, which was caused mainly by an immediate decrease in end-systolic volume, occurred even after exercise of mild intensity. This phenomenon appears to suggest the existence of a transient mismatch between cardiac contractility and afterload reduction during the recovery from mild-intensity exercise, even in normal subjects. *(CHEST 1999; 116:868–873)*

**Key words:** ejection fraction; mild-intensity exercise; overshoot phenomenon; stroke volume

**Abbreviation:** CdTe = cadmium telluride

Although there are numerous reports\(^1–6\) on the time course of cardiac function during exercise, the change in cardiac function during the recovery from exercise is not well understood. A sudden increase (overshoot) in the left ventricular ejection fraction during the recovery from maximal exercise has been reported\(^7\) in patients with coronary artery disease. However, its mechanism has not been fully clarified. It is also not known whether this phenomenon may occur in normal subjects. Further, there is no report on whether this phenomenon may occur even after exercise of submaximal or mild intensity.

We continuously monitored cardiac function after two levels of submaximal mild-intensity exercise performed at a constant work-rate in normal subjects. Our objectives included the following: (1) to determine whether the overshoot phenomenon of cardiac function during the recovery from exercise occurs in a subject even without significant heart disease; and (2) to evaluate whether this phenomenon depends on the intensity of exercise.

### Materials and Methods

**Subjects**

We evaluated 13 middle-aged healthy Japanese subjects (7 men and 6 women; Table 1), who were recruited from a medical screening clinic. They were found to be free of any significant disease on the basis of medical history, results of physical examination, chest radiograph, 12-lead ECG, and routine laboratory tests. These subjects showed normal ECG responses during screening that used a maximal ergometer exercise.

To examine whether the overshoot of cardiac function is influenced by age, we divided the subjects into two groups: six patients who were \(< 60\) years old (52.7 \pm 4.0 years old) and...
seven patients who were > 60 years old (65.1 ± 4.7 years old). We then analyzed the time course of ejection fraction during exercise recovery for both groups. The protocol for the study was approved by our institutional committee on clinical studies. The nature and purpose of this study were explained to each subject, and each consented to participate in the study.

Exercise Protocol

An electromagnetically braked cycle ergometer (model WLP-450; Load; Groningen, the Netherlands) was used in an upright position for the exercise tests. All subjects performed two repetitions of 25-W and 50-W constant-work-rate exercise each for 6 min and each started from rest. Thus, each subject consecutively performed four tests on the same day: (1) 25-W exercise; (2) 50-W exercise; (3) 25-W exercise; and (4) 50-W exercise. Each test was followed by a rest period of approximately 30 min. Pedaling was terminated immediately after the exercise was completed. Thereafter, the subjects remained seated on the bicycle for 3 min. The heart rate was continuously monitored using a stress analyzer (Case II; Marquette Medical Systems; Milwaukee, WI). Cuff BP was also determined every minute during the test with an automatic indirect manometer (model STBF-650; Collin Denshi; Aichi, Japan). The resting cardiac output was measured three times repeatedly before exercise. It was measured in the seated position by means of the dye dilution method with indocyanine green and by an ear photoelectric transducer. The output of the latter was analyzed with a cardiac output computer (model MLC-4200; Nihon-Kohden; Tokyo, Japan). We used the mean value of three measurements for the following calculations.

Monitoring of Left Ventricular Function

As previously described,4,10–12 a computerized cardiac monitoring system (model RRG-670; Aloka Co Ltd; Tokyo, Japan) was used for the continuous monitoring of left ventricular function throughout the test until 3 min of recovery. This system was composed of a cadmium telluride (CdTe) detector (model A-116; Radiation Monitoring Devices; Boston, MA), a preamplifier unit, a portable data acquisition unit, and a central processing unit (model PC-9801; NEC; Tokyo, Japan). After the patient’s red blood cells were labeled with 30 mCi of 99mTc by the semi-in vivo method, the CdTe detector was positioned over the left ventricular region of interest, which was chosen as the position with the

### Table 1—Physical Characteristics of 13 Subjects*

<table>
<thead>
<tr>
<th>Subject No.</th>
<th>Gender</th>
<th>Age, yr</th>
<th>Height, cm</th>
<th>Weight, kg</th>
<th>Maximal Work Rate, W</th>
<th>Percentage of 50-W Exercise Compared With Maximal Work Rate,</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F</td>
<td>61</td>
<td>155</td>
<td>50</td>
<td>80</td>
<td>62.5</td>
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<td>2</td>
<td>F</td>
<td>55</td>
<td>143</td>
<td>42</td>
<td>80</td>
<td>62.5</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>52</td>
<td>169</td>
<td>63</td>
<td>110</td>
<td>45.5</td>
</tr>
<tr>
<td>4</td>
<td>F</td>
<td>59</td>
<td>156</td>
<td>63</td>
<td>85</td>
<td>56.8</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>63</td>
<td>165</td>
<td>66</td>
<td>122</td>
<td>41.0</td>
</tr>
<tr>
<td>6</td>
<td>M</td>
<td>69</td>
<td>155</td>
<td>52</td>
<td>90</td>
<td>55.6</td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>53</td>
<td>159</td>
<td>62</td>
<td>110</td>
<td>45.5</td>
</tr>
<tr>
<td>8</td>
<td>F</td>
<td>49</td>
<td>152</td>
<td>59</td>
<td>84</td>
<td>60.0</td>
</tr>
<tr>
<td>9</td>
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<td>63</td>
<td>150</td>
<td>55</td>
<td>104</td>
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<tr>
<td>10</td>
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<td>74</td>
<td>156</td>
<td>48</td>
<td>98</td>
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<tr>
<td>11</td>
<td>F</td>
<td>48</td>
<td>157</td>
<td>59</td>
<td>80</td>
<td>62.5</td>
</tr>
<tr>
<td>12</td>
<td>M</td>
<td>64</td>
<td>173</td>
<td>65</td>
<td>111</td>
<td>45.0</td>
</tr>
<tr>
<td>13</td>
<td>M</td>
<td>62</td>
<td>164</td>
<td>69</td>
<td>109</td>
<td>45.9</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>59.3</td>
<td>158.7</td>
<td>57.9</td>
<td>97.4</td>
<td>52.5</td>
</tr>
<tr>
<td>SD</td>
<td></td>
<td>7.7</td>
<td>7.7</td>
<td>8.0</td>
<td>14.5</td>
<td>7.8</td>
</tr>
</tbody>
</table>

*Maximal work rate was obtained during the incremental exercise test. M = male; F = female.

### Table 2—Hemodynamic Data at Rest and During Exercise*

<table>
<thead>
<tr>
<th>Hemodynamic Variables</th>
<th>Rest</th>
<th>Exercise 25-W</th>
<th>Exercise 50-W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate, beats/min</td>
<td>72.0 ± 10.9</td>
<td>96.8 ± 22.1†</td>
<td>73.0 ± 10.6</td>
</tr>
<tr>
<td>Systolic blood pressure, mm Hg</td>
<td>134.8 ± 14.8</td>
<td>169.0 ± 23.6†</td>
<td>132.2 ± 13.6</td>
</tr>
<tr>
<td>Diastolic blood pressure, mm Hg</td>
<td>83.5 ± 10.1</td>
<td>94.8 ± 17.0†</td>
<td>80.9 ± 9.3</td>
</tr>
<tr>
<td>Ejection fraction, %</td>
<td>59.8 ± 6.0</td>
<td>66.5 ± 9.2†</td>
<td>59.7 ± 6.1</td>
</tr>
<tr>
<td>Stroke volume, mL</td>
<td>71.8 ± 17.2</td>
<td>84.8 ± 23.4†</td>
<td>71.8 ± 17.3</td>
</tr>
<tr>
<td>Cardiac output, L/min</td>
<td>5.1 ± 1.3</td>
<td>8.0 ± 2.3†</td>
<td>5.2 ± 1.3</td>
</tr>
<tr>
<td>End-diastolic volume, mL</td>
<td>120.7 ± 27.5</td>
<td>127.5 ± 29.1†</td>
<td>120.5 ± 27.5</td>
</tr>
<tr>
<td>End-systolic volume, mL</td>
<td>48.8 ± 13.5</td>
<td>42.7 ± 15.1†</td>
<td>48.7 ± 13.7</td>
</tr>
</tbody>
</table>

*Values are given as mean ± SD. Hemodynamic variables during exercise were measured at 6 min of exercise.

†p < 0.05 vs values at rest.

‡p < 0.05 vs values at 25-W exercise by a paired t test.
maximal ratio of stroke counts (end-diastolic counts minus end-systolic counts) to average counts (end-diastolic counts plus end-systolic counts divided by 2). Care was taken to avoid the right ventricle, left atrium, and pulmonary vasculature.

Data Analysis

The microcomputer calculated and displayed the counts over the region of interest during the cardiac cycle at 50-ms intervals throughout the test. Before the CdTe detector was positioned, a correction factor for background activity was determined in all subjects by measuring the resting ejection fraction using a first-pass technique. The ejection fraction determined by using the first-pass technique showed the best correlation with the ejection fraction, as determined by the CdTe detector, when the background activity of the CdTe was assumed to be 79% of the end-diastolic counts. The left ventricular ejection fraction was therefore calculated with 79% of the end-diastolic counts as the background activity, as follows:

\[ EF = \frac{SC}{(0.21 \times EDC)} \]

where EF is ejection fraction, SC is stroke counts (end-diastolic counts minus end-systolic counts), and EDC is end-diastolic counts.

Along with the ejection fraction derived by a CdTe detector, the resting stroke volume, which was calculated from the cardiac output using the dye dilution method, was used to calculate the absolute values of stroke volume during the recovery from exercise. Accordingly, we calculated stroke volume during the test by measuring the change in the ejection fraction from rest along with the resting stroke volume. After the test, absolute values of ejection fraction, stroke volume, end-diastolic volume, end-systolic volume, and cardiac output throughout the test were determined every 10 s. For both the 25-W and 50-W exercise, 10 s of data from each of the two repetitions were time aligned at the end of exercise and were superimposed to average the random noise and enhance the underlying pattern of response.

Variables of cardiac function at rest were determined as the average of 2 min of measurements with the subject sitting on the ergometer before he started the exercise.

Statistical Analysis

Data are presented as mean (± SD). Comparisons of hemodynamic variables at rest and those after 6 min of exercise were made by paired t test. Changes in cardiac function during exercise recovery were compared every 10 s by analysis of variance for repeated measures. When this test was significant, individual comparisons of end-exercise value (recovery time, 0) and values during 3 min of recovery were made by Duncan’s multiple-range test. A p value < 0.05 was accepted as statistically significant.

Results

At Rest

Hemodynamic variables measured at rest are shown in Table 2. There were no significant differences for resting values between 25-W and 50-W exercise.

During Exercise

Intensity of 50 W was 52.5 ± 7.8% of maximum work rate attained during preliminarily performed maximal exercise. All of the subjects were able to comfortably perform both the 25-W and 50-W exercise for 6 min. Heart rate, BP, ejection fraction, stroke volume, cardiac output, and end-diastolic volume during exercise were significantly higher than the respective resting values for exercise at both 25 W and 50 W (Table 2). The heart rate after 6 min of exercise at 50 W significantly exceeded that at 25 W. Also, the systolic BP and cardiac output after 6 min of 50-W exercise were significantly higher than those of 25-W exercise. However, the ejection fraction and stroke volume at 50-W exercise did not differ from those at 25-W exercise.

During Recovery

The change in cardiac function during recovery from 50-W exercise in one subject is shown in Figure 1. The heart rate and cardiac output quickly recovered after exercise, and almost reached pre-exercise
resting values during the 3 min of recovery. However, the ejection fraction and stroke volume increased abruptly during the first minute of recovery, showing an overshoot phenomenon.

Figure 2 shows the mean changes in heart rate and BP during recovery from 25-W and 50-W exercise. In both tests, heart rate and BP quickly recovered.

The mean changes in left ventricular ejection fraction and stroke volume during recovery from 25-W exercise in 13 subjects are shown in Figure 3. There was a significant increase (overshoot) in the ejection fraction during the first minute of recovery, as compared with the end-exercise value (recovery time = 0). The changes in the ejection fraction and stroke volume during recovery from 50-W exercise are shown in Figure 3. The overshoot in the ejection fraction during recovery from 50-W exercise was more apparent than that from 25-W exercise. In addition, stroke volume at 20 s of recovery from 50-W exercise (91.2 ± 25.8 mL) significantly exceeded the end-exercise value (85.6 ± 26.2; p < 0.05 by Duncan’s multiple-range test). Although the subjects in the present study were relatively old, there was still a significant overshoot of ejection fraction after the 50-W exercise for both the younger and the older subgroups.

Figure 4 shows the mean changes in end-diastolic volume and end-systolic volume during recovery from 25-W and 50-W exercise. In both tests, the end-systolic volume was profoundly decreased, especially during the first minute of recovery. The end-diastolic volume quickly returned to resting values.

**Discussion**

Several investigators⁷,¹⁴,¹⁵ have reported an overshoot of cardiac function during recovery from maximal exercise in patients with cardiac disease. However, apparently no study has clearly demonstrated the overshoot phenomenon during the recovery from submaximal exercise in normal subjects. The present study showed that this phenomenon was not only specific to cardiac patients, but that it occurred in subjects without heart disease. The overshoot phenomena of the ejection fraction as well as the stroke volume occurred even after brief exercise of mild intensity. This phenomenon was noted especially within the first minute of recovery from exercise.

In the present study, each subject completed two repetitions of 25-W and 50-W exercise. The data were superimposed to average the random noise and to enhance the underlying response pattern. Our findings contrast with those of previous reports. Plotnick et al¹⁶ evaluated the hemodynamic changes during recovery after maximal upright bicycle exercise in 56 normal subjects (age, 25 to 70 years old). However, those investigators did not observe a clear overshoot phenomenon in the ejection fraction or the stroke volume during the recovery from exercise. This was, in part, because of a lack of continuous measurement of cardiac function. They measured cardiac function at only two points during recovery; the first was at 2 to 4.5 min, and the second was at 4.5 to 7 min, after the cessation of exercise. In the present study, because the overshoot in the ejection fraction...
and stroke volume during recovery was more apparent after 50-W exercise compared with 25-W exercise, there should have been a more clear overshoot phenomenon after the maximal exercise, provided that the change in cardiac function was measured continuously.

The overshoot phenomenon has been reported to occur in cardiac patients several minutes after maximal exercise. In contrast, we noted this phenomenon within the first minute of exercise recovery in normal subjects. The discrepancy may be attributed to the severity of heart disease or to the intensity of the imposed exercise.

The overshoot of stroke volume observed during the recovery from 50-W exercise would result mainly from a sudden decrease in end-systolic volume (Fig 4). Cardiovascular function during recovery after exercise is controlled by several factors, including sympathetic and parasympathetic nervous systems and production

![Figure 3](image1.png)

**Figure 3.** Time course of left ventricular EF and SV measured at rest, at the end of exercise (recovery time = 0), and during recovery from exercise at 25 W (left) and 50 W (right). Values are mean ± SD. *p < 0.05 and **p < 0.01 compared with the value obtained at the end of exercise. See Figure 1 footnote for expansion of abbreviations.

![Figure 4](image2.png)

**Figure 4.** Time course of left ventricular EDV and ESV measured at rest, at the end of exercise (recovery time = 0), and during recovery from exercise at 25 W (left) and 50 W (right). Values are mean ± SD. **p < 0.01 compared with the value obtained at the end of exercise. See Figure 1 footnote for expansion of abbreviations.
of nitric oxide. Watson et al noted that, after maximal exercise, the peak plasma level of norepinephrine was attained at 108 s postexercise recovery. Perini et al demonstrated that during 50 s of recovery from moderate- to high-intensity exercise, blood norepinephrine concentration did not start to decrease, maintaining a similar level as that attained during the maximal exercise. Thereafter, norepinephrine concentration decreased exponentially. Thus, a high level of norepinephrine during the early period of recovery might have played an important role in the overshoot of cardiac function. Nitric oxide is assumed to play a significant role in vasodilation during exercise. Exhaled nitric oxide output increases proportionally with exercise intensity and decreases rapidly during recovery. Therefore, the rapidity of the decrease in nitric oxide production might have also contributed to the time course of cardiac function, i.e., the overshoot phenomenon. Because the levels of norepinephrine and nitric oxide become higher in proportion to the exercise intensity, it can be expected that the overshoot phenomenon would become more apparent after high-intensity exercise than after low-intensity exercise.

Because the rapidity of recovery of sympathetic and parasympathetic nerve activity and that of nitric oxide production are likely to be influenced by age, the overshoot of cardiac function may also be related to age. However, a significant overshoot of ejection fraction after the 50-W exercise was noted in both younger and older subgroups in the present study. Foster et al have also reported an overshoot phenomenon of ejection fraction during recovery from maximal exercise in young normal subjects (30.6 ± 7.6 years old).

The overshoot in cardiac function during the early phase of recovery, which was mainly caused by an immediate decrease in end-systolic volume, occurred in normal subjects even after exercise of mild intensity. This phenomenon seems to suggest the presence of a transient mismatch between cardiac contractility and afterload reduction during the recovery from exercise, even in normal subjects. Further study of young subjects is necessary to determine whether the overshoot in cardiac function observed after mild-intensity exercise is an age-related phenomenon.

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REFERENCES


