Diagnostic value of the ratio of recovery systolic blood pressure to peak exercise systolic blood pressure for the detection of coronary artery disease

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ABSTRACT It has been previously reported that at treadmill exercise testing an abnormal ratio of recovery systolic blood pressure (SBP) to peak exercise SBP is more sensitive than exercise-induced angina or ST segment depression for diagnosing coronary artery disease (CAD). To investigate whether the SBP ratio keeps its diagnostic value during upright bicycle exercise, we evaluated the ratio of postexercise SBP to peak SBP in 73 patients with angiographically documented CAD and in 48 patients with normal coronary arteries (OV group) undergoing maximal stress testing on a bicycle ergometer. Three minutes after exercise ended, SBP ratio was significantly higher in the CAD than in the OV group (0.79 ± 0.1 vs 0.71 ± 0.08; p < .001). Setting the upper normal limits of the recovery SBP ratio at 2 SDs from the mean for the OV group (SBP ratio = 0.98 and 0.88 at 1 and 3 min after exercise, respectively), with an increase or no change in SBP ratio at between 1 and 3 min of recovery considered an abnormal response, the sensitivity of SBP ratio was 30%, the specificity was 83%, and the accuracy was 51%. The respective values for ST depression were 81% (p < .001 vs SBP ratio), 48% (p < .001 vs SBP ratio), and 67% (p < .01 vs SBP ratio). Thus, for bicycle ergometer exercise testing, ST segment depression seems to be more accurate than SBP ratio in diagnosing CAD.


THE RATIO of postexercise systolic blood pressure (SBP) to peak exercise SBP at treadmill exercise testing has been proposed by Amon et al.1 as a highly sensitive and specific index for diagnosing coronary artery disease (CAD).

The diagnostic value of this criterion has been more recently confirmed at treadmill exercise testing in a small study population,2 but the usefulness of the ratio of recovery SBP to peak exercise SBP during bicycle exercise testing remains to be assessed.

The purpose of the present study was to verify the ability of the criterion to diagnose CAD during exercise testing on the bicycle ergometer.

Methods

Study population. One hundred twenty-one patients with chest pain were studied. All patients performed an exercise stress test on a cycloergometer and within 30 days underwent selective left and right coronary arteriography. Patients with valvular heart disease, cardiomyopathy, previous myocardial infarction, history or clinical evidence of systemic hypertension, electrocardiographic signs of left or right ventricular hypertrophy, left bundle branch block, or preexcitation syndrome were excluded from the study. Patients treated with digitalis, β-blocking agents, calcium antagonist, and antiarrhythmic drugs were also excluded.

Cardiac catheterization. Right- and left-sided cardiac catheterization and coronary arteriography were performed by the Sones techniques.

Left ventriculography was performed both in the right and left oblique projections. Left ventricular angiograms were divided into the following segments: anterobasal, anterolateral, apical, diaphragmatic, posterobasal, posterolateral, and septal. Left ventricular wall motion was defined as normal in cases of normal segmental contraction during systole and asynergic in cases of hypokinetic, akinetic, or dyskinetic contraction of one or more segments. The severity of impairment of left ventricular contraction was scored according to the number of asynergic segments. Each of the major coronary vessels and their branches were visualized in multiple projections, including the sagittal oblique projection. The extent of CAD was assessed by the number of diseased vessels with more than 70% luminal diameter narrowing. Left ventriculography and coronary arteriography were evaluated independently by two angiographers who were unaware of the exercise test results. Differences in angiographic interpretation were resolved by a third angiographer.

Exercise stress test protocol. Bicycle ergometer stress test-

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ing was performed in a thermostatically controlled room with an Ergo FIT 700 bicycle ergometer. Patients started cycling in the sitting position at a 50 W load, which was increased by 20 W every 2 min. Exercise was continued until diagnostic ST depression occurred or the patient reached 90% or more of his age- and sex-predicted maximal heart rate or had limiting signs or symptoms. Significant ST depression was defined as 1 mm ST depression below the resting level 60 msec from the J point if depression was horizontal or flat, and 1.5 mm depression 80 msec from the J point if the depression was upsloping. Electrocardiographic leads CM4, V, and VI were monitored continuously (OTE EP 12) and the recordings were made at rest, every 2 min during exercise, in the immediate postexercise period, and every 2 min during the first 5 min of recovery. At the same intervals blood pressure was measured by a standard sphygmomanometer cuff technique. To define the reproducibility of SBP recovery ratios 10 patients with normal coronary arteries and 20 patients with CAD performed two exercise stress tests. The exercise electrocardiograms were evaluated by two experienced observers without knowledge of clinical or angiographic data. Differences in interpretation were resolved by a consensus of the observers.

**Data analysis.** Postexercise SBP recovery ratios were derived by dividing the pressure at the first and the third minute of recovery by that at peak exercise. Recovery heart rate ratios for each subject were determined in a similar fashion.

Statistical analysis was performed by unpaired Student’s test, chi-square analysis, and McNemar’s test, as appropriate. Reproducibility of SBP ratios was tested by comparing by linear regression analysis the values obtained from two consecutive stress tests. Values were expressed as the mean ± SD. A probability value less than .05 was considered to indicate a statistically significant difference.

Sensitivity, specificity, positive and negative predictive value, and accuracy of the postexercise SBP recovery ratios were evaluated. The following definitions were used: sensitivity = (true positive)/(true positive + false negative) × 100; specificity = (true negative)/(true negative + false positive) × 100; positive predictive value = (true positive)/true positive + false positive) × 100; negative predictive value = (true negative)/true negative + false negative) × 100; accuracy = (true positive + true negative)/(all subjects) × 100.

**Results**

**Study population.** Clinical and angiographic characteristics of the study population are shown in table 1.

The 121 patients included 90 men and 31 women with a mean age of 49 ± 10 years (range 28 to 69 years). Forty-eight patients (40%) had normal coronary arteries (OV group), 27 (22%) had single-vessel disease, 30 (25%) had two-vessel disease, and 16 (13%) had three-vessel disease. No patient showed stenosis of the left main coronary artery. All patients without CAD manifested normal left ventricular wall motion, while 33 patients with CAD (45%) showed abnormal wall motion of at least one of the left ventricular sectors explored. Mean age of patients with CAD was significantly higher in comparison with that of patients in the OV group (52 ± 9 vs 45 ± 9; p < .001).

**Exercise testing.** The mean maximal workload achieved was 92 ± 25 W in the CAD and 105 ± 29 in the OV group.

The values for heart rate and systolic and diastolic blood pressure at baseline, peak exercise, and during the recovery phase are shown in table 2.

Heart rate was significantly higher in the OV than in the CAD group at rest (85 ± 13 vs 75 ± 14 beats/min; p < .001), at peak exercise (153 ± 20 vs 135 ± 21 beats/min; p < .001), and at the first (118 ± 20 vs 100 ± 20 beats/min; p < .001) and third minute of the recovery period (105 ± 17 vs 86 ± 19 beats/min; p < .001). SBP was significantly lower in the OV than in the CAD group at rest (127 ± 13 vs 134 ± 16 mm Hg; p < .05) and at the first (152 ± 20 vs 164 ± 25 mm

| TABLE 1 | Clinical characteristics and coronary arterial anatomy of the 121 study patients |
|-------------------|---------|-------------|-------------|-------------|
|                  | Age (yr) | Male/ female | ST+ | ST− | LV AWM |
|                  | n       | Mean | Range   | 26/22 | 25 | 23 | 0 |
| OV group         | 48      | 45 ± 9 | 28–59   | 26/22 | 25 | 23 | 0 |
| 1V group         | 27      | 48 ± 8 | 36–63   | 22/5  | 20 | 7  | 4 |
| 2V group         | 30      | 52 ± 9 | 39–69   | 27/3  | 25 | 5  | 18 |
| 3V group         | 16      | 61 ± 4 | 52–68   | 15/1  | 14 | 2  | 11 |
| CAD group        | 73      | 52 ± 9 | 36–69   | 54/9  | 59 | 12 | 33 |

OV = normal coronary arteries; 1V = single-vessel disease; 2V = two-vessel disease; 3V = three-vessel disease; ST+ = positive exercise test; ST− = negative exercise test; LV AWM = left ventricular abnormal wall motion.

| TABLE 2 | Mean value (±SD) of heart rate (HR), SBP, and diastolic blood pressure (DBP) in the 48 patients in the OV group and 73 patients in the CAD group |
|-------------------|---------|-------------|-------------|-------------|
|                  | HR (bpm) | SBP (mm Hg) | DBP (mm Hg) |
|                  | OV group | CAD group | p value | OV group | CAD group | p value | OV group | CAD group | p value |
| Rest             | 85 ± 13  | 75 ± 15    | <.001     | 127 ± 13  | 134 ± 16  | <.05     | 83 ± 8   | 85 ± 9    | NS       |
| Peak             | 153 ± 20 | 135 ± 21   | <.001     | 186 ± 26  | 189 ± 25  | NS       | 102 ± 16 | 106 ± 12  | NS       |
| Recovery 1       | 118 ± 20 | 100 ± 21   | <.001     | 152 ± 20  | 164 ± 25  | <.005    | 88 ± 11  | 90 ± 12   | NS       |
| Recovery 3       | 105 ± 17 | 86 ± 19    | <.001     | 132 ± 17  | 148 ± 23  | <.001    | 83 ± 10  | 85 ± 12   | NS       |
Hg; $p < .005$) and at the third minute ($132 \pm 17$ vs $148\pm 23$ mm Hg; $p < .001$) of the recovery phase. No significant differences in diastolic blood pressure were observed between patients with and without CAD at rest, during exercise, or in the recovery phase.

Postexercise SBP ratio was significantly higher in the CAD than the OV group at the first ($0.87 \pm 0.08$ vs $0.82 \pm 0.08$; $p < .005$) and at the third minute of the recovery period ($0.79 \pm 0.1$ vs $0.71 \pm 0.08$; $p < .001$). The postexercise heart rate ratio was significantly lower in the CAD than in the OV group at the third minute of recovery ($0.64 \pm 0.09$ vs $0.68 \pm 0.09$; $p < .01$) (figure 1).

Between minutes 1 and 3 of the recovery period SBP ratio decreased in all patients in the OV group and in 60 patients in the CAD group; in 13 patients in the CAD group it did not change or increased.

Peak exercise SBP correlated significantly with maximal workload ($r = .32$, $p < .001$; figure 2). No relation was found between SBP at 3 min after exercise and maximal workload ($r = .016$; $p = NS$).

**Accuracy of SBP ratio for predicting CAD.** The upper limit of normal SBP ratio at 1 and 3 min of the recovery period was defined as the mean value obtained in the OV group plus 2 SDs (SBP ratio = 0.98 and 0.88 at 1 and 3 min of the recovery period, respectively). An SBP higher than the upper normal limits and an increase or no change of the ratio between minutes 1 and 3 of the recovery period were considered positive exercise test responses. The sensitivity of the SBP recovery ratio was 30%, while the specificity was 83%. Positive predictive value, negative predictive value, and accuracy were, respectively, 73%, 44%, and 51% (table 3).

**Accuracy of ST segment evaluation for predicting CAD.** ST segment depression showed a sensitivity of 81% ($p < .001$ vs SBP recovery ratio), a specificity of 48% ($p < .01$ vs SBP recovery ratio), a positive predictive value of 70% ($p = NS$ vs SBP recovery ratio), a negative predictive value of 66% ($p < .01$ vs SBP recovery ratio), and an accuracy of 67% ($p < .01$ vs SBP recovery ratio) (table 3).

**Reproducibility of the SBP ratio.** A significant correlation of values for maximal workload achieved ($r = .88$), peak heart rate ($r = .87$), and peak SBP ($r = .55$) obtained during the first and second exercise tests was found. In contrast, SBP recovery ratios were not reproducible. The exercise response by SBP ratio criterion did not change between the first and the second test in 14 patients in the CAD group and in four patients in the OV group; a change from a positive to a negative test or vice versa was noted in the remaining 12 patients.

**Discussion**

Amon et al. have focused attention on the slower decline in postexercise SBP in patients with CAD in comparison with normal subjects. These authors reported that during treadmill exercise an abnormal ratio of recovery SBP to peak exercise SBP correctly identified patients with CAD with a specificity of 95% and a sensitivity of 90%, significantly better than ST segment depression.

**FIGURE 1.** Left, Comparison of SBP recovery ratios in the OV and CAD groups. Right, Comparison of heart rate (HR) recovery ratios in the OV and CAD groups.
An abnormal SBP ratio was defined by these authors as a recovery SBP to peak exercise SBP ratio higher than 1, 0.9, and 0.8 at 1, 2, and 3 min of recovery, respectively.

Crawford et al. confirmed the abnormal behavior of recovery SBP to peak SBP ratio after treadmill exercise in 18 of 20 patients with single-vessel CAD and reported that an abnormal SBP ratio is equal in sensitivity to exercise scintigraphy for detecting single-vessel disease.

More recently, early recovery SBP ratio has been shown to be higher in patients with CAD than in normal subjects after upright bicycle exercise. In contrast, the results of present study do not confirm the high sensitivity of the criterion in a larger number of patients who performed upright bicycle exercise. The discrepancy in terms of sensitivity between our data and those reported by Amon are probably not related to the different forms of exercise performed. In fact, it has been recently demonstrated that patients with CAD who achieve similar maximal workloads on the cycloergometer and treadmill exercise tests have comparable SBPs at peak exercise and at 1 min of recovery during the two forms of exercise. The contradictory results are probably the result of the significantly higher peak SBP achieved by our patients with CAD in comparison with that in the patients enrolled by Amon (189 ± 25 vs 154 ± 29 mm Hg; p < .001). This is not surprising and probably reflects the differences in patient selection. Among the 56 patients with CAD in Amon’s study, 32 had previous myocardial infarction, and more than half were on propranolol therapy; in contrast, in our study patients with prior myocardial infarction were excluded, and no patient was on antianginal drugs. Thus, a greater functional limitation of the patients and the influence of β-blocker treatment may explain the lower SBP values found by Amon at peak exercise. Because of the higher denominator, the ratio of the recovery to the peak exercise SBP, and hence the sensitivity of the criterion, was proportionately lower in our patients than reported by Amon. Our finding that peak exercise SBP, independent of recovery SBP, was significantly related to maximal workload suggests that exercise tolerance can influence the ratio independent of the presence of CAD, because of the inverse relation between exercise

**TABLE 3**

Recovery SBP to peak exercise SBP ratios and ST segment depression for predicting CAD

<table>
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<th>Specificity</th>
<th>Sensitivity</th>
<th>Positive predictive value</th>
<th>Negative predictive value</th>
<th>Accuracy</th>
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<td>22/73</td>
<td>22/30</td>
<td>40/91</td>
<td>62/121</td>
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<td></td>
<td>(83%)</td>
<td>(30%)</td>
<td>(73%)</td>
<td>(44%)</td>
<td>(51%)</td>
</tr>
<tr>
<td>ST</td>
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<td>59/73</td>
<td>59/84</td>
<td>23/35</td>
<td>81/121</td>
</tr>
<tr>
<td></td>
<td>(48%)</td>
<td>(81%)</td>
<td>(70%)</td>
<td>(66%)</td>
<td>(67%)</td>
</tr>
<tr>
<td>p value</td>
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<td>&lt;.001</td>
<td>NS</td>
<td>&lt;.01</td>
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</table>

**FIGURE 2.** Relationship between the maximal workload and the peak exercise SBP.
level and SBP ratio. Thus, normal SBP ratio in patients with high exercise tolerance should be used cautiously to exclude even severe CAD. It is also interesting to note that the lack of reproducibility of the SBP recovery ratios observed by us was in contrast to that reported by Amon. The reasons underlying the difference between our findings and those of Amon are unclear.

Our results are consistent with those of Amon in that SBP recovery ratio had a very high specificity for identifying subjects without CAD in both studies. In this regard it should be noted that values of SBP found by us in normal subjects at the peak of and after exercise are very similar to those reported by Amon (186 ± 26 vs 181 ± 23 mm Hg; p = NS).

In interpreting our findings several limitations must be considered. First, because of technical problems, evaluation of blood pressure during exercise by a standard sphygmomanometer technique may not be accurate; thus, the possibility of errors inherent in measurement of peak exercise SBP should not be excluded. Second, because of our exclusion criteria, extent and severity of CAD in our study population were lower than those generally reported for patients undergoing coronary angiography; therefore, diagnostic value of SBP ratio might be different in another study population. Third, we found that SBP recovery ratios offered a much better specificity that ST depression. However, we cannot exclude the possibility that some patients with normal coronary arteries and exercise-induced ST segment depression really experienced transient ischemia during exercise, possibly secondary to small-vessel disease, that was successfully picked up by ST segment analysis but not by the SBP ratio.

In conclusion, our results do not confirm the previously reported diagnostic value of SBP ratio during the upright bicycle exercise test. Because of its low sensitivity and lack of reproducibility, in our experience SBP ratio does not appear better than ST segment depression for diagnosing CAD.

Further prospective studies in a larger number of patients are necessary to better evaluate the diagnostic value of the slow postexercise decline in SBP exhibited by CAD patients.

References
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D Acanfora, L De Caprio, S Cuomo, M Papa, N Ferrara, D Leosco, P Abete and F Rengo

Circulation. 1988;77:1306-1310
doi: 10.1161/01.CIR.77.6.1306

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/77/6/1306

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