

# Heart Rate Recovery: Validation and Methodologic Issues

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<b>OBJECTIVES</b>	The goal of this study was to validate the prognostic value of the drop in heart rate (HR) after exercise, compare it to other test responses, evaluate its diagnostic value and clarify some of the methodologic issues surrounding its use.
<b>BACKGROUND</b>	Studies have highlighted the value of a new prognostic feature of the treadmill test—rate of recovery of HR after exercise. These studies have had differing as well as controversial results and did not consider diagnostic test characteristics.
<b>METHODS</b>	All patients were referred for evaluation of chest pain at two university-affiliated Veterans Affairs Medical Centers who underwent treadmill tests and coronary angiography between 1987 and 1999 were determined to be dead or alive after a mean seven years of follow-up. All-cause mortality was the end point for follow-up, and coronary angiography was the diagnostic gold standard.
<b>RESULTS</b>	There were 2,193 male patients who had treadmill tests and coronary angiography. Heart rate recovery at 2 min after exercise outperformed other time points in prediction of death; a decrease of <22 beats/min had a hazard ratio of 2.6 (2.4 to 2.8 95% confidence interval). This new measurement was ranked similarly to traditional variables including age and metabolic equivalents for predicting death but failed to have diagnostic power for discriminating those who had angiographic disease.
<b>CONCLUSIONS</b>	Heart rate at 1 or 2 min of recovery has been validated as a prognostic measurement and should be recorded as part of all treadmill tests. This new measurement does not replace, but is supplemental to, established scores. (J Am Coll Cardiol 2001;38:1980–7) © 2001 by the American College of Cardiology

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Recent studies have highlighted the prognostic value of an exercise treadmill test feature—heart rate (HR) recovery or the rate of decrease in HR after an exercise test (1–3). While earlier physiologic studies suggested a rapid HR recovery response to exercise to be a marker of physical fitness, only recently has its prognostic value been reported. The rate of HR return to baseline after exercise is theorized to be due to high vagal tone associated with fitness and good health.

As with any new finding, it is essential to validate its reproducibility and applicability in other populations as well as to demonstrate what methodology is required to obtain similar results. Heart rate recovery has been shown to be prognostic usually at 1 or 2 min after exercise in populations referred for standard exercise testing (1), referred for nuclear testing (2) and with the use of submaximal protocols (3), but the threshold value for an abnormal test (cut-point) has varied. In one previous study, the protocol used was staged with a cool-down walk, yet current guidelines suggest that ramp-testing and rapid supine patient placement after the exercise test offer advantages over other methods and should be considered (4). The effect of beta-blockers, the optimal time point in recovery to measure HR drop, as well as the appropriate cut-point to assess the magnitude of the decrease in HR remain unresolved. Moreover, while the prognostic value of HR recovery has been highlighted, its

relative value compared with other treadmill responses and its diagnostic value remain uncertain.

The purpose of this study was to validate this measurement, compare it with other test responses, evaluate its diagnostic value and clarify some of the methodologic issues surrounding its use.

## METHODS

**Population.** A total of 8,000 male patients underwent treadmill testing at two Veterans Affairs Medical Centers between 1987 and 1998. Of these, 3,454 were evaluated for chest pain with coronary angiography within three months of treadmill testing. Patients with previous cardiac surgery or angiography, valvular heart disease, left bundle branch block, paced rhythms or Wolff-Parkinson-White on their resting electrocardiogram were excluded from the study. Remaining were 2,193 patients for survival analysis; after excluding those with previous myocardial infarction (MI) by history or by Q-waves, there was a subgroup of 1,282. While the total remaining patients are appropriate for prognostic assessment, the evaluation of the diagnostic properties of a test should be performed in the subgroup without MI (4).

**Exercise testing.** Patients underwent symptom-limited treadmill testing using the U.S. Air Force School of Aerospace Medicine (5) or an individualized ramp treadmill protocol (6). The physiologic distinction of these protocols is that the patient is subjected to small, frequent increments in workload rather than uneven increases every 3 min.

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#### Abbreviations and Acronyms

CABG	= coronary artery bypass grafting
CAD	= coronary artery disease
HR	= heart rate
METS	= metabolic equivalents
MI	= myocardial infarction
PTCA	= percutaneous transluminal coronary angioplasty
RAS	= renin-angiotensin-sympathetic nervous system
ROC	= receiver operating characteristic

Information gathered from a questionnaire enabled maximal exercise to be reached at approximately 10 min (7). Patients did not perform a cool-down walk but were placed supine as soon as possible after exercise. The reasons for termination were angina, >2 mm of abnormal ST depression, drop in systolic blood pressure or ominous arrhythmias. Visual ST-segment depression was measured at the J junction and corrected for pre-exercise ST-segment depression. An abnormal response was defined as 1 mm or more of horizontal or downsloping ST-segment depression. Blood pressure was taken manually, and metabolic equivalents (METS) were estimated from treadmill speed and grade. Heart rate was measured supine, standing, during each minute of exercise, at maximum exercise and in recovery at 1, 2, 3 and 5 min. Heart rate recovery was defined as (maximum HR—HR at specified time period after exercise) and represented the drop in HR during that time interval. No test was classified as indeterminate (8); medications were not withheld, and maximal HR target was not used as an end point. The exercise tests were performed, analyzed and reported with a standard protocol utilizing a computerized database.

**Coronary angiography.** Coronary artery narrowing was visually estimated and expressed as percent lumen diameter stenosis. Patients with a 50% narrowing of the left main, left anterior descending, left circumflex or right coronary arteries or their major branches were considered to have significant angiographic coronary artery disease (CAD). Severe disease was considered to be two-vessel disease if the proximal left anterior descending was involved; otherwise, three-vessel or left main disease were considered severe. The 50% criterion was chosen to be consistent with definitions used by the Coronary Artery Bypass Graft Surgery Trialists' Collaboration (9). In addition, the Duke coronary artery jeopardy score was calculated (10). Ejection fraction was estimated from biplane left ventricular angiograms. Decisions for cardiac catheterization were consistent with clinical practice.

**Follow-up.** The social security death index was used to match all of the patients' names to their social security numbers. The index was updated weekly, and the most current records were used. Death status was determined as of July 2000 and was 100% complete. No other information regarding hospitalizations, cardiac interventions or cause of death during the follow-up was known.

**Statistical methods.** All-cause mortality was used as the end point for follow-up, and coronary angiography was utilized for diagnostic gold standard.

Survival analysis was performed using Kaplan-Meier curves to compare variables and cut-points, and the Cox hazard function was used to demonstrate which variables were independently and significantly associated with death. Automatic selection of variables was performed with a Z value cutoff of 2 and 20 iterations. Hazard ratios were calculated along with their 95% confidence intervals.

Logistic regression was used to separate subjects into those with and without significant angiographic disease, based on clinical and measured exercise variables in the diagnostic subpopulation. Forward selection was used with entry at a significance level <0.05. The general linear logistic regression model used took the following form:

$$\text{Probability (0 to 1)} = 1 / (1 + e^{-[a+bx+cy \dots]})$$

where a is the intercept, b and c are coefficients and x and y are variable values.

How well the models separated patients with and without a given outcome (abnormal angiogram or death) was assessed by means of the area under a receiver operating characteristic (ROC) curve, which ranged from 0 to 1, with 0.5 corresponding to no discrimination (i.e., random performance) and 1.0 to perfect discrimination.

Number Crunching System Software (Salt Lake City, Utah) was used for all statistical analyses.

## RESULTS

**Patient characteristics.** This male study population had a mean height of 69.6 in. ( $\pm 2.9$  in.), a mean weight of 191 lbs ( $\pm 34$  lbs) and a mean body mass index of  $28 \pm 9$ . Average resting HR was  $76 \pm 14$  beats/min, with a corresponding mean systolic blood pressure of  $125 \pm 20$  mm Hg. Regarding medications, 4.4% reported taking digoxin, and 34% were taking beta-blockers. No significant differences in these parameters were noted between those who survived and those who died. Other relevant variables for the entire population, for those who survived and the 413 patients who died over the mean seven-year (median six) follow-up are presented with significance levels in Table 1. There was an average annual mortality of 2%.

**Exercise test responses.** No complications were encountered during testing. Results for the entire population, and specifically for those who survived and the 413 patients who died, along with significance levels for differences are presented in Table 2.

**Validation of prior criteria.** Our first examination of HR recovery was to apply the previously published threshold values for abnormal at the specified time points. Figure 1 illustrates the Kaplan-Meier curves for three criteria (12 beats/min drop at 1 min after exercise, 18 beats/min drop at 1 min after exercise and 42 beats/min drop at 2 min after exercise), showing a significant ability of all criteria to

**Table 1.** Population Characteristics With Univariate Comparison Between Those Who Died and Those Who Survived

	Total Sample n = 2,193 (%)	Survived n = 1,780 (%)	Died n = 413 (%)	p Value
Age (mean)	59 ± 10	58 ± 10	63 ± 8	<0.001
Age ≥ 65 yrs	756 (34.5)	547 (30.7)	209 (50.6)	<0.001
BMI (mean)	28 ± 9	28 ± 4	27 ± 18	0.45
MI by history or by ECG	912 (41.6)	692 (38.9)	220 (53.3)	0.01
Resting ST depression	393 (17.9)	297 (16.7)	96 (23.2)	<0.001
History of typical angina	854 (39.1)	646 (36.5)	208 (50.4)	<0.001
Digoxin	96 (4.4)	53 (3.0)	43 (10.4)	<0.001
Beta-blockers	745 (34.0)	611 (34.3)	134 (32.4)	0.46
Stroke	87 (4.0)	56 (3.1)	31 (7.5)	<0.001
Pulmonary disease	136 (6.2)	90 (5.1)	46 (11.1)	<0.001
CHF	177 (8.1)	109 (6.1)	68 (16.5)	<0.001
Diabetes	337 (15.4)	267 (15.0)	70 (16.9)	0.32
Ever smoked	1,453 (66.2)	1,207 (67.8)	246 (59.5)	0.001
LVH	65 (3.0)	34 (1.9)	31 (7.5)	<0.001
Any CAD by angiography	1,538 (70.1)	1,190 (66.9)	348 (84.3)	<0.001
Severe CAD by angiography	651 (29.7)	468 (26.3)	183 (44.3)	<0.001
Duke coronary jeopardy score (mean)	4.53 ± 4.0	4.18 ± 4.0	6.02 ± 4.0	<0.001
Ejection fraction	62 ± 13	62.7 ± 12	59 ± 16	<0.001

BMI = body mass index; CAD = coronary artery disease; CHF = congestive heart failure; ECG = electrocardiogram; LVH = left ventricular hypertrophy; MI = myocardial infarction.

predict mortality (1-3). Significant hazard ratios were associated with each specified criterion.

**Best time/cut-point.** In order to compare the candidate cut-points with each other and with the published cut-points in this population, they were entered into a proportional hazards regression model with automatic selection. Heart rate recovery measurements at 2 min recovery were superior to all other time periods, and a value of 22 beats/min was optimal at that time period as judged by the Z values and significance levels. Figure 2 shows a Kaplan-Meier plot of this criterion for comparison with previously published cut-points presented in Figure 1.

**The effect of beta-blockers and maximal HR.** Previous results have been divided over the effects of beta-blockers. We found no difference in the Kaplan-Meier survival curves of those receiving beta-blockers when compared with those not receiving beta-blockers when both exhibited abnormal HR in recovery. The Kaplan-Meier curves in Figure 3 demonstrate no difference in the prognostic value of our

optimal criteria of a drop of 22 beats/min at 2 min whether or not patients were receiving beta-blockers. When beta-blocker administration was confirmed by not reaching target HR, the same result was obtained. In addition, the same result was obtained in those who did and those who did not obtain target HR.

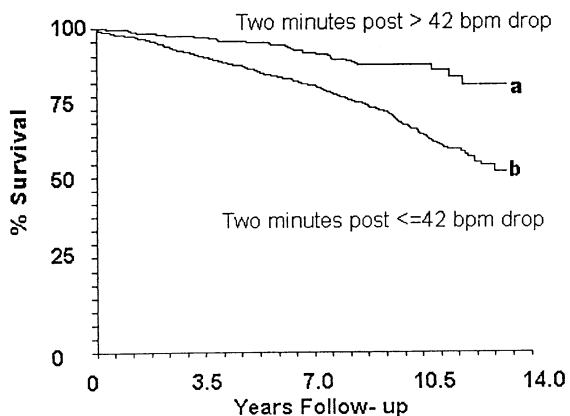
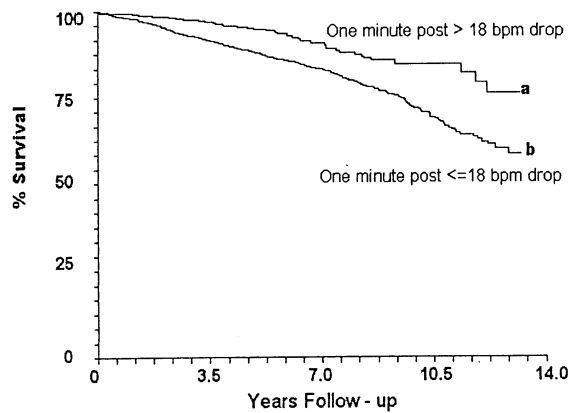
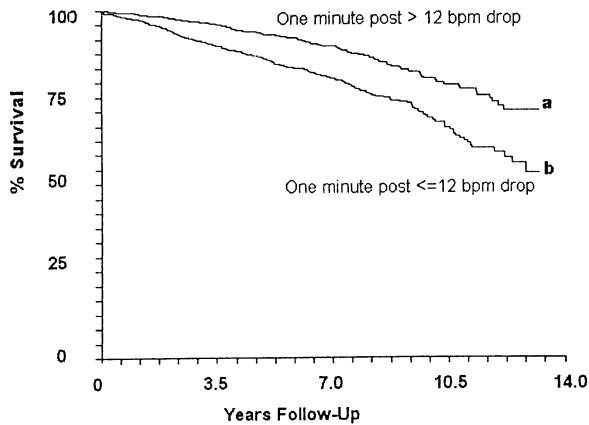
**Comparison with other variables.** We then determined how HR recovery ranks with traditional treadmill responses. To do this, we entered all of the traditional treadmill responses and several clinical variables that were univariately significant (resting HR and blood pressure along with HR recovery) into a proportional hazards regression model. The top variables chosen as significant predictors were METs, age, history of typical angina and HR drop at 2-min recovery. Notably, the treadmill angina index and exercise-induced ST depression—both ischemic variables—were not chosen.

**Prognostic score.** Because the ischemic components of the Duke treadmill score were not predictive of all-cause mor-

**Table 2.** Treadmill Test Responses With Univariate Comparison Between Those Who Died and Those Who Survived

	Total Sample n = 2,193 (%)	Survived n = 1,780 (%)	Died n = 413 (%)	p Value
Angina occurred	589 (26.9)	487 (27.4)	102 (24.7)	0.3
Angina reason for stopping	310 (14.1)	255 (14.3)	55 (13.3)	0.63
Predicted METs <5	548 (25.0)	380 (21.3)	168 (40.7)	<0.001
Exercise-induced ST depression (≥1 mm)	854 (38.9)	663 (37.2)	191 (46.2)	<0.001
Maximal HR	125 ± 23	126 ± 23	121 ± 21	<0.001
Maximal SBP	169 ± 29	164 ± 29	161 ± 30	0.06
Drop in HR at 1 min recovery	11.2 ± 8.0	11.8 ± 8.2	8.9 ± 7.0	<0.001
Drop in HR at 2 min recovery	31.7 ± 13.1	33.1 ± 12.9	25.8 ± 12.4	<0.001
Drop in HR at 3 min recovery	40.2 ± 14.7	41.5 ± 14.5	34.9 ± 14.5	<0.001
Drop in HR at 5 min recovery	42.7 ± 15.2	43.8 ± 15.0	37.9 ± 15.1	<0.001

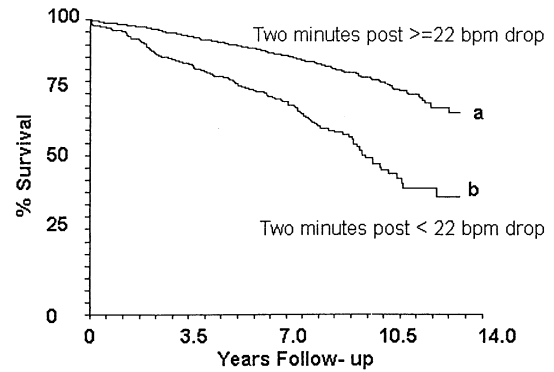
HR = heart rate; METs = metabolic equivalents; SBP = systolic blood pressure.



**Figure 1.** Kaplan-Meier survival curves for the three published criteria for heart rate recovery: (Top) 1 min post/12 beats/min drop, (Middle) 1 min post/18 beats/min drop and (Bottom) 2 min post/42 beats/min drop.

tality, we elected to consider the combined use of METS and HR recovery. Figure 4 presents a Kaplan-Meier plot using a METS criterion of 5 and HR recovery criterion of 22 beats/min as well as for abnormal by both criteria.

We also created a prognostic score using the variables



**Figure 2.** Kaplan-Meier survival curve for the 2 min post/22 beats/min drop criterion found to be optimal in our study.

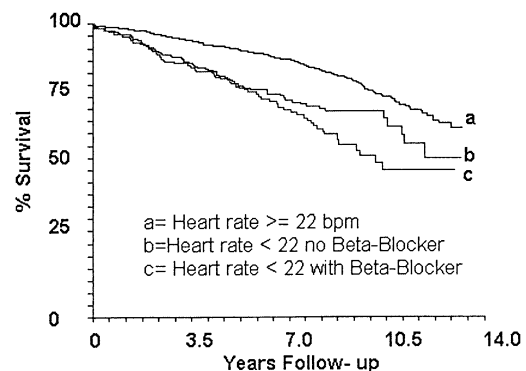
chosen in the Cox hazard model and their coefficients as follows:

$$\text{Age (years)} + 10 \cdot \text{definite angina pectoris (0 = no, 1 = yes)}$$

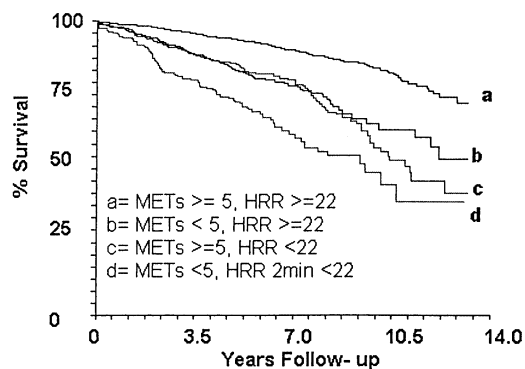
$$- \text{HR drop at 2 min recovery} - 5 \cdot \text{METs}$$

We chose cut-points in this prognostic score by which to stratify patients into high-, intermediate- and low-risk as illustrated in Figure 5. The high-risk group had a hazards ratio of greater than five times. The score was entered along with data from cardiac catheterization into a proportional hazards regression model with automatic selection. The above score was chosen first with a Z value of 13.3 ( $p < 0.001$ ) followed by ejection fraction with a Z value of 3 ( $p < 0.002$ ) and, finally, the Duke jeopardy score with a Z value of 2.6 ( $p = 0.01$ ). When cardiac catheterization variables were added to the Cox hazard model, they were superseded by the score variables.

**Diagnostic characteristics.** The diagnostic value of HR recovery (i.e., prediction of the presence of significant angiographic disease) was addressed in the subpopulation without MI. There was a 59% prevalence of significant angiographic CAD. When HR recovery was entered into the logistic regression model with variables previously noted to predict angiographic coronary disease (including maximal HR, ST depression, age and chest pain characteristics) (11,12), it was not chosen. The area under the curve of an



**Figure 3.** Kaplan-Meier survival curves for 2 min post/22 beats/min drop according to beta-blocker status.



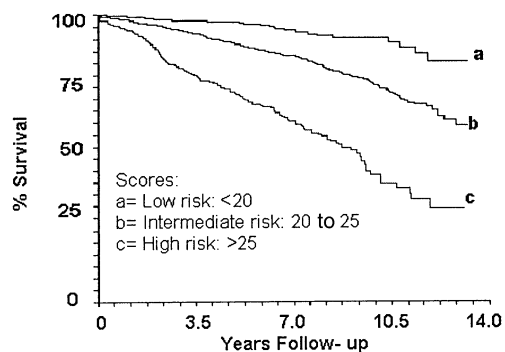
**Figure 4.** Kaplan-Meier survival curves for the criteria of 2 min post/22 beats/min drop or <5 metabolic equivalents (METs) exercise capacity and for patients who fulfilled both criteria. HRR = heart rate drop at 2 min post exercise.

ROC curve plotted with any of the continuous HR recovery measurements was never >0.58 ( $p < 0.001$ ) as compared with the area under the ROC curve obtained for the ST response alone (0.67) or that from a previously published diagnostic score (0.79) (11).

**DISCUSSION**

Heightened activation of the renin-angiotensin-sympathetic nervous system (RAS) at rest is associated with adverse outcomes in cardiovascular disease (13). The RAS hyperactivity has been shown to predict death in congestive heart failure, as demonstrated by studies of neurohormonal mediators, HR variability and baroreflex sensitivity (14). Recent attention has been paid to manifestations of the RAS and the balance between the sympathetic and parasympathetic nervous system during exercise testing (15). During exercise there is activation of the sympathetic nervous system and withdrawal of parasympathetic activity; the reverse occurs during recovery.

**Previous studies.** Recently, consideration has been given to the role of HR in recovery as a predictor of mortality. Heart rate recovery is mediated by vagal reactivation, and the rate at which HR declines appears to be a reflection of a faster recovery from the sympathetic drive necessary during exercise (16). Increased vagal activity associated with



**Figure 5.** Kaplan-Meier survival curves for the three levels of risk stratification according to the score.

a faster HR recovery has been shown to be associated with a decrease in risk of death (17). For this reason, several recent studies have looked at HR recovery after exercise as a prognostic tool. These studies are summarized in Table 3. In the first study, Cole et al. (2) looked at 2,428 adults who had been referred for exercise scintigraphy over six years. They found that using a drop of ≤12 beats/min at 1 min after exercise as the definition of an abnormal response, a relative risk of 4.0 for death was observed. The group with a value <12 had a mortality of 19%, while the group with an HR decrease >12 had a mortality of 5% over the six-year period. The study employed the symptom-limited Bruce protocol with a 2-min cool-down walk. Patients on beta-blockers were included in the study, and no difference was seen in the ability of the test to discriminate between low- and high-risk patients in those patients on beta-blockers. The investigators used all-cause mortality and performed survival analysis with and without censoring of interventions (coronary artery bypass grafting [CABG] and percutaneous transluminal coronary angioplasty [PTCA]) and found no difference in results.

These investigators then studied a different patient population (3). Asymptomatic patients enrolled in the Lipid Research Clinics Prevalence study underwent exercise testing using a Bruce protocol. The tests were stopped when 85% to 90% of peak HR was achieved, and no cool-down period was allowed. Heart rate recovery was measured at 2 min after exercise. Heart rate recovery continued to be a strong predictor of all-cause mortality; patients with an abnormal value had a mortality rate of 10%, while patients with a normal value had a mortality rate of 4% at 12 years of follow-up. Given the differences in methods, direct comparisons between the two studies were not possible, but this second study confirmed HR recovery as a powerful prognostic measurement.

To further elucidate the power of HR recovery in distinct populations, these investigators then published another study using patients referred for standard exercise treadmill testing (1). Using the same methods as the original study, the investigators found similar results, although, notably, the cut-off value for an abnormal test was different. Patients with an abnormal HR recovery had 8% mortality at 5.2 years, whereas patients with a normal HR recovery had only 2% mortality. Neither this nor the previous study censored for CABG or PTCA, and this study had 8% of patients with CABG enrolled along with 75% asymptomatic individuals. The investigators also compared the prognostic ability of HR recovery to that of the Duke treadmill score. While the individual components of the Duke score (except exercise capacity) did not have prognostic power, the score produced similar survival curves to HR recovery and, in patients with abnormal scores on both tests, survival was even further compromised.

**This study.** In our study, we attempted again to validate the use of HR recovery for prognosis in a male veteran population. The mortality rate in our study was higher than

**Table 3.** Previously Published Prognostic Studies Relating to the Decrease of HR After Exercise

Study	Population	Sample Size (% Women)	Exclusion Criteria	Follow-Up (y-mean)	Test Protocol/ Recovery Status	Minutes of Recovery/ Cut-Point	Mortality (All-Cause)	Sensitivity/Specificity for Death	Other Variables Studied	Beta-Blocker Status
Cole et al. (2)*	Referral for exercise perfusion; 9% with known CAD	2,428 (37)	CABG, angiography, CHF/digoxin use, LBBB	6	Bruce, with 2 min cool-down; Symptom-limited	1 min/ 12 beats/min	213 (9%)	(cut-point = 12 beats/min) 56%/77%; (cut-point = 8 beats/min) 33%/90%	METS, male gender, age, perfusion defects on scintigraphy, chronotropic incompetence	Used by 12% of study population; No association with abnormal test
Cole et al. (3)	Participants in Lipid Research Clinics Prevalence study, asymptomatic	5,234 (39)	Beta-blockers, other cardiac meds, history of cardiovascular disease	12	Bruce, without cool-down; 85% age-predicted HR	2 min/ 42 beats/min	325 (6.2%), 36% felt to be cardiovascular follow-up 100%	54%/69%	No comparison	Excluded
Nishime et al. (1)	Referral for ETT; 8% prior CABG, 75% screening asymptomatic, 9% prior MI	9,454 (22)	CHF, LBBB, digoxin, valvular heart disease	5.2	Bruce, with 2 min cool-down; symptom-limited	1 min/ 12 beats/min	312 (3%)	49%/81%	METS, maximal HR, Duke treadmill score; TM AP score and El-ST depression not prognostic	HR recovery not predictive of death in beta-blocker group
Shetler (present study)	Referral for standard ETT; 42% with prior MI	2,193 (all men)	CABG, angiography, LBBB, pacemaker	6.8	Ramp without cool-down; symptom limited	2 min/ 22 beats/min	413 (19%)	35%/83%	Age, METS, history of typical angina; treadmill AP score and El-ST depression not prognostic	Used by 34% of the study population; HR recovery equally predictive

AP = angina pectoris; CABG = coronary artery bypass grafting; CAD = coronary artery disease; CHF = congestive heart failure; El = elevated; ETT = exercise treadmill test; HR = heart rate; LBBB = left bundle branch block; METS = metabolic equivalents; MI = myocardial infarction.

it was in previous studies of HR recovery. Using similar statistical analyses, we found that a decrease of HR in recovery of <22 beats/min at 2 min after exercise identified a high-risk group of patients. While these data confirm the utility of HR recovery, it is important to note that several studies have employed different cut-points for defining an abnormal test, even when the testing protocol (e.g., presence or absence of cool-down, minute of recovery when measurements are made) are the same. Therefore, it is difficult to know which value is most applicable to the general population.

**Beta-blockade.** We also found that the clinical administration of beta-blockers had no significant impact on the prognostic value of HR recovery. Given the impact of beta-blockers on the ability to achieve maximum HR, it would not be unreasonable to imagine that the medication might have an impact on HR recovery. However, the same results were found in those who reached target HR and those who did not. Further analysis of this issue would be warranted to better understand the true impact of this medication and maximal HR.

**Multivariable analysis.** Through multivariate analysis, we evaluated the power of several other clinical and treadmill variables to see how they compared with HR recovery in their ability to predict outcome. Similar to Cole et al. (2), we found that a low MET capacity was the most powerful variable associated with outcome. This finding was not shared by Nishime et al. (1), in which the strongest predictor of death was resting tachycardia. It is important to note that in our study and those of Nishime et al. (1) and Cole et al. (3), ischemic ST responses on the treadmill did not predict death. Exercise-induced angina was also not a significant variable in the study by Nishime et al. (1) nor in our study. The Duke treadmill score (18) includes both of these variables, and they have been predictors of cardiovascular outcome in several other studies.

This raises the question as to why ischemic variables included in the Duke score that clearly have diagnostic power do not predict all-cause mortality. While all-cause mortality has advantages over cardiovascular mortality as an end point (19), the Duke score was generated using the end points of infarction and cardiovascular death (18). Furthermore, cardiology interventions such as bypass surgery or catheter interventions were censored in the Duke study (i.e., subjects were removed from the survival analysis when these events occurred). Such censoring should increase the association of ischemic variables with outcome by removing patients whose disease has been alleviated and, thereby, would not be as likely to experience the outcome. We did not censor patients in this study on the basis of whether or not they had a cardiovascular procedure during follow-up because we do not have that information. From a previous study using a similar patient population, our group found that 75% of deaths were cardiovascular deaths, and 20% of patients were censored in follow-up due to bypass surgery (20). If the proportions of these statistics are similar in our

current population, it would not be unreasonable to expect a bias against the predictive power of these variables. However, this hypothesis would need to be proven since censoring had no impact on HR recovery findings in the study that did censor (2) nor in the Duke score. In fact, exercise-induced ST depression predicted all-cause mortality with and without censoring in an earlier study (21). These contradictory results could potentially be due to the more effective methods of treatment currently available for coronary disease.

**Diagnostic characteristics.** A distinct advantage over previous studies is that we selected a group who underwent coronary angiography. This made it possible to evaluate the diagnostic ability of HR recovery. Surprisingly, HR recovery was not selected among the standard variables to be included in a logistic model, and the ROC curve did not indicate any discriminatory value. Thus, while HR recovery has been validated as an important prognostic variable, it did not help the diagnosis of coronary disease in this study.

**Study limitations.** While our study was unique in its strict adherence to guidelines in the performance of exercise testing and its inclusion of angiographic data, there were some limitations. The use of a ramp protocol differed from previous studies using the Bruce protocol, but, rather than being a limitation, this extends earlier findings to another protocol. The lack of inclusion of women is quite important, especially given the different characteristics of treadmill testing between women and men that have previously been shown. Additionally, we were unable to provide information on cause of death and did not have information about cardiovascular procedures during the follow-up period, so we could not censor on them. As mentioned earlier, the inability to censor may skew results. Without censoring, we are predicting prognosis in spite of, or in addition to, modern therapy rather than predicting who should have interventions. The pathophysiology of an inadequate HR decrease in recovery has not been explained by our study. Finally, as mentioned previously, our angiographic subset was subject to work-up bias.

**Conclusions.** We found that, among male patients with or without prior MI but without prior bypass surgery referred for clinical exercise testing done without cool-down walk but with prompt supine placement, an HR drop of 22 beats/min at 2 min recovery had prognostic, but not diagnostic, value. Heart rate at 1 or 2 min of recovery has been validated as a prognostic treadmill measurement and should be recorded as part of all treadmill tests. The prognostic power of this measurement does not appear to be affected by beta-blockade, but its cut-point is most likely affected by population selection and protocol. A score including HR recovery, METs, age and history of typical angina pectoris was superior to cardiac catheterization data for predicting prognosis. To date, this measurement has not been evaluated as a diagnostic indicator, and we found that it was not diagnostic of angiographic CAD. The drop of HR in recovery or its score should supplement, but not

replace, the Duke treadmill score that has been validated as a predictor of infarct-free survival and diagnostic of angiographic CAD. Though our analysis has not explained the pathophysiology of an inadequate decline of HR after exercise, it may well represent a marker of habitual physical activity level (16).

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