

Use of a Prognostic Treadmill Score in Identifying Diagnostic Coronary Disease Subgroups

Leslee J. Shaw, PhD; Eric D. Peterson, MD, MPH; Linda K. Shaw, MS;
Karen L. Kesler, MS; Elizabeth R. DeLong, PhD; Frank E. Harrell, Jr, PhD;
Lawrence H. Muhlbaier, PhD; Daniel B. Mark, MD, MPH

Background—Exercise testing is useful in the assessment of symptomatic patients for diagnosis of significant or extensive coronary disease and to predict their future risk of cardiac events. The Duke treadmill score (DTS) is a composite index that was designed to provide survival estimates based on results from the exercise test, including ST-segment depression, chest pain, and exercise duration. However, its usefulness for providing diagnostic estimates has yet to be determined.

Methods and Results—A logistic regression model was used to predict significant ($\geq 75\%$ stenosis) and severe (3-vessel or left main) coronary artery disease, and a Cox regression analysis was used to predict cardiac survival. After adjustment for baseline clinical risk, the DTS was effectively diagnostic for significant ($P < 0.0001$) and severe ($P < 0.0001$) coronary artery disease. For low-risk patients (score $\geq +5$), 60% had no coronary stenosis $\geq 75\%$ and 16% had single-vessel $\geq 75\%$ stenosis. By comparison, 74% of high-risk patients (score < -11) had 3-vessel or left main coronary disease. Five-year mortality was 3%, 10%, and 35% for low-, moderate-, and high-risk DTS groups ($P < 0.0001$).

Conclusions—The composite DTS provides accurate diagnostic and prognostic information for the evaluation of symptomatic patients evaluated for clinically suspected ischemic heart disease. (*Circulation*. 1998;98:1622-1630.)

Key Words: exercise ■ tests ■ prognosis ■ coronary artery disease

The exercise treadmill is used in the evaluation of symptomatic patients to predict the presence and extent of coronary artery disease and the short- and long-term prognosis.¹⁻⁷ Although a large number of noninvasive stress testing modalities are currently available, the exercise ECG is still used as a standard for comparison with other clinical and testing risk markers. It is also the least costly of all provocative noninvasive tests.

The limited sensitivity and specificity of standard exercise ECG testing for detection of coronary artery disease have stimulated increased use and development of noninvasive stress imaging technologies.⁸ However, the added diagnostic accuracy of stress imaging tests is associated with substantially higher cost. An alternative to the use of more expensive tests is the more efficient use of available low-cost data. Diagnostic and prognostic predictive accuracy increase when multiple pieces of information from the patient's clinical history and the treadmill test are integrated.^{9,10} Combining clinical and test information thus provides an opportunity to make efficient use of key predictors at each stage of an intervention or risk assessment at substantial cost savings.

In 1987, Mark and colleagues² described a prognostic exercise treadmill score that was based on the duration of

exercise, ST-segment deviation (depression or elevation), and the presence and severity of angina during exercise. This treadmill score has been shown to stratify prognosis accurately for both inpatient and outpatient ischemic heart disease populations.^{1,2} The purpose of this report is to examine the diagnostic accuracy of the Duke prognostic treadmill score and to examine the incremental value of treadmill test information beyond clinical data. To date, no composite stress-test score or noninvasive risk index has been shown to provide both accurate diagnostic and prognostic risk estimates.

Methods

Patient Population: Original and Validation Patients

Our original sample consisted of 2758 symptomatic patients who underwent exercise treadmill testing followed by cardiac catheterization at Duke University Medical Center from 1969 through 1980; this population has been reported previously.² A subsequent sample of 467 patients who underwent exercise treadmill testing and cardiac catheterization from 1984 through 1990 were used as the validation patients. Patients were included if their cardiac catheterization was performed ≤ 90 days from their exercise test and were excluded if they were asymptomatic or had significant valvular or congenital

Received October 24, 1997; revision received June 14, 1998; accepted June 18, 1998.

From the Center for Cardiovascular Epidemiology, Division of Cardiology, Emory University, Atlanta, Ga.

Presented in part at the 68th Scientific Sessions of the American Heart Association, Anaheim, Calif, November 13-16, 1995, and published in abstract form (*Circulation*. 1995;92[suppl I]:I-271).

Correspondence to Leslee J. Shaw, PhD, Center for Cardiovascular Epidemiology, Division of Cardiology, Room 638, 1518 Clifton Rd NE, Atlanta, GA 30322. E-mail lshaw@cces.emory.edu

© 1998 American Heart Association, Inc.

TABLE 1. Clinical Characteristics of the 2758 Original and 467 Test Sample Patients

Variable	Original Sample (n=2758)	Test Sample (n=467)	P
Male sex, %	70	66	0.054
Age, y	49 (43,55) [49]	58 (50,66) [57]	0.001
Clinical history, %			
Diabetes	9	14	0.001
Hypertension	34	45	0.001
Hyperlipidemia	22	31	0.001
Peripheral vascular disease	4	7	0.001
Prior myocardial infarction	30	16	0.001
Symptoms			
Typical angina, %	47	49	0.439
Atypical angina, %	38	49	0.001
Nonanginal pain, %	15	2	0.001
Episodes per week	5 (2,12) [10]	3.5 (1.5,7) [5.3]	0.001
Months with symptoms	16 (5,52) [38]	13 (2,55) [42]	0.001
Progressive symptoms, %	32	45	0.001
Exercise test			
Peak heart rate, bpm	140 (125,147) [135]	141 (122,156) [140]	
Peak systolic blood pressure, mm Hg	160 (140,180) [164]	180 (160,200) [180]	0.001
ST deviation, mm	0.0 (0,1.25) [0.62]	1.20 (0.0,2.0) [1.30]	0.001
Exercise duration, min	6.5 (4.1,9.0) [6.7]	5.3 (3.6,7.7) [5.8]	0.001
Exercise chest pain, %	50	51	0.86
Treadmill score	2.3 (-4.0,6.8) [0.7]	-3.3 (-8.5,1.8) [-3.3]	0.001
Cardiac catheterization			
Significant coronary disease, %	61	56	0.07
Severe coronary disease, %	27	23	0.088
Ejection fraction, %	60 (50,61) [56]	60 (54,66) [59]	0.001
Outcome status			
5-Year mortality, %	8.2	7.0	0.98

Values are n, median (25th, 75th) [mean].

heart disease, recent myocardial infarction, a prior revascularization procedure, an uninterpretable exercise ECG, or percutaneous or coronary surgery intervention ≤ 3 months from the exercise test.

Clinical, Catheterization, and Follow-Up Data

Our methods for collecting pretest demographic and clinical data have been described.^{1,2} Follow-up information was obtained by clinic visit, mailed questionnaire, or telephone interview at 6 months, 1 year, and then yearly thereafter. The reasons for death were classified as cardiac versus noncardiac by a review committee unaware of the patient's clinical or exercise test data.

Exercise Treadmill Testing

All patients underwent symptom-limited exercise testing according to the standard Bruce protocol. Resting heart rate, blood pressure, and 12-lead ECGs were recorded in the supine and upright positions before exercise. During each minute of exercise, heart rate and blood pressure measurements as well as a 12-lead ECG were recorded. Exercise testing was discontinued if exertional hypotension, malignant ventricular arrhythmias, marked ST depression (≥ 3 mm), or limiting chest pain was reported. An abnormal exercise ST response was defined as ≥ 1 mm of horizontal or downsloping ST depression (J point +80 ms) or ≥ 1 mm of ST-segment elevation in leads without pathological Q waves (excluding AVR lead). Exercise-induced

ST-segment deviation was coded to the nearest 0.25 mm for horizontal and downsloping ST-segment depression and ST-segment elevation in a non-Q-wave lead.

Duke Treadmill Score

The equation for calculating the Duke treadmill score (DTS) is $DTS = \text{exercise time} - (5 \times \text{ST deviation}) - (4 \times \text{exercise angina})$, with 0 = none, 1 = nonlimiting, and 2 = exercise-limiting.

The score typically ranges from -25 to +15. These values correspond to low-risk (with a score of $\geq +5$), moderate-risk (with scores ranging from -10 to +4), and high-risk (with a score of ≤ -11) categories.^{1,2}

Data Analysis

Descriptive statistics were generated with percentages for discrete variables and means and SDs for continuous variables. Discrete variables were compared by χ^2 analyses, continuous variables were compared with the DTS risk groups by the Wilcoxon rank-sum test, and continuous variables were compared by an unpaired *t* test.

Model End Points

We assessed the utility of the DTS for risk-stratifying 3 different but related outcomes: (1) the presence of significant disease (defined as a $\geq 75\%$ stenosis in at least 1 major epicardial coronary artery), (2)

TABLE 2. Frequency of Clinical History, Exercise, Cardiac Catheterization Data, and Cardiac Death by DTS Risk Group for 2758 Medically Treated Coronary Artery Disease Patients From the Original Sample

Variables	Low-Risk DTS (n=990)	Moderate-Risk DTS (n=1515)	High-Risk DTS (n=253)	P
Clinical history				
Male sex, %	71	67	91	0.001
Age, y	46 (39,51) [45]	51 (45,56) [51]	53 (47,60) [53]	0.001
Risk factors, %				
Diabetes	7	10	11	0.008
Hypertension	28	36	40	0.001
Hyperlipidemia	18	23	31	0.001
Symptoms				
Typical angina, %	25	54	87	0.001
Atypical angina, %	47	36	12	0.001
Nonanginal chest pain, %	28	9	1	0.001
Anginal frequency per week	3 (1,7) [7]	7 (2,4) [14]	10 (4,20) [15]	0.001
Congestive heart failure, %	3	6	9	0.001
Prior myocardial infarction, %	25	32	39	0.001
Exercise test				
Peak heart rate, bpm	147 (140,152) [144]	136 (120,145) [131]	127 (110,135) [124]	0.001
Peak systolic blood pressure, mm Hg	164 (150,190) [169]	160 (140,180) [161]	160 (130,180) [159]	0.005
≥1-mm ST depression, %	2	36	100	0.001
Exercise chest pain, %	15	67	94	0.001
Exercise duration, min	9.3 (7.3,10.5) [9.1]	4.8 (3.4,7) [5.5]	4 (3,5) [4.2]	0.001
Catheterization results				
Ejection fraction, %	60 (56,61) [58]	60 (49,61) [55]	52 (46,60) [52]	0.001
Significant coronary disease, %	40	67	100	0.001
Severe coronary disease, %	9	31	74	0.001

Values as in Table 1.

the presence of severe coronary disease (defined as a 3-vessel coronary disease or ≥75% left main disease), and (3) cardiac survival. For the first 2 outcomes, we used logistic regression analysis. For the survival outcome, we used a Cox proportional hazard regression analysis for assessing individual relations among clinical history and exercise testing variables that assess time to cardiac death.

Kaplan-Meier curves were used to compare time to cardiac death among the DTS risk groups. Patients undergoing coronary revascu-

larization were included up to the time of their procedure and then censored. A log-rank statistic was used to compare differences in survival.

Model Construction

Regression analyses for each of the above end points were performed in 2 stages. First, all clinical history and physical examination parameters were entered into the model to reflect the pretest probability or what was known about the patient before testing.

TABLE 3. Frequency of Coronary Disease Subsets and 5-Year Cardiac Survival for ST-Segment Depression, Chest Pain, and Exercise Duration Compared With the DTS for 2758 Medically Treated Coronary Artery Disease Patients From the Original Sample

	5-Year Mortality	No Stenosis ≥75% (n=1089)	1-VD ≥75% (n=363)	2-VD or Proximal LAD (n=349)	2-VD With LAD (n=214)	3-VD or Left Main (n=743)
ST depression ≥1 mm (29.3%)	18.5	11.5	9.7	15.0	10.5	53.3
Exercise chest pain (50%)	12.2	27.8	11.5	13.6	10.0	37.1
Exercise duration ≤6 min (45.2%)	12.7	28.7	10.2	11.8	9.6	39.7
DTS						
Low risk (35.9%)	3.1	59.9	16.4	10.3	3.9	9.5
Moderate risk (54.9%)	9.5	32.7	12.3	14.5	10.0	30.6
High risk (9.2%)	35.0	0.4	5.9	10.7	9.5	73.5

VD indicates vessel disease; LAD, left anterior descending. Values are percentages.

P<0.001 for mortality and disease subgroups.

TABLE 4. Unadjusted and Pretest Risk-Adjusted Odds Ratio* for the DTS in Predicting Significant and Severe Coronary Disease

DTS	Unadjusted Odds Ratio (95% CI)	Wald χ^2 (P)	Adjusted Odds Ratio (95% CI)	Wald χ^2 (P)
Significant CAD				
Original sample		LL† $\chi^2=439.6$		LL $\chi^2=1640.8$
Moderate risk	3.1 (2.6–3.6)	175.4 (0.0001)	2.0 (1.6–2.5)	40.8 (0.0001)
High risk	376.4 (52.6–2693.3)	34.9 (0.0001)	96.9 (13.3–707.1)	20.4 (0.0001)
Test sample		LL $\chi^2=53.3$		LL $\chi^2=189.1$
Moderate risk	4.7 (2.6–8.5)	26.2 (0.0001)	5.1 (2.2–11.8)	14.7 (0.0001)
High risk	18.1 (7.2–45.3)	38.1 (0.0001)	10.2 (3.2–32.2)	15.5 (0.0001)
Severe CAD				
Original sample		LL $\chi^2=435.0$		LL $\chi^2=864.2$
Moderate risk	4.2 (3.3–5.3)	138.3 (0.0001)	2.4 (1.8–3.1)	42.9 (0.0001)
High risk	26.5 (18.6–37.6)	334.7 (0.0001)	8.2 (5.6–12.0)	114.7 (0.0001)
Test sample		LL $\chi^2=34.5$		LL $\chi^2=90.1$
Moderate risk	8.1 (2.5–26.5)	11.8 (0.0006)	10.2 (2.3–45.1)	9.5 (0.0023)
High risk	19.2 (5.4–68.0)	20.9 (0.0001)	17.3 (3.6–83.8)	12.5 (0.0004)

*Risk-adjusted by the clinical history models listed in Appendix 1.

†LL indicates model log likelihood ratio statistic; CAD, coronary artery disease.

Separate clinical history and physical examination models for significant and severe coronary disease as well as cardiac mortality have been developed by Pryor et al¹¹⁻¹³; variables are listed in Appendix 1. All significant variables from each of the disease and mortality models were considered and have been described elsewhere.¹¹⁻¹³ Second, the DTS was added to the model. Finally, a combined model that included the clinical history, physical examination variables, and the DTS were evaluated for each of the above-listed regression models. Nomograms estimating each of the model end points are listed in Appendix 2.

To assess the incremental value of the exercise test data, for survival, we calculated the difference in the log likelihood ratio χ^2 statistic from the overall model with and without the DTS. The accuracy of the models for predicting significant and severe coronary disease was assessed by calculating the area under the receiver operating characteristics (ROC) curve for the model predictions.^{11,12}

Results

Study Populations

Of the 2758 original sample patients, 70% were male, the median age was 49 years, 30% had a prior myocardial infarction, and 47% had typical angina pectoris (Table 1). From the exercise test, mean ST deviation was 0.6 mm, the average exercise duration was 6.7 minutes, and angina occurred during exercise in 50% of patients. Cardiac catheterization revealed significant coronary disease in 61% of patients, whereas 27% of patients had severe coronary disease. Average ejection fraction was 56%. The overall cardiac mortality rate was 8.2%.

The validation sample patients were older, with diabetes, hypertension, and vascular disease occurring more frequently, whereas prior myocardial infarction occurred less often. In the validation sample, 56% had significant coronary disease and 23% had severe coronary disease. The average ejection fraction was higher (59%) in the validation patients than in the original sample ($P=0.001$). The overall cardiac mortality was 7.0%.

DTS Risk Groups (Table 2)

From the results of the exercise test, 36% and 9% of original sample patients were classified as low and high risk, whereas 55% were classified as moderate risk. High-risk patients were more often older and male, with a greater frequency of cardiac risk factors, typical anginal symptoms, congestive heart failure, and prior myocardial infarction. During the treadmill test, peak heart rate, systolic blood pressure, and exercise time were lower for high-risk than for low- or moderate-risk DTS patients. All of the high-risk patients had ≥ 1 mm of ST-segment deviation, and 94% had exertional chest pain.

Frequency of Coronary Disease Subsets

Table 3 provides the frequency of significant coronary disease by treadmill test results. Three-vessel or left main disease was present in 37%, 40%, and 53% of patients with exertional chest pain, exercise duration ≤ 6 minutes, and ≥ 1 mm of ST-segment deviation, respectively. By comparison, 83% of high-risk DTS

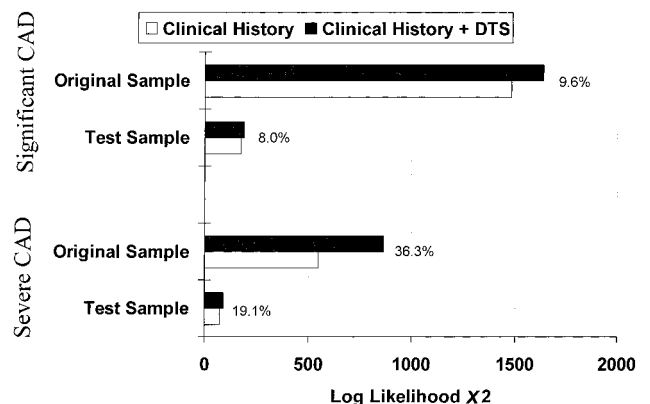


Figure 1. Incremental value of DTS in predicting significant coronary disease (CAD) (8% to 9.6% new information) and severe coronary disease (CAD) (19.1% to 36.3% new information).

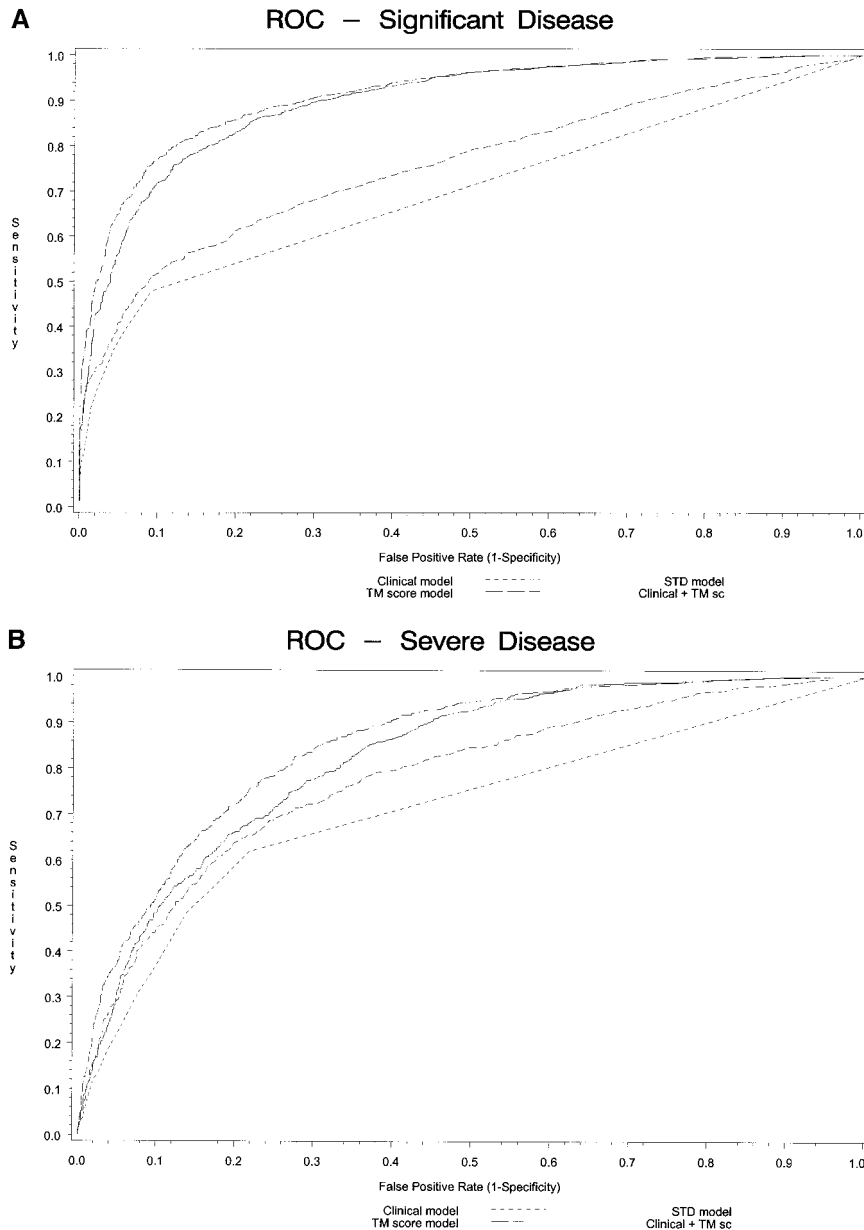


Figure 2. A, ROC curves for predicting significant coronary disease by clinical history (clinical model), maximum ST deviation (STD), DTS (TM score model), and posttest DTS (clinical+TM sc). B, ROC curves for predicting severe coronary disease by clinical history, maximum ST deviation, DTS, and posttest DTS.

patients had 2- (with proximal left anterior descending) or 3-vessel or left main coronary disease. Low-risk patients typically had no coronary lesion $\geq 75\%$ (60%) or 1-vessel coronary disease (16%). Although between 12% and 29% of patients with ST depression, chest pain, or a limited exercise duration had no coronary stenosis $\geq 75\%$, only 0.4% of high-risk DTS patients were without a significant coronary lesion. The comparison of significant coronary disease by DTS risk groups was statistically significant for the original and validation samples ($P < 0.0001$ for both).

Predicting Significant Coronary Disease

In predicting the presence of ≥ 1 -vessel disease with $\geq 75\%$ stenosis, the odds of significant coronary disease in the original sample were 3.1-fold (pretest risk-adjusted: 2.0-fold) greater for moderate- than for low-risk DTS patients (Table 4). For high-risk DTS patients, the odds of significant

coronary disease were 376-fold (risk-adjusted: 97-fold) for high-risk versus low-risk patients. In the validation sample, moderate- and high-risk patients were 4.7 (pretest risk-adjusted: 2.4) and 18.1 (pretest risk-adjusted: 8.2) times more likely to have significant coronary disease than low-risk DTS patients.

In predicting significant coronary disease, the treadmill score also added independent predictive information while contributing 8% to 9.6% of the total model information for the original and validation samples (Figure 1, $P = 0.0001$ for both groups). The area under the ROC curves for predicting significant coronary disease was 0.70 for ST deviation alone, 0.76 for the DTS alone, and 0.91 for posttest DTS+clinical history results (Figure 2A).

Predicting Severe Coronary Disease

In the original sample, the odds of severe coronary disease were 4.2-fold (pretest risk-adjusted: 2.4-fold) greater for

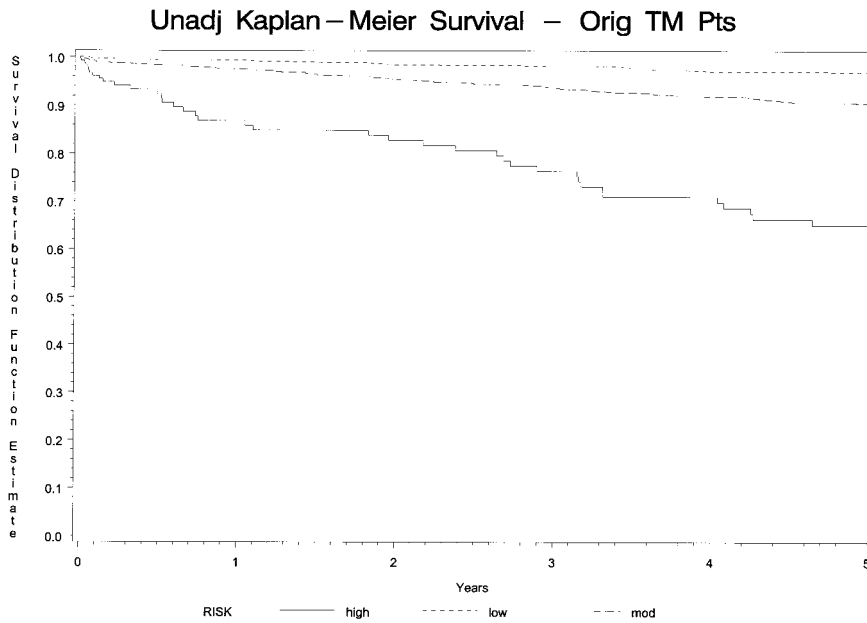


Figure 3. Overall 5-year survival was 97%, 90%, and 65% for low-, moderate- (mod), and high-risk patients ($P < 0.00001$). Unadj indicates unadjusted; Orig, original; TM, treadmill; and Pts, patients.

moderate- than for low-risk DTS patients (Table 4). For high-risk DTS patients, the odds of extensive disease were 26.4-fold (pretest risk-adjusted: 8.2-fold) for high-risk versus low-risk patients. In the validation sample, the odds of severe disease were 8.1-fold (pretest risk-adjusted: 10.2-fold) and 19.2-fold (pretest risk-adjusted: 17.3-fold) for moderate- and high-risk compared with low-risk DTS patients. When predicting severe coronary disease, the treadmill score also added independent predictive information, contributing 19.1% to 36.3% of the total model information ($P = 0.0001$, Figure 1). When predicting severe coronary disease, the area under the ROC curve was highest for posttest DTS results at 0.85 (compared with 0.72 for ST-segment depression alone, $P = 0.0001$).

Predicting Survival

Five-year cardiac death rates in the original sample were high for patients with ST-segment depression ≥ 1 mm (19%), exertional chest pain (12%), and exercise duration ≤ 6 minutes (13%) (Table 3, Figure 3). For low-, moderate-, and high-risk DTS patients, cardiac death rates at 5 years were 3%, 10%, and 35%, respectively ($P < 0.0001$). A Kaplan-Meier survival curve of the original sample is plotted in Figure 3 for low-, moderate-, and high-risk DTS patients. Compared with low-risk patients, the unadjusted relative risk of cardiac death was 3.0-fold (pretest risk-adjusted: 1.8-fold) and 13.0-fold (pretest risk-adjusted: 4.6-fold) for moderate- and high-risk DTS patients. The treadmill score provided 15.4% of independent, prognostic information beyond a patient's clinical history data for predicting survival ($P < 0.0001$).

Discussion

The results of the current report reveal that, in addition to providing accurate prognostic estimates, the DTS also provides valuable information about the presence and severity of coronary disease. Furthermore, the DTS adds independent

predictive information about these end points to the standard clinical (pretest) assessment.

Using the Treadmill Score to Improve Risk Estimates

If test interpretation and subsequent patient management is based solely on ECG signs of ischemia, then the classification and detection of at-risk patients will be less than that achieved with the DTS. Several previous reports have attempted to

TABLE 5. Clinical History and Physical Examination Parameters Considered for the Significant CAD, Severe Coronary Disease, and Cardiac Survival Multivariable Risk-Adjusted Models

Variables	Significant CAD	Severe CAD	Cardiac Survival
Age	x	x	x
Sex	x	x	x
Chest pain			
Type	x	x	x
Frequency	—	—	—
Course	—	x	—
Nocturnal	—	x	—
Length of time present	—	x	x
Diabetes mellitus	x	x	—
Smoking	x	x	—
Hyperlipidemia	x	x	—
Hypertension	—	x	—
Prior MI	x	x	—
Vascular disease	—	x	x
PVD history	—	—	x
CHF	—	—	x

CAD indicates coronary artery disease; MI, myocardial infarction; PVD, peripheral vascular disease; and CHF, congestive heart failure. — indicates variable not included in the final multivariable model.

TABLE 6. Risk of 5-Year Cardiac Mortality, Significant Coronary Disease, and Severe Coronary Disease

1. Find Points for Each Treadmill Score

5-Year Survival		Significant Coronary Disease		Severe Coronary Disease	
TM Score	Points	TM Score	Points	TM Score	Points
-45	100	-45	100	-45	100
-40	92	-40	92	-40	92
-35	85	-35	85	-35	85
-30	77	-30	77	-30	77
-25	69	-25	69	-25	69
-20	62	-20	62	-20	62
-15	54	-15	54	-15	54
-10	46	-10	46	-10	46
-5	38	-5	38	-5	38
0	31	0	31	0	31
5	23	5	23	5	23
10	15	10	15	10	15
15	8	15	8	15	8
20	0	20	0	20	0

2. Sum Points for Duke Treadmill Score

Point Total	Survival	Sig CAD	Severe CAD
-------------	----------	---------	------------

3. Look Up Risk Corresponding to Point Total

Total Points	Probability of 5-Year Survival, %	Total Points	Probability of Significant Coronary Disease, %
54	10	68	99
46	25	52	95
35	50	45	90
30	60	34	75
25	70	24	50
18	80	13	25
13	85		
6	90	Total Points	Probability of Severe Coronary Disease
2	92		
0	93		
		93	99
		75	95
		67	90
		55	75
		43	50
		31	25
		19	10
		11	5

TM Score indicates Duke treadmill score; Sig CAD, significant coronary disease.

correlate the presence of exercise-induced ischemia with the presence and extent of significant coronary lesions.^{3,18-22} When exercise test information is used, the sensitivities of ST-segment depression and ST/heart rate index in detecting severe 3-vessel or left main disease were 75% and 78% in a

2270-patient multicenter registry.²³ In a population of 607 male veterans, maximum ST depression during exercise or recovery was the single greatest discriminator among groups with differing disease severities.²⁴ Furthermore, for patients with ≥ 2 mm of ST-segment depression, the sensitivity was

55% and the specificity was 80% for predicting 3-vessel or left main disease. Exercise test indices, similar to the DTS score, have been developed by use of multiple pieces of information from the stress evaluation, including ST depression, chest pain, exercise time, peak systolic blood pressure, and heart rate.^{2,5,9} Morrow and colleagues⁵ developed the VA score within a population of older, male veterans. This index includes the change in systolic blood pressure, peak metabolic equivalents, a history of congestive heart failure or digoxin use, and exercise-induced ST depression. From the VA series, annual mortality was <2%, 7%, and 15% for low-risk (77% of population), moderate-risk (18% of cohort), and high-risk (6% of patients) VA patients. In general, our experience with the VA score is that it does not risk-stratify lower-risk populations as well as higher-risk patients; this is probably a function of the components of the score, including digoxin use, impaired systolic function, and poor exercise tolerance. In an analysis of the VA score in our patient series, few patients were classified as high-risk (ie, 3%), and survival differences were not apparent for low- to moderate-risk patients (92% for low- to intermediate- and 84% for high-risk VA scores). With the DTS, prognostic and diagnostic subsets may also be discerned on the basis of information presented in the present and previous series.^{1,2} The DTS contributed from 8% to 36% of the predictive information when predicting significant or severe coronary disease and cardiac mortality. Of the current series, >80% of high-risk patients had 2-vessel coronary disease with left anterior descending involvement or 3-vessel disease. Of those classified as low risk in our 3225-patient series, most had either no significant ($\geq 75\%$ stenosis) lesions or single-vessel coronary disease. Similarly, Iskandrian and colleagues¹⁵ reported that $\approx 50\%$ of low-risk treadmill score patients had no or single-vessel coronary disease, whereas 75% of high-risk patients had multivessel disease in a series of 834 patients undergoing myocardial perfusion imaging.

Using Pretest Risk Estimates to Maximize Posttest Predictions

The exercise treadmill test is used for the identification of patients who are at increased risk of significant or severe disease and future coronary events.^{14,15} Within the growth of managed care and capitated reimbursement schemes, management strategies that emphasize expensive stress imaging studies and cardiac catheterization are not likely to be favored in many practice environments. Although the treadmill test should not be considered to replace any imaging modality, if the efficient use of low-cost clinical data and risk stratification with a low-cost stress test are emphasized, evaluation costs may be reduced for many patients. Noninvasive testing has the potential to improve the efficiency of resource use by excluding patients at low risk from further intervention who have minimal disease and few cardiac events. Low-risk patients (36% of the population) have an excellent prognosis and may be risk-stratified by the treadmill test. This patient cohort may be managed safely with watchful waiting as well as symptomatic medical therapy without further testing. High-risk patients should be considered candidates for

more aggressive management that may include cardiac catheterization. Of the remaining moderate-risk patients, use of an imaging modality has been proposed to further risk-stratify these patients.^{14,15} Thus, only $\approx 50\%$ of our study population would require a stress imaging study before patient management is decided on. This provides a method for selective use of more expensive imaging or invasive testing.

Study Limitations

Although the study included only select patients who underwent diagnostic cardiac catheterization, several previous reports have validated use of the DTS in noncatheterized patient series and found similar results.^{1,14,15} Biases also may have been created by early and later referral to revascularization among members of the study population. These referral biases would not affect the diagnostic assessment and would probably make it more difficult to demonstrate a prognostic value of the DTS.

Conclusions

The DTS is useful for risk-stratifying important diagnostic and prognostic patient subsets. The majority of low-risk patients had no coronary disease or single-vessel coronary disease, whereas high-risk treadmill score patients had more extensive or multivessel coronary disease. Although constructed to predict prognosis, the DTS is also able to differentiate relevant coronary artery subsets, both alone and in conjunction with clinical data. Our study provides a linkage between the DTS and commonly used coronary anatomic risk groups.

Appendix 1

Appendix 1 is given in Table 5.

Appendix 2

Appendix 2 is given in Table 6.

Acknowledgment

This study was supported by research grant HS-06503 from the Agency for Health Care Policy and Research, Rockville, Md.

References

1. Mark DB, Shaw L, Harrell FE Jr, Hlatky MA, Lee KL, Bengston JR, McCants CB, Califf RM, Pryor DB. Prognostic value of a treadmill exercise score in outpatients with suspected coronary artery disease. *N Engl J Med.* 1991;325:849–853.
2. Mark DB, Hlatky MA, Harrell FE Jr, Lee KL, Califf RM, Pryor DB. Exercise treadmill score for predicting prognosis in coronary artery disease. *Ann Intern Med.* 1987;106:793–800.
3. Mark DB, Hlatky MA, Lee KL, Harrell FE Jr, Califf RM, Pryor DB. Localizing coronary artery obstructions with the exercise treadmill test. *Ann Intern Med.* 1987;106:53–55.
4. Hlatky MA, Pryor DB, Harrell FE Jr, Califf RM, Mark DB, Rosati RA. Factors affecting sensitivity and specificity of exercise electrocardiography. *Am J Med.* 1984;77:64–71.
5. Morrow K, Morris CK, Froelicher VF, Hideq A, Hunter D, Johnson E, Kawaguchi T, Lehmann K, Ribisl PM, Thomas R. Prediction of cardiovascular death in men undergoing noninvasive evaluation for coronary artery disease. *Ann Intern Med.* 1993;118:689–695.
6. Simonetti I, Rezaei K, Rossen JD, Winniford MD, Talman CL, Hollenberg M, Kirchner PT, Marcus ML. Physiological assessment of sensitivity of noninvasive testing for coronary artery disease. *Circulation.* 1991; 83(suppl III):III-43–III-49.
7. Detrano R, Janosi A, Steinbrunn W, Pfisterer M, Schmid J-J, Meyer M, Guppy KH, Abi-Mansour P. Algorithm to predict triple-vessel/left main

- coronary artery disease in patients without myocardial infarction. *Circulation*. 1991;83(suppl III):III-89-III-96.
8. Chaitman BR. The changing role of the exercise electrocardiogram as a diagnostic and prognostic test for chronic ischemic heart disease. *J Am Coll Cardiol*. 1986;8:1195-1210.
 9. Weiner DA, Ryan TJ, Parsons L, Fisher LD, Chaitman BR, Sheffield LT, Tristani FE. Long-term prognostic value of exercise testing in men and women from the Coronary Artery Surgery Study (CASS). *Am J Cardiol*. 1995;75:865-870.
 10. Okin PM, Kligfield P. Population selection and performance of the exercise ECG for the identification of coronary artery disease. *Am Heart J*. 1994;127:296-304.
 11. Pryor DB, Shaw L, McCants CB, Lee KL, Mark DB, Harrell FE Jr, Muhlbaier LH, Califf RM. Value of the history and physical in identifying patients at increased risk for coronary artery disease. *Ann Intern Med*. 1993;118:81-90.
 12. Pryor DB, Shaw L, Harrell FE, Lee KL, Hlatky MA, Mark DB, Muhlbaier LH, Califf RM. Estimating the likelihood of severe coronary artery disease. *Am J Med*. 1991;90:553-562.
 13. Pryor DB, Harrell FE Jr, Lee KL, Califf RM, Rosati RA. Estimating the likelihood of significant coronary artery disease. *Am J Med*. 1983;75:771-780.
 14. Hachamovitch R, Berman DS, Kiat H, Cohen I, Cabico JA, Friedman J, Diamond GA. Exercise myocardial perfusion SPECT in patients without known coronary artery disease: incremental prognostic value and use in risk stratification. *Circulation*. 1996;93:905-914.
 15. Iskandrian AS, Ghods M, Helfeld H, Iskandrian B, Cave V, Heo J. The treadmill exercise score revisited: coronary arteriographic and thallium perfusion correlates. *Am Heart J*. 1992;124:1581-1586.
 16. Jaeschke R, Guyatt GH, Sackett DL, for the Evidence-Based Medicine Working Group. Users' guides to the medical literature. *JAMA*. 1994;271:703-708.
 17. Silver MT, Rose GA, Paul SD, O'Donnell CJ, O'Gara PT, Eagle KA. A clinical rule to predict preserved left ventricular ejection fraction in patients after myocardial infarction. *Ann Intern Med*. 1994;121:750-756.
 18. Fuchs RM, Achuff SC, Grunwald L, Yin FCP, Griffith LSC. Electrocardiographic localization of coronary artery narrowings: studies during myocardial ischemia and infarction in patients with one-vessel disease. *Circulation*. 1982;66:1168-1176.
 19. Abouantoun S, Ahnve S, Savvides M, Witztum K, Jensen D, Froelicher V. Can areas of myocardial ischemia be localized by the exercise electrocardiogram? A correlative study with thallium-201 scintigraphy. *Am Heart J*. 1984;108:933-941.
 20. Tubau JF, Chaitman BR, Bourassa MG, Lesperance J, Dupras G. Importance of coronary collateral circulation in interpreting exercise test results. *Am J Cardiol*. 1981;47:27-32.
 21. Lim R, Kreidish I, Dyke L, Thomas J, Dymond DS. Exercise testing without interruption of medication for refining the selection of mildly symptomatic patients for prognostic coronary angiography. *Br Heart J*. 1994;71:334-340.
 22. Morise AP, Bobbio M, Detrano R, Duval RD. Incremental evaluation of exercise capacity as an independent predictor of coronary artery disease presence and extent. *Am Heart J*. 1994;127:32-38.
 23. Bobbio M, Detrano R, Schmid J-J, Janosi A, Righetti A, Pfisterer M, Steinbrunn W, Guppy KH, Abi-Mansour P, Deckers JW. Exercise-induced ST depression, and ST-heart rate index to predict triple-vessel or left main coronary disease: a multicenter analysis. *J Am Coll Cardiol*. 1992;19:11-18.
 24. Ribisl PM, Morris CK, Kawaguchi T, Ueshima K, Froelicher VF. Angiographic patterns and severe coronary artery disease. *Arch Intern Med*. 1992;152:1618-1624.