Prognostic Value of Treadmill Exercise Testing in Elderly Persons

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Background: Recent exercise testing guidelines recognized a gap in knowledge about the prognostic value of treadmill exercise testing in elderly persons.

Objective: To test the hypothesis that treadmill exercise testing has equal prognostic value among elderly (≥65 years of age) and younger (<65 years of age) persons and to examine the incremental value of this testing over clinical data.

Design: Inception cohort with a median follow-up of 6 years.

Setting: Olmsted County, Minnesota.

Patients: All elderly (n = 514) and younger (n = 2593) residents of Olmsted County who underwent treadmill exercise testing between 1987 and 1989.

Measurements: Overall mortality and cardiac events (cardiac death, nonfatal myocardial infarction, and congestive heart failure).

Results: Compared with younger patients, elderly patients had more comorbid conditions, achieved a lower workload (6.0 and 10.7 metabolic equivalents; $P < 0.001$), and had a greater likelihood of a positive exercise electrocardiogram (28% and 9%; $P < 0.001$). With median follow-up of 6 years, overall survival (63% and 92%; $P < 0.001$) and cardiac event–free survival (66% and 95%; $P < 0.001$) were worse among elderly persons than among younger persons. Workload was the only treadmill exercise testing variable associated with all-cause mortality in both age groups, and the strength of association was similar. Workload and angina with exercise testing were associated with cardiac events in both age groups, whereas a positive exercise electrocardiogram was associated with cardiac events only in younger persons ($P < 0.05$ for all comparisons). After adjustment for clinical variables, workload was the only additional treadmill exercise testing variable that was predictive of death ($P < 0.001$) and cardiac events ($P < 0.05$); the strength of the association was similar in both age groups. Each 1–metabolic equivalent increase in exercise capacity was associated with a 14% and 18% reduction in cardiac events among younger and elderly persons, respectively.

Conclusions: In elderly persons, treadmill exercise testing provided prognostic information that is incremental to clinical data. After adjustment for clinical factors, workload was the only treadmill exercise testing variable that was strongly associated with outcome, and its prognostic effect was of the same magnitude in elderly and younger persons.

Ann Intern Med. 2000;132:862-870.

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Over the past three decades, vital statistics data have shown a great decrease in age-adjusted mortality due to heart disease (1). However, this decrease reflects a shift in the disease burden toward the older segments of the population, and heart disease remains the leading cause of death in the United States (2–4). Treadmill exercise testing is widely used to evaluate coronary artery disease. More than 800 000 treadmill exercise tests are performed in the U.S. Medicare population each year (5), of which one third are conducted by noncardiologists. Despite widespread use of treadmill exercise testing in elderly persons, the prognostic value of such testing in these persons has not been fully characterized (5).

Few elderly patients were included in studies that produced and validated some of the most widely used prognostic scores calculated from treadmill exercise testing data (6, 7). The studies that included elderly patients were relatively small and did not use multivariate analysis to identify prognostic variables from treadmill exercise testing data (8, 9). A greater prevalence and severity of coronary disease and the presence of more comorbid conditions may alter the ability of treadmill exercise testing to predict outcome in elderly persons (10). In addition, increasingly sedentary lifestyle with aging and differences in exercise physiology may contribute to different interpretations of treadmill exercise testing results in elderly persons (11, 12).

Furthermore, studies of the prognostic value of treadmill exercise testing have been conducted in selected populations (13, 14). Some studies consisted of symptomatic patients from referral centers who had undergone angiography (6, 13, 15–18); others included healthy persons recruited from preventive medicine clinics or cohorts of healthy volunteers (19–26). Several studies did not evaluate the incremental value of treadmill exercise testing over clinical data (8, 9, 14, 27) or were not consistent in identifying prognostic variables (5, 26). These differences may be related to different study populations. Thus, it is uncertain whether results of previous studies can be generalized to a community-dwelling population of elderly patients.

This gap in knowledge, which was recognized in recent exercise testing guidelines (5), calls for data obtained in more representative samples of the population. We sought to examine the outcome of treadmill exercise testing in a geographically defined population, to characterize the treadmill exercise testing variables associated with outcome, and to test the hypothesis that the prognostic value of exercise treadmill testing is similar in elderly and younger persons.

Methods

Setting

The population of Olmsted County, Minnesota, is served by a largely unified medical care system that has accumulated comprehensive clinical records over an extended period. In 1990, the population was 96% white; except for the fact that a higher proportion of the working population is employed in the health care industry, the characteristics of the population of Olmsted County are similar to those of white persons in the United States as a whole (27).

Epidemiologic research in Olmsted County is possible because the Mayo Clinic and the Olmsted Medical Group deliver almost all medical care to local residents. The epidemiologic potential of this situation has been described elsewhere (27, 28). Each provider uses a unit record system that contains the details of every patient encounter.

The Rochester Epidemiology Project developed an extensive indexing system that links medical records from essentially all sources of medical care used by the Olmsted County population, including nursing home placement (29). In our study, data on nursing home placement were collected for elderly persons only; follow-up for this outcome was 96% complete.

Study Sample

The Rochester Epidemiology Project indices, augmented by the log books of the laboratories that perform treadmill exercise testing, were used to identify a retrospective, population-based cohort of Olmsted County residents who underwent treadmill exercise testing between 1 January 1987 and 31 December 1989. Trained nurse abstracters reviewed the medical records of potential cases.

Residency in Olmsted County was verified by using information from the medical record and city and county directories. The analysis included all persons who underwent an initial treadmill exercise test. Persons with previous treadmill exercise tests were excluded. The medical records and reports of treadmill exercise tests were reviewed to collect data on demographic characteristics, symptoms, cardiovascular risk factors, comorbid conditions, and results of exercise testing. Individually recorded comorbid conditions were combined into the Charlson Comorbidity Index score (30), a prospectively validated, weighted index that takes into account the number and seriousness of comorbid diseases. Details on testing of the reliability of data collection have been published (28). Briefly, data collection was evaluated in a random sample of 20 cases. The κ coefficient, which measures agreement beyond that expected by chance alone, was used to evaluate interobserver and intraobserver variability. The variables included comorbid conditions, symptoms, test results, occurrence of myocardial infarction, congestive heart failure, and cause of death.

Exercise Testing

Persons were referred for treadmill exercise testing at the discretion of their individual physicians. The indications for treadmill exercise testing were classified as follows.

1. Evaluation of documented coronary artery disease. Documented coronary artery disease was defined by a history of myocardial infarction, presence of significant coronary disease at angiography before treadmill exercise testing, or previous revascularization procedure (coronary artery bypass grafting or coronary angioplasty).
2. Diagnostic. In this case, the patient had symptoms (dyspnea or chest pain) but no documented coronary disease.
3. Other. In the absence of cardiac symptoms or documented coronary disease, treadmill exercise testing was done for such purposes as risk stratification before noncardiac surgery or evaluation of sedentary persons before starting an exercise program.

All exercise tests were performed by using standard protocols (Bruce, modified Bruce, or Naughton). The decision to interrupt therapy with medications before treadmill exercise testing was at the discretion of the attending physician. Throughout the test, symptoms, heart rate, and blood pressure were recorded. Workload was expressed in metabolic equivalents (METs). The value for METs was estimated from standard tables on the basis of protocol and duration of exercise (31). Predicted maximal functional aerobic capacity was calculated from published equations that included adjustment for age and sex (32). Persons studied were stratified into three groups defined a priori on the basis of percentage of functional aerobic capacity achieved on treadmill exercise testing: near-normal (≥85% functional aerobic capacity), intermediate (50% to 84% functional aerobic capacity), and severely abnormal (<50% functional aerobic capacity) exercise capacity (33).

A positive exercise electrocardiogram was defined by using conventional criteria (≥1 mm of hor-

Table 1. Baseline Characteristics*

Characteristic	Persons <65 Years of Age (n = 2593)	Persons ≥65 Years of Age (n = 514)	*P* Value
Mean age ± SD, *y*	44 ± 11	72 ± 6	<0.001
Men, %	68	52	0.001
No chest pain, %	60	45	0.001
Chest pain, %	40	55	
Typical	5	23	0.001
Atypical	17	20	
Indeterminate	18	12	
NYHA class III or IV congestive heart failure (vs. class I or II)	0.7	3.5	0.001
Risk factor, %			
Current smoking	19	10	0.001
Diabetes mellitus	3	10	0.001
Hypertension	19	43	0.001
Cholesterol level ≥ 6.22 mmol/L (≥240 mg/dL)	48	54	0.018
Family history of coronary artery disease	40	38	>0.2
Other clinical factors, %			
Overweight†	41	34	0.007
History of myocardial infarction	3	22	0.001
History of congestive heart failure	0.4	7.6	0.001
History of CABG or PTCA	3	16	0.001
Mean Charlson Comorbidity Index score ± SD	0.3 ± 0.9	1.4 ± 1.7	<0.001
Antianginal medications, *n*	15	51	0.001

* CABG = coronary artery bypass grafting; NYHA = New York Heart Association; PTCA = percutaneous transluminal coronary angioplasty.
† Body mass index ≥ 27.3 kg/m^2 for women and ≥ 27.8 kg/m^2 for men.

izontal or down-sloping ST-segment depression or elevation for at least 60 to 80 ms after the end of the QRS complex) (5).

Ascertainment of End Points

The end points of interest, ascertained from the medical records, were death and cardiac events, defined as cardiac death, nonfatal myocardial infarction, or congestive heart failure. Follow-up for death was 100%. Medical records were available for ascertainment of cardiac events and nursing home placement for all patients. Deaths were classified as cardiac, cancer, or other by using the State of Minnesota death certificate files, to which the records of all Olmsted County residents are linked. For myocardial infarction, a clinical definition was used that incorporated the occurrence of chest pain typical for an ischemic origin and characteristic changes in the electrocardiogram or cardiac enzyme levels (or both). For congestive heart failure, a clinician's diagnosis was used.

Statistical Analysis

Comparisons between younger and elderly persons were made for several characteristics. Bivariate associations between the two age groups were tested by using chi-square tests for categorical data and *t*-tests for continuous variables.

The Kaplan–Meier method was used to generate survival curves for two end points: overall mortality and cardiac event (including cardiac death, nonfatal myocardial infarction, and congestive heart failure) for each of the three exercise capacity categories. The log-rank test was used to examine differences in both end points among exercise capacity categories within the younger and elderly groups. Log-rank statistics were used to compare the survival observed in each age group, and exercise capacity category was compared with the expected survival in the age- and sex-matched population of Minnesota in 1990. Cox proportional hazard models were constructed to determine the association of predictor variables with all-cause mortality and cardiac events; variables included were age, sex, presence of symptoms, history of myocardial infarction, history of congestive heart failure, coronary disease risk factors (history of hypertension, diabetes mellitus, smoking, hyperlipidemia, familial coronary disease), obesity (body mass index > 27.3 kg/m^2 for women and >27.8 kg/m^2 for men), Charlson Comorbidity Index score, angina with treadmill exercise testing, positive exercise electrocardiogram, and workload achieved on treadmill exercise testing (expressed in METs). The incremental prognostic value of each of the three treadmill exercise testing variables over the clinical data was assessed separately. Separate models were constructed for younger persons and elderly persons.

Results

During the study period, 3107 initial treadmill exercise tests were performed in 2593 persons younger than 65 years of age (mean age, 44 years) and 514 persons 65 years of age or older (mean age, 72 years) residing in Olmsted County. Sixty-eight percent of younger persons and 52% of elderly persons were male (P = 0.001) (**Table 1**).

Table 2. Indications and Test Results

Variable	Persons <65 Years of Age (*n* = 2593)	Persons ≥65 Years of Age (*n* = 514)	*P* Value
Indication for exercise testing, %			
Diagnostic	43	52	0.001*
Evaluation of documented coronary artery disease	3	20	
Other	54	28	
Result of exercise testing			
Workload, *metabolic equivalents*†	10.7 ± 3.3	6.0 ± 2.5	<0.001
Peak heart rate, *beats/min*†	166 ± 25	130 ± 24	<0.001
Exercise systolic blood pressure, *mm Hg*†	178 ± 26	173 ± 30	<0.001
Peak rate pressure product†	29 545 ± 6332	22 625 ± 6278	<0.001
Positive exercise test result, %	9	28	0.001

* For difference in the distribution of types of indications for treadmill exercise testing between the two age groups.
† Expressed as the mean ± SD.

Baseline Characteristics

Compared with younger persons, elderly persons were more likely to be symptomatic and taking anti-anginal medications. They were also more likely to have hypertension, diabetes, hyperlipidemia, and a history of myocardial infarction or revascularization (**Table 1**). Older persons had a higher Charlson Comorbidity Index score, were more likely to have a history of heart failure, and were less likely to be overweight or actively smoking.

Indications and Results of the Stress Test

More older persons than younger persons (20% and 3%; $P = 0.001$) underwent treadmill exercise testing for evaluation of documented coronary disease (**Table 2**). Most of the persons (89%) exercised according to the Bruce protocol. Elderly persons were more likely than younger persons to undergo Naughton and modified Bruce protocols (35% compared with 6.5%; $P < 0.001$). Younger persons exercised to a higher workload (**Figure 1**). Treadmill exercise tests were more likely to be positive in elderly persons (28% and 9%; $P = 0.001$) (**Table 2**).

Outcome

Mean follow-up was 6.3 ± 2.0 years. Heart disease and cancer accounted for 66% of deaths observed in elderly persons and 63% of deaths observed in younger persons (**Table 3**).

Among younger persons, 86 deaths and 109 cardiac events (16 cardiac deaths, 68 nonfatal myocardial infarctions, and 25 cases of congestive heart failure) occurred during 28 172 person-years of observation. Among elderly persons, 138 deaths and 141 cardiac events (35 cardiac deaths, 59 nonfatal myocardial infarctions, and 47 cases of congestive heart failure) occurred during 3918 person-years of follow-up (**Table 3**).

All-Cause Death

With a median follow-up of 6 years, survival was worse among elderly persons than younger persons (63% and 92%; $P < 0.001$). On the basis of the percentage of predicted functional aerobic capacity achieved on treadmill exercise testing, patients were stratified into those with near-normal (>85% functional aerobic capacity), intermediate (50% to 84% functional aerobic capacity), or severely abnormal (<50% functional aerobic capacity) exercise capacity. Eight percent of younger persons and 22% of elderly persons had severely abnormal exercise capacity, 23% percent of younger persons and 35% of elderly persons had intermediate exercise capacity, and 69% of younger persons and 43% of elderly persons had near-normal exercise capacity. Patients with severely abnormal exercise capacity had the worst overall survival, whereas those with intermediate or near-normal exercise capacity had progressively better overall survival (both $P < 0.001$) (**Figure 2**). Younger persons with near-normal exercise capacity had an observed overall survival that was better than that expected of an age- and sex-matched population ($P < 0.001$). Persons with an intermediate exercise capacity had survival similar to that expected in an age- and sex-matched population ($P > 0.2$), but persons with severely abnormal exercise capacity had significantly worse survival than expected ($P < 0.001$). In contrast, among elderly persons, intermediate ($P = 0.038$) or near-

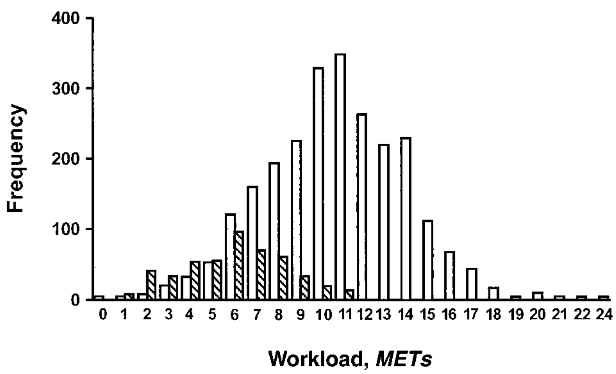

Figure 1. Frequency distribution of workload achieved by age group. White bars represent patients younger than 65 years of age; striped bars represent patients 65 years of age or older. MET = metabolic equivalent.

Table 3. Distribution of Events by Age Group

Variable	Persons <65 Years of Age (*n* = 2593)	Persons ≥65 Years of Age (*n* = 514)	*P* Value*
Deaths, *n*	86	138	0.032
Cardiac, *n* (%)†	20 (23)	54 (39)	
Cancer, *n* (%)†	34 (40)	37 (27)	
Other cause, *n* (%)†	32 (37)	47 (34)	
Cardiac events, *n*	109	141	0.005
Nonfatal myocardial infarction, *n* (%)†	68 (62)	59 (42)	
Congestive heart failure, *n* (%)†	25 (23)	47 (33)	
Cardiac death, *n* (%)†	16 (15)	35 (25)	

* For the difference in the distribution of types of events among patients who experienced events.
† Percentage of all events attributable to a given category.

mal ($P <$ 0.001) exercise capacity was associated with better-than-expected overall survival. Survival among elderly persons with severely abnormal exercise capacity was worse than expected but did not reach statistical significance ($P = 0.066$).

Several clinical variables were univariately associated with overall mortality in both age groups, including risk factors, Charlson Comorbidity Index score, age, and previous myocardial infarction ($P <$ 0.05 for all comparisons). Of the treadmill exercise testing variables, achieved workload had a strong univariate association with time to death in both age groups ($P < 0.001$). Neither changes on exercise electrocardiography nor angina with exercise was associated with mortality in either group.

After adjustment, a significant association remained between workload achieved and time to death (**Table 4**). The strength of this association was unchanged after adjustment for a residual effect of age. The workload achieved on exercise testing was inversely associated with risk for death. An increase of 1 MET in workload was associated with a 20% risk reduction in younger persons and an 18% risk reduction in elderly persons. The results were unchanged when the analyses were repeated after exclusion of persons with a history of congestive heart failure.

Cardiac Events

With a median follow-up of 6 years, cardiac event–free survival was worse among elderly persons than younger persons (95% and 66%; $P < 0.001$). Stratification into exercise capacity categories was predictive of cardiac events in both age groups (**Figure 2**). The worst event-free survival was noted among persons with severely abnormal exercise capacity; progressively better event-free survival was seen among both elderly and younger persons who had intermediate and near-normal exercise capacity ($P < 0.001$ for both) (**Figure 2**).

Several variables were univariately associated with clinical events in both age groups: risk factors, age, symptoms, Charlson Comorbidity Index score, and previous myocardial infarction ($P < 0.001$ for all). All three treadmill exercise testing variables were univariately associated with risk for cardiac events in younger patients ($P < 0.001$). Only angina with exercise ($P = 0.049$) and workload achieved ($P < 0.001$) were associated with risk for cardiac

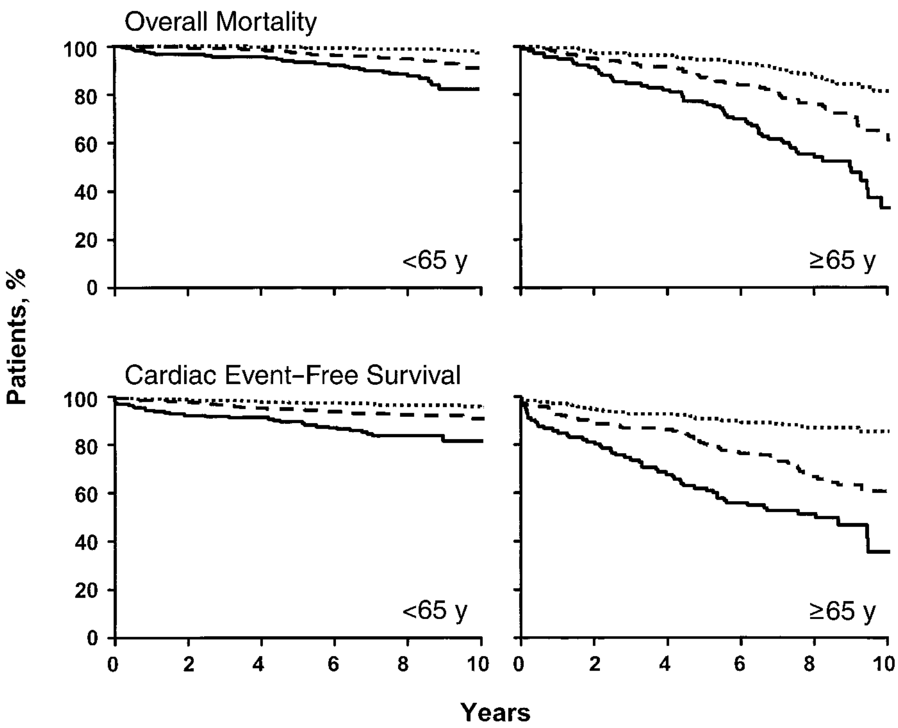

Figure 2. Kaplan–Meier survival curves for overall mortality and cardiac event–free survival among study patients, stratified by functional aerobic capacity. Patients were stratified into three exercise capacity categories: ≥85% functional aerobic capacity (*dotted line*), 50% to 84% functional aerobic capacity (*dashed line*), and <50% functional aerobic capacity (*solid line*). **Top.** Survival curves for overall mortality among persons younger than 65 years of age (*top left*) and those 65 years of age or older (*top right*). The log-rank test detected significant differences among the three functional aerobic capacity categories for both age groups ($P < 0.001$). **Bottom.** Curves for cardiac event–free survival among persons younger than 65 years of age (*bottom left*) and those 65 years of age or older (*bottom right*). The log-rank test detected significant differences among the three functional aerobic capacity categories for both age groups ($P < 0.001$).

Table 4. Multivariate Predictors of Time to Overall Death

Predictor	Relative Risk in Persons <65 Years of Age (95% CI)	Relative Risk in Persons ≥65 Years of Age (95% CI)
Male sex	1.85 (1.13–3.05)	1.46 (1.02–2.10)
Age	1.01 (0.99–1.04)	1.08 (1.05–1.11)
Overweight	1.14 (0.68–1.90)	0.73 (0.48–1.10)
Charlson Comorbidity Index score	3.26 (1.67–6.38)	3.11 (1.78–5.44)
Previous myocardial infarction	1.18 (0.61–2.28)	0.94 (0.63–1.40)
Previous congestive heart failure	1.37 (0.52–3.62)	1.21 (0.73–2.02)
Symptoms*	0.83 (0.52–1.33)	1.05 (0.59–1.85)
Risk factors†	1.15 (0.93–1.43)	1.20 (1.03–1.41)
Angina with exercise testing	0.77 (0.28–2.07)	0.94 (0.52–1.69)
Positive electrocardiogram	0.94 (0.46–1.90)	1.23 (0.73–2.01)
Workload achieved‡	0.80 (0.73–0.87)	0.82 (0.75–0.90)

* Absence of symptoms is the reference level.
† Number of risk factors, with absence of risk factors as the reference level.
‡ As measured in metabolic equivalents.

events in elderly persons. Coronary disease risk factors, Charlson Comorbidity Index score, symptoms, previous myocardial infarction, and age were potential confounders of the association between workload and cardiac events. After adjustment, a higher workload achieved on exercise testing remained associated with a lower likelihood of cardiac events in both age groups (**Table 5**). Neither a positive exercise electrocardiogram nor exercise-induced angina was independently related to time to cardiac event after workload was taken into account. The results were unchanged when the analyses were repeated with cardiac event defined as cardiac death or nonfatal myocardial infarction or when persons with a history of congestive heart failure were excluded.

Among younger patients, an increase of 1 MET in the workload was associated with a 14% decrease in risk for a cardiac event. Among elderly persons, the point estimate for the risk reduction indicated a slightly greater effect of workload: An increase of 1 MET in the workload was associated with an 18% risk reduction (**Table 5**).

Reliability of Evaluation

Analysis of interobserver variability revealed excellent agreement ($\kappa > 0.7$) for all but 4 of the 23 test variables (obstructive lung disease, type of chest pain, hyperlipidemia, and familial coronary disease). These 4 variables were reabstracted.

Nursing Home Placement

Nursing home placement was analyzed as a separate end point for elderly persons only. Eighty-four (17%) elderly persons were admitted to a nursing home during a median follow-up of 6 years. Age and workload were univariate predictors of nursing home placement. The risk ratio for each year of increase in age was 1.04 (95% CI, 1.00 to 1.08), and the risk ratio for a 1-MET increase in exercise capacity was 0.88 (CI, 0.79 to 0.97). On multivariate analysis, workload achieved on treadmill exercise testing was the only variable associated with nursing home placement, and the direction of this association suggested a 12% lower likelihood of nursing home placement for each 1-MET increase in exercise capacity.

Discussion

In a geographically defined population, treadmill exercise testing provided prognostic information incremental to clinical data in persons younger than 65 years of age and those 65 years of age or older. After adjustment for clinical factors, workload achieved was the only treadmill exercise testing variable that provided incremental prognostic information for mortality and cardiac events, and it predicted 20% and 18% reductions in overall deaths among younger persons and elderly persons, respectively. In elderly persons, exercise capacity on treadmill exercise testing was also inversely associated with the likelihood of nursing home placement.

Treadmill Exercise Testing Variables and Outcome in Elderly Patients

Several studies have examined the association between treadmill exercise testing variables and outcome (6, 7, 14, 34). However, many of the earlier reports did not use multivariate analysis to assess the incremental predictive power of clinical and treadmill exercise testing variables (14, 34). In addition, few or no elderly persons were included in these studies. The Seattle Heart Watch study provided important data on the prognostic value of treadmill exercise testing in healthy volunteers and emphasized the importance of exercise capacity (19, 25). However, that study included mostly young persons; fewer than 1% of the persons were 65 years of age or older. Moreover, these data were subject to

Table 5. Multivariate Predictors of Time to Cardiac Event

Predictor	Relative Risk in Persons <65 Years of Age (95% CI)	Relative Risk in Persons ≥65 Years of Age (95% CI)
Male sex	2.11 (1.30–3.42)	1.51 (1.05–2.18)
Age	1.03 (1.01–1.06)	1.05 (1.02–1.08)
Overweight	0.84 (0.53–1.35)	1.10 (0.73–1.65)
Charlson Comorbidity Index score	2.45 (1.32–4.54)	2.15 (1.22–3.76)
Previous myocardial infarction	1.63 (0.89–2.98)	1.13 (0.75–1.71)
Previous congestive heart failure	0.29 (0.07–1.28)	1.00 (0.58–1.73)
Symptoms*	1.28 (0.81–2.01)	1.18 (0.64–2.13)
Risk factors†	1.53 (1.26–1.89)	1.18 (1.00–1.39)
Angina with exercise testing	1.59 (0.80–3.18)	1.14 (0.65–1.99)
Positive electrocardiogram	0.85 (0.46–1.57)	1.36 (0.82–2.26)
Workload achieved‡	0.86 (0.79–0.94)	0.82 (0.75–0.90)

* Absence of symptoms is the reference level.
† Number of risk factors, with absence of risk factors as the reference level.
‡ As measured in metabolic equivalents.

the "healthy participant effect" (24). The Baltimore Longitudinal Study on Aging included healthy volunteers 40 to 96 years of age (mean age, 60 years) (20). Exercise duration and a concordant positive electrocardiogram and thallium test result identified a high-risk group. Although this study included older patients, inclusion of asymptomatic volunteers who were not seeking health care compromised its external validity (24). In addition to studying only healthy volunteers, neither of these investigations captured the experience of an entire community by including all persons who underwent exercise testing for evaluation of coronary disease.

A widely used treadmill exercise testing prognostic score was reported in landmark studies from Duke University (6, 7). On the basis of treadmill exercise testing data alone, this prognostic score was developed in a referral population that was younger (mean age, 49 years) than our community-based cohort of elderly persons (mean age, 72 years). As such, the applicability of the treadmill exercise testing score to elderly persons is unknown. Furthermore, it does not incorporate cardiac risk factors and comorbid conditions, predictors of outcome in our study that we took into account in hierarchical multivariate modeling. This analytical method, which parallels the clinical approach, is needed to assess the incremental prognostic value of each treadmill exercise test variable separately over clinical data. Indeed, when this approach was used, although exercise capacity was a powerful predictor of outcome, no independent prognostic value for exercise electrocardiography and angina on treadmill exercise testing was observed after clinical characteristics were taken into account.

Morrow and colleagues (35) reported a score that was developed after inclusion of several clinical and treadmill exercise testing variables in the multivariate model. They identified one clinical variable (congestive heart failure or digoxin use) and three treadmill exercise testing variables (ST-segment depression, change in systolic blood pressure, and METs achieved) as predictive of outcome at a mean follow-up of 2.7 years. However, this analysis was performed in a cohort of younger (mean age, 59 years) male veterans referred to a Veterans Affairs hospital. Patients with previous coronary bypass grafting and those who underwent coronary angiography within 3 months of the treadmill exercise testing were excluded. In addition, this score has not been validated in another study. Thus, its applicability to an unselected cohort of community-based elderly persons is unknown.

Weiner and colleagues' analysis of the Coronary Artery Surgery Study registry (16) revealed that treadmill exercise testing provided additive prognostic information, even when catheterization and clinical data were available. Their model consisted of two treadmill exercise testing variables: exercise duration and ST-segment depression. Whereas exercise capacity was predictive of outcome for both sexes, ST-segment depression was prognostic in men only. Only 16% of the patients in this cohort were older than 60 years of age, and an age-specific analysis was not reported. Our report confirms the strong and equal independent prognostic value of exercise capacity in all age groups.

Physical Activity and Outcome in the Elderly

Overall Effect

Level of physical activity was inversely associated with coronary disease and all-cause mortality in several case–control and cohort studies (26, 36–39). The risk for coronary disease associated with inactivity has been estimated to be of the same magnitude as that associated with hypertension, hypercholesteremia, and smoking (40). However, most of these studies did not include patients older than 65 years of age. Many studies included select groups of patients who were healthy middle-aged workers or cohorts of university alumni (22, 23, 38, 39). It may not be appropriate to apply their findings to a community-based elderly population undergoing treadmill exercise testing for diagnosis or evaluation of coronary disease.

Effect in Elderly Patients

Reports from the Honolulu Heart Program demonstrated that walking is associated with a decrease in all-cause mortality in elderly nonsmoking men of Japanese ancestry (37). Recent reports from the same group extended these observations by demonstrating an inverse relation between physical activity and incident coronary artery disease (36). A similar relation between all-cause mortality and physical activity in a group of older postmenopausal women was also reported (41). Unlike studies in younger patients (21–23), few of the prognostic studies of elderly patients included an objective measure of physical fitness, such as a stress test (8, 9). In one such study, Glover and colleagues (9) reported outcomes in a series of 104 older persons (>65 years of age) who underwent exercise stress testing between 1979 and 1983. At a mean follow-up of 24 months, 8 of 47 patients with a positive test result but only 1 of 57 patients with a negative result had died of cardiovascular causes. Although differences in overall mortality rates were present, they were not statistically significant. Our study confirms a strong and similar prognostic value of exercise capacity in patients of all ages.

Whereas exercise training has been shown to reduce mortality in randomized trials of patients who have had myocardial infarction, similar data are not available for lower-risk populations such as ours (42). Even in the absence of such evidence, it seems prudent to encourage exercise according to the published American Heart Association guidelines (43) in younger as well as older persons.

In recent years, institutionalization in nursing homes has been increasingly recognized as an important outcome in elderly persons (44–46). Previous studies demonstrated an association between a short battery of physical tests and short-term mortality and nursing home admissions (44). Other studies have related walking speed and stride length with 36-month mortality, institutionalization, and mortality in community-living elderly persons (46). Our finding of an association between performance on treadmill exercise testing and subsequent risk for nursing home placement in elderly persons complements the findings of previous studies and strengthens the relation between exercise capacity and subsequent risk for disability.

Limitations

Previous studies of exercise testing had limited external validity. Recruitment of volunteers exposes the cohort to the "healthy volunteer effect," yielding results that are difficult to extrapolate to the general population (24). On the other hand, cohorts of inpatients are generally sicker than community-dwelling adults who undergo treadmill exercise testing. Although our study does not represent a random sample of the community, it reports on a comprehensive experience with a geographically defined population. It may therefore have enhanced external validity compared with some previous studies. It should be possible to generalize our findings to similar ambulatory populations with comparable ethnic composition and socioeconomic status. However, because the population of Olmsted County is overwhelmingly white, further study in ethnically diverse populations is needed.

Because treadmill exercise tests were stopped at the discretion of the supervising physician, some tests might have been stopped at a submaximal exercise level. In addition, elderly patients were more likely to have a nondiagnostic electrocardiogram on treadmill exercise testing because of greater prevalence of left ventricular hypertrophy, coronary artery disease, and use of digoxin. These factors could have confounded the associations between treadmill exercise testing variables and outcomes. In addition, some variation in the interpretation of chest pain symptoms probably occurred because of involvement of multiple examiners. Such variation is, however, unavoidable in an effectiveness study focusing on the comprehensive experience of a geographically defined population. A relatively large proportion of patients who underwent treadmill exercise testing were asymptomatic at that time. However, our data represent the comprehensive experience of the Olmsted County population during this period, and analysis of practice patterns as they relate to published guidelines was beyond the scope of our study (47).

We did not use a quantitative treadmill score because its value was not clearly established at the start of the study period, which was chosen to allow adequate duration of follow-up (7).

Conclusions

Our study shows a strong inverse association between exercise capacity and outcome in a geographically defined population of elderly persons referred for treadmill exercise testing. This association was based on objective measures and persisted after adjustment for clinical variables. An exploratory analysis revealed a similar prognostic value of exercise capacity for nursing home placement in elderly persons. Although overall survival was much worse in elderly persons than in younger persons, the predictive value of exercise capacity was present and of the same order of magnitude in both age groups.

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Acknowledgments: The authors thank Jeannie Hill and Susan Stotz for assistance with data collection, Jill Killian and Erin Green for assistance with statistical analysis, and Kristie Shorter for secretarial assistance.

Grant Support: In part by research grants from the American Heart Association National Center (93-1325 and 96-1358) and a grant from the Public Health Service, National Institutes of Health (AR30582).

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