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A Technical Note

Initial clinical evaluation of a wheelchair ergometer for diagnostic exercise testing: A technical note

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Abstract—The purpose of this initial study was to evaluate a new wheelchair ergometer (WCE) and exercise test protocol for the detection of coronary artery disease in men with lower limb disabilities. Forty-nine patients (63 ± 9 yr) completed WCE tests without complications. Peak heart rate was 84 ± 15% (mean ± SD) of age-predicted maximum and peak double product was $223 \pm 62 \times 10^2$. The specified target heart rate (≥ 80% age-predicted maximal) or a positive result was achieved in 76% of tests. Fourteen tests were rated positive, 21 as negative and 14 as nondiagnostic for exercise-induced ischemia. In 18 patients who underwent coronary angiography, the predictive value was 100% (10/10) for a positive, and 50% (2/4) for a negative WCE test result. These results suggest that WCE is a viable initial diagnostic option for some persons who cannot adequately perform treadmill or cycle ergometry exercise.

Key words: *coronary artery disease, exercise testing, exertion, upper body exercise, wheelchair ergometry.*

INTRODUCTION

Signs and/or symptoms of clinically significant coronary artery disease (CAD) may be absent in the resting state. Therefore, graded exercise tests are frequently used to induce diagnostic myocardial ischemia in cases of suspected CAD. Available evidence suggests that persons with a variety of lower limb disabilities possess a greater than average risk of CAD morbidity and mortality (1–5). However, the inability of these patients to complete exercise tests on a treadmill or cycle ergometer presents the clinician with a unique diagnostic problem.

Current clinical practice is to utilize pharmacologic modalities (e.g., dobutamine, adenosine) in combination with echocardiography or thallium scintigraphy for diagnosis of CAD in persons with lower limb disabilities. These procedures are more costly than standard treadmill or cycle exercise tests, require intravascular access, and are less convenient to perform. Diagnostic testing utilizing upper body exercise represents a possible alternative. Several studies have evaluated arm crank ergometry for this purpose (6–20), but, to the authors' knowledge, no comparable evaluations have been carried out utilizing wheelchair ergometry (WCE). Manual wheelchair propulsion is the primary mode of mobility for many persons with lower limb disabilities. Therefore, WCE offers a more familiar and task specific mode of exercise testing for these individuals. Moreover, it is anticipated that the Americans with Disabilities Act will provide impetus for the production of commercially available wheelchair ergometers suitable for diagnostic exercise testing.

The present investigation was the initial clinical evaluation of a new wheelchair ergometer and exercise test

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protocol for persons unable to adequately perform treadmill or cycle ergometry exercise.

METHODS

Subjects

The subjects for this research were 49 consecutive male patients 63 ± 9 years of age (range 42–81) who were referred to the authors' laboratory for diagnostic WCE graded exercise testing. Forty-five patients had lower limb disabilities, one patient was visually impaired and three subjects were nondisabled. Disabilities included peripheral vascular disease of the lower extremities (n = 17), lower limb amputation (n = 7), hemiplegia (n = 6), spinal cord injury (n = 5) and other musculoskeletal or neurological disorders (n = 11). Subjects were primarily inpatients referred for cardiovascular assessment before surgery, evaluation of signs or symptoms suggesting the presence of CAD, or appraisal of antianginal or antihypertensive therapy. At the time of testing, 10 patients were taking digitalis, 31 were taking antianginal agents, and 23 were taking various antihypertensive medications.

The research protocol was approved by the Human Studies Subcommittee of Hines VA Hospital and all subjects provided written informed consent to participate in this study.

Wheelchair Ergometer Exercise Tests

Each subject performed a continuous graded exercise test on a magnetic eddy current braked WCE called the Wheelchair Aerobic Fitness Trainer (21,22). In preparation for testing, patients transferred to a Quickie GP (Motion Design Corporation, Fresno, CA) wheelchair which was loaded onto the WCE. Wheelchair tire pressure was maintained at 60–65 pounds per square inch.

Subjects were required to maintain a wheel speed of 2 mi·h^{-1}, with increments in upper body work accomplished by increasing braking resistance. Power output requirements began at 6 watts (W) in the first stage and increased by 5 to 7 W per stage. Stages were 3 minutes in length. Guidelines for terminating exercise tests were those published by the American College of Sports Medicine (23).

With a Quinton 3000B Stress Test Monitor (Quinton Instrument Company, Seattle, WA), a 12-lead ECG was recorded at rest, each minute during exercise and for at least 5 minutes into recovery. Three ECG leads were continuously monitored throughout the test. Because it was not possible to assess blood pressure during upper body exercise by auscultation, measurements were taken during brief pauses between stages as follows: the blood pressure cuff was pressurized during the final 5 seconds of each stage, the subject was told to stop wheeling, and the blood pressure was taken immediately. As soon as the diastolic pressure was determined (~ 15–20 sec) the subject began the next stage.

Ratings of perceived exertion were obtained using Borg's 15-point (6–20) graded scale (23). Ratings were taken during the last 30 seconds of every stage and at peak exercise. Prior to testing, each subject was asked to look over the rating of perceived exertion scale. An investigator then read aloud the instructions for the determination of rating of perceived exertion while the subject followed on a second copy. Ratings of angina were also obtained during the last 30 seconds of each stage using a 5-point (0–4+) scale (23).

Oxygen uptake ($\dot{V}O_2$) was determined in 23 subjects by the open circuit method. A Rudolph mask or mouthpiece equipped with a non-rebreathing valve was utilized. Expired gases were analyzed with the MMC Horizon™ System (SensorMedics Corp., Yorba Linda, CA), that was calibrated before and after each test with reference gases and room air.

Interpretation of the Exercise ECG Data

Each WCE exercise test was graded by a cardiologist as positive for ischemia, negative for ischemia, or nondiagnostic. Criteria for a positive test included 1) ≥ 0.10 mV horizontal or down sloping ST segment depression, or additional ST segment depression, persisting 80 msec after the J point, during or after exercise; 2) ≥ 0.10 mV ST segment elevation persisting 80 msec after the J point, during or after exercise, in the absence of significant Q waves; or 3) exercise induced angina (23,24).

The ECG was considered nondiagnostic in the presence of 1) left bundle branch block, 2) left ventricular hypertrophy with a strain pattern, 3) current use of digitalis (if exercise induced ST segment depression was present), or 4) failure to reach 80 percent of age-predicted maximal heart rate [APMHR = 220 – age(yr)] without ischemic ST segment changes or angina. Tests were still considered positive for the above categories if patients experienced exercise induced angina. The use of digitalis is known to increase the likelihood of a false positive exercise test. However, absence of ST segment depression in patients taking digitalis who reach adequate levels of cardiovascular stress provides strong evidence against myocardial

ischemia (25). Therefore, if a subject was free of angina and ECG ST segment displacement and reached an adequate HR (≥ 80 percent APMHR), his test was categorized as negative for ischemia.

Coronary Angiography

Selective coronary angiography, utilizing the Judkins technique, was performed before or after WCE exercise testing in 18 of the 49 subjects. The decision to proceed with angiography was made by each patient's physician and was not a required aspect of the research protocol. Multiple orthogonal views were obtained of each vessel. Coronary angiograms were visually inspected by a cardiologist and considered positive for clinically significant CAD if one or more major epicardial coronary artery or branch vessel showed a reduction of ≥ 70 percent of its luminal diameter.

Statistical Analysis

Chi-square analysis was used to determine if the distribution of WCE test results was independent of medication status and whether or not subjects completed metabolic testing. Mean differences in peak exercise responses between these groups were also compared using nonpaired Student's *t*-tests. Decisions regarding statistical significance were based upon an alpha level of 0.05. All statistical analyses were carried out using the Statview 4.0 statistical analysis package (Abacus Concepts, Calabasas, CA).

RESULTS

Physiologic Responses and Exercise Test Interpretation

A total of 49 exercise tests were administered without complications. Peak exercise cardiovascular responses are summarized in **Table 1**. Fourteen tests were rated as positive for ischemia, 21 as negative for ischemia, and 14 as nondiagnostic. Of the nondiagnostic tests, 10 were due to failure to reach 80 percent of APMHR (including one patient with complete left bundle branch block). An 80 percent threshold was considered appropriate since peak heart rate is expected to be lower for upper body as compared to lower body exercise (26). Had the more traditional 85 percent cutoff been adopted, three of the negative tests would have been classified as nondiagnostic. Four of the 10 subjects with nondiagnostic tests had significant ST segment depression but were taking digitalis. Of the 14 positive WCE tests, chest pain and significant ST segment displacement were present in two, ST segment displacement without angina was noted in five, and angina without ST segment changes appeared in seven.

Metabolic measurements were completed on 47 percent (n = 23) of the subjects. There were no statistically significant differences ($p > 0.05$) in age, peak heart rate, rate-pressure product, percent of APMHR, or $\dot{V}O_2$ between subjects completing and those not completing metabolic testing. In addition, chi-square analysis showed that the frequency of WCE test results (positive, negative,

Table 1.
Mean ± standard deviation for age, peak cardiovascular and metabolic responses, rating of perceived exertion (median) and power output grouped by wheelchair ergometry test results.

Parameter	All (n = 49)	Positive (n = 14)	Negative (n = 21)	Non-diagnostic (n = 14)
Age (yr)	63 ± 9	65 ± 5	61 ± 10	66 ± 9
Heart Rate ($b \cdot min^{-1}$)	132 ± 26	125 ± 26	149 ± 21	113 ± 20
% APMHR	84 ± 15	80 ± 15	94 ± 10	74 ± 11
Systolic BP (mmHg)	169 ± 29	162 ± 29	173 ± 30	168 ± 28
RPP ($\times 10^2$)	223 ± 62	205 ± 63	256 ± 53	193 ± 55
$\dot{V}O_2$($L \cdot min^{-1}$)	1.13 ± 0.40	0.91 ± 0.25	1.41 ± 0.47	0.99 ± 0.19
	(n = 23)	**(n = 6)**	**(n = 9)**	**(n = 6)**
RPE (median)	18.5	18	18	19
Power Output (watts)	23 ± 9	21 ± 8	23 ± 11	23 ± 6

HR = heart rate; RPP = rate pressure product; APMHR = age-predicted maximal heart rate; $\dot{V}O_2$ = oxygen uptake; RPE = rating of perceived exertion.

nondiagnostic) was independent of whether or not metabolic testing was completed ($p > 0.05$).

Peak metabolic and cardiovascular exercise responses for the entire group and patients in the three diagnostic categories are shown in **Table 1**. The peak rate-pressure product for the entire group was $223 \pm 62 \times 10^2$ and the peak heart rate was 132 ± 26 b·min^{-1} (84 ± 15 percent APMHR). Attainment of peak heart rate was precluded in a number of the positive tests where exercise was stopped due to signs or symptoms of myocardial ischemia. If positive tests are excluded, mean percent of APMHR was 86 ± 14 and the mean rate-pressure product was $231 \pm 61 \times 10^2$. Most patients (76 percent) were able to reach 80 percent of their APMHR or had positive tests (69 percent if an 85 percent cut-off is substituted) despite the fact that 55 percent of the group were taking beta adrenergic- and/or calcium channel blocking medications.

No difference in peak $\dot{V}O_2$ was found between patients taking antianginal medications (n = 30; calcium channel blockers and/or beta blockers and/or nitrates) and those not taking any of these medications (n = 19). In addition, no significant differences were found between peak $\dot{V}O_2$ of the 9 subjects taking beta receptor antagonists and the remaining 40 patients.

Coronary Angiography

Eighteen patients underwent coronary angiography before or after exercise testing. Two patients were free of significant CAD. Single-vessel CAD was found in six patients, two-vessel disease in seven, and triple-vessel disease in three (see **Table 2**). There were ten true positive and two true negative WCE tests. Two patients had false negative tests, one subject with single-vessel disease of the circumflex artery and the other with two-vessel disease. Four patients with nondiagnostic tests had positive angiograms. It should be noted that three of these patients had significant ST segment depression but their tests were classified as nondiagnostic because they were taking digitalis.

The overall diagnostic accuracy of WCE within the group receiving angiography was 67 percent (12/18). The predictive value of a positive test was 100 percent (10/10). The predictive value of a negative WCE test was 50 percent, although this is based on just four negative WCE tests. The sensitivity of the WCE test was 63 percent (10/16). Only two patients referred for angiography were found to be free of significant CAD. Both of these individuals had negative WCE tests (specificity = 100 percent). However, because of the small number of cases, a meaningful evaluation of WCE test specificity is not possible.

Table 2.
Angiography evaluation of subjects by wheelchair ergometer (WCE) test results.

WCE Test Result	No Significant CAD	One Vessel CAD	Two Vessel CAD	Three Vessel CAD
Positive	0	5	3	2
Negative	2	1	1	0
Non-Diagnostic	0	0	3	1

WCE = wheelchair ergometer; CAD = coronary artery disease

DISCUSSION

In the present study, WCE exercise was utilized for diagnostic testing of persons (most with lower limb disabilities) who had known or suspected CAD. This is, to the authors' knowledge, the first research to evaluate WCE exercise for this purpose.

Upper Body Exercise Testing for the Diagnosis of Coronary Artery Disease

Most investigators have found that upper body exercise testing is less sensitive than treadmill or cycle ergometer testing for the detection of CAD (6,11,15,16,27). Generally, upper body exercise elicits lower peak cardiovascular stress, though a few researchers have reported equivalent responses (12,14,18). There appears to be a consensus that upper body exercise provides an acceptable, but less sensitive, alternative to lower body exercise for testing patients who cannot adequately perform these modes of exercise (6,11,12,14,16–18).

Comparison of Arm Crank Ergometry and Wheelchair Ergometry

Peak $\dot{V}O_2$ has consistently been found to be similar whether measured with WCE or arm crank ergometry (28). Some investigators have concluded that WCE exercise elicits a lower peak heart rate than arm crank ergometry (28). However, this has not been a universal finding (29,30) and is not supported by a previous study conducted in the authors' laboratory (21,22,31). In that investigation, maximal WCE and arm crank ergometry tests were completed by a sample of apparently healthy lower limb disabled men,

most with lower limb paralysis due to spinal cord injury. The sample was divided into three groups, upper-, mid-, and lower level injury. Within each group, mean peak rate-pressure product, heart rate, and $\dot{V}O_2$ were equivalent or greater for WCE than arm crank ergometry (21). Peak rate-pressure product was slightly but significantly greater for WCE (221 ± 71 vs. $214 \pm 67 \times 10^2$; $p = 0.05$) when the combined data from the entire group was analyzed. Peak $\dot{V}O_2$ also tended to be greater with WCE (1.34 ± 0.46 vs. 1.29 ± 0.43 L·min^{-1}; $p = 0.06$). Because the subjects were all manual wheelchair users, higher peak values for WCE may reflect specificity of training and/or greater task familiarity. These observations suggest that WCE is at least equivalent to arm crank ergometry for the detection of CAD, and may be preferable for manual wheelchair users.

Tables 3 and **4** summarize a number of previously published arm crank ergometry investigations. The mean peak heart rate (132 ± 26 b·min^{-1}, 84 ± 15 percent of APMHR) and rate-pressure product (223×10^2) achieved with WCE in the current study were not unlike those reported for arm crank ergometry in comparable patient samples. Several factors must be considered in contrasting results of upper body exercise studies, including patient profile (sex, age, presence of CAD or other conditions), use of medications which could influence results (e.g., beta adrenergic blockers) and method of blood pressure measurement (intra-arterial or auscultation).

Differences in peak upper body exercise responses between persons with CAD or peripheral vascular disease and healthy age-matched individuals are illustrated by two recent investigations. Manfre et al. (15) compared the arm crank ergometry and treadmill responses of 19 men with documented CAD (mean age 58 yr) and 12 healthy men (mean age 56 yr). Peak percent of APMHR (96 vs. 81 percent) and rate-pressure product (262×10^2 vs. 215×10^2) during arm crank ergometry were significantly greater for the healthy men. Goodman et al. (11) compared the upper body ergometry (Schwinn Air Dyne) responses of

Table 3.
Sample demographics and test protocols of arm crank exercise tests from selected published investigations, 1965 to present.

Reference	Year	Subject Profile	Mean Age (yr)	Age Range	Stage (min)	Rest period
Present study	1992	Known/suspected CAD (n = 49)	63 ± 9	42–81	3	none
Blomqvist[32]	1965	Angina; 5 known CAD (n = 6)	57	46–49	N/A	none
Wahren[33]	1971	Signs of CAD (n = 10)	52 ± 12	25–65	6	none
Shaw[18]	1974	Ambulatory (a) (n = 21)	57	41–74	3	none
		Non-ambulatory (b)(c) (n = 26)				
Schwade[17]	1977	MI or suspected CAD (n = 33)	52	42–67	3	1 min
DeBusk[9]	1978	Known MI (d) (n = 40)	51 ± 7	34–63	3	1 min
Lazarus[13]	1981	Angina (e) (n = 11)	58	48–64	3	none
Balady[6]	1985	Known CAD (f) (n = 30)	59 ± 9	40–71	3	none
Balady[7]	1987	Known/suspected CAD (n = 50)	56 ± 10	37–77	2	none
Fletcher[10]	1988	Musculoskeletal (g) (n = 15)	65 ± 13	39–84	3	1 min
Hanson[12]	1988	PVD, male (n = 57)	61 ± 10		2	2 min
		PVD, female (n = 17)	63 ± 10			
Goodman[11]	1989	PVD (n = 32)	62 ± 8		3	none
		Healthy (n = 17)	59 ± 10			
Balady[8]	1990	Healthy (n = 20)		40–59	2	none
Levandoski[14]	1990	History of CAD (n = 21)	60 ± 7		3	none
Manfre[15]	1990	Healthy (n = 12)	57		2	none
		Known CAD (g) (n = 19)	58			
Cullinane[27]	1992	Healthy (n = 9)		50–59	1	none
		Healthy (n = 7)		60–69		
Sala[16]	1992	Previous MI, male (n = 108)	48 ± 7		3	none
		Previous MI, female (n = 20)	50 ± 6			
Davidoff[20]	1992	Dysvascular Amputees (n = 25)	63 ± 8		2.5	0.5 min

(a) all MI or abnormal angiogram; (b) 14 peripheral vascular disease, 4 arthritis, 2 amputees, 4 hip prostheses, 2 neurological disease; 7 MI or abnormal angiogram; (c) no digitalis within 10 days; no propranolol within 48 hours; (d) no subjects using digitalis; all medications discontinued on day of test; (e) no subjects using beta blockers; (f) no subjects using digitalis; (g) beta blockers discontinued 12–24 hours before testing. MI = myocaridal infarction; CAD = coronary artery disease; PVD = peripheral vascular disease.

Table 4.
Comparison of peak cardiovascular responses to arm crank exercise tests from selected published investigations, 1965 to present.

Reference	Systolic BP (mmHg)	Heart Rate ($b \cdot min^{-1}$)	Percent APMHR	RPP ($\times 10^2$)	$\dot{V}O_2$ ($L \cdot min^{-1}$) [$mL \cdot kg^{-1} \cdot min^{-1}$]
Present study	169 ± 29	132 ± 26	84.1 ± 14.6	223 ± 62	1.13 ± 0.4; n = 23 [14.20 ± 4.5; n = 23]
Blomqvist[32]	218 ± 34 (a,b)	120 ± 20 (b)			0.87 ± 0.4
Wahren[33]	207 ± 23 (a)	134 ± 23	79.9 ± 11.6	277 ± 57	
Shaw[18]	157 ± 7		81.0 ± 4.0	220 ± 12	
	167 ± 8		73.2 ± 1.9	224 ± 12	
Schwade[17]		122		234	
DeBusk[9]	158 ± 12	150 ± 11		236 ± 21	
Lazarus[13]	194 ± 19	127 ± 17		246 ± 43	0.99 ± 0.1
Balady[6]	161 ± 20	101 ± 18		160 ± 40	[13.00 ± 5.0]
Balady[7]		114 ± 22	70.0 ± 14.0	180 ± 48	
Fletcher[10]	127 ± 28	106 ± 22	(c)		
Hanson[12]	167 ± 34	142 ± 22	91.0 ± 14.0	239 ± 62	
	161 ± 38	132 ± 22	86.0 ± 13.0	211 ± 52	
Goodman[11]	197 ± 31	138 ± 20	77.1 ± 10.7	274 ± 68	[17.90 ± 4.4; n = 25]
	176 ± 20	153 ± 16	85.6 ± 8.9	271 ± 49	[22.00 ± 4.1; n = 15]
Balady[8]			91.0 ± 10.0		[18.30 ± 4.5]
Levandoski[14]		144 ± 23			1.63 ± 0.4
Manfre[15]	167		95.7	262	[21.40]
	165		80.7	215	[15.00]
Cullinane[27]	160 ± 20	149 ± 15		239 ± 43	1.63 ± 0.2
	161 ± 31	136 ± 12		222 ± 58	1.27 ± 0.3
Sala[16]	164 ± 24	130 ± 21	(d)	212 ± 45	
	171 ± 20	126 ± 17		215 ± 36	
Davidoff[20]	152 ± 29	119 ± 13		182	

(a) intra-arterial measurement; (b) measurement at onset of pain; (c) exercise target 75% of maximum; (d) exercise target 85% of maximum. BP = blood pressure; APMHR = age predicted maximal heart rate; RPP = rate pressure product; $\dot{V}O_2$ = oxygen uptake.

32 men with peripheral vascular disease (61.6 ± 7.8 yr) to 17 healthy age-matched controls. Peak percent of APMHR was lower for the peripheral vascular disease patients (77 vs. 86 percent). Because of a higher peak systolic blood pressure in the peripheral vascular disease patients (197 vs. 176 mmHg), peak rate-pressure product was similar (274 $\times 10^2$ vs. 271 $\times 10^2$). In comparison, Hanson et al. (12) obtained a mean peak heart rate of 142 $b \cdot min^{-1}$ (91 percent APMHR) and a mean peak rate-pressure product of 239 $\times 10^2$ in 57 men with peripheral vascular disease (61 ± 10 yr), whereas Davidoff et al. (20) reported a mean peak heart rate of 119 $b \cdot min^{-1}$ and rate-pressure product of 182 $\times 10^2$ in 25 dysvascular amputees (63 ± 8 yr).

Balady and colleagues (6,7) published two investigations in which arm crank ergometry was used to detect myocardial ischemia in patients with angina pectoris. Nearly all subjects in both studies were taking antianginal medications. Relatively low peak exercise responses were obtained, possibly secondary to the use of antianginal medications and/or the presence of signs and symptoms of CAD which limited exercise performance. Peak heart rate and rate-pressure product in the two reports were 101 and 114 $b \cdot min^{-1}$ and 160 $\times 10^2$ and 180 $\times 10^2$, respectively. Sala et al. (16) reported on arm crank ergometry tests performed in a large group of post-myocardial infarction patients, 108 men (48 ± 7 yr) and 20 women (50 ± 6 yr). As compared to the results of the present investigation, the mean peak heart rate (130 $b \cdot min^{-1}$ for men, 126 $b \cdot min^{-1}$ for women) and rate-pressure product (212 $\times 10^2$ for men, 215 $\times 10^2$ for women) were very similar.

Blood pressures measured by auscultation that are reported in this study, and by others, probably underestimate the true systolic pressure (and therefore rate-pressure product) during upper body exercise. Systolic blood pressures measured intra-arterially during arm crank ergometry (32,33) were substantially greater than those reported in studies utilizing the standard cuff method (**Tables 3** and **4**). Hollingsworth et al. (34) compared systolic blood pres-

sures taken by auscultation immediately upon cessation of each arm crank exercise stage with those estimated by using a Doppler flowmeter technique during exercise. They found that measurements taken immediately post-exercise underestimated the exercise pressure by 7–22 percent. The difference was greatest at higher workloads.

Mean peak $\dot{V}O_2$ for the 23 patients in the current study who completed metabolic testing was 1.13 ± 0.4 L·min^{-1} (14.2 ± 4.5 mL·kg·min^{-1}). This is higher than that observed by Blomqvist et al. (32) (0.87 L·min^{-1}, n = 6) and Lazarus et al. (13) (0.99 L·min^{-1}, n = 11) for arm crank ergometry by patients with angina or known CAD. Balady et al. (6) and Manfre et al. (15) reported the arm crank peak $\dot{V}O_2$ of patients with CAD to be 13.0 mL·kg·min^{-1} (n = 30) and 15.0 mL·kg·min^{-1} (n = 19), respectively. These values are similar to the peak aerobic capacity during WCE in the present investigation. Greater average peak $\dot{V}O_2$ measures were found by Levandoski et al. (14) (1.63 L·min^{-1}, n = 21) in patients with CAD performing arm crank ergometry and by Goodman et al. (17.9 mL·kg·min^{-1}, n = 25) in peripheral vascular disease patients during upper body ergometry on a Schwinn Air Dyne (11).

Upper body exercise tests are frequently terminated before significant cardiovascular stress is achieved due to local fatigue resulting from the use of a relatively small working muscle mass. This is considered a major limitation to the use of these modes of exercise for detection of CAD (19). By conventional criteria (35), most subjects in the present study were able to reach a clinically acceptable level of cardiovascular stress for diagnostic purposes, despite the fact that many were taking medications which would tend to limit the chronotropic response (beta receptor and calcium channel blockers). Sixty-nine percent of patients attained at least 85 percent of APMHR and/or had positive WCE tests. To account for the lower peak heart rate expected with upper body work, target heart rate for a diagnostic test was defined as 80 percent of APMHR (26,29). With this target, 76 percent of the subjects were able to acheive the target heart rate or had positive test results.

Coronary Angiography

The predictive value of a positive WCE test was 100 percent (10/10) for the subset of 18 subjects for whom angiographic data were obtained. This value is consistent with arm crank ergometry results reported by Travers et al. (19) (100 percent), Hanson et al. (12) (88 percent overall, 91 percent for men only), and Balady et al. (6) (100 percent). The predictive value of a negative WCE test was 50 percent, although this finding was based on only four angiograms. Travers et al. (19) found that the predictive value of a negative arm crank ergometry test was 37 percent. Again, this was based on a small number of angiograms (n = 9). The sensitivity and diagnostic accuracy of WCE testing for the patients who underwent angiography were 63 percent and 67 percent, respectively. These values were undoubtedly influenced by the small number of angiograms and selection bias in referral for angiography in that 72 percent of patients who underwent angiography had positive WCE tests. Test specificity could not be meaningfully evaluated because of the small number of subjects without significant CAD who underwent angiographic assessment (n = 2). These subjects both had negative WCE tests (specificity = 100 percent).

The most commonly employed noninvasive methods of testing for CAD in the lower limb disabled utilize thallium or echocardiographic imaging with pharmacologic stress (e.g., adenosine or dobutamine). These methods have been demonstrated to possess high degrees of sensitivity and specificity (36,37). Notable disadvantages associated with pharmacologic testing include drug side effects, exposure to radiation if radionuclide imaging is used, and expense. Also, pharmacologic stress provides no information regarding a patient's functional capacity. Based on the high predictive value of a positive WCE or arm crank ergometry test and the relative disadvantages associated with pharmacologic tests, it would be reasonable to first utilize WCE or arm crank ergometry testing in some patients for whom lower body exercise would not be an option. This might be a particularly useful and cost-effective strategy for those with a high pretest likelihood of disease.

Effects of Cardiovascular Medications on WCE Results

Antianginal medications were taken by 63 percent of the subjects at the time of WCE testing, which may have reduced sensitivity for the detection of ischemia. No significant differences were found in peak rate-pressure product, heart rate, or systolic blood pressure between patients taking antianginals and those patients not on these medications. Similarly, no differences were detected in these parameters between patients taking beta blockers and the remainder of the sample. The distribution of WCE test results was also independent of whether or not subjects were taking antianginals or beta-blockers ($p > 0.05$). Nevertheless, it is possible that a greater proportion of tests

would have been positive had these medications been discontinued before testing.

Four of the ten patients taking digitalis had significant ST segment depression. These tests were considered non-diagnostic because digitalis is known to increase the rate of false positive ST segment depression (25). Angiography was performed on three of these subjects and confirmed the presence of significant CAD in all of them (two with double- and one with triple vessel-disease). Had these tests been considered positive, the diagnostic accuracy and sensitivity of WCE would have been 83 percent and 81 percent, respectively.

Study Limitations

Caution is recommended in generalizing the findings of the present study to other patient groups. Angiographic data could only be obtained on a limited subset of subjects and there was a probable selection bias in referral for WCE testing and for angiography. Many patients also had a high pretest likelihood of disease based on their age, sex, and the presence of concurrent conditions (e.g., peripheral vascular disease, lower limb amputations) (3–5,25,38). However, the authors believe that this group was a fairly representative cross section of the veteran population with lower limb disablility and known or suspected CAD.

For Further Investigation

The current findings, in agreement with studies utilizing arm crank ergometry (6,12,19), provide evidence that a positive upper body exercise test is highly predictive of significant CAD. In order to assess the cost effectiveness of WCE as a diagnostic tool, further study will be required to determine the sensitivity, specificity, and the predictive value of a negative test. This will require direct comparison of WCE results with those obtained by coronary angiography in a larger sample of patients. The prognostic significance of upper body exercise capacity has also not been addressed. WCE should be compared directly to arm crank ergometry for detecting CAD in wheelchair users and non-users to assess the possible advantages related to specificity of training and task familiarity. In addition, research to evaluate the combined effectiveness of thallium imaging or echocardiography in conjunction with WCE exercise testing is indicated. Balady et al. (7) compared arm crank ergometry with and without thallium scintigraphy. Detection of significant CAD by ECG criteria alone showed a sensitivity of 54 percent and specificity of 67 percent. Thallium imaging improved the sensitivity to 83 percent and specificity to 78 percent. This suggests that, in some patients, ischemia may occur during upper body exercise that is not severe enough to be detected by ECG alone. Therefore, thallium scintigraphy or echocardiography may improve the sensitivity and specificity of upper body exercise testing. The observations of Goodman et al. (11), Manfre et al. (15) and Bauman et al. (39) also support this possibility.

CONCLUSIONS

The findings of this initial evaluation provide evidence that WCE exercise testing is at least equivalent to arm crank ergometry for detection of CAD. Peak rate-pressure product and percent of APMHR were similar to those reported for arm crank ergometry in comparable groups of patients, and a majority of subjects were able to achieve a clinically acceptable level of stress for diagnostic purposes. Furthermore, the high predictive value of a positive test suggests that WCE testing is a viable initial diagnostic alternative to pharmacologic stress for some patients (e.g., those with a high pretest likelihood of disease). As compared to pharmacologic stress, WCE is less costly, involves no exposure to radiation or intravascular access, has fewer side effects, and provides valuable information about patients' functional capacity, particularly for wheelchair users. Further research will be required to establish WCE test sensitivity, specificity, as well as the predictive value of a negative test and its usefulness as a prognostic tool.

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