Cardiovascular Safety of Maximal Strength Testing in Healthy Adults

Neil F. Gordon, MD, PhD, Harold W. Kohl III, PhD, Michael L. Pollock, PhD, Hylkia Vaandrager, BS, Larry W. Gibbons, MD, and Steven N. Blair, PED

In recent years, physical activity has gained increased recognition as an important health-related behavior with considerable potential for promoting public health.[1,2] Although aerobic exercise has traditionally been emphasized, both the American College of Sports Medicine and American Association of Cardiovascular and Pulmonary Rehabilitation have recently added resistance training guidelines to their exercise recommendations for healthy adults and low-risk cardiac patients.[3–5] In addition to its widespread use in the clinical assessment of patients with musculoskeletal disorders, maximal strength testing is now recommended as a method for evaluating baseline strength levels, determining the initial resistance to be used during training, and tracking changes in strength over time.[4,5] However, a marked pressor response is known to be elicited by an acute bout of high-intensity resistance exercise, and there is concern as to the cardiovascular safety of maximal strength testing.[6,7] Unlike maximal graded exercise testing,[8,9] no comprehensive data are currently available on the cardiovascular safety of maximal strength testing. This investigation describes the cardiovascular safety of maximal strength testing performed by 6,653 men and women under uniform conditions at a single facility.

• • •

The 6,653 study participants (aged 20–69 years) comprising 5,460 men and 1,193 women, were patients at the Cooper Clinic, a preventive medicine facility in Dallas, Texas. The patients were of moderate-to-high socioeconomic status and 99% were white. All patients underwent a comprehensive preventive medical examination between 1981 and 1989, and participated in a voluntary strength-testing procedure as an adjunct to the regular examination protocol.

The regular examination, performed after an overnight fast and after patients provided written informed consent, included a venous blood draw, extensive medical history, physical examination, and 12-lead electrocardiogram. Patients without contraindications also performed a maximal exercise treadmill test with electrocardiographic and blood pressure monitoring using a modified Balke and Ware protocol.[9] Treadmill tests were categorized as being normal, equivocal, or abnormal, as previously described.[9] All assessments were conducted according to a standardized protocol manual. More details of the assessments have been previously published.[9–13]

From The Cooper Institute for Aerobics Research, Dallas, Texas; Cooper Clinic, Dallas, Texas; University of Florida, Gainesville, Florida; and Savannah Cardiology, Savannah, Georgia. This work was supported by a research grant from the National Institute of Arthritis and Musculoskeletal and Skin Diseases (AR39715). Dr. Gordon's address is: Savannah Cardiology, Chandler Heart and Lung Building, 5356 Reynolds Street, Suite 300, Savannah, Georgia 31405. Manuscript received February 10, 1995; revised manuscript received and accepted July 13, 1995.

After completion of the regular examination, patients who voluntarily elected to perform the strength assessment were allowed to do so, provided their examining physician did not feel that they had any medical conditions that could worsen or that the strength assessment placed the patient at risk. In this respect, each individual physician used his or her own clinical judgment rather than a standardized set of contraindications. A standardized protocol was used for the administration of the strength tests, as previously described.[14] Briefly, maximal isokinetic strength of the knee flexor/extensor mechanism was measured, for the left and right leg, using a Cybex (Bay Shore, New York) isokinetic dynamometer. Patients performed 4 maximal-effort unilateral knee extensions and flexions at an angular velocity of 60°/s with the right and then the left leg, while seated in the upright position. Maximal upper and lower body isotonic strength were measured by determining the maximum weight that could be used to complete 1 repetition (i.e., 1-repetition maximum) on a variable-resistance Universal (Cedar Rapids, Iowa) supine bench press and seated leg press machine, respectively. The starting weight was set at approximately 70% and 100% of each patient's body weight for the bench press and leg press tests, respectively. After each successful repetition, the weight was increased until the 1-repetition maximum was deter-

TABLE I Demographic and Clinical Characteristics of Men and Women Undergoing Cooper Clinic Strength Assessment

	Men (n = 5,460)	Women (n = 1,193)
Age (yr)	42 ± 9	40 ± 10
Height (cm)	179 ± 6	164 ± 6
Weight (kg)	84 ± 13	59 ± 10
Body mass index (kg/m^2)	26 ± 4	22 ± 3
Systolic BP (mm Hg)	118 ± 12	109 ± 12
<130	81%	93%
130–139	12%	5%
140–159	6%	2%
160–179	<1%	<1%
>179	<1%	0
Diastolic BP (mm Hg)	80 ± 9	74 ± 9
<85	78%	89%
85–89	8%	5%
90–99	12%	5%
100–109	2%	<1%
>109	<1%	<1%
Cholesterol (mmol/L)	5.5 ± 1.1 (213 ± 43)	5.0 ± 1.0 (193 ± 39)
<5.2 (<200 mg/dl)	42%	61%
5.2–6.2 (200–239 mg/dl)	36%	27%
>6.2 (>239 mg/dl)	22%	12%
HDL cholesterol (mmol/L)	1.2 ± 0.3 (46 ± 12)	1.6 ± 0.3 (62 ± 12)
<0.9 (<35 mg/dl)	18%	2%
Current smokers	16%	13%

Values expressed as mean ± SD or as percent; numbers in parentheses are mg/dl equivalents.
BP = blood pressure; HDL = high-density lipoprotein.

TABLE II Number of Patients Undergoing Strength Assessments by Age and Sex

	Men		Women	
Age (yr)	n	%	n	%
<30	425	8	182	15
30–39	2,025	37	461	39
40–49	1,898	35	350	29
50–59	915	17	165	14
>59	197	3	35	3

mined. In most instances, this was attained within 5 attempts. Abdominal muscle endurance was measured by determining the maximum number of bent-knee sit-ups that could be completed in 1 minute. All strength tests were conducted by trained technicians who encouraged patients to exert their maximal effort. Patients were discouraged from performing a Valsalva maneuver during strength testing.

Between 1981 and 1989, 11,353 men and 3,966 women completed the comprehensive medical examination. Of these patients, 48% (n = 5,460) of the men and 30% (n = 1,193) of the women performed the voluntary maximal strength assessment. Selected demographic, clinical, and fitness variables are presented in Tables I through III for patients who performed the strength assessment. Although specific reasons for not performing the strength assessment are unavailable, it is of interest that no significant difference was noted between patients who performed the strength assessment and those who did not for any of the demographic and clinical variables listed in Table I.

The mean age (± SD) was 42 ± 9 years for the men and 40 ± 10 years for the women. A substantial number of the patients had major risk factors for cardiovascular disease, but only a small percentage of the men (1.4%) and women (1%) had a previous diagnosis of cardiac disease at the time of their clinic visit. In the men, 91% of the treadmill tests were normal, 6% were equivocal, and 3% were abnormal. In the women, 92% of the treadmill tests were normal, 6% were equivocal, and 2% were abnormal.

Of the 6,653 patients, none experienced a clinically significant, nonfatal (i.e., requiring medical consultation or intervention) or fatal cardiovascular event in association with strength testing.

TABLE III Fitness Characteristics of Men and Women Undergoing Cooper Clinic Strength Assessment

	Men	Women
Treadmill time (min)	19.4 ± 5.0 (5,460)	14.9 ± 4.6 (1,193)
1RM bench press (kg)	72.3 ± 17.4 (5,460)	32.2 ± 7.8 (1,193)
1RM leg press (kg)	138.7 ± 26.8 (5,460)	76.1 ± 17.1 (1,193)
Rt. knee extension (Nm)	179.6 ± 42.6 (5,336)	104.4 ± 28.5 (1,160)
Lt. knee extension (Nm)	174.9 ± 42.3 (5,333)	101.4 ± 28.6 (1,160)
Rt. knee flexion (Nm)	114.8 ± 28.7 (5,336)	69.7 ± 19.9 (1,161)
Lt. knee flexion (Nm)	112.4 ± 28.7 (5,329)	68.3 ± 19.4 (1,161)
Sit-ups	32 ± 10 (5,460)	24 ± 10 (1,193)

Values expressed as mean ± SD. Values in parentheses are number of patients for each fitness characteristic.
1RM = 1-repetition maximum; Lt = left; Nm = Newton meter; Rt = right; sit-ups = number of sit-ups completed in 1 minute.

• • •

Existing comprehensive studies on the safety of maximal exercise testing have focused exclusively on aerobic exercise.[8,9,15] Such data cannot necessarily be extrapolated to maximal strength testing, because the acute cardiovascular responses to resistance exercise differ from those of aerobic exercise in several fundamental ways.[4] In particular, heavy resistance exercise elicits a pressor response that involves only moderate increases in heart rate and cardiac output relative to aerobic exercise, but a greater elevation in arterial blood pressure.[6,7] Although the latter has been interpreted as being indicative of an accentuated risk for the precipitation of acute cardiovascular events, the present study serves to document the safety of maximal strength testing in certain subsets of the adult population.

There are several noteworthy limitations to the findings of our study. All of the patients underwent a comprehensive medical examination, which may have screened out those individuals at risk for cardiovascular complications during maximal strength testing. Therefore, our results cannot necessarily be extrapolated to persons who do not undergo a medical screening procedure similar to that used in our study. Similarly, although many of the patients in our study had major cardiovascular disease risk factors, only a small percentage had abnormal treadmill tests or documented cardiovascular disease. While our findings are supportive of the growing number of smaller studies that have used maximal strength testing in low-risk cardiac patients without any apparent adverse cardiovascular consequences, they also cannot necessarily be extrapolated to higher risk cardiac patients.[16,17] It should further be pointed out that recent studies have suggested an important role for external triggers in the fissuring of atherosclerotic plaque.[18] Because the resultant adverse clinical sequelae, including sudden cardiac death, are not always immediately apparent, we may have underestimated the risk for cardiovascular complications with maximal strength testing in our study. While no cardiovascular complications that may have occurred within several days after the strength evaluation were brought to our attention, we cannot entirely refute this possibility because we did not specifically follow up the patients for clinical events after their departure from the testing facility.

The present observations are corroborated by 2 additional data sets. First, an additional 1,819 maximal strength assessments have been performed on Cooper Clinic patients from January 1, 1990 through December 31, 1993. Complete demographic, clinical, and fitness data are unavailable for these individuals at the present time. Nonetheless, it is of considerable interest that none experienced a clinically significant cardiovascular event in association with maximal strength testing. Second, between 1986 and 1993, approximately 4,500 different subjects have completed approximately 20,000 maximal strength

tests at the Center for Exercise Science, University of Florida (M.L. Pollock, personal communication, October 27, 1993). The subjects, aged 18 to 93 years, were healthy participants in research studies requiring maximal static and dynamic strength testing. All subjects under age 60 years were screened for medical disorders using a 1-page questionnaire, with graded exercise testing being conducted by a minority of patients. All subjects aged 60 years or older were screened, in a manner similar to that described in this paper, prior to strength testing. As was the case for the Cooper Clinic patients, no fatal or nonfatal cardiovascular events occurred.

In conclusion, our study is the first to document the cardiovascular safety of maximal strength testing in a large adult population. The findings suggest that maximal strength testing is a safe procedure. However, further data are needed to confirm our observations in persons who do not undergo a comprehensive medical screening procedure prior to testing and patients at a higher risk for exercise-induced adverse cardiovascular events.

Acknowledgments: We gratefully acknowledge Cybex Corporation for providing strength testing equipment, student interns for conducting strength evaluations, and Cooper Clinic physicians for their support throughout the course of the study.

1. Fletcher GF, Blair SN, Blumenthal J, Caspersen C, Chaitman B, Epstein S, Falls H, Froelicher ES, Froelicher VF, Pina IL. Statement on exercise: benefits and recommendations for physical activity programs for all Americans. *Circulation* 1992; 86:340–344.
2. Pate RR, Pratt M, Blair SN, Haskell WL, Macera CA, Bouchard C, Buchner D, Ettinger W, Heath GW, King AC, Kriska A, Leon AS, Marcus BH, Morris J, Paffenbarger RS, Patrick K, Pollock ML, Rippe JM, Sallis J, Wilmore JH. Physical activity and public health. A recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine. *JAMA* 1995; 273:402–407.
3. American College of Sports Medicine. Position stand. The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscle fitness in healthy adults. *Med Sci Sports Exerc* 1990;22:265–274.
4. American College of Sports Medicine. Guidelines for Exercise Testing and Prescription, 4th ed. Philadelphia: Lea and Febiger, 1991.
5. American Association of Cardiovascular and Pulmonary Rehabilitation. Guidelines for Cardiac Rehabilitation Programs. Champaign, IL: Human Kinetics, 1994.
6. MacDougall JD, Tuxen D, Sale DG, Moroz JR, Sutton JR. Arterial blood pressure response to heavy resistance exercise. *J Appl Physiol* 1985;58:785–790.
7. Haslam DRS, McCartney N, McKelvie RS, MacDougall JD. Direct measurements of arterial blood pressure during formal weightlifting in cardiac patients. *J Cardiopulm Rehabil* 1988;6:213–225.
8. Rochmis P, Blackburn H. Exercise tests: a survey of procedures, safety, and litigation experience in approximately 170,000 tests. *JAMA* 1971;217:1061–1066.
9. Gibbons L, Blair SN, Kohl HW, Cooper K. The safety of maximal exercise testing. *Circulation* 1989;80:846–852.
10. Blair SN, Cooper KH, Gibbons LW, Gettman LR, Lewis S, Goodyear N. Changes in coronary heart disease risk factors associated with increased treadmill time in 753 men. *Am J Epidemiol* 1983;18:352–359.
11. Blair SN, Goodyear NN, Gibbons LW, Cooper KH. Physical fitness and incidence of hypertension in healthy normotensive men and women. *JAMA* 1984;252: 487–490.
12. Blair SN, Kohl HW III, Paffenbarger RS Jr, Clark DG, Cooper KH, Gibbons LW. Physical fitness and all-cause mortality: a prospective study of healthy men and women. *JAMA* 1989;262:2395–2401.
13. Kohl HW, Gibbons LW, Gordon NF, Blair SN. The prevalence of abnormal exercise tests by age and health status: an application of the ACSM Guidelines. *Med Sci Sports Exerc* 1990;22:533–539.
14. Kohl HW, Gordon NF, Scott CB, Vaandrager H, Blair SN. Muscular strength and serum lipid levels in men and women. *Med Sci Sports Exerc* 1992;24: 1080–1087.
15. Kohl HW III, Gordon NF, Powell KE, Blair SN, Paffenbarger RS Jr. Physical activity, physical fitness and sudden cardiac death. *Epidemiol Rev* 1992;14:37–58.
16. Verrill D, Shoup E, McElveen G, Witt K, Bergey D. Resistive exercise training in cardiac patients. Recommendations. *Sports Med* 1992;13:171–193.
17. Featherstone JF, Holly RG, Amsterdam EA. Physiologic responses to weight lifting in coronary artery disease. *Am J Cardiol* 1993;71:287–292.
18. Falk E. Why do plaques rupture? *Circulation* 1992;86(suppl 111):111-30–111-42.

Real-Time Comparison of Pressure-Predicted and Doppler-Measured Jet Velocities Distal to Left-Sided Obstructions Throughout Systole

Rolando Zamora, MD, and Richard L. Donnerstein, MD

The clinical "gold standard" for determining a pressure decrease across an obstruction is the difference in pressures measured at catheterization. Intravascular pressure manometers provide a more accurate pressure measurement than can be obtained with fluid-filled catheters. In clinical practice, pressure decrease is frequently estimated from the Bernoulli equation by noninvasive transthoracic Doppler echocardiography.[1] Importantly, most studies verified the Doppler method by comparing instantaneous Doppler-predicted pressure decreases across obstructions to simultaneously or nonsimultaneously measured intravascular pressure differences obtained with fluid-filled catheter systems.[2–4] Moreover, because of difficulties in obtaining continuous comparisons, only peak pressure differences estimated by Doppler have been compared with those measured intravascularly. This report introduces a new real-time method for comparing throughout systole instantaneous velocities measured by Doppler echocardiography with instantaneous velocities predicted from dual intravascular pressure manometers placed on either side of vascular obstructions, and describes the advantages and limitations of this technique.

From the Steele Memorial Children's Research Center, University Heart Center, and Department of Pediatrics (Cardiology), The University of Arizona, Tucson, Arizona. Dr. Zamora's address is: University of Arizona Health Sciences Center, Department of Pediatrics, Steele Memorial Children's Research Center, 1501 North Campbell Avenue, Tucson, Arizona 85724. Manuscript received April 4, 1995; revised manuscript received and accepted June 26, 1995.

• • •

The patient group consisted of 12 randomly selected children, aged 0.6 to 17.5 years (mean ± SD 6.2 ± 4.8), with left-sided obstructive lesions (7 with coarctation of the aorta and 5 with aortic stenosis). Patient information and Doppler-measured and pressure-predicted peak instantaneous velocities are summarized in Table I. Pressures on both sides of the obstruction were measured