High-Intensity Strength Training of Patients Enrolled in an Outpatient Cardiac Rehabilitation Program

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Purpose. *This randomized controlled study assessed whether adding a program of high-intensity strength training (80% of maximum) to an outpatient cardiac rehabilitation program would be a safe and effective means of improving muscle strength and body composition.*

Methods. *Thirty-eight cardiac patient volunteers (29 men and 9 women) were randomized to either high-intensity strength training or flexibility training added concurrently to a 12-week outpatient cardiac rehabilitation aerobic exercise program. Muscle strength, local muscle endurance, joint flexibility, maximum treadmill tolerance time, and body composition were measured before and after completion of the training.*

Results. *The strength-trained patients ($n = 18$) had greater increases in mean strength ($90 \pm 19\%$ versus $9 \pm 4\%$, $P < 0.0001$) and local muscle endurance (20 versus 6 times, $P < 0.0001$), and decreases in mean perceived exertion for lifting the initial one repetition maximum load (11 ± 1 versus 15 ± 1, $P < 0.001$) when compared with flexibility-trained patients ($n = 16$). The strength group lost more body fat (2.8 ± 2.0 versus 1.3 ± 2.0 kg, $P < 0.01$), tended to gain more lean tissue (1.5 ± 2.3 versus 0.5 ± 1.2 kg, $P < 0.10$), and had greater improvements in treadmill time (2.3 ± 1.3 versus 1.2 ± 1.0 minute, $P < 0.02$) than did the flexibility group. Improvements in joint flexibility were similar for each group. None of the subjects had evidence of cardiac ischemia or arrhythmia during the training sessions.*

Conclusions. *Medically supervised high-intensity strength training is well tolerated when added to the aerobic training of cardiac rehabilitation programs and allows patients to aggressively gain the strength and endurance they will need to complete daily living tasks at lower perceived efforts. Strength training also reduces cardiac risk factors by improving body composition and maximum treadmill exercise time.*

Key words: exercise, cardiac rehabilitation, cardiovascular fitness, body composition.

Low- to moderate-intensity strength training (40%–60% of maximum strength) has been recommended for patients participating in supervised cardiac rehabilitation programs to restore strength necessary for daily living activities.[1] Previous studies have shown that such training is physiologically safe[1–4] and results in moderate strength gains (range 6%–52%).[5–7] High-intensity strength training (70%–80% of maximum) outcomes have been reported for two groups of 9 to 10 male cardiac patients who had previously completed 12 weeks of aerobic training in cardiac rehabilitation programs.[8,9] There were no cardiovascular complications, but the strength gains were not much greater than those reported for low-intensity strength training and were not accompanied by significant changes in body composition.[8] High-intensity strength training performed concurrently with initial cardiac rehabilitation aerobic exercise programs has not been reported. Such a regimen would allow higher strength gains earlier in recovery and allow supervision of the strength training by cardiac rehabilitation staff.

In our study, male and female patients were randomly enrolled in either high-intensity strength training or flexibility training added concurrently to their initial outpatient cardiac rehabilitation aerobic exercise program. Changes in muscle strength, local muscle endurance, joint flexibility, body composition, and maximum treadmill tolerance time are reported.

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Patients

Male (n = 29) and female (n = 9) cardiac patients accepted into an outpatient cardiac rehabilitation aerobic exercise training program were recruited for this study. The patients were 6 to 16 weeks post cardiac event (myocardial infarction, coronary bypass, coronary angioplasty, or new-onset angina) and had completed their first maximum treadmill tolerance test post cardiac event. Patients were excluded from the study if they were unable to participate in the full aerobic training program because of uncontrolled arrhythmias, resting systolic blood pressure >160 mm Hg or diastolic BP >100 mm Hg, unstable angina pectoris, unstable congestive heart failure, ejection fraction <30% by echocardiogram or cardiac catheterization, abnormal hemodynamic response or ischemic electrocardiogram changes (≥0.1 mV ST depression from baseline ≥80 msec from the junction) during stage 1 of the maximum graded treadmill tolerance test (Bruce protocol), orthopedic limitations or uncontrolled metabolic disease (e.g. uncontrolled diabetes or thyroid disease). Of the 135 patients enrolled in the aerobic exercise program during the 12-month study enrollment period, only 5 subjects were excluded from the study because of medical reasons, 2 with ejection fractions less than 30% and 3 with orthopedic limitations. Sixty-two patients were not interested in participating in the research study. It was the policy of the study investigators to avoid any pressure on patients to participate by having the study presented as an option by the cardiac rehabilitation intake coordinator (not involved in the research project). The investigators contacted the patients only if they expressed an interest in participating. Thirty patients were unable to participate because of limits in their insurance, extended vacation plans, or inability to accommodate the exercise times. The study protocol was approved by the Human Investigations Review Committees at New England Medical Center and at the Cardiovascular Health Center research site, and written informed consent was obtained from all subjects before participation.

Methods

Study Design

In the first 2 weeks of the study, the subjects began the cardiac rehabilitation aerobic exercise training. The aerobic training consisted of 30 to 40 minutes of continuous exercise on a treadmill, stationary bicycle, rowing machine, or a combination of these activities, followed by 5 minutes of stretching activities. The aerobic training intensity was maintained at 65% to 80% of the maximum heart rate for each patient. The Borg rating of perceived exertion, known to be a valid index of physical exertion intensity during aerobic exercise,[10–12] was kept in the 12 to 13 ("somewhat hard") range on a scale of 20 during the aerobic sessions. Blood pressures were checked frequently and electrocardiograms were monitored by radiotelemetry during the first month of training. In addition to the exercise, a 1-hour weekly group counseling session was provided to discuss cardiac risk factor reduction techniques, including diet modification for blood lipid reduction and weight control, exercise, stress reduction, and smoking cessation.

The subjects were also individually oriented to both study training programs during the first 2 weeks, including instruction on equipment use, correct body position during exercise, proper exercise movement, speed of movement, range of motion, and breathing patterns to prevent breathholding (Valsalva's maneuver). Flexibility, strength, body composition and anthropometric measurements were completed for each subject during this period and repeated again at the end of 12 weeks of training. Flexibility and strength were also measured midstudy. After orientation and initial testing were completed, subjects were randomized to 1 of the 2 study programs according to gender and beta blocker use. All subjects trained 2 times per week on nonconsecutive days for 12 weeks. The supervised training began 30 minutes before the aerobic exercise training sessions, and consisted of a 5-minute noload warm-up on a stationary bike, followed by strength or flexibility training for 20 to 25 minutes. Subjects who missed sessions made up the sessions. All training- and study-related testing took place at one outpatient facility with the exception of the maximum treadmill tolerance tests of 6 patients which were completed at other facilities for insurance reasons. All study sessions were supervised by an American College of Sports Medicine Certified Preventive/Rehabilitative Exercise Specialist.[13] Electrocardiograms were continuously monitored via radiotelemetry during the first 4 training sessions of the study.

Interventions

Strength training. Four resistance exercises were used: chest press, latissimus dorsi pull down, leg press, and knee extension, alternating upper and lower body exercises. Abdominal flexion was optional (16 of 18 subjects) as time permitted. All exercises were performed on a multistation, multistack Bio-Dyne F-14 weight station (Bio-Dyne Corporation, Atlanta, GA). Subjects performed 2 sets of 8 repetitions followed by 1 set of 8 to 12 repetitions. Each repetition lasted 6 to 9 seconds, with a 1-minute rest period between sets, and a 2-minute rest period between exercises. Rating of perceived exertion was assessed after each set. Loads equal to 50% of each subject's initial maximum strength were used during the first week of training and advanced to 80% in the second week. Training loads were adjusted such that when 12 repetitions could be performed in the third set, the load was increased by 5% at the next session. Instructions and safety guidelines were posted. Subjects received written guidelines for proper performance of each of the exercises.

Flexibility training. Four exercises were used: overhead towel stretch, triceps flexion, chair seated hip flexion, and floor seated hamstring stretch, alternating upper and lower body exercises.[14] Each stretch was was performed with slow controlled movements, sustained for 30 seconds, and repeated 3 times with 1 minute rest between each of 3 repetitions and 2 minutes rest between exercises. Stretching to videos was optional (11 of 16 subjects) to complete the program time. Subjects received written guidelines for proper performance of each of the exercises.

Exercise Testing

Maximum strength. The 1-repetition maximum strength for each exercise was measured as the maximum load the subject could lift, using correct form, through the full range of motion for 1 repetition only.[15] The 1-repetition maximum was determined within 5 to 6 trials (with at least one trial in excess of maximum) and corresponded to a rating of perceived exertion of 19 ("very, very hard"). Electrocardiograms were continuously monitored via radiotelemetry during baseline maximum strength measurements and blood pressures were checked manually by sphygmomanometer immediately after this testing. As reported by Wiecek et al.,[16] blood pressures were near resting values immediately after lifting and the electrocardiograms were unchanged during lifts. Two baseline 1-repetition maximum strength measurements were made on nonconsecutive days and the highest value used. The correlation between these two measurements was $r = 0.94$, $P < 0.001$. The intensity of training (percent) was calculated for each subject by dividing their training load by their measured one repetition maximum (×100).

Local muscle endurance. Subjects repeatedly lifted their pretraining 1-repetition maximum weights at a rate of 10 lifts/minute until unable to continue, and the number of repetitions was recorded.[9,17] A rating of perceived exertion was recorded for the first lift of the test. By definition, the pretraining muscle endurance value for all subjects was 1 repetition and the rating of perceived exertion was 19.

Range of motion. Three goniometer (Leighton Flexometer, Spokane, WA) measurements of range of motion in degrees were made of shoulder flexion, shoulder extension, hip flexion and trunk flexion, and the highest value used for analysis. Reported test–retest coefficients for these measurements range from $r = 0.817$ to $r = 0.972$.[18]

Sit and reach. Lower back area and posterior thigh flexibility were measured using a sit and reach test.[19] Three measurements were made with reference to a defined zero point and the highest used for analysis. The coefficient of reliability for successive same day measures has been reported to be 0.98.[20]

Maximum treadmill tolerance time. Each subject performed a maximum exercise tolerance test on a treadmill, using the Bruce protocol,[10,21] before and on completion of the cardiac rehabilitation aerobic exercise training program. These treadmill tests were standard requirements for the cardiac rehabilitation program and were not modified for the research protocol. Patients were required to rest their hands on the front handrails for support during the tests. Maximum treadmill tolerance time was recorded as an index of aerobic exercise capacity.[22] Blood pressure (by auscultation) and a 12-lead electrocardiogram were recorded at rest, every 3 minutes during exercise, in the last 15 seconds of exercise, and at intervals during recovery until heart rate and electrocardiogram had returned to baseline. The treadmill tests were terminated according to the guidelines recommended by American College of Sports Medicine.[13] All treadmill tests were supervised by a hospital cardiologist blinded to the treatment group.

Anthropometry

Fasting body weight was measured in light indoor clothing without shoes and after voiding. Body height was measured without shoes to the nearest 0.1 cm. Triplicate skinfold thickness measurements to the nearest 0.5 mm (Lange calipers, Cambridge Scientific Industries, Cambridge, MD) were averaged for each of 4 sites on the right side of the body, triceps, biceps, subscapular, and suprailiac.[23] Waist and hip circumferences were measured with a flexible tape.

Body Composition

Total body scans were performed by dual energy radiographic absorptiometry and analyzed using an extended analysis program for body composition (Lunar Radiation Corporation, model DPX-L, Manual 1.3

DPX-L, Madison, WI; total radiation dose 2 mRem/subject). The *in vivo* coefficient of variation for total body percent fat and lean tissue mass using repeated measures on the same subject has been reported to be 1.4 and 0.6%, respectively,[24] and to be <2.9% for percent body fat, and <1.2% for lean tissue mass in all regions measurements.[25]

Statistical Analyses

Muscle strength, local muscle endurance, joint flexibility, maximum treadmill tolerance time, and body composition were analyzed by using repeated measures analysis of variance with treatment as the between subject factor. When no significant time by group interaction was found, Student's *t*-test for paired samples was used to assess the difference between time points. Student's *t*-tests for independent samples were used to compare the treatment groups at each time point. A $P \leq 0.05$ was considered to be statistically significant. All data are reported as mean ± SD. The statistical analyses were performed using SYSTAT Statistical Software for Macintosh, version 5.2 (SYSTAT, Inc., Evanston, IL).

Results

Clinical Characteristics

Baseline descriptive data for the subjects are shown in Table 1. There were no significant differences in age, anthropometric data, time after cardiac event, or ejection fraction between the study groups before the study. The male to female ratios, cardiac diagnoses, number of subjects on beta blocker medication, and the number of smokers were similar for both groups at the start of the study. After the initial treadmill tests, one patient assigned to the strength training group had an increase in beta blocker medication for treatment of hypertension.

Adherence to the Study and Adverse Effects

Of the 38 study subjects randomized, 34 completed the 24 training sessions in 12 to 15 weeks. Four subjects dropped out before completing the study, all within the first month of the study; the reported reasons were: decision not to participate before training began (1 flexibility), sciatic nerve pain after a golf game (1 flexibility), exacerbation of

Table 1. *Subject Characteristics*

	Flexibility (n = 16)	*Strength (n = 18)*
Age, yrs	59 ± 12	58 ± 12
Male/Female	12/4	13/5
Weight, kg	82.5 ± 15.4	82.4 ± 17.4
Height, cm	176 ± 11	172 ± 11
Waist/Hip Ratio	0.87 ± 0.02	0.90 ± 0.01
Cardiac Diagnosis*		
Myocardial infarction	6	3
Coronary bypass	4	8
Coronary angioplasty	4	5
Angina	2	2
Time post cardiac event, months	3.1 ± 2.0	2.7 ± 2.1
Beta blocker medication		
Metoprolol (25–200 mg/day)†	7	7
Atenolol (25–50 mg/day)	4	6
Sotalol (160 mg/day)		1
Propranolol (160 mg/day)		1
Smokers	3	4
Ejection Fraction, % (range)‡	54.5 ± 8.9 (45–73)	53.1 ± 8.3 (35–60)

Data are presented as mean ± SD.
*Number of subjects with primary diagnosis.
†Range of dosage.
‡Data from medical records includes values estimated by 2 dimensional echocardiography (n = 11 flexibility; 13 strength) and coronary catheterization (n = 5 flexibility; 5 strength).

preexistingarthritic knee pain (1 flexibility), and development of unstable angina before the first training session (1 strength). Only the exacerbation of knee pain was considered a possible adverse effect of the combined program of aerobic and flexibility exercises. There was little or no muscle soreness after any of the strength or flexibility training sessions. None of the subjects had any signs or symptoms of cardiac ischemia or arrhythmia during the training sessions.

Maximum Muscle Strength

The flexibility group showed small improvements in the leg press and knee extension muscle strength over time (4 exercise mean: 9 ± 4%), and the strength group showed marked improvements (mean: 90 ± 19%, $P < .0001$) in all of the tested exercises with significant group effects for all exercises (Table 2; Figure 1). The mean rating of perceived exertion during strength training was 13 ± 1 during the first week (50% of maximum) and 15 ± 1 during the high intensity training. The average training load was 78 ± 6.5% and 78 ± 4.2% of measured 1-repetition maximum at 6 and 12 weeks, respectively (range 50%–90%). Consistent with literature reports for aerobic exercise,[11,12] there was a significant correlation between strength training intensity, which ranged between 50% and 90% of maximum, and the rating of perceived exertion for these training loads ($r^2 = 0.72$, $P < 0.001$).

The number of women in the strength group was too small for separate statistical analysis. The women averaged 30% to 50% lower initial strengths and gained less total strength than the men, but had 100% to 200% mean percent improvements in muscle strength compared with 45% to 95% mean improvements in men (Figure 1).

Local Muscle Endurance

Both study groups had significant improvements in local muscle endurance (Table 2) and rating of perceived exertion for all the muscle groups tested. The strength group had greater increases in local muscle endurance and decreases in perceived exertion for the initial 1 repetition maximum than the flexibility group, with significant group effects for all exercises. At the end of the study, the initial 1-repetition maximum load that had been perceived as "very very hard" by all subjects (19), became "fairly light" for the strength group (11 ± 1), and remained "hard" (15 ± 1) for the flexibility group ($P < 0.001$). The outcomes for the men and women were similar.

Flexibility

Subjects in both groups showed small but significant increases in flexibility in the five joint sites and in sit and reach, and no differences were found between groups (Table 3).

Maximum Treadmill Tolerance Time

Both study groups showed significant improvements in maximum treadmill times (Table 3). The treadmill times of the strength group increased by a mean of 39 ± 10% (2.3 ± 1.3 minutes), significantly greater than the 18 ± 12% (1.2 ± 1.0 minutes) increase in the flexibility group. The hemodynamic parameters did not change in either group with the exception of

Table 2. *Strength Outcomes*

	Flexibility (n = 16)				*Strength (n = 18)*			
	Maximum muscle strength, kg*			*Endurance†*	*Maximum muscle strength, kg*			*Endurance*
Time	0 wk	6 wk	12 wk	12 wk	0 wk	6 wk	12 wk	12 wk
Chest Press	38 ± 17	38 ± 16	39 ± 17	4.1 ± 2.6	35 ± 18	48 ± 25	54 ± 27‡	16.1 ± 7.0‡
Lat Pull	32 ± 10	32 ± 10	32 ± 10	4.9 ± 3.0	28 ± 14	38 ± 17	47 ± 19‡	22 ± 13§
Leg Press	67 ± 22	71 ± 20	77 ± 28‖	9.7 ± 8.4	68 ± 23	89 ± 26	104 ± 30‡	25 ± 14¶
Knee Extension	41 ± 14	46 ± 16	45 ± 15‖	7.1 ± 2.3	38 ± 18	61 ± 29	73 ± 30‡	16.2 ± 5.9‡
Mean	44 ± 14	46 ± 14	48 ± 16	6.4 ± 3.0	42 ± 17	59 ± 22	70 ± 24‡	19.7 ± 8.1‡

Data are presented as the mean ± SD. Lat: latissimus dorsi.
*Maximum muscle strength was measured by 1 repetition maximum testing.
†Repetitions; pertaining value = 1 for each subject.
‡Time by group interaction, $P < 0.0001$.
§Time by group interaction, $P < 0.001$.
‖Significantly different from initial values within group, $P < 0.01$.
¶Time by group interaction, $P < 0.005$.

Table 3. *Flexibility Variables and Maximum Treadmill Variables*

	Flexibility (n = 16)		*Strength (n = 18)*	
Flexibility Variables	*Initial*	*Final*	*Initial*	*Final*
Shoulder flexion*	138 ± 16	152 ± 16†	136 ± 16	149 ± 16†
Shoulder abduction*	141 ± 24	156 ± 20†	152 ± 20	164 ± 20†
Trunk flexion*	68 ± 16	77 ± 16†	65 ± 12	76 ± 12†
Hip flexion*	75 ± 12	83 ± 12†	76 ± 12	82 ± 12†
Sit and reach, cm	11 ± 11	19 ± 12†	13 ± 10	19 ± 9†
Treadmill variables‡	*Initial*	*Final*	*Initial*	*Final*
Resting heart rate, bpm	66 ± 10	63 ± 12	70 ± 13	66 ± 10
Resting systolic BP, mm Hg	125 ± 16	125 ± 14	124 ± 19	118 ± 17
Heart rate at 3 min, bpm§	97 ± 12	88 ± 14¶	103 ± 20	94 ± 13‖
Peak heart rate, bpm	128 ± 19	128 ± 21	134 ± 24	142 ± 19
Peak systolic BP, mm Hg	161 ± 25	165 ± 22	170 ± 27	169 ± 25
Peak RPP§	209 ± 60	214 ± 56	230 ± 64	242 ± 56
Exercise time, min	7.8 ± 2.8	9.0 ± 2.8¶	8.1 ± 3.2	10.4 ± 2.8¶#

Data are mean ± SD. BP: blood pressure; RPP: rate-pressure product at peak of treadmill test (bpm × mm Hg/100).
*Range of motion in degrees.
†Significantly different from initial value within group, $P < 0.005$.
‡From maximum graded treadmill tolerance testing using Bruce protocol.
§For these measures, $n = 14$ flexibility patients; 18 strength.
‖Significantly different from initial value within group, $P < 0.02$.
¶Significantly different from initial value within group, $P < 0.001$.
#Time by group interaction, $P < 0.02$.

decreases in 3-minute heart rates in both groups, consistent with aerobic conditioning.

Body Composition

There were no significant differences in anthropometric or body composition measurements between groups at baseline (Table 4). At the end of the study, the two study groups had lost similar amounts of body weight. The strength group lost significantly more total body fat (2.8 ± 2.0 versus 1.3 ± 2.0 kg fat lost, $P < 0.01$) and tended to gain more lean tissue (1.5 ± 2.3 versus 0.5 ± 1.1 kg lean tissue gained, $P < 0.10$) than the flexibility group. The skinfold data confirm the higher loss of body fat in the strength group. There were also significant decreases in percent fat in the legs and trunk in the strength group without significant changes in regional lean tissue mass.

Discussion

Our results show for the first time that high-intensity strength training added concurrently to the initial cardiac rehabilitation aerobic exercise program of men and women improved their physical function as measured by muscle strength, local muscle endurance, body composition, and maximum treadmill tolerance time; and was not associated with clinically apparent cardiac ischemia, arrhythmia, or other complications. The control flexibility training was specifically designed to provide similar exercise times, social support, and cardiac rehabilitation activities.

The strength gains (78 ± 47%) in our study averaged higher than those reported in previous studies of high-intensity strength training in cardiac patients.[8,9] Crozier Ghilarducci et al.[8] reported a 29% increase in strength of 9 men after a 10-week program (one set of 10–12 repetitions, 3 days per week). The total training volume per exercise [(total repetitions/training session) × total number of sessions] in their study ranged from 192 to 288, compared with 576 to 676 in our study. McCartney et al.[9] also reported a 29% increase in muscle strength and increased muscle endurance to 14 repetitions in 10 male cardiac patients after 10 weeks of training. While training volume (2–3 sets of 10–15 repetitions, 2 days per week) was similar to our study,

Table 4. *Anthropometric and Body Composition Data*

	Flexibility (n = 16)		*Strength (n = 18)*	
	Initial	*Final*	*Initial*	*Final*
Body Weight, kg	83 ± 15	81 ± 14	82 ± 21	81 ± 21
Waist/Hip Ratio	0.87 ± 0.07	0.85 ± 0.06	0.90 ± 0.06	0.89 ± 0.06
Body Mass Index, kg/m^2	26.8 ± 5.4	26.4 ± 14.9	27.5 ± 4.5	27.1 ± 4.9
Skinfolds, mm				
Sum of 4 skinfolds	78 ± 32	73 ± 28	87.2 ± 5.7	77.5 ± 5.7*
Triceps	19.7 ± 9.9	18.3 ± 8.6	21.9 ± 8.4	19.4 ± 8.3
Biceps	13.6 ± 8.3	12.2 ± 8.0	16.1 ± 9.3	13.8 ± 8.6
Scapula	21.7 ± 7.9	20.5 ± 7.1	22.3 ± 5.5	20.3 ± 4.8
Iliac	23.0 ± 9.3	22.7 ± 7.8	28.2 ± 6.3	24.9 ± 7.2*
Body Composition (dual photon x-ray absorptiometry)				
Total % Fat	31.5 ± 11.6	30.7 ± 11.2	33.7 ± 7.2	30.8 ± 7.4†
Arm	31.2 ± 13.8	29.5 ± 12.8	32.9 ± 9.9	29.7 ± 9.7
Leg	29.9 ± 13.1	30.1 ± 13.5	31.8 ± 9.7	28.9 ± 9.5‡
Trunk	33.2 ± 11.3	32.1 ± 10.6	35.7 ± 5.8	32.6 ± 6.3*
Total Lean Mass, kg	51.4 ± 9.2	51.9 ± 9.6	50.1 ± 10.9	51.6 ± 12.0§
Arm	5.8 ± 1.5	5.8 ± 1.5	5.7 ± 1.6	5.8 ± 1.7
Leg	16.6 ± 3.2	16.7 ± 3.5	16.2 ± 3.9	16.6 ± 4.3
Trunk	25.8 ± 4.5	26.1 ± 4.6	25.1 ± 5.3	26.1 ± 5.8

Data are mean ± SD.
*Time by group interaction, $P < 0.05$.
†Time by group interaction, $P < 0.005$.
‡Time by group interaction, $P < 0.001$.
§Time by group interaction, $P < 0.10$.

the training intensity increased gradually, from 40% to 50% of the 1-repetition maximum, initially, to "approximately 80% of the 1-repetition maximum by the end of the study."[9] When our data are averaged for men only, the mean gain in strength was 65 ± 30%, still considerably higher than previously reported. Most of our subjects gained strength continuously through 12 weeks, similar to some,[26,27] but not all,[28] previous studies of high-intensity strength training in older adults. Our muscle endurance outcomes were also greater than those reported by McCartney et al.,[9] suggesting that our total training stimulus was higher than has been reported previously in cardiac patients. The higher gains in strength and endurance may be also related to undefined differences in type of equipment used, instructor to patient ratio, training protocols or differences in patient populations (e.g. our patients were slightly older than those of previous investigators[8,9] and may have had higher levels of neuromuscular deconditioning because of earlier intervention post cardiac event).

It seems likely that increases in muscle strength and local muscle endurance of the type reported here would enable cardiac patients to more easily accomplish repeated strength requiring activities of daily living that were extremely fatiguing or impossible before strength training. Strength-trained patients should also benefit by experiencing reduced myocardial oxygen demands for a given load after training, as any load would be a lower fraction of the posttraining 1-repetition maximum than its fraction of the pretraining 1-repetition maximum.[29] This concept is supported by the rating of perceived exertion data. Maximum loads before training were still perceived by the flexibility-trained patients as near maximal, whereas the strength-trained patients reported submaximal perceptions. Further research is needed to determine whether the strength gains from a 12- week program can be sustained for a significant period after the program completion or whether additional maintenance training should be recommended.

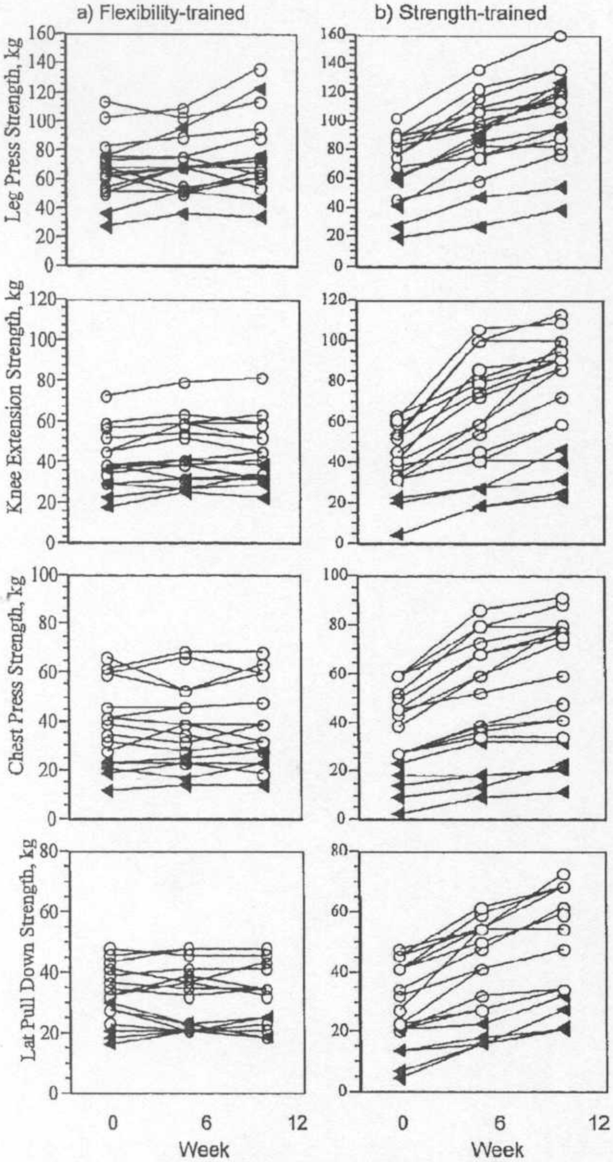

Figure 1. One-repetition maximum muscle strength of individual patients for each of 4 weight training exercises at weeks 0, 6, and 12; (○): men, (◀) : women.

The improvements in maximum treadmill tolerance times in both groups in the present study were similar in magnitude to those reported for both younger[30] and older[31,32] patients completing cardiac rehabilitation aerobic exercise programs. Similar to our findings, greater improvements in maximum ergometer exercise capacity in strength-trained cardiac patients were reported by McCartney et. al.[9] Improved peripheral muscle strength and perfusion,[33] and/or improved self-efficacy[34] may have allowed the strength-trained patients to tolerate higher levels of maximum treadmill exercise tolerance test exercise. In addition, the strength group had a higher mean maximal heart rate on the treadmill test at the end of the study, a factor which, while statistically insignificant, may have positively influenced their exercise time and may represent a higher motivation to perform. The lack of oxygen consumption data in both studies leaves a question as to whether the increases in treadmill time by the strength group represent improvements in fitness (maximum oxygen consumption).

In contrast to the decreased body fat in our strength-trained patients, Crozier Ghilarducci et al.[8] reported no significant changes in body composition after high-intensity strength training in cardiac patients. However, most studies in healthy older populations report that high-intensity strength training decreased body fat[35,36] and led to small increases in lean tissue mass.[37] The loss of fat in the trunk region may decrease the risk of coronary heart disease and diabetes in strength trained patients.[38] The greater loss of body fat in the strength group may reflect an increased motivation by subjects to control their calorie intakes, but neither the trend to increased lean mass in the strength group nor the greater mean weight loss in the flexibility group are consistent with a greater reduction in calorie intake in the strength group. More likely, the greater loss of body fat was associated with increased total energy expenditure from some combination of the training energy expenditure, increased physical activity and training induced increases in resting metabolic rate.[36] In addition to the benefits of loss of body fat with strength training, increases in lean tissue should enhance functional capacity[39] and improve health status. The improvements in the flexibility of our strength-trained subjects contrast with published data showing that strength training impairs flexibility,[40] but are consistent with the data of Trash and Kelly.[18]

Our lack of complications during the more than 400 patient strength-training sessions is consistent with previously published data.[1,8,9] However, the nearly 50% of the eligible population who chose not to enroll in the study may have been significantly less healthy or less motivated than the study population, resulting in a possible bias when compared with the average cardiac rehabilitation patient. Additional data on physiologic responses to high-intensity strength training are needed to assess whether there are significant cardiac risks of the training to the general population of cardiac rehabilitation patients, including those patients specifically excluded in this study. However, it is our experience that adding a high-intensity strength training program such as we describe in this study to the aerobic training of a cardiac rehabilitation program requires limited patient time, is well tolerated, and does not require excessive expenditures for equipment. Exercise prescriptions should include instructions regarding the number and type of exercises, training intensity, sets and repetitions, rest periods, the times per week, the number of weeks, and patient education on proper exercise movement and breathing.[1,2,41] Until more patient data are available supporting the safety of high-intensity strength training in this population, we recommend that professionals such as an exercise specialist or a physical therapist supervise the training of cardiac patients to ensure against complications from inappropriate training techniques as well as to be assured of the preparedness of the staff should a cardiac problem occur. Additional research would be needed to determine the optimal strength training regimen (e.g. number of weeks, frequency per week, number of sets, number of exercises, and type of equipment) for cardiac rehabilitation patients.

Conclusion

Addition of high-intensity strength training to the initial aerobic exercise of cardiac rehabilitation programs provides patients with an opportunity, while in the care of exercise professionals, to aggressively restore the strength they need to complete daily living tasks. In addition, high-intensity strength training may enhance general health status and promote secondary prevention of coronary heart disease by improving body composition and maximum treadmill tolerance time.

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