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Combined aerobic and resistance exercise training improves functional capacity and strength in CHF

ANDREW MAIORANA,[1,2] GERARD O'DRISCOLL,[2,3] CRAIG CHEETHAM,[1] JULIE COLLIS,[1] CARMEL GOODMAN,[1] SARAH RANKIN,[1,2] ROGER TAYLOR,[3,4] AND DANIEL GREEN[1,2,3]
[1]*Departments of Human Movement and Exercise Science and* [4]*Medicine, The University of Western Australia, Nedlands 6907; and* [2]*Cardiac Transplant Unit,* [3]*Department of Cardiology and West Australian Heart Research Institute, Royal Perth Hospital, Perth 6000, Western Australia, Australia*

Maiorana, Andrew, Gerard O'Driscoll, Craig Cheetham, Julie Collis, Carmel Goodman, Sarah Rankin, Roger Taylor, and Daniel Green. Combined aerobic and resistance exercise training improves functional capacity and strength in CHF. *J Appl Physiol* 88: 1565–1570, 2000.—This study examined the effect of a novel circuit weight training (CWT) program on cardiorespiratory fitness, muscular strength, and body composition in 13 patients with chronic heart failure (CHF), using a prospective randomized crossover protocol. Peak exercise oxygen uptake ($\dot{V}O_{2peak}$) increased after the 8-wk CWT program (19.5 ± 1.2 vs. 22.0 ± 1.5 ml·kg^{-1}·min^{-1}, $P < 0.01$), as did exercise test duration (15.2 ± 0.9 vs. 18.0 ± 1.1 min, $P < 0.001$). Submaximal exercise heart rate was lower after training at 60 and 80 W (121 ± 3 vs. 134 ± 5 beats/min, $P < 0.01$) as was rate pressure product, whereas ventilatory threshold increased, from 52 ± 3 to 58 ± 3% of $\dot{V}O_{2peak}$ ($P < 0.05$). CWT also increased maximal isotonic voluntary contractile strength for seven different muscle groups, from 392 to 462 kg ($P = 0.001$). CWT, an exercise prescription specifically targeting peripheral abnormalities in CHF, improves functional capacity and muscular strength in these patients.

chronic heart failure; exercise training; peak oxygen uptake; maximal voluntary contraction; anthropometry

PATIENTS WITH CHRONIC HEART failure (CHF) exhibit an impaired exercise tolerance that severely limits their functional capacity and quality of life. Recent studies suggest that peak exercise oxygen uptake ($\dot{V}O_{2peak}$), a measure of cardiopulmonary exercise capacity, strongly predicts prognosis in CHF, exhibiting a higher positive correlation with mortality than clinical indexes, including pulmonary capillary wedge pressure and left ventricular ejection fraction (19, 27, 28). In addition, improvement in $\dot{V}O_{2peak}$ is associated with enhanced survival in patients awaiting cardiac transplantation (29).

Although central hemodynamic abnormalities initiate and underlie the disease process, measures of cardiac function correlate poorly with exercise capacity in patients with CHF (23). A number of studies reporting skeletal muscle atrophy, changes in fiber type, and bioenergetics favoring anaerobic metabolism and impaired skeletal muscle blood flow suggest that peripheral factors may impair oxygen transport and utilization and may limit exercise performance in CHF (7, 11, 14, 24). The similarity between these peripheral abnormalities and those characteristic of prolonged inactivity or bed rest encouraged initial studies of the effect of exercise training on CHF.

It is now well established that a variety of exercise prescriptions can improve $\dot{V}O_{2peak}$ and other measures of exercise tolerance, reverse skeletal muscle histochemical abnormalities, enhance nutritive blood flow, and possibly improve the quality of life and clinical outcomes of patients with CHF (2, 6, 31, 32). However, the majority of training studies have used aerobic modalities, which improve cardiorespiratory fitness but are not specifically targeted at skeletal muscle. Because skeletal muscle abnormalities are an important limitation to exercise tolerance in CHF patients (24), and muscular strength impacts their capacities to perform daily tasks, we examined the effects of an exercise training program combining aerobic cardiorespiratory exercise with muscular resistance training.

METHODS

Subjects and Screening Measures

Thirteen male subjects were recruited after completing a screening program consisting of a medical history, a medical examination, and hematologic and biochemical profiles, including measurements of serum electrolytes, urea and creatinine, uric acid, liver function, and serum lipids. The following were excluded: smokers and subjects with renal impairment or proteinuria, hepatic impairment, gout, or hyperuricemia, and those with hypercholesterolemia, exercise-induced ischemia, non-insulin-dependent diabetes, or hypertension (see Table 1). Several women were screened but did not satisfy the selection criteria. Those subjects enrolled in the study had the following characteristics: 60 ± 2 (SE) yr old, 26 ± 3% ejection fraction from echocardiography and 28.7 ± 1.0 kg/m^2 body mass index (BMI). Seven subjects had coronary heart disease, six had dilated cardiomyopathy, and all were in New York Heart Association class I to III. Ten patients were in sinus rhythm; the remaining three were in atrial fibrillation. No patient medications were altered during the course of the trial. The numerical breakdown of patients and their medications is as follows: angiotensin-converting enzyme inhibitors, 12; aspirin, 8; warfarin, 7; a diuretic, 6; digoxin, 4; a statin, 5; a nitrate, 3; a K^+ supplement, 3; carvedilol, 2; and an

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Table 1. *Subject characteristics following trained and untrained periods*

	Untrained	Trained
Plasma lipids, mmol/l		
Total cholesterol	4.8 ± 0.3	4.7 ± 0.3
LDL-C	2.8 ± 0.2	2.7 ± 0.2
HDL-C	1.1 ± 0.1	1.0 ± 0.1
Triglycerides	2.0 ± 0.3	1.9 ± 0.3
Mean arterial pressure, mmHg	83 ± 3	84 ± 3
Resting heart rate, bpm	70 ± 4	69 ± 4

Values are means ± SE. LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol; bpm, beats per minute. No significant differences were evident between conditions.

antiarrhythmic drug, 2. The study protocol was approved by Royal Perth Hospital Ethics Committee, and subjects gave written, informed consent.

Experimental Design

Subjects were randomly assigned to either an 8-wk exercise training program or to an 8-wk nontraining period, during which they were instructed not to undertake any formal exercise. Experimental measures were assessed at entry, after 8 wk, and, following crossover, 16 wk after entry. These measures included respiratory gas-exchange assessment at submaximal steady state and at peak workloads during an incremental bicycle ergometer test, muscular strength measurement, and anthropometric assessment of body composition. Familiarization exercise tests and strength assessments were undertaken during a 2-wk lead-in period preceding randomization.

Experimental Measurements

Anthropometric assessment. Body weight and height were measured before each exercise test, and BMI was calculated. Skinfolds were measured using spring-loaded calipers (Harpenden) at eight standard sites (3): triceps, biceps, subscapulare, supraspinale, iliocristale, midabdominal, anterior thigh, and medial calf. All sites were measured in triplicate, with the median score recorded. Muscle girths were similarly recorded at the following standard sites using an anthropometric steel tape (Lufkin): relaxed arm, flexed arm, waist, hip, and thigh. Waist-to-hip ratio was also calculated.

Exercise testing and respiratory gas-exchange variables. Exercise testing was undertaken on an electronically braked bicycle ergometer (Orival 400, Lode), with initial resistance set at 20 W and increased stepwise in 20-W increments every 3 min. Heart rate (HR) and rhythm were continuously recorded by 12-lead electrocardiogram, and blood pressure was measured during the last 30 s of each 3-min stage. Arterial oxygen saturation was continuously monitored using a pulse oximeter (Oxypleth 520A, Oximetrics), and subjects reported their rating of perceived exertion (RPE) on the 15-point Borg scale at the end of each 3 min stage.

The volumes of oxygen consumed ($\dot{V}O_2$) and carbon dioxide produced ($\dot{V}CO_2$) during exercise were calculated from minute ventilation ($\dot{V}E$), measured using mass flow ventilometry and simultaneous mixing chamber analysis of expired gas fractions ($\dot{V}_{max}$, Sensormedics). Gas analyzers and flow probes were calibrated before each test. $\dot{V}O_2$ and $\dot{V}CO_2$ were recorded during the final 40 s of each stage of the test and expressed in liters per minute and relative to body weight ($ml \cdot kg^{-1} \cdot min^{-1}$). $\dot{V}O_{2peak}$ was calculated as the average of the two highest consecutive 20-s periods of gas-exchange data occurring in the last minute before volitional exhaustion, which generally occurred due to leg fatigue or breathlessness. Rate pressure product (RPP) was calculated at the end of each stage of exercise as the product of submaximal HR and systolic blood pressure, while oxygen pulse (O_{2pulse}) was calculated by dividing $\dot{V}O_2$ by HR. The ventilatory threshold (T_{vent}) was assessed by two investigators using a combination of break points in the relationship between $\dot{V}O_2$ and $\dot{V}CO_2$ (the V-slope method) and a systematic increase in the $\dot{V}E/\dot{V}O_2$ without a concomitant increase in $\dot{V}E/\dot{V}CO_2$.

Assessment of muscular strength. Maximal isotonic voluntary contractile strength (MVC) was assessed for 7 distinct muscle groups (MVC_7) using the one-repetition-maximum (1-RM) technique and custom-designed, pin-loaded weight stack resistance equipment (Pulsestar, Cheshire, UK), with minimum 2.5 kg-increments. These machines were also used during the exercise training program. The seven resistance exercises consisted of dual-seated leg press, left and right hip extension, pectoral exercises, shoulder extension, seated abdominal flexion, and dual-leg flexion. Subjects were instructed in correct lifting techniques, to avoid Valsalva maneuver and hand gripping. MVC_7 was calculated as the sum of strength measures on each apparatus.

Exercise Training Regime

The exercise intervention was structured and supervised by an experienced exercise physiologist in a dedicated gymnasium at Royal Perth Hospital. The 8-wk training regime consisted of three, 1-h sessions of whole body exercise each week, concentrating on the large muscle groups of the lower limbs with selected torso and upper body exercises also included. Each of these sessions commenced and concluded with a l0-min warm-up or cooldown and stretching period.

The conditioning phase of each session involved circuit weight training (CWT), a combination of cycle ergometry, treadmill walking, and resistance weight training. An exercise circuit consisted of seven resistance exercises alternated with eight aerobic exercise (cycling) stations. Each exercise was performed for 45 s, with 15-s intervals, signaled by a timer, for the purpose of moving to the next station. To conclude the circuit, subjects spent 5 min walking on a treadmill. The active recovery (aerobic cycling) exercise between resistance stations was designed to maintain exercise HR within the training zone and to facilitate changes in cardiorespiratory fitness. Intensity and duration of the exercise program were progressively increased throughout the 8-wk program, as individually tolerated. Initially, this was done by increasing the number of exercise circuits from one to three, followed by increasing the resistance or cycling load.

Resistance training intensity commenced at 55% of pretraining MVC_7, as determined from initial 1-RM strength tests, and increased to 65% by *week 4* of the program. Cycle ergometry and treadmill walking commenced at 70% of the peak HR observed during the initial incremental exercise test and increased to 85% by *week 6*. During resistance exercise, subjects were instructed to perform one complete exercise every 3 s, resulting in 15 repetitions in 45 s.

Treatment and Analysis of Data

Results are expressed as means ± SE. The responses after exercise training were compared with nontraining responses using Student's paired *t*-tests.

RESULTS

Six of the thirteen patients were randomized to receive exercise training during the first 8 wk, seven

during the last 8 wk. All patients completed 24 exercise sessions. No significant adverse events occurred during exercise testing procedures or training sessions.

Comparison of Subject Characteristics

There were no significant differences in resting HR or systolic, diastolic, or mean arterial pressures after exercise training (Table 1). In addition, no differences were evident in plasma total cholesterol, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, or triglyceride concentrations following training.

Anthropometric Assessment and Muscular Strength

Anthropometric and strength data are presented in Table 2. Exercise training significantly enhanced MVC_7 from 392 to 462 kg ($P = 0.001$). Body weight did not significantly decrease after training, and, although the sum of skinfolds decreased on average, this difference did not achieve statistical significance. Changes in muscle girths, BMI, and waist-to-hip ratio were also insignificant.

Peak and Submaximal Exercise Test Data

Exercise training was associated with significant increase in $\dot{V}O_{2peak}$, from 19.5 ± 1.2 to 22.0 ± 1.5 $ml \cdot kg^{-1} \cdot min^{-1}$ ($P < 0.01$, Fig. 1), also evident when $\dot{V}O_{2peak}$ data were expressed in absolute terms; 1.7 ± 0.1 to 1.9 ± 0.1 l/min ($P < 0.01$). Exercise test duration improved from 15.2 ± 0.9 to 18.0 ± 1.1 min ($P < 0.001$, Fig. 1) and peak O_{2pulse} increased from 0.127 ± 0.006 to 0.144 ± 0.007 $ml \cdot kg^{-1} \cdot beats^{-1} \cdot min^{-1}$ ($P < 0.01$). Peak HR (151 ± 5 vs. 154 ± 6 beats/min, $P < 0.4$), RPP (26,323 ± 1,273 vs. 25,823 ± 1,578, $beats \cdot min^{-1} \cdot mmHg$, $P = 0.6$), and RPE (17 ± 2 vs. 16 ± 1, $P = 0.8$) did not significantly differ after training.

All subjects completed all exercise test workloads up to, and including, 60 W. Eleven patients completed 80 W, eight completed 100 W, and three completed 120 W. HR was significantly lower after training at 60 (108 ± 3 vs. 120 ± 4 beats/min, $P < 0.01$) and 80 W (121 ± 3 vs. 134 ± 5 beats/min, $P < 0.01$). RPP was also significantly lower at 60 (15,153 ± 651 vs. 18,110 ± 1,241 $beats \cdot min^{-1} \cdot mmHg$, $P < 0.05$) and 80 W (18,851 ± 988 vs. 21,363 ± 1,386 $beats \cdot min^{-1} \cdot mmHg$, $P < 0.05$), whereas RPE did not differ at any workload. The T_{vent} occurred at a higher relative proportion of $\dot{V}O_{2peak}$ after training (52 ± 3 vs. 58 ± 3%, $P < 0.05$).

Table 2. *Anthropometric characteristics following trained and untrained periods*

	Untrained	Trained
Body weight, kg	87.3 ± 3.4	86.6 ± 3.2
BMI	28.7 ± 1.0	28.5 ± 0.9
Hip-to-waist ratio	1.04 ± 0.02	1.05 ± 0.02
Sum of 8 skinfolds, mm	138.8 ± 10.0	132.9 ± 8.1
Sum of 5 segment girths, mm	325.6 ± 6.8	322.3 ± 6.3
Muscle strength		
Sum of 7 maximal contractions, kg	392 ± 26	462 ± 22*

Values are means ± SE. BMI, body mass index. Exercise training significantly increased muscular strength (*$P = 0.001$). No significant differences were evident for other variables.

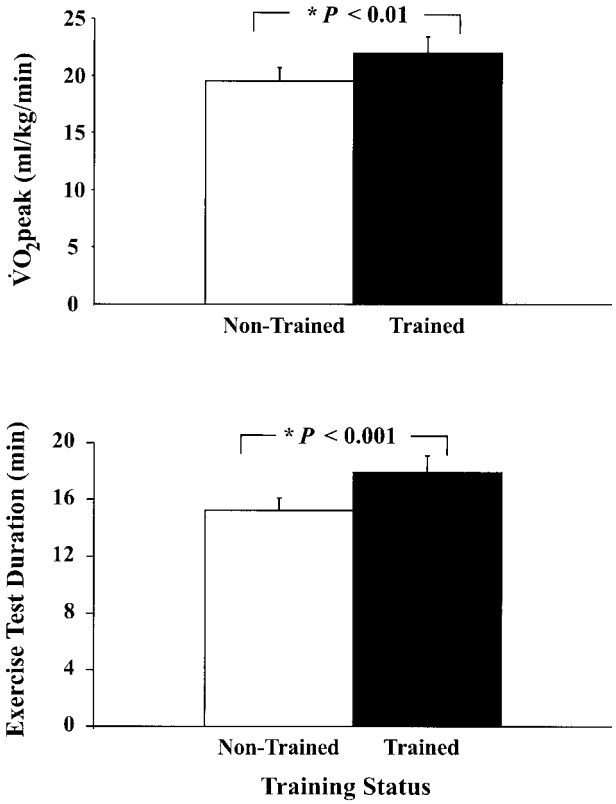

Fig. 1. Peak oxygen uptake ($\dot{V}O_{2peak}$) (*top*), and exercise test duration (*bottom*) after 8 wk of inactivity (open bars) or 8 wk of circuit weight training (CWT) (solid bars) in patients with chronic heart failure. Values are means ± SE. Both $\dot{V}O_{2peak}$ ($P < 0.01$) and test duration ($P < 0.001$) were enhanced after CWT.

Figure 2 depicts trained and untrained $\dot{V}O_{2peak}$ data according to order of administration of exercise training, comparing those who received exercise training first with those who trained second. The effect of exercise training on $\dot{V}O_{2peak}$ was not different between these subgroups ($P < 0.6$). Figure 3 presents a similar analysis of the strength data. The difference between trained and untrained MVC_7 was, on average, less in

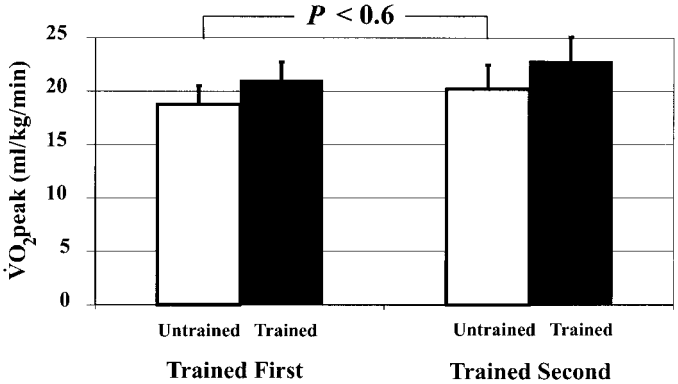

Fig. 2. $\dot{V}O_{2peak}$ after 8 wk of inactivity (open bars) and 8 wk of CWT (solid bars). Values are means ± SE. Untrained $\dot{V}O_{2peak}$ did not differ between the groups, suggesting that the effect of training did not persist.

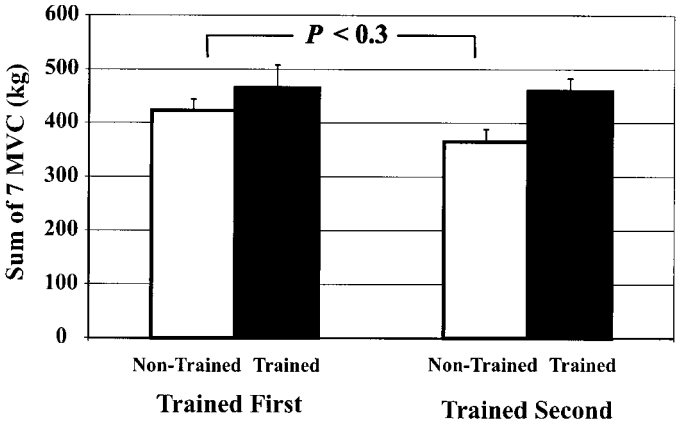

Fig. 3. Maximal isotonic voluntary contractile strength for 7 different muscle groups (MVC_7) after 8 wk of inactivity (open bars) and 8 wk of CWT (solid bars). Values are means ± SE. Untrained MVC_7 was, on average, greater in the group who trained first, suggesting some persistence of the training effect on this parameter.

those who trained first, although not significantly so ($P < 0.3$), suggesting that persistence of the training effect on this parameter was not significant. On this basis, data from both training groups were pooled.

DISCUSSION

Peak exercise capacity, assessed by $\dot{V}O_{2peak}$, is the best predictor of survival in patients with CHF (19). In addition, increases in functional capacity in these patients is associated with improved quality of life and is possibly associated with improved prognosis (2). Exercise training programs aimed at improving exercise capacity in patients with CHF should, therefore, be designed to specifically target the limitations of functional capacity in these patients. In recent years, it has become evident that peripheral skeletal muscle abnormalities are responsible for exercise limitation in many patients with CHF (4, 7). Although previous controlled trials have demonstrated beneficial effects following exercise training, the majority of these have utilized prolonged, repetitive, dynamic aerobic modalities that are often poorly tolerated due to localized muscle fatigue. Other exercise prescriptions specifically targeting the peripheral abnormalities present in heart failure have not been investigated. In the present study, we hypothesized that, due to its interval nature and the rotation between active muscle groups, CWT would be well tolerated by patients, minimize localized muscle fatigue, and combine the beneficial effects of both aerobic conditioning and skeletal muscle strength training. The major finding is that CWT improves cardiorespiratory fitness and muscular strength in patients with CHF. This study is unique because it documents the occurrence of adaptations in response to brief, alternating bouts of aerobic and resistance exercise that involve different muscle groups and are separated by minimal periods of rest.

Respiratory gas analysis during exercise revealed significant improvement in $\dot{V}O_{2peak}$. The magnitude of this improvement (~13%) compares favorably with previous trials that used aerobic exercise modalities such as cycling, walking, and running over a time period of similar length (5, 6, 12). Unlike many of these previous trials, all patients in this trial undertook a peak exercise test during the 2-wk lead-in period that preceded the initial experimental measure. This was done to ensure that patients were familiar with the test procedures and that a learning effect did not influence the results. Studies reporting larger improvements in exercise capacity as a result of exercise training have typically taken place over a longer time span or have not reported familiarization procedures (2, 8, 10, 13).

Traditionally, resistance exercise has been avoided in CHF because of fears that it may increase hemodynamic burden, decrease myocardial perfusion, or cause wall motion abnormalities or arrhythmias (21). However, in one study that compared hemodynamic responses to both resistance exercise and continuous aerobic exercise (cycling) of similar relative intensities, the resistance modality was associated with favorable responses (22). In addition, studies performed after myocardial infarction indicate decreased ischemia during resistance when compared with aerobic exercise, possibly due to improved coronary artery filling as a result of increased diastolic pressure in combination with decreased HR (21). In accordance with these findings, it should be noted that the exercise modality in the present study, a moderate-intensity resistance training program, was well tolerated by closely supervised and monitored patients and resulted in no adverse events.

A recent nonrandomized trial that investigated the effects of high-intensity knee extensor exercise in CHF patients reported significant improvements in muscle strength, capillarization, and oxidative capacity of the trained muscle group (16), indicating improvement in localized skeletal muscle function in response to training. However, peak exercise responses were not measured in that trial. The present study is the first to demonstrate that a circuit training program structured with alternating bouts of aerobic and resistance exercise, separated by minimal rest periods, maintains HR and $\dot{V}O_2$ within an effective training zone throughout the exercise session, leading to an enhancement of aerobic capacity. In contrast, consecutive bouts of resistance exercise alone, separated by relatively long periods of rest, have not been shown to have an effect on aerobic capacity.

Improvement in submaximal data was also evident following CWT. RPP was lower after training, suggesting that myocardial oxygen demand decreased. This may have resulted from increased peripheral vasodilation and, consequently, decreased afterload following exercise, a result supported by recent findings that exercise training improves resistance vessel dilatation in CHF (18). Because the vascular benefits of exercise training are not limited to the skeletal muscle bed involved in the exercise stimulus, it is also possible that epicardial coronary vasodilation during exercise increases after training. In addition to changes in RPP, submaximal HR was lower after training, further suggesting improved cardiorespiratory fitness. Finally, the

percentage of $\dot{V}O_{2peak}$ at which T_{vent} occurred increased significantly after training, indicating that patients could train at higher submaximal exercise intensities before the onset of blood lactic acid accumulation.

The increase in muscular strength is also of clinical relevance. Patients with CHF exhibit skeletal muscle atrophy and impaired muscular strength (15, 17, 20, 26). Although previous studies have reported changes in skeletal muscle histology and biochemistry as a result of training (1, 9, 25, 30, 31), ours is the first controlled trial to report generalized improvement in skeletal muscle strength; seven isolated muscle strength sites were assessed, with improvement evident at each. This has important implications for patient capacity to perform tasks of daily living, many of which are dependent on muscular strength, and indicates that CWT is an effective modality for improving peripheral muscle function in addition to $\dot{V}O_{2peak}$.

It is possible, from the results of this crossover trial, to determine whether the effects of CWT on strength and $\dot{V}O_{2peak}$ persist after the cessation of exercise. The data suggest that improvement in strength persists longer than that for $\dot{V}O_{2peak}$, although the effect of CWT was not fully sustained for either. Therefore, it is likely that patients need to maintain a regular regime of exercise to preserve the benefits of CWT, although previous data suggest that such benefits may be sustained with a reduced exercise commitment (2).

It is pertinent to mention certain limitations of the present study. Patients with severe heart failure were not included; thus the results cannot necessarily be extrapolated to those subjects. In addition, most patients were not receiving β-blocking therapy because the study commenced before these agents were frequently administered for the management of heart failure. Although several women were screened for the study, none satisfied the inclusion criteria, and the conclusions may have no pertinence to women. Finally, the use of sophisticated imaging techniques, such as dual-energy X-ray absorptiometry, may have provided more precise information regarding changes in body composition. Traditionally, skinfold and girth measurements have been accepted for this purpose, and we took care to collect multiple measures from a range of sites. However, the increase in muscle strength we observed does not necessarily infer increased muscular hypertrophy.

In conclusion, it is now widely acknowledged that exercise training is an important component of the management of CHF that can improve functional capacity, quality of life, and prognosis. The results of this study suggest that CWT, an exercise training modality that specifically targets the peripheral limitations to exercise tolerance evident in patients with CHF, improves cardiorespiratory fitness and skeletal muscle strength. Although our program was formal and structured, a simplified program combining aerobic and resistance components should provide similar benefits that could be associated with improved prognosis and an increased capacity to perform tasks of daily living.

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Address for reprint requests and other correspondence: D. Green, Dept. of Human Movement, The Univ. of Western Australia, Nedlands 6907, Western Australia, Australia.

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