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Effect of Resistance Training on Physical Disability in Chronic Heart Failure

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Abstract

Purpose—Patients with chronic heart failure (CHF) report difficulty performing activities of daily living. To our knowledge, however, no study has directly measured performance in activities of daily living in these patients to systematically assess their level of physical disability. Moreover, the contribution of skeletal muscle weakness to physical disability in CHF remains unclear. Thus, we measured performance in activities of daily living in CHF patients and controls, its relationship to aerobic capacity and muscle strength and the effect of resistance exercise training to improve muscle strength and physical disability.

Methods—Patients and controls were assessed for performance in activities of daily living, self-reported physical function, peak aerobic capacity, body composition and muscle strength before and after an 18-wk resistance training program. To remove the confounding effects of several disease-related factors (muscle disuse, hospitalization, acute illness), we recruited controls with similar activity levels as CHF patients and tested patients >6 months following any disease exacerbation/hospitalization.

Results—Performance in activities of daily living was 30% lower ($P<0.05$) in CHF patients versus controls and was related to both reduced aerobic capacity ($P<0.001$) and muscle strength ($P<0.01$). Moreover, resistance training improved ($P<0.05$ to <0.001) physical function and muscle strength in patients and controls similarly, without altering aerobic capacity.

Conclusion—CHF patients are characterized by marked physical disability compared to age- and physical activity-matched controls, which is related to reduced aerobic capacity and muscle strength. CHF patients respond to resistance training with normal strength/functional adaptations. Our results support muscle weakness as a determinant of physical disability in CHF and show that interventions that increase muscle strength (resistance training) reduce physical disability.

Keywords

cachexia; sarcopenia; skeletal muscle; quality of life

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CONFLICTS OF INTEREST
The authors recognize no conflicts of interest.

INTRODUCTION

Patients with chronic heart failure (CHF) have high rates of physical disability, based on self-reported difficulty in performing of activities of daily living (29). An impaired ability to perform simple everyday tasks reduces patients' quality of life, increases health care costs by increasing the need for supportive services and is an independent predictor of mortality (10, 11). Knowledge of the factors that determine physical function in CHF patients, therefore, has implications for improving quality of life and prognosis.

The ability to perform daily activities involves a complex interaction of physiological and psychological factors (6). In CHF patients, to our knowledge, no study has directly assessed disability by measuring performance in a range of common activities of daily living that encompass the physical skills required to function independently. The one exception is that many studies have evaluated 6 minute walk distance (28), a surrogate of aerobic fitness (13), as an index of functional capacity in daily activities. Arguably, this historical focus on indices of cardiorespiratory fitness is reasonable considering that the hallmark symptoms of CHF--dyspnea and fatigue --are emblematic of a reduction in aerobic capacity. Walking endurance, however, is only one aspect of physical function in daily activities. Moreover, performance in many daily activities has been shown to be poorly correlated to aerobic fitness in some cardiac disease populations (24), arguing that factors other than aerobic fitness likely contribute to physical disability. Compared to the number of studies that have measured indices of aerobic fitness, the relative paucity of studies examining muscle strength is surprising considering evidence for marked muscle weakness in CHF patients (14, 38) and the fact that many common daily activities (eg, lifting objects, rising from a seated position, climbing stairs, etc) are strongly dependent on muscle strength (3, 7, 30). Despite the importance of muscle strength, its role in determining physical function in real-world activities of daily living in CHF patients has not been examined.

Numerous studies have demonstrated that aerobic training can improve exercise capacity, walking endurance and clinical status in CHF patients (15, 16, 25). Despite these beneficial effects, aerobic training generally does not alter muscle strength (22) and, therefore, would not likely remediate aspects of physical disability associated with muscle weakness. Resistance-type exercise, in contrast, improves muscle strength, with little or no effect on aerobic fitness (32). Therefore, resistance exercise training may provide unique functional benefits to CHF patients. Additionally, it provides an experimental paradigm to evaluate the unique effects of improvements in muscle strength on physical function. Comparatively few studies, however, have examined the singular effects of resistance training in CHF patients, with most examining the combined effects of resistance and aerobic training (see for review (8, 34)). Perhaps more importantly, aside from assessment of walking endurance (32), no study to our knowledge has explored the effects of resistance training on directly measured performance of activities of daily living to evaluate the real-world, functional benefits or resistance training in CHF patients.

The purpose of this study was two-fold: 1) to compare performance in activities of daily living in CHF patients and healthy controls of similar age and habitual physical activity level to evaluate the extent of physical disability and its relationship to aerobic capacity and muscle strength; and 2) to determine the effects of 18 weeks of resistance training on muscle strength and performance of activities of daily living. We hypothesized that CHF patients would be characterized by considerable physical disability and that this would be related to both diminished aerobic capacity and muscle weakness. Additionally, resistance exercise training effectively increases muscle strength and the ability to perform activities of daily living independent of alterations in aerobic fitness. To isolate the effects of CHF, we recruited patients to limit the confounding effects of age, muscle disuse and acute disease

exacerbation. In light of these considerations, our results likely reflect the unique effects of CHF on physical disability, muscle strength and their response to training, rather then the effects of age, muscle disuse or acute illness.

METHODS

Subjects

Thirteen patients (9 men, 4 women) with CHF were recruited. Ten patients (7 men, 3 women; mean ± SEM; age: 73.4 ± 2.4 yrs; height: 170.0 ± 2.7 cm; weight: 95.6 ± 9.4 kg) completed the trial and were included in the analyses. Of these ten patients, 7 were characterized by systolic failure with diminished ejection fraction (EF; 32 ± 2%, range = 28 to 38%), while 3 subjects had preserved systolic function (EF>40; 50 ± 3%, range = 44 to 53%). One patient was classified as New York Heart Association class I, 6 as class II and 3 as class III. The etiology of CHF was ischemic in 4 patients and idiopathic in 6. Patients were excluded if they had: 1) aute myocardial infarction or unstable angina within 3 months, 2) atrioventricular block greater than first degree without a functioning pacemaker, 3) severe hepatic or renal disease, 4) exercise-limiting peripheral vascular disease or orthopedic problems that limit their ability to perform exercise, 5) inflammatory arthritis or autoimmune disease or 6) an active neoplastic process or history of cancer within 5 yrs. To limit any effects of acute disease exacerbation/hospitalization on muscle performance and physical function, we included only patients who were clinically stable and had not been hospitalized for at least 6 months prior to study. Medications were maintained unchanged during the study and included: angiotensin-converting enzyme (ACE) inhibitors (100%), beta-blockers (90%), diuretics (50%) and HMG CoA reductase inhibitors (40%) and one female patient was receiving levothyroxine. The population included 3 patients with non-insulin dependent diabetes mellitus. Plasma creatine kinase levels were normal in all patients. All were weight-stable (± 2 kg during the prior 6 months), non-smokers and were not taking sex steroid replacement therapy.

All eleven (6 men, 5 women; age: 72.1 ± 2.1 yrs; height: 167.3 ± 3.4 cm; weight: 85.5 ± 5.4 kg), healthy volunteers self-reported being sedentary to minimally-active (≤2 sessions of ≥30 min of exercise/week) and were not participating in any exercise or weight loss programs. This recruitment criteria was included to obtain a control group with habitual activity levels that match the reduced level of physical activity in the CHF population (36). Controls were non-smokers, weight-stable and not taking sex steroid replacement therapy and had no signs or symptoms of heart failure, coronary heart disease or diabetes. Left ventricular EF (>55%) was normal (62 ± 4%; range= 57 to 70%), as were blood counts/ biochemical values. Five controls had hypertension. Three were treated with diuretics (27%) and two with ACE inhibitors (18%). All were normotensive at testing and showed no evidence of left ventricular hypertrophy or atrial enlargement by echocardiography. Three controls were on stable doses of HMG CoAs (27%) and one female was on levothyroxine. Plasma creatine kinase levels were normal in all controls.

Written informed consent was obtained from all volunteers and the protocol was approved by the Committees on Human Research at the University of Vermont. Baseline, pre-training data from a sub-set of volunteers in this study have been published in reports of the effects of CHF on whole muscle and single fiber protein content and contractile performance and myosin-actin cross-bridge kinetics (20, 21, 38).

Body composition

Total and regional body composition was assessed by dual energy x-ray absorptiometry (GE Lunar, Madison, WI), as described previously (37). Body composition measurements were not performed on one CHF patient because he exceeded the weight limit of the machine.

Echocardiography

Left ventricular size and function was evaluated by echocardiography (Siemens Accuson Sequoia 512; Siemans Medical Solutions, Malvern, PA). Ventricular volumes and EF were determined by the biplane Simpsons' method (17).

Peak oxygen consumption (peak VO_2)

Respiratory gas analysis (SensorMedics Vmax 29c metabolic cart; Yorba Linda, CA) was performed during treadmill exercise until volitional exhaustion using the Naughton protocol (23).

Directly measured performance in activities of daily living

The Physical Functional Performance Test-10(PFP-10) is a validated battery of tests based on ordinary activities of daily life, performed at a self-paced, maximal effort (12). The PFP-10 tasks include: 1) transferring a weighted pot; 2) putting on and removing a jacket; 3) picking 4 scarves off the floor; 4) maximal overhead reach; 5 & 6) unloading and loading a washing machine and dryer; 7) getting down to a seated position on the floor and returning to a standing position; 8) grocery carry; 9) stair climbing; and 10) 6-minute walk. All tasks are performed with supervision and are quantified by time, distance and/or weight carried. Each task is scored 0–100, based on an empirically derived range of individual functional abilities (12). The test yields a total score (0–100) that is the average of the following 5 separate physical domains scores: 1) upper body strength; 2) lower body strength; 3) balance and coordination; 4) flexibility and 5) endurance. The PFP-10 has been validated over a broad range of functional levels to assess physical performance in healthy and diseased elderly (12), including older cardiac patients (3).

Self-reported quality of life/physical function

The Medical Outcomes Study Short-Form-36 (MOS SF-36) was used to assess "self-reported" physical function and quality of life, as described (2, 35), and has been validated in CHF patients (19).

Exercise Protocol

Approximately 1 week following baseline evaluations, volunteers entered an 18-week resistance training program (3 X/wk). The resistance exercise training program was designed to improve whole body skeletal muscle strength with the goal of determining whether improvements in muscle strength can improve functional performance in activities of daily living. The training intensity was set to 80% of 1RM commensurate with guidelines for improving muscle strength and inducing hypertrophy (5). The range of exercises, the progression of exercise volume and intensity and the length of the program were derived from our previous studies in healthy elderly and those with cardiac disease (1, 4, 9), and are supported by data from others (32). Primary goals were to achieve significant strength gains and functional improvements. Additionally, we wanted the length of the program to be similar to most cardiac rehabilitation programs. Because this is the first study to assess the impact of resistance training on directly measured physical function in activities of daily living, our data have relevance for the clinical utility of resistance training for improving functional independence.

Subjects were asked to not undertake any additional exercise during the study period. Compliance with the protocol was excellent (91%) and was similar between CHF and control groups (47.6 ± 2.1 vs. 48.9 ± 0.9 sessions/patient, respectively, P=0.55). The original CHF cohort consisted of 13 patients. Three heart failure patients did not complete the training study: one because he became injured in a motor vehicle accident, another because of acute worsening of his heart failure and the last for personal reasons.

The resistance training intervention was individually designed based on 1-repetition maximum (1 RM; maximum weight an individual can lift once), as described in detail (4). At baseline, 1 RM was determined on each of 7 exercises, including: 1) leg extension; 2) leg press; 3) leg curls; 4) shoulder press; 5) bench press; 6) bicep curls; and 7) lateral pull-downs. A "composite 1 RM" was calculated by tallying the 1 RM for each of the 7 different exercises to provide an index of whole body muscle strength. Each session was supervised by an exercise physiologist or physical therapist. The progression of the program was gradual in both intensity and volume of exercise to orient the volunteers to the resistance training stimulus. The intensity of exercise began at 50% 1RM for 1 set of 10 repetitions during the first week. On week 2, the intensity was increased to 60% for 2 sets of 8 repetitions. On week 3, the intensity was increased to 70% for 3 sets of 8 repetitions. By week 4, all volunteers were exercising at 80% of 1RM for 3 sets of 8-repetitions. This ensured that the volunteers were exposed to the 80% 1RM stimulus for at least a 3 month period. 1RM was reassessed every 2 wks to account for improvements in strength. At the completion of the training program, all baseline evaluations were repeated, including 1 RM measurements. The only exception was echocardiography, which was repeated in CHF patients, but not controls.

Statistic Analysis

Unpaired *t*-tests were used to compare baseline values between groups. Baseline 1RM was compared between groups after statistical control for body weight using analysis of covariance. Pearson correlations were used to measure associations between variables. Repeated measures analysis of variance was used to assess group, training and group X training interaction effects. Paired t-tests were used to evaluate the effect of training on cardiac function in CHF patients. All statistical analyses were carried out using Stat View 5.01 (SAS Institute, Cary, NC).

RESULTS

Baseline data

At baseline, study groups were similar by age, sex distribution, body size and composition and physical activity; whereas, as expected, CHF patients had lower EF and peak VO_2, and greater left ventricular end systolic volume (all P<0.001; Table 1).

Muscle strength (1 RM) was similar between groups for all exercises, as was the composite 1 RM (Table 2). The lack of difference in muscle strength between groups was explained by variation among groups in body size. When composite 1RM was statistically controlled for body mass, whole body muscle strength was significantly reduced by 24% in CHF patients vs. controls (222.9 ± 20.2 vs. 293.5 ± 19.3 kg; P=0.023). Similarly lower (25%) muscle strength was found in CHF patients when leg extension measurements were adjusted for body mass (38.0 ± 4.1 vs. 50.6 ± 3.9 kg; P=0.042), in keeping with our prior report examining knee extensor strength in a sub-set of this cohort using dynamometry (38). Additionally, after adjustment for body weight, 1RM for bench press (−28.9%; P=0.031), shoulder press (−34%; P=0.05) and leg press (−15%; P=0.05) were lower in CHF patients; whereas, there was a strong trend towards a lower 1RM for leg curl (−37%; P=0.061).

Although no differences were found for 1RM values for lat pull down (P=0.125) or arm curl (P=0.172).

CHF patients had a lower (P<0.01) total PFP-10 score at baseline (Table 3), because of reduced (P<0.05 to P<0.01) lower body strength, balance and endurance; whereas, upper body strength and flexibility were similar between groups. Additionally, baseline 6 min walk distance was reduced (P<0.001) in CHF patients. CHF patients self-reported lower physical and mental component summary scores as a result of lower (P<0.05 to P<0.001) scores for: physical function, role-physical, bodily pain, general health, vitality, and social function (P<0.05 to P<0.001; Table 4).

Correlation analysis evaluated which physiological and psychological factors predict reduced physical function (Table 5). We examined both measured (i.e., PFP-10) and self-reported physical function (i.e., MOS SF-36 sub-domain) as indices of true physiological capacity for daily activities and self-perceived functional capacity, respectively, and also evaluated predictors of 6-minute walk performance, because it is a commonly used index of functional capacity in CHF populations. For directly measured functional capacity (ie, PFP-10 total score), peak VO_2 (P<0.001), 1 RM composite (P<0.01) and MOS SF-36 mental component score (P<0.05) were significant correlates. For 6 min walk distance, the correlates were similar to PFP-10 total score, but also included EF (P<0.01). For self-reported physical function, peak VO_2, measured physical functional capacity (ie, PFP-10 total score), MOS SF-36 Mental Component Score and ejection fraction (all, P<0.01) were significant correlates, whereas 1RM composite was not.

Resistance training data

No training or group by training effects were observed for body weight, adiposity, appendicular skeletal muscle mass or peak VO_2 (Table 1 and Figure 1). Resistance training increased (P<0.01 training effect) arm fat free mass and there was a trend toward an increase in fat free mass (P=0.057). CHF patients showed a greater increase in fat free mass with training when compared to controls (P=0.03 group X training effect). For CHF subjects, there were no changes in LV volumes or EF with training.

Resistance training resulted in significant improvements in all 1 RM measures, including composite 1 RM (all, P<0.001 training effect; Table 2 and Figure 1) and these improvements did not differ between groups (ie, no group X training effect).

Total PFP-10 score improved with training in both groups (P<0.001 training effect; Table 3 and Figure 1), as a result of improvements in upper and lower body strength and balance scores (P≤0.02 to 0.001); whereas, no improvements in upper body flexibility or endurance were noted. Training-induced increases in performance of activities of daily living were similar between groups (ie, no group X training effect). Training increased 6 minute walk distance in both groups similarly (P<0.05). Conversely, there was no training effect on MOS SF-36 scores (Table 4), although there were trends toward improvement in the physical function and mental health sub-domains (P=0.06 and P=0.08, respectively).

DISCUSSION

Our study is novel because it is the first to directly measure the extent of physical disability in common activities of daily living in CHF patients and its response to resistance exercise training. Our results demonstrate that CHF patients are markedly impaired in their physiological capacity to perform activities of daily living compared to controls of similar age and habitual physical activity level and that this impairment is associated with both reduced aerobic capacity and muscle weakness. Furthermore, resistance training is an

effective intervention to enhance muscle strength and performance in activities of daily living. In light of our careful selection of volunteers to control for a variety of confounding disease-related factors, we are confident that group differences in physical function and muscle performance and their response to training reflect the unique effects of heart failure. Collectively, our findings support a role for muscle strength as a determinant of the physiological capacity to perform daily activities in CHF patients.

Although many studies have reported reduced walking endurance in CHF patients (ie, 6 min walk test (28)), this measure reflects but one facet of daily physical functioning. In the current study, we directly measured performance in a variety of real-world, daily activities that better reflect the range of physical attributes (ie, strength, endurance, balance and flexibility) required to function independently. Since CHF patients are profoundly inactive (27, 36), it could be argued that the extent of physical disability we observed is related to the secondary effects of chronic muscle disuse. This is unlikely since we recruited controls with similar habitual physical activity levels as CHF patients (Table 1) and tested patients distal to periods of acute muscle disuse (ie, hospitalization). Thus, we are confident that the observed functional differences are attributable to the effects of the CHF syndrome, rather than muscle disuse.

From a physiological standpoint, two of the most important factors determining physical function in the elderly are muscle strength and aerobic capacity (31). Although numerous studies have evaluated reduced aerobic capacity in CHF, the role of muscle weakness in physical disability, to our knowledge, has not been investigated. The focus on aerobic capacity is likely due to the fact that patients perceive their physical limitations through symptoms such as dyspnea and fatigue, which are emblematic of reduced aerobic fitness. In support of this notion, we found that self-reported functional capacity, as measured by the MOS SF-36, was correlated to aerobic capacity, but not to muscle strength. In contrast, our direct measurement of performance in activities of daily living (ie, PFP-10 score) was related to both aerobic capacity and muscle strength, substantiating a role for muscle strength as a determinant of physical function. These results highlight an often overlooked limitation of indices of self-reported physical function, which have formed the basis for nearly all of our current estimates of physical disability in the CHF population; namely, that they measure the patient's perception of their limitations, rather than their actual capacity to perform activities. Perhaps more importantly, although all of the metrics used in this study suggest a similar relative degree of physical disability (~30% lower functional capacity in CHF patients), the fact that their underlying determinants differ substantially (Table 5) demonstrates that each measure reflects a unique mix of the physiological and psychological determinants of physical disability. Our study provides the most rigorous assessment of the determinants of disability in CHF to date since we employed direct assessments of performance in activities of daily living as an index of physical disability. Our findings demonstrate that, as in populations of elderly without cardiac disease (31), muscle weakness conspires with diminished aerobic fitness to limit the capacity to perform daily activities in CHF.

Although it was not a goal of our study, the relative contribution of aerobic exercise intolerance and muscle weakness to physical disability deserves comment. Based solely on the strength of the statistical relationships, reduced aerobic capacity appears to be the more important determinant. However, peak VO_2 measurements reflect more than just aerobic fitness level. For instance, muscle strength is a strong correlate of peak VO_2 (14), which is likely explained by the fact that muscle force production is a determinant of power output during treadmill exercise (ie, contractile force x velocity = muscle power output). In this sense, the correlation between peak VO_2 and physical function reflects, in part, the effects of muscle strength. Additionally, because peak VO_2 serves as a physiological index of disease

severity in CHF patients (18, 39), its correlation to PFP-10 reflects, in part, the fact that HF patients were more functionally impaired. Both of these examples highlight the fact that peak VO_2 has a high degree of colinearity with other determinants of physical disability, which complicates our ability to define its true contribution. There are statistical approaches to account for these problems of colinearity (33) and partial correlation analysis shows that control for the effects of 1RM composite score diminishes the relationship between peak VO2 and PFP-10 score (partial r=0.695; P<0.01). However, caution is urged with drawing physiological conclusions from such statistical analysis that seeks to circumvent the fact that our study was not designed specifically to address this issue. Instead, we believe that delineation of the unique contributions of aerobic fitness and muscle strength to physical disability should be derived from studies that are carefully designed for this purpose.

Building on the last point, with respect to the unique effects of muscle strength on physical functional performance (ie, PFP-10 score), if the aforementioned correlation between muscle strength and function in daily activities reflects an underlying cause-effect relationship, we would predict that interventions which increase muscle strength, such as resistance training, would improve physical function. Consistent with this hypothesis, performance of activities of daily living was increased in CHF patients following 18-weeks of resistance training (Figure 1). In fact, improvements were similar to controls, suggesting that CHF does not impair neuromuscular adaptations to training in patients with mild to moderate disease. Perhaps more importantly, because peak VO_2 was not altered with training, improvements in physical function are likely explained primarily by enhanced muscle strength, rather than altered aerobic capacity. We acknowledge that our resistance training program may have improved other factors that determine physical function, such as balance and flexibility. Thus, we cannot completely ascribe the improvements to improvements in muscle strength alone. Nonetheless, together with our correlation analyses, these findings strongly support a role for skeletal muscle strength as a determinant of performance in activities of daily living.

Participants with CHF had baseline total PFP-10 scores of 48.5, which is well below the score of 57 suggested by Cress et al. (12) as a threshold for physical disability. Although physical function improved with training in CHF patients to 53.9, it remained below this putative threshold. The inability of our training regimen to correct physical disability may relate to its short-term nature (4 months). The extent of muscle hypertrophy achieved during this period was minimal. Programs of longer duration that stimulate hypertrophy would certainly yield greater strength and functional benefits. Additionally, a singular intervention of resistance training may not be sufficient to correct disability in CHF patients because physical function is partially dependent on cardiorespiratory fitness (Table 5), which was not altered by our training program. Exercise regimens that combine both resistance and aerobic training may be needed to optimize functional improvements. Parenthetically, the fact that we observed no training-induced increase in physical activity level in CHF patients (via accelerometry) suggests that patients did not increase the amount of activity in their daily life despite their improved physiological capacity (ie, PFP-10 score). This result may be explained by psychological barriers to performing daily activities in CHF patients (26) and suggests the need for cognitive behavioral training to accompany exercise interventions so that patients can exploit their improved physiological capacity to reduce physical disability in their everyday life.

Limitations to the current study include the small number of subjects and a lack of participants randomized to a non-exercise control group. Importantly, our intent was not to conduct a randomized, controlled trial of the clinical efficacy of resistance training, as numerous studies have examined resistance training in CHF (8, 34). Instead, we sought to examine the role of muscle strength as a determinant of physical disability in CHF patients

and the effects of an exercise intervention that specifically enhances muscle strength to improve physical function. While we compromised statistical power with our approach, the rigorous selection criteria allowed us to experimentally remove a number of confounding factors from baseline disability levels and their responsiveness to training, a stronger experimental approach than post hoc statistical adjustment. Lending credibility to our results, the strength and functional (eg, 6 minute walk) improvements observed in our study were similar to those found in randomized, controlled trials utilizing similar intensity resistance training in CHF patients (32). Nonetheless, larger randomized, controlled trials are needed to assess the clinical utility of resistance training, alone and in combination with aerobic exercise, in reversing or delaying the onset of disability and improving clinical outcomes in CHF patients. Additionally, future studies should assess physical function and clinical outcomes following cessation of resistance exercise interventions to assess its long-term effects.

In summary, the ability to perform necessary activities of daily living is markedly impaired in CHF patients and is related to reduced aerobic capacity and muscle weakness. Resistance training is an effective intervention to improve strength and direct measures of physical function in CHF patients and these effects are independent of alterations in aerobic fitness. Collectively, these findings strongly support a role for muscle strength in determining the physiological capacity to perform activities of daily living. From a clinical perspective, our results suggest that interventions designed to lessen physical disability in CHF patients should consider improving muscle strength as one of their goals.

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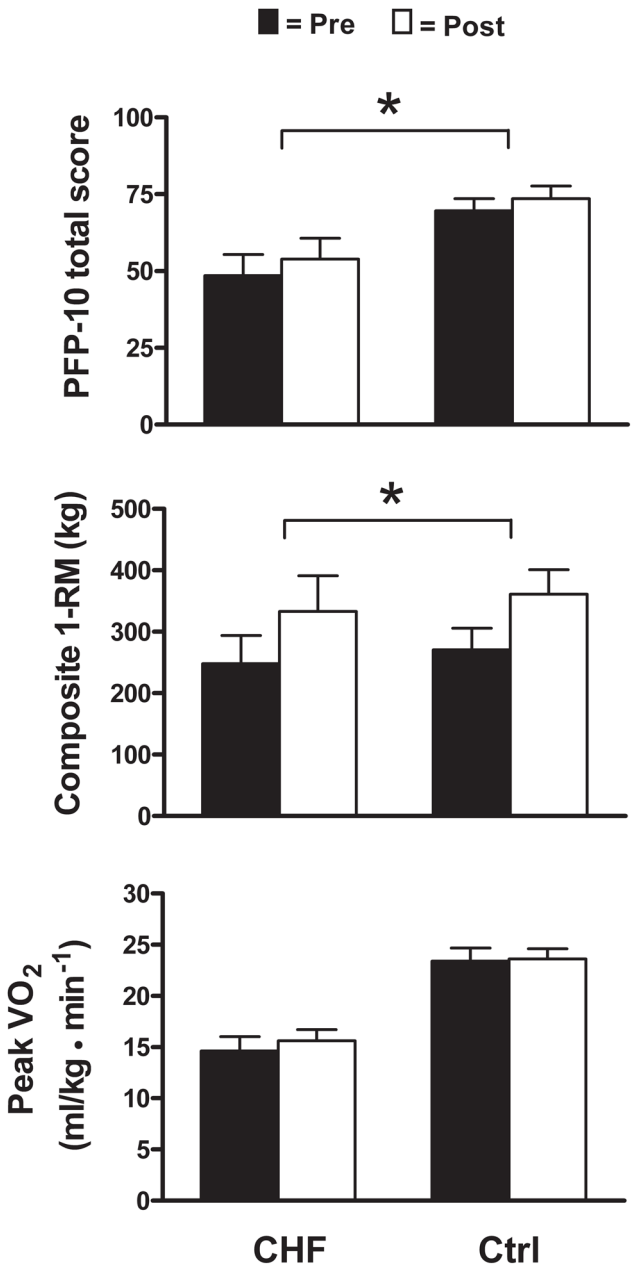

Figure 1.

Baseline (ie, pre; closed bars) and post-training (open bars) data for performance in activities of daily living (PFP-10 total score), composite 1 RM and peak VO_2 in chronic heart failure (CHF) patients and controls (Ctrl). Data were analyzed by 2 × 2 repeated measures analysis of variance to examine group, training and group by training interaction effects. Note that baseline PFP-10 and peak VO_2 were lower in CHF patients compared to controls ($P<0.01$ and $P<0.001$, respectively) and that composite 1RM was lower in CHF patients compared to controls ($P<0.05$) when statistically adjusted for body size. *, $P<0.01$ for training effect.

Table 1

Physical and clinical characteristics, aerobic capacity and physical activity levels and their response to resistance exercise training.

	Control		Heart Failure		P Value		
	Pre	Post	Pre	Post	Group	Training	Group x Training
Age (years)	72.1 ± 2.1		73.4 ± 2.4				
Sex (Male/Female)	6/5		7/3				
Height (cm)	167.3 ±3.4		170.0 ± 2.7				
Weight (kg)	85.5 ± 5.4	85.0 ± 5.1	95.6 ± 9.4	96.0 ± 9.1	0.32	0.94	0.44
Fat mass (kg)	31.7 ± 2.1	30.8 ± 2.0	35.3 ± 4.6	35.6 ± 4.5	0.38	0.58	0.32
Fat free mass (kg)	51.0 ± 4.3	50.9 ± 4.4	51.9 ± 5.0	53.2 ± 5.2	0.81	0.06	0.03
Fat (%)	38.9 ± 2.4	38.1 ± 2.5	39.5 ± 2.6	39.5 ± 2.7	0.78	0.11	0.13
Leg fat free mass (kg)	15.7 ± 1.4	15.7 ± 1.3	14.3 ± 1.5	14.4 ± 1.3	0.50	0.95	0.72
Arm fat free mass (kg)	5.5 ± 0.6	5.7 ± 0.6	4.7 ± 0.6	5.0 ± 0.6	0.39	0.001	0.44
Appendicular muscle mass (kg)	21.3 ± 1.9	21.4 ± 1.9	19.1 ± 2.1	19.4 ± 1.9	0.47	0.24	0.57
Ejection fraction (%)	62.3 ± 1.2 ≠	NP	37.7 ± 3.2	37.9 ± 4.5			
Left ventricular end diastolic volume (mL)	87.0 ± 13.7	NP	118.4 ± 9.4	122.7 ± 14.9			
Left ventricular end systolic volume (mL)	34.6 ± 6.1 ≠	NP	75.2 ± 8.3	79.9 ± 13.8			
Stroke volume (mL)	52.4 ± 7.8	NP	43.2 ± 4.0	42.8 ± 5.6			
Peak VO_2 ($mLO_2*kg^{-1}*min^{-1}$)	23.4 ± 1.3 ≠	23.6 ± 1.0	14.6 ± 1.4	15.6 ± 1.1	0.0001	0.24	0.47
Accelerometer (kcal/day)	248.6 ± 40.3	285.8 ± 55.0	269.5 ± 41.4	214.5 ± 33.7	0.63	0.80	0.19

Data are mean ± SEM for n=11 controls and 10 and patients, except body composition measures, which reflect n=9 CHF patients. NP = not performed.

≠ = P<0.001, differences between groups for pre-training values.

Table 2

Muscle strength measures and their response to resistance exercise training.

	Control		Heart Failure		P Value		
	Pre	Post	Pre	Post	Group	Training	Group x Training
Bench press (kg)	47.9 ± 9.6	73.8 ± 12.0	44.1 ± 9.9	72.7 ± 7.3	0.89	<0.001	0.72
Arm curl (kg)	18.9 ± 3.5	29.1 ± 5.2	17.0 ± 3.5	24.5 ± 4.3	0.60	<0.001	0.29
Lateral pulldown (kg)	37.8 ± 7.3	52.9 ± 5.9	37.5 ± 5.8	50.0 ± 4.5	0.85	<0.001	0.42
Shoulder press (kg)	34.2 ± 13.7	51.5 ± 10.1	30.7 ± 8.5	47.7 ± 8.0	0.78	<0.001	0.96
Leg curl (kg)	18.0 ± 5.9	32.0 ± 4.3	13.8 ± 4.0	25.5 ± 5.2	0.36	<0.001	0.61
Leg press (kg)	66.1 ± 6.9	80.0 ± 3.8	63.9 ± 3.6	73.9 ± 5.8	0.64	<0.001	0.43
Leg extension (kg)	47.9 ± 9.7	70.2 ± 4.7	40.9 ± 7.3	59.1 ± 3.5	0.32	<0.001	0.45
Composite 1 RM (kg) *	271 ± 35	361 ± 40	248 ± 46	333 ± 58	0.69	<0.001	0.79

Data are mean ± SEM. No group differences were found between pre-training values for any measure. Composite 1 RM represents the sum of 1 RM values from each of the 7 different exercises.

* Lower composite 1RM values were found in CHF patients after statistical adjustment for differences in body size (ie, see text in *Results* section).

Table 3

Directly measured physical function (Physical Functional Performance Test, PFP-10) and their response to resistance exercise training.

	Control		Heart Failure		P Value		
	Pre	Post	Pre	Post	Group	Training	Group x Training
Total PFP-10 Score	69.6 ± 3.9 †	73.5 ± 4.2	48.5 ± 6.9	53.9 ± 6.8	0.01	0.001	0.47
Upper body strength	62.6 ± 6.9	74.0 ± 6.0	53.9 ± 9.5	59.3 ± 10.1	0.32	0.001	0.15
Lower body strength	64.3 ± 4.6 *	70.4 ± 4.7	43.7 ± 6.8	48.9 ± 7.2	0.02	0.001	0.65
Upper body flexibility	71.8 ± 4.2	72.5 ± 4.6	59.9 ± 6.3	65.7 ± 6.0	0.20	0.20	0.31
Balance	73.0 ± 3.8 †	74.7 ± 4.4	48.1 ± 7.0	53.8 ± 6.6	0.01	0.02	0.20
Endurance	72.7 ± 3.6 †	74.7 ± 4.1	47.4 ± 6.6	52.6 ± 6.4	0.01	0.15	0.24
6 min walk (meters)	536 ± 23 ‡	554 ± 21	361 ± 33	389 ± 32	0.001	0.05	0.64

Data are mean ± SEM. Differences between groups for pre-training values:

* = P<0.05;

† = P<0.01;

‡ = P<0.001.

Table 4

Self-reported quality of life measures (MOS SF-36) and the response to resistance exercise training.

	Control		Heart Failure		P Value		
	Pre	Post	Pre	Post	Group	Training	Group x Training
Physical Function	82.3 ± 5.3 *	90.9 ± 1.9	62.0 ± 5.7	67.0 ± 6.2	0.01	0.06	0.61
Role-Physical	95.5 ± 3.1 ‡	86.4 ± 7.8	50.0 ± 11.7	55.0 ± 12.8	0.01	0.77	0.32
Bodily Pain	83.9 ± 5.0 *	71.5 ± 5.7	67.6 ± 6.3	65.9 ± 8.3	0.18	0.11	0.22
General Health	75.5 ± 3.0 †	79.6 ± 4.1	56.4 ± 5.6	61.6 ± 5.1	0.01	0.19	0.89
Physical Component Summary Score	84.3 ± 2.4 ‡	82.1 ± 3.8	59.0 ± 5.1	62.4 ± 6.2	0.001	0.86	0.69
Vitality	73.2 ± 4.1 *	77.7 ± 3.5	59.0 ± 3.2	55.5 ± 6.6	0.005	0.85	0.14
Social Function	100.0 ± 0.0 †	100.0 ± 0.0	82.8 ± 5.8	86.1 ± 5.8	0.01	0.59	0.59
Role-Emotional	91.0 ± 4.6	84.9 ± 9.4	70.1 ± 10.5	73.4 ± 10.9	0.11	0.87	0.58
Mental Health	85.5 ± 2.9	86.9 ± 3.4	81.6 ± 2.9	86.8 ± 3.4	0.56	0.08	0.31
Mental Component Summary Score	87.4 ± 2.0 †	87.4 ± 2.6	73.3 ± 4.1	75.4 ± 4.6	0.01	0.71	0.70

Data are mean ± SEM. Differences between groups for pre-training values:

* = P<0.05;

† = P<0.01;

‡ = P<0.001.

Table 5

Baseline correlates of directly-measured physical function (PFP-10), 6-minute walk distance and self-reported physical function.

	PFP-10	6 minute walk distance	Self-reported physical function
Peak VO_2	0.78 ‡	0.89 ‡	0.59 ‡
Composite 1 RM	0.64 †	0.46 *	0.02
Mental component score (MOS SF-36)	0.44 *	0.49 *	0.69 ‡
Ejection fraction	0.38	0.59 †	0.57 †
PFP-10	----	----	0.63 †

Data represent Pearson correlation coefficients for n=21. Composite 1 repetition maximum (1 RM) reflects the sum total of 1 RM data from 7 different exercises and self-reported physical function represents the physical function sub-domain of the MOS SF-36.

* $P<0.05$;

† $P<0.01$;

‡ $P<0.001$. Note that the PFP-10 data were not correlated to 6 min walk distance because the latter is a component of the overall PFP-10 score.