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Resistance Versus Aerobic Exercise Training in Chronic Heart Failure

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Abstract It is now accepted that exercise training is a safe and effective therapeutic intervention to improve clinical status, functional capacity, and quality of life in people with chronic heart failure (CHF). Nevertheless, this therapeutic modality remains underprescribed and underutilized. Both aerobic and resistance training improve exercise capacity and may partially reverse some of the cardiac, vascular, and skeletal muscle abnormalities in individuals with CHF. Aerobic training has more beneficial effects on aerobic power (peak oxygen consumption) and cardiac structure and function than resistance exercise training, while the latter is more effective for increasing muscle strength and endurance and promoting favorable arterial remodeling. Combined aerobic and resistance training is the preferred exercise intervention to reverse or attenuate the loss of muscle mass and improve exercise and functional capacity, muscle strength, and quality of life in individuals with CHF. The challenge now is to translate these research findings into clinical practice.

Keywords Heart failure · Exercise training · Aerobic training · Resistance training · Peak oxygen consumption · VO_{2peak} · Nonpharmacologic therapy

Introduction

A hallmark of chronic heart failure (CHF) is severely reduced exercise capacity with symptoms of fatigue and shortness of breath during exercise. Reduced exercise capacity (measured as peak oxygen consumption [VO_{2peak}]) is a major contributor of poor quality of life and is an independent predictor of rehospitalization and mortality in patients with CHF [1, 2]. It is also one of the criteria for optimal timing of cardiac transplantation [2]. Although CHF is characterized by a severe reduction in cardiac pump function (systolic heart failure), the underlying mechanisms responsible for the CHF-mediated decline in VO_{2peak} are not exclusively related to abnormal left ventricular systolic function. In fact, it has been suggested that exercise intolerance in patients with CHF is largely due to changes in the periphery (skeletal muscle); this is known as the "muscle hypothesis" [3]. Peripheral abnormalities, including impaired blood flow to exercising muscles [4], a reduced capacity of exercising muscle to utilize oxygen [5, 6], and increased levels of proinflammatory cytokines [7], oxidative stress [7], and inducible nitric oxide synthase [8], all contribute to exercise intolerance in CHF. Therefore, reduced exercise capacity in patients with CHF is due to alterations in both cardiovascular and musculoskeletal function.

Recently, new diagnostic techniques have been developed to identify diastolic heart failure as a separate diagnosis to

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systolic heart failure, with the former being defined as impaired cardiac function in the setting of preserved ventricular ejection fraction. The main cause of diastolic heart failure is poorly controlled hypertension leading to hypertrophic cardiomyopathy. Given the recent recognition of both the diagnosis and categorization of diastolic heart failure, there currently is limited evidence on the effects of exercise interventions for this condition, and thus, a need exists for additional data on the effects of exercise for this large patient group.

Accumulating evidence suggests that exercise training is a safe and effective therapeutic intervention for improving VO_{2peak} in individuals with CHF [9–12]. In addition, the benefits of exercise training in individuals with CHF may translate into favorable clinical outcomes, including improvements in vascular function [13••], health-related quality of life [10, 12, 14], and New York Heart Association (NYHA) functional class [4] and reduced risk of death or hospitalization [15, 16]. Despite a considerable amount of evidence supporting its beneficial effects as well as safety and cost-effectiveness of exercise training in CHF patients, this therapeutic modality continues to be underprescribed and underutilized for people with CHF. This may be partly due to concerns harbored by cardiologists and other medical practitioners that habitual exercise training for their patients with CHF may cause worsening of heart failure by accelerating cardiac hypertrophy and remodeling, and cause deterioration in central hemodynamics and neurohormonal activity. However, there is substantial evidence countering these concerns, indicating that exercise training may actually engender small improvements in cardiac structure and function [9, 12] in addition to marked improvements in peripheral blood flow and neurohormonal activity [17].

Initial understanding of the benefits of exercise training in patients with CHF has come primarily from investigations employing aerobic training. Resistance training was once thought to be unsafe in CHF, but recent studies have demonstrated that resistance training is not only safe but offers other benefits to complement the benefits of aerobic exercise for people with CHF [14, 17]. This review summarizes the evidence on the effects of aerobic and resistance training in patients with CHF.

Exercise Training Improves Exercise Tolerance in Chronic Heart Failure

The effects of exercise training on cardiovascular function, the musculoskeletal system, oxidative stress, and inflammatory markers in patients with CHF are summarized in Table 1. Aerobic training or combined aerobic and resistance training for patients with CHF produces clinically significant improvements in VO_{2peak} (range +12% to +30%) [18] for exercise interventions ranging from 3 to 52 weeks. Smart and Marwick [19] reviewed the literature and reported an average increase in VO_{2peak} of 17% after aerobic training, 9% with resistance training, and 15% after combined aerobic and resistance training in patients with CHF [19]. Variations in the improvements in VO_{2peak} are probably related to dose effects of exercise interventions (especially intensity and volume) [20], as well as mode of exercise.

Many mechanisms have been proposed to explain improvements in VO_{2peak} with exercise training in patients with CHF; these have frequently focused on partial reversal of peripheral abnormalities (as described above), including improvements in vascular endothelial function [4, 7, 9, 13••] and greater utilization of oxygen by the working muscles [21]. Improvements in endothelial function after aerobic training in CHF correlates positively with improvements in VO_{2peak} [4] and is reversible within 6 weeks of cessation of training [22]. Improvements in skeletal muscle function after training have been explained by corrections of impaired muscle oxidative capacity [21, 23, 24] as well as a reversal of CHF-mediated decline in skeletal muscle mass [24]. Moreover, exercise training may lead to more favorable redistribution of nutritive blood flow and oxygen to the skeletal muscle [17, 25], and lead to a partial shifting from type II to type I muscle fibers, resulting in greater oxidative capacity [23]. In addition to its effects on cardiac, vascular, and skeletal muscle function, exercise training has anti-inflammatory and antioxidative effects [7]. Decreased levels of cytokines and reduced local oxidative stress after exercise training reduce muscle damage and skeletal muscle apoptosis in patients with CHF [7]. Therefore, the mechanisms responsible for the improvement in VO_{2peak} after exercise training in CHF have been attributed to favorable changes in cardiac, vascular, and skeletal muscle function that result in improved oxygen delivery and/or utilization by the active muscle.

Aerobic Training

Most early studies of exercise training in CHF examined the effects of aerobic training. Aerobic training improves exercise capacity and may partially reverse vascular and skeletal muscle abnormalities in patients with CHF [7, 9, 26, 27]. Some but not all investigations have found that aerobic training is associated with small improvements in preload [28], myocardial contractile reserve [9, 27], and left ventricular ejection fraction [9] in patients with CHF. Other studies have demonstrated that aerobic training improved ejection fraction and reduced end-diastolic and end-systolic volumes and partially reversed abnormal left ventricular remodeling in clinically

Table 1 Effects of exercise training on cardiovascular and skeletal muscle function in CHF patients

Effects of exercise training	Consequences
Cardiac function	
↑↔ Peak exercise cardiac output	↑ Oxygen delivery to active muscles
↑↔ Stroke volume	
↑↔ Left ventricular diastolic filling (preload)	
Vascular function	
Improved vascular endothelial function	↑ Vasodilation
↑ Nitric oxide production	↓ Total peripheral resistance (i.e., reduced afterload)
↑ Shear stress; ↑ eNOS production	↑ Nutritive flow to skeletal muscle (hypothesized)
↓ Nitric oxide degradation	
↑ Antioxidative enzyme activity	
↓ Oxidative stress	
↓ Proinflammatory cytokines	
Skeletal muscle function	
↑ Oxidative enzyme activity	↑ Skeletal muscle oxidative capacity
↓ Phosphocreatine depletion	↓ Skeletal muscle atrophy
↑ Capillary density	↓ Workload imposed on individual muscle fibers
↓ Percent of type II (glycolitic) muscle fibers	
↑ Percent of type I (oxidative) muscle fibers	
↑ Muscle cross-sectional area	
↑ Muscle strength and endurance	
Other	
↓ Proinflammatory cytokines	Anti-inflammatory effects
↓ Oxidative stress	Anti-oxidative effects
↓ Neuroendocrine activation	↓ Adverse long-term effects of neuroendocrine activation

↑—increase; ↓—decrease; ↔—no effect; ↑↔—previous studies showing both increase and no effect; CHF—chronic heart failure; eNOS–endothelial nitric oxide synthase

stable patients with CHF [12, 29]. Improved left ventricular function in these studies could be in part related to exercise-mediated reductions in systemic vascular resistance [9, 27], secondary to improvements in vascular endothelial function [9, 13••, 30]. In addition to improving cardiovascular and skeletal muscle function, aerobic training also has been demonstrated to be effective in improving quality of life in patients with CHF [10, 12].

The latest guidelines for aerobic training for patients with CHF recommended engaging in moderate intensity aerobic training at 40% to 70% VO_{2peak} (rating of perceived exertion [RPE] 11–14 on 6–20 scale) [31••]. The duration of exercise training should initially be 10 to 15 min and gradually increased to 45 to 60 min per session. High-intensity interval training is generally well tolerated by CHF patients and has more favorable effects on left ventricular remodeling, aerobic capacity, endothelial function, and quality of life compared to moderate continuous training [32]. Current guidelines for patients with CHF (NYHA functional class I to II) recommend that exercise to rest ratio for interval training should be 1:1 initially, increasing gradually to 2:1 [31••]. Adequate qualified supervision for patients with CHF should be available [31••], particularly in the early sessions of an exercise intervention.

Resistance Training

Skeletal muscle mass predicts exercise capacity [33] and is an independent predictor of prognosis in patients with CHF [34]. Recent guidelines emphasize the importance of incorporating resistance training for optimal exercise prescription in these patients [18, 31••]. These recommendations are based on the finding that resistance training may be more effective than aerobic training in attenuating or reversing skeletal muscle atrophy in patients with CHF [35]. In addition, resistance training imposes a stress to peripheral muscles without overloading the cardiovascular system [36].

Resistance training alone [17, 21, 24] or in combination with aerobic training [11, 21, 37, 38•] has been shown to attenuate the CHF-mediated decline in muscle mass [24] and improve muscle strength [11, 14, 17, 21, 24, 37, 38••] and endurance [21, 24, 38•]. Resistance training also may partially reverse vascular and skeletal muscle abnormalities in CHF patients [17, 21, 24, 30] without an adverse effect and may promote a small improvement in left ventricular systolic function [14, 24]. It has been speculated that the increased muscle mass after exercise training in patients with CHF may reduce the workload imposed on muscle fibers and consequently reduce metabolic stress [25]. Therefore, improved muscle function allows patients to perform submaximal physical tasks at a lower percentage of maximal voluntary contraction, resulting in a reduced cardiovascular load. In addition, increased muscle mass also increases muscle oxygen consumption and, therefore, oxygen extraction from the blood during exercise leading to an increase in total body oxygen consumption. Increases in muscle strength and endurance after resistance training may improve patients' capacity to perform activities of daily living, promote independent living, and translate into improved quality of life [14, 39].

Resistance training modalities appropriate for patients with CHF include circuit weight training and exercise using elastic bands or body weight for resistance [31••]. High repetition/low resistance training is recommended for CHF patients. For patients with NYHA functional class I or II heart failure, guidelines recommend performing 1 to 3 sets of 6 to 15 repetitions of 4 to 8 resistance exercises at RPE in the range of 11 to 15 (6- to 20-point Borg scale) [31••]. These guidelines are slightly modified for patients with NYHA functional class III to IV heart failure with decreased numbers of resistance exercises (3–4), sets (1–2), and repetitions (4–10) and lower intensity (RPE 10–13). To reduce the load on the cardiovascular system, exercise prescription for resistance training in stable patients with CHF should incorporate low resistance initially (40%–50% of one-repetition maximum), and involve small muscle groups with short work phases, a small number of repetitions per set, and a 1:2 work to rest ratio [36]. In later stages of exercise training, resistance training intensity can be increased to 50% to 60% of one repetition maximum [36]. This type of resistance training is well tolerated in chronic stable patients with CHF [36].

Aerobic Versus Resistance Training

Recent studies have compared the effects of aerobic versus resistance training in patients with CHF [13••, 40, 41•]. Feiereisen et al. [40] randomly assigned 45 patients with CHF to 12 weeks of aerobic training, resistance training, or combined aerobic and resistance training, with 15 patients who could not attend training sessions serving as a control group. All training types significantly improved VO_{2peak} (aerobic 11%, resistance 17%, combined 14%), peak workload, left ventricular ejection fraction (aerobic by 30.2%, resistance by 17.8%, combined by 29.3%, control 9.7%), thigh muscle volume, and knee extensor endurance with no differences between the groups. Knee extensor strength improved with resistance and combined training but not with aerobic training. The authors concluded that combined aerobic and resistance training may be the most beneficial intervention in patients with CHF because it combines important improvements in cardiac function and in peripheral muscle strength, endurance, and muscle mass. However, Jakovljevic et al. [41•] reported that 12 weeks of aerobic training increased VO_{2peak} and peak cardiac output, mainly due to increases in stroke volume, while no changes were observed in the resistance training group, suggesting the aerobic training may be more beneficial for left ventricular function.

On the other hand, Maiorana et al. [13••] reported that both aerobic and resistance training increased VO_{2peak} compared to a control group. However, leg strength increased only in the resistance training group, and resistance training was superior to aerobic training in inducing brachial artery remodeling. Resistance training increased arterial diameter, decreased arterial wall thickness, and consequently decreased the wall to lumen ratio of the brachial artery. Aerobic training increased arterial diameter without modifying wall thickness or wall to lumen ratio. These findings suggest that improvements to peripheral artery wall structure and function are potential benefits of exercise training, particularly resistance training, while aerobic training causes more beneficial effects on cardiac function.

Combined Aerobic and Resistance Training

The effects of aerobic, resistance, and combined aerobic and resistance training on exercise capacity and cardiac, vascular, and skeletal muscle function are summarized in Table 2. As described above, it appears that the combination of resistance exercise and whole body aerobic training is important to provide patients with clinical and functional benefits. In addition, the beneficial effects of aerobic and resistance training modalities in patients with CHF may be additive and further improve quality of life and physical function. Studies examining the effects of combined aerobic and resistance training in CHF have mainly focused on the muscle component of exercise intolerance, although improvements in VO_{2peak} as well as skeletal muscle strength and endurance have been reported. Several studies have reported improved peripheral vascular endothelial function [30] and quality of life [39, 42] after combined aerobic and resistance training in individuals with CHF.

Delagardelle et al. [43] found that patients randomly assigned to combined aerobic and resistance training experienced improvements to VO_{2peak} by 7.8% and left ventricular ejection fraction at rest by 18%. In contrast, an aerobic training group exhibited decreased left ventricular ejection fraction and did not improve VO_{2peak}, although these findings are contrary to most other published data. Both training modalities improved leg muscle strength and endurance with the greater improvements observed in the combined

Table 2 Effects of aerobic, resistance, and combined aerobic and resistance training in CHF patients

	AT	RT	AT+RT
Exercise capacity			
Peak VO_2	↑↑	↑↔	↑↑
Cardiac function			
Peak cardiac output	↑↔	↔	
Peak stroke volume	↑	↔	
Ejection fraction	↑↔	↔	↑↔
End-systolic volume	↑	↔	↔
End-diastolic volume	↑	↔	↔
Vascular function			
Endothelial function	↑↑	↑	↑
Arterial remodeling	↑	↑↑	?
Skeletal muscle function			
Muscle strength	↔↑	↑↑↑	↑
Muscle endurance	↑	↑↑	↑
Oxidative enzymes	↑	↑	↑

↑—slight improvement; ↑↑—moderate improvement; ↑↑↑—large improvement; ↔—no effect; ?—Unknown; AT—aerobic training; RT—resistance training; AT+RT—combined aerobic and resistance training; CHF—chronic heart failure; peak VO_2—maximal oxygen consumption

group. The authors concluded that combined aerobic and resistance training was superior to aerobic training alone to improve VO_{2peak}, left ventricular function, and muscle strength in patients with CHF.

Haykowsky et al. [44] randomly assigned older women with CHF to a 3-month supervised aerobic training or combined aerobic and resistance training intervention. The authors reported increased upper extremity muscle strength in the combined aerobic and resistance training group while no change was observed in the aerobic training group. Improvements in VO_{2peak}, leg muscle strength, and quality of life after these two training interventions were similar between the groups.

More recently, Beckers et al. [42] reported that 6 months of combined aerobic and resistance training improved submaximal exercise capacity, increased upper extremity muscle strength, and reduced cardiac symptoms to a greater extent than aerobic training alone. Both training modalities improved VO_{2peak} and left ventricular ejection fraction to a similar extent. Combined training did not have detrimental effects on left ventricular remodeling. The authors concluded that combined aerobic and resistance training is feasible and safe for patients with CHF, and more effective for improving submaximal exercise capacity and health-related quality of life than aerobic training alone.

Mandic et al. [38] compared the effects of 12 weeks of aerobic training alone, combined aerobic and resistance training, and no exercise training (control) on VO_{2peak}, left ventricular systolic function, skeletal muscle strength and endurance, and quality of life in patients with CHF. Compared to control patients, both training modalities were effective in improving VO_{2peak} in compliant CHF patients. Combined aerobic and resistance training was more effective for improving muscle strength while aerobic training alone was more effective in improving quality of life. Neither training modality affected left ventricular function at rest.

Bouchla et al. [45•] and Degache et al. [46] found similar improvements in exercise capacity after 8 to 12 weeks of aerobic interval training or combined aerobic and resistance training. Combined aerobic and strength training increased muscle strength to a greater extent compared to aerobic training alone in both studies. Bouchla et al. [45•] reported that changes in leg muscle mass were not different between the groups, suggesting that adaptations other than muscle hypertrophy may contribute to increased muscle strength after combined aerobic and resistance training in patients with CHF.

Taken together, these studies suggest that combined aerobic and resistance training is a beneficial exercise intervention to reverse or attenuate loss of muscle mass and to provide improvements in exercise capacity, muscle strength, vascular function, and quality of life in individuals with CHF. However, the effects of combined training warrant further investigation; a meta-analysis by Haykowsky et al. [29] concluded a lack of changes in left ventricular ejection fraction, end-systolic volume, or end-diastolic volume after combined aerobic and resistance training in patients with CHF. In contrast to the equivocal data for combined aerobic and resistance exercise training in terms of cardiac structure and function, it seems that aerobic exercise training alone produces small benefits for the heart in terms of structure and function [9, 12].

Prescribing Exercise for Patients with Chronic Heart Failure

It is beyond the scope of this review to provide exercise guidelines for patients with CHF; these have recently been provided in other publications [31••]. The current challenge is to translate into practice the many benefits of exercise for people with CHF that have been demonstrated by research over the past two decades. This depends on the willingness of medical practitioners and other health care professionals to advocate exercise for patients with CHF, as well as on the wider acceptance of exercise as a valuable adjunct to medical treatment by patients (especially adherence), and the availability of sufficiently qualified exercise professionals to deliver safe and effective exercise interventions. Considering multiple physiological and clinical benefits of exercise training in patients with CHF [18], high dropout rates from the long-term exercise interventions, and a quick loss of benefits of exercise training after termination of exercise training [47], exercise programs designed for CHF patients need to be enjoyable and safe to increase adherence and promote regular long-term physical activity among these patients. Addition of resistance exercise to aerobic training provides variety and may further encourage compliance with exercise training.

Clinical Implications

Aerobic training alone and combined aerobic and resistance training are effective in improving exercise tolerance and lead to clinically significant improvements in quality of life in compliant patients with CHF. However, the addition of resistance training to aerobic training is superior to aerobic training alone for improving skeletal muscle strength, endurance, and quality of life. Therefore, both training modalities should be employed as part of rehabilitation programs to optimally improve exercise tolerance and quality of life in patients with CHF. Frail or cachectic CHF patients may benefit more from a greater emphasis on resistance training. From a clinical perspective, it is important to emphasize that regular exercise may be beneficial in patients with CHF even if it does not significantly improve VO_{2peak}; evidence suggests that exercise programs improve quality of life and enhance skeletal muscle function independent of changes in VO_{2peak}. In addition, training reduces the decline in VO_{2peak} that is exacerbated by the sedentary lifestyle common in CHF patients [38•]. The decline in VO_{2peak} [48] and quality of life [49] as a result of a sedentary lifestyle in CHF patients leads to a loss of functional independence, progression of the disease [48], and is associated with higher mortality rates [50]. These combined influences of training on clinical outcomes in CHF support the concept that regular exercise should be an integral part of the standard treatment paradigm for patients with CHF. One of the major challenges that remains is to increase the referral rate for rehabilitation, particularly for this population.

Conclusions

Both aerobic and resistance training improve exercise capacity, clinical outcomes, and quality of life and may partially reverse vascular and skeletal muscle abnormalities in individuals with CHF. Resistance training is more effective for increasing muscle strength and endurance and promoting favorable arterial remodeling, while aerobic training has more beneficial effects on cardiac function. Combined aerobic and resistance training is superior to aerobic exercise training to reverse or attenuate the loss of muscle mass and improve exercise capacity, muscle strength, and quality of life in individuals with CHF. Regular exercise, irrespective of the training modality, is beneficial for patients with CHF to reduce or prevent the decline in exercise capacity that is exacerbated by the typical sedentary lifestyle in these patients. Designing an enjoyable, safe, and individualized exercise program is essential to encourage regular physical activity and optimize adherence with exercise in patients with CHF. Research is also needed to identify the effects of exercise training for people with the specific diagnosis of diastolic heart failure.

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improvements in exercise capacity and greater increase in muscle strength following combined aerobic and resistance training versus aerobic training alone.

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