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Resistance Exercise Training in Patients with Heart Failure

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Abstract

The utility, safety and physiological adaptations of resistance exercise training in patients with chronic heart failure (CHF) are reviewed and recommendations based on current research are presented. Patients with CHF have a poor clinical status and impaired exercise capacity due to both cardiac limitations and peripheral maladaptations of the skeletal musculature. Because muscle atrophy has been demonstrated to be a hallmark of CHF, the main principle of exercise programmes in such patients is to train the peripheral muscles effectively without producing great cardiovascular stress. For this reason, new modes of training as well as new training methods have been applied. Dynamic resistance training, based on the principles of interval training, has recently been established as a safe and effective mode of exercise in patients with CHF. Patients perform dynamic strength exercises slowly, on specific machines at an intensity usually in the range of 50–60% of one repetition maximum; work phases are of short duration (≤60 seconds) and should be followed by an adequate recovery period (work/recovery ratio >1 : 2). Patients with a low cardiac reserve can use small free weights (0.5, 1 or 3kg), elastic bands with 8–10 repetitions, or they can perform resistance exercises in a segmental fashion. Based on recent scientific evidence, the application of specific resistance exercise programmes is safe and induces significant histochemical, metabolic and functional adaptations in skeletal muscles, contributing to the treatment of muscle weakness and specific myopathy occurring in the majority of CHF patients. Increased exercise tolerance and peak oxygen consumption ($\dot{V}O_{2peak}$), changes in muscle composition, increases in muscle mass, alterations in skeletal muscle metabolism, improvement in muscular strength and endurance have also been reported in the literature after resistance exercise alone or in combination with aerobic exercise. According to new scientific evidence, appropriate dynamic resistance exercise should be recommended as a safe and effective alternative training mode (supplementary to conventional aerobic exercise) in order to counteract peripheral maladaptation and improve muscle strength, which is necessary for recreational and daily living activities, and thus quality of life, of patients with stable, CHF.

Patients with chronic heart failure (CHF) have a poor clinical status and impaired exercise capacity due both to cardiac limitations (significant left ventricular impairment) and to peripheral maladaptations of the skeletal musculature. The latter include the reduction of peripheral blood flow and impaired perfusion as well as deficiencies in skeletal muscle function, morphology and metabolism. These skeletal muscle disturbances increase cardiovascular stress, deteriorate symptoms and reduce further exercise capacity.[1-3] Recently, it has been reported[4] that muscle strength was a better predictor of long-term survival than workload or peak oxygen consumption ($\dot{V}O_{2peak}$) in patients with severe congestive heart failure, indicating the importance of maintaining a normal skeletal muscle mass in order to improve the outcome of these patients.

Traditionally, patients with CHF have been advised to avoid exercise because of the concerns that their condition would further deteriorate.[5] However, since the late 1970s, several studies have indicated that exercise training can induce favourable physiological adaptations and improve symptoms, clinical outcome and quality of life of these patients.[6-12] The majority of these studies were based on aerobic exercise, which was traditionally the main exercise mode in rehabilitation programmes. Nowadays, new methods of exercise training (interval training) have been developed in order to allow heart failure patients to exercise at higher intensities and at lower cardiovascular stress, since most are extremely deconditioned.[10,13]

Resistance exercise (and especially isometric or static exercise) was not routinely prescribed to patients with CHF because this type of exercise was associated with undesirable and pathological cardiovascular responses.[14,15] During the last decade, however, increasing evidence indicated that dynamic resistance training alone[16-20] or in combination with aerobic exercise[21-28] is beneficial and counteracts the negative peripheral side effects seen in patients with CHF. The present review examines the utility, safety and physiological adaptations of resistance exercise training in patients with CHF and, based on current literature, presents evidence and recommendations for resistance training.

1. Modes and Methods of Resistance Training

Resistance training in cardiac rehabilitation is basically applied according to the principles of interval training. During interval training, the work phases are of short duration (e.g. 30–60 seconds) and are followed by short recovery periods of the same or longer duration; thus, interval training allows heart failure patients to train at higher power output with lower haemodynamic and left ventricular stress compared with steady-state exercise.[10,29] Patients perform dynamic strength exercises rhythmically on specific machines or use free weights activating different muscle groups every time. It should also be pointed out that the induced muscular contraction is primarily dynamic, which means that the movement is carried out throughout the changes of muscle length and not through the alteration of muscular tension, as in the case during isometric exercise.[30]

This kind of training cannot be compared to strenuous training undertaken by weight-lifting athletes, where the basic characteristic is the high intensity (>90% of the one repetition maximum; 1RM). Neither can it be compared to the strength training of body builders who perform many repetitions with sub-maximal intensity until exhaustion. This misinterpretation, along with the acute increase of blood pressure caused by isometric exercise, has been the main reason leading to the contraindications of resistance training for patients with heart disease for many years.[31]

Nevertheless, this approach has completely changed[15] and nowadays resistance training has been proven to be beneficial even for patients with CHF.[17,18,32,33] For safety reasons, however, clinicians should be aware of the appropriate prescription (training methods and modalities) of resistance training due to the high risk of these patients. These issues, based on current literature, are further discussed.

2. Isometric Exercise

During this form of contraction, force is generated without a change in muscle length. Muscle blood flow and oxygen delivery are compromised because the increase in intramuscular pressure compresses arterial blood vessels. As isometric exercise exceeds 70% of maximal voluntary contraction, there is a complete obstruction of arterial flow, so that energy requirements are met by anaerobic metabolism.[34] As a consequence, systolic blood pressure increases to maintain muscle perfusion; the mean arterial pressure for isometric exercise is much higher for any given oxygen consumption ($\dot{V}O_2$) at equivalent dynamic exercise.[35] Thus, isometric work imposes greater pressure than volume load on the left ventricle, which is directly related to the intensity, the activated muscle mass and the duration of contraction.[36-38] Based on the above, sustained or high-intensity isometric exercise has been considered unsafe in patients with mild to severe left ventricular impairment and congestive heart failure.

3. Dynamic Resistance Exercise

During dynamic resistance exercise, force is produced while the length of the muscle changes (shortens during concentric action and lengthens during eccentric action). Dynamic exercise can be applied against a constant resistance, as in the case of dumbbells or weighted bags, or against a variable resistance using machine weights.[39] This kind of exercise has been established as the proper and safe training mode of strength training in cardiac and heart failure patients. Eccentric exercise, a specific type of muscular contraction, requires special equipment and is based on the lengthening rather than the shortening of the muscle mass involved.[39] The mechanical power output with this kind of muscle action is three to four times higher than the output obtained with the usual type of muscle contraction without affecting the metabolic and cardiovascular demands.[40] The type of exercise using eccentric muscle action has been found to improve muscle strength and muscle mass without affecting the oxidative capacity of muscle cells at the same level.[40] Although the theoretical basis of this type of exercise is valid in patients with heart failure, there is only one study (and this is in patients with coronary artery disease [CAD]) that examines the acute haemodynamic and metabolic responses during eccentric exercise.[41] More studies concerning the acute responses and the chronic adaptations of eccentric exercise are needed in patients with CHF.

4. Combined Isometric/ Dynamic Exercise

This type of exercise concerns the combination of both dynamic and static contractions (e.g. weight-loaded walking, weight-carrying, or vocational work simulation).[30] In patients with cardiovascular disease, the combined isometric/isotonic exercise is well tolerated and results in acceptable haemodynamic responses.[30,42,43] In patients with CHF, however, no research exists on the central haemodynamic changes that occur during combined isometric/dynamic exercise. Therefore, recommendations of this form of exercise cannot be suggested yet.

5. Isokinetic Exercise

Isokinetic resistance exercise requires specific devices that allow the muscle to produce force at a constant predetermined speed. The nature of contraction can be either concentric or eccentric. The advantage of this type of exercise is that a homogeneous strength development can be reached throughout the entire range of motion using different angular velocities of the activated muscle groups.[39] Several investigators used isokinetic machines to evaluate maximal resistance in patients with CHF.[4,17,22,44] No follow-up studies, however, have examined the effects of isokinetic resistance training in patients with CHF.

The above modes of resistance exercise can be theoretically applied in practice. Their indication and appropriateness in patients with heart failure, however, based on the existing literature, are further discussed in sections 6 and 9.

6. Acute Responses during Resistance Exercise

Resistance exercise was not routinely prescribed to patients with heart failure because this type of exercise has the potential to trigger ventricular arrhythmia, pathological haemodynamic responses, ventricular wall stress, decreased myocardial perfusion and wall motion abnormalities.[14] The acute cardiovascular responses expected during resistance exercise, however, depend on a variety of factors, including the kind and intensity of muscular contraction (rhythmic and dynamic vs static and isometric), the amount of muscle mass involved (i.e. large vs small muscle groups), the number of repetitions, and the duration of contraction.[35,37,38]

6.1 Isometric Exercise

When cardiovascular stress is measured during static exercise, undesirable haemodynamic alterations and an excessive level of myocardial pressure work were observed[45-50] in patients with CHF. These include decreases in cardiac output, stroke volume and ejection fraction (EF), increases in systolic, mean arterial pressure and left-ventricular end-diastolic pressure, and wall motion abnormalities, mitral regurgitation and dysrhythmia.[45-50] The protocols applied to the above studies, however, include sustained isometric contractions of small muscle groups to an intensity of 30–50% of maximum voluntary contraction and lasted 3–5 minutes. Yet, such exercise stimuli, do not exactly reflect the nature of daily activities.

6.2 Dynamic Resistance Exercise

On the other hand, favourable cardiovascular responses were observed in recent studies where dynamic contractions of large muscle groups were used during resistance exercise (table I). Haemodynamic responses (heart rate, systolic blood pressure and rate-pressure product) during single leg press at 70% of 1RM were lower than those found during cycling exercise at 70% of $\dot{V}O_{2peak}$ in patients with moderate CHF,[32] whereas similar results were obtained during bilateral leg press and biceps curl exercises (at 40% of maximum voluntary contraction [MVC]) compared with submaximal cycling exercise in patients with more severe CHF.[51] In addition, there was no evidence of significant deterioration in left ventricular function during resistance exercises performed at 60–70% of 1RM in patients with stable CHF (mean EF: 35%, New York Heart Association [NYHA] class: I–II).[52] Furthermore, Meyer et al.[33] investigated the safety and tolerability of rhythmic resistance exercise regarding cardiac function in patients with heart failure (mean EF: 26%) and observed increased left ventricular stroke work index and decreased systemic vascular resistance during rhythmic double leg press exercise at 60% and 80% of maximum voluntary contraction (60-second work phase/120-second recovery), suggesting left ventricular adaptability of the failing heart to dynamic resistance exercise.

Data from our laboratory[56] confirm the above observations in patients with coronary heart disease and show that dynamic resistance exercises performed at 40%, 60% and 80% of 1RM produced much lower haemodynamic responses than those obtained during a stress test (figure 1).

King et al.[53] reported that dynamic resistance exercise using hand-held weights (unilateral arm curls at 50%, 65% and 80% of calculated 1RM) was tolerated haemodynamically and clinically in patients with advanced heart failure (mean EF: 20%, NYHA class III or IV). When the intensity of a combined aerobic and resistance exercise circuit training session was compared with the exercise intensity of continuous aerobic exercise in patients with CHF (mean EF: 25%, NYHA class I–III), no significant differences in oxygen demand or haemodynamic responses were found (69% and 68% of $\dot{V}O_{2peak}$, respectively).[54]

In a recent study, Werber-Zion et al.[55] demonstrated the safety of resistance testing (1RM) and training up to 60% of 1RM in patients with mild to moderate left ventricular dysfunction using two-dimensional echocardiography. During only the knee extension exercise (10 repetitions at 60% of 1RM) a slight but significant reduction in EF was observed during the final repetitions (see also table I).

Based on existing knowledge, dynamic resistance exercise performed using large muscle groups (bilaterally) or small muscle groups (unilaterally) at appropriate intensities (up to 10 repetitions at 70% of 1RM) was well tolerated in patients with well compensated, stable CHF, since it generated stable left ventricular function and acceptable haemodynamic loads.

7. Adaptations of Resistance Training

Resistance training in patients with CHF is associated with increased exercise tolerance (exercise time) and correction of skeletal muscle abnormalities. This can be better achieved, however, when the combination of resistance and aerobic exercise is used. Changes in muscle composition, increase of muscle mass, alterations in skeletal muscle metabolism, and improvement in muscular strength and endurance have also been reported by most investigators after resistance training alone or in combination with aerobic exercise.[16-28]

7.1 Exercise Time and Peak Oxygen Consumption

Significant improvements in exercise time (13%)[18] and maximal exercise capacity (10%, defined as the maximal watts tolerated on the cycle-ergometer)[16] without changes in $\dot{V}O_{2peak}$ have been reported in patients with CHF after 8 weeks of resistance training. In addition, a lower $\dot{V}O_2$ at submaximal workloads (without improvement in $\dot{V}O_{2peak}$) has been observed after an 11-week resistance training programme in patients with moderate CHF (mean EF: 26%, NYHA class II–III). Nevertheless, a significant increase in $\dot{V}O_{2peak}$ (14.5%) was observed after 12 weeks of training using

Table I. Acute responses of dynamic resistance exercise in patients with chronic heart failure

Study (year)	Patients	Resistance programme	Major findings
McKelvie et al.[32] (1995)	n = 10, EF = 27%, NYHA class I–III mild-moderate HF	2 × 10 reps at 70% of 1RM (unilateral leg press exercise) vs 5 min steady-state cycle ergometry at 70% of peak power output	No significant differences in LV response between resistance exercise and cycling performed at the same relative intensity
Meyer et al.[33] (1999)	n = 9, EF = 26%, well compensated HF	4 × 12 reps at 60% plus 4 × 12 at 80% of MVC (bilateral leg press exercise) vs 5 min steady-state cycle ergometry at 25W	Stability of central haemodynamics during resistance exercise
King et al.[53] (2000)	n = 34, EF = 20%, NYHA class III–IV advanced HF	2 × 10–12 reps at 50% plus 1 × 8 reps at 65% plus 1 × 8 reps at 80% of calculated 1RM (unilateral arm curls)	Dynamic weightlifting exercise was tolerated haemodynamically and clinically
Green et al.[54] (2001)	n = 6, EF = 25%, NYHA class I–III chronic HF	1 × 15 reps at 50–60% of 1RM (10 resistance exercises) vs 10 × 45 sec at 70–80% of peak HR (10 aerobic exercises)	Circuit training was associated with similar oxygen and haemodynamic demand to aerobic exercise
Cheetham et al.[51] (2002)	n = 17, EF = 25%, NYHA class III–IV severe HF	2 × 100 sec at 40% of MVC (bilateral leg press and biceps curl exercise) vs cycling exercise until exhaustion (20W initial, 20W every 3 min)	Resistance training performed at 40% of MVC induces a lower haemodynamic burden than the traditional submaximal aerobic exercise
Karlsdottir et al.[52] (2004)	n = 12, EF = 35%, NYHA class I–II stable HF	1 × 10 reps at 60–70% of 1RM (bilateral leg press, unilateral biceps curl and shoulder press) vs 12 min steady-state cycling at 90% of the ventilatory threshold	LV function remains stable during moderate-intensity resistance exercise in patients with congestive HF
Werber-Zion et al.[55] (2004)	n = 15, EF = 42%, NYHA class I–II moderate LV dysfunction	1 × 15 reps at 20%, 1 × 12 reps at 40%, 1 × 10 reps at 60% of 1RM (bilateral knee extension and unilateral biceps curl) vs exercise stress test	Greater occurrence of new wall motion abnormalities was seen during 60% (of 1RM) of knee extension compared with prior workloads, biceps curl and stress test; however, this did not indicate reduced cardiac performance

EF = ejection fraction; **HF** = heart failure; **HR** = heart rate; **LV** = left ventricular; **MVC** = maximum voluntary contraction; **NYHA** = New York Heart Association; **reps** = repetitions; **RM** = repetition maximum.

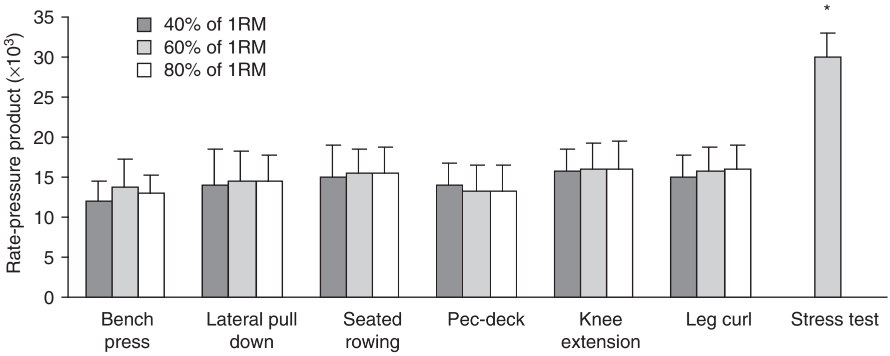

Fig. 1. Rate-pressure product during six different exercises and during stress testing in patients with coronary artery disease (reproduced from Tokmakidis,[56] with permission). **RM** = repetition maximum; * $p < 0.001$.

weight collars in patients with CHF awaiting heart transplantation.[19]

Comparative studies have shown that the combination of strength and aerobic exercise results in better adaptations of $\dot{V}O_{2peak}$ and exercise tolerance than aerobic training alone. Maiorana et al.[23] reported increases in exercise time of 18.4% and in $\dot{V}O_{2peak}$ of 13% following a 12-week circuit weight-training programme in patients with CHF (mean EF: 26%, NYHA class I–III). When a combined strength and aerobic training programme was conducted for 24 weeks in outpatients with congestive heart failure (mean EF: 36%, NYHA class 2.2 ± 0.1), an 18% increase of working capacity and a 10% increase in $\dot{V}O_{2peak}$ was found.[21] Recently, Selig et al.[28] reported a 21% improvement of $\dot{V}O_{2peak}$ in a prospective, randomised study after 3 months of a moderate-intensity resistance and aerobic exercise programme in patients with CHF (mean EF: 27%, NYHA class II–III).

Based on the above observation, resistance exercise alone may[19] or may not[17,18] improve $\dot{V}O_{2peak}$, although the combination of strength and aerobic training seems to induce significant adaptations in $\dot{V}O_{2peak}$ (table II). This is clinically important since $\dot{V}O_{2peak}$ in these patients strongly predicts quality of life and prognosis. In addition, the improvement in $\dot{V}O_{2peak}$ is associated with enhanced survival in patients awaiting cardiac transplantation.[57] Therefore, the combination of strength and aerobic exercise is suggested as the best form of training compared with resistance or aerobic training alone in order to improve $\dot{V}O_{2peak}$ in patients with CHF.

7.2 Histological and Metabolic Adaptations

There are few studies that have examined the adaptations in skeletal muscle histology and biochemistry as a result of resistance training in patients with heart failure. Minotti et al.[60] were among the first who observed improved oxidative capacity of the skeletal musculature, as indicated by the lower inorganic phosphate to phoshocreatine ratio (Pi/PCr) during submaximal workload, after 1 month of non-dominant wrist flexor training. Increases of cross-sectional area of quadriceps femoris (9%)[16] and muscle fibre area (9.5% for type 1 and 13.6% for type 2 muscle fibres)[18] as well as significant improvements in skeletal muscle oxidative capacity (increase of citrate synthase activity by 35%)[18] have been reported after resistance training. These improvements in skeletal muscle metabolism and histology were directly associated with changes (13%) in the overall functional capacity measured by the 6-minute walking test[18] (figure 2). The above oxidative adaptations observed after resistance training may be explained by the severe deconditioning of these patients. In addition, combined strength and endurance exercise prevented loss of hamstrings muscle mass during an intervention period of 26 weeks.[61] Despite these promising findings, however, further studies are required to establish the long-term histological and metabolic

Table II. Summary of trials of resistance training in patients with heart failure

Study	(n, M/F, aetiology)	EF (%)/NYHA class	Duration/frequency	Intensity/type of training	Muscular adaptations	Exercise tolerance
Magnusson et al.[16] (1996)	6	28	8wk/3 days/wk	AE at 65–75% of HR_{peak}	↑ 24% of maximal strength	↑ 18% of exercise time
	5 (3 CAD, 8 DCM)	11.4	8wk/3 days/wk	ST at 80% of 1RM	↑ 40% of maximal strength	↑ 10% of exercise time
Adams et al.[58] (1999)	18M	24	8wk	ST at 60–80% of 1RM plus AE at 70% of HR_{peak}	↑ 15–17% of maximal strength	Not reported
Hare et al.[17] (1999)[a]	9M (8 CAD, 1 DCM)	26/II–III	11wk/3 days/wk	30–60 sec of ST at low intensity	↑ 17–40% of maximal strength	↑ 4.4% of exercise time, no change in $\dot{V}O_{2peak}$
Delagardelle et al.[21] (1999)	11M/3F (7 CAD, 5 DCM,1 HT, 1 VD)	29/2.7 ± 0.5	24wk/3 days/wk	ST at 60–80% of 10RM plus AE at 50–75% of $\dot{V}O_{2peak}$	↑ 18–25% of muscular endurance	↑ 10% of $\dot{V}O_{2peak}$
Maiorana et al.[23] (2000)	13M (7 CAD, 6 DCM)	26/I–III	8wk/3 days/wk	ST at 55–65% of 1RM plus AE at 70–85% of HR_{peak}	↑ 18% of maximal strength	↑ 13% of $\dot{V}O_{2peak}$
Barnard et al.[22] (2000)	14M (10 CAD, 4 DCM)	25	8wk/3 days/wk	ST at 60–80% of 1RM plus AE at 60–80% of HR_{peak}	↑ 18–33% of maximal strength	Not reported
Grosse et al.[19] (2001)[a]	11M/3F (5 CAD, 9 DCM)	28/3.0 ± 0.4	12wk/2 days/wk	ST at 65% of 1RM	↑ 80–102.4% of muscular endurance	↑ 14.5% of $\dot{V}O_{2peak}$
Pu et al.[18] (2001)[a]	9F (6 CAD, 2 DCM, 1 VD)	36/2.2 ± 0.1	10wk/3 days/wk	ST at 80% of 1RM	↑ 43% of maximal strength	↑ 13% distance walked at 6 min test, no change in $\dot{V}O_{2peak}$
Tynni-Lenné et al.[20] (2001)[a]	8M/8F (10 CAD, 6 DCM)	30/II–III	8wk/3 days/wk	2 × 25 reps until 13 on Borg's scale using elastic bands	Not reported	↑ 13% of peak work rate and 8% of $\dot{V}O_{2peak}$
Selig et al.[28] (2004)	15M/4F (11 CAD, 8 DCM)	27/2.4 ± 0.5	12wk/3 days/wk	30 sec of ST at moderate intensity	↑ 21% of maximal strength and 21% of muscular endurance	↑ 11.0% of $\dot{V}O_{2peak}$
Levinger et al.[59] (2005)[a]	8M	35	8wk/3 days/wk	ST at 40–80% of 1RM	↑ 18% of maximal strength	↑ 19% of $\dot{V}O_{2peak}$

a In these studies only ST was applied.

AE = aerobic training; **CAD** = coronary artery disease; **DCM** = dilated cardiomyopathy; **EF** = ejection fraction; **F** = female; **HR_{peak}** = peak heart rate; **HT** = hypertension; **M** = male; **NYHA** = New York Heart Association; **reps** = repetitions; **RM** = repetition maximum; **ST** = strength training; **VD** = valve dysfunction; **$\dot{V}O_{2peak}$** = peak oxygen consumption; ↑ indicates increase.

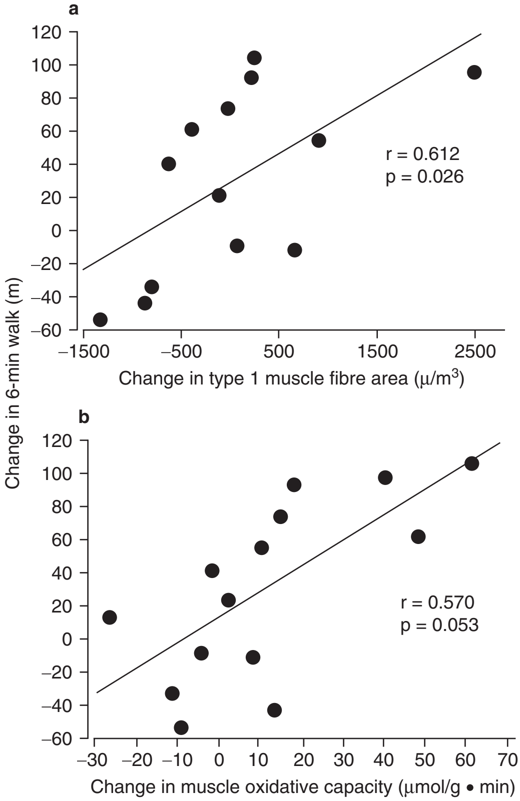

Fig. 2. Correlations between the improvement in functional capacity and (**a**) the changes in type 1 muscle fibre area and (**b**) the changes in muscle oxidative capacity after resistance training in patients with chronic heart failure (reproduced from Pu et al.,[18] with permission).

adaptations of this type of training in patients with CHF.

7.3 Muscular Adaptations

Patients with heart failure exhibit skeletal muscle atrophy (muscle wasting) and impaired muscular strength. Although it has been demonstrated that aerobic training reverses the histochemical and metabolic abnormalities in skeletal muscle,[9,62] the improvements in muscle function (increases in muscular strength and endurance) can be obtained only after specific resistance training programmes.

Indeed, resistance exercise training in patients with CHF results in a significant improvement of muscular strength (range 15–43%)[16-19,21-23] and muscular endurance (range 18–299%; see also figure 3). Even at high intensities, resistance training is well tolerated and without cardiovascular abnormalities or orthopaedic complications (table III). In the study by Pu et al.,[18] who conducted a randomised controlled trial to determine the efficacy of resistance training at 80% of 1RM in older patients with CHF, maximal muscle strength improved from 33.5% to 68% for different muscle groups, whereas muscular endurance also increased by 299% after 10 weeks of training. Furthermore, it is important to note that β-blocker therapy did not inhibit strength gains following resistance training in patients with CHF.[59]

Maintaining a satisfactory level of strength in these patients is very important, since it facilitates the execution of daily activities and enhances their quality of life. In patients with CHF, and especially the elderly, the normal physiological (age-dependent) type 2 fibre decrease adds to the CHF-induced reduction of type 1 fibres.[63] Therefore, regular resistance training programmes are very efficient in counteracting these negative skeletal muscle abnormalities seen in CHF.

8. Vascular Function, Immunity and Autonomic Control

Decreased peripheral blood flow and impaired perfusion are common in patients with CHF.[64] There are also autonomic derangements in CHF patients, including excessive sympathetic activation and depressed heart rate variability (HRV).[65] In addition, impaired function of the vascular endothelium and both local and systematic inflammation

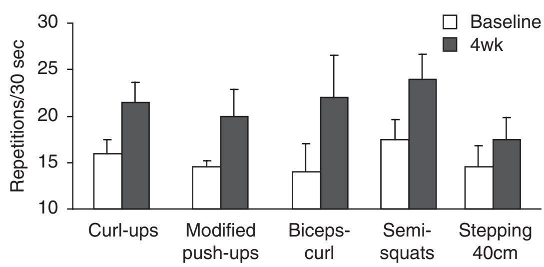

Fig. 3. Muscular endurance before and after 4 weeks of a combined strength and aerobic training programme in patients with chronic heart failure (data from our laboratory).

Table III. Adverse events during resistance training in patients with chronic heart failure

Study	No. of patients	Age (y)	EF (%)/NYHA class	Type of training	Adverse events
Magnusson et al.[16] (1996)	5	57	11	Segmental (localised) muscular training using free weights	Intermittent atrial fibrillation (n = 1)
Hare et al.[17] (1999)	9	63	26/II–III	Whole body training (CWT)	None
Barnard et al.[22] (2000)	14	55	25	Whole body training (CWT)	None
Maiorana et al.[23] (2000)	13	60	26/II–III	Whole body training (CWT)	None
Pu et al.[18] (2001)	16	77	36/2.2	Whole body training (CWT)	None
Grosse et al.[19] (2001)	14	56	28/3.0	Segmental (localised) muscular training using hand-held weights (weight collars)	None
Tynni-Lenné et al.[20] (2001)	16	63	30/II–III	Segmental (localised) muscular training using elastic bands	Increased oedema (n = 1)
Conraads et al.[26] (2002)	23	57	27/I–IV	Whole body training (CWT)	Not reported
Delagardelle et al.[27] (2002)	10	56	27/2.7	Segmental (localised) muscular training using machines and dumb bells	None
Selig et al.[28] (2004)	19	65	27/2.4	Whole body training (CWT)	Sudden death (n = 1), noncardiac illness (n = 1)

CWT = circuit weight training; **EF** = ejection fraction; **NYHA** = New York Heart Association.

have been suggested to play an important role in the pathogenesis and progression of disease.[66,67]

Promising findings have recently been reported indicating that resistance training alone[17,28] or in combination with aerobic exercise[24,26] may correct the above abnormalities seen in patients with CHF relating to vascular function, immunity and autonomic control. In an uncontrolled study,[17] an 11-week resistance exercise training programme resulted in a significant increase (69%) of basal forearm blood flow. However, baroreflex sensitivity showed a non-significant improvement and heart rate variability was unchanged after training. Selig et al.[28] reported significant increases of forearm blood flow at rest (20%) and when stimulated by submaximal exercise (24%) or limb ischaemia (26%) in a prospective, randomised study of moderate resistance training in 19 patients with CHF. In contrast to the study of Hare et al.,[17] Selig et al.[28] reported significant improvements in HRV in response to resistance training. Maiorana et al.[24] used a randomised crossover design and provided evidence that indicated improvements in both endothelium-dependent and endothelium-independent vascular function and peak vasodilatory capacity after a combined resistance and aerobic training programme in patients with CHF. Favourable effects on circulating soluble tumour necrosis factor-α receptors in patients with CHF due to CAD have been reported after 4 months of combined aerobic/resistance training, indicating the anti-inflammatory effect of this type of exercise programme, but not in the case of idiopathic dilated cardiomyopathy.[26] Furthermore, the same investigators[68] found that a combined endurance/resistance training programme reduces the N-terminal fragment of brain natriuretic peptide, which reflects left ventricular diastolic wall stress without evidence of adverse remodelling. More studies are needed, however, to fully clarify the effects of resistance training on vascular and immunity functions and autonomic control in patients with CHF.

9. Resistance Training Recommendations

When prescribing resistance exercise training to patients with CHF, caution should be taken to avoid pressure as well as volume overload of the left ventricle. This can be accomplished with short training intervals stimulating the peripheral muscles without inducing high cardiovascular stress. In

2001, Meyer,[40] in an excellent review, stated that "resistance training can be recommended when small muscle groups are involved, using short bouts of work phases and small number of repetitions", while Pina et al.[69] in the American Heart Association (AHA) scientific statement in 2003 reported that "small free weights (1, 2 or 5lb), elastic bands or repetitive isolated muscle training can be used". Nowadays, based on current literature evidence, more specific recommendations concerning the characteristics of resistance training (intensity, duration, frequency, number of repetitions, sets of exercise, contraction intensity, exercise/recovery ratio) can be obtained.

9.1 Intensity

Patients with a very low cardiac reserve (for example those awaiting heart transplantation) use small free weights (0.5, 1 or 3kg) with 8–10 repetitions,[19] whereas those in a better condition (NYHA class I–II) can perform resistance exercises at an intensity level of 50–60% of 1RM using machine weights.[16,22] NYHA class IV patients should be excluded from participation in resistance training programmes. To minimise cardiovascular stress and during the first weeks of the programme, training can be performed in a segmental manner (unilateral performed exercises). During resistance exercise, the rate of perceived exertion should range from 'fairly light' to 'somewhat hard' on the Borg scale to fatigue. It should be noted that even higher intensities of resistance training (80% of 1RM) have been reported in the literature for CHF patients[16,18,22] (see table I and table IV). Although this intensity has been well tolerated, the majority of CHF patients should exercise at lower intensities (i.e. start from 40%) and reach about 60% for routine training progressively (table II and table V). There is a need, however, to differentiate intensity of training according to the severity and the clinical status of the patients and in relation to the muscle mass involved (segmental or whole body muscle training). This issue needs to be clarified in further studies.

9.2 Duration and Frequency

Work phases during resistance training should be of short duration (≤60 seconds) and should be followed by an adequate recovery period (work to recovery ratio >1 : 2).[40] The recommended duration per session should range from 20 to 30 minutes (15–20 minutes at the early stages of training) with a frequency of one to two times per week. Despite the frequency of training being three times per week in the majority of studies,[16-18,21-23] we believe that a resistance training frequency of two times per week as a supplement to conventional aerobic training represents an optimal stimulus to obtain desirable cardiovascular and muscular adaptations in patients with CHF (table V).

9.3 Mode of Training

Of the available studies, six used whole body[17,18,22,23,28,58] and four used segmental muscular training.[16,19-21] The former tended to recruit patients with less severe left ventricular dysfunction (EF range: 25–36% vs 11–29%). Until official guidelines exist, we suggest whole body (bilateral) resistance training for NYHA class I patients and segmental (unilateral) training for patients with NYHA class II–III (table V). Because there are only two studies[51,53] that have examined the acute effects of resistance exercise in very severe CHF patients (NYHA class IV) using only two exercises (leg press and biceps curl) and because only one intervention study has been conducted with these patients (NYHA class IV),[26] additional data are required before resistance training can be recommended for patients with very severe CHF.

9.4 Number of Repetitions/Sets

In previous studies involving heart failure patients, 10–15 repetitions of each exercise were performed in 2–4 sets. Most often they were applied at intensities ranging from 60% to 80% of 1RM when segmental (localised) muscle training was used.[16,19,21] Similar training characteristics were used (8–15 reps in 2–4 sets at 50–80% of 1RM) in studies where the whole body training was pre-

Table IV. Aetiology and severity (according to New York Heart Association [NYHA] classification) of the recruited patients with heart failure reported in different resistance training studies

Study (year)	Aetiology (n)	NYHA class [n (%)]	Programme[a]
Acute studies			
McKelvie et al.[32] (1995)	10 CAD	Patients had NYHA class I–III (not specified)	2 × 10 reps at 70% of 1RM
Meyer et al.[33] (1999)	7 CAD, 2 DCM	Not reported	4 × 12 reps at 60% plus 4 × 12 at 80% of MVC
King et al.[53] (2000)	Not reported	Patients had NYHA class III–IV (not specified)	2 × 10–12 reps at 50% plus 1 × 8 reps at 65% plus 1 × 8 reps at 80% of calculated 1RM
Green et al.[54] (2001)	4 CAD, 2 DCM	I: 3 (50) II: 1 (17) III: 2 (33)	1 × 15 reps at 50–60% of 1RM
Cheetham et al.[51] (2002)	12 CAD 4 DCM, 1 viral aetiology	Patients had NYHA class III–IV (not specified)	2 × 100 sec at 40% of MVC
Karlsdottir et al.[52] (2004)	Not reported	Patients had NYHA class I–II (not specified)	1 × 10 reps at 60–70% of 1RM
Werber-Zion et al.[55] (2004)	15 CAD	Patients had NYHA class I–II (not specified)	1 × 15 reps at 20%, 1 × 12 reps at 40%, 1 × 10 reps at 60% of 1RM
Intervention studies			
Magnusson et al.[16] (1996)	3 CAD, 8 DCM	II: 5 (45.5) III: 5 (45.5) IV: 1 (9)	4 × 6–10 reps at 80% of 1RM
Adams et al.[58] (1999)	Not reported	Not reported	2 × 8–12 reps at 60–80% of 1RM, 5 exercises
Hare et al.[17] (1999)	8 CAD, 1 DCM	II: 5 (66) III: 4 (44)	30–60 sec of ST at low intensity, 3 exercises
Delagardelle et al.[21] (1999)	7 CAD, 5 DCM, 1 HT, 1 VD	2.7 ± 0.5 (not specified)	3 × 15 reps at 60–80% of 10RM, 6 exercises
Maiorana et al.[23] (2000)	7 CAD, 6 DCM	Patients had NYHA class I–III (not specified)	15 reps at 55–65% of 1RM, 7 exercises
Barnard et al.[22] (2000)	10 CAD, 4 DCM	Not reported	2 × 8–12 reps at 60–80% of 1RM, 5 exercises
Grosse et al.[19] (2001)	5 CAD, 9 DCM	3.0 ± 0.4 (not specified)	2 × 15 reps at 65% of 1RM, 4 exercises
Pu et al.[18] (2001)	6 CAD, 2 DCM, 1 VD	I: 1 (11) II: 6 (67) III: 2 (22)	2 × 8 reps at 80% of 1RM, 5 exercises
Tynni-Lenné et al.[20] (2001)	10 CAD, 6 DCM	II: 11 (69) III: 5 (31)	2 × 25 reps until 13 on Borg's scale
Selig et al.[28] (2004)	11 CAD, 8 DCM	2.4 ± 0.5 (not specified)	30 sec of ST at moderate intensity, 3 exercises

a Commonly used exercises: leg extension, leg press, chest press, shoulder press, lateral pull-down, biceps curl.

CAD = coronary artery disease; **DCM** = dilated cardiomyopathy; **HT** = hypertension; **MVC** = maximum voluntary contraction; **reps** = repetitions; **RM** = repetition maximum; **ST** = strength training; **VD** = valve dysfunction.

Table V. Circuit weight-training characteristics for patients with chronic heart failure reported in the literature and modified according to the severity[16-23,26]

Characteristic	Reported in the literature	Recommendations	
		NYHA I	NYHA II–III
Intensity	50–80% of 1RM	50–60% of 1RM	40–50% of 1RM
Repetitions	8–15	6–10	4–6
Number of stations	3–9	4–6	3–4
Sets	1–4	1–2	1–2
Duration of training	15–30 min	15–20 min	12–15
Rest intervals between exercises	1–2 min	60 sec or longer if necessary, (work/recovery ratio >1 : 2)	60 sec or longer if necessary, (work/recovery ratio >1 : 2)
Speed of muscle contraction	3–6 sec	6 sec (3 for the eccentric and 3 for the concentric phase	6 sec (3 for the eccentric and 3 for the concentric phase)
Frequency	2–3/wk	2/wk as a supplement to aerobic training	1–2/wk as a supplement to aerobic training
Mode of training	Whole body training segmental muscular training	Segmental training during the first months, whole body training if tolerated thereafter	Segmental training mainly, whole body training rarely

NYHA = New York Heart Association; **RM** = repetition maximum.

scribed.[17,18,22-24,26,27] There is a need to establish precise guidelines concerning the number of repetitions and sets depending on the severity and the clinical status of patients and according to the training mode and/or method chosen each time.

9.5 Number of Exercises/Stations

The number of exercises performed in each training session depends on several factors: mainly the muscular fitness level, the severity of left ventricular impairment of the patient, and the type of resistance training chosen (whole body or localised training) [table V]. In previous studies, the number of exercises most often prescribed was on average 4–6 and ranged from one to nine exercises (table IV).[16-28]

9.6 Intensity of Contraction

Resistance exercises should be performed through the maximum range of motion that does not elicit pain or discomfort. Each repetition must be performed at a slow tempo to elicit the training effects (muscle hypertrophy) and to minimise stress overload of the left ventricle. In relevant studies where resistance testing and training were applied in patients with CHF, the time allowed for a complete lift was 3–6 seconds.[23,27,33,51,54,55] According to current knowledge and until official guidelines are given, we suggest the available time for each repetition during resistance exercise be 4–6 seconds (2–3 for the concentric phase and 2–3 for the eccentric phase).

9.7 Safety Aspects

Patients with CHF have a greater morbidity and mortality than patients with other heart disease manifestations. However, no adverse events occurred during or immediately after resistance exercise testing in patients with CHF.[18,33,51,52,55] Furthermore, no ventricular arrhythmias, need for increased drugs, increase in symptomatology were reported within the next few days after the resistance exercise protocols of participating patients. Pu et al.[18] reported that they performed 91 maximal strength tests in their study without cardiovascular complications in nine women with severe CHF.

From the long-term resistance training studies conducted to date and including 139 patients with CHF, the overall rate of adverse events seems to be low (table III). Furthermore, no differences were found between the combined resistance and aerobic training group compared with the aerobic group alone.[22,27] Despite the fact that no adverse outcome occurred during or after the experimental protocols in studies where patients with very severe CHF were recruited,[51,53] we believe that resistance testing and training should be avoided in patients with severe CHF (NYHA class IV).

9.8 Lifting Technique/Musculoskeletal Injury Risk

Attention should be given to and patients must be trained in the correct lifting technique in order to avoid Valsalva's manoeuvre. For this reason, they must breathe out during weight lifting (concentric phase) and inhale when the weight is lowered (eccentric phase). In healthy subjects who underwent regular resistance training, Pollock et al.[70] found an average of 2.2 minor muscle joint ligament injuries per 1000 training hours. In the study by Barnard et al.,[22] no injury or complaints of muscular soreness occurred immediately after and the week following maximal strength testing in patients with CHF. Conversely, four of the nine women with heart failure (mean age: 77 years) in the study by Pu et al.[18] developed mild intermittent musculoskeletal symptoms during 1RM testing. Therefore, patients with orthopaedic limitations or at risk of musculoskeletal injury, and especially those aged >65 years, should avoid maximal strength testing.

9.9 Determining Training Workloads

Various methods have been used to determine training workloads during resistance training in patients with CHF. The most commonly used is the 1RM method, which represents the maximal weight lifted in one full range of motion. Another approach is to measure the maximum number of repetitions performed before the prohibition of fatigue for the completion of an additional repetition (3RM, 5RM, or 10RM).[31] From the existing studies, seven used the 1RM method[16,18,22-24,26,27] and two used the 10RM or the 15RM method[19,21] to assess the intensity of training in patients with CHF. Furthermore, in three studies[17,25,28] no maximal testing or other strength evaluating procedure was reported. Although several studies demonstrate the safety of maximal testing in patients with CHF, it should be performed carefully, under medical supervision and with proper cardiovascular monitoring. However, there is a need for standardised procedures to determine training workloads with respect to the differing severity of heart failure patients.

Table VI. Contraindications for resistance training in patients with heart failure according to the exclusion criteria applied in the relevant studies

NYHA class IV
Hospitalisation for CHF within 2mo
Change of CHF therapy within 1mo
Worsening of exercise tolerance or symptoms of heart failure during the previous 3–5 days
Increase of bodyweight within 24h more than 1kg
Unstable angina pectoris
Abdominal aortic aneurysm >4cm
Significant exercise-induced ischaemia (>3mm ST-segment depression)
New onset of atrial fibrillation
Obstructive valvular disease
Severe pulmonary hypertension or other severe pulmonary disease
Blood pressure decrease of >20mm Hg during exercise stress test
Resting systolic BP >160mm Hg and diastolic BP >90mm Hg
Complex ventricular arrhythmias at rest or arrhythmias that worsens with exercise
Third-degree atrioventricular block
Resting heart rate >100 bpm
Resting systolic BP >180mm Hg and diastolic BP >105mm Hg
Moderate to severe aortic stenosis
Recent embolism
Acute systemic illness or fever
Active pericarditis, myocarditis or endocarditis

BP = blood pressure; **bpm** = beats/minute; **CHF** = chronic heart failure; **NYHA** = New York Heart Association.

9.10 Supervision of Training

In the relevant studies, patients participated in the resistance training programmes under the supervision of a physical therapist,[20] an exercise physiologist,[23] a research assistant[16,18] or one cardiologist and two physiotherapists.[21] Two studies gave no information about training supervision,[22,28] while in one study resistance training took place at home.[25] However, there is an absence of essential data regarding the type of supervision used in order to prevent cardiovascular complications during training, since few studies give sufficient information. Patients must be monitored by continuous electrocardiography, and blood pressure should be measured before and after training as well as randomly during each resistance training session.[17,21] There are no guidelines available yet on the optimal level of supervision required for resistance training in CHF patients, and this issue needs further verification. Until then, we suggest physician supervision during resistance training for all heart failure patients.

9.11 Resistance Exercise Equipment

For the development of muscular strength, a variety of resistance equipment exists such as machine weights, free weights (barbells and dumbbells), elastic bands, and hand, wrist or ankle weights. These resistance modalities have their advantages and disadvantages.[30,39] Machine weights are safe, easy to learn and illustrate a reduced isometric component. They are a gold standard of training for CHF patients. Of the free weights, the barbells demand an increased skill level and there is concern about safety, since they have an increased isometric component. They are not appropriate, therefore, for CHF patients. Dumbbells (or hand-held weights) are strongly recommended for the most deconditioned patients at the initial stages of training, since they allow a better isolation of single-joint exercises and require a reduced level of technique. Elastic bands are relatively inexpensive, and when properly applied they have the potential to ameliorate flexibility. Finally, ankle weights are not recommended, due to their possible adverse haemodynamic response and the increased risk of musculoskeletal injury in some patients. The above suggestions are based mainly on the results of studies conducted in healthy subjects and in patients with CAD and hypertension.[30,71,72] Further studies are needed to fully establish the haemodynamic response of resistance exercise performed using different resistance training modalities in patients with CHF.

9.12 General Suggestions

Each training session should be preceded by 10–15 minutes of light aerobic activities such as walking, stationary cycling or light calisthenics for warm-up and ended with 5–10 minutes of cool-down. Stretching exercises of the neck, trunk and the extremities must be included in each session during the warm-up and cool-down period. Before each training session, patients must be controlled for weight changes (increase of ≥1kg of bodyweight indicates early cardiac decompensation), existence of oedema and changes in heart rhythm or resting blood pressure.[40] During resistance training, patients must be checked for the proper body position and lifting technique to avoid orthopaedic complications; dyspnoea, fatigue and overall well-being must also be evaluated.

9.13 Circuit Weight Training

According to the scientific basis for the recommendations of resistance training outlined in the previous sections, circuit weight training (CWT) seems to be the most appropriate approach for patients with CHF (see table V). During CWT, patients perform dynamic strength exercises on specific machines rhythmically, activating different muscle groups every time. If machine weights are not available, exercise stations can be developed using other resistance modalities (e.g. hand-held weights or elastic bands).

It should be noted that most of the exercises chosen can be performed in either a bilateral manner (using both limbs at the same time; whole body training) or unilaterally according to the concept of localised muscle training (separately using only one limb each time; segmental training). In patients with CHF, local muscle training allows close to maximal skeletal muscle effort without pushing the impaired cardiac function to its limits,[40,73] thus facilitating the manifestation of the beneficial peripheral adaptations. Specific information concerning the training characteristics (e.g. intensity, duration, frequency, number of repetitions, sets of exercise) can be found in table V.

10. Contraindications of Resistance Training

Generally, patients must be clinically stable and under stable pharmacological therapy for at least 2 months before they begin resistance exercise.[16,18,19,21] To the best of our knowledge, specific contraindications for resistance training in patients with heart failure have not been reported yet. However, according to the exclusion criteria applied in relevant studies, some suggestions can be made (see table VI).

11. Clinical Implications of Resistance Training

Skeletal muscle mass appears to be a good predictor of $\dot{V}O_{2peak}$ and minute ventilation/carbon dioxide release ($\dot{V}_E/\dot{V}CO_2$) slope independently of age, NYHA class, sex, resting haemodynamic and neurohormonal activation.[74] It therefore seems important for patients with CHF to maintain a normal skeletal muscle mass in order to avoid functional impairment. Recently, Huelsmann et al.[4] documented the importance and the clinical implication of maintaining a normal skeletal muscle mass in order to improve outcome in these patients. In their study, the isokinetic strength of the knee flexor muscles was a better predictor of long-term survival (up to 60 months) in 122 patients with severe congestive heart failure than workload or $\dot{V}O_{2peak}$ (figure 4).

Expanding the findings of the above studies, we can hypothesise that a reversal of the skeletal muscle, histochemical, metabolic and functional abnormalities are possible throughout resistance training programmes. Whether this hypothesis will result in an improvement of exercise tolerance, clinical status and prolonged survival of patients with CHF needs to be confirmed in future studies. Preliminary data already exist, since some studies reported a decrease in NYHA status after resistance training alone[19] or in combination with aerobic training[26,27] in patients with CHF. Oka et al.[25] reported that a moderate-intensity home-based walking and resistance exercise programme of 3 months duration was effective in reducing symptoms and improving quality of life (dyspnoea, fatigue, emotional function and perceived control over symptoms) in patients with stable, moderate heart failure (NYHA class II–III).

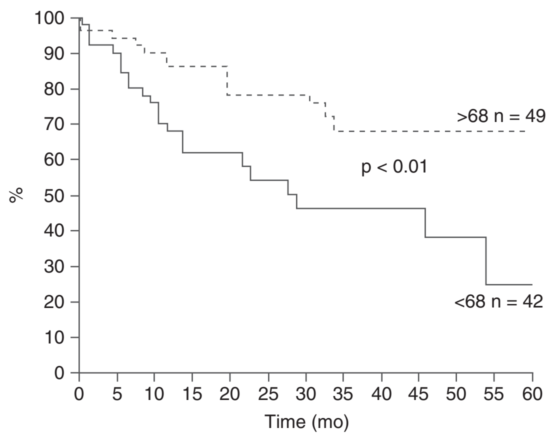

Fig. 4. Kaplan-Meier lifetime analysis of survival stratified by peak torque index of the knee flexor muscles at a cut-off point of 68 Nm × 100/kg bodyweight (reproduced from Huelsmann et al.,[4] with permission from the European Society of Cardiology).

12. Conclusions and Recommendations for Future Research

Based on recent scientific evidence, the application of specific exercise programmes using dynamic resistance training is safe and induces significant histochemical, metabolic and functional adaptations in skeletal muscles of properly screened patients with CHF (EF: 20–30%, NYHA I–III).

Table IV provides detailed information regarding the aetiology and severity of the recruited patients who participated in various studies. Note that NYHA classes II and III represent the most frequently appearing subgroups of CHF patients and that coronary artery disease was the primary cause of CHF followed by dilated cardiomyopathy. No studies have examined the applicability and adaptations of resistance training with regard to the different aetiology of CHF and further research is required on this topic.

Resistance training seems to contribute significantly to the treatment of specific myopathy and muscle weakness occurring in the majority of CHF patients. Thus, multiple health-related and socioeconomic benefits could be achieved when professionals involved in the rehabilitation process are aware of the practical implications of resistance training and encourage patients to exercise regularly.

Furthermore, the present literature is largely based on trials involving a small number of patients with heart failure and may not be representative of all groups with heart failure. Little is known, for example, about the appropriateness and the effects of resistance training in women and elderly patients with CHF. In previous studies, where the training periods lasted between 2 and 4 months, resistance training was safely applied and resulted in positive left ventricular responses and adaptations. Recently, resistance training was applied without causing a reduction in LV contractile function or structure.[75] Further studies are needed, however, to establish the effects of longer resistance training periods on left ventricular size and function, and examine whether improvement in cardiac and muscular parameters induced by resistance training can improve the outcome of patients with CHF. Finally, because changes in peak $\dot{V}O_2$ after training have been reported to be greater in patients with non-ischaemic than with ischaemic cardiomyopathy,[69] it is important to know whether the adaptations of resistance training depend upon the different aetiology of heart failure.

This article provides preliminary recommendations on resistance training based on current scientific knowledge in order to improve muscle strength and functions necessary for recreational and daily living activities (and thus quality of life) in patients with stable CHF. Nevertheless, the haemodynamic and cardiovascular responses to resistance exercise (heart rate, systolic pressure, EF, cardiac output, left ventricular end-diastolic volume) in relation to the training characteristics (e.g. intensity, number of repetitions, muscle mass involved) and according to the severity of heart failure need to be studied further in order to fully establish the applicability of resistance training in these patients.

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