Hemodynamic Responses During Aerobic and Resistance Exercise

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- **PURPOSE:** Resistance training has become an accepted part of cardiac rehabilitation programs. Because of the potential for a high afterload to have a negative impact on left ventricular function, there has been concern regarding the safety of resistance training for patients with congestive heart failure.
- **METHODS:** This study addressed this concern by studying 12 healthy volunteers, 12 patients with stable coronary artery disease, and 12 patients with stable congestive heart failure during upright cycling at 90% of ventilatory threshold, and during one set of 10 repeated leg presses, shoulder presses, and biceps curls at 60% to 70% of 1-repetition maximum. Left ventricular function was measured by echocardiography.
- **RESULTS:** The pattern of changes in heart rate, blood pressure, left ventricular ejection fraction, wall thickness, and left ventricular internal diameters was similar across all three groups of subjects, although there were large differences in absolute values. Despite elevations in diastolic and mean arterial pressures during resistance exercise, there was no evidence of significant rest-to-exercise deterioration in left ventricular function during leg press (ejection fraction, 60%-59%, 56%-55%, and 38%-37%), shoulder press (66%-65%, 59%-53%, and 38%-35%), or biceps curls (63%-58%, 53%-54%, and 35%-36%), as compared with cycle ergometry (63%-69%, 51%-57%, and 35%-42%) in the healthy control subjects, the patients with coronary artery disease, and the patients with congestive heart failure, respectively.
- **CONCLUSIONS:** Left ventricular function remains stable during moderate-intensity resistance exercise, even in patients with congestive heart failure, suggesting that this form of exercise therapy can be used safely in rehabilitation programs.

K E Y W O R D S

ejection fraction

left ventricular function

exercise training

rehabilitation

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Recent studies have shown that patients with stable congestive heart failure (CHF) benefit from aerobic exercise training, largely because of peripheral adaptations.[1-3] These adaptations have been associated with improved quality of life for patients with CHF.[2,4,5] Furthermore, findings have shown that more strenuous exercise programs including interval training are well tolerated by patients with CHF, and that such programs enhance improvement in functional capacity[6] without evidence of inappropriate stress on the left ventricle.[7]

However, there has been concern about the use of resistance training, particularly for patients with compromised left ventricular (LV) function, because of the potentially high afterload during resistance training. Resistance training was first recommended for selected patients with coronary artery disease (CAD) in the American Association of Cardiovascular and Pulmonary Rehabilitation guidelines only in 1991.[8] Results from recent studies have shown that resistance training appears to be safe for a wider variety of patients, including low- to intermediate-risk cardiac patients, on the basis of evidence suggesting that the hemodynamic loads during resistance training are similar to those observed during traditional aerobic exercise.[9-12]

It is known that endurance training alone does not enhance skeletal muscle strength.[13] Because structural and metabolic changes in the skeletal muscle account for much of the decreased exercise capacity in patients with CHF,[14,15] resistance training might be expected to benefit this patient group. Recent studies, including both endurance and resistance training for patients with CHF, have shown that both types of training are well tolerated, and that such training increases muscular strength and endurance.[16-18] However, it has been observed that during sustained isometric contractions, a pressure load is put on the heart as a result of the pressor response and a significant rise in mean arterial pressure occurs.[19-22] Consequently, patients with cardiac disease could potentially experience unfavorable increases in LV end-diastolic pressure and end-systolic volume, a decrease in LV end-diastolic volume and ejection fraction with arrhythmias,[23] and exaggerated wall motion abnormalities.[24]

Studies of patients with heart disease[24-27] suggest that afterload remains high during upper extremity exercise. Furthermore, studies of patients with CHF suggest that during sustained isometric hand-grip contraction, increases in systemic vascular resistance become evident along with a decrease in LV ejection fraction and stroke work index, supporting the concept of an overload on the left ventricle. Because dynamic resistance exercise has a large isometric work component, a potential rise in afterload could be critical in this group of patients.[25,26] However, recent measurements of central hemodynamics during lower body resistance training in patients with CHF have demonstrated an appropriate decrease in afterload and stable LV function.[26,27]

Because upper body resistance training may further contribute to functional recovery in patients with CHF, and because there still are at least theoretically valid concerns regarding the safety of resistance training in these patients. The current study was designed to evaluate the acute hemodynamic responses and the stability of LV function during upper and lower body resistance training versus cycle ergometry in patients with CHF, as compared with healthy controls and patients with stable CAD.

METHODS

The study protocol was approved by the university ethics committee, and each subject provided informed consent. Three groups of subjects were recruited for the study. Their physical characteristics are summarized in Table 1.

The CHF group included 12 subjects (7 men and 5 women) with stable CHF (New York Heart Association class I-II). The average sitting LV ejection fraction was 35% ± 8%. All the patients in this group had experienced one or more episodes of acute heart failure, but had been clinically stable for more than 8 weeks. Six of the patients were participants in a regular exercise program.

The CAD group consisted of 12 clinically stable patients (11 men and 1 woman) with ischemic cardiovascular disease, but minimal LV dysfunction and no clinical history of CHF. The average sitting resting LV ejection fraction was 51% ± 11%. All 12 patients in this group were participants in a regular exercise program.

The control group consisted of 12 clinically healthy and physically active subjects (8 men and 4 women). The average sitting resting LV ejection fraction was 63% ± 8%. Younger subjects were chosen rather than age-matched controls in an effort to maximize the likelihood that LV functional responses during aerobic and resistance training would represent a truly normal response pattern.

Table 1 • MEAN (± SD) PHYSICAL CHARACTERISTICS OF PARTICIPANTS

	CHF Group	CAD Group	Healthy Group
Age, y	62 ± 9	69 ± 9	29 ± 8
Height, cm	171 ± 10	177 ± 8	177 ± 7
Weight, kg	85 ± 15	85 ± 14	75 ± 14
Maximum exercise capacity			
Power output, W	90 ± 34	132 ± 37	267 ± 58
Oxygen uptake, mL/kg/min	15.3 ± 4.2	21.2 ± 3.7	41.8 ± 7.7
Heart rate, beats/min	148 ± 33	140 ± 12	178 ± 11
Ventilatory threshold			
Power output, W	50 ± 25	69 ± 22	145 ± 50
Oxygen uptake, mL/kg/min	10.2 ± 2.5	13.5 ± 2.5	27.1 ± 7.1
90% of ventilatory threshold			
Power output, W	39 ± 19	59 ± 19	129 ± 44
Oxygen uptake, mL/kg/min	9.1 ± 2.2	12.1 ± 2.3	24.2 ± 6.4

CHF, congestive heart failure; CAD, coronary artery disease.

The patients with CHF/CAD were receiving the following medications: angiotensin-converting enzyme inhibitors (9/1), beta-blockers (8/7), alpha blockers (0/1), calcium-channel blockers (1/0), diuretics (9/1), digitalis (8/0), nitrates (1/4), aspirin therapy (11/9), and antilipidemics (6/9). All the patients continued their usual medications during all the procedures because the purpose of this study was to evaluate responses under conditions representing those experienced in rehabilitation programs. In any case, the medical therapy of the patient groups was not remarkable. Two of the patients with CHF were experiencing well-controlled atrial fibrillation that did not interfere with testing. No patient had angina, electrocardiogram evidence of exertional ischemia, hemodynamically significant valvular disease, serious ventricular arrhythmias, serious pulmonary disease, orthopedic disorders, neurologic disorders, or peripheral vascular disease that limited exercise.

All the study participants initially underwent a maximal incremental exercise test on an electrically braked cycle ergometer with measures of respiratory metabolism using open-circuit spirometry. After a 3-minute seated resting period and a 3-minute warmup of unloaded pedaling, the power output was increased by 10 to 25 W every minute, depending on the predicted exercise capacity of the participant. The electrocardiogram and blood pressure were monitored throughout this test according to conventional clinical guidelines.

All the participants were tested during a training session 1 to 7 days after the incremental exercise test. Both the cycle exercise and the resistance training were designed to approximate a typical cardiac rehabilitation exercise training session.

The participants completed the 15-minute cycling exercise first. A 3-minute warmup on the cycle at approximately 35% of their maximal exercise capacity was followed by 12 minutes of cycling at a power output requiring an oxygen uptake that was 90% of their ventilatory threshold.

After cycling, they rested briefly (approximately 5 min), and then performed resistance training exercises in the following order: seated leg press using a specialized leg press device, then shoulder press and biceps curls using free weights. The shoulder press and biceps curls were performed unilaterally to facilitate echocardiography and blood pressure measurements. Before each resistance exercise, the 1-repetition maximum was determined by having the participants lift heavier weights successively until they felt that they could lift no additional weight. The exercise required to determine the 1-repetition maximum also served as a warmup for the resistance training exercises. Each participant then repeated one set of three exercises 10 times at a resistance that was 60% to 70% of their 1-repetition maximum. This percentage range was chosen because resistance training studies of CHF patients commonly have used 50% to 80% of 1-repetition maximum.[16-18]

Resting blood pressure, heart rate, and echocardiographic images were obtained while the participant was sitting upright on the bicycle. These images were measured during minute 15 of the cycling exercise. During resistance training, resting heart rate, blood pressure, and echocardiographic images were obtained with the participant holding the weight. Heart rate, blood pressure, and echocardiographic images also were obtained during the last 5 repetitions of each 10-repetition set. Blood pressure was measured by auscultation of the nonexercising arm.

The LV functional images were acquired by using two-dimensional echocardiography (Acuson Corporation, Mountain View, CA). The LV end-diastolic and end-systolic dimensions were measured from the parasternal long-axis view just below the level of the mitral valve. Anteroseptal and posterior systolic and diastolic wall thicknesses also were measured just below the level of the mitral valve. The ejection fraction was calculated according to Schiller et al.[28] Groups, exercise type, and trials (rest and peak) were compared statistically using a three-way analysis of variance (ANOVA) with repeated measures (groups × exercise type × trials). Because there were no significant three-way interactions, a two-way ANOVA with repeated measures comparing exercise type and trials was conducted for each group. Specific pairwise comparisons for trials (rest versus peak) were made using the Tukey test. Statistical significance was determined by an alpha .05.

RESULTS

All the participants completed the testing procedures without untoward events. The patients with CHF reported moderate muscle tiredness, and three patients experienced moderate shortness of breath during steady-state cycling, which was managed with brief reductions in power output. The mean responses for each group are presented in Tables 2, 3, and 4.

The hemodynamic responses for the different types of exercise were remarkably similar among the groups of participants (Figures 1 and 2).The heart rate response (Figure 1) was characterized by greater absolute values in the healthy subjects. The main specific difference was a significantly larger increase in heart rate during cycling in the healthy group. The pattern of increase in mean arterial pressure (Figure 2) generally was similar across types of exercise within the subject groups. The only statistically significant difference was that the mean arterial pressure during cycling remained stable in the healthy group, whereas it increased significantly in the

Table 2 • MEAN (± SD) HEMODYNAMIC AND LEFT VENTRICULAR RESPONSES DURING CYCLING, LEG PRESS (LP), SHOULDER PRESS (SP) AND BICEPS CURLS (BC) IN CONGESTIVE HEART FAILURE GROUP

	Cycling		LP		SP		BC	
	Rest	Peak	Rest	Peak	Rest	Peak	Rest	Peak
Heart rate, beats/min	80 ± 11	113 ± 18	88 ± 13	94 ± 11	88 ± 10	100 ± 15	90 ± 10	96 ± 12
Systolic blood pressure, mm Hg	120 ± 17	146 ± 21	122 ± 18	136 ± 19	121 ± 14	137 ± 16	121 ± 14	137 ± 19
Diastolic blood pressure, mm Hg	77 ± 10	78 ± 11	82 ± 8	91 ± 14	81 ± 11	100 ± 12	84 ± 12	97 ± 17
Mean arterial pressure, mm Hg	91 ± 11	100 ± 14	95 ± 10	106 ± 14	95 ± 10	112 ± 12	96 ± 11	110 ± 16
Ejection fraction, %	35 ± 8	42 ± 11	38 ± 9	37 ± 10	38 ± 10	35 ± 7	35 ± 9	36 ± 11
End systolic dimension, mm	46 ± 7	42 ± 7	44 ± 7	45 ± 8	44 ± 7	44 ± 7	44 ± 8	44 ± 8
Systolic post wall thickness, mm	13 ± 2	12 ± 3	13 ± 2	12 ± 2	13 ± 3	13 ± 2	12 ± 2	12 ± 2
Systolic ant-sept wall thickness, mm	13 ± 2	13 ± 3	14 ± 3	13 ± 3	12 ± 3	12 ± 2	12 ± 3	13 ± 3
End diastolic dimension, mm	55 ± 5	54 ± 6	54 ± 7	55 ± 8	54 ± 6	53 ± 7	53 ± 7	53 ± 7
Diastolic post wall thickness, mm	10 ± 2	11 ± 2	11 ± 2	11 ± 1	11 ± 2	12 ± 2	11 ± 2	12 ± 2

ant-sept, anterio-septal.

patient groups. This difference appears to be a function of a large decrease in diastolic blood pressure during cycle exercise among the healthy participants, as compared with stable values of diastolic blood pressure among the two patient groups (Tables 2, 3, and 4).

The results showed the expected difference among the groups in the absolute value of LV ejection fraction (Figure 3). Otherwise, the LV ejection fraction did not change significantly from rest to peak during any of the exercises in any of the groups.

DISCUSSION

The major finding of this study shows that the pattern of both hemodynamic and LV functional responses in patients with CHF are remarkably similar to that observed in clinically stable patients with CAD, and in young, healthy control subjects. According to the authors' interpretation, this supports the safety of resistance training in well-compensated patients with CAD or CHF. It suggests that the documented clinical efficacy of resistance training as a component of rehabilitation in patients with CAD[5] may be extended to patients with CHF. In addition, the authors believe that these results should help to allay safety concerns associated with overhead exercise among patients with cardiovascular disease.

The results of the cycle exercise are similar to those of prior studies. In healthy individuals, the LV ejection fraction usually is thought to increase somewhat during submaximal steady-state exercise,[29-32] consistent with the current results. In patients who have CAD but no active ischemia, the LV ejection fraction also generally increases slightly during the course of steady-state exercise.[12,30] This also is supported by the current results. In

Table 3 • MEAN (± SD) HEMODYNAMIC AND LEFT VENTRICULAR RESPONSES DURING CYCLING, LEG PRESS (LP), SHOULDER PRESS (SP) AND BICEPS CURLS (BP) IN CORONARY ARTERY DISEASE GROUP

	Cycling		LP		SP		BC	
	Rest	Peak	Rest	Peak	Rest	Peak	Rest	Peak
Heart rate, beats/min	79 ± 11	109 ± 11	82 ± 13	95 ± 15	88 ± 13	96 ± 13	89 ± 12	94 ± 12
Systolic blood pressure, mm Hg	139 ± 16	171 ± 20	149 ± 16	164 ± 15	145 ± 17	167 ± 14	145 ± 15	158 ± 13
Diastolic blood pressure, mm Hg	88 ± 7	82 ± 11	93 ± 8	97 ± 10	92 ± 8	111 ± 6	92 ± 7	107 ± 9
Mean arterial pressure, mm Hg	105 ± 6	112 ± 12	112 ± 8	120 ± 9	110 ± 9	130 ± 6	110 ± 6	124 ± 6
Ejection fraction, %	51 ± 11	57 ± 8	56 ± 8	55 ± 9	59 ± 12	53 ± 13	53 ± 12	54 ± 7
End systolic dimension, mm	33 ± 6	30 ± 6	31 ± 5	33 ± 5	29 ± 8	30 ± 7	30 ± 6	29 ± 5
Systolic post wall thickness, mm	14 ± 2	14 ± 3	14 ± 3	14 ± 2	15 ± 3	14 ± 3	15 ± 3	15 ± 2
Systolic ant-sept wall thickness, mm	16 ± 3	16 ± 3	16 ± 3	16 ± 4	17 ± 3	16 ± 3	17 ± 3	17 ± 4
End diastolic dimension, mm	44 ± 5	45 ± 6	46 ± 7	47 ± 7	43 ± 6	41 ± 6	42 ± 6	41 ± 5
Diastolic post wall thickness, mm	11 ± 1	11 ± 2	11 ± 2	12 ± 2	13 ± 1	13 ± 2	13 ± 2	12 ± 2
Diastolic ant-sept wall thickness, mm	13 ± 1	13 ± 2	13 ± 3	14 ± 3	14 ± 2	14 ± 2	14 ± 3	14 ± 3

ant-sept, anterio-septal.

Table 4 • MEAN (± SD) HEMODYNAMIC AND LEFT VENTRICULAR RESPONSES DURING CYCLING, LEG PRESS (LP), SHOULDER PRESS (SP) AND BICEPS CURLS (BC) IN HEALTHY GROUP

	Cycling		LP		SP		BC	
	Rest	Peak	Rest	Peak	Rest	Peak	Rest	Peak
Heart rate, beats/min	68 ± 12	135 ± 16	84 ± 14	117 ± 17	98 ± 14	110 ± 20	87 ± 12	109 ± 16
Systolic blood pressure, mm Hg	131 ± 14	175 ± 18	142 ± 21	173 ± 17	151 ± 8	166 ± 19	136 ± 18	166 ± 18
Diastolic blood pressure, mm Hg	89 ± 9	68 ± 12	86 ± 11	109 ± 9	95 ± 11	114 ± 11	90 ± 8	117 ± 9
Mean arterial pressure, mm Hg	106 ± 15	104 ± 12	105 ± 11	130 ± 9	113 ± 9	132 ± 10	105 ± 11	133 ± 11
Ejection fraction, %	63 ± 8	69 ± 7	60 ± 10	59 ± 8	66 ± 5	65 ± 11	63 ± 10	58 ± 6
End systolic dimension, mm	28 ± 6	25 ± 6	29 ± 5	28 ± 4	25 ± 5	25 ± 8	28 ± 6	27 ± 6
Systolic post wall thickness, mm	15 ± 4	15 ± 3	15 ± 3	15 ± 4	15 ± 4	14 ± 3	14 ± 3	14 ± 3
Systolic ant-sept wall thickness, mm	14 ± 3	15 ± 2	15 ± 3	15 ± 3	15 ± 3	15 ± 3	14 ± 3	15 ± 4
End diastolic dimension, mm	44 ± 7	43 ± 7	44 ± 6	43 ± 6	39 ± 6	40 ± 8	42 ± 6	40 ± 8
Diastolic post wall thickness, mm	12 ± 3	12 ± 2	11 ± 3	12 ± 2	12 ± 2	11 ± 2	11 ± 2	12 ± 1
Diastolic ant-sept wall thickness, mm	11 ± 2	12 ± 2	12 ± 3	12 ± 2	12 ± 2	13 ± 3	12 ± 2	12 ± 2

ant-sept, anterio-septal.

patients with stable CHF, the LV ejection fraction is thought to increase somewhat or remain constant during steady-state exercise,[12,33] as observed also in the current results. In healthy individuals, the results observed during resistance exercise parallel those of other studies in terms of large increases in systolic, diastolic, and mean arterial pressure.[22,34,35] However, the magnitude of the hemodynamic response in the current study was smaller than in previous studies and much less than in the classic work of MacDougall et al[22] involving competitive body builders. In patients with CAD but no active ischemia during lifting, Sagiv et al[27]

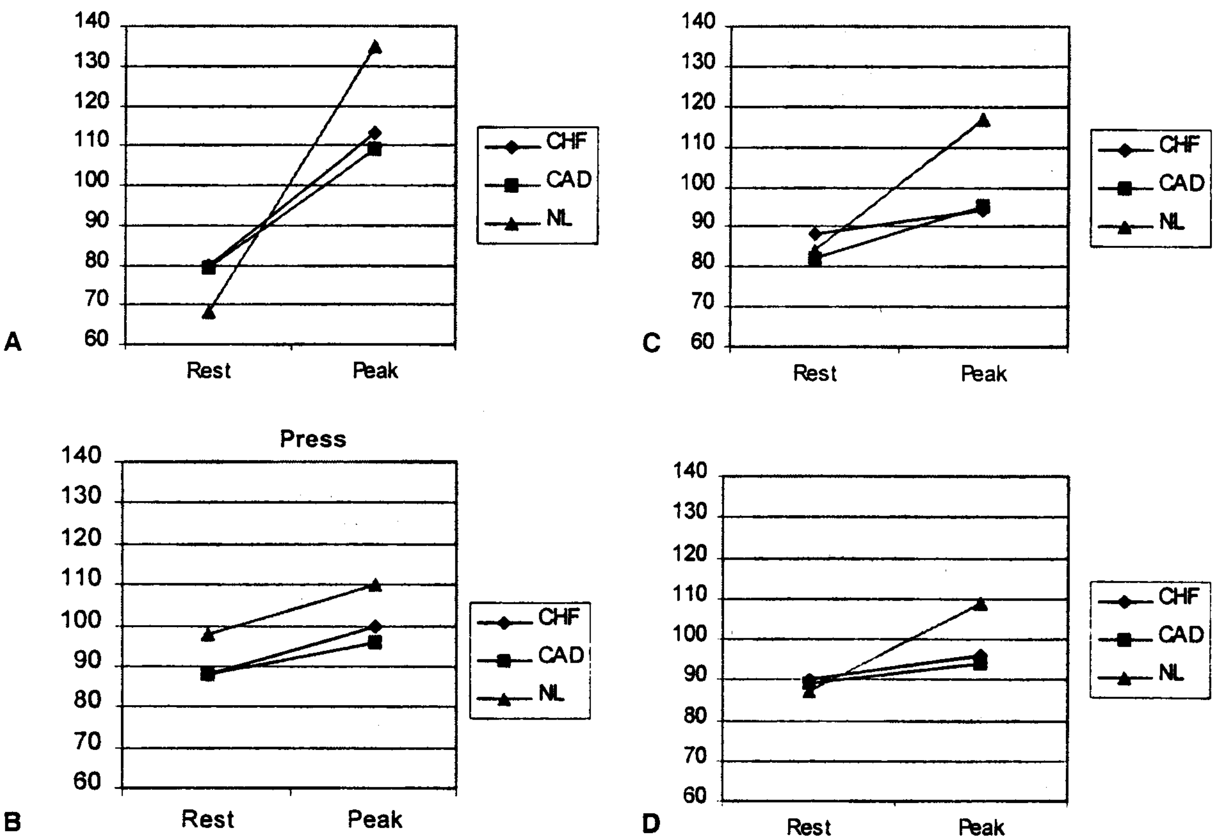

Figure 1. Serial responses of heart rate (beats per minute) during aerobic and resistance exercise in the three groups of study participants. A, cycling; B, shoulder press; C, legpress; D, biceps curls. Note the general similarity in the response patterns among the three groups and the similarity among the types of exercise, with the largest heart rate response during cycling.

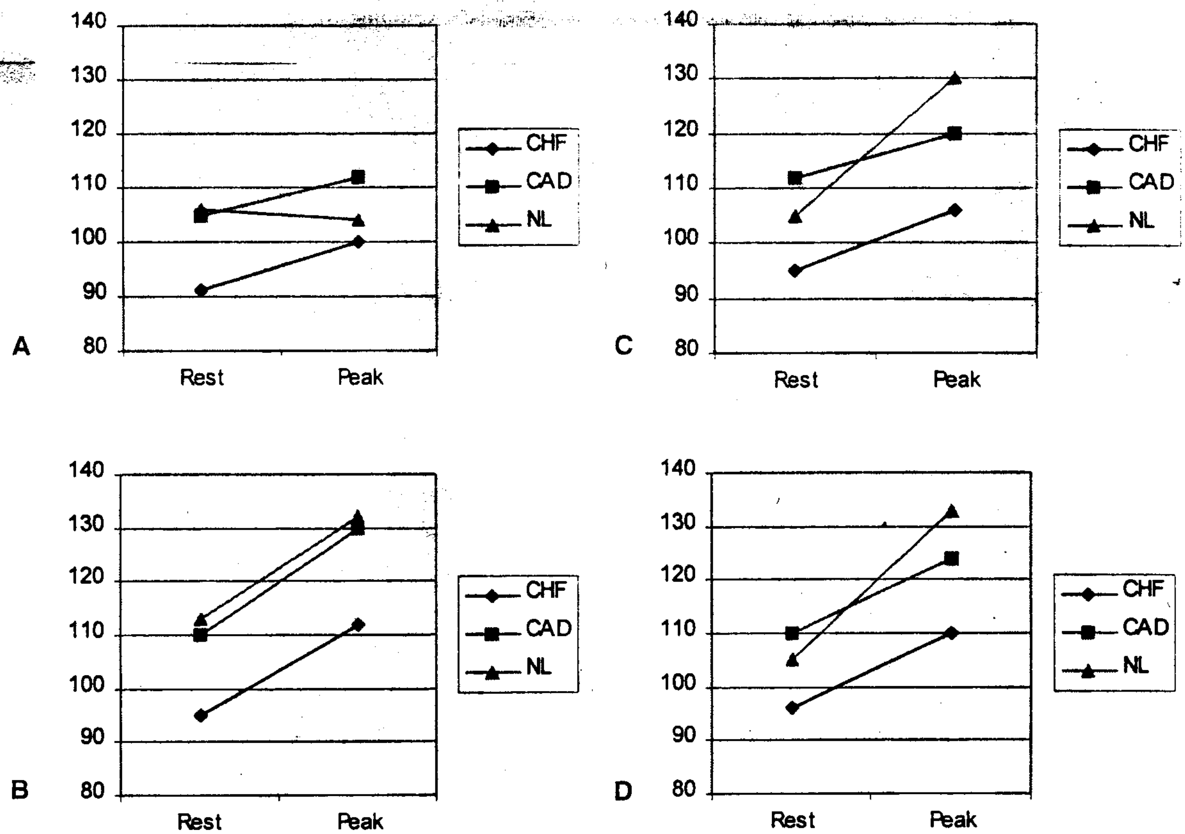

Figure 2. Serial responses of mean arterial pressure (mmHg) during aerobic and resistance exercise. A, cycling; B, shoulder press; C, leg-press; D, biceps curls. Note the general similarity in the patterns of response among the three groups and the generally larger blood pressure response during resistance exercise.

and Featherstone et al[24] found increases in heart rate, systolic blood pressure, and diastolic blood pressures similar to those observed in the current study. In patients with stable CHF, resistance exercise studies have been conducted using only the leg press.[26] In these studies the systolic, diastolic, and mean arterial pressures during resistance exercise have been similar to the results of the current study. Despite the observed hemodynamic challenges, LV function remained stable during resistance exercise, as shown in the current results.

The current study was limited by the echocardiographic imaging technique. No volumes could be calculated because only the diameters from the parasternal long axis view were measured. This was done purposely. The authors chose to optimize the exercise component at the expense of better echocardiographic imaging (eg, postexercise, supine, apical four-chamber view), because one of their primary purposes was to measure LV function during exercise. Evaluation of both hemodynamic and LV responses potentially would have been compromised if a protocol more optimal for imaging had been chosen.

In conclusion, this study demonstrates the stability of both hemodynamic responses and LV function during aerobic and resistance exercise in patients with CAD and CHF. It also shows a similarity between the pattern of these responses and those of young, healthy individuals. This suggests that resistance exercise is as safe as steady-state aerobic exercise in these patient groups (eg, CAD patients with essentially normal resting LV function and New York Heart Association class I-II patients with CHF). Resistance exercise may therefore be included in a rehabilitation program for well-compensated patients with CHF, increasing the quality and effectiveness of the program.

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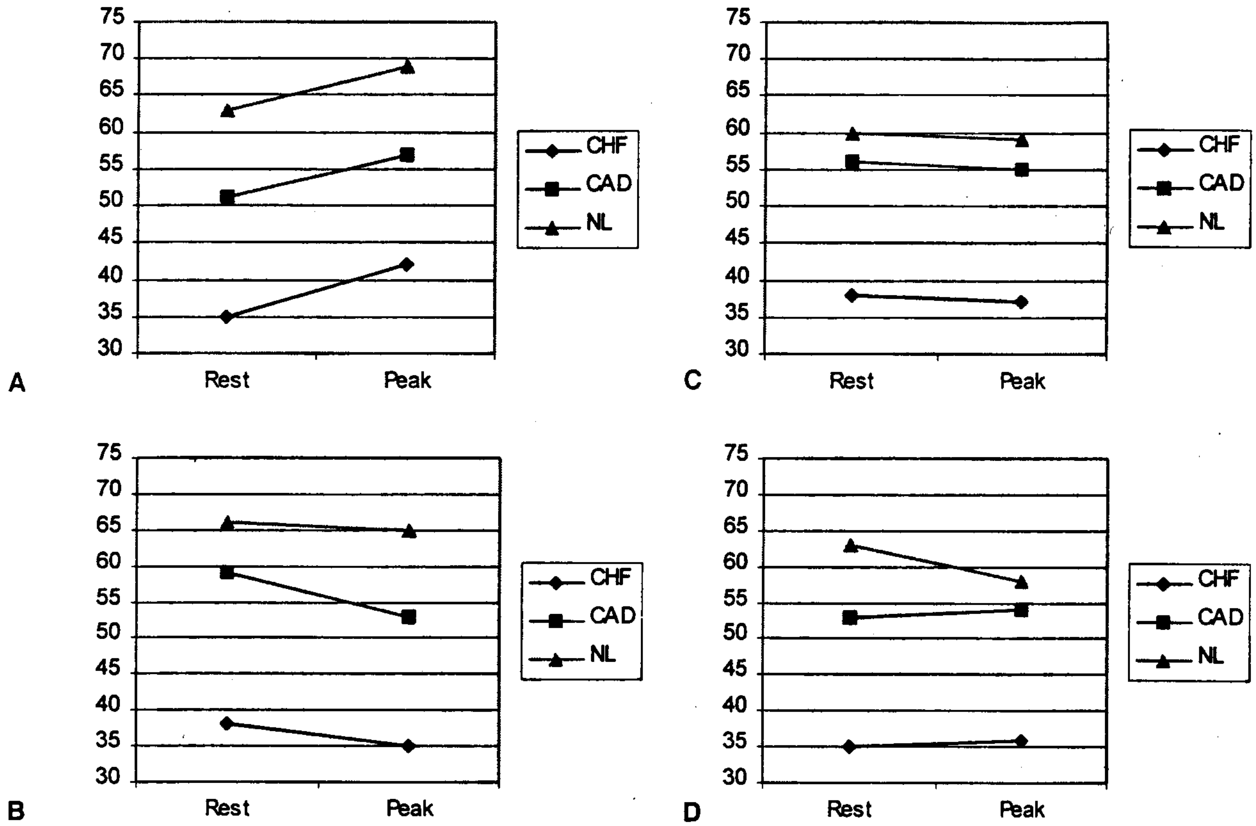

Figure 3. Serial responses of left ventricular ejection fraction (%) during aerobic and resistance exercise in the three groups of study participants. A, cycling; B, shoulder press; C, legpress; D,,biceps curls. Besides the clearly evident group differences in the absolute value of the ejection fraction, the similarity of responses within groups to different types of exercise and between groups to the same exercise is very clear.

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