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Aerobic Exercise Improves Fitness and Heart Rate Variability After an Implantable Cardioverter Defibrillator

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Abstract

PURPOSE—The purpose of this study was to determine the effects of an 8 week aerobic exercise program on 1) cardiopulmonary fitness and activity, 2) heart rate variability (HRV), 3) health outcomes, and 4) high sensitivity C-reactive protein (hsCRP) in survivors of sudden cardiac arrest (SCA) who have an implantable cardioverter defibrillator (ICD).

METHODS—A single group pre-post exercise program with a 6 month follow-up was used in 10 ICD recipients. The exercise intervention consisted of supervised outpatient aerobic exercise 3 hours/week plus home walking 2 hours/week for 8 weeks. Subjects were told to walk for 30 minutes on all or most days of the week for the remaining 4 months. Measures were taken at baseline, 8, and 24 weeks.

RESULTS—Cardiopulmonary fitness (exercise time, oxygen uptake at anaerobic threshold, metabolic equivalents, HRV [standard deviation (SD) of all R-R intervals, root mean square of successive differences (RMSSD), high frequency (HF) power), health outcomes (Short Form-12 physical and mental health, anxiety, depression), and hsCRP were improved after 8 weeks of exercise. Sustained effects of the exercise program were noted in daily activity (RT3 vm/min), HRV (SD5 minute segments, RMSSD, percent R-R change by 50 milliseconds (pRR50, HF power), and health outcomes (SF-12 physical health).

CONCLUSION—Sudden cardiac arrest survivors who have an ICD are a group of cardiac patients who can potentially benefit the most from exercise by stabilizing autonomic function and reducing the incidence of arrhythmias. While causal conclusions can not be drawn from this study, further testing of aerobic exercise interventions in this population appears warranted.

Keywords

Aerobic exercise; sudden cardiac death; heart rate variability; ICD; ventricular fibrillation

Lethal ventricular arrhythmias responsible for sudden cardiac arrest (SCA) have been attributed to multiple causes. Evidence points to the important role of the autonomic nervous system (ANS) in producing susceptibility to ventricular fibrillation in subsets of patients with heart disease. Findings demonstrate that patients at risk for cardiac arrest exhibit a reduction in parasympathetic nervous system activity. Protection against SCA may be achieved through mechanisms that increase parasympathetic tone,¹ exercise being one of these therapies.²

Exercise interventions in cardiac arrest survivors who have an implantable cardioverter defibrillator (ICD) have not been well studied. Health care providers are often reluctant to prescribe exercise for this group because of the belief that it will provoke ventricular arrhythmias and cardiac arrest. Patients are often afraid to exercise because of concern for receiving an ICD shock. It has been unclear if the amount of exercise required to improve cardiopulmonary function and parasympathetic nervous system activity can be achieved in this group. However, exercise offers the potential benefit of stabilization of autonomic function and protection against future arrhythmic occurrences, in a population of cardiac patients who could potentially benefit the most.³ Exercise training is an inexpensive, non-pharmacological intervention that is essentially available to everyone. Therefore the purpose of this study was to determine the impact of 8 weeks of aerobic exercise on: 1) cardiopulmonary fitness and activity, 2) heart rate variability (HRV), 3) health outcomes, and 4) high sensitivity C-reactive protein (hsCRP) in persons who have an ICD for the secondary prevention of cardiac arrest. Follow-up at 6 months after completing the exercise program was done to determine if early effects of aerobic training were sustained.

METHODS

A single group pre-post test design with 6 month follow-up was used to describe effects of aerobic exercise in 10 survivors of sudden cardiac arrest (SCA) who had an ICD implanted in the previous 6 months. Subjects were identified by registered nurses working in the arrhythmia service at a northwestern university medical center. Confirmation of SCA and the need for ICD implantation was verified with medical records and electrophysiological reports. Only first time SCA survivors with a definitive diagnosis of ventricular fibrillation or ventricular tachycardia arrest due to a cardiac-related cause were selected. Subjects were excluded if they had unstable angina, myocardial infarction (MI), or heart surgery within the previous 3 months or concurrent participation in a regular exercise program (20 minutes/3 times per week).

Protocol

Subjects were screened with a portable 12-lead electrocardiogram and 24 hour Holter monitor prior to determining exercise capacity to rule out atrial fibrillation and frequent ventricular arrhythmias. Ejection fraction was determined from the echocardiogram at the time of ICD implantation using reported values. At baseline and after 8 weeks of exercise, subjects participated in a cardiopulmonary exercise test (CPET) for maximal oxygen uptake ($\dot{V}O_2$ max) measurements, Holter monitoring for 24 hours, RT3 triaxial activity monitoring for 4 days, and completed study questionnaires. At the end of 6 months (4 months after completing the exercise intervention), subjects had a repeat Holter monitor, RT3 monitoring, and completed questionnaires. The dose, type, route, or frequency of medications during the 8 week study condition as well as the numbers of arrhythmias and ICD shocks were carefully monitored. Changes in diuretic medications were made by cardiology providers as needed during the study, without changes in other medications. A signed consent form and institutional review board approvals were obtained before data collection.

Exercise Intervention

Supervised exercise plus home walking, included outpatient aerobic training in 1 hour sessions repeated 3 days per week for a total of 8 weeks (24 sessions) and 1 hour of home walking for 2 hours each week. Each outpatient exercise session was supervised by a trained exercise specialist and began with warm-up and stretching exercises followed by bicycle ergometry and treadmill walking, the intensities titrated gradually to achieve and maintain 60–80% of heart rate maximum. All subjects were monitored continuously with electrocardiography (ECG) to ensure that arrhythmias were not occurring regularly during supervised exercise training. Home walking was performed on a flat surface for a total of 1 hour, 2 times/week, for 8 consecutive

weeks. The total volume of exercise prescribed for 8 weeks was 5 hours each week (40 hours) of aerobic training. Each subject was given an individualized target heart rate zone based on the cardiopulmonary exercise test and ICD settings. Home walking was monitored using the Polar Beat Heart Rate Monitor. At the end of 8 weeks of exercise, subjects were told to continue walking for 30 minutes on all or most days of the week, without further support or monitoring provided by the study. All subjects returned for repeat data collection 4 months later (6 months from the start of exercise training).

Measures

Cardiopulmonary fitness was assessed using peak VO₂ from the CPET at entry and after 8 weeks of exercise. The subject's ICD was turned off during the exercise test using an ICD programmer. This technique was used in order to prevent the subject from being inadvertently shocked by the ICD for sinus tachycardia. The CPET was completed according to a protocol described by Young et al.⁴ Expired gases were analyzed breath by breath using a Medical Graphics Cardio-2 Metabolic Exercise System. Inspiratory flow, expiratory oxygen and carbon dioxide concentrations, and oxygen uptake and carbon dioxide production were calculated using standard formulas. Peak oxygen uptake was determined as the average value observed over the last 30 seconds of exercise.

Daily activity was measured as body movement in vector magnitude/minute (vm) using the Stayhealthy RT3 triaxial accelerometer over a 4 day measurement period that will include 2 weekdays and 2 weekend days. The RT3 accelerometer measures movement in 3 dimensions by 3 accelerometers oriented orthogonally. Accelerometers have attained gold standard status for measuring daily physical activity.^{5,6}

HRV was assessed with 3 leads of ECG recorded over a 24 hour period on a digital Holter recorder. Standards of measurement set forth by the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology were used when computing HRV.⁷ Five time domain measures of HRV were used in this study: 1) standard deviation of all R-R intervals for 24 hours (SDNN),⁸ 2) Standard deviation index (SDI index) or the mean of the standard deviation of R-R intervals for 5 minute segments, 3) standard deviation of the mean of R-R intervals for 5 minute segments (SDANN index),⁹ 4) root mean square of successive differences of the R-R intervals (RMSSD),¹⁰ and 5) percent of R-R intervals changing from preceding R-R interval by 50 milliseconds (pRR50).¹¹ Four frequency domain measures of HRV were used in this study: 1) very low frequency (VLF) power (0.003–0.04 Hz) or the sympathetic frequency, 2) low frequency (LF) power or the combined sympathetic/parasympathetic frequency (0.04–0.15 Hz), 3) high frequency (HF) power or the parasympathetic frequency (0.15–0.40 Hz), and 4) ratio of low to high frequency power (LF/HF) for a 24 hour period.⁷

Health outcomes (general health related quality of life, anxiety, depression) were assessed using the Short Form Health Survey (SF-12), the State-Trait Anxiety Inventory (STAI), and the Center for Epidemiologic Studies-Depression scale (CES-D), respectively. The SF-12 is the shortened version of the SF-36, a health outcome survey developed as part of the Medical Outcomes Study (MOS) to assess physical and mental health concepts.^{12,13} Reliabilities on each of the subscales range from 0.65 to 0.96. Anxiety was measured using the state scale of STAI¹⁴ which has been used extensively in cardiovascular populations, specifically in hypertension, coronary artery disease, and SCA and has been found to be sensitive to change.¹⁴ Depression was measured using the CES-D¹⁵ which quantifies depressive symptoms with a focus on depressed mood.

High sensitivity C-reactive protein was obtained through a superficial venipuncture. The blood samples were processed within 30 minutes and analyzed in the medical center's clinical

laboratory. The hsCRP was assayed from plasma on the automated chemistry instrument, Abbott LX1 using immunoturbidity.

Descriptives, frequencies, and plots of all variables were done to determine outliers and clean data. Paired t-tests were used to determine changes in baseline to 8 week scores. Analysis of variance was used to determine statistical changes between baseline, 8 week, and 6 month measures. SPSS 14.0 was used in computing all analyses.

RESULTS

The average age was 54.8 ± 9.7 years (range 36–70 years) and body mass index was 28.5 ± 4.1 (range 20–33). Participants were Caucasian (100%), male (90%), taking beta blocker medication (100%), prior MI (30%), prior coronary artery bypass graft (CABG) surgery (40%), and coronary artery disease (40%). Four of the participants received an ICD for an out-of-hospital VF arrest, while the other 6 participants received an ICD for sustained or recurrent VT. The average ejection fraction was $39.2\% \pm 19.8$ (range 16–84%). Subjects completed 24/24 outpatient exercise sessions and walked an average of 2.21 ± 0.45 hours/week (more home walking hours than required) (See Table 1).

Cardiopulmonary Fitness/Activity

All exercise parameters indicated that there was an improvement in fitness after completing 8 weeks of aerobic exercise training. Total exercise time (9:10 seconds to 10:15 seconds, $P=0.04$) and VO_2 at anaerobic threshold, $P=0.05$. In addition, both oxygen pulse (a measure of stroke volume) as well as METS improved after the program although not significantly. Maximum heart rate achieved during CPET was unchanged. There were no lethal cardiac arrhythmias experienced during the exercise test and no subjects required cardioversion. After the exercise test was completed, all subjects were ECG monitored for 15 minutes to ensure there were no ventricular arrhythmias before being discharged from the test. There were no sustained ventricular arrhythmias during supervised exercise or home walking sessions in any of the study subjects.

Total vector magnitude averaged over 4 days improved after 8 weeks of exercise. This effect continued to improve at 6 months, indicating that subjects continued to exercise after the formal study period ended.

HRV was improved by the exercise intervention in both the time and frequency domain measures [SDNN, SD5 min, RMSSD, pRR50, VLF, LF, HF, TP]. Average HR over 24 hours was reduced after completing the exercise program ($P=0.07$). The largest changes in HRV were found in the measures representing parasympathetic nervous system function (RMSSD, pRR50, high frequency power). At 6 months, there were sustained effects on HRV without significant slippage back to baseline values.

Health outcomes

Improvements were found in physical health (SF-12 Physical Composite Summary) and mental health (SF-12 Mental Composite Summary) after exercise at 8 weeks. Anxiety and depression were also reduced after the 8 week exercise program. At 6 months, self-reported physical health continued to improve, while a slight decline in SF-12 mental health was noted. Both anxiety and depression increased slightly as well at 6 months after exercise. The average hsCRP was noted to be reduced after completing 8 weeks of aerobic exercise.

DISCUSSION

Aerobic exercise 5 hours/week for 8 weeks in SCA survivors who have an ICD contributed to a positive impact on cardiopulmonary fitness, total physical activity, heart rate variability, and health outcomes. Improvements in HRV and health outcomes were sustained at 6 months despite subjects' not having consistent support to continue home walking from the study. While all benefits were not sustained at the same level, subjects did not slip backwards to previous baseline values on outcomes. The findings of this study are limited by the lack of a control group and small sample size. In addition, subjects in this study received an ICD for the secondary prevention of cardiac arrest, and did not have extremely low ejection fractions; thus, findings may not be generalizable to those who receive an ICD for primary prevention of cardiac arrest who have significant heart failure. Sudden cardiac arrest survivors who have an ICD are a group of cardiac patients who can potentially benefit the most from exercise by stabilizing autonomic function and reducing the incidence of arrhythmias. While causal conclusions can not be drawn from this study, further testing of aerobic exercise interventions in this population appears warranted.

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Table 1
DEMOGRAPHICS AND CLINICAL CHARACTERISTICS (N=10)

Variable	
Age (mean $\pm$ SD)	54.82 (9.73)
Ejection fraction (mean $\pm$ SD)	39.18 (19.79)
Body mass index (cm/m ³) (mean $\pm$ SD)	28.49 (4.12)
Gender N	
Male	9 (90.0 %)
Female	1 (10.0 %)
Congestive heart failure N	3 (33.3 %)
Beta blocker N	10 (100 %)
Diuretic N	3 (33.3 %)
ACE inhibitor N	2 (25.0 %)
Nitrate N	0 (0 %)
Calcium channel blocker N	0 (0 %)
Anti-arrhythmic medication N	3 (33.3 %)
Potassium supplement N	1 (10.0 %)
Aspirin or Coumadin N	5 (50.0 %)
Vitamins, herbs, supplements N	2 (20.0 %)
Non-steroidal anti-inflammatory N	1 (10.0 %)
Caucasian Race	10 (100 %)
Income N	
30k - 49,999k	3 (27.3 %)
> 90k	2 (20.0 %)
Not willing to answer	5 (50.0 %)
Reason for ICD	
Ventricular fibrillation arrest	4 (36.4 %)
Ventricular tachycardia	5 (45.5 %)
Recurrent ventricular tachycardia	1 (9.1 %)

N indicates number; ACE, angiotensin converting enzyme; ICD, implantable cardioverter defibrillator

Table 2
CARDIOPULMONARY FITNESS, HEART RATE VARIABILITY, AND HEALTH OUTCOMES (N=10)

Variable	Baseline (mean ± SD)	8 weeks (mean ± SD)	6 month (mean ± SD)	F/T	p
Fitness/Activity					
Exercise time (min:sec)	0:09:17 ± 0:05:18	0:10:22 ± 0:05:56	not collected	2.50	0.04
O ₂ pulse (VO ₂ /HR)	14.23 ± 4.27	16.97 ± 4.29		1.67	0.13
VO ₂ at AT (L/min)	1.58 ± 0.44	1.86 ± 0.67		2.25	0.05
VO ₂ peak (ml/kg)	25.59 ± 9.29	26.00 ± 11.30		0.28	0.78
METS	6.63 ± 2.61	7.00 ± 2.94		1.05	0.33
Maximum HR (bpm)	137.56 ± 19.19	136.78 ± 14.77		0.13	0.89
RT3 (vml/min)	143.02 ± 41.44	230.0 ± 121.78		1.22	0.17
RT3 (MET/min)	0.78 ± 0.69	1.05 ± 1.01		0.22	0.84
HRV					
HR/24hr (bpm)	75.59 ± 15.07	67.04 ± 9.14	68.11 ± 10.65	3.32	0.07
R-R intervals/24 hr (msec)	823.33 ± 173.03	911.33 ± 137.58	900.89 ± 145.87	3.62	0.05
SD-NN/24 hours	124.00 ± 50.40	132.00 ± 47.05	128.63 ± 50.64	0.23	0.80
SDANN	112.00 ± 5.85	109.38 ± 44.17	105.13 ± 44.1	0.27	0.77
SD5min	43.63 ± 18.19	55.50 ± 23.91	59.63 ± 20.30	1.61	0.23
RMSSD	33.13 ± 11.41	49.38 ± 42.08	55.5 ± 33.53	1.15	0.34
pRR50	7.96 ± 7.94	13.30 ± 18.30	13.42 ± 11.63	1.39	0.28
VLF	559.92 ± 566.81	568.42 ± 522.68	441.41 ± 323.53	0.06	0.93
LF	429.58 ± 357.70	620.75 ± 514.25	572.5 ± 422.11	0.55	0.58
HF	143.5 ± 125.88	227.69 ± 294.27	229.03 ± 196.79	1.08	0.36
TP	1142.42 ± 923.65	1652.75 ± 1348.93	1291.25 ± 836.14	0.35	0.71
LF/HF	3.28 ± 2.20	2.97 ± 2.83	3.12 ± 2.77	0.02	0.97
Health Outcomes					
SF-12 PCS	44.33 ± 10.77	47.19 ± 9.11	49.36 ± 9.14	1.47	0.19
SF-12 MCS	51.33 ± 11.68	55.03 ± 8.04	49.43 ± 8.38	0.73	0.48
STAI	31.56 ± 11.83	28.22 ± 9.68	33.6 ± 14.29	2.21	0.06
CES-D	11.00 ± 13.08	9.22 ± 11.88	10.4 ± 12.62	0.76	0.46
Serum Marker					
hsCRP	6.56 ± 3.78	4.33 ± 2.61	not collected	0.42	0.69

HR indicates heart rate; $\dot{V}O_2$, oxygen consumption; METS, metabolic equivalents; AT, anaerobic threshold; $\dot{V}O_2/HR$, oxygen pulse; SD, standard deviation; SD-NN, standard deviation of all R-R intervals for 24 hours; SD5min, standard deviation of all R-R intervals average over 5 minutes; SDNN, standard deviation of the mean of normal R-R intervals for 5 minute segments; RMSSD, root mean square of successive R-R intervals; pRR50, percent of R-R intervals changing by 50 milliseconds; VLF, very low frequency power; LFF, low frequency power; HF, high frequency power; TP, total power; LF/HF, ratio of low frequency to high frequency power; SF-12 PCS, Short Form Health Survey 12 Physical Composite Score; SF-12 MCS, Short Form Health Survey Mental Composite Score; STAI, State Trait Anxiety Inventory; CES-D, Center for Epidemiological Studies-Depression Scale; hsCRP, high sensitivity C-reactive protein.