Research Report

Effects of Exercise Training on Heart Rate Variability After Coronary Angioplasty

Background and Purpose. Cardiac autonomic dysfunction is associated with risk of restenosis and cardiovascular mortality in patients after percutaneous transluminal coronary angioplasty (PTCA). Analysis of heart rate variability (HRV) is an important, widely used method for assessing cardiac autonomic regulation. The purpose of this study was to investigate the effect of exercise training on HRV in subjects after PTCA. **Subjects and Methods.** A total of 84 subjects who had undergone PTCA were recruited for this study. The subjects (age [mean±SD]=57.0±9.3 years) were randomly assigned to either an exercise group to undergo an 8-week outpatient exercise program or a control group to undergo usual care. Heart rate variability was measured for 5 minutes in the supine resting position at baseline and at the end of 8 weeks. **Results.** The parasympathetically modulated HRV of the subjects in the exercise group increased significantly compared with the HRV of subjects in the control group. The effects of training on HRV were independent of angioplasty type (balloon or stent) and were unrelated to whether the subjects had received previous PTCA. **Discussion and Conclusion.** Exercise training can increase parasympathetic modulation of cardiac function in people after they have undergone successful PTCA. Our results suggest that analysis of HRV can be extended to assess the effect of exercise training on cardiac autonomic dysfunction in people after coronary angioplasty. [Tsai MW, Chie WC, Kuo TBJ, et al. Effects of exercise training on heart rate variability after coronary angioplasty. *Phys Ther.* 2006;86:626–635.]

Key Words: *Exercise training, Heart rate variability, Percutaneous transluminal coronary angioplasty.*

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Autonomic dysfunction plays a major role in the pathophysiology of ischemic heart disease.[1] Analysis of beat-to-beat heart rate variability (HRV) provides a simple, reproducible, and noninvasive method for quantitatively assessing cardiac autonomic regulation.[1–3] A high variability in heart rate is a sign of good adaptability, implying that an individual's autonomic control mechanisms are functioning well. On the contrary, lower variability is often an indicator of abnormal and insufficient adaptability of the autonomic nervous system (ANS), implying the presence of a physiological malfunction.[1,2]

Heart rate variability commonly is analyzed in the time and frequency domains.[2,3] Time domain methods use simple mathematical techniques to measure the amount of variability in a continuous electrocardiogram (ECG) in a prespecified time period. Most time domain indices, such as the standard deviation of intervals between normal beats and the mean of successive normal R wave peak intervals (the mean of R-R intervals), reflect the overall autonomic modulation of heart rate but provide no information regarding sympathetic and parasympathetic activities individually.[2] In contrast, the frequency domain method, which involves power spectral analysis of HRV, can partially separate parasympathetic effects from sympathetic effects on the heart.[2,3] It is generally accepted that overall HRV is mediated mainly by vagal activity.

Heart rate oscillations at high frequency (HF) are equivalent to respiratory sinus arrhythmia and are considered a marker of cardiac parasympathetic activity, whereas heart rate oscillations at low frequency (LF) are a marker of both sympathetic and parasympathetic nerve activities.[2–4] However, the LF in normalized units, representing LF relative to the total power, is considered by some investigators to reflect sympathetic modulations.[2–4] The ratio of LF to HF (LF/HF) indicates sympathovagal balance, that is, the balance between the sympathetic system and the parasympathetic system.[2–4]

Some people with cardiac abnormalities show altered HRV, such as a reduction in overall HRV or a shift in the sympathovagal balance toward a sympathetic predominance instead of a vagal predominance. Alterations in HRV have been observed consistently in patients with acute myocardial infarction (AMI) and chronic heart failure.[1,5–8] Reduced HRV has been linked to an increased risk of cardiovascular mortality and cardiac events.[5–9] This increased risk may be a result of electrical instability in the heart rate because of an autonomic environment dominated by sympathetic nervous system influences.[1,2,5,8] Thus, it has been proposed that HRV

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can be used as a prognostic factor for risk stratification and therapeutic intervention for patients with cardiac disease.[1,2]

Percutaneous transluminal coronary angioplasty (PTCA) is an effective and minimally invasive intervention for coronary revascularization.[10–14] Several reports[15–19] have shown that HRV, especially parasympathetically modulated indices, is reduced in patients after PTCA. Some studies[15,16] have shown that the reduction in HRV after coronary angioplasty is only a transient phenomenon, whereas other studies[17–19] have shown that the HRV remains lower than that in control subjects who are healthy for more than 6 months after PTCA, especially in people with mixed multiple-vessel disease or comorbidities. Alterations in HRV also have been found to be associated with the degree of revascularization and a greater risk of restenosis after PTCA.[16,19]

Besides the well-known benefits of exercise-based cardiac rehabilitation for recovery after cardiac events,[20,21] studies[22–25] have shown that it also can benefit HRV and modify altered HRV in a prognostically favorable direction for patients with cardiac conditions. Data from studies of patients after myocardial infarction demonstrated that exercise training, performed for either 8 weeks or 3 months, modified HRV toward a persistent increase in parasympathetically modulated cardiac function.[22,23] Even a 2-week residential exercise training program increased HRV and baroreflex sensitivity in patients with coronary artery bypass grafting.[24] Finally, exercise training also could be effectively performed under home-based conditions.[25] To our knowledge, however, there are no data from trials with subjects who have undergone PTCA. Although cardiac rehabilitation for people with PTCA has been proposed to be similar to that for other patients with cardiac disease, the exact effect of cardiac rehabilitation on patient outcome has yet to be investigated fully.[20,21,26] It is still unclear whether exercise training modifies the attending autonomic alterations in people with PTCA.

In addition, factors specific to the PTCA procedure, such as the type of angioplasty and the history of angioplasty, have been shown to be associated with the prognosis of patients after PTCA.[27–30] For example, angioplasty with a stent resulted in a significantly lower incidence of restenosis than did angioplasty with a balloon.[28,29] However, whether the type of angioplasty procedure influences cardiac autonomic regulation after coronary angioplasty is still unknown. Whether a history of angioplasty is a related factor has not been fully addressed in intervention studies of people after PTCA.[16,18,31] Therefore, the purposes of the present study were to identify the effects of exercise training on alterations in HRV after PTCA and to delineate whether the type of angioplasty and the history of the PTCA procedure influence the effects of exercise training on HRV.

Method

Subjects and Study Design

Consecutive subjects who had undergone a coronary angioplasty in a university hospital and who met the selection criteria were included in this study. The criteria were as follows: subjects needed to be 75 years or younger and had to have successfully undergone PTCA with residual stenosis of less than 50%.[27,32] Subjects were excluded if they had a history of cardiac surgery; had been diagnosed as having congestive heart failure, a left ventricular ejection fraction of less than 40%, or both; had been diagnosed as having diabetic neuropathy; or had any complication of unstable angina, significant arrhythmias, severe hypertension (resting systolic blood pressure of >160 mm Hg or diastolic blood pressure of >100 mm Hg or both), or uncontrolled diabetes (fasting plasma glucose level of >250 mg/dL) in the period between PTCA and the baseline measurements of this study (about 1 month after PTCA). Over a period of 2 years, 641 subjects were screened for eligibility; 84 subjects were enrolled, and 557 were excluded from this study for reasons related to cardiac status (37.5%); because of comorbidities that contraindicated vigorous exercise (10.0%), disability or age (14.0%), or unwillingness to participate or early discharge from the hospital (11.2%); and for logistic reasons (28.3%), such as residence in another city (Fig. 1).

This study was a single-center, randomized controlled trial. A stratified randomization design was used; the 2 predefined factors were previous PTCA (yes or no) and the type of coronary angioplasty (balloon or stent). To ensure equal numbers within the groups and to reduce predictability, randomly permuted blocks of 4 within strata were used to produce the random sequence of subject assignment. Subject identities were concealed in numbered envelopes until interventions were assigned. Participants were randomized to the exercise group (n=42) or the control group (n=42) after all of the baseline measurements had been obtained. All participants signed written informed consent forms.

Interventions

The exercise group attended an outpatient exercise program of supervised training combined with home exercise for 8 weeks. In the outpatient hospital setting, subjects exercised on a cycle ergometer under the supervision of registered physical therapists. An individualized exercise program was prescribed on the basis of the results of a symptom-limited maximal exercise test on a bicycle ergometer at the beginning of the study. Training intensity was initially about 60% of the heart

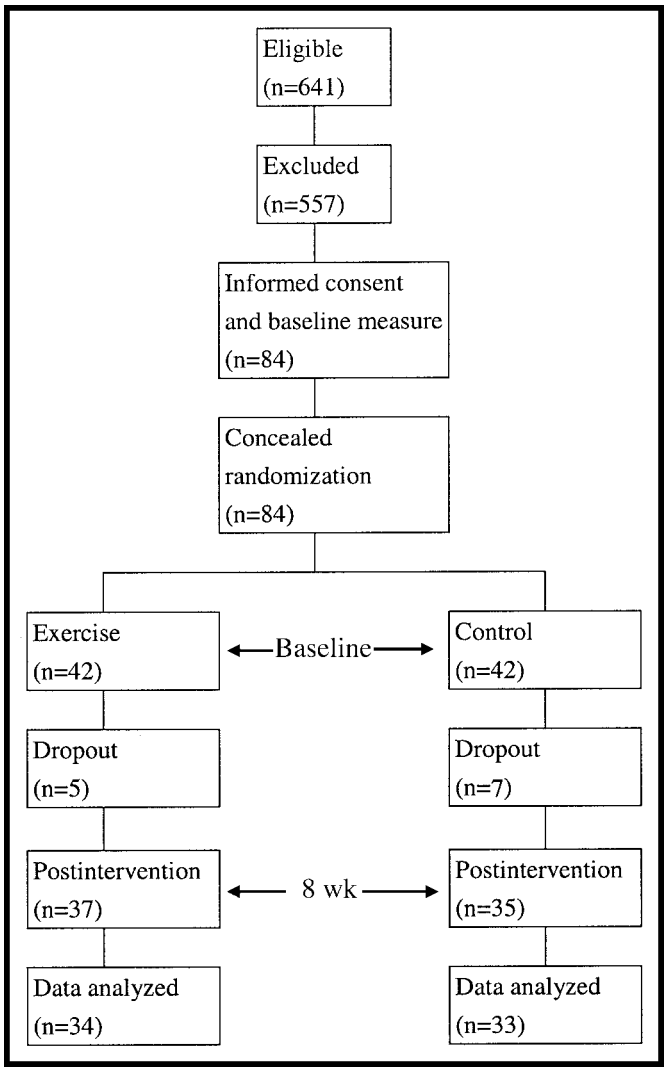

Figure 1.
Flow chart of subject randomization and dropout from this trial.

rate reserve and was close to the anaerobic threshold. It was increased to 85% of the heart rate reserve progressively as the subjects experienced the training effect. Training duration was 40 minutes per session, including the 5- to 10-minute warm-up and cool-down phases, and frequency was 1 to 3 sessions per week. For the home program, subjects were instructed to exercise with a tolerable intensity similar to that in their supervised exercise sessions. They were free to perform any aerobic exercises available to them, such as bicycling, walking, or jogging. Subjects were instructed on how to assess heart rate and on how to rate perceived exertion and to record any adverse events in their exercise log. The data were checked every week by the physical therapists to make sure that the home program was optimal and was being adhered to. Subjects in the control group were advised to maintain their usual daily activities without restriction. Subjects in both groups were given a health information instruction session about coronary disease risk factors, diet, stress management, safety guidelines for daily activities, and energy conservation after measurement of the baseline parameters and before the start of the trial. All subjects received normal medical care by their cardiologists and took their medications as prescribed throughout the course of the study.

Measurements

Short-term HRV, which has been successfully demonstrated to estimate tonic ANS functions and to have good reproducibility,[4,33,34] was assessed at baseline and at the end of 8 weeks. Each subject underwent HRV measurements during the same time of day on repeat testing. Electrocardiogram tracings were taken over a 5-minute period after the subjects had rested for at least 10 minutes. Each subject was tested in a supine position while breathing normally. The pericardial ECG signals were recorded and amplified with a gain of 1,000 and band-pass filtered (0.68–16 Hz). Signals were digitized by use of an analog-to-digital converter with a sampling rate of 256 Hz. The digitized ECG signals were analyzed online and were stored on a hard disk for off-line verification. Signal acquisition, storage, and processing were performed on an IBM-compatible portable personal computer. Our computer algorithm identified each QRS complex and rejected each ventricular premature complex or noise according to the likelihood that it would fit a standard QRS template. Stationary R-R intervals were resampled and interpolated at a rate of 7.11 Hz to obtain continuity in the time domain. Frequency domain analysis was performed by use of a nonparametric method (fast Fourier transformation). The direct-current component was deleted, and a Hamming window was used to attenuate the leakage effect.[33] For each time segment (288 seconds; 2,084 data points), our algorithm estimated the power spectrum density on the basis of fast Fourier transformation. The resulting power spectrum was corrected for attenuation resulting from the sampling and the Hamming window. The power spectrum was quantified into various frequency bands as standards.[2] The HRV was reported in terms of both time and frequency domain indices, including the mean of R-R intervals, the variance of the mean of R-R intervals (variance), HF power (0.15–0.4 Hz), LF power (0.04–0.15 Hz), LF in normalized units (LF%), and LF/HF (Tab. 1). Variance, HF, LF, and LF/HF were logarithmically transformed to correct for severe skewness before statistical analysis.[4]

Before and after the 8-week period, the physical activity of subjects in both groups was surveyed and categorized into 4 levels: none (engaging in no physical activity most days of the week), light (engaging in light activity at least 30 minutes most days of the week), moderate (engaging in moderate or vigorous activity for 20 minutes 1 or 2 days of the week), and regular (engaging in moderate or vigorous activity for 20 minutes 3 or more days of the

Table 1.
Variables Measured for Heart Rate Variability (HRV)

HRV Index	Unit	Definition[2,4]
Mean of R-R intervals	ms	Mean of all intervals between adjacent QRS complexes (R-R intervals) in a period of 5-min recordings
Variance	ms^2	Variance of mean of R-R intervals
Total power	ms^2	Total power of spectral analysis of the R-R time series; frequency band=0.003–3.6 Hz
Very low frequency (VLF)	ms^2/Hz	Power of VLF band (0.003–0.04 Hz)
Low frequency (LF)	ms^2/Hz	Power of LF band (0.04–0.15 Hz)
High frequency (HF)	ms^2/Hz	Power of HF band (0.15–0.4 Hz)
LF/HF		Ratio of LF to HF
LF%	Normalized units	LF normalized to total power; [LF/(total power−VLF)]×100

week).[35] At baseline, each subject's demographic and related medical variables also were collected by questionnaire interview and chart review.

Data Analysis

Statistical analysis was conducted with SPSS* for Windows,† version 10.0. The intention-to-treat principle was applied to the analysis of outcome for all subjects on the basis of their assigned treatments. Baseline information was compared for the 2 groups (exercise and control) by independent *t* tests and chi-square tests, taking into account the measurement scales. The alpha level was set at .05 for these tests. An analysis of covariance adjusted for stratified factors was used to compare the differences between groups with regard to the change from the baseline for each of the HRV indices. The adjustments for multiple comparisons used a *P* value of .008 because of cross-correlation among HRV indices.[33] Furthermore, the effects of previous PTCA treatment and the type of angioplasty on the changes in HRV after interventions were assessed by analysis of covariance (the exercise and control groups were used as covariants). In addition, we explored the possible effects of clinical characteristics on the changes in the HRV indices by using subgroup analyses.

Results

Subject Characteristics

Of the 84 subjects who were enrolled, 12 subjects (14.3%, 5 in the exercise group and 7 in the control group) dropped out of the study (Fig. 1): 3 had unstable angina requiring PTCA, 1 was hospitalized and required surgery to treat peptic ulcers, 1 was injured in a car accident, 1 had severe back pain, and 6 refused to continue the study (3 in the exercise group and 3 in the control group). An additional 5 subjects were excluded at the time of analysis for the following reasons: 1 had missing ECG recordings, and 4 had poor ECG signals, which affected HRV data acquisition (3 had atrial fibrillation and 1 had a right bundle branch block) (Fig. 1). Therefore, a total of 67 subjects (81% men; age [mean±SD]= 57.0±9.3 years), comprising 34 subjects in the exercise group and 33 subjects in the control group, were used for data analysis. Demographic and clinical characteristics did not differ significantly between the groups (Tab. 2). Most of the subjects kept the same prescriptions of medicines during the course of the study; however, 6 subjects (17.6%) in the exercise group and 7 subjects (21.2%) in the control group did change their medicines, although changes in prescriptions did not differ significantly between the groups ($\chi^2=0.085$; $df=1,7$; $P=.71$) (Tab. 3).

Subjects who adhered to the outpatient training in the exercise group attended an average of 18.6±5.7 sessions out of a total of 24 possible sessions; their average aerobic exercise frequency was 3.2±1.1 times per week when both the hospital setting and the home program were counted. No cardiovascular or other adverse effects were reported in relation to exercise. Our strategy of combining home exercise with outpatient exercise sessions significantly increased the level of physical activity in which subjects in the exercise group engaged (Tab. 3). With a similar exercise capacity at baseline (Tab. 2), the peak oxygen consumption of subjects in the exercise group (20.1±6.2 mL/kg/min) also was significantly greater than that of subjects in the control group (16.8±5.5 mL/kg/min) at the end of the 8-week period (change in peak oxygen consumption from baseline: 1.8±2.8 versus –1.0±2.8 mL/kg/min; $P<.001$).

Effects of Exercise Training on HRV

At baseline, the HRV indices did not differ significantly between the groups (Tab. 4); however, after interventions, the HRV of the subjects in the exercise group changed significantly compared with the HRV of subjects in the control group (Tab. 4). We found a 10% increase in HF, a 5% increase in the mean of R-R intervals, and a 5% increase in the variance in the exercise group, whereas decreases in these HRV indices were found in the control group. There were no signif-

* SPSS Inc, 233 S Wacker Dr, Chicago, IL 60606.
† Microsoft Corp, One Microsoft Way, Redmond, WA 98052-6399.

Table 2.
Comparison of Clinical Characteristics of Groups at Randomization and Completion of the Study[a]

Characteristic	Randomization		Completion	
	Control Group (n=42)	Exercise Group (n=42)	Control Group (n=33)	Exercise Group (n=34)
Age (y), $\bar{X}\pm$SD	56.7±9.8	57.0±8.3	56.8±9.9	57.1±8.9
Men	32 (76.2)	37 (88.1)	25 (75.8)	29 (85.3)
Body mass index (kg/m^2), $\bar{X}\pm$SD	26.0±2.5	25.5±3.0	25.9±2.3	25.0±2.9
No. of coronary vessels involved				
1	11 (26.2)	14 (33.3)	9 (27.3)	9 (26.5)
2	19 (45.2)	16 (38.1)	14 (42.4)	15 (44.1)
3	12 (28.6)	12 (28.6)	10 (30.3)	10 (29.4)
Ejection fraction (%), $\bar{X}\pm$SD	58.5±14.1	62.9±11.2	61.3±10.0	62.4±11.1
Type of PTCA				
Balloon	13 (30.9)	12 (28.6)	9 (27.3)	9 (26.5)
Stent	29 (69.1)	30 (71.4)	24 (72.7)	25 (73.5)
Previous PTCA	21 (50.0)	22 (52.4)	15 (45.5)	18 (52.9)
AMI	6 (14.6)	3 (7.1)	5 (15.2)	2 (5.9)
Previous MI	17 (40.5)	17 (40.5)	14 (42.4)	13 (38.2)
Comorbidity				
Hypertension	23 (56.1)	30 (71.4)	17 (51.5)	23 (67.6)
Diabetes	15 (36.6)	9 (21.4)	12 (36.4)	8 (23.5)
Hyperlipidemia	21 (52.5)	29 (70.7)	18 (56.3)	22 (66.7)
Other diseases	17 (40.5)	21 (50.0)	13 (40.6)	15 (44.1)
Peak exercise capacity (mL/kg/min), $\bar{X}\pm$SD	17.8±3.8	18.0±5.2	17.9±4.5	18.3±5.3

[a] Data are expressed as number (percentage) of subjects, unless otherwise indicated. Not all characteristics were found to be significantly different between randomization group and completion group when analyzed with independent *t* tests or chi-square tests. PTCA=percutaneous transluminal coronary angioplasty, AMI=acute myocardial infarction, MI=myocardial infarction.

Table 3.
Comparison of Medications and Levels of Activity for Groups Over Time[a]

Medication or Level of Activity	Control Group (n=33)		Exercise Group (n=34)	
	Baseline	8 wk	Baseline	8 wk
Medications				
ACE inhibitors	7 (21.2)	5 (15.2)	6 (17.6)	5 (14.7)
Beta-blockers	22 (66.7)	21 (63.6)	26 (76.5)	27 (79.4)
Ca^{2+} blockers	6 (18.2)	5 (15.2)	8 (23.5)	9 (26.5)
Diuretics	2 (6.1)	2 (6.1)	2 (5.9)	2 (5.9)
Digitalis	1 (3.0)	0 (0.0)	0 (0.0)	0 (0.0)
Anticoagulants	31 (93.9)	30 (90.9)	33 (97.1)	33 (97.1)
Lipid-lowering agents	17 (48.6)	18 (54.5)	16 (43.2)	16 (47.1)
Antidiabetic agents	8 (24.2)	8 (24.2)	7 (20.6)	9 (25.4)
Level of activity[b]				
None	10 (30.3)	8 (24.2)	6 (17.6)	0 (0.0)[c]
Light	15 (45.5)	13 (39.4)	15 (44.1)	12 (35.3)
Moderate	6 (18.2)	7 (21.2)	8 (23.5)	6 (17.6)
Regular	2 (6.1)	5 (15.2)	5 (14.7)	16 (47.1)[c]

[a] Data are expressed as number (percent) of subjects, unless otherwise indicated. ACE=angiotensin-converting enzyme.
[b] See the text for definitions of activity levels.
[c] $P<.05$, as determined by chi-square tests to test homogeneity for medications and the level of activity between the groups at baseline and after 8 weeks and as determined by McNemar tests to test homogeneity for medications and the level of activity between baseline and after 8 weeks by group.

icant differences between the groups with regard to changes in LF, LF%, and LF/HF.

Effects of Angioplasty Procedure and Clinical Factors on HRV

Subjects with a history of PTCA (yes or no) or with different types (balloon or stent) of PTCA had similar HRV alterations at baseline; after the interventions, no significant difference was found among subjects who had undergone various angioplasty procedures (Fig. 2). However, a significant interaction between the risk factors of AMI and exercise training was found for the changes in HF and the mean of R-R intervals (Fig. 3). The results indicated that exercise had a greater effect on HRV in subjects with AMI than in subjects without AMI. In the present study, AMI was defined as an acute episode within 1 month of undergoing PTCA.

Table 4.
Comparison of Heart Rate Variabilities (HRVs) for Groups at Baseline and After 8 Weeks[a]

HRV Index	Control Group (n=33)	Exercise Group (n=34)	*P*
Mean of R-R intervals (ms)			
Baseline	887.0±146.2	877.9±127.9	.79
8 wk	856.1±156.4	911.6±142.3	.007[b]
Change from baseline	−42.6±106.7	33.7±115.0	.006[b]
Variance [ln(ms^2)]			
Baseline	6.9±1.0	6.4±0.6	.01
8 wk	6.3±1.1	6.9±0.8	.002[b]
Change from baseline	−0.4±0.9	0.3±0.7	.001[b]
HF [ln(ms^2/Hz)]			
Baseline	4.3±1.2	3.9±0.7	.06
8 wk	3.8±1.1	4.4±0.9	.004[b]
Change from baseline	−0.4±1.0	0.3±0.7	.002[b]
LF [ln(ms^2/Hz)]			
Baseline	4.8±1.3	4.7±0.9	.67
8 wk	4.6±1.2	5.0±0.9	.04
Change from baseline	−0.1±0.9	0.3±0.7	.06
LF% (normalized units)			
Baseline	55.5±20.1	63.3±17.8	.10
8 wk	60.7±19.6	63.5±15.8	.84
Change from baseline	5.2±13.6	0.3±15.6	.93
LF/HF			
Baseline	0.5±0.9	0.9±0.8	.10
8 wk	0.6±0.9	0.8±0.8	.69
Change from baseline	0.2±0.6	−0.07±0.8	.76

[a] Data are expressed as mean ± standard deviation. The values at baseline were tested by independent *t* tests. The values at 8 weeks were tested by analysis of covariance (ANCOVA) adjusted for baseline value and stratified factors (previous angioplasty and type of angioplasty). The values for change from baseline were tested by ANCOVA adjusted for stratified factors. HF=high frequency, LF=low frequency, LF%=LF in normalized units, LF/HF=ratio of LF to HF.
[b] Determined with multiple-comparison adjustment.

Discussion

This randomized controlled trial demonstrated that an 8-week exercise program increased parasympathetic modulation of cardiac function in subjects who had undergone successful coronary angioplasty. The present study provides evidence that there are beneficial effects to exercise training in terms of HRV alterations for people after coronary angioplasty.

Our subjects appeared to have lower parasympathetic modulations of heart rate (HF power) and relatively higher sympathetic activity (LF%) at the time of the baseline measurements (4.0±1.2 weeks after PTCA) than did a comparable healthy population in a previous study.[4] The pattern of HRV after PTCA in our subjects was similar to the pattern reported in other studies.[16–18] In the present study, the relevant clinical variables and HRV indices were comparable between the exercise group and the control group at baseline. The use of drug therapies was not statistically significantly different between the groups during the interventions. Thus, the changes observed in parasympathetically modulated HRV in the exercise group most likely were attributable to exercise training.

We found significant increases in parasympathetic modulations of HRV indices in subjects who had undergone PTCA after 8 weeks of exercise training. Our results are similar to the findings of previous studies of subjects with myocardial infarction and coronary bypass.[22–25] However, in the present study, an average increase of 10% in HF after exercise training was relatively lower than increases of approximately 7% to 27% reported for other populations with cardiac disease.[22–25] A subgroup analysis by Tygesen et al[25] showed that subjects with coronary bypass achieved more pronounced HRV gains than did subjects with myocardial infarction when using the same exercise program. The authors of that analysis suggested that the factors and clinical features underlying heart disease, such as a low-risk status, could explain the lower increase in HRV in their subjects with myocardial infarction. In addition, different basal states of cardiac autonomic tone under various study conditions also may have contributed to the discrepancy in HRV gains.[3]

Previous studies[1,2,5–7,9] demonstrated that the risk for cardiovascular mortality and further cardiac events is higher among subjects who have more depressed HRV. However, the degree of increases in HRV that may produce a truly protective effect is still unknown. Evidence from animal studies has indicated that the risk for ventricular fibrillation or sudden cardiac death after acute myocardial ischemia is reduced markedly by interventions that increase vagal activity.[36–38] These studies suggested that the improvement in cardiac electrical stability and adaptations in peripheral and central neural pathways may contribute to the training effect of exercise on vagal activity. Our results showed that exercise training up-regulated a lower HRV after PTCA, especially for HF and parasympathetically modulated HRV indices. This finding may reflect an improved cardiac autonomic environment and may provide a favorable situation for cardiovascular health.

The type of angioplasty and a history of angioplasty were associated with patient outcome after PTCA[27–30]; however, their association with the effect of exercise training

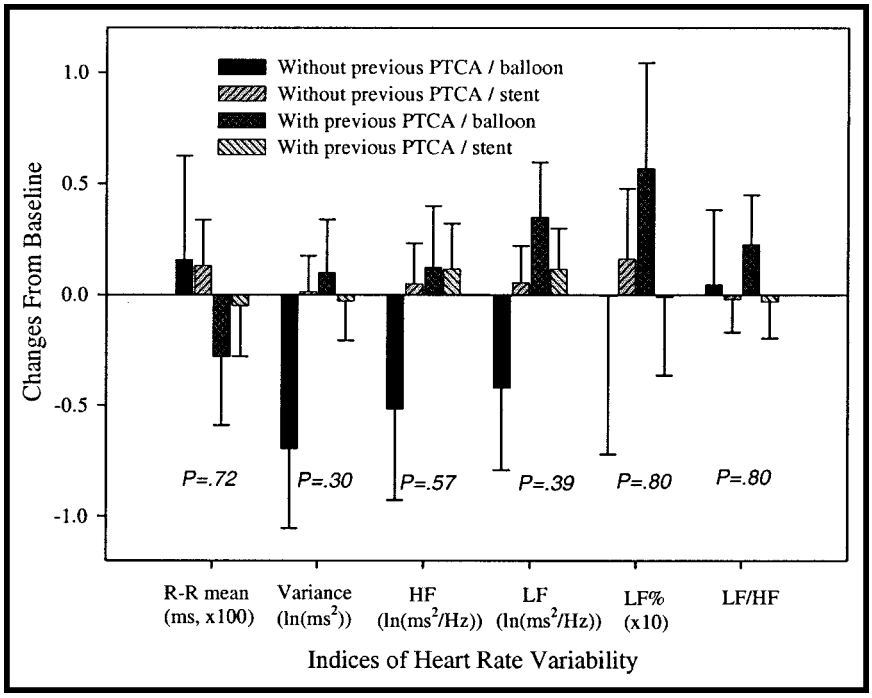

Figure 2.
Changes in heart rate variability among subjects grouped by previous percutaneous transluminal coronary angioplasty (PTCA) and type of PTCA. The bar charts are expressed as mean ± standard error. Data were analyzed by analysis of covariance adjusted for intervention group. R-R mean=mean of R-R intervals, HF=high frequency, LF=low frequency, LF%=LF in normalized units, LF/HF=ratio of LF to HF.

is not fully understood. In the present study, we used a stratified randomization design to control for possible confounding effects and to identify any different effects in subgroup analyses. Neither the type of angioplasty nor previous PTCA was associated with changes in HRV after exercise training. Because complete revascularization with almost no residual stenosis was observed in most of our subjects (50 of 67 subjects), our findings seem to show that the type of angioplasty may not play a role in the changes in HRV induced by exercise training for people after successful angioplasty.

Many researchers[1,2,5–7] have reported data showing that HRV tends to decrease in people with clinical evidence of hypertension, diabetes, or myocardial infarction. In the present study, we found that subjects with AMI showed a greater increase in parasympathetically modulated heart rate after exercise training than did subjects without AMI. The disparate patterns of training gains were similar to those previously observed in subjects after AMI.[22,23,25] This finding suggested that the presence of AMI could influence the effect of exercise training on the autonomic balance in people after PTCA. No other clinical features were found to have significant influences on the baseline values for HRV. The findings may be partly attributable to a relatively small population within each stratum and the exclusion of subjects who had diabetic neuropathy or severe hypertension.

The major limitation of the present study was lack of masking, which may have influenced subjects' attitudes toward therapy and which also may have influenced the eventual responses. However, it is often not feasible to conduct a double-blind trial for an exercise intervention.[39] The potential bias of the subject response may have been minimized with more objective measurements of HRV. In addition, subject adherence to the therapy regimen, such as low participation in exercise for some subjects in the exercise group or having an active lifestyle for some subjects in the control group, may have had some influence on the study results. However, our intention-to-treat analysis could provide a valid assessment of treatment efficacy, as it relates to actual clinical practice.[39]

Despite the potential underestimation of effect size from this analysis, the findings of the present study still demonstrated that exercise training increased HF and overall HRV in subjects after PTCA. As yet it is not known how large training gains in HRV are clinically meaningful in terms of providing adequate health benefits. In addition, it may be debated as to how long the exercise period should be or how much the exercise capacity should be increased to obtain adequate training gains in HRV.[20,21,40] Further research is needed to delineate the dose-response relationship between exercise and autonomic functions and how both functions relate to health benefits in patients with cardiac disease.

Clinical Implications

Heart rate variability reflects cardiac autonomic modulation and has provided some insights into the pathophysiological conditions in ischemic heart disease,[1,2] thereby contributing to additional prognostic information beyond traditional outcome measures in physical therapist practice. The HRV is a function of the synergistic action between the 2 branches of the ANS, which act in balance through neural, humoral, and physiological mechanisms to maintain cardiovascular functions in an optimal range. If the dynamics of regulation are disturbed or the activity of 1 of the branches decreases, the probability of diseases, complications, and fatal outcomes increases. On the other hand, augmentation of the ability to control the regulatory systems is helpful

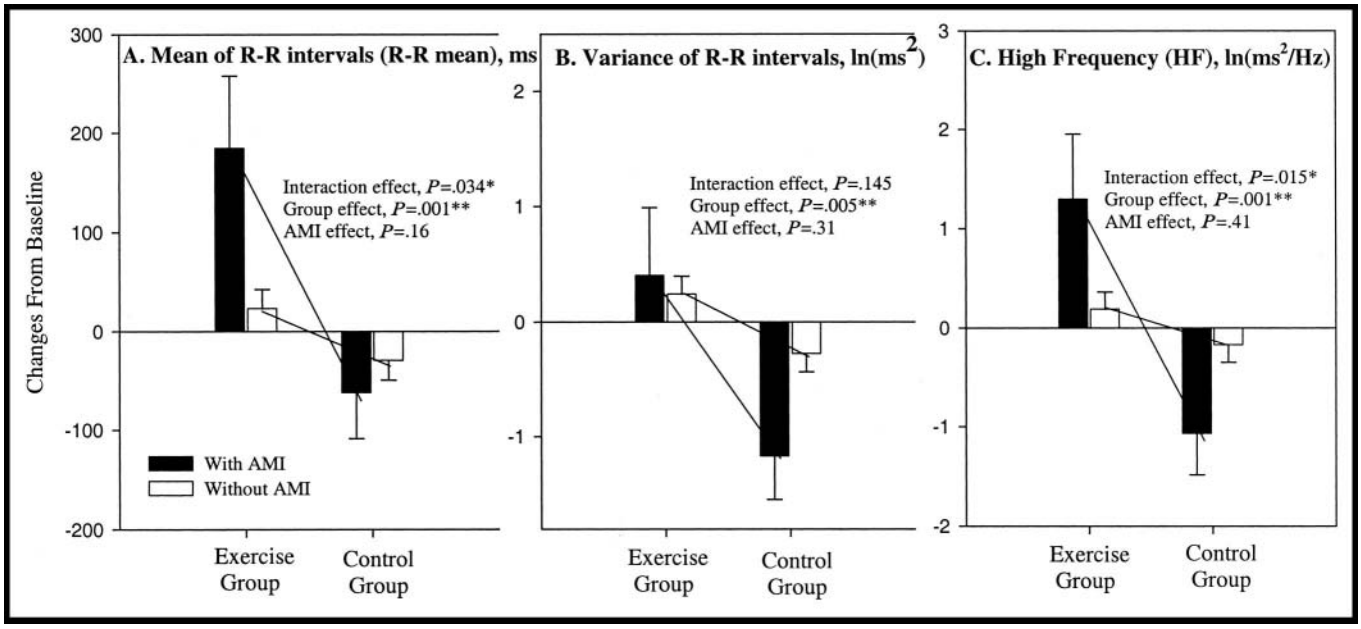

Figure 3.
Effect of recent acute myocardial infarction (AMI) on changes in heart rate variability. (A) Mean of R-R intervals (R-R mean). (B) Variance of the mean of R-R intervals. (C) High-frequency power after intervention. The bar charts are expressed as mean ± standard error. Data were analyzed by 2-way (exercise × AMI) analysis of covariance with stratified factors (previous percutaneous transluminal coronary angioplasty [PTCA] and type of PTCA).

in creating favorable situations for producing better prognoses and treatment results. From our experience, analysis of HRV is a simple procedure and requires only minimal cooperation from the patients being tested, especially with the availability of well-developed computer algorithm technology. The present study may help shed light on the importance of understanding ANS responses and may provide new knowledge regarding the effects of exercise training on the behavior of ANS in people undergoing PTCA.

Conclusion

Our results reveal that the beneficial effects of exercise training on HRV alterations can be extended to people after coronary angioplasty. We found that exercise increases parasympathetically modulated HRV regardless of previous angioplasty or stent insertion. Such an improvement in parasympathetic modulation of the heart may play a critical role and may be of prognostic value for patients.

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