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A Randomized Trial of the Effects of 1 Year of Exercise Training on Computer-Measured ST Segment Displacement in Patients With Coronary Artery Disease

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As part of a randomized trial of the effects of 1 year of exercise training on patients with stable coronary artery disease, 48 patients who exercised and 59 control patients had computerized exercise electrocardiography performed initially and 1 year later. The patients who had exercise training as an intervention had a 9% increase in measured maximal oxygen consumption and significant decreases in heart rate at rest and during submaximal exercise. ST segment displacement was analyzed 60 ms after the end of the QRS complex in the three-dimensional X,Y and Z leads and utilizing the spatial amplitude derived from them. Statistical analysis by *t* testing yielded no significant differences between the groups except for less ST segment displacement at a matched work load, but this could be explained by a lowered heart rate. Analysis of variance yielded some minor differences within clinical subgroups, particularly in the spatial analysis. Obvious changes in exercise-induced ST segment depression could not be demonstrated in this heterogeneous group of selected volunteers with coronary artery disease secondary to an exercise program.

Substantial evidence underlies the relation between exercise-induced ST segment depression and myocardial ischemia (1,2). The exercise electrocardiogram has been used to identify subclinical coronary artery disease (3), diagnose the cause of chest pain (4), estimate prognosis of coronary artery disease (5) and evaluate interventions including medications and surgery (6,7). In regard to evaluating exercise training as an intervention, numerous studies (8) have utilized the exercise electrocardiogram. Advances in computer techniques have enhanced the reproducibility of the exercise electrocardiogram, making it even more suitable for serially evaluating patients.

Since exercise-induced ST segment depression is most likely caused by ischemia in patients with known coronary artery disease, a reduction in the degree of ST segment depression at matched points after training may indicate either an improvement in coronary blood flow or oxygen delivery, or a change in the hemodynamic determinants of myocardial oxygen demand. Regardless of the mechanism, a lessening of exercise-induced ST segment depression suggests that inequities between myocardial oxygen supply and demand have been improved.

To determine if 1 year of exercise training in patients with coronary artery disease could result in beneficial cardiac changes, we designed a randomized trial. Although radionuclide imaging was primarily emphasized (9), computerized exercise electrocardiography was included. This presentation deals with the latter results and attempts to answer the following questions: 1) does exercise training lessen exercise-induced ST segment displacement?; and 2) if not in all patients, does lessening occur in certain groups?

Methods

Selection of patients. Men with stable coronary artery disease (aged 35 to 65 years) were recruited for a free exercise program. All had coronary artery disease docu-

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mented by one or more of the following: 1) a history of myocardial infarction from chart review; 2) stable exertional angina pectoris confirmed by angiography or an abnormal exercise test, or both; and 3) coronary artery bypass surgery. Patients with severe congestive heart failure, unstable arrhythmias, diabetes mellitus, symptomatic pulmonary disease, systemic hypertension, severe claudication or locomotive limitations were excluded. Disease stability was assured by history and by not allowing any patient to participate within 4 months after a cardiac event, a change in symptoms or surgery.

The patients were scheduled for three exercise tests done on separate days usually within a 2 week period. Their cardiac medications were stopped for testing (digoxin for 2 weeks and beta-adrenergic blocking agents for 3 days). Testing included a thallium treadmill test, a separate maximal treadmill test for electrocardiography and oxygen uptake and a supine bicycle radionuclide ventriculography study.

One hundred forty-six patients who completed testing were randomized, resulting in 74 patients in supervised exercise and 72 receiving usual community care. Initial and 1 year rest and exercise electrocardiograms were analyzed by computer in 107 patients. There were 17 patients who dropped out, 8 patients with complete left bundle branch block at rest or during exercise and 14 in whom initial data were lost due to technical problems. This left 48 patients in the exercise intervention group and 59 control patients.

For statistical analysis, patients were classified into the following subgroups: 1) history of prior Q wave myocardial infarction versus no Q wave infarction; 2) angina induced by the exercise test versus no angina; 3) coronary artery bypass surgery versus none; and 4) Q wave patterns on the current electrocardiogram versus no Q wave pattern.

Exercise testing. Subjects in each group initially underwent a maximal exercise test on a motor-driven treadmill, using a modification of the Balke-Ware protocol (10). The test consisted of 2 minute exercise stages that progressed by increasing the grade (by 5%) with each stage. Treadmill speed began at 2 mph and increased to 3.3 mph after the fourth minute. All tests were symptom- or sign-limited maximal efforts. Tests were terminated for any of the following reasons: angina pectoris of moderate severity, serious arrhythmia, systolic blood pressure decrease of 20 mm Hg or 0.30 mV ST segment depression. Maximal oxygen consumption ($\dot{V}O_2max$) was determined by collecting expired gases.

Electrocardiogram. The Dalhouse square was used to assure reproducible electrode placement (11). Fourteen electrodes were placed according to the modified Mason-Likar method for the 12 lead electrocardiogram (12) and the Mayo Clinic adaptation for the Frank lead vectorcardiogram (13). The spatial vector length was calculated as the square root of $X^2 + Y^2 + Z^2$, where X,Y and Z are the ST segment shifts in these leads.

The data were acquired with a MAC I data logger (Marquette Electronics); signals were digitized at 250 samples/s and stored on 8 inch (20.32 cm) floppy disks. A Digital Equipment Corporation PDP 11/34 computer was used to process the digital vectorcardiographic data for waveform analysis and ST vector computation off-line. The software for data acquisition and analysis has been described in detail previously (14).

To compare ST segment responses at matched exercise intensities and myocardial oxygen consumption, electrocardiographic measurements were evaluated at rest, at matched submaximal rate-pressure product and heart rate, at matched submaximal work load, at angina threshold, at maximal exercise and at 1 and 3 minutes of recovery. Although the submaximal heart rate points were approximately 75% of maximal, they were specifically matched at pre and post 1 year studies for each patient. Computerized measurements were made 60 ms after the end of the QRS complex (ST60).

Exercise program. Patients in the exercise intervention group underwent a program of medically supervised exercise consisting of three sessions a week of 45 minutes' duration for a period of 1 year. Dynamic exercise was performed and consisted of treadmill, bicycle, arm ergometry, stair stepping or jogging, or a combination of the latter two. Exercise was prescribed at individually targeted intensities, 70 to 80% of the differences between the maximal heart rate and heart rate at rest (15). The patients randomized to the control group were offered a low intensity home walking program to maintain normal exercise capacity. Careful follow-up evaluation confirmed that none of the control patients went on to higher levels of exercise.

Statistics. Differences in ST segment amplitude between the initial and 1 year exercise tests are reported in millivolts (mean ± 1 standard deviation). The Student's *t* test was used to assess the significance of differences at randomization and between the initial and 1 year exercise tests. An exploratory pre-post analysis was then performed on the basis of univariate two and three-way analysis of variance for 2^k factoral designs. A simultaneous multivariate study of the variables was not considered, since the samples would be small, and by the nature of the study, not gathered under the conditions necessary for valid interpretations. The UCLA biostatistical software package (BMDP) was used for all analyses.

Results

No cardiovascular events occurred among the patients during the 1 year study period or during the tests. The clinical characteristics of the patients in each group were similar at randomization except for age, which only differed by 3 years (Table 1). It should be noted that the criteria and the need to be without any medicines possibly resulted in

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Table 1. Clinical Characteristics at Randomization

	Exercise Intervention Group (n = 48)	Control Group (n = 59)
Age (yr) (mean ± SD)	52 (±8.0)	55 (±7.0)*
Electrocardiogram		
Anterior Q wave	11 (23%)	15 (25%)
Inferior Q wave	18 (38%)	20 (33%)
Lateral Q wave	3 (6%)	6 (10%)
Post coronary artery bypass surgery	19 (40%)	18 (31%)
Medications		
Digitalis	4 (8%)	8 (14%)
Beta-blocking agents	19 (39%)	23 (39%)
Antiarrhythmic agents	6 (13%)	7 (12.1%)
Antihypertensive agents	7 (15%)	11 (19%)
Nitrates	19 (39%)	29 (50%)
Resting ejection fraction		
> 50%	37 (77%)	42 (71%)
< 50%	11 (23%)	17 (29%)
Coronary angiography		
1 vessel disease	2 (4.2%)	8 (13.5%)
2 vessel disease	10 (20.8%)	12 (20.3%)
3 vessel disease	17 (35.4%)	13 (22.0%)
Left main disease	4 (8.3%)	2 (3.4%)
Not done	18 (37.5%)	24 (40.7%)
Exercise test stopped because of angina	11 (23%)	15 (25%)

*$p < 0.05$.

a lower risk group of patients (only 25% had their exercise test stopped because of angina).

Training intensity and attendance. After completion of the study, the exercise records of the patients in the exercise intervention group were extensively reviewed. Attendance at the exercise sessions averaged 78%. Average training intensity by percent maximal oxygen uptake and percent maximal heart rate by the method of Karvonen et al. (15) was 60%; the average percent of maximal heart rate and measured maximal oxygen uptake was 80%.

Treadmill performance variables. Initial treadmill performance variables in both groups and mean differences between initial and 1 year measurements are presented in Table 2. There were no initial differences between exercise and control groups. A significant effect of exercise intervention was found. Mean maximal measured oxygen uptake increased 9.5% in the exercise group (25.3 to 26.7 ml/kg per min; $p < 0.01$), whereas in control patients it decreased 9.4% (26.7 to 25.1 ml/kg per min; $p < 0.001$). Significant differences between the groups occurred at 1 year in measured (in liters/min) ($p < 0.001$) and estimated (in ml/kg per min) ($p < 0.001$) maximal oxygen consumption. Heart rate at rest was significantly lowered in the exercise group (7 beats/min; $p < 0.05$), whereas it did not change in control patients. At 3.3 mph, 5% grade, both heart rate and rate-pressure product were decreased significantly in the exercise intervention group after training, whereas neither of these values changed significantly in the control patients. Respiratory quotient, maximal heart rate and perceived exertion did not differ between the groups either at the initial or the 1 year test; thus, the initial and 1 year test end points were comparable.

Initial ST segment measurements. Electrocardiographic data at randomization are presented by clinical subgroups combining exercise intervention and control group patients in Table 3 to present the baseline levels for the subgroups. The anterior Q wave versus no anterior Q wave subgroup values were significantly different in leads X and Z at all four measurement stages, and spatially at all stages except the submaximal work load. In the angina and no angina subgroups, significant differences existed in lead Y at submaximal heart rate and work load and matched rate-pressure product. No significant differences were found within the history of infarct and no infarct and bypass and no bypass subgroups.

ST60 measurements in the exercise intervention and control groups at randomization are presented in Table 4. Only 2 of 32 t tests were significantly different (unpaired t test; $p < 0.05$). Since they occurred in lead Z during recovery, they could well have occurred by chance alone.

ST segment differences between initial and 1 year. Table 5 presents mean differences in ST60 amplitude between initial and 1 year measurements. No significant differences using unpaired t testing were found, except at 3.3 mph, 5% grade, in lead X.

In addition to this two sample analysis (exercise inter-

Table 2. Treadmill Test Variables Initially and Mean Differences After 1 Year

Variables	Control Group		Exercise-Intervention Group		
	Initial	Mean Difference	Initial	Mean Difference	Between Group Probability
Measured maximal oxygen consumption (ml/min per kg)	26.7 (6)	−1.6 (3)	25.3 (5)	1.4 (4)	< 0.001
Measured maximal oxygen consumption (liters/min)	2.18 (0.5)	−0.11 (0.3)	2.21 (0.6)	0.15 (0.3)	< 0.001
Estimated maximal oxygen consumption (ml/min per kg)	33.3 (8)	−1.2 (6)	32.6 (9)	5.2 (6)	< 0.001
Respiratory quotient	1.1 (0.1)	0.00 (0.1)	1.1 (0.1)	−0.03 (0.1)	NS
Heart rate (beats/min)					
Standing, rest	77.4 (10)	0.36 (11)	81.0 (15)	−7.4 (13)	< 0.05
Submaximal work load (3.3 mph/5%)	124 (16)	−3 (10)	127 (16)	−10 (12)	< 0.001
Maximal	155 (18)	−5.7 (13)	157 (22)	−1.4 (11)	NS
Systolic blood pressure (mm Hg)					
Rest	130 (14)	0.12 (16)	131 (16)	1.6 (14)	NS
Maximal	181 (27)	1.3 (24)	186 (27)	3.2 (26)	NS
Maximal perceived exertion	16.5 (2)	−0.44 (2)	16.9 (2)	−0.58 (2)	NS

Numbers in parentheses indicate the standard deviation.

vention versus control), tentative two- and three-way analysis of variance by subgroup was considered (Table 6). ST segment depression could be compared 16 ways, including leads X, Y and Z and spatially, at the four stages during exercise testing: 1) standard submaximal work load (3.3 mph, 5% grade); 2) matched rate-pressure product; 3) matched submaximal heart rate; and 4) angina threshold. ST segment analysis will be presented according to these four measurement stages.

Matched submaximal work load (3.3 mph, 5% grade). Exercise intervention versus control analysis (two sample) revealed a significant lessening of exercise-induced ST segment depression occurring after training in lead X (0.38 mV; $p = 0.04$) (Table 5). However, the mean heart rate was lowered at this point in the exercise group (127 beats/min initially to 117 at 1 year) ($p < 0.001$).

Matched rate-pressure product. Significant exercise intervention effects and interactions based on analysis of var-

Table 3. ST60 Measurements by Subgroup at Randomization

	Angina/ No Angina	Infarct/ No Infarct	Bypass/ No Bypass	Anterior Q wave/ No Anterior Q wave
Rate-pressure product				
X	−0.04/−0.02	−0.03/−0.03	−0.02/−0.03	0.04/0.05*
Y	−0.05/0.00*	−0.01/−0.03	0.00/−0.02	−0.00/−0.02
Z	−0.08/−0.04	−0.06/−0.04	−0.05/−0.05	−0.13/−0.03†
Spatial	0.16/0.15	0.16/0.14	0.16/0.15	0.23/0.14†
Submaximal heart rate				
X	−0.05/−0.04	−0.04/−0.06	−0.03/−0.05	0.04/−0.06†
Y	−0.05/0.00*	−0.00/−0.03	0.01/−0.03	0.01/−0.02
Z	−0.06/−0.04	−0.06/−0.03	−0.03/−0.06	−0.12/−0.03*
Spatial	0.02/0.17	0.19/0.16	0.18/0.17	0.25/0.16*
Submaximal work load				
X	−0.07/−0.02†	−0.03/−0.05	−0.03/−0.04	0.01/−0.05†
Y	−0.06/−0.00†	−0.01/−0.04	−0.00/−0.03	−0.03/−0.02
Z	−0.06/−0.05	−0.07/−0.03	−0.05/−0.06	−0.12/−0.04†
Spatial	0.14/0.13	0.14/0.11	0.13/0.13	0.18/0.12
Angina threshold				
X	−0.08	−0.09/−0.07	−0.04/−0.09	0.06/−0.10*
Y	−0.07	−0.07/−0.04	−0.07/−0.06	−0.05/−0.06
Z	−0.05	−0.07/−0.02	−0.14/−0.05	−0.02/−0.02†
Spatial	0.18	0.19/0.16	0.16/0.18	0.25/0.16*

*$p < 0.05$; †$p < 0.01$. Values are given in millivolts. ST60 = ST amplitude 60 ms after the end of the QRS complex.

Table 4. ST60 Measurements by Group at Randomization

	Vectorcardiographic Lead							
	X		Y		Z		Spatially	
	C	EI	C	EI	C	EI	C	EI
Rest								
Mean	0.02	0.02	0.03	0.02	0.06	0.08	0.09	0.10
± SD	0.04	0.05	0.04	0.03	0.06	0.05	0.05	0.04
Submaximal rate-pressure product								
Mean	−0.02	−0.03	−0.01	−0.05	−0.08	−0.08	0.15	0.18
± SD	0.11	0.12	0.09	0.10	0.10	0.12	0.10	0.12
Submaximal heart rate								
Mean	−0.03	−0.05	−0.01	−0.03	−0.05	−0.08	0.18	0.19
± SD	0.13	0.12	0.09	0.08	0.11	0.13	0.12	0.11
Submaximal work load								
Mean	−0.03	−0.04	−0.02	−0.04	−0.05	−0.05	0.13	0.13
± SD	0.10	0.09	0.08	0.07	0.08	0.09	0.08	0.08
Maximal work load								
Mean	−0.05	−0.05	−0.01	−0.02	−0.05	−0.09	0.20	0.21
± SD	0.14	0.14	0.09	0.10	0.12	0.15	0.12	0.13
Angina threshold								
Mean	−0.08	−0.05	−0.05	−0.03	−0.04	−0.00	0.18	0.18
± SD	0.11	0.15	0.09	0.06	0.10	0.13	0.09	0.10
1 minute recovery								
Mean	0.03	0.02	0.05	0.04	−0.08*	−0.13	0.18	0.21
± SD	0.13	0.13	0.10	0.09	0.13	0.14	0.13	0.14
3 minutes recovery								
Mean	0.00	−0.02	0.02	0.02	−0.04	−0.08	0.14	0.16
± SD	0.10	0.09	0.10	0.18	0.08	0.12	0.10	0.11

*$p < 0.05$. Values given in millivolts. C = control; EI = exercise intervention; ST60 = ST amplitude 60 ms after the end of the QRS complex.

iance are presented in Table 6. A first order (exercise intervention versus control) effect spatially was demonstrated using the two-way analysis of variance for intervention and history of Q wave infarction. The estimated effect of intervention was − 0.022 mV, indicating less ST displacement.

The intervention history of Q wave infarct analysis yielded a persistently significant interaction for lead Z. The difference in the effect of training between patients with a history of Q wave myocardial infarction and those without was −0.021 mV ($p < 0.02$) with the patients with prior myocardial infarction being significantly less altered by the exercise intervention. Since lead Z is opposite in polarity relative to leads V_1 or V_2, the negative sign reflects a greater degree of anterior elevation. In the subgroup with no prior Q wave infarction, the exercise intervention resulted in less ST segment depression. These changes in opposite directions explain why no effect of intervention was evident from *t* testing.

Two-way analysis of variance by intervention and bypass surgery yielded significant interactions in both leads Y and Z (0.020 mV; $p < 0.01$ and 0.024 mV; $p < 0.001$, respectively). A difference in the effects of intervention existed between those with and those without bypass; in both of these subgroups, training was more beneficial to patients who had undergone coronary artery bypass surgery, as evidenced by a lessening of ST segment displacement after 1 year.

The two-way analysis of variance by group and angina and no angina subgroups demonstrated a significant intervention effect (−0.022; $p < 0.05$) with less absolute ST segment displacement after 1 year. No significant changes occurred among patients with or without angina in the X,Y and Z leads after matching rate-pressure product.

Match submaximal heart rate. ST60 data acquired at matched submaximal heart rate yielded little information. Exercise intervention did not emerge as having a group effect on the ST segment response in any lead. In lead Z, there was a second order interaction between intervention and infarction history at a probability value of 0.01 level, similar to that which occurred at matched rate-pressure product.

Angina threshold. Since only 15 control and 11 exercising patients stopped exercise testing because of angina, only a smaller number of measurements could be analyzed. The intervention, bypass history analysis yielded first order effects spatially only (−0.036 mV; $p = 0.02$). Exercise intervention resulted in less absolute ST segment displacement at the angina threshold. A significant interaction was present in this subgroup also. Patients with a history of coronary artery bypass surgery had less absolute ST segment displacement after exercise training.

Table 5. Mean Difference (1 year initial) in ST Amplitude at 60 ms After the End of the QRS Complex Comparing Exercise Intervention and Control Patients

	Vectorcardiographic Lead							
	X		Y		Z		Spatially	
	C	EI	C	EI	C	EI	C	EI
Rate-pressure product								
Mean difference	−0.02*	−0.00	0.00	−0.01	−0.01	−0.01	0.01	−0.02
±SD	0.06	0.10	0.06	0.08	0.04	0.10	0.06	0.13
Submaximal heart rate								
Mean difference	−0.02	0.01	0.00	0.00	−0.02	−0.03	0.01	0.02
±SD	0.07	0.09	0.06	0.06	0.05	0.10	0.07	0.09
Submaximal work load (3 mph/5%)								
Mean difference	0.01*	0.04	0.01	0.02	−0.01	−0.02	0.01	−0.00
±SD	0.06*	0.07	0.05	0.07	0.06	0.08	0.07	0.09
Angina threshold								
Mean difference	−0.01	−0.06	−0.02	−0.04	−0.02	−0.00	0.03	0.01
±SD	0.07	0.12	0.08	0.07	0.09	0.03	0.09	0.04

*p < 0.05. A negative number indicates less ST segment displacement spatially, more elevation in lead Z and more depression in leads X and Y. A positive number indicates more ST displacement spatially, less elevation in lead Z and less depression in leads X and Y. C = control; EI = exercise intervention.

Discussion

Basis for the study. Inadequacy of oxygen supply to the myocardium has been related to the displacement and slope of the ST segment (2,16). Exercise programs have been widely used in the rehabilitation of patients with coronary artery disease and have often resulted in improvement in work capacity (17,18). However, it has not been demonstrated whether training results in changes in myocardial oxygenation during exercise. Although a number of animal studies (19) have shown changes in cardiac perfusion secondary to long-term exercise, this has not been demonstrated in human subjects.

An exercise program for patients with coronary artery

Table 6. Estimated Effects of Exercise Intervention Based on Univariate Two- and Three-Way Analysis of Variance in Three Subgroups of Patients

	Q Wave Infarction	No Q Wave Infarction		
Exercise intervention	0.00	−0.06	RPP/spatially	Intervention = −0.02*
Control	0.02	0.01		Interaction = 0.13
Exercise intervention	−0.05	0.01	SHR/Z	Intervention = −0.01
Control	−0.01	−0.02		Interaction = −0.02†
Exercise intervention	−0.04	0.03	RPP/Z	Intervention = 0.01
Control	−0.00	−0.02		Interaction = −0.02*
	Bypass	No Bypass		
Exercise intervention	0.02	−0.03	RPP/Y	Intervention = 0.00
Control	−0.02	0.01		Interaction = 0.02*
Exercise intervention	0.02	−0.04	RPP/Z	Intervention = 0.00
Control	−0.03	0.00		Interaction = 0.02†
Exercise intervention	0.01	0.01	ANG THR/spatially	Intervention = −0.04†
Control	0.17	−0.01		Interaction = −0.04†
	Angina	No Angina		
Exercise intervention	−0.04	−0.01	RPP/spatially	Intervention = −0.02*
Control	0.02	0.02		Interaction = 0.01

*p = 0.05; †p = 0.01. Intervention value reflects estimated effects of exercise intervention on ST60 measurements over 1 year. Interaction value reflects estimated effects by exercise intervention and subgroup. RPP = matched rate-pressure product; SHR = matched submaximal heart rate; ANG THR = angina threshold.

disease has been shown to decrease myocardial oxygen requirements as determined both directly and indirectly (17,20). Detry et al. (21) demonstrated that hemodynamic indexes of myocardial oxygen consumption are so closely related to ST segment depression that comparisons are valid only if electrocardiographic findings are compared at the same rate-pressure product or heart rate. Rate-pressure product is generally considered the most accurate noninvasive index of myocardial oxygen consumption during exercise (22).

Review of previous investigations. Previous studies (8) have been limited methodologically and have not been in agreement. Among eight investigations, three (17,23,24) concluded that long-term exercise resulted in lessened ischemic responses to exercise at matched myocardial oxygen demand. Raffo et al. (23) studied the effects of 6 months of exercise in 12 patients; 8 of these demonstrated a significantly higher heart rate at the same degree of ST segment depression (the HR/ST threshold). Ehsani et al. (17) demonstrated a 34% increase in maximal oxygen uptake after 12 months of intense training in 10 patients and a corresponding 22% increase in the rate-pressure product required to induce 1.0 mm of ST segment depression. Sidney and Shepherd (24) trained an apparently healthy elderly study group for 14 weeks. A frequent but low intensity training program demonstrated a significant lessening in the degree of ST segment displacement in lead CM_5 at a heart rate of 120 beats/min.

In contrast to these three studies, Detry and Bruce (25) found no significant alterations in the relation between the magnitude of ST segment depression and the heart rate or rate-pressure product in 14 patients trained for 3 months. Costill et al. (26) studied the abnormal electrocardiographic responses of 24 men before and after 3 months in an exercise program. Although the exercise level required to elicit ST segment depression was increased, the degree of ST depression and heart rate at the onset of the same ST depression were not different. Watanabe et al. (27) applied computer techniques to acquire and analyze spatial ST segment shifts before and after 3 to 8 months of training in 14 cardiac patients. A lessening in ST60 measurements in a derived spatial lead at matched submaximal heart rates was the only significant change. Salzman et al. (18) studied 100 men before and after an average 33 months of exercise. Favorable ST segment changes at similar work loads were strongly related to improved fitness, but they could be explained by changes in heart rate. Kattus et al. (28) observed 4 of 13 subjects to have a reversion of ST segment depression to normal after 5 months of training, but several control patients did also.

Our study design. Included in the present analysis initially were ST segment data at rest, maximal exercise and at 1 and 3 minutes of recovery. However, these results were not informative, so only the measurements at matched work load (3.3 mph, 5% grade), matched heart rate, matched rate-pressure product and at the angina threshold are presented. To separate sources of variability and to increase homogeneity, patients were categorized into prior myocardial infarction, angina and coronary artery bypass surgery subgroups.

Unique to the present investigation was the use of the three-dimensional corrected orthogonal lead system for spatial analysis of ST segment shifts (29). The three-dimensional electrocardiographic analysis is capable of viewing the entire repolarization process spatially and measuring the absolute or total deviation of the ST segment from the baseline (3). Using the absolute or spatial ST value, if either a positive or negative ST shift occurs in a direction closer to the zero value, it is a favorable finding (a negative number). If the changes are away from the zero reference (a positive number), the ST segments are worsening.

Many computerized electrocardiographic criteria for myocardial ischemia have been demonstrated (14). Sixty milliseconds after the end of the QRS complex (ST60) was used in our study since Simoons (30) has demonstrated this index to be the optimal criterion for ischemia with exercise testing. The computerized data acquisition system was reproducible in the control group before and after the year (Tables 5 and 7).

Findings in this study. The most consistent finding was favorable ST segment changes occurring at a matched submaximal work load (3.3 mph, 5% grade). Exercise training of patients with coronary disease improves the efficiency of the heart so that any submaximal work load may be accomplished at a lower heart rate and blood pressure. The heart rate at the same work load was significantly lower (7 beats/min) in our exercise group after 1 year. Although these findings underline the value of exercise training for cardiac patients, they do not support the hypothesis that augmentation of

Table 7. Correlations (standard error of the estimate) Between Values Obtained Before and at 1 Year in Control Patients Only

Vectorcardiographic Lead	Rate-Pressure Product	Submaximal Heart Rate	Angina Threshold	Submaximal Work Load
X	0.88 (0.16)	0.87 (0.16)	0.84 (0.32)	0.83 (0.15)
Y	0.77 (0.15)	0.81 (0.15)	0.60 (0.33)	0.78 (0.15)
Z	0.86 (0.15)	0.88 (0.15)	0.75 (0.32)	0.78 (0.15)
Spatial	0.86 (0.15)	0.79 (0.15)	0.57 (0.32)	0.74 (0.15)

oxygen supply to the myocardium occurs secondary to an exercise program. This is in contrast to our positive findings using thallium scintigraphy in this same group (9).

The other finding was the lack of significant changes secondary to the exercise intervention. This led to the use of statistical techniques that would look for differences within subgroups (analysis of variance). Unfortunately, this analysis failed to find meaningful changes in lead X; however, changes were found particularly using the spatial analysis and lead Z. A significant lessening of exercise-induced ST segment displacement at matched rate-pressure product was found spatially using analysis of variance in the angina and no history of Q wave infarction subgroups. Caution is in order, however, when dependencies among many simultaneous inference procedures are considered and since similar changes did not occur by matching heart rate. In addition, the patients with angina who underwent exercise training showed a significant improvement spatially at anginal threshold.

Although these ST segment changes occurring spatially and in lead Z in the present study are noteworthy, they did not occur consistently. It has been suggested (17,23) that the failure to reduce ST segment depression may reflect an insufficient training intensity. Our exercise intensity was approximately 70% of maximal capacity for 45 minutes, 3 days per week. In the study of Ehsani et al. (17), the intensity and duration of exercise were increased throughout 1 year so that patients were exercising to 80 to 90% capacity for 1 hour, 6 days per week. Such an exercise regimen may not be practical or safe for the general cardiac population. In the study by Raffo et al. (23), which demonstrated a favorable change, patients exceeded 12 minutes daily at modest intensities for 6 months.

Conclusion. This comprehensive randomized study examined the effects of 1 year of exercise training on computer-analyzed ST segment displacement measured during exercise. Improvement in maximal oxygen uptake in the exercise-intervention group was accompanied by a decrease in heart rate at a submaximal work load. Statistical analysis by *t* testing between the two groups only detected a lessening of ST displacement at that point. Attempting to account for clinical subgroups using analysis of variance detected other significant improvements. However, the analysis was exploratory and these changes were small and not universally demonstrated. We conclude that obvious changes in exercise-induced ST segment displacement could not be demonstrated in our heterogeneous group of cardiac patients secondary to exercise training.

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