ST Segment Depression with Near-Maximal Exercise: Its Modification by Physical Conditioning

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Three hundred nine male insurance underwriters had near-maximal treadmill exercise tests following clinical evaluation. Thirty of the subjects developed ischemic type ST segment depression during or after exercise not associated with anginal pain. Thirteen of the ischemic responders participated in a supervised physical training program which led to increased exercise capacity. Four of these had reversion of the ischemic exercise ECG patterns to normal. Among those ischemic responders who did not train there was no improvement of exercise capacity yet two of these had reversion of ischemic ECG patterns to normal.

In a recent study of 314 male insurance underwriters it was found that 30 of them developed ischemic electrocardiographic changes when they were subjected to near maximal exercise stress on a motor driven treadmill. Since these subjects were all asymptomatic and engaged in a relatively sedentary occupation, it was decided to investigate the effect of a supervised exercise training program on the ischemic responders with the idea of determining to what extent physical conditioning might improve exercise capacity and whether the ischemic ECG manifestations might be modified by training. The hope was that the poor prognosis associated with the ischemic ST segment depression induced by exercise might be improved by judiciously applied exercise.

Subjects and Methods

The subjects of this study comprised 30 men who emerged from a larger population of 314 members of the Los Angeles County Association of Certified Life Underwriters who volunteered to be surveyed for coronary risk factors and to have near maximal exercise stress testing. The study cohort is made up of the 30 men who developed ST segment depression during or after performance of a near maximal exercise test. Their ages ranged from 41 to 75 years, with an average of 56.7 years. Details of the study and the methods have been published elsewhere. To summarize briefly, the subjects filled out history questionnaires, had a physical examination of the cardiovascular system and a resting electrocardiogram (ECG) prior to the treadmill test. The test consisted of six stages of treadmill walking, each stage of three minutes duration, beginning with a low level workload and progressing to higher work loads. The sixth stage represented a workload that could be completed only by a well conditioned person. The first three stages were done at a constant upgrade of 10 percent with walking speeds of two, three and four miles per hour (MPH). In the next three stages the walking speed was held constant at four MPH, while the grade was increased to 14, 18 and 22 percent.

Prior to the test the subjects were instructed to continue walking until they were experiencing somewhat more than mild discomfort but not to the point of maximally severe exhaustion. Most of the subjects stopped walking because of fatigue or aching in the calf muscles. Only one said that he had experienced a slight pressure sensation in the chest at cessation. The maximal pulse rates recorded at cessation were near the maximal predicted rates for the age groups represented by our subjects. Thus, we regard our exercise test as a near-maximal one. The ECG was monitored continuously before, during and after the test by means of a single bipolar
The ECG signal was displayed continuously on an oscilloscope and strips were recorded for 6 to 10 seconds at the end of each minute. At the end of the exercise the ECG monitoring was continued until the heart rate had returned to near the pre-exercise level, usually a duration of about 10 minutes. The ECG signal was scrutinized continuously for changes in the rhythm and for appearance of ST segment shift indicative of myocardial ischemia. The ischemic response is defined as at least 1 mm of horizontal or downsloping of the ST segment which is present either during exercise or in the post exercise recovery period. Three gradations in the severity of the ischemic response have been defined, grade 1 consisting of ST segment depression appearing only in the post exercise recovery period; grade 2—appearance of ST segment depression during exercise with almost immediate disappearance at the end of exercise; grade 3—ST segment depression appearing during exercise with progressive deepening to a maximum at the end of exercise with persistence for several minutes into the post exercise period, often with deep T wave inversions prior to return to control pattern. Examples of these 3 grades are seen in Figure 2. Figures 3 and 4 represent grade 3 responses.

RESULTS

Of 314 volunteers, five were excluded from exercise testing because of orthopedic problems or the discovery of pre-existing heart disease. Of 309 men subjected to near maximal exercise testing, 30 had ischemic electrocardiographic changes provoked by the test. Twenty-eight of these returned for repeat tests to confirm the original finding. All but one of the 28 had ischemic responses similar to the original test. One man originally displaying a grade 2 response had a normal response when tested four months later. The two subjects who failed to return for confirmatory tests had grade 3 responses of an entirely unequivocal pattern.

All 30 of the ischemic responders were invited to enter a supervised physical conditioning program. Two refused all further participation. Thirteen volunteered to participate in the exercise training sessions. Fifteen found it impossible to participate in the training program but agreed to return for repeat treadmill tests in the future. Thus, nearly half of the group became participants in the training program while another 15 subjects, though not constituting a randomly selected control group, did serve as a comparison group that could be followed in parallel with the training group.

Training sessions were held at the UCLA Rehabilitation Center for one hour on Monday, Wednesday and Friday of each week over a period of five months. The training consisted of an initial warm-up period of 15 minutes during which loosening up and muscle stretching calisthenics were performed. The endurance portion of the program consisted of a 12 minute period of jogging with intermittent walking and running at a rate set by the subject himself so as not to produce exhaustion or significant discomfort. Each subject kept track of the number of laps (¼th mile) covered in each of the jogging sessions and in almost all instances these increased in number as the training program progressed. The last part of the hour was recreational with doubles tennis, paddle tennis, volley ball, handball and swimming as the options. All exercise was supervised by a physician who was assisted by a graduate student in physical education. Defibrillation and resuscitation equipment was readily available. No untoward events took place during the supervised sessions. However, one subject who had been making good progress during the program, manifested by improvement in treadmill performance, undertook additional jogging activity on his own outside the supervised program in spite of repeated warnings to the contrary. He fell dead while jogging alone after three months in the training program.

The subjects in the training program had varying attendance records. There were only four who had 75 percent or better attendance and eight who had 50 percent or better attendance. Five had attendance of less than 50 percent. All are included in the analysis. Several were encouraged to carry out supplementary exercises at home if their treadmill test performances were adequate, while others with

![Figure 1. Results of exercise training program. Training group to left, non-participating group to right. Change of exercise pulse to the left of center. Change of treadmill walking time to right of center. Average values connected by dashed lines. Persons whose ischemic ECG responses reverted to normal indicated by asterisks.](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21551/ on 06/25/2017)
Types of Ischemic Responses and Numbers of Those Reverting from Positive to Negative

<table>
<thead>
<tr>
<th>Grade 1</th>
<th>Grade 2</th>
<th>Grade 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST↑ After Exercise</td>
<td>ST↑ During Exercise &amp; After Exercise</td>
<td>ST↑ During Exercise</td>
</tr>
<tr>
<td>No.</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Total, %</td>
<td>10</td>
<td>17</td>
</tr>
<tr>
<td>No. reverted to normal-exercise group</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>No. reverted to normal non-exercise group</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

poor performance were advised against home exercise. All 15 of the non-participating group returned for repeat treadmill testing three to six months after the initial study. One of these, who displayed an increase in exercise tolerance and an excellent training effect manifested by reduction of pulse rates at all levels of exercise, and whose exercise ECG reverted from grade 1 positive to negative, disclosed that he had undertaken a vigorous training program on his own outside supervision.

Figure 1 displays the results of the training program comparing the supervised exercise group with the non-participating group. Each subject in

the graph has his performance indicated by four points. The point just to the right of center represents the number of minutes during which the subject walked on the treadmill before starting the exercise program. This was usually the second or confirmatory treadmill test. The point to the far right of center represents the duration of treadmill walking at the conclusion of the training program. The points to the left of center represent the change of the work pulse rate due to training, with the near center point representing the original pulse rate for a given work level and the point to the far left the change in pulse rate for the same work level after training. In each instance the pulse rates were compared for the highest work levels for which comparisons were possible. For example, Figure 3 shows that the four MPH, 10 percent grade, stage is the highest level in which full three minute work periods could be compared. After training the pulse rate for that work level has been reduced by 26 beats. Likewise in Figure 4 the four MPH, 14 percent grade, stages may be compared and after training the pulse rate for this work level has been reduced by 10 beats.

All of the trained subjects increased their exercise tolerance and all but one had a reduction of the work pulse rate. The average increase in performance was 2.2 minutes of treadmill walking. The

Figure 2. Change in ischemic response from positive to negative in five subjects.
most striking improvement was found in those subjects who were in better condition at the outset as seen at the top of the graph. However, two excellent training responses were also found in two subjects who began at the seven minute level of initial performance. In the non-participating group there were eight subjects whose exercise capacity did not change or declined, while there were six who showed slight increase and one who showed a striking increase in exercise capacity along with a large reduction of the working pulse rate. This latter subject had, in fact, carried out his own private training program. There was virtually no change in the average treadmill walking duration for the group as a whole, and only a slight reduction in the average work pulse rates.

The effect of the training program on the ischemic ECG response to exercise was examined and compared with the responses found in the non-exercising subjects. The table summarizes the distribution of the various grades of ischemic ECG responses to treadmill exercise. It indicates that two of the subjects with grade 1 responses reverted to normal or non-ischemic responses. One of these was in the supervised training group, while the other was the man in the non-training group who did his own private program with a good training response. Thus, the two subjects who had reversion of the ischemic ECG response from grade 1 to normal carried out exercise training. One subject in the non-exercising group reverted from grade 2 to normal.

Among those displaying the grade 3 response, there were three in whom the ischemic ECG pattern resulting from treadmill exercise reverted to normal. Two of these were in those who trained and one was in the non-training group. The ECG changes in all of the subjects who reverted to normal are shown in Figures 2 and 3. The subject displayed in Figure 3 had an excellent training response which enabled him to finish all six stages of the treadmill test. The grade 3 ischemic ECG response is converted to a pattern displaying only J point depression. Reference to Figure 1 discloses that four of the six subjects having reversion to the exercise ECG response from abnormal to normal.

Figure 3. Diagram of treadmill tests on subject with ischemic exercise ECG before training and nonischemic response after training. Each block represents 3 minutes of treadmill walking at speed and grade indicated at left. Maximal heart rate for each 3 minute stage inside box. ECG at end of each stage to right of column. Increased exercise tolerance is shown by increase of treadmill walking time from 11 to 18 minutes, slowing of the work heart rate in stage 3 (4 MPH, 10% grade) from 180 to 154 and disappearance of the ischemic response in ECG.

Figure 4. Treadmill tests on an asymptomatic man who showed improved performance after training with walking time increasing from 12 to 18 minutes. Ischemic ST segment response persists but appears at higher work load and heart rate and is less severe after training.

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(indicated by stars) were those who had excellent training effects manifested by increased treadmill walking time and reduction of the work pulse. Three of these were in the training group and the fourth was the man who trained on his own. One subject with grade 3 and another with grade 2 ischemic responses reverted to normal during periods of relative inactivity.

It appears that the training probably had something to do with converting the abnormal response to normal. There were two others in the exercising group whose ischemic ECG changes appeared at a higher stage of the treadmill test, but eight of the exercisers had no change in time of appearance of the ST segment depression. Among the non-participants in the supervised training program in addition to the two who reverted from positive to negative treadmill tests, there were two whose ischemic ST segments appeared one stage higher in the follow-up treadmill test and nine in whom the ECG pattern did not change.

**Discussion**

This study of asymptomatic men who developed ischemic ST segment depression with near-maximal treadmill exercise shows that exercise training results in enhancement of physical working capacity and in some instances in disappearance of the ischemic ECG abnormality. The findings are similar to what we have previously found in patients with angina pectoris who experienced chest pain along with ST segment depression during near maximal exercise testing. Some of these have had complete relief of anginal symptoms as well as disappearance of exercise-provoked ST segment depression during an exercise training program. Others have had enhancement of exercise capacity with only partial relief of symptoms and with persistence of the ST segment shifts even though higher intensity work loads were required to elicit them. The similarities of responses between the symptomatic angina patients and the asymptomatic subjects with the ischemic ECG response to exercise suggests that both groups have inadequacies of adaptation of the coronary blood flow to the myocardial demand under conditions of exercise. Our data suggest that a favorable adaptation might be brought about in the coronary circulation of such subjects by the imposition of an exercise program adjusted to the measured working capacity of the subjects.

Among the several mechanisms by which physical activity might have a favorable influence on inadequacy of the coronary circulation is the development of an increased myocardial efficiency, making it possible for the body to perform a given work load at a lower energy cost to the heart. Most of the studies reporting improvement with training in patients with coronary heart disease disclose that reduction of ST segment depression on the exercise ECG at a given rate of external work is associated with a decrease in heart rate at that load. Since myocardial O₂ consumption correlates well with heart rate during upright exercise, one might expect this result. The study of Mazzarella et al provides the most definitive information on this point. The degree of ST segment depression during exertion was quantitated precisely using computer analysis and found to increase linearly with heart rate. The post training decrease in ST segment depression at a given work load was due to a decrease in heart rate, with the degree of ST segment depression at a given heart rate being the same as it was prior to training. Their findings are similar to what we have documented in the subject depicted in Figure 4. However, our finding that a training program faithfully adhered to could bring about a complete normalization of the ischemic ECG response even at the highest possible level of exercise differs from their findings and suggests that mechanisms depending on factors other than heart rate may be operating in this training effect. For example, the subject illustrated in Figure 3 had ischemic changes at a work load of four MPH and 14 percent grade with a heart rate of 180 before training, but after training he had not attained this heart rate until a load of four MPH at 22 percent grade was reached, and then he had only J point depression in the ECG.

The observations could best be explained by an increase of O₂ delivery to the myocardium being brought about by the training program. A recent study from our laboratory indicates that this adaptation is not brought about by enhancement of the coronary collateral circulation at least as far as it can be discerned from coronary angiograms. Whatever the adaptation is that results from exercise, it appears to lessen the incidence of myocardial infarction and coronary death as shown by Kannel in the Framingham study.

In a study of 186 men at the Seattle YMCA, Most and associates found 31 who had ischemic ST segment depression provoked by maximal exercise testing. Over a two-year period 14 of the positives reverted to normal. It cannot be ascertained from their report whether or not the reversions to normal were associated with exercise training.

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REFERENCES

5 Robinson BF: Relation of heart rate and systolic blood pressure to the onset of pain in angina pectoris. Circulation 35:1073-1083, 1967

The "Bolero" by Ravel

In three months Ravel (1875-1937) completed the work which in his opinion was a joke, a composition made of a "crescendo on a commonplace melody." Later he made the following statement: "I am particularly desirous that there should be no misunderstanding about this work. It constitutes an experiment in a very special and limited direction. Before its first performance I issued a warning to the effect that what I had written was a piece consisting wholly of orchestral tissue without music—of one long gradual crescendo. There is practically no invention save the plan and the manner of execution. The themes are folk tunes of Spanish and Arabian kind, the orchestral writing is simple and straightforward throughout, without the slightest attempt at virtuosity." Contrary to Ravel's own prediction that this would never be played at symphony concerts, Bolero, after a triumphant performance on January 11th, 1930, at the Concert Lamoureux, achieved a popularity which has never been surpassed.

Seroff, VI: Maurice Ravel, New York, Henry Holt, 1953