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ON AN INDIVIDUAL BEFORE AND AFTER
SUFFERING A MYOCARDIAL INFRACTION**

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Oklahoma City, Oklahoma
January 1964



THE EFFECT OF PHYSICAL CONDITIONING ON AN INDIVIDUAL BEFORE AND AFTER SUFFERING A MYOCARDIAL INFARCTION

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The value of regular physical activity in the prevention of clinically manifest coronary artery disease has received much emphasis during the past few years^(1,2,3,4). Its place and worth in the treatment of patients with coronary atherosclerosis is still an unsettled question. European investigators have pioneered in using physical exercise for the rehabilitation of certain cardiac disorders⁽⁵⁾. It is only recently that investigators in this country have voiced strong opinions supporting programs of physical training for many patients with organic heart disease⁽⁶⁾.

The fact remains that basic questions concerning the cardiac patient's reaction to and capacity for work are unanswered. Despite encouraging reports of the beneficial effects from systematic physical training on many types of heart disease patients, there is a lack of physiological evidence for the quality of functional responses to work with or without training.

In this report some physiological and biochemical observations recorded on an individual who engaged in a program of regular physical training for the control of obesity and hypertension, had a myocardial infarction, and resumed physical conditioning after an adequate interval of recuperation are presented.

The experimental material will be presented in three phases: Phase I includes the physical

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Research supported in part by Public Health Service Research Grant #HE-06286-03.

evaluation before a conditioning program was started; then the progress during regular training, and the re-evaluation of work capacity after a six-week training period. Phase II, beginning only hours after the latter test, presents the evidence of myocardial infarction and reports the clinical and experimental data obtained from that time until the patient's return to work on a part-time basis. Phase III covers the period of re-training, its progress and its effects on the capacity for making functional adjustments to gradual increments in energy demands.

Phase I

The individual (RDC), a 54 year old white male with a one year history of hypertension, had heard about the effects of daily exercise on blood pressure⁽⁷⁾, and volunteered for participation in a systematic, long-range, exercise program.

After essential measurements had been made in the resting state the experimental subject performed a standard work capacity test on a treadmill^(8,9).

In this test procedure the treadmill speed remains constant at 91.5 m/min and walking begins on a grade of 1 per cent. Each minute the slope is increased 1 per cent by tilting the treadmill bed. Blood pressure, pulse rate and ECG are monitored from minute-to-minute; measurements of the respiratory gas exchange are made every other and during the last minute. The test is terminated at a heart rate considered to be near maximum, usually around 180 per min. It is at this point that the systolic pressure does not attain the previously measured maximum height and/or a simultaneous rise in diastolic pressure is recorded. Other indications for terminating the test are: obvious dyspnea, signs of pallor, claudication, or chest pain.

During rest blood pressure was 162/120 mm Hg, heart rate 80 per minute, serum cholesterol 285 mgm per 100 ml; body weight was 106 kg and height 176 cm.

The cardiovascular and respiratory adjustments to the gradually increasing work demands are illustrated in Figure 1. The peak level of aerobic work capacity attained was indicative of a level of physical fitness classified as "poor," slightly below the average value obtained from studying a large male population.

Following this evaluation of work capacity an interval training program was begun and adhered to on 5 out of 7 days. Initially, working and resting intervals of 30 or 45 seconds followed each other for periods of 20 minutes; these were gradually increased to 40 minute periods. Exercise consisted of walking on the treadmill at a speed of 3.4 mph on varying grades, depending on the functional response to given work intensities.

The resting blood pressures recorded before each day's exercise slowly declined during the first three weeks of training (Figure 7). Then, although work capacity improved ostensibly, these routine blood pressure measurements became erratic and occasionally were close to the original hypertensive values. No attempt was made to establish a connection between this cardiovascular inconsistency and any possible interferences of a psychological nature at home or on the job.

After six weeks of training the subject returned for a re-evaluation of work capacity. He did not look well and was not as cheerful as usual, but insisted that he felt fine. The functional response to the test task was far from that usually seen after a period of physical training involving increasingly greater energy expenditures each day, and was also different from measurements and observations made during the training itself (Figure 1).

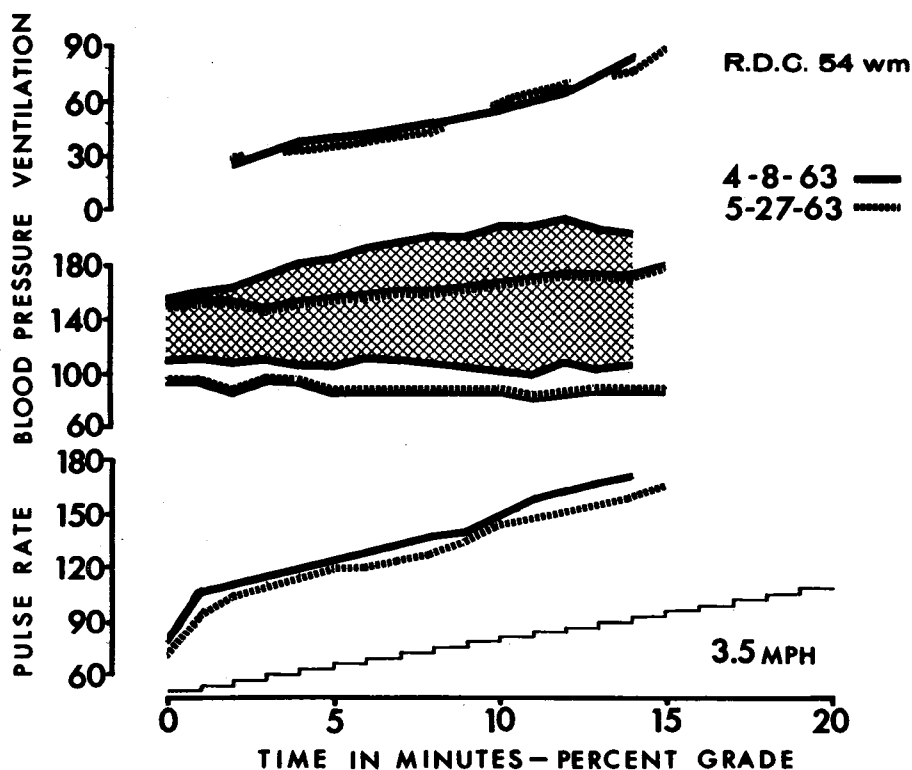


FIGURE 1: An elevated resting blood pressure was recorded prior to the initial work capacity test. The systolic pressure rose approximately 35% above the resting value during the work. The diastolic pressure remained elevated. A very minimal systolic pressure elevation occurred during the second test. In addition, the pulse rate was relatively rapid instead of being slower after the training period. These findings suggested the existence of a myocardial insufficiency.

The pulse rate, although expected to be 12 to 16 beats slower at each comparable level of work intensity, was only slightly changed. But more strikingly, the systolic pressure which had risen 35% above its resting value toward the peak load in the control test, now increased slightly more than only 15% above the resting level. The resting diastolic pressure was slightly lower than during the control test, and remained constant throughout the test. Such an insignificant blood pressure response to this type of work test has been considered indicative of myocardial insufficiency⁽¹⁰⁾. Since the continuously monitored ECG, obtained from one screening chest lead, showed normal tracings, the test was continued to an energy demand which had been easily maintained during the latter part of the training. Considering the slight decrease in body weight from 105.5 to 102.5 Kg. the peak loads — pre- and post-training — were almost identical.

Following this test dizziness occurred while taking a warm shower. Upon reclining the blood pressure was 120/80 mm Hg, apparently very low for this previously hypertensive individual. Raising the legs, feeding sugar and sipping coffee (the last meal had been the night before) brought on an uneventful recovery, and the subject returned to his job. Four hours later he again complained of light-headedness. He nearly fainted in his attempt to walk back to the laboratory in an outside temperature near 100° F. A standard electrocardiogram revealed evidence of an acute inferoseptal myocardial infarction (Figure 2). The patient was hospitalized.

Samples of venous blood drawn prior to the clinical manifestation of myocardial infarction revealed pre- and post-exercise elevation of the serum glutamic oxaloacetic transaminase (SGOT) of 85 and 120 units respectively.

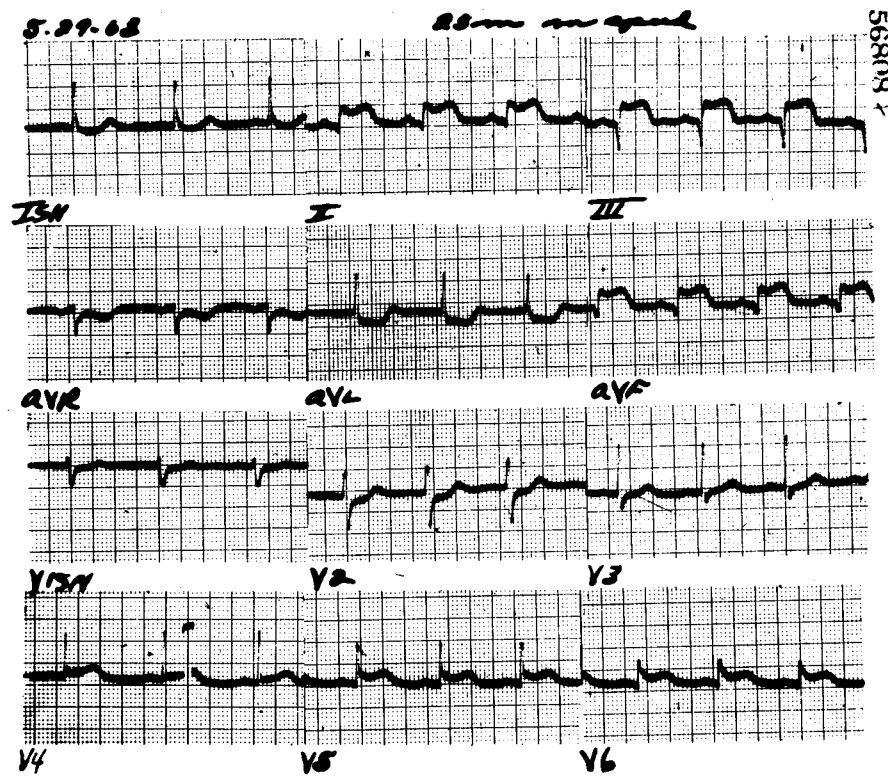


FIGURE 2: The standard electrocardiogram obtained 4 hours after the second work capacity test showed a deep Q deflection in II, III and aVf. Positive junction displacement was present in II, III, aVf, V₅, V₆. These findings were compatible with an acute inferoseptal myocardial infarction which probably involved the lateral region.

Phase II

In the hospital, activities were initially limited to bathroom privileges. Dietary intake was limited to 1200 calories per day. The proportion of saturated to unsaturated fat was not altered.

Additional history revealed that the patient had been under severe emotional stress during the week prior to his infarction. It was during this period that a chronic employer-employee conflict reached a new peak with the patient coming out second best, in his opinion; his son left the home for military service in an atmosphere clouded by misunderstanding and hostility; and the patient's wife and ex-daughter-in-law clashed over the idea of possible marital reconciliation with their son. Two days prior to hospitalization the patient experienced malaise and several episodes of epigastric distress characterized as indigestion. The next day he was observed to be ashen and sweating while talking with his neighbors.

During the second week in the hospital the patient was allowed to walk down the hall several times a day. On the 15th day the biodynamic potential, i.e., the adaptability of the cardiorespiratory system to increased energy demands, was evaluated with a modified work capacity test⁽¹⁰⁾.

This test is conducted in a manner similar to the standard work capacity test with the following exceptions: The treadmill speed is 2.0 mph (53.6 m/min) and walking begins on a horizontal level. This provides a load nearly twice the basal metabolic rate. After intervals of 3 minutes, the treadmill bed is raised 3.5% each time, thus providing load increases equivalent to metabolic rates of approximately 3, 4, etc., times the BMR. For the appropriate termination of the test the same criteria are used as in the standard work test, with two exceptions: The experimental subject—usually an ambulatory patient—is free to stop at any time for any reason; secondly, the load of seven mets (multiples of BMR) is never exceeded because a further steepening of the slope (beyond 17.5%) becomes too difficult to negotiate for the majority of people in a relatively poor state of health.

Figure 3 shows that the blood pressure was much lower than before the myocardial infarction, but its gradual increase during work was an indication of a satisfactory recovery of the damaged heart muscle. After this evaluation the patient was allowed to ambulate freely, and was discharged on the 17th post-infarct day. He did well at home and a program of regular daily exercises was initiated several days later. Exercise was performed as interval training on the treadmill and under careful supervision its intensity and duration was increased each day.

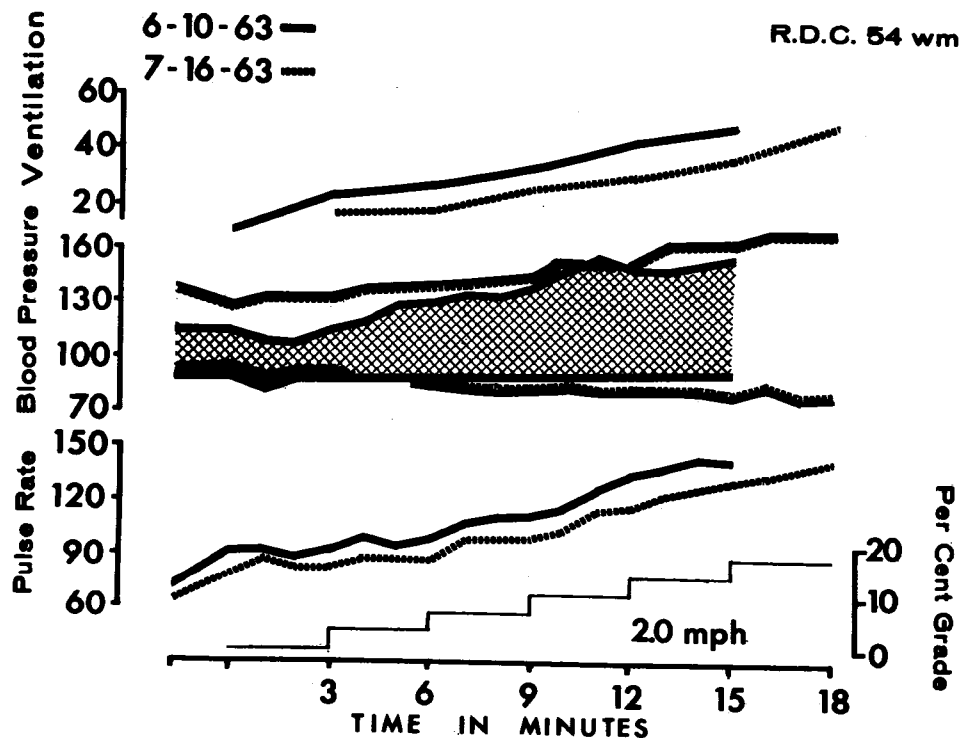


FIGURE 3: A gradual but steady increase in systolic pressure occurred during the modified work capacity test two weeks post-infarction. The diastolic pressure remained constant. A second modified work capacity test 7 weeks post-infarction showed evidence of increased cardiorespiratory efficiency and no evidence of any underlying myocardial insufficiency.

A re-evaluation of work capacity was ascertained during the 7th week post-infarction. A marked restoration of cardiopulmonary adaptive capacity became evident when compared with the results obtained 5 weeks earlier (Figure 3). The lower heart rate and augmented blood pressure at any given workload was indicative of improved cardiac dynamics. This improved response suggested that the patient could return to his regular job.

Phase III

After resumption of his normal work, R.D.C. began a physical exercise program and adhered to it regularly during the following weeks. A walking speed of 3.4 mph was selected for the supervised work-outs on a treadmill. Again, with alternating periods of effort and rest, gradually increasing the former and shortening the latter, cardiovascular response to exercise improved steadily.

On occasions when the heart rate attained rates of 140 per minute, the subjective impressions about the individual's general appearance guided the observers in lessening or adjusting the demands. Frequently, sweating was not accompanied by a healthy looking flushing of the body surface, but by a grayish pallor. It was because of this that the treadmill exercises were terminated and two simple ball games introduced into the training program.

The advantage of these games is their simplicity. In one game a player throws a basketball (eventually a medicine ball) across a fairly high net; the other player has to catch and to return it from the location where caught. Throwing beyond or out of established boundary lines, not catching the ball, or not clearing the net properly scores for the opponent. In the second game a volley ball is hit with the hand or fist in such a way that it bounces from the players field across a slightly lowered tennis net into the opponent's field. Only one bounce is allowed before the opponent returns the ball in exactly the same manner. For the return each player has the choice of bouncing the ball back immediately or after he has played it by either one or two additional bouncing actions into a better aggressive position. Although these games are undemanding in special skills, they require continuous body movements in all possible directions and result in high energy expenditures. By adjusting the rules and regulations to the players capacity, the games have a highly competitive note.

This change in the training routine led to several remarkable observations. The patient enjoyed playing these games and worked harder than he realized, becoming more relaxed despite a highly competitive attitude. During play he developed a natural peripheral vaso-dilatation instead of the grayish pallor observed during treadmill work. Electrocardiograms telemetered during the games revealed that heart rates near 160 per minute were tolerated without the slightest symptoms of distress. These high rates were recorded when the patient played against opponents giving him fierce competition. On the other hand, against players with less experience, he dominated the game and, in saving efforts, demonstrated lower heart rates (Figure 4).

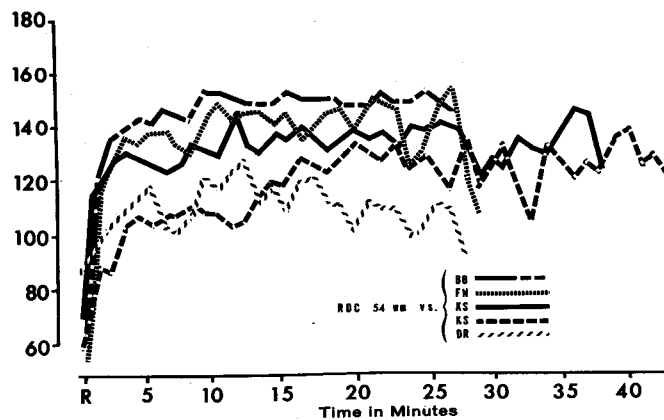


FIGURE 4: The heart rate responses of R.D.C. during competitive ball games against various opponents. These continuous pulse recordings were made approximately 16 to 20 weeks after the coronary incident.

The next modified work capacity test was performed 12 weeks after returning to his job. The patient performed this test with ease and had a response similar to that usually seen only in better trained individuals (Figure 5). Pulse rates were 20 to 40 beats per minute lower than at identical work rates during the third week post-infarct. Resting blood pressure was normal

with a response during work much like that observed in normal healthy people. Minute ventilation values of 10 to 15 liters per minute less for any given grade on the treadmill suggested a lessening of respiratory effort. Since this test had not provided the intensities of work needed to ascertain the potential adaptive capacity of the heart, the standard treadmill test was performed 3 weeks later.

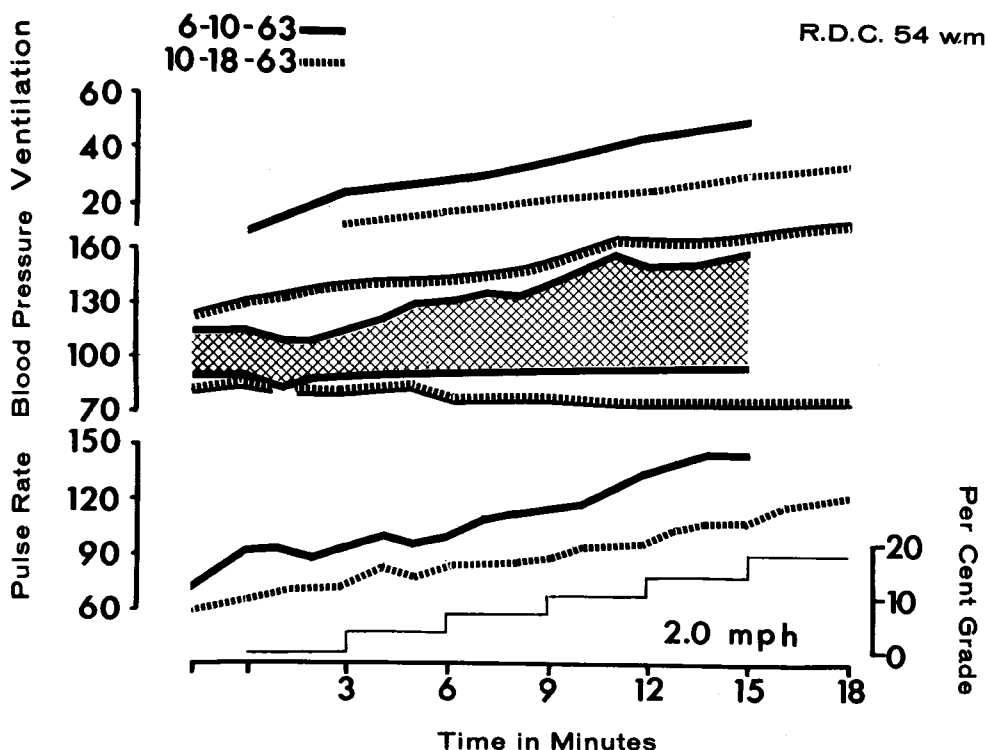


FIGURE 5: The post-training response to a modified work capacity test is compared with that two weeks post-infarct. At rest there is a much slower pulse rate with a wider pulse pressure. During work there was greater elevation of the systolic pressure with a very slow rise in pulse rate to 120/min at the test's termination. For the first time a decline in diastolic pressure was recorded during work. Increased ventilatory efficiency is demonstrated by the decreased minute ventilation at each comparable work load.

The results of this test were plotted and compared with the values obtained in the initial work capacity test in Phase I (Figure 6). The resting blood pressure was "normal." The systolic pressure increased commensurate with work intensities and similarly as in normal subjects. The diastolic pressure showed the decline usually observed in better conditioned examinees. The response of heart rate as well as pulmonary ventilation were evidence of improved

cardiorespiratory economy. Physiological limitations were not evident when this test was terminated at a pulse rate of 168/min. In view of the disease history, no attempts were made at this time to evaluate the maximum aerobic capacity. Even at this level of energy expenditure a work performance was achieved slightly superior to the average fitness level of a normal healthy male population, and greater than his performance capacity before the myocardial infarction.

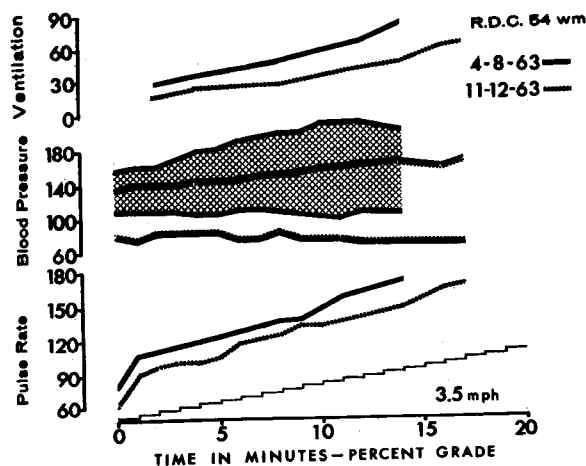


FIGURE 6: Twenty weeks of regular physical training post coronary infarction have not only restored but improved the pre-infarct capacity for making cardiorespiratory adjustments to increased metabolic demands. While work capacity, initially, was rated as "poor to fair," the repeat test, although not continued toward physiological limitations, revealed a "good" functional potential.

Resting blood pressure, serum cholesterol and body weight changed dramatically during the three phases of observation (Figure 7). The original hypertension gave way to a mild hypotension as an effect of heart trauma but reverted slowly to a normotensive state which per-

sisted. The originally elevated cholesterol value of 280 mgm per 100 ml decreased considerably and was 188 mgm per 100 ml on the last examination. Body weight, as a consequence of restricting caloric intake and increasing caloric output, declined from 106 to 81 kg.

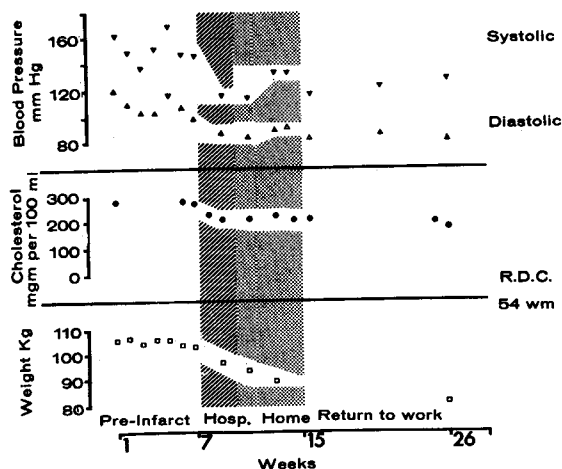


FIGURE 7: The initial evaluation revealed that the patient had high blood pressure, an elevated serum cholesterol concentration and that he was overweight. The blood pressure declined during the first three weeks, but the pattern became erratic during the next three week period. A relative hypotension persisted during the early hospital period. Since recovery it has remained in normotensive ranges. The serum cholesterol changed little in the pre-infarct period. With the training and caloric restriction it fell gradually reaching a rather constant normal level of 188 mg per 100 ml. Vigorous caloric restriction without altering the proportion of saturated to unsaturated fat led to a 25 kg weight loss during the period of observation.

Environmental conflicts decreased in intensity and frequency in the post-infarct period. This was due in part, at least, to strong supportive psychotherapy aimed at helping the patient understand the genesis of his emotional disturbances. In addition, a conference held with his employers led to measures that were instituted to improve the employer-employee relationship without destroying the patient's ego and self-confidence.

A single oblique lead ECG (Figure 8) was recorded during each test since the coronary occlusion⁽¹¹⁾. It consistently recorded a deep Q deflection with an inverted T. No abnormal RS-T junction displacement occurred during work or recovery in any of these tests.

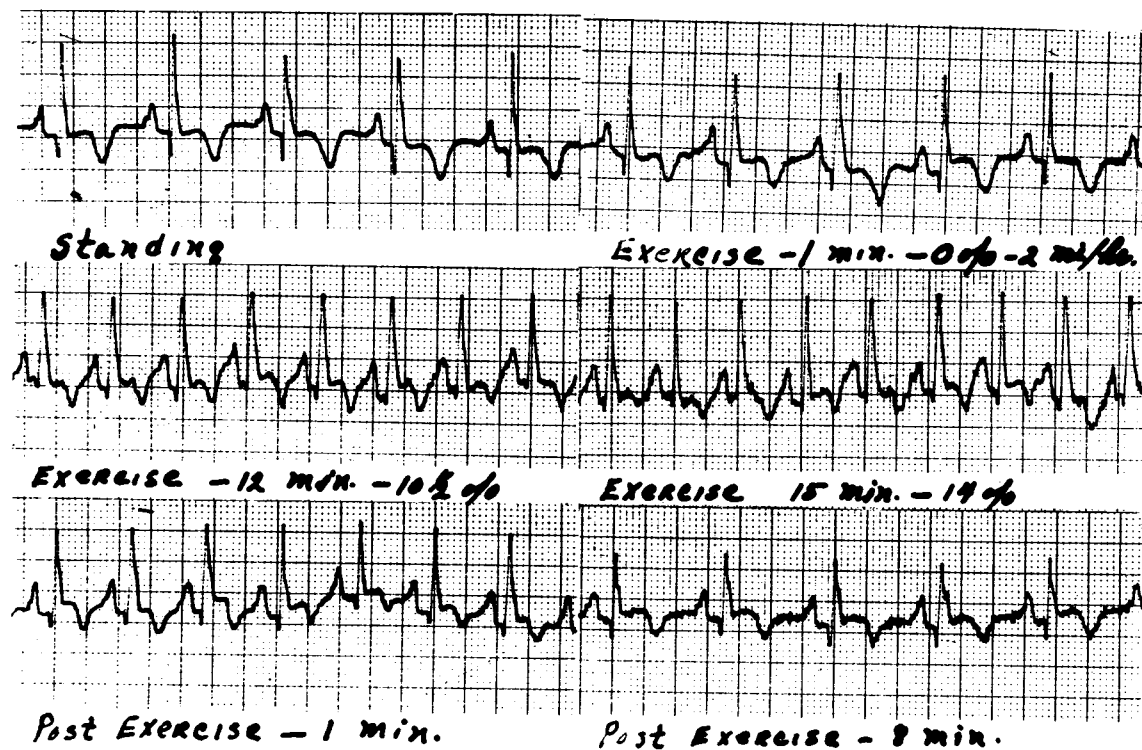


FIGURE 8: The oblique lead ECG was used to record the exercise electrocardiogram. A representative example of tracings obtained in this patient is shown here. There was a deep Q deflection with an inverted T wave. These findings were compatible with a moderately recent myocardial infarction. During work no significant RS-T displacement occurred.

DISCUSSION

The value of adequate physical activity as a therapeutic adjunct in the treatment of an uncomplicated myocardial infarction is not clearly defined by experimental investigation. Subjective and objective improvement in such patients participating in a physical training program has been observed by Hellerstein⁽⁶⁾. Dalton⁽¹²⁾ reported his efforts to return 900 cardiac patients to appropriate jobs, and expressed the opinion that exercising such patients provides better results than keeping them inactive. He emphasized, however, the great need for quantitating such observations.

A quantitative and qualitative evaluation of the capacity for functional adjustments to varying physiological demands appears to be as important as the recording of the electrocardiogram. Much more has to be learned about the qualitative differences in cardiorespiratory responses to work between normal and coronary artery disease prone individuals. One available method is the study of the cardiorespiratory reactions to known work intensities. The amounts of oxygen required have to be supplied to the active tissue by the arterial blood. Therefore, the determination of cardiac output and arteriovenous oxygen difference, should render valuable information concerning possible differences

between healthy people and cardiac patients. Chapman^(13, 14) following this approach reported however that the coronary patient increased cardiac output during work in exactly the same manner as is found in normal individuals.

Experiments in our laboratories⁽¹⁵⁾ have indicated that an evaluation of work capacity alone was insufficient to differentiate the "normal healthy" man from the individual who either had or was going to have a coronary occlusion. This could only mean that an intact myocardium, that was not acutely damaged, could furnish the blood flow needed to meet the demands of any submaximal work task. The suspicion existed, however, that any acute coronary insufficiency leading to a relative myocardial insufficiency was apt to have an effect on cardiac dynamics.

We thought that this effect would be reflected in the pulse pressure and pulse rate response recorded during the work performance. The cardiac efficiency of a well-developed, powerful heart is usually expressed by greater stroke volumes at lower heart rates. On the other hand, in cases of general physical fatigue, in the juvenile growing phase and in any myocardial insufficiency the heart rate is rapid and the volume of blood leaving the heart during systole is relatively small.

As it is, the heart rate can be counted readily, but there is no rapid, simple method available for measuring stroke volume. However, the observation has been made that changes in energy demands from rest to work and during exercise caused relative changes of blood pressure quantitatively indicative of the simultaneously occurring changes of stroke volume⁽¹⁶⁾. Therefore, the heart rate and blood pressure pattern during the treadmill test revealed some clues about the hemodynamic response of the test subjects. It was assumed that the relatively diminished stroke volume in the case of myocardial insufficiency should be manifested by only a slight increase of the systolic pressure with increasing work intensities.

That such physiological conditions do exist was readily demonstrated in this patient. The initial test response (Figure 1) revealed that he possessed a low work capacity and that he had a sustained elevation of his diastolic pres-

sure. The response to work indicated that he raised the cardiac output by increasing both stroke volume and heart rate.

During the second test one would have expected to find evidence of an increased cardiac efficiency. Instead, the physiological adaptation to work was accomplished by a relatively rapid heart rate with only a minimal elevation of systolic pressure, suggesting the possibility of a heretofore unsuspected myocardial insufficiency. Its existence was confirmed by the elevated SGOT levels and the electrocardiogram. The clinical history and elevated pre-exercise SGOT indicated that the infarction had occurred before this second test.

Whether or not the physical training hastened the onset of or lessened the consequences of the infarct is not known. Some investigators have suggested that training may be advantageous in lessening the severity of a coronary occlusion by stimulating the development of increased collateral circulation. Eckstein⁽¹⁷⁾ demonstrated that exercise was a stimulus to increased coronary collateral circulation in dogs when relative coronary insufficiency had been surgically induced.

The course following the patient's uneventful recovery was quite remarkable. He volunteered to continue a training program. The systolic pressure response to low energy demands 2 and 7 weeks post-infarct (Figure 3) suggested a more efficient myocardium than was present during the second standard work capacity test. The added stimulation of physical training led to physiological effects similar to those seen in normal healthy individuals. These included a lower resting pulse rate, lowering of the blood pressure and greater cardiorespiratory efficiency. In the final standard work capacity test there was no way to differentiate his performance from that of a healthy individual, trained or untrained.

Several of the questions raised by the idea of physically training cardiac patients have been partly answered by this experiment. As suspected from an earlier report⁽¹⁵⁾, the uncomplicated asymptomatic, healed myocardial infarct patient does react to physical training in the same manner as normal individuals. In a well-supervised, gradually progressing training program the

patient will work well within his range of physiological capabilities. He should therefore benefit, not suffer from such a program. The effects of such a therapeutic approach are probably as much psychological as well as physiological. The improved physiological status should in itself promote an emotional climate of confidence and a state of well-being. It seems reasonable to conclude that if the coronary personality is characterized by a sense of striving for undefined goals and a state of chronic dissatisfaction⁽¹⁸⁾, then a program of physical competition might provide tangible, realizeable goals which, once achieved, would be satisfying. Such an approach seems more rational than the potentially demasculinizing regimens imposed on cardiac patients by long-term estrogen therapy.⁽¹⁹⁾

Whether or not patients treated in this manner will have greater longevity with fewer complications from their underlying disease than do other cardiac patients needs further study. We feel that longevity is just one of the problems. Is it not a more important consideration that the patient be able to have a fruitful, meaningful and comfortable existence while he is "living?"

SUMMARY

A 54 year old white male with hypertension, obesity and elevated serum cholesterol level volunteered for a physical training program. During the sixth week he became ill and a repeat work capacity test revealed physiological evidences of myocardial insufficiency. The pre-exercise SGOT was elevated. A routine ECG four hours later revealed evidence of an acute inferoseptal myocardial infarction.

The course of the disease was uneventful and uncomplicated. One month post-infarct the patient resumed a physical activity program which provided for a slow increase in metabolic demands compatible with his capacity. Repeat work capacity tests 20 and 23 weeks post-infarct showed that he responded to training in exactly the same manner as has been observed in normal, healthy individuals. At that time he was normotensive with a normal serum cholesterol

concentration and near-normal body weight. The capacity for adequate cardiorespiratory adjustments to high metabolic demands was rated as "good."

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