Physical Training in the Management of Coronary Artery Disease

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SUMMARY
The effects of 4 to 6 weeks' physical conditioning on the cardiovascular and respiratory response to exercise were studied in nine patients with coronary artery disease. Clinical improvement and increased physical working capacity were observed in all patients. The average cardiac output during exercise was unchanged. The stroke volume increased and the myocardial work, assessed by the tension-time index, decreased during exercise at a given work load. It is suggested that at submaximal work loads a reduction of the blood flow to the working muscles occurs after training. Such change might be fundamental for the altered circulatory regulation by allowing a reduced general sympathetic vasoconstriction during exercise. It is concluded that the hemodynamic changes form a rational physiologic basis for the use of physical training in the management of patients with coronary artery disease.

Additional Indexing Words:
Cardiac output Tension-time index Muscle blood flow

Within the last decade several investigators have demonstrated that physical conditioning programs have an incontestable beneficial effect on the majority of patients with coronary artery disease.1–10 When it is considered that the management of patients with angina pectoris presents an unsolved problem, it is astonishing that the use of this active therapeutic principle has not gained wider extension. The reserved attitude to a treatment which breaks with well-established concepts concerning the management of cardiac disorders is comprehensible, however, as so far no well-documented physiologic mechanism of the effect is given.11 It is still not practicable in man to get reliable information about eventual changes in the arteriosclerotic process or the myocardial vascularization induced by training similar to those demonstrated in animals.12,13 However, the results obtained by Varnauskas and associates7 and later by Frick and Katila10 suggested that the beneficial effect of training can be explained primarily by alterations in the hemodynamic

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response to exercise. Thus, this study was undertaken to elucidate further the hemodynamic reactions to exercise before and after conditioning training in patients with coronary artery disease.

**Materials**

Nine males with coronary artery disease (CAD), 34 to 61 years of age (mean, 52 years), volunteered for the physical training program. The informed consent of each patient was obtained. Clinical data are listed in table 1. All but one (J.C.) had moderate to severe angina pectoris on exertion, and eight had suffered from well-established myocardial infarction. None of the patients were in cardiac failure or had persistent rhythm disturbances. All of the patients had sedentary habits, and none of them had participated in athletic activities during the last 20 years. Four of the patients were actively employed (V.P., G.O., R.A., and H.B.). Two had retired from their occupation more than a year before the study because of cardiac disability (G.A. and K.A.). Due to severe exertional angina pectoris two patients (O.P. and O.B.) had been forced to give up their work immediately before they started the training. The last patient (J.C.) was convalescing after a myocardial infarction, which occurred 4 wk prior to the start of the training.

**Procedure and Methods**

Before training, the patients underwent a physical examination, and their working capacity was estimated by a preliminary bicycle ergometer test including exercise at several submaximal work loads with registration of the electrocardiogram (ECG) in the three standard limb leads and three precordial leads. At the same time the following clinical routine determinations, which were repeated after the training, were made:

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**Table 1**

<table>
<thead>
<tr>
<th>Subject</th>
<th>Occupation</th>
<th>Age (yr)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>History</th>
<th>Chest x-rays</th>
</tr>
</thead>
<tbody>
<tr>
<td>G.A.</td>
<td>Bus driver*</td>
<td>61</td>
<td>172</td>
<td>86.0</td>
<td>Infarct 10 mo before; angina for 10 mo</td>
<td>Heart slightly enlarged</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(84.0)†</td>
<td>(moderate)</td>
<td></td>
</tr>
<tr>
<td>O.P.</td>
<td>Workman</td>
<td>44</td>
<td>172</td>
<td>82.0</td>
<td>Angina for 7 yr</td>
<td>Heart slightly enlarged</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(82.0)</td>
<td>(severe)</td>
<td></td>
</tr>
<tr>
<td>V.P.</td>
<td>Typographer</td>
<td>54</td>
<td>178</td>
<td>78.6</td>
<td>Infarct 3 yr before; angina for 3 yr</td>
<td>Normal</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(78.0)</td>
<td>(moderate)</td>
<td></td>
</tr>
<tr>
<td>G.O.</td>
<td>Electrician</td>
<td>53</td>
<td>173</td>
<td>89.5</td>
<td>Infarct 2 yr before; angina for 2 yr</td>
<td>Normal</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(88.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K.A.</td>
<td>Workman*</td>
<td>57</td>
<td>174</td>
<td>96.1</td>
<td>2 previous infarcts (last 1 yr before);</td>
<td>Heart slightly enlarged</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(95.0)</td>
<td>angina for 3 yr (moderate)</td>
<td></td>
</tr>
<tr>
<td>R.A.</td>
<td>Janitor</td>
<td>58</td>
<td>180</td>
<td>87.5</td>
<td>Infarct 3 mo before; angina for 1 yr</td>
<td>Normal</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(86.0)</td>
<td>(moderate)</td>
<td></td>
</tr>
<tr>
<td>J.C.</td>
<td>Salesman</td>
<td>33</td>
<td>167</td>
<td>73.0</td>
<td>Infarct 4 wk before;</td>
<td>Normal</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(72.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O.B.</td>
<td>Toolmaker</td>
<td>59</td>
<td>164</td>
<td>70.0</td>
<td>Infarct 4 yr before; angina for 4 yr</td>
<td>Heart slightly enlarged</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(70.0)</td>
<td>(severe)</td>
<td></td>
</tr>
<tr>
<td>H.B.</td>
<td>Crane engineer</td>
<td>47</td>
<td>167</td>
<td>64.0</td>
<td>Infarct 8 yr before; angina for 6 yr</td>
<td>Normal</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(63.0)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* No longer active in occupation.
† Figures in parentheses are post-training values.
fasting values for hemoglobin, erythrocyte sedimentation rate, serum creatinine, serum transaminases (GOT and GPT), serum lactic acid dehydrogenase and cholesterol, chest x-ray, and respiratory function tests (determination of vital capacity, residual volume, maximal breathing capacity, and forced expiratory volume).

In two patients (R.A. and J.C.) the blood flow in the m. vastus lateralis was measured by the $^{133}$Xe-clearance method over during exercise at the same work load three times before and three times after the training program. The determinations, which were done on both legs simultaneously, were preceded by a 5 min warming-up period at the same work load which was to be used for the blood flow determination. The patient then rested for 5 min on the bicycle ergometer before 0.1 ml of $^{133}$Xe dissolved in saline was injected into the thickest part of the muscle. After an additional rest period (5 to 6 min) the patient started pedalling. The $^{133}$Xe clearance was registered by light-weight scintillation crystal detectors fixed to the thigh with adhesive tape. The detectors were connected to a logarithmic recording potentiometer (Meditronic, Inc., Copenhagen). The flow was calculated from the initial slope of the clearance curves. Only curves which were monoexponential for at least 80% of a decade were accepted.

To reduce the influence of methodological random error, anxiety caused by the test situation, and differences in motivation and to permit evaluation of eventual individual variations in the pattern of response, all exercise values were determined at least in duplicate before and after the training. Thus, determination of cardiac output, ventilation, oxygen uptake, heart rate, intra-arterial blood pressure, blood oxygen and carbon dioxide content, and lactic acid concentration at rest and during exercise were carried out at an interval of 3 to 6 days twice before and twice after the training program. These studies were performed in the morning. The patients were allowed a light breakfast prior to the investigation and received no premedication. Two polyethylene catheters were inserted percutaneously, one through an antecubital vein to the right atrium and another into the brachial artery. At the end of a 30-min rest period in the supine position expired air was collected during a 5 to 7-min period, in the middle of which arterial and mixed venous blood were simultaneously sampled. Immediately after this, cardiac output was determined by the dye-dilution method. The ECG was registered continuously during this procedure and intra-arterial blood pressure recorded several times in 60-sec periods. When these determinations were completed the patient mounted the bicycle ergometer for the exercise test which was performed in the sitting position. An individually predetermined work load was used which in the preliminary work test was found not to evoke angina pectoris before 10 to 15 min, in other words, the time needed to accomplish the examination. After 5 min of exercise the procedure described above was repeated in exactly the same way, except that the air-collection period was only 3 to 5 min and the ECG recording was extended to cover the warming-up period of exercise also. Each patient exercised on the same work load in all four examinations (two before training and two after training).

In the pretraining study two patients (O.B. and H.B.) were unable to perform exercise at steady-state conditions with indwelling catheters during the time needed to accomplish the examinations. Thus, this part of the investigation was also omitted after training in these patients. One patient (J.C.) developed prodromal symptoms of vasovagal syncope in the sitting position immediately after he had mounted the bicycle ergometer on both pretraining examinations. Normal blood pressures and subjective well-being were regained soon after the patient started exercising, but the increase in blood pressure during exercise was less pronounced on both occasions than it was during the post-training examinations.

An electrically braked bicycle ergometer was used (Elema-Schönander AN 368) for the exercise studies. Ventilation was measured by collection of expired air into Douglas bags through low resistance valves. Oxygen consumption and carbon dioxide elimination were calculated from oxygen and carbon dioxide content of expired air determined by a modified Haldane technic (Lloyd, Gallenkamp).

Cardiac output was measured by the dye-dilution technic with collection of 1-sec multiple samples of arterial blood into tubes with dry heparin by means of an automatic sampling apparatus after injection of 10 to 15 mg Evans blue (T-1824, Warner-Chilcott) in 3 ml of 5% human albumin saline solution through the venous catheter. The dye concentration in the blood samples was determined spectrophotometrically, and the cardiac output was calculated from the injected amount of dye and the area under the time-concentration curve.

The blood samples were analyzed for oxygen and carbon dioxide content by the manometric method of van Slyke; carbon dioxide tension was measured with a Severinghaus Pco$_2$ electrode (E. I. L.). Arterial concentrations of lactate were determined by an enzymatic method (Boehringer kit: TC-B no. 15972).
Arterial blood pressures were recorded using a pressure transducer (EMT 34, Elema-Schönander) coupled to a monograph 81, which also was used for the registration of ECGs. The heart rate was calculated from the ECG recordings every 60 sec for 30 sec.

The following values were computed from the above-mentioned parameters: peripheral vascular resistance, in mm Hg/L/min (arterial mean blood pressure divided by cardiac output); and tension-time index, in mm Hg sec/min (the area under the systolic brachial artery pressure curve multiplied by the heart rate17).

**Physical Training Program** (Table 2)

The patients came to the laboratory daily 5 days a week for 4 to 6 weeks for the conditioning training. This was performed on a mechanically braked bicycle ergometer18 as intermittent work,19 in other words, exercise periods of 3 to 5 min interrupted by rest periods of equal duration. The effective work time was 20 to 30 min corresponding to a total distance of 10 to 15 km. The work load was adjusted individually according to the working capacity of each patient. After a 5 min warming-up period at a moderate exercise level the patients worked on a load which they could tolerate for at least 3 min. As training progressed, exercise tolerance increased, and the resistance was then augmented in order to maintain approximately the same relative work load throughout the entire training program.

The training was supervised by a physician and a nurse. Resuscitation equipment was ready for use but was never needed. The patients were ordered to stop bicycling if chest pain occurred. The work was resumed only when pain had disappeared, eventually at a lower work load. Such interruptions were only necessary a few times and especially at the beginning of the training program. The attendance at the training was satisfactory; only on one occasion was a patient absent. No interference with the patients' general patterns of living was attempted apart from the training. No changes were made in dietary and smoking habits or medical treatment.

**Table 2**

<table>
<thead>
<tr>
<th>Subject</th>
<th>Days of training</th>
<th>Total work performed (kpm/100)</th>
<th>Work load (kpm/min)</th>
<th>Difference</th>
<th>Heart rate during training work</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Initial</td>
<td>Final</td>
<td>Kpm/min</td>
</tr>
<tr>
<td>G.A.</td>
<td>27</td>
<td>335.5</td>
<td>540</td>
<td>900</td>
<td>360</td>
</tr>
<tr>
<td>O.P.</td>
<td>27</td>
<td>175.9</td>
<td>360</td>
<td>470</td>
<td>110</td>
</tr>
<tr>
<td>V.P.</td>
<td>23</td>
<td>303.4</td>
<td>630</td>
<td>790</td>
<td>160</td>
</tr>
<tr>
<td>G.O.</td>
<td>19</td>
<td>207.4</td>
<td>576</td>
<td>720</td>
<td>144</td>
</tr>
<tr>
<td>K.A.</td>
<td>21</td>
<td>252.7</td>
<td>630</td>
<td>720</td>
<td>90</td>
</tr>
<tr>
<td>R.A.</td>
<td>25</td>
<td>696.6</td>
<td>810</td>
<td>990</td>
<td>180</td>
</tr>
<tr>
<td>J.C.</td>
<td>31</td>
<td>669.6</td>
<td>540</td>
<td>810</td>
<td>270</td>
</tr>
<tr>
<td>O.B.</td>
<td>23</td>
<td>155.3</td>
<td>360</td>
<td>430</td>
<td>70</td>
</tr>
<tr>
<td>H.B.</td>
<td>27</td>
<td>235.5</td>
<td>250</td>
<td>430</td>
<td>180</td>
</tr>
<tr>
<td>Mean</td>
<td>24.8</td>
<td>336.9</td>
<td>522</td>
<td>696</td>
<td>174</td>
</tr>
</tbody>
</table>

Clinical Results

No complications were seen during the training program. As stated in the introduction, the main concern of this investigation was to study the hemodynamic effects of training on patients with coronary artery disease (CAD). Attempts were not made to provide quantitation of the clinical effect in these few patients. However, beyond all doubt general subjective improvement and elevated threshold for precipitation of angina pectoris were observed in all patients. The best results occurred in the patients who had only moderate angina pectoris. They reported that they were practically free from attacks during their normal daily activity after the physical conditioning. The two patients who suffered from the most severe and frequent attacks when admitted to the laboratory had, after the training, increased exercise tolerance like the other patients, but they were not relieved of angina pectoris to the same extent. Nevertheless, one of these (O.P.), who had given up his work, is now back at work again. He no longer has attacks of chest pain at rest, and heavier work loads are needed to provoke pain during exercise. The other one (K.A.) suffered from severe attacks at rest as well as on exertion.

_Circulation, Volume XL, August 1969_
Table 3
Respiratory and Circulatory Parameters at Rest and During Exercise Before and After Physical Training

<table>
<thead>
<tr>
<th></th>
<th>At rest</th>
<th></th>
<th>During exercise</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean value</td>
<td>Difference* (%)</td>
<td>sp (%)</td>
<td>P value</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>-----------</td>
<td>----------------</td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td>Ventilation (L/min, BTPS)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxygen uptake (ml/min, STPD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiac output (L/min)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heart rate (beats/min)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brachial artery mean blood</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pressure (mm Hg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tension-time index (mm Hg sec/</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>min)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blood lactate (mEq/L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Difference (%) = mean of individual differences in per cent between pretraining and post-training values.
† ns = not significant = P > 0.05.
After the training he is still afflicted with severe attacks at rest, but he seldom has angina on exertion.

**Physical Working Capacity**

The maximal oxygen uptake was not measured directly. In the eight patients with angina pectoris the improvement in working capacity can be assessed by comparing the work loads used for the daily training at the beginning and at the end of the training program. The mean increase was 162 kpm/min (kilopound meters) or 34.4%. Individual values are listed in table 2. These work loads reflect in reality the maximal working capacity since the patients were unable to exercise more than 3 to 5 min at this level without having pain.

The heart rate at this "maximal" exercise level was essentially unchanged after training in six patients. In three patients (G.A., O.P., and V.P.) a significant increase amounting to 9 to 15 beats/min was seen ($P < 0.0025$). This increase in "maximal" heart rate, which could be due to altered attitude to cardiac pain caused by less anxiety, did not entirely account for the increased working capacity in these three patients. The work load which could be performed after training at their initial "maximal" heart rate increased an average of 147 kpm/min or 28.8%.* The patient who did not suffer from angina pectoris (J.C.) had a mean heart rate of 150 during training and the corresponding work load increased 235 kpm/min or 42%.

The work loads just below the threshold for angina pectoris have been converted into oxygen uptake per kilogram using the work efficiency measured in the cardiac output studies (mean value, 19%). The calculated initial group mean value ($N = 8$) was 16.0 ml O$_2$/kg/min; the final value was 21.2 ml O$_2$/kg/min. Thus, the difference was 5.2 ml or 32.5%.

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*If angina pectoris was not provoked, a linear relationship between work load and heart rate was seen both before and after training when the patients were tested at several submaximal work loads.

**Cardiac Output Studies**

The mean values of the duplicate determinations performed before and after training have been used for evaluation of the effect of the physical conditioning. The average values for the group for the most important respiratory and circulatory parameters registered at rest and during exercise, before and after the training, are given in table 3, and individual values appear in figures 1 through 5. The results from one patient (J.C.) are not included in the statistical calculations involving the blood pressure values due to the above-mentioned vasovagal reaction in the pretraining studies.

**Rest**

Only small changes were observed in the values obtained at rest in the supine position after the training compared with the same

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**Figure 1**

*Individual values for heart rate during exercise. Each point represents the mean of the double determinations performed before and after training.*

*Circulation, Volume XL, August 1969*
Effect of training on individual exercise values for cardiac output. The mean of the two values obtained after training is plotted against the mean of the two pretraining values. The line of identity is shown. The open circle represents the patient who developed a vasovagal attack before the exercise test.

Effect of training on individual exercise values for stroke volume. The mean of the two values obtained after training is plotted against the mean of the two pretraining values. The line of identity is shown. The open circle represents the patient who developed a vasovagal attack before the exercise test.

Effect of training on individual exercise values for tension-time index. The mean of the two values obtained after training is plotted against the mean of the two pretraining values. The line of identity is shown. The open circle represents the patient who developed a vasovagal attack before the exercise tests.

decrease in diastolic pressure from 78 to 73 mm Hg was not significant. The heart rate derived from the experiments with the indwelling catheters did not decrease significantly, but a decrement of 7.4% ($P < 0.005$)
was observed in the resting pulse rate registered in the sitting position before the daily training sessions.

**Submaximal Exercise**

The exercise oxygen uptake at a given work load was the same for the group after the conditioning, indicating that the work efficiency was not improved (table 3). A significant decrease in the pulmonary ventilation caused, therefore, a reduction of the daily training was not indicating in volume both in 1, great individual figure with the patients (O.P., (- when heart observed (table 3), great individual figure with the patients (O.P., (- when heart observed (table 3). An increase of the heart rate, registered synchronously with the cardiac output determination, decreased (table 3), but, as it appears from figure 1, great individual variations were observed when heart rate during the entire exercise period was considered. In some of the patients (O.P., V.P., G.O., and K.A.) the heart rate was only lower in the first 5 to 10 min. At the end of the exercise the pulse rate equalled the pretraining value.

The mean cardiac output for the whole group was unchanged for the same oxygen uptake (table 3). However the duplicate determinations made it possible to evaluate individual variations in the response to training. The standard deviation for the double determinations performed on different days was 6.1% and a change of the mean value exceeding 10% was considered statistically significant. In three patients differences of this magnitude were seen. In two (G.A. and R.A.) a significant reduction was found, and in one (O.P.) a significant increase (fig. 2).

The stroke volume, calculated from the cardiac output and the simultaneously recorded heart rate, was greater after training in all patients but one (G.A.) (table 3; fig. 3). It should be noted that in spite of the lower stroke volume this patient also had a clear reduction in heart rate after training (fig. 1). The brachial artery mean blood pressure decreased (table 3; fig. 4) due to a reduction in both systolic and diastolic blood pressure. The group average systolic blood pressure decreased from 173 to 155 mm Hg (P < 0.005); the corresponding diastolic pressures were 92 mm Hg and 79 mm Hg, respectively (P < 0.025). The calculated peripheral vascular resistance decrease averaged 14.9% (SD 9.6%; P < 0.01). The tension-time index was reduced significantly owing to the reduction in systolic blood pressure and the heart rate (table 3; fig. 5).

The oxygen and carbon dioxide content, the oxygen saturation, and the carbon dioxide tension in arterial blood were unchanged after training. The mean oxygen saturation for the whole group was higher during exercise than at rest (95.7% and 94.3%, respectively); whereas the carbon dioxide was lower (41.5 mm Hg and 42.8 mm Hg, respectively). The respiratory quotient (RQ) was lower at the same work load after the training (diff. 5.5%; SD 4.1%; P < 0.01). The lactate concentration in the arterial blood increased less during exercise following training (table 3).

**Other Measurements**

The muscle blood flow in the vastus lateralis decreased 21.1% at the same work load (P < 0.05). The mean value was 43.9 ml/100 g/min before and 34.2 ml/100 g/min after the training period. The standard error for the method has been calculated from 79 double determinations performed on 11 subjects. It was found to be 16.5%.

The ECG at rest was normal in three patients. The remaining six patients had changes indicating coronary insufficiency. Abnormal patterns during or after exercise, or both, were seen in all patients but one. The ECG registered after training was essentially unchanged. The most clear-cut difference seen after training was the complete disappearance of ventricular ectopic beats in two patients who exhibited frequent series of extrasystoles during exercise before the training period.

The respiratory function tests and the chest x-ray did not show any differences. The same was true for the blood hemoglobin concentration (mean value, 13.9 g/100 ml), the sedimentation rate, the serum creatinine concentration, and the serum transaminases and...
lactic-acid-dehydrogenase, which were all normal before the training. The serum cholesterol concentration was significantly lower in the post-training determination (mean value, 285 mg% before and 250 mg% after) \( (P < 0.0025) \). A moderate weight reduction was seen in seven of the nine patients (mean difference, 1 kg; \( P < 0.005 \)).

Discussion

This study supports the previous experience that marked improvement in subjective well-being and reduced frequency of angina pectoris can be obtained in patients with CAD by means of physical conditioning.\(^1\)\(^-\)^\(^10\) Before the significance of the hemodynamic changes in this effect are evaluated, it should be realized that these patients are highly susceptible to the psychotherapeutic aspects of the management. It has been demonstrated, however, that increased physical activity is an indispensable condition for the improvement.\(^1\),\(^3\),\(^4\) This indicates that the psychologic factor probably is closely connected to the patient's recognition of the harmlessness of physical effort and to increased self-confidence caused by enhanced exercise tolerance. Beyond all doubt a considerable increase in exercise tolerance was obtained in this investigation, although only a rough quantitative estimation of the extent was possible. The augmentation in maximal working capacity expressed in oxygen uptake (5.2 ml/kg/min) corresponds well with the results obtained in other investigations involving training of healthy persons.\(^20\)-\(^22\) The percentage increment (32.5%) is higher in these patients than the values normally found in healthy subjects (10 to 20%). This is due to the very low initial values observed in our patients.

The physical working capacity of patients with coronary artery disease (CAD) is most often subnormal even when symptoms of cardiac failure are not present.\(^23\),\(^24\) This could be exclusively the result of impaired cardiac function related to myocardial fibrosis.\(^20\),\(^26\) The results obtained in this and in previous investigations show, however, that cardiac patients are able to improve their physical performance by training despite the impaired cardiac response to exercise. The very low initial values for maximal working capacity are, therefore, partly the result of inactivity.

The tension-time index was derived from the brachial artery systolic pressure curve. Considerable differences between the peak systolic pressure in the ascending aorta and peripheral arteries have been observed. It is justifiable, however, to evaluate left ventricular pressure work by means of the brachial artery curve because the areas beneath the central and peripheral curves are almost identical.\(^27\) The tension-time index is considered to be correlated to myocardial oxygen uptake\(^27\) and it has been demonstrated that the precipitation of angina occurs at a fixed level of the tension-time index in each patient.\(^28\) This seems to indicate the existence of a specific critical value for myocardial oxygen uptake in the individual, and thus for myocardial perfusion,\(^29\) which cannot be exceeded without concomitant inducement of regional ischemia in the myocardium in these patients. In the present study the tension-time index decreased following the training. This finding supports the results from one earlier study where this parameter was directly measured.\(^10\) It seems natural to relate the reduced frequency of angina pectoris to this reduction of the tension-time index at a given work load. The finding that after training higher work loads are tolerated before angina pectoris occurs does not necessarily mean that the blood supply to some areas of the myocardium is improved by enhanced development of collateral circulation. The less pronounced increase in heart rate and systolic blood pressure during exercise (in other words, change in the relation between the work of the myocardium and the total work carried out by the patient) may explain the changed threshold for cardiac pain.

The stroke volume has been measured before and after training in patients with CAD in two earlier investigations,\(^7\),\(^10\) and in only one of them did an increase of the stroke volume occur.\(^10\) The results presented here
confirm that it is possible in some cardiac patients to improve the pump function of the heart by training. The changes in heart rate during the exercise period (fig. 1) suggest, however, that in some cases the greater stroke volume could be preserved only for shorter periods. Moreover the increased stroke volume does not inevitably involve an enhanced myocardial contractility but might be secondary to the decreased total peripheral resistance (in other words, less load resisting shortening). 25

The exercise cardiac output changes showed individual variations. It is especially interesting that there was a significant decrease in the cardiac output for a given oxygen uptake in two patients (G.A. and R.A.). The same tendency was seen in one other patient (J.C.). Varnauskas and associates 7 found a significant decrease in cardiac output during exercise after training in six patients with CAD, and similar reduction has been observed in sedentary normal persons, 21 22 30 athletes, 30-32 and patients without cardiac disorders. 33 34 In all these investigations the exercise was performed in the upright position. The decrease in cardiac output for a given oxygen uptake involves an increase of the arteriovenous oxygen difference, and this has been ascribed to a redistribution of blood flow from other tissues to the working muscles. 7 21 33 It has been suggested that after training the perfusion of the exercising muscles was favored by a more pronounced restriction of splanchnic and renal blood flow. However, it is clearly demonstrated that the decrease in the splanchnic and renal blood flow during exercise is less pronounced in trained than in untrained persons, 35-38 and the same differences probably exist for the perfusion of other nonexercising tissues supplied by sympathetic vasoconstrictor nerves. Thus, as blood flow to nonexercising tissues is relatively increased, it can be deduced that the reduction in cardiac output at submaximal work loads takes place in the working muscles. This inference finds support in data from the literature relating muscle blood flow to training. 39 40 Furthermore, our observation of a reduction in muscle perfusion at a given submaximal exercise level after training is affirmative, although by no means conclusive, since muscle blood flow was only measured in two of the patients. As total oxygen uptake was unchanged, the diminished muscle perfusion implies increased oxygen extraction capacity in the muscle cells. This is in accordance with the finding that Po2 in venous blood from working muscles can be decreased to lower values after training. 41 42 An explanation might be that training causes alterations in the biochemical composition of the muscle fibers. 43 It has been demonstrated that the capacity of the mitochondrial enzymatic systems in animal muscles can be doubled by strenuous training. 44 If similar changes also occur in human muscle, this could explain the increased ability for oxidative metabolism after training, reflected in the lower blood lactate values and lower respiratory quotients during exercise. Exercise hyperemia is supposed to be mediated by metabolically linked vasoactive chemicals. 45 Increased oxidative capacity might limit the release of such vasodilator metabolites from the muscle cells and thus cause reduced perfusion.

If a decrease of blood flow in the working muscles is a basic effect of training, an augmentation of the flow to the nonworking tissues occurred in patients who did not exhibit a decrement in cardiac output. An acceptable explanation for this phenomenon is available when it is considered that patients with CAD generally have subnormal values for stroke volume and cardiac output for a given oxygen consumption. 7 23 24 As a consequence, a more pronounced restriction of the flow to nonworking tissues, effected by an abnormally steep rise of the general sympathetic vasoconstrictive tone, is needed at a given work load, to provide a sufficient blood supply to the working muscles. 46 The same circulatory regulation pattern is seen after rest in bed 42 and is extremely marked in patients with mitral stenosis. 47 If the same work can be performed after physical conditioning with lower muscle blood flow, a reduction of the sympathetic tone, and thus of the peripheral
resistance, is possible. Hereby a more adequate perfusion of the nonexercising tissues could be obtained.

These individual variations in the circulatory adaptation to exercise, which depend on the patient’s initial condition and ability to react to the training, do not interfere with the changes which, in all likelihood, are essential for the beneficial effect of training on symptoms related to CAD. A lower heart rate and systolic blood pressure causing a reduction in myocardial work was seen in all the patients. The same is true for the increase in physical working capacity and the respiratory changes, which cause a more effective pulmonary function. On the basis of our own findings and the results from two previous investigations,7-10 we conclude that physical training has a rational physiologic basis in the management of coronary artery disease. In contrast to what is seen in young healthy persons,42 the training does not directly improve the cardiac performance in many of these patients but causes alteration of the peripheral circulatory regulation.

References


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