Effect of Exercise on Coronary Tree Size in the Rat

By James A. F. Stevenson, M.D., Vera Feleki, Peter Rechnitzer, M.D., and John R. Beaton, Ph.D.

It has been proposed by some that lack of physical exercise may be an important factor in the occurrence of coronary inadequacy of various types. Recently, Tepperman and Pearlman developed a technique for estimating the size of the coronary tree in the rat from the weight of a vinyl acetate cast of the tree. Using this technique they observed that swimming for a period of 30 minutes twice daily caused a significant increase in coronary-cast weight and a cardiac hypertrophy of borderline significance in rats.1 Our experiments were done to investigate this subject further and to ascertain the effects on coronary tree size of exercise of different types, frequency, and duration.

Methods

In all our experiments, male rats of the Sprague-Dawley strain were housed in individual, screen bottomed cages and maintained in a temperature-controlled room at 23 ± 1°C except during periods of exercise when they were brought to the exercise room at approximately the same temperature. Control rats remained in the temperature-controlled room during exercise periods. Except where indicated otherwise, Purina laboratory chow and water were provided ad libitum. The rats were exercised either on a motor-driven treadmill turning at 15 rev/min (10.5 m/min) or by having the animals swim in a tank of water at 30°C. After swimming, the rats were dried and replaced in their cages.

For preparation of vinyl casts of the coronary tree the method of Tepperman and Pearlman was followed precisely as described.1 Heart and cast weights were measured on a Cahn electromagnetic balance; coronary cast weights were measured to the nearest 0.01 mg. The original authors1 have discussed possible errors due to differences in vinyl acetate perfusion pressures among animals. As they did, we minimized these possible errors by performing “blind” experiments to randomize differences in technique among experimental groups, i.e., the operator did not know to which experimental group any animal belonged until after the coronary casts had been prepared and weighed.

Results

COMPARISON OF EFFECTS OF CONTINUOUS AND INTERMITTENT EXERCISE (TREADMILL) ON THE SIZE OF THE CORONARY TREE

Twenty-four rats having an initial average body weight of 215 g were divided into four groups of six rats each and treated as follows: Group I: controls, standard cages, no enforced exercise; Group II: treadmill exercise (1.3 km/day) twice a week for four weeks, (one rat died during the experiment); Group III: treadmill exercise (1.3 km/day) five days a week for two weeks, followed by two weeks without enforced exercise; Group IV: treadmill exercise (1.3 km/day) five days a week for four weeks.

The results of this experiment are shown in figure 1 and table 1. It can be seen that exercise twice a week resulted in a significant increase in the weight of the coronary cast relative to the heart weight, an indication of the size of the coronary tree relative to the muscle mass that it supplies. On the other hand, strenuous exercise five days a week for four weeks did not result in any significant increase in the relative size of the coronary tree, nor did exercise five days a week for two weeks followed by two weeks of rest.

EFFECT OF INTERMITTENT EXERCISE (TREADMILL) AND DEPRIVATION OF FOOD ON THE SIZE OF THE CORONARY TREE

Eighteen rats having an initial average body weight of 240 g were divided into three groups
of six rats each and treated as follows: Group I: treadmill (1.3 km/day) twice a week for three weeks, food ad libitum throughout; Group II: treadmill (1.3 km/day) twice a week for three weeks with deprivation of food for 24 hours before each exercise; Group III: no enforced exercise but deprived of food for same period as Group II.

As shown in table 2 intermittent forced exercise only twice a week caused a maintenance, or increase, of the size of the coronary tree even in the face of intermittent starvation. In this experiment the effect of muscular exercise on the coronary circulation is well demonstrated, for the variations in body size, heart weight, and heart/body weight ratio among the groups are not statistically significant and, indeed, are very small. It is also apparent that the exercise does not need to occur every day to have this effect.

**EFFECT OF MODERATE REGULAR SWIMMING EXERCISE ON THE SIZE OF THE CORONARY TREE**

In this experiment the effect of constant and intermittent swimming at regular intervals on the size of the coronary tree was determined in 24 rats that weighed approximately 240 g at the beginning of the experiment. They were divided into four groups of six rats each and treated as follows: Group I: controls, no swimming; Group II: constant swimming (60...
TABLE 2

Effect of Intermittent Exercise (treadmill) on the Size of the Coronary Tree

<table>
<thead>
<tr>
<th>Group</th>
<th>No. of animals</th>
<th>Body weight (g)</th>
<th>Heart weight (g)</th>
<th>Heart/body weight</th>
<th>Cast weight (mg)</th>
<th>Cast/heart weight (mg/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-I Exercised; fed ad libitum</td>
<td>6</td>
<td>415 ± 14.27</td>
<td>1.34 ± 0.077</td>
<td>0.32 ± 0.011</td>
<td>3.75 ± 0.17</td>
<td>2.83 ± 0.11</td>
</tr>
<tr>
<td>B-II Exercised; 24 hr fast prior to exercise</td>
<td>6</td>
<td>398 ± 12.24</td>
<td>1.25 ± 0.083</td>
<td>0.32 ± 0.014</td>
<td>3.38 ± 0.014</td>
<td>2.74 ± 0.29</td>
</tr>
<tr>
<td>B-III Not exercised; 24 hr fast as with II</td>
<td>6</td>
<td>407 ± 7.83</td>
<td>1.38 ± 0.058</td>
<td>0.34 ± 0.010</td>
<td>2.30 ± 0.043</td>
<td>1.69 ± 0.35</td>
</tr>
</tbody>
</table>

Results expressed as mean ± standard error of the mean.

*P < 0.02 as compared with Group III.
†P < 0.05 as compared with Group III.

min/day) five days a week for four weeks; Group III: intermittent swimming (60 min/day) five days a week for four weeks; Group IV: constant swimming (60 min/day) twice a week for four weeks.

In the "constant swimming" groups the animals had to swim constantly while in the tank, whereas in the "intermittent swimming" group there was a ledge on which they could place their forepaws to rest. In the latter group, most of the animals spent the majority of their time resting. All animals were fed ad libitum throughout. As shown in table 3, the relative sizes of the coronary trees were greater in all the groups that swam, but the increase was significant only in the two groups exposed to the constant swimming. These results would indicate that swimming twice a week causes as great an increase in the size of the coronary tree as does swimming five days each week.

EFFECT OF CONTINUOUS SEVERE EXERCISE (SWIMMING) ON THE SIZE OF THE CORONARY TREE

Twenty-four rats having an initial average body weight of 268 g were divided into four groups of six rats each and treated as follows: Group I: controls, no swimming; Group II: swimming four days a week for four weeks (30 minutes in the morning and 30 minutes in the afternoon); Group III: swimming four days a week for four weeks (one hour in the morning and one hour in the afternoon); Group IV: swimming four days a week for four weeks (two hours in the morning and

TABLE 3

Effect of Moderate Regular Exercise (swimming) on the Size of the Coronary Tree

<table>
<thead>
<tr>
<th>Group</th>
<th>No. of animals</th>
<th>Body weight (g)</th>
<th>Heart weight (g)</th>
<th>Heart/body weight</th>
<th>Cast weight (mg)</th>
<th>Cast/heart weight (mg/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-I Controls; no swimming</td>
<td>6</td>
<td>370.3 ± 9.79</td>
<td>1.47 ± 0.050</td>
<td>0.40 ± 0.020</td>
<td>3.37 ± 0.40</td>
<td>2.31 ± 0.26</td>
</tr>
<tr>
<td>C-II Constant swimming; 60 min, 5 days/wk</td>
<td>6</td>
<td>344.8 ± 10.94</td>
<td>1.43 ± 0.087</td>
<td>0.41 ± 0.018</td>
<td>4.29 ± 0.28</td>
<td>3.00 ± 0.048</td>
</tr>
<tr>
<td>C-III Intermittent swimming; 60 min, 5 days/wk</td>
<td>6</td>
<td>329.8 ± 13.59†</td>
<td>1.44 ± 0.080</td>
<td>0.43 ± 0.018</td>
<td>4.07 ± 0.19</td>
<td>2.88 ± 0.23</td>
</tr>
<tr>
<td>C-IV Constant swimming; 60 min, 2 days/wk</td>
<td>6</td>
<td>329.7 ± 4.61*</td>
<td>1.42 ± 0.051</td>
<td>0.44 ± 0.018</td>
<td>4.33 ± 0.24</td>
<td>3.04 ± 0.14†</td>
</tr>
</tbody>
</table>

Results expressed as mean ± standard error of the mean.

* P < 0.01.
†P < 0.05.
two hours in the afternoon), (one rat died during experiment).

These animals swam constantly while in the tank. Changes in body weights of all groups are shown in figure 2. All swimming groups lost weight, the loss being approximately proportional to the amount of swimming. As shown in table 4, the relative size of the coronary tree was increased in all groups that swam but this increase attained statistical significance only in the group forced to swim two hours per day, although the rats that swam four hours per day had a significant cardiac hypertrophy relative to body weight ($P < 0.05$).

### Discussion

In agreement with the earlier observation of Tepperman and Pearlman, we have found that, under certain circumstances at least, enforced physical exercise leads to an increase in the apparent size of the coronary tree as measured by the vinyl acetate corrosion-cast technique. Those authors have discussed the possible importance of the gross size of the coronary tree in adaptation of the heart to exercise and in the development of coronary thrombosis.

Although there was no evidence of significant increases in absolute heart weight with the exercises used in our experiments, we

### Table 4

<table>
<thead>
<tr>
<th>Group</th>
<th>No. of animals</th>
<th>Body weight</th>
<th>Heart weight</th>
<th>Heart/body weight</th>
<th>Cast weight</th>
<th>Cast/heart weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$g$</td>
<td>$g$</td>
<td>$mg$</td>
<td>$mg$</td>
<td>$mg/g$</td>
</tr>
<tr>
<td>D-I Control</td>
<td>6</td>
<td>344 ± 2.60</td>
<td>1.23 ± 0.050</td>
<td>0.36 ± 0.014</td>
<td>3.58 ± 0.15</td>
<td>2.92 ± 0.13</td>
</tr>
<tr>
<td>D-II 1 hour swimming/day</td>
<td>6</td>
<td>315 ± 13.68</td>
<td>1.19 ± 0.073</td>
<td>0.38 ± 0.017</td>
<td>3.69 ± 0.31</td>
<td>3.15 ± 0.27</td>
</tr>
<tr>
<td>D-III 2 hours swimming/day</td>
<td>6</td>
<td>300 ± 8.72*</td>
<td>1.19 ± 0.074</td>
<td>0.40 ± 0.024</td>
<td>4.31 ± 0.21</td>
<td>3.68 ± 0.28</td>
</tr>
<tr>
<td>D-IV 4 hours swimming/day</td>
<td>5</td>
<td>303 ± 12.16</td>
<td>1.28 ± 0.087</td>
<td>0.42 ± 0.019</td>
<td>4.06 ± 0.34</td>
<td>3.29 ± 0.35</td>
</tr>
</tbody>
</table>

Results expressed as mean ± standard error of the mean.

* $P < 0.001$.
† $P < 0.02$.
‡ $P < 0.05$.
§ $P < 0.01$.
observed increases in the cast weight/heart weight ratios; increases in the absolute coronary cast weight were usually not significant. This suggests that the primary effect was an increase of vascularization per unit mass of myocardium. From the results of the various experiments it is apparent that coronary tree size is not simply dependent upon change in total heart size but is, at least in part, related to the state of anabolism of the body as a whole during the total period of exercise. This relation is demonstrated in figure 3 where the differences at the end of the experiment in mean body weight of each exercised group and its respective control group are plotted against the difference in the mean coronary cast weight/heart weight ratio for the same groups. All but two of the exercised groups failed to gain weight as well as their controls, whereas all showed some increase in the cast/heart weight ratio; the greater the failure to gain weight, the smaller the increase in cast/heart weight ratio tended to be ($r = 0.81 \pm 0.11$).

In general, the heavier and the more frequent the enforced exercise, the poorer were the gain of body weight and the increase in relative coronary cast size. Moderate and relatively infrequent exercise (treadmill or swimming twice weekly) caused a significant increase in coronary cast/heart weight and this increase of apparent coronary tree size occurred even in the face of intermittent starvation. Under conditions of frequent exercise (treadmill five times weekly) and very strenuous exercise (swimming four hours a day, four times weekly), a significant increase in relative coronary tree size did not occur. It should be remembered that the rat living in an individual cage is not inactive and shows evidence of a fair degree of activity although the intensity and duration are spontaneously chosen.

The conclusions to be drawn from these investigations of the effect of exercise on the coronary circulation may seem obvious. It appears that, in the rat at least, physical exercise if not too strenuous or continuous causes an increase in the relative size of the coronary tree. It is realized, however, that there is not necessarily a relation between blood flow in vivo and the size of the coronary cast. Application of these results to other species and to other situations must be treated with reservations. For example, Tepperman and Pearlman did not demonstrate an effect of exercise on coronary cast weight in guinea pigs exercised on a treadmill, although right-to-left anastomoses of the coronaries were observed in these animals, which may be an even more important adaptation. Our results support the view that moderate exercise with adequate rest may benefit the heart more than heavy frequent exercise.

Summary

Using the vinyl acetate corrosion cast technique devised by Tepperman and Pearlman, it has been demonstrated that, in the rat, forced physical exercise (treadmill or swimming) causes an increase in apparent coronary tree size provided the exercise is not too strenuous or frequent.

References

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