Studies on the Effect of Exercise on Cardiovascular Function

II. The Blood Pressure and Pulse Rate

By Robert S. Fraser, M.D., and Carleton B. Chapman, M.D.

Attempts to follow changes in blood pressure induced by exercise, using indirect sphygmomanometry, have yielded conflicting results. In the following study, blood pressure measurements were made at rest (standing), during a standard treadmill work load, and during a six-minute recovery period, using a direct method and a suitably damped recording system. It was found that during exercise systolic pressure rises and that diastolic pressure falls, the net result being very little change in the mean pressure. In some subjects there is a secondary rise in all three items between 10 and 30 seconds after cessation of exercise. Changes in pulse rate during exercise and recovery are also discussed.

A NUMBER of authors have drawn attention to the difficulty of measuring the changes in blood pressure which take place immediately after the cessation of exercise in man. It is well known that rapid fluctuations may occur in the first 15 seconds of recovery, a situation which makes measurement of blood pressure impossible by ordinary sphygmomanometric means. The error introduced by use of indirect measurement of blood pressure during and after exercise has recently been studied by Henschel and colleagues. Partly because of these difficulties a number of conflicting reports have appeared, and these have been reviewed by Nielsen, Simonson and Enger and Glaser.

Numerous reports are available concerning changes in pressure during exercise, and it is generally agreed that systolic pressure increases. There is less agreement concerning corresponding changes in diastolic pressure. In a study on eight subjects, bicycled at various rates, Christensen found that systolic pressure increased, reaching a constant level by the end of five minutes of exercise, and that diastolic pressure also showed increases which ranged from 13 to 38 per cent depending on the rate of work. Simonson and Enger stated that diastolic pressure remains constant or increases slightly during exercise; others have reported that it shows no change.

In spite of the difficulty in recording rapid changes in blood pressure during recovery from exercise with the mercury manometer some workers have made such observations. On the strength of such data, Barringer set up criteria of normality based on the time taken by the blood pressure to return to the resting level. Bruce and colleagues recorded the blood pressure in normal subjects 10 times during a nine-minute recovery period which followed a walk on a treadmill for 10 minutes at 2.6 miles per hour. They noted little change between the resting and recovery pressures, and no significant difference between responses of men and women. Stevenson and others found a reduction in diastolic pressures at two, three and five minutes after cessation of exercise. Return of both systolic and diastolic pressures to pre-exercise values generally did not occur until the tenth minute of recovery although systolic pressures were close to the resting values at the fifth minute. Similar reductions in diastolic pressures have been noted by others, as reviewed by Glaser. In a study of the effect of exercise on blood pressure in undernourished and subsequently well-nourished civilians in German prison camps, Glaser

From the Department of Medicine and the Variety Club Heart Hospital, University of Minnesota, Minneapolis, Minn.

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found both increases and decreases in diastolic pressure during recovery from stair climbing. He concluded that there was no diagnostic value to blood pressure measurements after exercise.

Recently, blood pressure changes during exercise have been measured intra-arterially by Eskildsen and co-workers, who concluded, on the basis of 20 experiments performed with this much more exact technic, that: (1) systolic pressure rises rapidly after the start of work; (2) systolic pressure falls rapidly immediately after cessation of work, then more slowly, reaching values which are sometimes below the resting ones by the fourth or fifth minute; and (3) diastolic pressure varies little, but may follow the systolic changes on a minor scale.

Changes in pulse rate with exercise have been studied by many workers in an attempt to relate the increase in pulse rate during exercise and the time taken for it to return to resting levels, on the one hand, and the cardiac status, on the other. In normal subjects the pulse rate quickly reaches a plateau during steady work. It has been shown that the pulse rate not only increases more, but also takes longer to return to resting levels in anxious and "preoccupied" subjects than in normal ones. In a small number of normal subjects, Biering found that the pulse rate increased in a linear manner with increase in work and decreased during recovery to a constant level somewhat above the resting rate. He further stated that in normal persons the pulse rate during recovery never fell below the resting rate.

Use of a treadmill to provide a standard work load, and of intra-arterial pressure recording in order to follow rapid changes in blood pressure, offers means of overcoming the difficulties encountered in some of the previous studies. The following investigation, embodying these two technical features, was undertaken in the hope of resolving some of the confusion that now exists in this important area.

Methods and Materials

Subjects were divided into three groups: 11 young women, aged 22 to 30; 19 young men, aged 18 to 39; 11 older men, aged 40 to 57 years. All subjects were in good health and gave no history of cardiovascular disease. All were fasting.

The recording system consisted of a polyethylene catheter (inside diameter, 0.58 mm.; outside diameter 0.96 mm.) connected by a 22 gauge needle, an orifice damping device (a modified 23 gauge needle), and a three-way stopcock to a Statham strain gauge (0 to 75 cm. Hg). Impulses were recorded on a Sanborn Polyviso recorder. The damping device was so adjusted that the system provided a flat frequency response to 19 cycles per second.

The catheter was inserted into the brachial artery through a thin-walled 18 gauge needle and was then connected to the other parts of the system described above. The catheter was kept filled with heparinized saline which was introduced, when necessary, from a pressure system. The resting blood pressure was recorded while the subject stood quietly on a motor-driven treadmill. The subject then walked on the treadmill at 3 miles per hour on a simulated grade of 5 per cent for 10 minutes. At the end of this time, the subject having reached a steady state, a second recording was made for 30 seconds with the exercise continuing. The treadmill was then stopped and a continuous record was made for one minute after cessation of exercise. Recordings were made for the first 20 seconds of each subsequent minute for a total of five minutes.

Each blood pressure tracing was calibrated by introducing known pressures with a mercury manometer. Systolic and diastolic pressures were measured, covering one or more respiratory cycles, in each portion of the tracing except that taken during the first minute of recovery. Complexes recorded during that time were measured throughout each five-second interval for the first 30 seconds and each 10-second interval for the second 30 seconds.

Mean pressures were obtained by electric integration and recorded on a second channel at the same time that the pulse contour tracing was being recorded. Comparison of mean pressures obtained by electric, with those obtained by planimetric, integration showed that both methods gave substantially the same result.

Discussion

Blood pressure changes during exercise and recovery for each of the groups of subjects, expressed as per cent change from resting values, are shown in figures 1, 2, and 3. Values for the fourth, fifth, and sixth minutes did not differ significantly from those recorded at the beginning of the third minute and are not included in these figures. The average absolute blood pressures are given in table 1. Continuous pressure recordings were obtained.
throughout the first minute of recovery in only seven of the group of younger men (fig. 1); pressures during exercise and at the beginning of each minute, after the first minute, were obtained for all 19 young men, and the mean values for the whole group for those times do not differ from the mean values for the seven subjects (which are used in the construction of fig. 1).

Changes during exercise were similar in each group. There was a rise in systolic pressure and a fall in diastolic pressure. Both changes were statistically significant. The mean pressure showed little change from resting values in any group.

During the first minute of recovery in both the younger and older men there was an immediate and significant fall in systolic pressure by the 6 to 10-second point. In contrast the systolic pressure in the young women fell gradually until the end of the first minute. A second significant rise in systolic pressure occurred between 10 and 30 seconds in the older men but not in the younger men.

In each of the three groups the diastolic pressure slowly rose and by the end of the first minute had risen to the resting level or exceeded it. In the group of older men the rise above the resting level attained statistical significance.

The mean pressure fell to a statistically significant degree during the first 10 seconds of recovery in both the younger and older men. There was no significant change in mean pressure during this time in the young women, but a significant increase in mean pressure occurred between 10 and 50 seconds in both the young women and older men.

By the beginning of the sixth minute the systolic pressure was practically the same as the resting value in the older men and only slightly less than the resting values in the younger men and young women; in each group the diastolic pressure exceeded the resting value at this point. The mean pressures in each
EXERCISE AND CARDIOVASCULAR FUNCTION. II

TABLE 1.—Average Systolic, Diastolic, and Mean Blood Pressures in Normal Subjects at Rest, during and after Exercise

<table>
<thead>
<tr>
<th></th>
<th>Rest</th>
<th>Exercise</th>
<th>Seconds after exercise</th>
<th>Minutes after exercise</th>
</tr>
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<tr>
<td></td>
<td></td>
<td></td>
<td>0-5</td>
<td>6-10</td>
</tr>
<tr>
<td>Younger men</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Syst. mean</td>
<td>117.8</td>
<td>132.4</td>
<td>133.8</td>
<td>123.4</td>
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<tr>
<td>SD</td>
<td>10</td>
<td>19</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Diast. mean</td>
<td>74.2</td>
<td>67.0</td>
<td>71.2</td>
<td>68.6</td>
</tr>
<tr>
<td>SD</td>
<td>11</td>
<td>11</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>Mean mean</td>
<td>90.9</td>
<td>89.3</td>
<td>91.3</td>
<td>87.5</td>
</tr>
<tr>
<td>SD</td>
<td>8</td>
<td>15</td>
<td>15</td>
<td>7</td>
</tr>
<tr>
<td>Older men</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Syst. mean</td>
<td>123.4</td>
<td>141.5</td>
<td>139.2</td>
<td>125.9</td>
</tr>
<tr>
<td>SD</td>
<td>17</td>
<td>17</td>
<td>18</td>
<td>20</td>
</tr>
<tr>
<td>Diast. mean</td>
<td>76.1</td>
<td>69.4</td>
<td>72.9</td>
<td>70.4</td>
</tr>
<tr>
<td>SD</td>
<td>9</td>
<td>6</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Mean mean</td>
<td>94.8</td>
<td>94.7</td>
<td>95.0</td>
<td>89.8</td>
</tr>
<tr>
<td>SD</td>
<td>13</td>
<td>11</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>Young women</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Syst. mean</td>
<td>115.5</td>
<td>128.6</td>
<td>130.1</td>
<td>127.1</td>
</tr>
<tr>
<td>SD</td>
<td>9</td>
<td>12</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>Diast. mean</td>
<td>71.5</td>
<td>64.4</td>
<td>70.1</td>
<td>69.2</td>
</tr>
<tr>
<td>SD</td>
<td>5</td>
<td>7</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>Mean mean</td>
<td>87.5</td>
<td>86.1</td>
<td>91.4</td>
<td>89.2</td>
</tr>
<tr>
<td>SD</td>
<td>6</td>
<td>8</td>
<td>14</td>
<td>10</td>
</tr>
</tbody>
</table>

group closely approached the resting value.

Considerable variation was noted in the pattern of blood pressure response in individual subjects. The most consistent change was a rise in systolic pressure during exercise which occurred in all but two subjects; the next most consistent item was a fall in diastolic pressure at the same time (37 of 41 subjects). Other changes varied more between individuals. In two male subjects, 27 and 45 years old, the systolic, diastolic and mean pressures all fell below their respective resting values for the whole period of recovery. In the man aged 45 even the exercise values were less than the resting ones.

It has been suggested in the past that satisfactory mean pressures can be calculated by halving the sum of the diastolic and systolic pressures. It is apparent from the blood pressure graphs presented (figs. 1, 2, and 3) that this method provides misleading values. At one point, the per cent change for mean pressure exceeds both diastolic and systolic per cent changes, and at other points it shows less change than either. This observation indicates that the mean pressure does not bear a fixed relationship to the systolic and diastolic pressures under changing conditions of exercise. Examination of blood pressure tracings from these subjects revealed well-marked changes from time to time in the contour of the pulse pressure waves, and the broader the pressure wave becomes (the systolic and diastolic remaining unchanged), the higher the true mean pressure. This change in mean pressure passes unnoticed if only the systolic and diastolic pressures are used for the calculation. It thus becomes obvious that the true mean pressure is not synonymous with the average pressure and, indeed, bears no fixed relationship to it under varying hemodynamic conditions.

The average increase in pulse rate during and after exercise followed much the same pattern in each of the groups. In the women there was a secondary increase in pulse rate recorded at the beginning of the third and fourth minutes after exercise, but at six minutes the average rates in all three groups were 15 to 23 per cent above resting values. The latter observation confirms Bierring's finding in normal subjects.11

We interpret these changes to mean that exercise induces a net decrease in peripheral
resistance as well as an increase in cardiac output, measurements of which have recently been reported. Presumably the vascular bed in the voluntary muscles is enormously expanded, while that in other regions, such as the splanchnic area, is unchanged or even constricted. The net result is that mean arterial pressure changes vary little, since the alterations in systolic and diastolic pressures are opposite in direction. The physiologic significance of the pressure changes during recovery are poorly understood but undoubtedly complex. The possibility that the secondary, or "rebound," rise in pressure early in recovery in the male subjects may have special diagnostic significance was not investigated. Any project of this sort must take into account the fact that such a secondary rise is frequently seen in normal men and that the degree of secondary rise varies considerably from individual to individual.

Conclusions

1. During exercise in normal subjects the systolic pressure rises, the diastolic pressure falls, and the mean pressure does not change significantly when measured by a direct intra-arterial method.

2. In men, during the first few seconds after cessation of exercise, the systolic pressure falls precipitously, the diastolic pressure changes little, and the mean tends to fall. In women, the systolic pressure falls more gradually than in the men, but the validity and the significance of this sex difference are uncertain.

3. Between 10 and 30 seconds after cessation of exercise, the older men show a significant secondary rise in all three pressure items. Younger men and women fail to show a secondary rise in systolic pressure but demonstrate a gradual increase in both diastolic and mean pressures.

4. By the beginning of the sixth minute of recovery from exercise, the mean pressure returns to, or nearly to, the resting level in all three groups of subjects. Systolic pressure is close to, or slightly less than, the resting value, and the diastolic pressure in each group remains somewhat above the resting level.

5. Changes in pulse rate during and after exercise are similar in all three groups. By the sixth minute after exercise pulse rates in each group still exceed the respective resting values by about 15 per cent.

Sumario Español

Atentados a observar los cambios en presión arterial inducidos por el ejercicio usando esfigmomanometria indirecta ha producido resultados controversiales. En el siguiente estudio, las presiones arteriales fueron determinadas durante el descanso (parado), durante una caminata standard en el molino de rueda de andar, y durante un período de recuperación de seis minutos, usando un método directo y un sistema registrador convenientemente apagado. Se encontró que la presión sistólica aumenta y la diastólica disminuyó el resultado neto siendo un cambio muy pequeño en la presión promedio. En algunos sujetos hay una elevación secundaria en los tres ítems entre 10 y 30 segundos luego de el cese e ejercicio. Cambios en la frecuencia del pulso durante el ejercicio y la recuperación también se discuten.

References


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ROBERT S. FRASER and CARLETON B. CHAPMAN

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