Vasomotor Responses to Exercise in the Extremities of Subjects with Vascular Disease

By W. Redisch, M.D., K. de Crinis, M.D., A. Antonio, M.D., A. Bogdanovitz, M.D., and J. M. Steele, M.D.

With the technical assistance of Gordon Gilbert, B.S., and Raleigh Wheeler, B.S.

Response of peripheral blood flow was studied in subjects of various age groups with and without vascular disease. Under constant environmental conditions, the skin-muscle distribution of total flow to the lower extremity showed the following trend. In young healthy adults the muscles get a somewhat higher share; in elderly persons without vascular disease the distribution is about equal; in patients with nongangrenous obliterative arteriosclerosis the skin is favored over the muscle. Exercise increases total flow in all groups, but does not alter the distribution. Sympathectomy does not seem to influence response to exercise.

Evidence is lacking that neurogenic vasomotor impulses cause the dilatation of small muscle vessels during exercise, while evidence exists for metabolic or humoral vasodilator mechanisms. It has been shown in animals that splanchnic constriction may precede the commencement of muscular effort but does not contribute to a shift of blood flow from the splanchnic to the muscular vascular bed, since no subsequent change in the degree of constriction occurs. Spalteholz explained an increase in blood flow following the contraction of skeletal muscle by anatomic distribution: The small blood vessels and capillaries in the muscle run parallel to the cylindrical muscle fibers; when the muscle fiber contracts, more space is given to the vessels, and thus resistance to blood flow is decreased. Rein and co-workers explained the increase in blood flow following a muscular contraction by the liberation of a chemical vasodilator substance, and assumed that during contraction the resistance to blood flow in the skeletal muscle diminished.

Anrep proved experimentally that during the muscular contraction the arterial in-flow to the muscle is actually stopped, and interpreted this phenomenon as vasoconstriction produced by the contracting muscle fiber. Each contraction is, however, followed by vasodilatation, and the blood flow rapidly increases well above resting values. Barcroft and his co-workers showed that basal blood flow to the muscles is regulated by the vasomotor centers, but that this central regulation is not responsible for the circulatory changes occurring during activity. Barcroft therefore considered it likely that there may be 2 separate circulations in the skeletal muscle, one controlled by the vasomotor centers and the other by a metabolic mechanism. Saunders and his co-workers have supplied a rather impressive anatomic basis for this assumption in microscopic x-ray evidence for the existence of 2 separate sets of vasculature in the muscle, which makes Barcroft’s theory very probable.

A study of vascular responses to exercise in the lower extremity of man is reported here. Efforts to establish a suitable way of exercising the calf muscles of a leg and to measure plethysmographically the changes occurring in blood flow thereafter met with considerable difficulties. Finally, a method of fairly well controlled exercise within the casement of the large limb—plethysmograph was devised, which is described under "methods." A number of experiments on patients with obliterative arteriosclerosis could not be completed because the onset of pain precluded the conclusion of exercise.

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TABLE 1.—Total Blood Flow of Foot and Leg in Response to Exercise (ml./100 ml. tissue/min.)

<table>
<thead>
<tr>
<th></th>
<th>Young adults</th>
<th>Elderly adults</th>
<th>Elderly adults with obliterative arteriosclerosis</th>
<th>Arteriosclerosis after sympathectomy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of cases</td>
<td>11</td>
<td>13</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Average basal blood flow</td>
<td>14.1</td>
<td>10.4</td>
<td>6.6</td>
<td>10.3</td>
</tr>
<tr>
<td>Range of basal flow</td>
<td>4.5-24.8</td>
<td>6.8-19.3</td>
<td>1.8-11.6</td>
<td>8.0-11.7</td>
</tr>
<tr>
<td>Average maximal flow</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>response to exercise</td>
<td>21.7</td>
<td>18.1</td>
<td>9.1</td>
<td>13.6</td>
</tr>
<tr>
<td>Range of response flow</td>
<td>13.6-34.2</td>
<td>11.2-25.4</td>
<td>2.5-15.2</td>
<td>10.2-16.5</td>
</tr>
</tbody>
</table>

TABLE 2.—Estimation of Blood Flow to Skin and Muscle (Average for Each Group in ml./100 ml. Tissue/min.)

<table>
<thead>
<tr>
<th></th>
<th>Young adults</th>
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<tr>
<td>Total number of cases</td>
<td>7</td>
<td>7</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Basal blood flow</td>
<td>14.4</td>
<td>10.2</td>
<td>5.2</td>
<td>7.7</td>
</tr>
<tr>
<td>Response to exercise</td>
<td>22.4</td>
<td>13.5</td>
<td>7.4</td>
<td>9.9</td>
</tr>
<tr>
<td>Skin flow before exercise</td>
<td>6.5</td>
<td>6.0</td>
<td>2.7</td>
<td>4.4</td>
</tr>
<tr>
<td>Skin flow after exercise</td>
<td>9.8</td>
<td>6.3</td>
<td>3.8</td>
<td>5.6</td>
</tr>
<tr>
<td>Muscle flow before exercise</td>
<td>7.9</td>
<td>4.2</td>
<td>2.5</td>
<td>3.3</td>
</tr>
<tr>
<td>Muscle flow after exercise</td>
<td>12.6</td>
<td>7.2</td>
<td>3.6</td>
<td>4.3</td>
</tr>
</tbody>
</table>

METHODS AND MATERIAL

The response of peripheral blood flow to exercise was studied in 12 young healthy adults, 16 elderly persons without demonstrable vascular disease, 7 patients with nongangrenous obliterative arteriosclerosis, and 5 patients with nongangrenous obliterative arteriosclerosis in whom sympathectomy of a lower extremity had been performed. The blood flow to the lower extremity was measured plethysmographically. In corresponding smaller groups, skin flow and muscle flow had been estimated by means of individual skin mass/muscle mass ratios. Surface temperature was recorded to ascertain “adaptation” to the environment. All experiments were performed in a constant-temperature room at 22 to 23 C. and 55 per cent humidity, with the subjects under basal conditions, and measurements were not begun until surface temperature remained constant for half an hour. After measurements of resting flow had been made, the subject exercised for 5 minutes by rhythmically pressing down on a footboard, adjusted within the plethysmograph case- ment, at a rate of 60 cycles down and up per minute; the completion of each cycle was indicated by a bell connected to the footboard. Recordings were made immediately after the exercise and every 2 minutes for 1 hour thereafter.

RESULTS

Under the experimental conditions described, basal flows were higher in young healthy adults than in the group of elderly persons without demonstrable vascular disease. They were lowest in patients with obliterative arteriosclerosis; sympathectomized limbs had a higher basal flow than the comparable nonsympathectomized ones. After exercise, there was an increase in total blood flow in all groups (table 1).

When "skin flow" and "muscle flow" were estimated separately in smaller groups (7 young adults, 7 elderly people, 4 arteriosclerotic and 4 sympathectomized patients), the figures listed in table 2 were obtained. Although the over-all increase after exercise was smaller in these subjects than in those reported in table 1, there was no difference in directional responses.

Statistical evaluation of the figures obtained in various groups yielded the following: 1. Although the blood flow in elderly people without vascular disease is persistently lower
than in young persons, the number of subjects tested is not large enough to make the average difference statistically significant.

2. Blood flow in patients with obliterative arteriosclerosis is significantly lower than in both (young and elderly) control groups (p = .002). 3. Resting blood flows in patients with obliterative arteriosclerosis after sympathectomy are significantly higher than in non-sympathectomized limbs (p = .05).

CONCLUSIONS

"Basal" flow figures corresponded to what might have been reasonably expected. Unfortunately, we do not have readings before and after sympathectomy in the cases reported here. All subjects who had been sympathectomized unilaterally had higher basal flow on the operated side than in the other limb.

It is of considerable interest that the apportioning of the total blood flow to the skin and muscle beds respectively shows the following trend. In the young healthy adults at rest, somewhat more blood goes to the muscles than to the skin; in elderly people without vascular disease the reverse is the case. Exercise increases muscle flow somewhat more than skin flow in these 2 groups. In patients with nongangrenous arteriosclerosis, the distribution is about equal. When sympathectomy has been performed, however, the skin obtains a greater share. The distribution is not significantly altered by the increase in total blood flow associated with exercise. In these experiments, sympathectomy did not seem to influence the over-all response to exercise. We know that vascular responses in the extremity to body warming are materially altered by sympathectomy. If we assume that our method of quantitating skin and muscle is correct, then we must conclude that the increase of blood flow in response to exercise is mediated by a mechanism different from that active in the Gibbon-Landis procedure.

SUMMARIO IN INTERLINGUA

Le cifras pro le fluxo "basal" correspondeva a lo que debeva esser expectate. Infelizmente nos non ha lecturas ante e post sympathectomia in le casos hic reportate. Omne subjectos con sympathectomia unilateral habeva un plus alte fluxo basal al latera operate que in le extremitate intacte.

Il es de grande interesse que le apportionamento del total fluxo de sanguine al vasculaturs cutane e musculea demonstra le sequente tendentias: In normal juvane adultos in stato de reposo, un paucio plus sanguine va al musculos que al pelle. In subjectos de etates plus avanitate sed sin morbo vascular, le contrario es ver. Exercitio augmenta le fluxo muscular un paucio plus que le fluxo cutane in le mentionate 2 gruppus. In patiintes con arteriosclerosis non-gangrenose, le distribution es quasi equal. Tamen, post sympathectomia le portion del pelle predominia. Le distribution non es alterate significativamente per le augmento del total fluxo de sanguine que es associate con exercitio. In iste experimentos, sympathectomia non pareva influen- tiar le responsa general a exercitio. Nos sape que responsas vascular evocate in le extremi- tates per calefaction del corpore es materialmente alterate per sympathectomia. Si nos suppose que nostre methodo de quantification pro pelle e musculo es correcte, nos debe concluder que le augmento del fluxo de sanguine in responsa a exercitio es mediate per un mechanismo que differe ab le mechanismo que es active in le procedimento de Gibbon-Landis.

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