Effect of Small Degrees of Venous Distension on the Apparent Inflow Rate of Blood to the Human Calf

By D. R. Coles, M.B., B.Sc. AND B. S. L. Kidd, M.B.

The apparent blood flow through the human calf has been measured by venous occlusion plethysmography in the horizontal subject both at rest, and while the volume of the calf was increased by up to 3 per cent by venous congestion. When this degree of venous distension was continued for 5 min., the apparent blood flow through the calf was not altered significantly. Since the perfusion pressure is presumably reduced, this suggests that the vessels of the calf offering resistance to flow are slightly dilated.

When the leg is lowered from the horizontal while the body remains in a constant recumbent position, plethysmographic observations suggest that the blood flow in the calf decreases (Beaconsfield and Ginsburg1). The veins of the leg become distended and the leg volume increases (Turner, Newton and Haynes2). A similar distension of the veins may be produced in the horizontal limb by the inflation of a pneumatic cuff around the thigh. Greenfield and Patterson3 have shown, however, that in the forearm the apparent rate of inflow is almost unaltered in the presence of a venous back-pressure sufficient to increase the resting forearm volume by amounts of up to 2 per cent.

In the present experiments we have studied the apparent rate of inflow to the calf measured by the classical method of venous occlusion plethysmography in the presence of venous back-pressure sufficient to increase the resting calf volume by amounts of up to 3.0 per cent for periods of from 1 to 5 min.

METHODS

The subjects were 9 healthy young men who lay on a couch with the head and shoulders slightly raised. The experimental procedure was similar to that employed by Greenfield and Patterson3. The blood flow through both calves was measured 4 times a minute, using plethysmographs with the water at 35 C. and the water level 5 cm. above the sternal angle. The collecting pressure was 50-70 mm. Hg. Between collections the cuff on the right leg was always returned to atmospheric pressure, but that on the left leg was returned to atmospheric pressure during “rest” periods and to a pressure 10-25 mm. Hg above atmospheric during “distension” periods. In some experiments the distension periods lasted for 1 min. and in others for 5 min. Measurements of mean blood flow per cent and distension per cent were made as for the forearm3.

RESULTS

The results of 81 observations on 6 subjects for distension periods lasting 1 min. are summarized in table 1, together with 80 control observations where the collecting cuff was returned to atmospheric pressure during distension as well as during rest periods. It can be seen that venous distension sufficient to cause an increase in calf volume of up to 1.5 per cent has a negligible effect on the apparent inflow rate of the calf. When the increase in calf volume is in the range 1.5-2.0 per cent, the apparent inflow rate is reduced, although it should be noted that the low flow rates were recorded mainly from one subject.

Table 2 summarizes the results of 32 observations on 4 subjects in whom the distension period lasted 5 min., together with 32 control observations. Here, although the calf volume was increased by as much as 3 per cent for 5 min., the effect on the apparent inflow rate was so slight as to be negligible.

DISCUSSION

These observations provide no evidence that slight venous congestion leads to a real or apparent reduction in the rate of blood inflow, or to an increased local resistance to blood flow. On the contrary, since the apparent rate of inflow is substantially unchanged when the venous pressure is presumably raised, and the
TABLE 1.—Effect of Small Degrees of Venous Distension Lasting One Minute on the Apparent Rate of Blood Inflow to the Calf

<table>
<thead>
<tr>
<th>Distension per cent</th>
<th>Number of observations</th>
<th>Mean blood flow per cent</th>
<th>S.E.</th>
<th>p for difference from 100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>80</td>
<td>99.8</td>
<td>0.595</td>
<td>0.8 &gt; p &gt; 0.7</td>
</tr>
<tr>
<td>0.51-1</td>
<td>32</td>
<td>101</td>
<td>0.85</td>
<td>0.3 &gt; p &gt; 0.2</td>
</tr>
<tr>
<td>1.01-1.5</td>
<td>31</td>
<td>100</td>
<td>1.26</td>
<td>1 &gt; p &gt; 0.9</td>
</tr>
<tr>
<td>1.51-2.0</td>
<td>18</td>
<td>92.05</td>
<td>2.38</td>
<td>0.1 &gt; p &gt; 0.001</td>
</tr>
</tbody>
</table>

TABLE 2.—Effect of Small Degrees of Venous Distension for Five Minutes on the Apparent Rate of Blood Inflow to the Calf

<table>
<thead>
<tr>
<th>Minute of distension</th>
<th>Number of observations</th>
<th>Mean distension per cent</th>
<th>Mean blood flow per cent</th>
<th>S.E.</th>
<th>p for difference from 100% per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>32</td>
<td>1</td>
<td>99</td>
<td>1.23</td>
<td>0.5 &gt; p &gt; 0.4</td>
</tr>
<tr>
<td>1</td>
<td>32</td>
<td>1.2</td>
<td>99</td>
<td>1.7</td>
<td>0.6 &gt; p &gt; 0.5</td>
</tr>
<tr>
<td>3</td>
<td>32</td>
<td>1.7</td>
<td>101</td>
<td>1.9</td>
<td>0.2 &gt; p &gt; 0.1</td>
</tr>
<tr>
<td>5</td>
<td>32</td>
<td>2.1</td>
<td>103</td>
<td>1.8</td>
<td>0.2 &gt; p &gt; 0.1</td>
</tr>
</tbody>
</table>

net perfusion pressure reduced, it would seem that the local resistance to blood flow must be reduced. A similar conclusion was reached by Edholm, Moreira and Werner. In the experiments of Beaconsfield and Ginsburg the leg was lowered, the venous pressure was increased but the net perfusion pressure probably remained unaltered. Their plethysmographic recordings were interpreted as showing that under such conditions the blood flow through the calf was reduced, presumably due to an increase in resistance to blood flow. One possible explanation for the difference between our results and theirs is that the degree of venous back pressure produced by the inflation of the thigh cuff was less than that produced by dependency. A second explanation is that an increase in arterial rather than venous pressure was responsible for the reduction in the flow through the dependent calf. Since dependency increases the pressure on both the arteries and veins it is probable that the transmural pressure in the blood vessels concerned with resistance to flow in the calf is increased more by dependency than by the application of a venous congestion cuff. Increases in transmural pressure, produced by local exposure to subatmospheric pressures, in the blood vessels of the calf have been shown to be followed by a vasoconstriction (Coles, Kidd and Patterson), and it could be that this reaction may account for the reduced flow recorded by Beaconsfield and Ginsburg.

Finally it should be noted that other workers, Wilkins and associates, Rosensweig, England and Johnston, and Roddie, using other methods, have concluded that the blood flow through certain parts of the dependent limb is increased. Possibly, therefore, the apparent rate of blood flow as measured by venous occlusion plethysmography is an underestimate of the real rate under these conditions.

The present observations confirm the findings of Greenfield and Patterson on the forearm that there is no evidence that local vascular reactions to the collection of blood in the part invalidate the classical method of venous occlusion plethysmography.

SUMMARY

The apparent rate of blood inflow to the calf, as measured by venous occlusion plethysmography, is not significantly affected in the presence of venous back pressure sufficient to increase the resting volume by up to 3 per cent.

ACKNOWLEDGMENT

We wish to thank Professor A. D. M. Greenfield for help and advice during this project.
Pioneer Experimentation on Edema

Up to the end of the seventeenth century, dropsy was attributed to laceration of lymph and chyle vessels. The physiologic mechanisms were discovered through experiments primarily done for other purposes.

Richard Lower (1631–1691), as shown in his Tractatus de Corde, among other experiments, ligated the jugular vein and inferior vena cava of dogs. The former led to swelling of muscles and glands and the latter to accumulation of abdominal fluid. He correctly inferred that plasma was filtered through the vessel walls while the thicker constituents remained behind. He also demonstrated that the lymph channels of sheep with edema remained intact. “The belief that dropsy was always due to tearing of lymph vessels was thus dispelled.”

Stephen Hales (1677–1761), in his Statistical Essays, mentions an experiment in which the blood of a horse was diluted by continuous pouring of warm water into an elevated funnel connected by tubing with a carotid artery. In half an hour the body swelled more and more due to ascites and anasarca. “Hales, too, concluded from his necropsy findings that the dropsical fluid did not result from tearing of lymph vessels.”

Thus ‘Lower performed the basic research on stasis edema and Hales on ‘hydraulic or cachectic’ edema.”

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