Effects of Experimental Coarctation of the Aorta on the Blood Pressure of Sheep

By P. R. Magarey, M.D., W. E. Stehbens, M.B., B.S., and Alan Sharp, F.R.C.S.

Blood pressures have been taken from the carotid and femoral artery in sheep following experimental coarctation of the aorta at about the level of the ligamentum arteriosum. Systolic, diastolic, mean, and pulse pressures have been recorded at intervals of from 3 to 6 months over a period of as long as 3 years in some cases. Unoperated sheep have been used as controls. The main changes are a rise in all the carotid pressures and in the femoral diastolic, a fall in the femoral systolic and pulse pressures, and no significant change in the femoral mean pressure. These changes in hemodynamics resulting from coarctation may be adequately explained by the mechanical effects of the coarctation. Over a period of 3 years there is a slight rise of blood pressures in both the normal and the coarctated sheep.

In the course of a series of long-term experiments for investigating the pathogenesis of atherosclerosis, coarctation of the aorta has been experimentally produced in sheep, and blood pressures have been recorded at intervals of 3 to 6 months for as long as 3 years in both the carotid and femoral artery. The sheep was selected for experimentation because of its availability and ease of maintenance.

The normal blood pressures of sheep have been previously reported and those figures are slightly modified in this communication as the number of readings has been increased. Changes in the various pressures above and below the coarctation are recorded, and certain changes in the serial blood pressures are also noted.

Methods

Altogether, 105 sheep were used in the experiment, 18 of which were kept as normal controls. All the sheep were hand-fed Merino cross breeds, both ewes and wethers, and their ages when operated upon varied from a few weeks to about 18 months.

The surgical operation was performed under intravenous thiopental anesthesia, the usual dose being about 0.75 gm. Atropine sulfate (65 mg.) was injected intramuscularly a short time before induction of the anesthetic, this very large dose being needed in the sheep to diminish mucus secretion. Using intermittent hand pressure, respiration was controlled by means of a cuffed endotracheal tube and a closed circuit anesthetic machine.

The animal was placed on its right side with fore-quarters slightly raised and a curved skin incision was made over the left side of the thorax, which was opened through the fourth or fifth intercostal space, the ribs being forcibly retracted. Using intermittent hand pressure, respiration was controlled by means of a cuffed endotracheal tube and a closed circuit anesthetic machine.

The animal was placed on its right side with fore-quarters slightly raised and a curved skin incision was made over the left side of the thorax, which was opened through the fourth or fifth intercostal space, the ribs being forcibly retracted. With the lung collapsed and packed aside, the parietal pleura could be dissected from the descending portion of the arch of the aorta. The constricting ligature was then passed loosely around the aorta about 1 cm. below the attachment of the ligamentum arteriosum. When the ligature was tied, and after inflation of the lung, the wound was closed.

Various types of ligature material were tried—no. 3 silk, coarse nylon ligature threaded through a plastic (Xylex) tube of 2 mm. external diameter, and finally, cotton tape a quarter of an inch wide. It was found that there was not a great deal to choose between these different ligatures as in each case an occasional one cut through the aortic wall, this complication being slightly less frequent with the tape.

At the time of operation, only an approximate estimate could be made of the degree of aortic constriction achieved, as aortic blood pressures recorded simultaneously were not helpful, being very labile, especially below the constriction. It was, however, an important point to decide, for if the ligature was too tight the animal did not survive, and if too slack, significant coarctation was not achieved. It was decided that the best estimate of the degree of constriction was obtained by palpation of the aorta below the ligature, and a roughly graded scale was adopted depending...
TABLE 1.—Blood Pressures of Normal and of Coarctated Sheep

<table>
<thead>
<tr>
<th></th>
<th>Normal (70 readings)</th>
<th>Coarctated (186 readings)</th>
<th>Changes produced by coarctation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (mm. Hg)</td>
<td>Standard deviation</td>
<td>Mean (mm. Hg)</td>
</tr>
<tr>
<td>Carotid artery</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systolic</td>
<td>137.5</td>
<td>17.1</td>
<td>161.9</td>
</tr>
<tr>
<td>Diastolic</td>
<td>114.1</td>
<td>15.7</td>
<td>125.2</td>
</tr>
<tr>
<td>Mean</td>
<td>124.1</td>
<td>15.2</td>
<td>139.8</td>
</tr>
<tr>
<td>Pulse pressure</td>
<td>24.5</td>
<td>6.5</td>
<td>36.2</td>
</tr>
<tr>
<td>Femoral artery</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systolic</td>
<td>152.1</td>
<td>16.8</td>
<td>143.2</td>
</tr>
<tr>
<td>Diastolic</td>
<td>115.9</td>
<td>14.8</td>
<td>124.0</td>
</tr>
<tr>
<td>Mean</td>
<td>127.9</td>
<td>14.2</td>
<td>131.6</td>
</tr>
<tr>
<td>Pulse pressure</td>
<td>35.7</td>
<td>6.7</td>
<td>18.9</td>
</tr>
</tbody>
</table>

upon the characteristics of the pulsation and the concomitant thrill. As the ligature was tightened, an intermittent thrill first appeared; with further reduction of the lumen, the thrill became continuous and finally weaker, to disappear altogether when there was complete occlusion of the aorta. The aim at the time of operation was to procure a weak, continuous thrill below the coarctation with pulsation at this site practically eliminated.

This operation was performed on a total of 87 animals and we have been able to take postoperative blood pressures at least once on 66 of these. In most animals a number of readings were taken at 3 to 6 month intervals.

All the blood pressures were measured under intravenous thiopental anesthesia, with the animal lying on its side. The carotid and femoral arteries were exposed through short skin incisions and a 22 gage needle inserted into the lumen. This needle was connected by a short piece of polythene tubing to the pressure head of a capacitance manometer, the system being filled with 2.6 per cent sodium citrate solution with sufficient heparin added to prevent clotting in the needle. The pulse wave and the mean blood pressure were recorded in ink and calibration against the mercury column of a clinical sphygmomanometer was performed after each reading.

RESULTS

Mortality has been fairly high from various causes, 9 of the 18 controls (50 per cent) and 47 of the 87 experimental animals (54 per cent) having succumbed.

If the aorta was constricted too much at operation, the animal lost the power of its hind limbs and died within a few days. In these animals, the diameter of the aortic lumen, which was measured post mortem with a stepped cone gauge, was invariably found to be reduced to less than 2 mm. Since in the young sheep the usual diameter of the lumen is about 11 mm., survival was not likely if the area of cross section of the lumen was reduced to less than about 5 per cent of the original.

In those animals in which the residual lumen has been found post mortem to be greater than about 4 mm., the blood pressure had not deviated much from normal. In a few animals dying from extraneous causes, the diameter of the coarctation was found to be 3 to 4 mm. In these animals, typical blood pressure changes were generally recorded and not infrequently a well developed post-stenotic dilatation had developed. It appears, then, that the diameter of the coarctation to be achieved should be between 3 and 4 mm., that is, the cross section should be reduced to between about 8 and 13 per cent of the original lumen.

Altogether 70 control readings were taken on 40 animals and when multiple readings had been made, at least three months were allowed to elapse between them. Included in these control readings were 27 recordings taken from animals prior to operation.

One hundred and eighty-six readings have been made under identical conditions from 66 animals following coarctation. Table 1 shows the blood pressures of the normal and coarctated animals and the changes produced by coarctation. It must be realized that in a number of the experimental animals, the coarctation achieved was less than the optimum 3 to 4 mm. In some animals dying from extraneous causes, the lumen was found reduced...
to only 5 to 7 mm., and in others the ligature had cut through the aortic wall so that the appropriate constriction was not obtained. If some of these obviously unsuccessful cases were to be excluded, the average figures would show even greater deviation from normal, especially the femoral pulse pressure.

Some of our animals now have survived for three years, during which their blood pressures have been recorded a number of times. It was thought that, by grouping the readings into intervals after operation, some indication of the trend of pressures over a period of time may be achieved. Table 2 compares those readings, both experimental and control, taken during the first 12 months, with those taken subsequently.

**DISCUSSION**

From the figures presented in table 1, it can be seen that in normal sheep the femoral systolic and pulse pressures are higher than the carotid. This difference is highly significant ($p < 0.001$), whereas there is no significant difference between the carotid and femoral diastolic ($0.3 < p < 0.4$) and mean pressures ($0.05 < p < 0.1$). A similar state exists in the axillary and femoral pressures in man.

In comparing the pressures with and without coarctation very definite changes in the hemodynamics are to be found. Following ligation, there is a highly significant rise in the carotid systolic, diastolic, mean and pulse pressures, and in the femoral, a highly significant fall in the systolic pulse pressures and a rise in the diastolic pressures. On the other hand, the change in the mean pressure in the femoral artery is not significant; further reference will be made to this fact.

The theories of the cause of the changes in the blood pressures in coarctation can be mainly grouped into renal (or chemical), and mechanical. The mechanical theory would seemingly explain the rise in pressures above the constriction, for assuming that the blood supply to the caudal half of the animal were to remain constant, a higher pressure would be required to deliver the necessary volume of blood per unit of time against the increased peripheral resistance afforded by the coarctation. If this were so, it might be expected that the carotid pressures would gradually fall as the collateral circulation developed, but, as can be seen from table 2, instead of this anticipated fall in the experimental sheep, there is a distinct rise in systolic and diastolic pressures both above and below the constriction. The normals show a similar rise, which is probably a function of age.

Regarding the distal blood pressure changes, a mechanical factor might also readily account for the lowered femoral systolic and pulse pressure. Likewise, by a simple damping effect on the pulse wave, which has been postulated by Bing et al., the raised diastolic pressure can be explained, while mean pressure would be expected to remain relatively unchanged.

In figure 1, the amplitude of the femoral pulse wave of the control animals is depicted on the left and that of the experimental group, on the right. It can be seen that, after coarctation, the systolic pressure is diminished and the diastolic raised by about the same amount,
while the mean is relatively unchanged. These findings favor a mechanical damping effect of the coarctation.

**Summary**

Aortic coarctation has been produced in sheep, and blood pressures have been recorded above and below the constriction at intervals for a period of up to 3 years.

The significant changes are a rise in the systolic, diastolic, mean, and pulse pressures in the carotid, a rise in the femoral diastolic and a fall in the femoral systolic and pulse pressure. The change in the mean pressure in the femoral artery is not significant.

These blood pressure changes are interpreted as being of mechanical origin, those in the femoral pulse as resulting from a simple damping effect on the pulse wave by the aortic constriction.

**Acknowledgment**

We are indebted to the Department of Illustration of the University of Sydney for the preparation of the tables and figure, and to Dr. Lancaster for assistance in the statistics.

**Summario in Interlingua**

Coarctation aortic esseva produce in oves, e le pression de sanguine supra e infra le constriction esseva registrate a intervalllos durante periodos de usque a 3 annos.

Le alterationes significative es elevation del pressiones systolic, diastolic, medie, e de pulso in le carotide, un augmento del diastolic pression femoral, e un reduction del pression de pulso a del pression systolic femoral. Le alteration del pression medie in le arteria femoral non es significative.

Es presentate le interpretation que iste alterationes del pression de sanguine es de origine mechanic. Le alterationes in le pulso femoral resultarea de un simple effecto amortante producite per le constriction aortic in le unda de pulso.

**References**

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