Further Evidence for a Critical Vessel Caliber in Experimental Coronary Shock

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New experiments confirm previous observations that production of protracted coronary shock in the closed-chest dog following microsphere embolization is a critical function of the embolus size. The vessels occluded by the critical emboli have been located by a plastic coronary injection-tissue corrosion technic, and a definite relationship has been demonstrated between vessel caliber and anatomic type, in a dog heart, for the gradient from epicardium through endocardium.

CORONARY shock has been induced in the closed-chest dog by embolizing the coronary arteries with plastic microspheres of 325 μ diameter. Spheres of 190 μ or 450 μ did not produce this form of shock although fatal cardiac injury did occur. This selectivity of the sphere diameter seemed so important in establishing the mechanism of coronary shock that it was decided to expand the study. Further, it was necessary to establish the following facts: (1) the caliber of the vessels occluded by emboli of different diameters; (2) the relationship, in the dog heart, between vessel caliber and anatomic level; (3) the extent to which the myocardium was deprived of circulation by these emboli; and (4) the explanation for the finding that emboli of a specific diameter produce the same effect in dogs which varied in weight from 11 to 30 Kg. It was found that these questions could best be answered by plastic injection studies of the coronary arteries because of the adhesion of the plastic microspheres to the injection mass.

METHOD

Embolization of the coronary arteries was performed by a method previously reported. The plastic injection technic used was essentially that developed by Wagner and co-workers and Kazzaz and Shanklin. The coronary tree was perfused with saline and 95 per cent ethanol at pressures of 150 mm. Hg, acetone at 200 mm. Hg, and the vinylite injection mass at 250 mm. Hg. These perfusion pressures did not exceed the coronary filling pressure at the time of sphere embolization (200–250 mm. Hg), so that the spheres would not be dislodged by the injection process. The hardening properties of alcohol and acetone further insured that the spheres were firmly fixed in their original positions. Direct observation of the epicardial vessels showed that the position of the spheres was not changed by the procedure.

The depth of the coronary tree which was penetrated by the plastic mass was dependent upon the viscosity of the material. A mixture of vinylite resins so prepared as to contain 20 per cent total solids and injected at 250 mm. Hg filled vessels down to 50 μ in diameter, leaving the capillary bed uninjected.

Following injection of the coronary arteries with the plastic mass, the myocardium was digested with 20 per cent KOH leaving an accurate vinyl plastic replica of the postmortem coronary tree.

A most fortunate result of this technic has been the adherence of the microspheres to the injected plastic, so that location of the emboli could be accurately determined. The diameters of the major and minor vessels, of the adherent microspheres, and the caliber of the vessels at the point of occlusion were measured by a dissecting microscope equipped with an ocular micrometer. In most instances the spheres were found adhering to the plastic “vessel,” particularly in the case of the...
spheres of 325 \( \mu \) diameter; however, when they were dislodged in the process of digestion, characteristic cup-like depressions could be found in the vinylite cast.

**RESULTS**

1. **Blood Pressure Response to Graded Emboli**

Three dogs were embolized with spheres of 190 \( \mu \) diameter, eight dogs with spheres of 325 \( \mu \) diameter, and five dogs with spheres of 450 \( \mu \) diameter. The average fall of mean arterial pressure for the 190 \( \mu \) diameter spheres was 10.2 per cent. For the spheres of 325 \( \mu \) the fall was 31.7 per cent, and with spheres of 450 \( \mu \) diameter the average fall in blood pressure was 9.1 per cent. According to the criteria already published,1 "coronary shock" occurred only with the 325 \( \mu \) diameter spheres.

2. **Location of Microspheres**

**Spheres of 450 \( \mu \).**

Careful measurements were made of the coronary artery vinylite casts of three dog hearts which had been embolized with 450 \( \mu \) spheres. The average caliber of the vessels occluded by these spheres was 416 \( \mu \). The spheres were found to be lodged in the terminations and lateral branches of the subepicardial arteries (see fig. 1). Very rarely were these spheres found in the "right angle vessels", arising from these arteries and when found they were lodged close to their origin from the main coronary rami.

**Spheres of 325 \( \mu \).**

Four dog hearts were studied after embolization with spheres of 325 \( \mu \) diameter. The average caliber of the vessels occluded by these spheres was found to be 292 \( \mu \). These spheres were lodged near the distal bifurcation of the right angle branches and in large lateral branches arising from these right angle vessels.

**Spheres of 190 \( \mu \).**

Two dog hearts were studied after embolization with 190 \( \mu \) spheres. The occluded vessels averaged 160 \( \mu \) in diameter. These were arterioles which branched from the right angle vessels.

**TABLE 1.**—Relationship of Embolus Size, Caliber of the Occluded Vessel, and the Incidence of Coronary Shock. Combined Data Including both the Present Series and the Previously Reported Series of Experiments.

<table>
<thead>
<tr>
<th>Sphere Size in ( \mu )</th>
<th>Number of Expts.</th>
<th>Ave. Percent Fall M. A. P.</th>
<th>Number of Shocks</th>
<th>Number of Immediate Fibrillators</th>
<th>Number of Hearts Injected</th>
<th>Average Diameter of Occluded Vessel</th>
</tr>
</thead>
<tbody>
<tr>
<td>325</td>
<td>14</td>
<td>31.9</td>
<td>14</td>
<td>0</td>
<td>4</td>
<td>292 ( \mu )</td>
</tr>
<tr>
<td>190</td>
<td>13</td>
<td>12.6</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>190 ( \mu )</td>
</tr>
<tr>
<td>450</td>
<td>14</td>
<td>9.0</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>416 ( \mu )</td>
</tr>
</tbody>
</table>

3. **Coronary Vessel Caliber as Related to Body Weight**

Ten dog hearts were studied in an effort to correlate vessel caliber with the body weight. In these studies the diameters of the distal bifurcations of right angle vessels were measured for each heart and were found to average 291 \( \mu \), with a maximum variation of only 270 \( \mu \) to 305 \( \mu \). There was no suggestion of any correlation between the diameter of these vessels and dog weight, in spite of the fact that the dog weights in this series varied from 10.9 Kg. to 30.0 Kg. These data indicate that despite widely varying weights of the dogs, the size of the right angle muscular branches was remarkably constant.

4. **Extent of Infarct with Graded Emboli**

Gross inspection of the heart showed that the 190 \( \mu \) spheres produced small infarcts measuring 2 by 3 mm.; those produced by

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* Right angle vessels are the muscular branches which course directly into the myocardium from the subdivisions of the main coronary rami (see fig. 1).
occlusion with 450 μ spheres measured 1 by 2 cm.; and the areas of infarct with 325 μ spheres were intermediate in size. This finding has also been confirmed in color cinemagraphs of the beating heart. Further, when the heart was perfused with ethanol, there was immediate blanching of the areas supplied with blood, while the ischemic areas remained unblanched. Here again, the infarct areas were largest with the 450 μ emboli.

**DISCUSSION**

The results of the expanded studies on the production of shock with graded emboli are remarkably similar to the original data. For the 325 μ group, the percentile fall in mean arterial pressure was 31.7 per cent as compared with 32 per cent; in the 190 μ group the figure was 10.2 per cent as compared with 15 per cent; in the 450 μ group, the percentile fall was 9.1 per cent as compared with 9 per cent. Grouping the total number of dogs in both sets of experiments, there were 16 animals for the 325 μ group with an average mean arterial pressure fall of 31.9 per cent; for the 190 μ group—13 dogs with a fall of 12.6 per cent; and for the 450 μ group—14 dogs with a fall of 9 per cent (see table 1). For this number of animals, the possibility that the difference in blood pressure response between the 325 μ group and the 190 and 450 μ groups was due to chance is less than 1 in 10,000.

The injection studies have shown that the effective embolus (325 μ) lodged in the right angle vessels originating from the superficial descending coronary rami. The caliber of these vessels was found to average 290 μ. It is also remarkable that at this level in the coronary tree, these vessels are of a constant size regardless of the diameter of the major coronary trunks. This explains why shock is produced by the same sized embolus regardless of the size of the animal.

It has been observed that the ischemic areas were more extensive when larger blood vessels were occluded. It is to be remembered that animals given 450 μ spheres in which "shock" did not occur were still subjected to fatal injury. In considering the mechanism of coronary shock, this lends added weight to the concept that the occurrence of this form of shock is not directly related to the amount of muscle damaged. Furthermore, the coronary anatomy of the dog hearts studied by the plastic injection technic offers no explanation of the critical vessel caliber on the basis of intracoronary anastomoses.

**CONCLUSION**

These findings have led to the consideration of two hypotheses concerning the mechanism of coronary shock. They are: first, the possibility that selective emboli may cause intracoronary spasm; and second, the possibility that there may be nerve endings in the right angle coronary vessels which may be stimulated by these emboli. Both of these hypotheses are under investigation.

**SUMMARY**

1. Experiments have been carried out which confirm the previously reported data on the effect of embolus size on the production of experimental coronary shock in the closed-chest dog.

2. The locations of these graded emboli in the coronary tree have been determined by a plastic injection technic (see fig. 1).

3. A definite relationship between vessel caliber and anatomic level has been established in the coronary tree of dogs weighing from 11 to 30 Kg. Vessels of approximately 300 μ in caliber are "right angle vessels."

4. The plastic injection studies support the concept that experimental coronary shock in the closed-chest dog is a function of a critical embolus size and not directly related to the amount of myocardium deprived of circulation.

**REFERENCES**


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