A SIMPLE DEVICE FOR THE PERFUSION OF THE MAMMALIAN HEART

IN the course of some experiments in which we used the heart-beat to test the properties of some balanced salt solutions, the apparatus here described was devised. Most devices for the perfusion of the mammalian heart[1,2,3] are elaborate and present considerable difficulties in manipulation. While this is undoubtedly necessary in experimentation on some physiological function of the heart we found the simplified apparatus here presented adequate to our purpose. We are presenting it with the expectation that a device so easily assembled might be found useful in lecture demonstrations or classroom experiments.

There are three factors, the control of which presents the greatest difficulty in the perfusion of the mammalian heart: (1) Temperature of the fluid; (2) Pressure of the fluid; (3) Oxygenation.

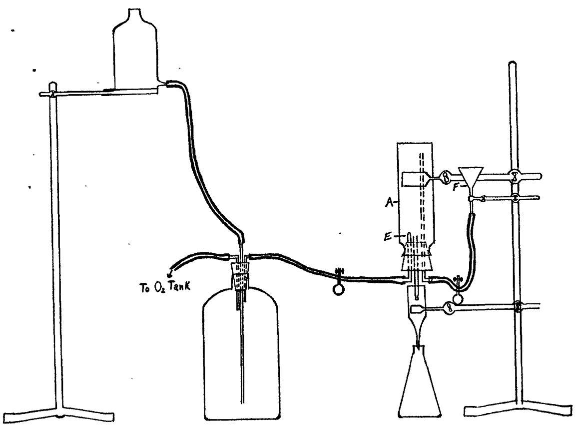

FIG. 1.

As far as the temperature is concerned it is merely necessary to control it within a degree or a degree and a half. This is readily accomplished by means of the vacuum flask (A). The cannula to which the heart is attached is inserted in rubber tubing which is attached to a piece of glass tubing inserted in the rubber stopper of the flask. The cannula and tubes are all as short as possible to avoid cooling of the fluid. The heart is suspended in a filter tube the mouth of which can be closed by a wad of moist cotton. The temperature of the heart is maintained by the passage of the perfusion fluid through it. Unless the room is very warm it is desirable to warm the filter tube by an electric lamp suspended near it. However crude this temperature control may seem to the physiologist who is accustomed to working with apparatus capable of control to a tenth or even a hundredth of a degree C., we have found it quite sufficient to keep the heart beating vigorously 6 to 8 hours.

Pressure and oxygenation are controlled by a single apparatus. Medical oxygen is released from a cylinder into a gasometer consisting of two bottles at different levels, connected by a rubber tube, the lower partly filled with water. As pressure is increased water is displaced within the lower bottle and rises in the upper. Pressure is controlled by the difference in the level of the bottles. The oxygen is conducted from the gasometer through a tube drawn out into a capillary (E) inserted in the rubber stopper of the flask, where it bubbles through the perfusion fluid. This gas is then allowed to escape through the trap (F) consisting of a funnel on a rubber tube, filled with water to counterbalance the pressure in the gasometer. This funnel may be raised and lowered to keep the pressure constant as the fluid within the flask is used. By this device the perfusion fluid is very readily kept saturated with oxygen at any desired pressure.

In our experiments we have used hearts of rat, guinea-pig and rabbit. Of these we have had the greatest success with the rabbit. The rat heart and frequently that of the guinea-pig stopped beating during the manipulation in attaching it to the apparatus. If it resumed beating at all the beat was irregular and of short duration. This is apparently the phenomenon of fibrillation or delirium cordis.[4]

Our procedure in setting up an experiment is as follows: The flask, previously warmed by the introduction of water heated to 37.5° C, is filled with perfusion fluid also warmed to 37.5° C. The fluid, preparatory to the beginning of the experiment, is saturated by a lively stream of oxygen. The animal is killed by a blow on the head and bled quickly from the carotid artery. The heart is immediately removed, taking particular care to leave the systemic aorta sufficiently long to accommodate the tip of the cannula. The heart is then placed in a small dish of warm perfusion fluid and permitted to beat in it, under the slight pressure of the finger, to clear itself of blood. The aorta is carefully dissected away from the surrounding tissue to make sure that none of the nerves will be tied in the ligature. The cannula, already attached to the flask, has now a slow stream of perfusion fluid, controlled by a clamp on the rubber tube (C), passing through it. The heart is lifted by the aorta, and the aorta is drawn over the tip of the cannula. The aorta is held in position so that the cannula does not protrude beyond the semi-

1 Knowlton and Starling, *Journ. of Phys.*, 44: 206. 1912.

2 Anrep and Hausler, *Journ. of Phys.*, 65: 357. 1928.

3 Gunn, *Journ. of Phys.*, 46: 506. 1913.

4 Starling, "Human Physiology," p. 758. Philadelphia. 1926.

lunar valves and in this position is firmly tied. The clamp on the rubber tube is then completely opened. The filter tube is raised to enclose the heart and its top closed with moist cotton.

For perfusion simply to maintain the heart-beat as long as possible we have had the greatest success with Locke's fluid as given by Baylis,[5] with the difference that it was buffered with 100 mg of sodium bicarbonate and 50 mg of primary sodium phosphate per liter.

We have found that the size and shape of the cannula and the care with which it was tied in the proper position in the aorta were very important in the success of the experiment. The cannula must be sufficiently large to permit the fluid expelled by the beating heart to flow rapidly back through it. The tip of the cannula must be above the semi-lunar valves so that at the beginning of the beat the full pressure of the perfusion fluid is not exerted on the wall of the ventricle. A complete relaxation of the ventricles is necessary to insure a proper perfusion of the coronary vessels. This will not be possible if the cannula projects beyond the semi-lunar valves into the left ventricle and maintains a constant distention of the ventricle. Even when the cannula is correctly inserted a certain amount of fluid accumulates in the ventricles. This may come from leakage past the valves or from the Thebesian vessels. It is for the rapid release of the pressure of this fluid as the heart contracts that it is necessary to make the aperture of the perfusion cannula as large as possible. If, in spite of all precautions, a distention of the ventricle does develop during the experiment it may be relieved by inserting a cannula through the pulmonary vein and the mitral valves into the ventricle. It is obviously necessary to be certain that the tip of the perfusion cannula does not project so far into the aorta that its wall occludes the opening into the coronary arteries.

As the perfusion continues, the pressure in the gasometer is maintained at a constant level by admitting oxygen from the tank as necessary. Oxygen is permitted to bubble slowly through the perfusion fluid by adjusting the level of the funnel of the trap. If the fluid in the flask becomes exhausted it is merely necessary to fill another flask and replace the one originally used.

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SPECIAL ARTICLES

THE PERIHELION OF MERCURY

THE law of Newton states that every particle of matter in the universe attracts every other particle with a force that varies directly as the product of the masses and inversely as the square of the distance. For two bodies this law gives accurate results (a), as they are very far apart and (b), as their dimensions are small in relation to the distance between them but, when two bodies of substantial size are near together and when a small body is near to a large one, there is ground for doubting its precision.

Let the formula for the force of gravitation F, be written,

$$F = G\frac{M_1}{d} \times \frac{M_2}{d}$$

G being the gravitational constant, M_1 and M_2 the individual masses of two bodies and d the distance between their centers. From this it may be inferred that gravitation is the resultant of two forces each varying directly as the mass which produces it and inversely as the distance from the other. These forces are directed toward each other. Each acts at the distance d from the other and their product is the resultant which is called Gravitation.

If the above proposition be true, then the actual attraction between two spheres can not be the same as that which is computed on the supposition that the entire mass of each is concentrated at its center as on the basis of the inverse square.

In Fig. 1, M_1 and M_2 are homogeneous spheres, M_2 being very small, and $M_1M_2 = d$. The inner circle

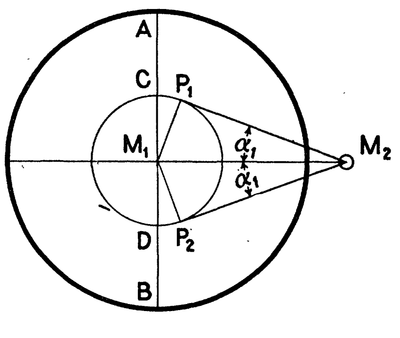

FIG. 1

CP_1P_2 DC is drawn so that $M_1C = 0.4244 M_1A$ and it is, therefore, the locus of the centers of gravity of all the halves of the circle AB which is a diametral section of M_1; M_2P_1 and M_2P_2 are tangents to this circle and P_1 and P_2 are the points at which the resultant attractions on M_2 of the upper and lower semi-circles of M_1 may be considered as concentrated. The value of the attraction of each of the semi-circles, if a rep-

5 Baylis, "Principles of General Physiology," p. 211. London. 1927.