SOME PROBLEMS OF THE EXTRACORPOREAL CIRCULATION*

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The problem of the 'dry heart' has been with us for many years and any progress in this subject is bound to bring with it an increase in our knowledge of the circulation. At St. Thomas's Hospital in London for the past 5 years my colleagues Drs. Kent Harrison and MacMillan and I have had a modest research programme devoted to learning something of the difficulties imposed by the interruption of the circulation.

Up to 2 years ago our energy was devoted to developing and learning something of the limitations of the technique of surface cooling in hypothermia. The reduction in cellular metabolism appeared to be an ideal method of achieving a temporary interruption of the circulation. It is true to say that hypothermia has not lived up to our original expectations. The main problem is to explain the reason for the increased irritability of the myocardium as the temperature falls. There are 4 favourite theories concerning factors which may account for this, but in none is the evidence conclusive.

1. Anoxia—low oxygenation of the coronary blood.
2. Electrolyte Changes, particularly rise in ionized calcium·
3. Alterations in the pH of the Blood.
4. Excess of Catechol Amines i.e. adrenaline or noradrenaline.

Today, hypothermia is used clinically down to 30°C (normal, 37°C) and this allows the surgeon approximately 10 minutes in which to carry out some intracardiac procedure. Meanwhile our attention has been turned to the other possible line of approach to this problem, namely the extracorporeal circulation.

I feel it would be very wrong to create the impression that we have been or are contributing anything original in this field. Our aim has to be to learn the difficulties involved, and as there are so many little problems it seems clear that progress will be made only if each group of workers fully discusses its failures.

There are two big subdivisions in the type of mechanical pump that can be used. In the first, the principal aim is to supply only a limited quantity of oxygenated blood to the brain and vital organs, and no attempt is made to ensure an adequate flow. These machines are called 'low-flow oxygenators' and the Lillehei machine is the best example. The principle is based on the finding of Andreasen and Watson (1953) that at normal body temperature the dog requires only the very low flow of about 50-60 ml. per minute to maintain life during a period of occlusion of the heart from the circulation. Dr. Lillehei with his bubble oxygenator has applied these findings to man and has now performed many successful operations with this technique. Our experience with this type of oxygenator was very satisfactory but it was difficult to obtain more than 200-400 ml. of oxygenated blood per minute. Physiologically it would not seem correct to supply a very reduced flow of blood to the vital organs, but rather to try to perfuse all the body with the same flow rates as it would normally receive. Here the problem immediately grows, and machines of the 'high-flow' type are more complex.

I have had the honour of working in Dr. John Gibbon's laboratory in Philadelphia, USA. For nearly 15 years now he has pioneered the development of a machine capable

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of handling the whole circulation, and the recent reports of the application of this machine for human cases at the Mayo Clinic have more than justified the enormous effort that has been made. The Gibbon machine is extremely complex but essentially it consists of a metal screen oxygenator and rotatory squeeze pumps. In England we are using the Melrose pump, which incorporates compression pumps and a rotating disc oxygenator. Whatever the machine, the problems are still the same. First and foremost is the training of a team that is familiar with all the problems involved. In this type of work the days of the one-man band are over, and progress will only be made by a conjoint effort.

There are a certain number of factors involved that, in the light of our own experience, deserve special mention.

Donor blood. In human cases this is no problem because there are ample supplies of fresh blood available. The oxygenator and pump must be primed with freshly taken heparinized blood. In dogs the supply position is far more difficult and a mixed supply of mongrel blood appears to be better than that of a single pedigree donor such as a greyhound. The blood must be freshly taken and should not be stored, for the use of stored blood leads to continued bleeding at the end of the experiment.

Blood volume. Minute care must be taken to assess any alterations in blood volume. All quantities infused or lost through haemorrhage must be calculated and recorded. In nearly every case there is a distinct tendency to overload the circulation with fluid.

Blood flow. In animal work the blood flow per minute is related to body weight for simplicity, but in man it should be represented as the number of millilitres per minute per square metre of body surface.

In dogs, a good perfusion is one in which the flow is great than 70-80 ml./min./kg., i.e. 700 ml. per minute for a 10 kg. dog. In man the ideal flow rate is 2·2-2·5 litres per minute per square metre of body surface (Kirklin *et al*, 1957). Flows lower than this tend to cause inadequate perfusion of the tissues and a severe metabolic acidosis develops during and after the perfusion.

Venous drainage is best performed by gravity drainage rather than by mechanical sucking and the optimum height can be calculated before the pumping commences. Too great a venous suction will only result in collapse of the vessel walls. The venous catheters are placed one in the superior vena cava through the azygos opening and one in the inferior vena cava through the right atrium. The aterial perfusion in dogs is done through the carotid artery, and in man through a branch of the subclavian.

Blood coagulation. The animal is heparinized on the basis of 2 mg. of heparin per kg. of body weight. Each pint of blood is taken into a solution containing 25 mg. of heparin and 50 ml. of 5% dextrose solution. At the cessation of the artificial circulation the animal is given 2 mg./kg. of protamine sulphate to aid clotting. After a few minutes an intravenous infusion containing 100 ml. of saline with a further 2 mg./kg. of protamine is commenced at a very slow rate and the total quantity is given over the next 3 hours.

Air emboli. Particular care is taken to siliconize the whole machine before commencing the experiment and then to circulate the blood well before use to remove any small air bubbles that might be adhering to the tubing walls. A filter of some type is necessary to ensure that no fine clots are injected.

Significance of arterial and venous pressure. Both are important measurements which reflect on the progress of the artificial circulation. A rise in venous pressure during the circulation suggests that there is a partial obstruction to the venous catheters and this must be remedied immediately. After the pumping, a rise in venous pressure indicates either a failing myocardium or overloading of the circulation with fluid.

Anaesthesia. One of the principal features of all cases involving extracorporeal circulation is the prolonged time taken both in the dog and in man to recover consciousness. It is important, therefore, to use only the minimal anaesthetic requirements and, in particular, those that can be eliminated rapidly at the end of the circulation. The possible causes of failure, and thus death of the experimental animal, are legion in this type of research. Yet after training and removal of obvious errors of technique there still remains a disturbingly high mortality. As yet no one major factor has been elucidated. In the first 12 hours after the conclusion of the experiment the animal requires constant attention to replace haemorrhage, sustain the systolic pressure, and prevent pulmonary collapse and many other hazards that lie in wait.

To end on a personal note, I do not think I know of any other type of experimental work which is so completely and continuously demanding of our attention and yet is so often attended by a frustrating result. This can only mean that we have a lot to learn.

REFERENCES

Andreasen, A. T. and Watson, F. (1953): Ann. Roy. Coll. Surg., **12**, 261.

Kirklin, J. W., Patrick, R. T. and Theye, R. A. (1957): Thorax, **12**, 93.