Invited Lecture

TO LIVE WITHOUT HEART AND KIDNEYS*

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ARTIFICIAL HEART INSIDE THE CHEST

The irreparably sick human heart will be replaced in the near future by a mechanical pump. Although I have been told that nobody will want such a machine inside his chest, I think that the person who said this did not realize that for the person who really needs it, the alternative is not popular either.

An artificial heart should not be put in an animal before it is determined whether or not it works in a test circulation. Perhaps the most important thing to find out is whether or not an equilibrium exists between the right side and the left side.

If an artificial heart is any good at all, the right side and the left side should pump equal amounts and, consequently, in a mock circulation, the levels in the right atrial and the left atrial reservoirs should remain constant. You can accomplish this if you make each side of the heart respond to the venous pressure of its own side. In other words, if each side follows Starling's law.

There are many ways in which you can make an artificial heart. In 1959 we had an artificial heart inside the chest driven by solenoids (magnets) arranged in a rosette\(^1\). When these solenoids contracted they compressed oil and the oil in turn compressed the ventricles.

This heart was put inside a dog after its own heart had been removed. It so happened that the dog's heart had failed to beat after a mitral valve had been put inside - so, too, the first patient to become a subject for an artificial heart might well be one in whom a valve replacement has failed. This dog then, with an artificial heart inside the chest had a normal arterial pressure.

We took it to the image amplifier of Dr. F. Mason Sones, Jr., and he injected contrast material into the right atrium. It was a remarkable sight to see the contrast medium flow through the dog's circulatory system. There was no pulmonary oedema and there were normal markings of the pulmonary circulation.

You can drive an artificial heart in a relatively simple manner, or you can drive it in a complicated manner that may be useful if you want to study, for example, the effect of various forms of pulse waves on the physiologic functions of the animal\(^2\). Moreover, we can follow the movements of the ventricles on an oscilloscope. One line indicates the movements of the right ventricle, and another line indicates the movements of the left ventricle. From this we know the cardiac output from stroke to

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stroke, from minute to minute, from hour to hour, and, we hope, eventually from year to year. This should give us an advantage over the clinician, who can only guess at the cardiac output.

We currently prefer to drive the artificial heart with compressed air. A motion picture film shows a dog with an air-driven artificial heart inside its chest. Five hours after its own heart was removed the dog drinks water. Eight and ten hours after replacement of its own heart, the dog is on the floor eager to be petted.

Technically successful experiments in dogs always ended in the same manner, and that was with thrombosis inside the heart and the formation of emboli\(^3\). We undertook an extensive study to determine the principles that govern the formation of thrombosis on plastics implanted inside the natural hearts of dogs. From this we deduced the rules that must be followed to avoid the occurrence of thrombosis on plastics in the heart, and they are:

1. The plastic should be smooth, not rough.
2. The plastic should be exposed only to high-velocity flow.
3. Dead pockets of stagnating blood must be avoided.
4. The insertion lines, seams, or suture lines, should be screened off from the blood flow, or be exposed to high-velocity flow.

Today, we make artificial hearts according to a model worked out by Dr. Tetsuzo Akutsu, formerly in our department, which we have called the sac heart\(^4\). Air is blown into a cavity between the artificial ventricle and a relatively rigid housing. This air compresses the ventricle and pushes the blood out towards the aorta or pulmonary artery. We can make these hearts out of one piece so that we avoid seams and suture lines. A cast is made of Cerrotru, a metal with low melting point, and two ball-valves are placed in the sites of the aortic and mitral valves. Then, the cast is further finished and polished, and it is then layered or dressed with sheets of uncured Silastic, a silicone rubber.

When layering of the heart is completed it is baked in an oven - this vulcanizes and cures the Silastic, and at the same time it melts out the Cerrotru cast. The balls for the ball-valves can withstand the heat and remain in the proper place over the valve seats.

For our experiments we use calves because they take artificial hearts the size of an adult human heart. Also, the clotting problems are perhaps less difficult than they are in dogs.

We have been able to maintain the circulation of a calf for 30 hours after removal of its natural heart\(^5\). When the artificial heart failed it was usually because of mechanical failure. Our hardware and software are not good enough, but so far we have not lost a calf from thrombosis and embolism, which makes me end my presentation with an optimistic note.

In brief, I believe that the symbol of life, the site of love, and the habitat of the soul, the human heart, will be replaced by a mechanical pump.