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TWO APPROCHES TOWARD A TOTALLY IMPLANTABLE ARTIFICIAL HEART

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We have been developing two different types of totally implantable artificial hearts; a pulsatile motor-driven assist pump and an intra-cardiac axial flow pump. Each system has different advantages. The pulsatile pump maintains the circulation physiologically for a long period. On the other hand, the nonpulsatile pump has simple structure and small volume. *In vitro* and *in vivo* tests show that the pulsatile motor-driven assist pump system has adequate hemodynamic performances, high actuator efficiency, and long-term durability. *In vitro* studies also indicate that the intra-cardiac axial flow pump is a feasible implantable artificial heart.

The motor-driven assist pump consists of a brushless direct current (DC) motor driving a miniature ball screw, a pusher-plate type blood pump (stroke volume: 65 ml), a compliance chamber (volume: 70 ml), and a controller. The blood pump and the actuator are magnetically coupled. During a diastole a vacuum pressure less than -25 mmHg is applied to the blood pump. The motor-driven assist pump (actuator and blood pump) displaces 350 ml. Stroke of the blood pump is controlled by a PID-follow up controller on an 8-bit one chip microcomputer. Pusher-plate position and motor speed are measured using pulses from a magnetic encoder. The controller compares the actual pusher-plate position with the reference pattern stored in a ROM, and regulates motor current so that the pusher-plate follows the preset pusher-plate trajectory.

The pump was tested *in vitro* for 87 to 14 days. A pump flow of 4.8 to 4.2 l/min was obtained with a motor input power of 5.6 to 4.7 watts. Efficiency (pump output/motor input) was 21 to 17 %. Temperature rise of the actuator from room temperature was less than 11 to 6°C. An acute implantation of the assist pump was conducted in two sheep (81 and 91 kg) between the left atrium and the aorta. Maximum temperature of the actuator was 41 and 40.5°C.

The intra-cardiac axial flow pump is implanted at the heart valve position while preserving the myocardium. The axial pump consists of an impeller, a DC brushless motor, and a seal. The impeller has an outer diameter of 22 mm and a boss diameter of 13 mm. The impeller has four vanes. An outer discharge angle of the vane is 19.2 degrees. the motor has a torque of 0.013 Nm at a motor speed of 9000 RPM. The motor is water-proofed by a ferrofluidic seal. A maximum seal pressure is 220 mmHg at a motor speed of 9000 RPM. The seal has a shield to prevent the magnetic fluid from leaking into the blood. The axial flow pump displaces about 21 ml.

A flow of 5 L/min was obtained at a differential pressure of 95 mmHg at 6780 RPM *in vitro*. A flow of a 13.4 L/min was obtained at a pressure difference of 100 mmHg at 8730 RPM. The seal was perfect at 9000 RPM against a pressure of 150 mmHg over 24 hours.

In conclusion the pulsatile motor-driven assist pump and the intra-cardiac axial flow pump are promising as a totally implantable artificial heart.