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Development and Implantation of Pendulum-Type Moving Actuator Total Artificial Heart (Korean Heart) for Human-size Animal

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= Abstract =A new version of a moving actuator electromechanical total artificial heart was designed to improve the total efficiency, durability, and fit inside the thoracic cavity.

Compared with our present type of rolling-cylinder actuator, this new model has a pendulum-type actuator with reciprocating motion around a fixed circular path connected through the gear mechanisms to the motor. By using this mechanism, efficiency and durability improved by replacing the sliding mechanism with rolling contact elements. Also, the height of the pump decreased from 9 cm to 7 cm with a static stroke volume of 65 cc.

With this new pump, we performed two animal experiments. We also evaluated the engineering feasibility of implanting this pump into a small, human-size animal (less than 70 Kg).

Key Words: ***Moving actuator, Pendulum-type pump, Tether-free, Human chest cage***

INTRODUCTION

The objective of this paper is to present a new type (pendulum) of moving-actuator, electromechanical artificial heart. In our previous paper (Min *et al.* 1989), we reported the mock-circulation and animal experimental results of the moving-actuator pump based on a rolling cylinder mechanism. This rolling cylinder pump decreased the total size of the implanted pump to occupy a total volume of one ventricle and one actuator size, compared with two ventricles and one actuator size of the conventional pusher-plate motor-driven pump. However, the rolling cylinder pump has two problems that need improving. One is the mechanical contact and its energy loss on the bottom rack and the side's guide bar. The other problem is the relatively long length of the flexing which corresponds to the center length of the actuator's circular path.

The present new pump based on pendulous motion has corrected the above two problems while maintaining the advantage of the moving-actuator type's small total volume.

We also evaluated the engineering feasibility of implanting of our new pump into a small, human-size animal (less than 70 Kg), compared with our previous experiment and other groups' implantations into large-size animals (more than 100 Kg body weight) (Min *et al.* 1988; Pierce 1986; Jarvik *et al.* 1978).

MATERIALS AND METHODS

Blood Pump Design

The pendulum-type actuator is composed of three main parts: a brushless DC motor, three-stage planatary gear, and a fixed gear with a shaft for pendulous motion. Figure 1 shows the schematic diagram of the pendulum-type

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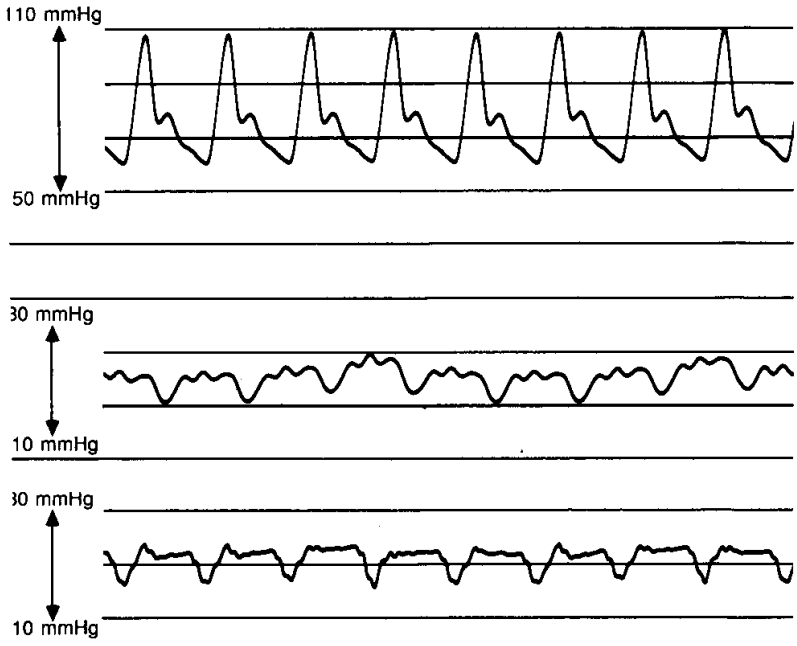

Fig. 7. Waveforms of AoP, LAP, and RAP of the implanted TAH (Top: AoP, Middle: LAP, Bottom: RAP).

stopping time at the end of each stroke in our pump without any additional compliance chamber. As discussed in in-vitro results, this maintenance of low atrial pressure without any compliance chamber may be possible due to a large variable volume space and flexible pump housing. But we need a more exact estimate of the variable volume size and careful experiments dealing with the imbalance problem of our new pump, since the volume size is a critical parameter of the imbalance operation in the case of tissue encapsulation of the implanted TAH.

A small degree of adjustment of the atrial pressure level was possible even with a moderate degree of active suction by an actuator attached to the outer sacs. In addition to the volume difference in the left and right sacs by 10%, this controller adjustment of the stopping time was necessary to maintain a mean atrial pressure of less than 15 mmHg for both left and right ventricles.

At the end of the experiments, we tried a tether-free operation using a battery and a portable controller for 10 minutes. After 10 minutes, we returned to the computer control, as the logic circuit became unstable with low battery storage power. However, this shows the possible advantages of the electrical type total artificial heart in comparision with the pneumatic type (Weiss *et al.* 1989).

In conclusion, our moving actuator pendulum pump showed the engineering feasibility of implanting a TAH inside the human chest cage by means of a tether-free operation. Before carrying out long-term survival experiments, we need more time to improve the pump's function and reliability. But this implantation of an electrical pump inside of the thoracic cage of a human-size animal (less than 70 Kg body weight) is the first reported case to our best knowledge.

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= 국문초록 =

원추형 이동작동기 방식 완전 인공심장의 개발 및 동물 실험

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기존의 이동작동 방식 완전인공심장이 갖고 있는 단점으로는 좌우 받침대(guide bar)의 마찰로 인하여 효율이 낮고, 전체 부피가 크다는 점이 있었다. 따라서 이러한 형태는 사람 크기의 동물을 대상으로 하는 이식실험이 불가능하다. 이에 대한 해결 방법으로 고정기어(fixed gear)를 이용한 원추형 이동작동기를 새로이 설계 및 제작하여, 펌프의 효율을 20% 정도 높이고, 전체 부피를 18% 정도 축소시켰다. 이 새로운 완전인공심장을 가지고, 사람 크기의 70 Kg 이하의 양과 소에 대한 이식실험을 수행하여 각각 5시간 및 12시간의 생체내 구동실험을 수행하였다. 이러한 동물실험을 통하여, 본 연구팀이 개발한 원추형 인공심장이 사람크기의 동물 흉곽 이식 가능성을 확인하였다.