BE302 Biofluid Mechanics

# Brief Discussion of The Artificial Heart:

# Using the Japanese Engineering Point of View

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Behind the dramatic advance of the medical technology, the artificial heart has been developing since the tragic accident which was occurred in 1982. According to TIME Magazine, “Washington dentist Barney Clark (suffered) 112 miserable days to die after being fitted with the Jarvik-7 heart back in 1982.” During the four months of his life with the Jarvik-7, he experienced convulsions, kidney failure, respiratory problems, a mental instability, and, finally, multi-organ system failure. This was not the idea of the artificial heart, which is supposedly to help the patient and not involving the new problem. However, this artificial heart, the Jarvik-7, named for its designer, American physician Robert K Jarvik, was an innovative product at that time.

Thus, because of indecisive results, not only the artificial heart but also the research in this field was stuck with the label, “Dracula of Medical Technology” (Lemonick). However, even though the artificial heart could be named “Dracula” permanently, the research has been continuing since then. Because Time Magazine reports, “every year some 105,000 cardiac patients require a heart transplant, and only about 3,000 hearts become available.” Thus, while the patients’ lives are getting shorter and shorter, they wait for the next available heart, or just wait for their hearts to stop completely. Considering the demands from patients who have heart diseases, the artificial heart has been developed as an alternative to heart transplant as replacing all or part of their failing heart. Recently, the concept of the artificial heart is changing from temporary to permanent solution of heart disease; on the other words, the role is from the bridge of the heart transplant to permanently to keep patient’s life.

In order to understand the artificial heart more, the purpose of this paper is to briefly focus on an entire field of the artificial heart and to go over the situation of the Japanese artificial heart as well.

1. Blood pump.

The main purpose of the artificial heart is to work alternately as a blood pump for the body. The Encyclopedia of the Medicine by the American Medical Association defines; the artificial heart as “an implantable mechanical device that takes over the heart’s action in pumping blood to maintain the circulation.” The basic figuration of the artificial heart is that the incoming and outgoing entrances are connected to the right or left atrium and ventricle respectively. Typically, because of creating the pulsatile flow, the artificial heart has the artificial or biological valves in each entrance. Moreover, driving as a blood pump, the artificial heart is controlled three different ways. One is to synchronize the right and left pumping motion. The second is to synchronize right and left pumping, but there have the phase difference 180 degrees to each other. The third method of driving is to desynchronize the right and left pumping motion. In addition, depending on the patients’ condition such as the types of congenital heart disease, the artificial heart supports the right side of the heart, the left side, or both sides. Therefore, even though many types of artificial hearts have been developed, they could be categorized into three major groups: the intraaortic balloon pump (IABP or IAB), ventricular assist device (VAD), and total artificial heart (TAH).

Working as a replaced heart, the artificial heart has to be considered in many aspects. The inside of the artificial heart, especially the place which contacts the blood directly, is trying to use material which has the characteristics of antithrombotic materials because the antithrombotic is known to be the main failure of the artificial heart. Moreover, the artificial heart is designed not to disturb the anatomical position of organ functions, and its specific density is kept to one. In order to prevent hemolysis and blood clotting, the shear stresses of the blood have to be measured and controlled.

2. Energy source.

It is roughly known that the artificial heart needs to drive approximately 1W in resting respiratory level and 5W in moving one; however, considering the energy conversion efficiency, the artificial hearts would need more than 10W. One idea has come up, although it is not an acceptable power source to the human life. The nuclear power is the best solution to keeping constant such energy levels to the artificial heart. Therefore, the easiest way of supplying the energy to the device is the electrical energy, instead of using nuclear power. Electric energy is able to transfer and store it in existing device -storage cell-, which is placed in side the body.

Even though the energy source is ready to use, next question has come up, “how it does transfer from.” Two possibilities are available; one is to make a hole on the body, and the second does not have to make a hole. Biologically, the points which connect the inside to the outside body by using the common electric wire and the tube have a huge chance of infection, so highly familiarized materials to the body such as hydroxyapatite would be used to compose the access plug in which the electric wire and the other pipe is placed. On the other hand, avoiding the high possibilities of infection, another method, which does not require making a hole on the human body, has been developed. This idea tries not to get infection, and it helps more patients without recognizing they are connected.

Without making the hole on the patient’s body requires the transcutaneous transfer system, which uses the law of electromagnetic induction. This theory is the same concept of the electric transformer, which can transfer the electricity without connecting both ends. One end, circle shaped, is placed out side the body, and the other end is placed in side the body which should make the pair each other. This method’s total energy efficiency is estimated 80%, which is better number to drive the artificial heart.

When the energy is proofed to transfer from outside to inside of the body, before

spending this energy, it should be stored in the charging battery which is placed inside the body. This is considered that the compositions of the charging battery are LiF, NaF, or $MgF_2$ salt, which can store about 128Wh of energy, so if using this energy transfer system and keeping this method, the artificial heart could be driven for 8 hours completely working independently.

3. Transducer of energy.

Basically, the pumping device of the artificial heart can be categorized as outside or inside of the body. Because the heart is the main part of the whole body, the artificial heart needs to have strictly controllable pumps, measuring systems, and intelligent controlling systems; therefore, the whole system of the artificial heart is so big to place inside the body. However, technological improvement has enabled to develop a smaller size of the artificial heart more effectively. Subject to this, it is already mentioned in preceding clause, the artificial heart is divided into three major groups: the intraaortic balloon pump (IABP or IAB), ventricular assist device (VAD), and total artificial heart (TAH).

The intraaortic balloon pump (IABP) is “an intravascular catheter-mounted counterpulsation device with a balloon volume between 30 and 50ml”(Braunwald). Because the balloon is inserted into the aorta by repeated balloon inflation and deflation in less than 0.5 litter/min, the greater systematic circulation could be supported. Thus, it is possible to reduce “the peak left ventricular pressure and myocardial oxygen consumption”(Braunwald). Because of the constant inflation and deflation of the balloon, the IABP is able to create counterpulsation which could be the patients who have the ventricular tachyarrhythmias.

Compared to the IABP, the ventricular assist device (VAD) mimics natural heart motion more closely. As the word mentioning the meaning of the device, various types of the mechanical blood pump support or replace the function of the right, left, or both ventricles. The

basic concept of the artificial heart is the blood pump, so a lot of hydrodynamic engineering knowledge was involved to develop the VAD, which can be categorize into three major groups: the roller, centrifugal, and pulsatile pump.

The roller type VAD is known as the heart assist machine in the operating room. Using the inflatable and deflatable tube, when the rubber roller rotates around that tube, the roller pushes the tube to move the blood forward constantly. Because of this simple mechanism, the roller VAD can be operated very easily and made very inexpensively. However, this device has the flow limitation such as nonpulsatile flow, and the device can be the reasons of blood trauma and the systemic anticoagulation. Although this device is simple to operate, it requires short-term use and constant supervision.

The centrifugal VAD is also widely available in the operation room, nowadays. Because of its simple mechanism (the centrifugal pump), it is easy to operate, to get without paying high costs, and is durable against the blood. However, because of its mechanical characteristics, the centrifugal VAD cannot create the pulsatile flow which affect is not known on the patient. Moreover, this device strongly requires full systemic anticoagulation and constant supervising.

The developers think the pulsatile VAD is the more ideal artificial heart, but the system of the artificial heart would be complexed mechanical system, which makes increasing the device price. Even though the pulsatile VAD is expensive, its pulsatile flow and low blood trauma rate attracts patients more and more. This device is becoming more widely acknowledged and available. In addition, its most advanced technology does not really require constant supervision because this device comes with the most intelligent measuring and controlling unit. Recently, because the effectiveness of the pulsatile VAD is recognized, it has been studying and developing all over the world.

Approaching the artificial heart from a different aspect, the most ideal stage of is to develop the total artificial heart (TAH), which gives the hope of life to the patient because the cardiac patients do not have to wait until the transplantable heart is available. The tragic accidents recall people's memory, "though the TAH is the biventricular device that is able to replace from failure natural heart, can you live with TAH, but it might be waiting the miserable days?" However, the persistent doctors, engineers, and scientists have been trying to solve this chaos, and the pneumatic and electric TAH can be the solutions of the extrication from the suffering.

4. Story from the transpacific islands.

In Japan, cardiac patients had very long hard time because the real organ transplants law was finally enforced in 1999, in which the US and all around the countries have already began real heart transplant operation actively. Thus, up to 1999/still now, if cardiac patients need to have heart transplant surgery, the best way was they had to go to the USA for the transplant surgery because the Japanese government prohibited the real heart transplant surgery. Therefore, the second choice was getting more common that they had to use the artificial heart from the US, which artificial heart size is usually bigger than Japanese people's heart size. This using artificial heart was not illegal medical technic. In addition, usually, the price of the artificial heart is three times more expensive than in the US, which is higher than buying round trip airline tickets. Thus, high demands of developing domestic artificial heart have came up.

In spite of the fact that Japan is known highly advanced country of engineering and medical science world, Japan cannot compete in the field of biomedical engineering against the United States of America. It is general speech in Japan that not only the artificial heart but also all kind of the medical devices are usually made in the US or the US companies. This story is

told by the medical doctors of the writer that Japanese medical doctors recognize Japanese medical devices are available on the market, but they do not prefer to choose Japanese ones. Most of the time, they choose US devices because they are a better quality and tested compared to their own country's products. The artificial heart is also same situation, so expensive imported artificial heart is placed in cardiac patients' body. This is strange enough, but this is the real situation of Japanese medical and engineering field.

Although "made in Japan" artificial heart is not available on the Japanese market, research of the artificial heart is very actively performed entire country. The Department of Biomedical Engineering, University of Tokyo, known as the highest level of the universities in Japan, documents the world longest surviving record of the goat implanted the total artificial heart (TAH). Thus, the study level of Japanese artificial heart can be compared to the US study level. Because the US artificial heart is more tested than Japanese does, the US artificial heart is best model of the Japanese artificial heart.

Recently, the Research Institute of the National Cardiovascular Center (NCVC) and many universities are trying to make the completed products of the artificial heart. Especially, the NCVC is pressing on with leading-edge researches such as the perfect shape of TAH and centrifugal pumps. The NCVC is trying to develop the artificial heart from the medical side, and the Mechanical Engineering Laboratory (Agency of Industrial Science and Technology, Ministry of International Trade and Industry) is also hardly trying to design the artificial heart from the engineering side.

The writer still remembered that medical TV documentary reported one cardiac patient's speech, who was implanted the artificial heart, "as soon as I get up, I always make sure the mechanical rhythmic beats can be heard, and realize, 'I am still living.' Thank you for my new heart…" Even though some points of view define the artificial heart is "Dracula," others think the artificial heart is "Savior." Because of the mystery of the human body, it does require huge amounts of time to clear the mystery. As well as the artificial heart, it has been developed since 1960's, but it has never reached completed man made artificial heart. However, in the near future, it will be possible to see that the human made machine keeps humans alive.

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