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Final Paper

A Suitable Replacement Heart

Statement of Problem

For a long time, scientists and doctors alike have been trying to engineer an efficient man-made heart. Today, estimates suggest that although 35,000 Americans could benefit from a heart transplant, fewer than 4,000 actually place themselves on the waiting list. Given that only 2,200 hearts are donated per year, many Americans spend months, years and even die before replacement organs are made available to them. Although patients who do receive replacement hearts consider themselves fortunate, they cannot escape the many problems that are linked to the use of donor organs, such as tissue rejection, infection, and long time compatibility.

Historical Background

The quest for replacement body parts has interested the scientific community since ancient times. In ancient Egypt, healers grafted human skin to the faces of disfigured warriors to improve their appearances. Since then, the process, called transplant, has been broadly defined to refer to the transfer of any organ or tissue from one part of the body to another or from one body to a different body.

As the importance of the human heart is increasingly recognized by the medical community, more and more engineers are interested in its design in hopes of creating suitable replacements. For the most part, their attempts have been largely unsuccessful.

The first artificial heart patent was filed in 1956 by Dr. Paul Winchell. The principles of his model were similar to that which Dr. William Kolff of the University of Utah Medical School had been working on for some time. In 1957, Kolff transplanted a version of his model into the chest of a dog. The experiment was regarded as a failure since the animal only lived for ninety minutes after the operation, yet pioneers were hopeful that future trials would yield more fruitful results.

In 1972, Robert K. Jarvik managed to develop out of aluminum, polyester, and plastic the first human artificial heart. He named it Jarvik 3. Cows implanted with this device can live up to four months with little or no medical intervention. Four years later, Jarvik improved his design and created Jarvik 7, a two chambered device made of polyethylene with valves molded inside. Jarvik 7 ran on compressed air provided by an exterior air compressor connected to the artificial heart by a short, flexible tube, keeping a calf alive for 268 days. In 1981, Jarvik 7 was approved for human implantation.

In 1982, the first human artificial heart was placed in the chest of Dr. Barney Clark, a 61-year old Seattle dentist. Clark was dying from cardiomyopathy, an irreversible, degenerative disease of the heart muscle that eventually rendered his condition so bad that he was classified as a Class IV patient. He was not eligible for a heart transplant and would not survive if taken off a heart-lung machine following open-heart surgery. An artificial heart implantation was the only choice left. Thus, when his situation worsened, Clark willingly served as the artificial heart's first human guinea pig.

Surgeons William DeVries and Lyle Joyce used the two top atria chambers of Clark's heart to anchor Jarvik 7 in a procedure that lasted seven and a half hours. Although the operation prolonged his life by 112 days, Clark suffered from leaking lungs, seizures, and a broken valve before finally succumbing to complicated infections that resulted in multiple organ failure.

After Clark's surgery, the artificial heart was implanted in many other patients with varying degrees of success. All patients suffered from infections and tissue rejection. Their general low quality of life after surgery raised questions regarding ethics and patient care. In 1990, the Food and Drug Administration withdrew its approval of Jarvik-7 on the premise that the device was too crude for human use.

Current Techniques

Today, an artificial heart that can completely and permanently replace the functions of its predecessor without causing long-term medical complications has yet to be engineered. Most devices on the market prolong the lives of its consumers while they await replacement human hearts.

Companies such as Thoratec, VentraCor, and MicroMed Technology market left ventricular assist devices (LVAD) to ease the heart's workload. Some can be implanted directly in the aorta. Others are placed outside of the body, with input and output tubes passing through the chest and into the aorta. The latter type is used mostly in hospitals. However, LVAD's are ultimately hazardous to the health of its patients and are meant to be removed after recovery or transplant.

Drawbacks of Present Methods

The body is composed of organ systems that are innately opposed to metal, plastic, and polyester. In our internal aqueous environment, the development of infection due to the presence of a fist-sized device composed of non-biological materials is in many ways inevitable. If infection does not strike, blood clots form, leading to strokes and other complications. Decades of implantation have shown that the design of artificial hearts using anything that is not tissue can only be so successful. In most instances, the heart continues to pump although the body is no longer viable.

Even if the problem of tissue rejection is somehow resolved, mechanical devices are still ultimately subject to wear and tear. Unlike living tissue, machines cannot repair themselves and in the long run, cause damage to cellular elements of the heart, such as red blood cells.

The problem of a viable power source is also an interesting one. Most current models require the patient to carry an outside battery supply. In the past, there have been a few instances where device malfunctions have led to complications.

Due to the various problems discussed, artificial hearts today are mostly used as bridges to transplant. These devices assist in maintaining blood circulation through the body until replacement organs are made available.

A Possible New Approach: Genetic Engineering

Today, engineers hope to design a heart completely out of biomaterials. In 1997, we managed to clone a sheep from udder cells through complex genetic manipulation. Although it took 277 times before scientists finally managed to produce Dolly, the process was dubbed a success and followed up by other companies, many of which managed to produce the same result with greater efficiency.

In the following years, we succeeded in cloning pigs, calves, and many other animals. It may be possible that in the near future, we can use the process of genetic engineering to develop artificial organs for people.

The Potential of Stem Cells

Recently, there has been a tremendous stir regarding the great potential of stem cells- the premature, undifferentiated cells in the body, in the treatment of a wide range of diseases, including heart disease, stroke, spinal cord injuries, and burns. Unlike the specific adult cells in the body, embryonic stem cells can develop into a great variety of cell types, leading many to believe that they hold the answer to many medical problems.

Much research is currently devoted to understanding what directs stem cells to differentiate to serve different functions in the body. Researchers inject human embryonic stem cells into developed animals to determine if these cells can be properly engineered to produce the tissues and organs that we greatly need. Recently, scientists have succeeded in the creation of chimeras- animals genetically engineered to possess human characteristics.

Their creation, as controversial as it is, gives scientists unique opportunities to watch how organs develop, mature, and interact with each other in the body. For the first time, scientists can have as many so-called "humanized patients" as they care to generate. The possibilities of experimentation in medicine are endless.

The sheep heart is approximately the same size of a human's. Dissections have shown that the anatomies of the two are remarkably similar. We know that humans reject the blood of other animals, yet body parts have been successfully transplanted. The valves of calves and pigs are so routinely used in humans today that the process is no longer questioned. Sheep livers remarkably close to that of humans' have already been developed. It would just be a small step more to suggest that with the proper genetic engineering, the heart of sheep can be manipulated so that it is acceptable to the human population at large.

Tissue Engineering at MIT

Researchers in the LangerLab at MIT are interested in analyzing the interaction between human embryonic stem cells and different materials, in hopes of ultimately being able to repair the human heart. Initially, they used adult stem cells derived from the bone marrow as their cell source. Due to its limited flexibility, they are currently pursuing the same goal using human embryonic stem cells. Researchers culture and differentiate stem cells in vitro, target the cardiac cells in the body by applying them to an organ built on a 3-D scaffold, and then vascularize the system. Ideally, the man-made scaffold would degrade at the same rate at which new cells are produced.

Currently, cultures result in a mix of endothelial and small muscle cells. Researchers are trying to maximize the amount of cells of the type that they want by understanding which growth factors are responsible for shear and stress influences.

Conclusion

We have come a long way since Barney Clark was wheeled into the operation room on that faithful day in 1982 to receive the world's first human heart. Clark died a painful death, yet the dream of engineering a suitable heart that can completely replace that of its predecessor lives on. In 2000, Jarvik produced a new model of his design and implemented it for patient use. However, through the years, researchers have gradually stirred away from mechanical engineering in favor of tissue and genetic engineering as the ultimate solution. Today, researchers use the stem cell lines made available by the National Institute of Health and other cells lines to realize their goal.

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