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"Life 2.0: Blurring the Boundary Between our Tech and Ourselves"

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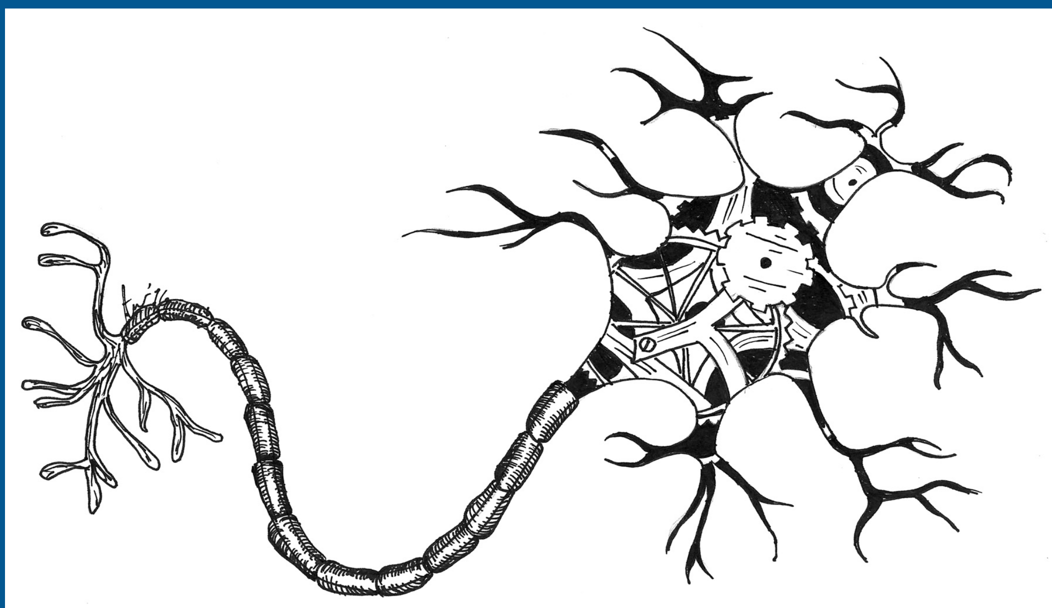

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Total Artificial Hearts

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Final Research Paper
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The medical world is facing a dilemma as the number of individuals diagnosed with heart disease and awaiting heart transplant continues to increase while the number of heart donors remains unchanged (Ryan et al, 2015). There are an estimated 2 million people living with congenital heart disease in the US, including children (Ryan et al, 2015). In addition, acquired heart diseases such as coronary artery disease and cardiomyopathies are becoming more visible as patients live longer and diagnostic technologies improve (Ryan et al, 2015). Individuals with failing hearts must meet apparently contradictory requirements in order to obtain a heart: they must be sick enough to need the heart, but healthy enough to receive and tolerate the heart transplant. This becomes essentially impossible when an individual enters end-stage biventricular heart failure, a state of disease that often indicates imminent death. A solution for those individuals, and potentially a long-term solution to the shortage of heart donors is a Total Artificial Heart (TAH).

Biology Background: The Heart

The heart is a muscle that pumps blood throughout the body, facilitating the dispersal of oxygenated blood, nutrients and hormones to organs and tissues (Weinhaus, 2015). The result is a mechanical system in which the right atrium collects deoxygenated blood from the body, pumps it into the right ventricle and into the lungs before the left atrium collects the oxygenated blood to pass it to the left ventricle to be pumped throughout the body (Weinhaus, 2015). Four valves maintain the one-way flow: tricuspid, bicuspid, pulmonary, and aortic. In addition, there is a separate vascular system specifically to provide oxygen to the heart, and the pericardium, a sack enclosing the heart, which prevents friction (Weinhaus, 2015).

The Total Artificial Heart (TAH) and a Hybrid System:

A TAH is a device made of man-made materials that replaces both biological heart ventricles and all four of the heart valves (National Institute of Health, 2012). The man-made ventricles work in conjunction with biological components of the heart and greater cardiopulmonary system: atriums, lungs, arteries, and veins. This hybrid system maintains blood flow, prevents organ failure, and allows damaged organs to recover (SynCardia Systems Inc., 2014). This is a “front-door merger” (Buchanan, 2011) of biology and technology in which scientists and doctors actively sought a technology to alleviate end-stage biventricular heart failure.

TAH therapy has been in use for over 30 years, with the first artificial heart, Jarvik-7, implanted in 1982 (Ryan et al, 2015). The SynCardia 70cc TAH, a modern version of the Jarvik-7, remains one of the most commonly used models. All current TAH models are physiologically responsive, meaning they are able to adjust the amount of blood they pump out based on the volume of blood that the body is pumping in. (SynCardia Systems Inc., 2014). The SynCardia TAH is pneumatically powered, utilizing air compression to inflate and deflate balloon-like sacs in each ventricle, pumping up to 9.5 L/min of blood through each ventricle (SynCardia Systems Inc., 2014). The use of pneumatics requires drivelines (plastic tubes) attached internally to the TAH and externally to an air compressor. Original external air sources were large and required the patient to remain in the hospital. Recent developments have decreased the size of the air compressor and patients can now carry it in a backpack (SynCardia Systems, 2014).

However, there remain multiple barriers to long-term and widespread use of these devices. Perhaps the largest issues are hemocompatibility and thrombus formation, which result when introducing a foreign object into the biological system. These cause side effects of strokes and hemorrhage in patients, leading to complicated recovery and potentially to death (Carpentier et al, 2015). In conjunction with internal complications, the use of drivelines to connect the heart to the external air compressor allows for the introduction of infections (Carpentier et al, 2015).

In hopes of resolving the biological complications, the Carmat TAH model has taken the technology in a new direction by using bio-prosthetics *(Figure 1)* (Carpentier et al, 2015). This model is made of biomaterials with the outer membrane covered in polytetraflouroethylene, a known blood-compatible substance currently used in vascular surgeries. Analysis of the devices during autopsy showed no sign of clotting or infection, indicating the potential of this model in resolving some of the barriers inherent in the hybrid system (Carpentier et al, 2015).

Additionally, there remains the issue of energy source. In contrast to the Jarvik-7 and SynCardia 70cc, which require an air compressor, the Carmat model is electrically powered and the battery is charged through the skin (National Institute of Health, 2012). This precludes the need for drivelines, reducing the possibility of infection due to skin penetration. The Carmat model utilizes a transcutaneous energy transmission system (TETS). TETS includes an internal wire coil implanted into the abdomen, and an external wire coil connected to a charger. When placed next to each other, the external charger acts through the skin to induce a current in the internal wire, providing energy to the heart system (Fu et al, 2015).

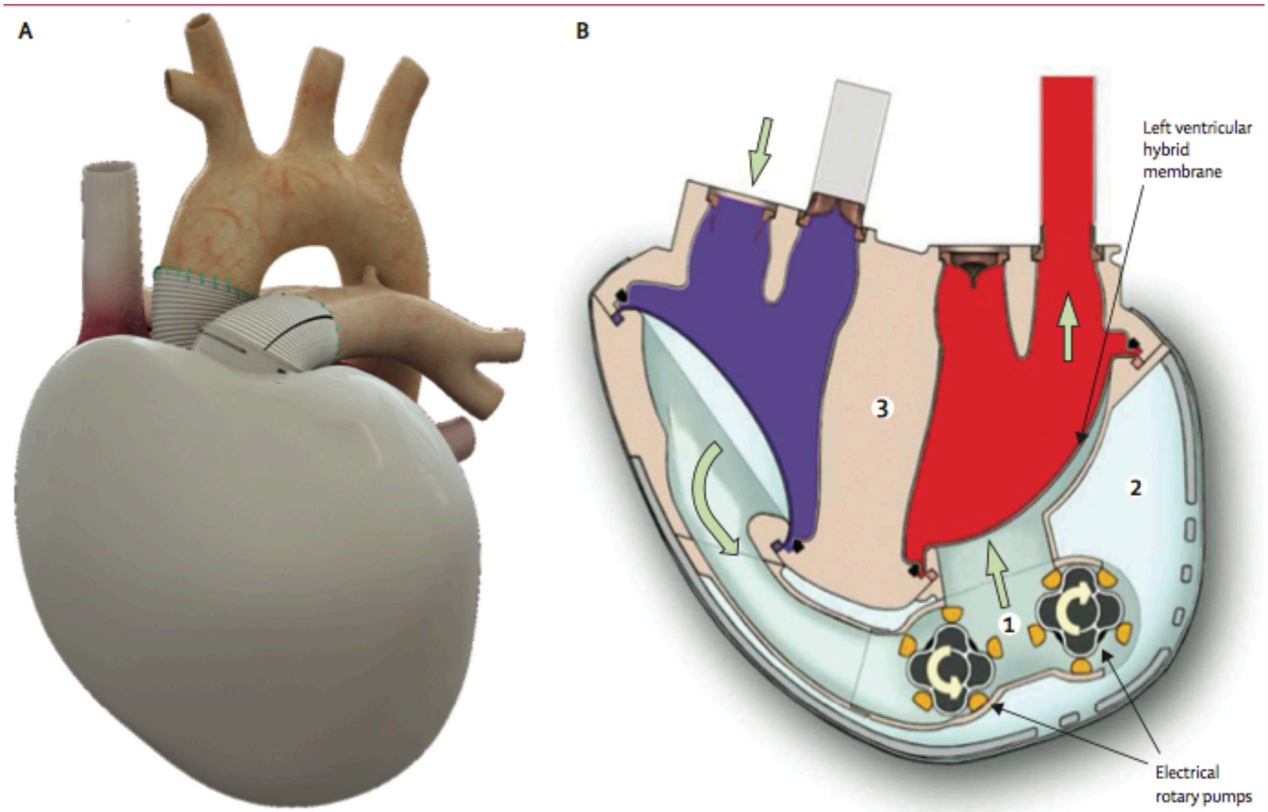

Figure 1. Carmat Total Artificial Heart external and internal views. A) the external view of the device; B) the interior functioning of the device: electrically-powered wheels (1) initiate movement of silicone oil in the chamber (2), which moves the membranes back and forth, creating blood flow through the ventricles. Electrical mechanisms are located in the central chamber of the device (3) (Figure from Carpentier et al, 2015, http://dx.doi.org/10.1016/S0140-6736(15)60511-6).

Despite these advances in technology, a remaining barrier is the actual size of the device. Current TAH models are simply too large for the chest cavity of many humans, restricting the population that is able to receive this intervention. For example, the size and weight of the Carmat TAH causes the heart to only fit 84% of men and 16% of women (Carpentier et al, 2015). To address this issue, SynCardia recently received FDA approval for a smaller version, 50cc, for emergency use in smaller patients such as women and children (SynCardia Systems Inc., 2014).

Future Directions:

Due to FDA regulations and the limitations of current TAH models, TAHs are currently used only as a temporary therapy to rejuvenate organs and bridge the gap from impending heart failure to a heart transplant. However, TAHs are already acting as a destination therapy for patients that are unsuitable for a transplant or if a donor cannot be found (Ryan et al, 2015). A destination therapy means it is the final therapy implemented, instead of acting as a bridge to another therapy. Although currently only temporary, the artificial heart will evolve into a permanent hybrid system that will treat a variety of heart diseases or even to extend life.

With artificial hearts we have the potential to resolve heart disease, prevent or treat a wide range of heart problems, and decrease the need for heart donors. The advancements in size, material, and energy source indicate the rate at which this field is progressing. Beyond use as a medical treatment, futurist Zoltan Istvan proposes that TAHs will soon become an elective surgery (2014). With technological improvements imminent, Istvan foresees a heart that will be controllable via an app. This app would allow heart rate control, monitoring of blood sugar levels, hormones, or detection of HIV, or determining blood alcohol level (Istvan, 2014). Current wearable health technology will be integrated into the artificial heart, becoming more effective. In conjunction with Ray Kurzweil's projection of the rate of technology enhancements, I agree with Istvan's view of the future (Kurzweil, 2005). Due to the potential of a technologically enhanced organ, I propose that the development of artificial hearts is simply one step in the journey to voluntary artificial organs. With these implants humans will begin the journey towards living longer without subjection to biological degradation.

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I have abided by the Wheaton Honor Code in this work.
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