Singularity now: using the ventricular assist device as a model for future human-robotic physiology

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Abstract

In our 21st century world, human-robotic interactions are far more complicated than Asimov predicted in 1942. The future of human-robotic interactions includes human-robotic machine hybrids with an integrated physiology, working together to achieve an enhanced level of baseline human physiological performance. This achievement can be described as a biological Singularity.

I argue that this time of Singularity cannot be met by current biological technologies, and that human-robotic physiology must be integrated for the Singularity to occur. In order to conquer the challenges we face regarding human-robotic physiology, we first need to identify a working model in today's world. Once identified, this model can form the basis for the study, creation, expansion, and optimization of human-robotic hybrid physiology.

In this paper, I present and defend the line of argument that currently this kind of model (proposed to be named “IshBot”) can best be studied in ventricular assist devices – VAD.

Keywords: singularity, human-robot hybrid, ventricular assist devices, ethics

Introduction

When Isaac Asimov first defined the 3 laws of robotics in the short story Runaround, he imagined a 21st century world in which a sentient machine faced the ethical dilemma of balancing self-preservation and maintaining the societal order of the laws governing human-robotic interactions.

In our 21st century world, human-robotic interactions are not what Asimov predicted in 1942 that they would be. In fact, they are far more complicated than that. Instead of having sentient robotic beings working with us to solve common challenges, the future of human-robotic interactions also includes human-robotic machine hybrids (“IshBot”, combining the Hebrew word for Man and English for Robot) with an integrated physiology, working together to achieve an enhanced level of baseline human physiological performance. This achievement can be described as a biological Singularity.

Ray Kurzweil defines the Singularity as "... a future period during which the pace of technological change will be so rapid, its impact so deep, that human life will be irreversibly transformed. Although neither utopian nor dystopian, this epoch will transform the concepts that we rely on to give meaning to our lives, from our business models to the cycle of human life, including
death itself” [1]. I propose that this time of Singularity cannot be met by current biological technologies, and that human-robotic physiology must be integrated for the Singularity to occur.

I propose that in order to meet the challenges we face regarding human-robotic physiology, we first need to identify a working model of integrated human and machine physiology in today’s world. This model should focus on the multi-disciplinary consequences of long-term machine implantation within the human host. Once identified, this model can form the basis from which we may study, create, expand, and optimize human-robotic hybrid physiology.

I propose that in order to advance towards the biological Singularity, a model for study of human-robotic physiology must have the following characteristics:

a. The robotic hybrid must be fully integrated into the cardiovascular physiology of the human host.
b. The robotic hybrid must be able to be integrated over sustained periods of time without unacceptable damage to the native physiology of the human host.
c. The robotic hybrid must interface with the human in a way that allows for the study of psychosocial effects of said integration on the human host over a sustained period of time.
d. The robotic hybrid must be integrated with the human host to allow for otherwise normal activities of daily living.
e. The robotic hybrid must enhance the baseline physiological performance of the human host.

In this paper, I argue that currently this IshBotic model can best be studied in ventricular assist devices – VAD.

**The case for IshBots**

The mere presence of foreign material within the human body does not make a human-robotic machine hybrid. Current examples of integration between machine and human may meet some of these criteria and provide insight into particular challenges faced with combining human-robotic physiology, but no example provides for a complete model for study and development as well as the ventricular assist device (VAD).

Integration of metal stents into the cardiovascular physiology has been studied since the landmark paper in the New England Journal of Medicine in 1987 [2], but the ability to use this as a model for human-robotic hybrid development has been limited in scope.

A cardiovascular pacemaker, placed into the human host as a physiological stabilizing tool in the setting of cardio-electrical disruption, meets the above laws yet it fails to significantly change the physiological nature of the host in which it is implanted. Given the dramatic potential future effect of human-robotic hybrids, a model should be identified that allows for not only significantly leaps in physiological achievement, but also significant changes to the host’s daily routines and activities as a result of implantation.

Others may point to the use of cardiopulmonary bypass or extracorporeal membrane oxygenation, or ECMO, as early examples of human robots. While these human-machine hybrids provide excellent models for the study of acute changes in integration of external devices to human physiology, they are cumbersome, require constant expert care, are mechanically wanting, and do not provide sustained enhancement of human physiology – they only correct physiological failures.

Often, the focus of developing human-robotic hybrids is on engineering structures that focus on external enhancement of the musculoskeletal system [3, 4]. Once again, while important, using this as a model for studying human-robotic physiology fails to allow for integration between robot and host, and is more of a tool comparable to a hammer than a true human-robotic hybrid. Only when the exoskeleton machine is seamlessly integrated into the human physiology will this model be a true human-robotic hybrid.

Finally, the development of a neurological hybrid between human and robot, which many would point to as the moment of true Singularity, is currently studied as an external tool via which the human brain and computers interact, and lacks true integration of a human-robot hybrid [5].

**The case for VAD as a primordial IshBot physiology**

A ventricular assist device is defined as an implantable mechanical device that pumps blood from the failed lower chambers of the heart to the rest of the body [6]. In doing so, the VAD is completely integrated into the cardiovascular system over long periods of time, and enhances the patient’s physiology to allow for increased activities of daily living over pre-implantation baseline values.

Current indications for placement of a VAD include both as a bridge to heart transplantation, and as definitive (“destination”) therapy. Patient receiving VADs generally have significant medical conditions, including depressed systolic ejection fraction, renal dysfunction, and advanced New York Heart Association (NYHA) functional classifications of heart failure [6].

The physiological risks of VAD implantation first must be considered. Currently, a patient receiving a left ventricular assist device (LVAD) must undergo a general anesthetic with invasive hemodynamic monitoring including an arterial line, central venous access,
and transesophageal echocardiography. Once general anesthesia is induced, surgical access is obtained via a median sternotomy, and the patient is connected to a cardiopulmonary bypass circuit in order to obtain access to an immobile surgical field. A core of heart muscle is removed, and the inflow and outflow LVAD cannulas are sutured to the left ventricle and ascending aorta, respectively. The sternotomy is closed, and the patient is recovered for several days in the intensive care unit. Complications are possible during each step of this process, from induction of anesthesia to discharge from the hospital.

In the absence of perioperative complications, the physiological consequences of VAD implantation are generally positive, in that improvements occur not only in the patient’s activities of daily living, but also in baseline physiological markers of organ function [7]. However, implantation and maintenance are associated with a number of potential adverse physiological sequelae, including: pump failure, hemorrhage, stroke, LVAD hardware infection, right ventricular failure, renal failure, hepatic dysfunction, and thrombosis [8].

The mechanical devices generate what is known as “non-pulsatile blood flow,” meaning that the blood entering the VAD is propelled forward at a constant rate of flow, as opposed to the normal physiology of ventricular contractions that lead to one’s pulse. While the patient’s baseline physiological state pre-VAD implantation can have post-VAD physiological effects, there are clear consequences in the human host physiology due to the implanted robotic device.

Financial consequences of IshBots

The problems we face when developing human-robotic integration are not merely physiological: non-physiological aspects of the integration must be considered as well.

The first consideration is the cost of the actual robotic implant. A HeartMate II Left Ventricular Assist Device (Thoratec Corporation, Pleasanton, CA) costs approximately $150,000. The costs of implantation, including anesthetic, surgical, and perioperative care are difficult to calculate due to patient variability, and some experts have estimated the quality-adjusted life-year mean cost of a HeartMate II to be $415,000 [9]. The life-expectancy of the LVAD recipient is improved as compared to the medical management of heart failure patients, recently estimated at 4.4 years after implantation as compared to 9.4 months with medication alone [10]. While economics of healthcare are constantly changing, there seems to be little doubt that the manufacturing of a robotic implant for integration into human physiology would be quite costly – at least using today’s technology.

Risk of complications and economic costs are not associated only with the acute event of implantation and initial hospitalization. Financial costs associated with chronic maintenance really begin after discharge from the hospital. Patients with LVAD must have routine physician checkups, device testing, and medication management in order to optimize the combined human-robotic physiology.

Psychological effects of IshBots

Psychological considerations of human-robotic hybrids have been described within the VAD population. A recent study reports that sleep imbalances, anxiety, and fatigue have been shown to occur up to 6 months post implantation [11].

While physiological consequences arise from this non-pulsatile flow, one key consequence is the lack (or great diminishment) of peripheral pulsations over arterial sites in the body. This has been described by patients privately as “living without a pulse”, and a literature search yields no studies to date that have evaluated the psychological impact of this altered physiology upon patients.

In addition to living without a pulse, psychological considerations must also be given to the fact that patients are required to “live on a battery”, with packs being changed as frequently as every 12 hours [12]. This need for “tethering” to a source of energy often leads to a significant restriction in activities of daily living. These restrictions are actually quite diverse, and range from limitations of travel, to more mundane difficulties of securing appropriate type of clothing for the patient to wear.

These psychological factors are compounded in patients with more extensive robotic hybridization, and while implantable batteries with self-regeneration properties using piezoelectric generators are under development [13], the fact remains that this issue will continue to be a factor in the viability of long-term human-robotic hybrids for quite some time.

Ethical considerations of IshBots

Human-robotic hybridization will face ethical challenges as well. The financial burdens associated with selection, implantation, and maintenance will separate along socio-economic lines, as the technology are likely to be available only to those who can immediately afford it. Future ethical considerations include potential population discrimination, either by hybrids toward those lacking physiological robotic enhancers or amongst the general population against those who are human-robotic hybrids.
Finally, ethical and psychological screenings should evaluate those presenting for hybridization not only during the implantation phase, but also during the maintenance phase, as acute psychological rejection of robotic hybrid implants is an important issue. In some cases, the removal of the robotic implant may be nearly impossible given physiological risks, as is sometimes the case with LVAD explantations.

The future of IshBotics

Given the complexity of developing a functioning human-robotic hybrid, a model within the current body of scientific knowledge must be identified that allows us to study the physiological, psychological, and ethical questions that stand to prevent us from reaching a more perfect biological Singularity. I proposed in this article that this model must meet certain criteria, and have constructed arguments that those requirements are met within the current realm of implanted ventricular assist devices.

Further areas of research will need to examine the physiological, psychological, and ethical areas not only separately, but in combination.

Physiologically, research should focus on eliminating the pro-thrombotic risks of LVAD physiology, and therefore the need for long-term anticoagulation. Specifically, focus should be directed toward the development of new polymers that are immunologically and hematologically inert, as the interface between human blood and existing polymers almost immediately results in activation of the complement system and blood coagulation pathways, with particularly dire consequences observed in the cardiopulmonary bypass population. The consequences of this physiology as well as treatment will result in significant risks of morbidity and mortality [14].

Furthermore, safety systems for unwanted sequelae of mechanical propulsion of blood, such as gaseous and non-gaseous microemboli, should be perfected for long-term integration into the human-robotic hybrid. The conduits for human blood should be modeled with sensors that are reactive to circulating biological substances within a closed system, so they can adapt and adjust as in vivo vascular endothelium. These sensors should integrate into a wireless network that can be adjusted by a physician or the hybrid itself, particularly in anticipation of acute changes in physiological requirements such as strenuous exercise or rest, in order to add to the efficiency of the human-robotic hybrid facing dynamic external environments.

Psychologically, research should focus on several areas. One is the effect of non-pulsatile blood flow and its psychological effect not only on the human-robotic hybrid, but on close family members such as spouses or parents. While battery development is improving, the psychological effect of having one’s life on an electrical source that requires frequent daily maintenance is another aspect that should be pursued.

Ethically, research should focus on social impact, both on an interpersonal and societal level, of human-robotic hybrids. This not only includes socioeconomic considerations, but the ethical responsibility of the implanting physicians to develop psychosocial screening tools during the implantation and maintenance phase. Finally, we have an ethical responsibility to develop secure data networks and interfaces that not only protect the autonomy and privacy of the human-robotic hybrid, but also the cyber-security of the robotic implant, to avoid any unwanted interference from outside parties.

Conflict of interest

Nothing to declare

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Singularity now: a model for human-robotic physiology


Singularitate azi: utilizarea dispozitivului de asistare ventriculară ca model pentru fiziologia viitorului hibrid om-robot

Rezumat

În lumea secolului XXI interacțiunile om-robot nu apar așa cum au fost prevăzute de Asimov în 1942. De fapt, acestea sunt mult mai complicate. În locul roboților „simțitori” care să lucreze alături de noi în situații dificile, viitorul acestor interacțiuni include hibrizi om-robot cu o fiziologie complexă, lucrând integrat pentru obținerea unei performanțe fiziologice umane primare superioare. Această performanță poate fi descrisă ca o „singularitate” biologică.

Susținem că acest tip de Singularitate nu poate fi obținut prin utilizarea tehnologiilor biologice actuale, iar fiziologia om-robot va trebui integrată pentru ca Singularitatea să fie obținută. În scopul depășirii dificultăților impuse de noua fiziologie om-robot, avem de identificat mai întâi un model funcțional dintre cele utilizate în prezent. Odată identificat, acest model poate reprezenta baza de studiu, creare, expansiune și optimizare a fiziologiei hibride om-robot.

Această lucrare prezintă și argumentează faptul că în prezent acest model hibrid (propus să se numească „IshBot”) poate fi studiat cel mai bine cu ajutorul dispozitivelor de asistare ventriculară – VAD.

Cuvinte cheie: singularitate, model hibrid om-robot, dispozitiv de asistare ventriculară, etică